Deep Habits and the Dynamic Effects of Monetary Policy Shocks[*]

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Abstract

This paper introduces deep habits into a sticky-price sticky-wage economy and asks whether the countercyclical markup movements induced by deep habits is helpful for accounting for the dynamic effects of monetary policy shocks. We find that this is the case: When allowing for deep habits, the model can account very precisely for the persistent impact of monetary policy shocks on aggregate consumption and for the impact on inflation that other models have hard a time explaining. In particular, the model can account both for the price puzzle and for inflation persistence. We also show that the deep habits mechanism and nominal rigidities are complementary: The deep habits model can account for the dynamic effects of monetary policy shock at low to moderate levels of nominal rigidities. We show that the results are stable over time and are not caused by monetary policy changes.

Keywords: deep habits, monetary policy, price puzzle, inflation persistence, countercyclical markups

JEL classifications: E21, E31, E32, E52

1 Introduction

A large number of papers have studied the dynamic impact of monetary policy shocks using vector autoregression based methods. This literature has demonstrated that monetary policy shocks are associated with persistent effects on output and its components but also that the dynamic effects on inflation are associated with two puzzles: The "inflation persistence puzzle" (a slow and delayed rise in inflation in response to an expansionary monetary policy shock) and the "price puzzle" (a temporary drop in the price level after an expansionary monetary policy shock). These latter two findings are termed as puzzles because they appear contrary to conventional monetary wisdom. This paper examines whether a model of countercyclical markups is helpful for understanding these and other features of the dynamic effects of monetary policy shocks. We extend a standard sticky-price sticky-wage model with goods-specific ("deep") habits in which firms engage in dynamic pricing even in the absence of nominal rigidities. We find that this model can provide a very precise account of the dynamic effects of monetary policy shocks.

In its simplest version, the standard new Keynesian model gives rise to the "New Keynesian Phillips" curve which relates current inflation to current marginal costs and to future expected inflation. The purely forward looking feature of this relationship implies that it cannot account for inflation persistence.[1] A large number of papers have addressed this issue by introducing features that either to give rise to persistent movements in marginal costs or that introduce backward looking features into the relationship between current inflation and marginal costs. Galí and Gertler (1999) examine the impact of allowing for backward looking price setters. The presence of such backward looking price setters introduces a lagged inflation term in the new Keynesian Phillips curve and therefore helps explaining the sluggish adjustment of prices to monetary policy shocks. Fuhrer and Moore (1995) introduce a relative contracting model in which workers care about the past real wages of other workers and show that this may help explain sluggish inflation adjustments to monetary policy shocks.[2] More directly, Erceg, Henderson

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[1]This result holds in Calvo style sticky price models and in models where there are costs of changing prices. Chari, Kehoe and McGrattan, 2000, show that the same result also holds in Taylor type staggered contracts models.

[2]Holden and Driscoll (2003) challenge the results of Fuhrer and Moore (1995) on the grounds that the relative contracting model assumes that workers care about past not current relative real wages. They show that when

and Levin (2000) assume that nominal wages as well as prices adjust sluggishly. While these authors do not explicitly address the inflation persistence puzzle, other authors have shown that the combination of sticky prices and sticky wages may be helpful for explaining inflation persistence, see e.g. Christiano, Eichenbaum and Evans (2005), Rabanal and Rubio-Ramirez (2003), or Smets and Wouters (2003). There has been less theoretical work on the price puzzle an exception being Catelnuovo and Surico (2008) who propose a monetary model in which passive policy gives rise to indeterminacy. When the equilibrium is indeterminate, inflation expectations become very persistent and implies that a structural VAR will (wrongly) lead one to conclude that expansionary monetary policy shocks give rise to a drop in the price level.

We focus instead upon goods market features. We study a monetary model in which it is costly for producers to change prices and for labor unions to change nominal wages. We introduce into this environment the deep habit mechanism proposed in Ravn, Schmitt-Grohe and Uribe (2006). The deep habits model assumes that households are subject to keeping up with the Joneses at the level of *individual* goods varieties. This feature implies, in the fashion of customer markets models, that the demand function facing producers depends on past sales. This features leads to time variation in optimal markups for two reasons. First, variations in aggregate demand affect the price elasticity of demand facing producers. An increase in current aggregate demand increases the price elasticity and therefore leads producers to set lower markups. Secondly, when setting prices today, producers need to be forward looking and a producer that expects high future demand will have an incentive to lower prices today in order to attract more future demand. In this sense, this model gives rise to a countercyclical markup. In other papers we have shown that this mechanism is helpful for understanding the impact of technology shocks and of government spending shocks (see Ravn, Schmitt-Grohe and Uribe, 2006, 2008). The countercyclicality of the markup is the key reason why the deep habits model may be an interesting model in which to consider the dynamic effects of monetary policy.

In order to evaluate this issue we first estimate a VAR on post-war U.S. data and derive the impact of a monetary policy shock using standard identifying assumptions. We study a low-dimensional VAR that consists of aggregate consumption, the CPI inflation rate, the federal funds rate, and the commodity price index. We include the commodity price index in the VAR

workers care about other workers' current real wages, the model has no inflation persistence in the sense that the Phillips curve is entirely forward looking.

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in order not to bias our results towards the existence of a price puzzle.[3] Monetary policy shocks are identified assuming that a monetary policy shock has no within-quarter impact on output and inflation, a standard assumption in this literature. The VAR measurement of the dynamic effects of a monetary policy shock conforms with the conventional wisdom regarding inflation persistence and the price puzzle. We find that the price level drops for 2 quarters after an expansionary monetary policy shock and that the maximum increase in inflation appears as late as 3 years after the initial expansion of monetary policy. These results are completely in line with results from much higher dimensional VARs, see e.g. Christiano, Eichenbaum and Evans (2005). We also find that aggregate consumption increases persistently and in a hump-shaped manner in response to an expansionary monetary policy shock.

We estimate key parameters of the model using a limited information approach and compare the results to two alternative economies. The first alternative economy replaces the deep habits mechanism with a standard aggregate habit model. The second alternative economy corresponds to the standard new Keynesian model that abstracts from habits. We find that the model with deep habits provides a superior fit to the identified dynamic effects of monetary policy shocks. In particular, this model can account simultaneously for the persistent impact of monetary policy shocks on consumption, for the price puzzle, and for inflation persistence. Moreover, the estimates of the extent of nominal rigidities are significantly lower in the deep habits economy than in the economy with aggregate habits. The standard aggregate habit model in contrast can account for neither the price puzzle nor fully for inflation persistence. The model without any habits can account for the price puzzle but only by relying on absurd implications for the extent of price rigidity and odd monetary policy reaction functions.

We show that the key reason for the ability of the deep habits model to account for the impact of monetary policy shocks is due to a complementarity between nominal rigidities and the customer markets feature of the data. In response to an expansionary monetary policy shock, the presence of nominal rigidities implies that aggregate consumption increases. In the deep habits economy, the increase in consumption gives producers an incentive to lower the markup. This by

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[3]A common argument is that the price puzzle is an expression of misspecification of VAR models in the sense that it is important to include variables that are forward looking reflecting that central banks target future inflation. Following Sims (1992) much of the literature has addressed this point by augmenting VARs with the commodity price index. In our VAR, as well as in higher dimensional VARs, see e.g.Christiano, Eichenbaum and Evans, 2005, the price puzzle remains but is weaker than when commodity prices are excluded.

itself gives rise to a smaller inflation impact of an expansionary monetary policy shock in the deep habits economy than in models that assumes either no habits or that assume habits that operate at the level of aggregate consumption. When the deep habit effect is sufficiently strong, the deep habits model generates a fall in inflation on impact after an expansionary monetary policy shock. As the consumption boom dies out, producers slowly increase prices and this implies that the model also can account for inflation persistence.

Our results show that a simple structural model that combines nominal rigidities with deep habits is able to account for the impact of monetary policy shocks. Parts of the literature, however, has claimed that the inflation persistence puzzle is not "structural" but is caused by changes in monetary policy and to instability of the inflation process. It has been pointed out that inflation persistence appears to be sensitive to the monetary policy regime (see e.g. Benati, 2008), and that there appears to have been breaks in the inflation process which renders inflation less persistent when controlled for (see e.g. Levin and Piger, 2003). For that reason we repeat our analysis for two sub-samples breaking the data in the third quarter of 1979 when Volcker became the chairman of the Fed. Consistently with earlier results in the literature, we find that the earlier sub-sample is associated with more pronounced price and inflation puzzles than the late sample. Both of these puzzles, however, still hold true in the VAR reestimated using data for the late sample only. We then reestimate the structural parameters and find that monetary policy has become less accommodating over time, that price rigidity has increased while wage rigidity has declined, but the extent and importance of deep habits have remained roughly constant. Therefore, we conclude that the customer markets feature of our model appears to be key for understanding the dynamic impact of monetary policy.

The remainder of the paper is structured as follows. Section 2 describes the model. In Section 3 we describe our estimation approach and discuss the impact of monetary policy shocks in the U.S. Section 4 analyses the results. Finally we conclude in Section 5.

2   The Model

We consider an economy with monopolistically competitive firms that are subject to costs of changing nominal prices. We also allow for sticky nominal wages assuming that households act as monopolistically competitive suppliers of labor but that it is costly to change nominal wages. The key contribution of the paper is that we introduce is a customer markets feature on the

demand side of the economy. We adopt the deep habits model of Ravn, Schmitt-Grohe and Uribe (2006) which assumes that households form habits to individual goods varieties. This habit model implies that firms face dynamic pricing problems and will set non-constant markups in response to shocks to the economy even in the absence of any nominal rigidities. It is the implied dynamics of markups that makes this an interesting model in which to study the dynamic effects of monetary policy.

2.1 Households

There is a continuum of households indexed by $j \in [0, 1]$. Households are identical, infinitely lived, and maximize the expected present discounted value of their utility stream. They derive utility from consumption of a continuum of differentiated goods and have dis-utility of supplying labor. As in Erceg, Henderson and Levin (2000), households are assumed to supply a differentiated labor input and act as monopolistically competitive labor unions in the labor market. They also face costs of changing nominal wages. Households own firms and receive dividend payments on their equity shares.

We deviate from the standard constant elasticity of substitution modeling of preferences that is common in the literature. We assume instead that households are subject to good-specific habits and adopt the external deep habits model of Ravn, Schmitt-Grohe and Uribe (2006). This model assumes that the marginal utility derived from the consumption of *individual* goods varieties is subject to a consumption externality that we specify as a catching up with the Joneses feature. Thus, the important extension is that the habits operate at the level of marginal utility of *individual* goods varieties rather than at the level of the consumption basket.

Household j consumes a basket of goods, c_{it}^j, $i \in [0, 1]$ and supplies labor to the firms.

Household preferences are given as:[4]

$$V_0^j = E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} \left(x_t^j \right)^{1-\sigma} - \frac{\gamma}{1+\kappa} \left(h_t^j \right)^{1+\kappa} \right] \tag{1}$$

$$x_t^j = \left[\int_0^1 \left(c_{it}^j - \theta^d c_{it-1} \right)^{1-1/\eta} di \right]^{1/(1-1/\eta)} \tag{2}$$

$$c_{it} = \int_0^1 c_{it}^j dj \tag{3}$$

where E_t denotes the mathematical expectations operator contingent on all information available at date t, $\beta \in (0,1)$ is the subjective discount factor, σ is a curvature parameter, $1/\kappa > 0$ is the Frisch elasticity of labor supply, $\gamma > 0$ is a preference weight, h_t^j denotes the household j's labor supply in period t, and x_t^j is the definition of the consumption basket from which the household derives utility. This latter variable is defined in equation (2).

The household derives utility from a CES-aggregate of "habit adjusted" consumption levels of each of the continuum of differentiated goods. We model the habit relating to the consumption of *variety* i as the past *aggregate* consumption of this *variety*.[5] The household is assumed to take c_{it}, the aggregate consumption of good i, as exogenously given. The parameter $0 \leq \theta^d < 1$ measures the importance of the habit. When $\theta^d = 0$, preferences are separable over time and the consumption aggregator is a standard CES function. In this case, $\eta > 0$ denotes the standard intratemporal elasticity of substitution between goods. When $\theta^d > 0$, preferences display "catching up with the Joneses" at the goods level.[6] As we will return to below, this formulation of the habit introduces a key supply-side channel through which habits affect price setting.

The goods demand functions are found as the solutions to the following expenditure minimization problem:

$$\min_{c_{it}^j} E_t^j = \int_0^1 P_{it} c_{it}^j di$$

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[4]Implicitly, households also derive utility from real money balances and we assume that the utility function is separable in money and its other arguments. Because we later specify a monetary policy reaction function in terms of an interest rate rule, we do not explicitly need to look at the demand for money.

[5]It is straightforward to allow for persistence in the habit by introducing a habit stock. Here we adopt the simpler formulation to keep the analysis more focused.

[6]Ravn, Schmitt-Grohe and Uribe (2006) also deal with the case of internal habits in which the household's current marginal utility of consumption of variety i depends on its *own* past consumption of that variety. Nakamura and Steinsson (2008) examine pricing implications of this specification.

subject to:

$$\left[\int_0^1 \left(c_{it}^j - \theta^d c_{it-1}\right)^{1-1/\eta} di\right]^{1/(1-1/\eta)} = x_t^j$$

where P_{it} denotes the nominal price of variety i.

The demand functions that solve this problem are given as:

$$c_{it}^j = \left(\frac{P_{it}}{P_t}\right)^{-\eta} x_t^j + \theta^d c_{it-1} \tag{4}$$

where P_t is an aggregate price index given as:

$$P_t = \left[\int_0^1 P_{it}^{1-\eta} di\right]^{1/(1-\eta)} \tag{5}$$

According to the demand function (4), the household's demand for each goods variety depends negatively on its relative price, P_{it}/P_t, and when $\theta^d > 0$ current demand also depends positively on the habit stock of the goods variety in question.

Households act as monopolistically competitive labor unions in the labor market. In return for their market power, they must stand ready to satisfy any demand for their labor services at the quoted wage. The demand for household j's labor (see the next section) is given by:

$$h_t^j = \left(\frac{W_t^j}{W_t}\right)^{-\psi} h_t \tag{6}$$

where W_t^j denotes the nominal wage of household j's labor good, W_t is an aggregate wage, $\psi > 1$ is the labor demand price elasticity, and h_t is a measure of aggregate labor demand. Individual households take W_t and h_t for given.

The household makes its choices subject to the following sequence of budget constraints:

$$P_t x_t^j + \varkappa_t + B_t^j = R_{t-1} B_{t-1}^j + W_t^j h_t^j + \Phi_t^j - P_t \frac{\zeta_w}{2} \left(\frac{W_t^j}{W_{t-1}^j} - \tilde{\pi}_{wt}\right)^2 \tag{7}$$

$$\varkappa_t = \theta^d \int_0^1 P_{it} c_{it-1} di$$

and subject to a no-Ponzi game restriction.

Our formulation of the household budget constraint assumes that the household has access to a nominal risk free bond which allows it to spread consumption expenditure (and labor supply) over time. B_t^j denotes the household's purchases of one-period nominal bonds, R_t denotes the gross nominal interest rate and Φ_t^j is the household's receipts of dividend payments on its equity portfolio.[7]

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[7] The formulation of the budget constraint uses the fact that $P_t x_t^j = \int_0^1 P_{it} \left(c_{it}^j - \theta^d c_{it-1}\right) di$.

The last term on the right hand side of the budget constraint denotes nominal costs of adjusting nominal wages. The parameter $\zeta_w \geq 0$ parametrizes the extent of nominal wage rigidity. When $\zeta_w = 0$, nominal wages are flexible while $\zeta_w > 0$ implies that households incur a nominal cost of changing wages which is quadratic in the deviation of nominal wage growth from an indexation factor $\widetilde{\pi}_{wt}$. We assume that this latter variable is given as:

$$\widetilde{\pi}_{wt} = \vartheta_w \pi_w^* + (1 - \vartheta_w) \pi_{wt-1}$$

where $\vartheta_w \in [0, 1)$ is a measure the extent of indexation of nominal wages. When $\vartheta_w = 1$ households can costlessly increase wages with the steady-state wage inflation rate (π_w^*) while $\vartheta_w = 0$ implies that wages are fully indexed to the realized past inflation rate of aggregate nominal wages, $\pi_{wt-1} = W_{t-1}/W_{t-2}$.

The household's labor supply, the nominal wage, and its intertemporal allocation of x_t^j can be found as the solutions to the maximization of (1) subject to $(6) - (7)$ taking as given P_t, ϑ_t, W_0^j, R_t, and Φ_t^j. The first-order conditions are:

$$\gamma \left(h_t^j\right)^\kappa = \left(x_t^j\right)^{-\sigma} \frac{W_t^j}{P_t} - \lambda_{j,t}^h \tag{8}$$

$$\psi \lambda_{j,t}^h h_t^j \left(x_t^j\right)^\sigma = \gamma \left(h_t^j\right)^\kappa \frac{W_t^j}{P_t} - \zeta_w \frac{W_t^j}{W_{t-1}^j} \left(\frac{W_t^j}{W_{t-1}^j} - \widetilde{\pi}_{wt}\right)$$

$$+ \beta \zeta_w E_t \frac{W_{t+1}^j}{W_t^j} \left(\frac{W_{t+1}^j}{W_t^j} - \widetilde{\pi}_{wt+1}\right) \left(\frac{x_{t+1}^j}{x_t^j}\right)^{-\sigma} \tag{9}$$

$$\left(x_t^j\right)^{-\sigma} = \beta R_t E_t \frac{P_t}{P_{t+1}} \left(x_{t+1}^j\right)^{-\sigma} \tag{10}$$

where $\lambda_{j,t}^h$ is the multiplier on the labor demand function in equation (6).

We note from $(8) - (10)$ that the labor supply decision and the intertemporal consumption allocation depends on the presence of habits in the consumption aggregator. According to (8), the household's labor supply is increasing in the real wage. Equation (9) is a forward looking "wage setting curve". When wages are flexible $(\xi_w = 0)$, equations $(8) - (9)$ imply that the household sets the real wage as a fixed markup over the marginal rate of substitution between labor and consumption. This markup is given as $\psi/(\psi - 1) \geq 1$.[8] In the presence of nominal wage stickiness, the household sets a forward looking nominal wage. Finally, equation (10) is the intertemporal Euler equation which implies that the (habit adjusted) consumption profile

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[8] Given that our focus is not upon optimal monetary policy issues, we choose not to neutralize the steady-state monopoly power by a labor supply subsidy. This has no impact on our results.

is increasing in the expected real interest rate. It is important to notice that the impact of deep habits on the household's intertemporal allocation and on labor supply is equivalent to the impact of assuming aggregate habits.

2.2 Firms

Firms are assumed to be monopolistically competitive. They produce output using inputs of labor and we assume that the production function is linear:

$$y_{it} = h_{it} \tag{11}$$

where y_{it} denotes firm i's output and h_{it} is firm i's input of labor. The labor input is defined as:

$$h_{it} = \left(\int_0^1 (h_{it}^j)^{1-1/\psi} \, dj \right)^{1/(1-1/\psi)}$$

where h_{it}^j is firm i's input of labor variety j at date t. The firm purchases the labor varieties at the nominal price W_t^j. Therefore, it follows that the labor demand functions are given as:

$$h_{it}^j = \left(\frac{W_t^j}{W_t} \right)^{-\psi} h_{it} \tag{12}$$

where W_t is given as:

$$W_t = \left[\int_0^1 W_{jt}^{1-\psi} dj \right]^{1/(1-\psi)}$$

Aggregating (12) across firms gives (6).

The demand function for firm i's product is found by aggregating across consumers:

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\begin{aligned}
c_{it} &= \left(\frac{P_{it}}{P_t} \right)^{-\eta} x_t + \theta^d c_{it-1} \tag{13} \\
c_{it} &= \int_0^1 c_{it}^j dj \\
x_t &= \int_0^1 x_t^j dj
\end{aligned}
$$

Thus, the demand function facing firm i inherits the properties of the individual demand function. Importantly, the demand facing firm i at date t depends both on the variety's relative price and on the firm's past sales of its product. This latter feature of the demand function implies that firms face dynamic pricing problems even in the absence of nominal rigidities, a feature that is shared by other customer markets models. As analyzed in detail in our previous

work, the preference model assumed here implies that firms have an incentive to lower prices today if they expect future demand (i.e. x_t^j) to be high relative to current demand.[9] Moreover, an increase in current demand, x_t, over habitual demand (c_{it-1}), increases the price elasticity of the demand facing the firm since it increases the weight on the price elastic term in the demand function in equation (13). This increase in the price elasticity give firms an incentive to lower prices. For these reasons, this model provides new channels through which monetary policy shocks may affect the economy relative to standard models that assume CES-utility structures.

Firm i sets the price of its product, P_{it}, subject to the household demand functions taking as given all aggregate quantities and prices. In return for having market power, firms must stand ready to serve any demand at the announced prices, i.e. $c_{it} \geq y_{it}$. As in the case of households, we assume that it is costly for firms to change prices. Following Rotemberg (1982), we assume that there are quadratic adjustment costs associated with changing nominal prices. Firms therefore face the following profit maximization problem:

$$\max_{P_{it}} E_0 \sum_{t=0}^{\infty} q_t \Phi_{it} \tag{14}$$

$$\Phi_{it} = P_{it}c_{it} - W_t h_{it} - \frac{\zeta_p}{2} P_t \left(\frac{P_{it}}{P_{it-1}} - \widetilde{\pi}_t \right)^2 \tag{15}$$

subject to (13) taking as given q_t, P_{i0}, P_t, W_t, x_t and $\widetilde{\pi}_t$. Φ_{it} denotes the nominal profits of firm i in period t and q_t is the rate at which the firm's owners, i.e. the households, discount the stream of nominal profits. This discount factor is given as:[10]

$$q_t = \beta^t x_t^{-\sigma} \frac{1}{P_t}$$

The parameter $\zeta \geq 0$ parametrizes the extent of nominal rigidities. When $\zeta \to 0$ prices are flexible and the model exhibits super neutrality in the short and long run run. Positive values of ζ implies that firms have an incentive to smooth price changes over time. Symmetrically to wage setting, we allow for the possibility of indexation through the term $\widetilde{\pi}_t$ which is assumed to

[9]Notice from the demand function that there is a price insensitive term that derives from past sales. One might be tempted to conclude that the firm can set a price of infinity making infinite profits due to this term. However, in equilibrium such a policy will not be consistent with household budget constraints and can therefore be ruled out.

[10]This equation imposes homogeneity across households, an assumption that we impose below.

be given as:

$$\widetilde{\pi}_t = \vartheta_p \pi^* + (1 - \vartheta_p) \pi_{t-1}$$

where π^* is the steady state inflation rate and $\pi_{t-1} = P_{t-1}/P_{t-2}$ is the lagged *realized* aggregate inflation rate. When $\vartheta_p = 1$ this specification implies that there are no adjustment costs along a balanced growth path with constant inflation. When $\vartheta_p = 0$, there is full indexation.

The first order conditions for h_{it}, c_{it}, and P_{it}, in that order, are given as:

$$W_t = P_t \lambda_t^y \tag{16}$$

$$P_t \lambda_t^c + P_t \lambda_t^y - P_{it} = \theta^d E_t \frac{q_{t+1}}{q_t} P_{t+1} \lambda_{t+1}^c \tag{17}$$

$$E_t \frac{q_{t+1}}{q_t} \zeta_p P_{t+1} \frac{P_{it+1}}{P_{it}^2} \left(\frac{P_{it+1}}{P_{it}} - \widetilde{\pi}_{t+1} \right) = \zeta_p \frac{P_t}{P_{it-1}} \left(\frac{P_{it}}{P_{it-1}} - \widetilde{\pi}_t \right)$$
$$+ \eta P_t \lambda_t^c \frac{x_t}{P_{it}} - c_{it} \tag{18}$$

where λ_t^y is the multiplier on the production function (11), i.e. marginal costs, and λ_t^c is the multiplier on the demand function in (13).

When there are no habits $(\theta^d = 0)$ and prices are flexible $(\zeta_p = 0)$, equations $(17) - (18)$, imply that prices are set as fixed mark-up over nominal marginal costs. When there are nominal rigidities and/or preferences display deep habits, the markup will be time-varying in response to shocks to the economy. It is instructive to consider the two special cases when either prices are flexible or there are no deep habits. In these special cases, equations $(17) - (18)$ can be expressed as:

$$\zeta_p = 0 : P_{it} \left(1 - \frac{1}{\eta} \frac{c_{it}}{x_t} \right) = P_t \lambda_t^y - \theta^d E_t \frac{q_{t+1}}{q_t} P_{it+1} \frac{1}{\eta} \frac{c_{it+1}}{x_{t+1}}$$

$$\theta = 0 : c_{it} \left(1 - \eta \left(1 - \lambda_t^y \frac{P_t}{P_{it}} \right) \right) = \zeta_p \frac{P_t}{P_{it-1}} \left(\frac{P_{it}}{P_{it-1}} - \widetilde{\pi}_t \right) - \zeta_p E_t \frac{q_{t+1}}{q_t} P_{t+1} \frac{P_{it+1}}{P_{it}^2} \left(\frac{P_{it+1}}{P_{it}} - \widetilde{\pi}_{t+1} \right)$$

According to the first expression, when there are deep habits, firms will vary the markup in response to changes in current aggregate demand in response to expected changes in future consumption growth. An increase in current demand or in the expectations about future demand for the variety give firms an incentive to lower the current markup. The second of these equations is standard in sticky price models and implies that firms smooth price increases over time in response to changes in marginal costs or in aggregate demand.

2.3 Monetary Policy

We assume that the monetary policy authority sets the monetary stance according to a simple interest rate rule:

$$R_t = R^* + \rho_R \left(R_{t-1} - R^*\right) + \left(1 - \rho_N\right) \left[\alpha_\pi \left(\pi_t - \pi^*\right) + \alpha_y \left(\frac{y_t - y^*}{y^*}\right)\right] + \varepsilon_t \qquad (19)$$

where ε_t is a stochastic "monetary policy shock" with variance υ^2. R^*, π^* and y^* are positive constants which denote the steady state levels of the nominal interest rate, inflation and output, respectively. The parameter $\rho_R \in [0, 1)$ denotes the extent of interest rate smoothing.

2.4 Market Clearing

We close the model by the market clearing conditions. The labor market clearing conditions are:

$$h_t^j = \int_0^1 h_{it}^j di$$
$$h_{it} = \int_0^1 h_{it}^j dj$$

2.5 Symmetric Equilibrium

We concentrate upon a symmetric equilibrium in which all consumers make the same choice over consumption and set the same wage, and in which all firms set the same prices. The symmetric

equilibrium is summarized by the following set of equations:

$$x_t = c_t - \theta^d c_{t-1} \tag{20}$$

$$\gamma h_t^\kappa = x_t^{-\sigma} w_t - \lambda_t^h \tag{21}$$

$$\psi \lambda_t^h h_t x_t^\sigma + \zeta_w \pi_{wt} (\pi_{wt} - \widetilde{\pi}_{wt}) = \gamma h_t^\kappa w_t + \beta \zeta_w E_t \pi_{wt+1} (\pi_{wt+1} - \widetilde{\pi}_{wt+1}) \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \tag{22}$$

$$x_t^{-\sigma} = \beta R_t E_t x_{t+1}^{-\sigma} \frac{1}{\pi_{t+1}} \tag{23}$$

$$c_t = h_t - \frac{\zeta_p}{2} (\pi_t - \widetilde{\pi}_t)^2 - \frac{\zeta_w}{2} (\pi_{wt} - \widetilde{\pi}_{wt})^2 \tag{24}$$

$$\lambda_t^y = w_t \tag{25}$$

$$\lambda_t^y + \lambda_t^c = 1 + \theta^d \beta E_t \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \lambda_{t+1}^c \tag{26}$$

$$\eta \lambda_t^c x_t + \zeta_p \pi_t (\pi_t - \widetilde{\pi}_t) = c_t + \beta \zeta_p E_t \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \pi_{t+1} (\pi_{t+1} - \widetilde{\pi}_{t+1}) \tag{27}$$

$$R_t - R^* = \rho_R (R_{t-1} - R^*) + (1 - \rho_R) [\alpha_\pi (\pi_t - \pi^*)$$
$$+ \alpha_y \left(\frac{y_t - y^*}{y^*} \right) + \varepsilon_t \tag{28}$$

$$\widetilde{\pi}_t = \vartheta_p \pi^* + (1 - \vartheta_p) \pi_{t-1} \tag{29}$$

$$\widetilde{\pi}_{wt} = \vartheta_w \pi_w^* + (1 - \vartheta_w) \pi_{wt-1} \tag{30}$$

$$w_t = w_{t-1} + \pi_{wt} - \pi_t \tag{31}$$

where w_t denotes the real wage, π_{wt} is the wage inflation rate, and π_t is the price inflation rate. We solve for the equilibrium by log-linearizing this system of equations around the steady-state.

It is instructive to consider the implications for inflation dynamics on the basis of the log-linearized version of equation (27). The log-linearized version of this equation can be expressed as:

$$\widehat{\pi}_t = \frac{(1 - \vartheta_p)}{1 + \beta (1 - \vartheta_p)} \widehat{\pi}_{t-1} + \frac{\beta}{1 + \beta (1 - \vartheta_p)} E_t \widehat{\pi}_{t+1}$$
$$+ \psi_1 \widehat{mc}_t - \psi_2 (\widehat{c}_t - \theta^d \widehat{c}_{t-1}) - \psi_3 \widehat{\lambda}_{t+1}^c \tag{32}$$

where we let $\widehat{x}_t$ denote the percentage deviation of x_t from its steady-state value, and mc_t denotes marginal costs. The coefficients are given as:

$$\psi_1 = \left(\eta (1 - \theta^d) - (1 - \theta^d \beta) \right) / \left(\zeta_p \frac{\overline{\pi}^2}{\overline{c}} (1 + \beta (1 - \vartheta_p)) \right)$$

$$\psi_2 = \frac{\theta^d}{(1 - \theta^d)} / \left(\zeta_p \frac{\overline{\pi}^2}{\overline{c}} (1 + \beta (1 - \vartheta_p)) \right)$$

$$\psi_3 = \theta^d \beta / \left(\zeta_p \frac{\overline{\pi}^2}{\overline{c}} (1 + \beta (1 - \vartheta_p)) \right)$$

where $\bar{x}$ denotes the steady-state value of x.

In the absence of deep habits and when prices are not indexed ($\theta^d = 1 - \vartheta_p = 0$), equation (32) generates the standard new Keynesian Phillips curve. Indexation introduces a backward looking inflation term which implies a more persistent response to shocks to marginal costs. The presence of deep habits moderates the Phillips curve in three important ways. First, the habit increases the impact of marginal cost changes on inflation. Secondly, the deep habit introduces a backward looking term in the Phillips curve even in the absence of indexation through the impact of the habit stock on this period's demand. Third, the presence of habits introduces an additional forward looking term through $\widehat{\lambda}^c_{t+1}$.

3   Estimation

In this section we provide empirical evidence on the dynamic effects of a monetary policy shock. We then estimate key parameters of the model presented in the preceding section and evaluate its ability to account for the empirically estimated impact of a monetary policy shock. We estimate the structural parameters by matching the empirical estimates of the impact of a monetary policy shock in the U.S. taking into account that the identifying assumptions made when estimating the monetary policy shock may impact on the measurement.

3.1   SVAR Estimates of the Impact of Monetary Policy Shocks

We study U.S. quarterly data for the sample period 1954:2 - 2008:2. The dynamic impact of a monetary policy shock are estimated using a standard structural VAR estimator. Consider the following reduced form VAR:

$$x_t = B\left(L\right)x_{t-1} + e_t \tag{33}$$

where x_t is a vector of observables, $B\left(L\right)$ is a lag-polynomial, and e_t is a vector of reduced form errors. We specify the vector of observables as:

$$x_t = [c_t, \pi_t, p^s_t, r_t]$$

where c_t denotes the logarithm of per capita consumption, π_t is the inflation rate, p^s_t is the commodity price index, and r_t is the federal funds rate. We measure consumption as personal consumption expenditure in chained year 2000 prices divided by the civilian non-institutional

population. Inflation is measured as the change in CPI (of all urban consumers). The commodity price index is the PPI of commodities. All variables are de-seasonalized.

We include consumption rather than output in the VAR because our model excludes investment and for the same reason we measure inflation on the basis of the CPI rather than the GDP deflator. The commodity price index is included in order to partially address the price puzzle. The small dimension of the VAR relative to other recent papers, see e.g. Christiano, Eichenbaum, and Evans (2005), is due to the fact that our model is focused entirely on the impact of monetary policy shocks on consumption and inflation.

The monetary policy shock is identified using standard timing assumptions. We assume that the interest rate is affected contemporaneously by shocks to the first three components of the VAR but that none of these variables respond contemporaneously to the monetary policy shock. Consider the structural VAR:

$$A_0 x_t = \sum_{i=1}^{p} A_p x_{t-p} + \varepsilon_t \tag{34}$$

where A_i, $i = 0, .., p$, are square matrices and ε_t is the vector structural innovations with the restriction that its covariance matrix is diagonal. The last component of this vector is the monetary policy shock and it is identified by assuming that the last column of A_0 consists of zeros apart from its last element (which is normalized to unity).

The impulse responses to the identified monetary policy shock are illustrated in Figure 1. The estimations allow for constant terms and trends in the empirical VAR and we estimated the VAR allowing for 8 lags (but shorter lag structures give almost identical results). We show the impact of a one standard error decline in the federal funds rate (i.e. an expansionary monetary policy shock) along with 95 percent (bootstrapped, non-centered) confidence intervals for a forecast horizon of 20 quarters.

The monetary policy shock itself corresponds to a persistent decline in the nominal interest rate which remains low for around 6 quarters before eventually returning to its long-run value. The monetary policy loosening gives rise to a hump-shaped and persistent increase in aggregate consumption which peaks at 4 percent above trend around 6 quarters after the monetary policy shock. The increase in consumption persists until approximately 3.5 years after the decline in the interest rate.

The response of inflation confirms conventional wisdom. We find that the inflation response is negative for the first 2 quarters after the expansionary monetary policy shock (recall that the

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impact response is by definition equal to zero). Inflation only starts increasing around a year and a half after the decline in the interest rate and it then rises very persistently. The peak response occurs as long as 3 years after monetary policy shock. Thus, the low-scale VAR confirms the presence of the price puzzle and the inflation persistence puzzle.

3.2   Estimation of the Structural Parameters

The model introduces quite a large number of parameters some of which we have little idea about realistic values. For that reason we will estimate structural parameters. We do this by matching the impulse responses identified above.

Let the vector of parameters be given by Θ. We partition this vector into two subsets, Θ_1 and Θ_2. Θ_1 consists of parameters that we will calibrate rather than estimate formally. We make this distinction between the structural parameters because not all of them are easily identifiable from our estimation approach since they may have little effect on the dynamics of the model but instead matter for the steady state. Moreover, for some of the parameters there are good grounds for calibration. The vector of parameters that we calibrate consists of $\Theta_1 = [\beta, \pi^*, \gamma, \kappa, \sigma, \psi]$ while the parameters that are estimated formally are $\Theta_2 = \left[\eta, \zeta_p, \vartheta_p, \zeta_w, \vartheta_w, \theta^d, \rho_R, \alpha_y, \alpha_\pi, \upsilon\right]$.

3.2.1   Calibration of Θ_1

The calibration of the parameters in Θ_1 is summarized in Table 1. We calibrate β so that it implies a 4 percent annual real interest rate in the non-stochastic steady-state. π^* is normalized to 1^{11} while γ is calibrated so that it is consistent with a steady-state level of hours work equal to thirty percent.

Ideally, we would like to estimate the parameters κ, σ, and ψ. However, we found that these parameters are not well-identified from the data. Following Erceg et al (2000), we set $\psi = 4$. This implies that the real wage is set as a 33 percent markup over the marginal rate of substitution between consumption and leisure. We set $\kappa = 0.5$. This is a custom value in the macro literature but implies a higher labor supply elasticity that commonly estimated in the micro literature. Nevertheless, given the simplicity of our model, we adopt the lower value of κ used in the macro literature. Finally, we set $\sigma = 3$ which implies an intertemporal elasticity of substitution of consumption of 1/3 which is in the range of values that is viewed as "reasonable".

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[11] The value of π^* has no impact on the impulse responses and is therefore calibrated.

3.2.2 Estimation of Θ_2

We estimate Θ_2 using a limited information approach. The idea of the estimation is to derive Θ_2 by matching the model based impact of a monetary policy shock with the empirical VAR estimates.

We do this the following way. First, collect the empirical estimates of the responses of consumption, inflation, and the nominal interest rate to a one standard error monetary policy shock in the $3Rx1$ vector $\widehat{\Phi}^{data}$ and let W be a $3R$ square diagonal matrix with the inverse of the standard errors of $\widehat{\Phi}^{data}$ along its diagonal. The structural parameters are then estimated from the following minimization problem:

$$\widehat{\Theta}_2 = \arg\min_{\Theta_2} \left(\widehat{\Phi}^{data} - \widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory} \right) W \left(\widehat{\Phi}^{data} - \widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory} \right)' \tag{35}$$

where $\Phi\left(\Theta_2|\Theta_1\right)^{theory}$ denotes the impulse response of the observables in the model economy given the parameters that are estimated, Θ_2, contingent upon our calibration of Θ_1.

When estimating Θ_2 we need to take into account one subtle issue. Recall that when estimating $\widehat{\Phi}^{data}$ we assumed that consumption and inflation do not respond contemporaneously to the monetary policy shock. In our model this identifying assumption is not correct. To address this problem we introduce a simulation step in which we measure the model's impulse responses subject to the empirical identification strategy.[12] Thus, $\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory}$ does not correspond directly to the "true" responses of the observables to the monetary policy in the model economy, but instead to the impact of a **<u>measured</u>** monetary policy shock on the model equivalents of the observables. That is, we derive the measure $\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory}$ using the following strategy:

Step 1: Solve the model for a given value of Θ_2 and for the assumed value of Θ_1.

Step 2: Simulate N times time series of length T of the observables given Θ. Let the observables be consumption, inflation and the nominal interest rate. Add a small amount of measurement error to each of the artificial time series.

Step 3: Estimate a VAR for each of the N artificial time series and calculate $\widehat{\Phi}_i\left(\Theta_2|\Theta_1\right)^{theory}$ of the i'th simulation from the impulse responses assuming that consumption and inflation do not respond contemporaneously to the monetary policy shock.

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[12]Christiano, Eichenbaum and Evans (2005) address this issue instead by introducing timing assumptions in the model economy that renders it consistent with the identifying assumption in the data.

Step 4: Calculate $\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory}$ as the mean of $\widehat{\Phi}_i\left(\Theta_2|\Theta_1\right)^{theory}$ for $i = 1, 2, ..N$.

The measurement errors are added in step 2 in order to address the stochastic singularity of the VAR using the artificial data given that there is a single source of variation in the time series. We then calculate the standard errors of $\widehat{\Theta}_2$ following Hall et al (2007) as:

$$\Omega_{\Theta_2} = \Gamma\left(\Theta_2|\Theta_1\right)^{theory} \frac{\partial\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory\prime}}{\partial\Theta_2} W\Sigma_N W \frac{\partial\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory\prime}}{\partial\Theta_2} \Gamma\left(\Theta_2|\Theta_1\right)^{theory}$$

$$\Gamma\left(\Theta_2|\Theta_1\right)^{theory} = \left[\frac{\partial\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory\prime}}{\partial\Theta_2} W \frac{\partial\widehat{\Phi}\left(\Theta_2|\Theta_1\right)^{theory\prime}}{\partial\Theta_2}\right]^{-1}$$

$$\Sigma_N = \Sigma + \frac{1}{N^2}\sum_{i=1}^{N}\Sigma_i$$

where Σ_i is the covariance matrix of $\widehat{\Phi}_i\left(\Theta_2|\Theta_1\right)^{theory}$ and Σ is the covariance matrix of the impulse responses in the data.

This estimator is applied subject to various parameter restrictions. We assume that $\xi_p, \xi_w, \alpha_y, \upsilon \geq 0$, $0 \leq \vartheta_p, \vartheta_w \leq 1$, $\eta, \alpha_\pi > 1$, $0 \leq \theta^d < 1$, and $-1 < \rho_N < 1$. We use 100 simulations in step 3 and the (vector of) measurement error added in step 2 is assumed to be normally distributed with mean 0 and variance 0.0001.

4 Results

In this section we discuss the estimation results and the extent to which the deep habits model is useful for understanding the impact of monetary policy shocks. In order to bring out the insights clearer we compare the results for the deep habits model with two alternative models. The first alternative model is a standard "aggregate" habit new Keynesian model. In this model preferences are given by:

$$V_0 = E_0\sum_{t=0}^{\infty}\beta^t\left[\frac{1}{1-\sigma}\left(c_t^j - \theta^a c_{t-1}\right)^{1-\sigma} - \frac{\gamma}{1+\kappa}\left(h_t^j\right)^{1+\kappa}\right] \tag{36}$$

$$c_t^j = \left[\int_0^1\left(c_{it}^j\right)^{1-1/\eta}di\right]^{1/(1-1/\eta)} \tag{37}$$

$$c_t = \int_0^1 c_t^j dj$$

which is the specification used in much of the literature. θ^a here denotes the importance of the aggregate (external) habit. A crucial difference between this model and the deep habits model is

that the aggregate habit does not impact directly on firms' pricing policies and leaves markups constant unless there are impediments to changing prices. The second alternative model is the standard new Keynesian model with *no* habits which corresponds to our baseline model with the restriction that $\theta^d = 0$. The estimates of the parameters and their standard errors of the deep habits model and the parameters of the two alternative models are reported in Table 2.

It is instructive first to consult Figures 2-4 which illustrate the VAR based impulse responses of the observables to a monetary policy shock for the three alternative models along with the empirical counterparts of these responses. Even a visual inspection makes it clear that the deep habits model provides a superior fit to the empirical estimates of the impact of a monetary policy shock. The deep habits model captures very precisely the hump-shaped impact of the monetary policy shock on aggregate consumption and the interest rate path is also matched extremely well. Importantly, the fit to the impact on inflation is extremely good: The model can account simultaneously for the price puzzle and for inflation persistence. As far as the latter phenomenon is concerned, the model not only is consistent with an outdrawn increase in inflation but it also correctly identifies the period of maximum impact on the inflation rate.

The aggregate habit model gives rise to a consumption response to the monetary policy shock that is very similar to the deep habits model. The reason for this is that the deep habits and aggregate habits model imply identical Euler equations for the intertemporal allocation of aggregate consumption. However, the aggregate habits model provides a worse fit to both the interest rate path and to the inflation response. As far as the interest rate path is concerned, the initial size of the shock appears to be under-estimated. In terms of the inflation response, the aggregate habits model can account neither for the price puzzle nor for the extent of the inflation persistence since the maximum impact on inflation occurs around a year earlier in the model than in the US data.

By far the worst fit occurs in the standard new Keynesian model in which the interest rate path is rather odd, and the consumption response is very different from what is observed in the data. The model does appear to be consistent with the main features of the inflation response but this is due to the rather odd interest rate path and comes at the cost of the poor fit to the consumption dynamics.

The impression of the superior fit of the deep habits model is confirmed by the minimized value of the quadratic form reported in the last row of Table 2. The deep habits model attains a minimum of the quadratic form that is 40 percent lower than the aggregate habits model and

70 percent lower than the standard new Keynesian model. The parameters estimated with the standard new Keynesian model are rather absurd. In particular, this model implies an extremely high cost of changing nominal prices while the estimate of the nominal wage rigidity is moderate. The former of these findings echo results in Ireland (2001). For that reason, we concentrate the discussion on two habit formation models.

The point estimate of the key deep habits parameter, θ^d, is 0.852. Interestingly, when we instead assume a standard aggregate habit model, we find a very similar point estimate of the aggregate habit parameter, $\theta^a = 0.826$. The associated standard errors are in both cases very small. Thus, the two models have very similar implications for how habits affect the intertemporal allocation of consumption but as we have seen lead to very different implications for the dynamics of inflation.

The most interesting parameters apart from those relating to habits, are those that relate to the extent of nominal rigidities. The estimates of ζ_p and ζ_w are much lower in the deep habits economy relative to the aggregate habit model. When we allow for deep habits we find that $\zeta_p = 14.5$ and that $\zeta_w = 41$. In the aggregate habits economy instead we find more than twice as high estimates of both parameters, $\zeta_p = 31$ and $\zeta_w = 103$. Thus, not only does the deep habits model account better for the dynamic adjustment of prices in response to a monetary policy shock, but it does so relying on smaller impediments to price and wage adjustment. Notice also that both of the habit models gives estimates of ϑ_p that imply full indexation of prices while the models disagree on the extent of wage indexation.

The monetary policy function parameter estimates imply a great deal of interest rate smoothing with a point estimate of ρ_R of 0.74 in the deep habits economy and 0.85 when assuming aggregate habits. However, the relative weight on inflation varies quite substantially across the two models with the deep habits model being consistent with a more hard nosed anti-inflationary central bank reaction function.

Recall that the impulse responses illustrated in Figures 2-4 do not correspond directly to the impact of a monetary policy shock in the model since they are measured subject to the VAR filter. In order better to understand the results, we now examine the exact impulse responses of the two habits models. These are illustrated in Figure 5 and 6. The exact impulse responses for the aggregate habits model confirm the lack of a good fit to the inflation process. In fact, in this model the inflation rate rises slightly upon impact and reaches its peak two years after the cut in the interest rate. Moreover, the consumption response is much more muted according to the

exact impulse responses than the VAR-based impulse responses. The deep habits model instead paints a different picture. For this model the consumption and interest rate paths according to the VAR-based measurement are as good as identical to the exact impulse responses. The exact impulse responses of the inflation dynamics instead indicate an even larger price puzzle than the VAR based results. This is interesting since it implies that the price puzzle does not seem to be caused by measurement.

The adjustment of markups is the key difference between the two habit models. To see better the impact of introducing deep habits, Figure 7 illustrates the paths of the markup in response to a monetary policy shock. We plot three markup paths. The first two correspond to the responses of markups in the deep habits and aggregate habits economies using the parameter estimates reported in Table 2. The third path corresponds to the impulse response of the markup using the parameter estimates of the deep habits economy but setting θ^a equal to the corresponding estimate for the deep habit and setting the deep habits parameter to zero. Comparing the first and third paths of the markup thus tells us the impact of allowing for deep habits rather than the standard aggregate habit assuming that all other parameters are unchanged.

Comparing the paths of the markup when assuming common parameters so that the two economies differ only in the modeling of habits illustrates that the deep habits mechanism gives rise to a much steeper decline in the markup in response to the monetary policy shock than the standard aggregate habit model. The reason for this is that the producers in the deep habit economy find it optimal to lower the markup in response to the increase in current demand (which increases the price elasticity of demand) and the expectation of future consumption growth (which makes future market share valuable) that take place following the decline in the interest rate. This leads to a period of declining inflation despite the monetary injection. As time goes by, current consumption and habitual consumption become aligned and future consumption growth declines. This reverses producers' incentive to lower the markup and at this point prices start rising rather fast. This mechanism brings about a persistent increase in the inflation rate which matches the response of inflation observed in the US data.

Recall that the estimates of the costs of changing prices and wages are lower when we allow for deep habits than in the standard aggregate habit economy (see Table 2). Despite this, the markup declines more in the deep habits economy than in the aggregate habit economy when we allow for differences in parameter values. This shows that the deep habits mechanism and nominal rigidities are complementary in terms of giving rise to a prolonged period of low markups

after the monetary policy shock. The presence of nominal rigidities thus creates a role for deep habits in accounting for the dynamic impact of monetary policy shocks while the introduction of deep habits implies less need for extreme degrees of impediments to the adjustment of prices and wages.

4.1   Constrained Markup

One worry with the results discussed above is that the markup in the deep habits model may be somewhat large and is far too small in the standard new Keynesian model. In the deep habits model the steady-state markup is given as:

$$\mu = \left[\frac{\eta - 1}{\eta} - \frac{1 - \beta}{\eta} \frac{\theta^d}{\left(1 - \theta^d\right)} \right]^{-1} > \frac{\eta}{\eta - 1}$$

while in the two alternative models the steady-state markup is $\frac{\eta}{\eta-1}$. Thus, given the point estimates in Table 2, the steady-state markup in the standard new Keynesian model is approximately 0, it is 24 percent in the standard habit model, while it is as high as 74 percent in the deep habits model.

In Table 3 we report the parameter estimates when we constrain the markup to be 50 percent. In the deep habits economy we introduce this restriction by allowing θ^d to be estimated and then imposing the value of η that is consistent with a 50 percent markup. In the other two economies we instead impose $\eta = 3$ directly.

Introducing this restriction leads to much more reasonable estimates of the degree of nominal rigidities for the standard new Keynesian model but its fit is still much worse than any of the two alternative models. The parameters of the two habit economies are to a large extent unchanged. In particular, the estimates of θ^d and θ^a are very similar to those reported in Table 2 and still indicate significant habit effects. We find a slight drop in the estimate of the extent of nominal rigidities in the deep habits economy but the parameters now appear more precisely estimated. In the aggregate habits economy instead, the estimate of ζ_p falls but we obtain an even higher estimate of ζ_w. Most importantly, according to the quadratic form, the deep habits model still provides a much better fit to the data than the standard habit model.

Figure 8 illustrates the VAR based impulse responses for the constrained version of the deep habits model. We note that the results are approximately unchanged relative to those shown in Figure 3. Thus, our results do not derive from unreasonable assumptions regarding the markup.

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4.2 Sub-Sample Stability

During the sample period US monetary policy has undergone fundamental changes. These changes have elsewhere been shown to have given rise to important changes in the monetary reaction function and it has also been claimed that these structural changes are partially responsible for price puzzle and for the extent of the inflation puzzle. Therefore, it is potentially an important issue to take into account as far as the current exercise is concerned.

Perhaps the most fundamental change in US monetary policy took place in August 1979 when Volcker took office at the Federal Reserve. His chairmanship marked the beginning of a less accommodating US monetary policy regime which has been associated with a decline in the US inflation rate. For this reason we now examine the consequences of allowing for a structural change that takes place in the third quarter of 1979. To be precise, we reestimate the empirical VAR by splitting the sample into a pre-1979:3 sample and a post-1979:2 sample. We then reestimate the structural parameters and examine the extent to which the change in monetary policy affects our results.

The parameter estimates relating to the sub-samples are reported in Table 4. The key message from this table is that although we find changes in some parameters, the estimates of the deep habits parameter are constant across sub-samples and very similar to the full sample results.

Parameter instability relates instead mainly to (a) the parameters relating to the monetary policy reaction function, and (b) the parameters that determine the extent of nominal rigidities. As far as the interest rate rule is concerned, the late sub-sample is associated with a hard nosed interest rate rule which depends on inflation only while the early sample was characterized by accommodating monetary policy with a large weight associated with fluctuations in output. We also find some decline in the extent of interest rate smoothing. In terms of nominal rigidities we find that the extent of rigidity of prices has increased over time while wages have become more flexible. These results square well with conventional wisdom.

Figure 9 shows the impact of a monetary policy shock in the late sub-sample. We find a smaller price puzzle and a less persistent impact of monetary policy shocks on the inflation rate in recent sub-sample relative to the full sample. However, the post-1979:3 sub-sample still implies a negative impact response of an expansionary monetary policy shock on the inflation rate, and the peak response of inflation still occurs as late as 10 quarters after the monetary loosening. Importantly, the deep habits model provides a good fit to the observed dynamic impact of

monetary policy shocks even in the late sub-sample. We conclude from this that although the extent of the price puzzle and the inflation persistence puzzle are related to structural changes, the deep habits mechanism is key for understanding the dynamic impact of monetary policy shocks.

5 Conclusions

In this paper we have asked whether a parsimonious sticky-price sticky wage model extended with deep habits can account for the dynamic effects of monetary policy shocks. We find that this is indeed the case. In particular, when allowing for customer market effects modeled through deep habits, one can simultaneously account for the persistent effects of monetary policy shocks on aggregate consumption and for the impact on inflation. One important aspect of our results is that the introduction of deep habits allows one to account for the price puzzle and for inflation persistence without relying on unreasonable extents of nominal rigidities. The reason for this is that nominal rigidities in the form of impediments to price and wage adjustments and deep habits are complementary. The existence of nominal rigidities introduces a role for deep habits in accounting for the impact of monetary policy shocks and the countercyclical nature of markups that derive from deep habits decreases the need for nominal rigidities when accounting for the sluggish adjustment of inflation to monetary policy shocks. We have also shown that while inflation persistence and the price puzzle were more pronounced pre-Volcker, the importance of the deep habit mechanism has remained constant over time. In that sense, our paper points towards structural reasons for the impact of monetary policy shocks on inflation.

Our results indicate that more attention should be directed towards goods market features when examining the impact of monetary policy shocks. The previous literature has examined in great detail how marginal cost persistence, backward looking price setting, and labor market frictions impact on monetary policy, but much less attention has been paid to goods market features which we here have shown to be key. We think that this may also have important implications for issues relating to optimal monetary policy design but we leave this issue for future research.

6 References

Benati, Luca, 2008, "Investigating Inflation Persistence Across Monetary Regimes", **Quarterly Journal of Economics** 123(3), 1005-60.

Brissimis, Sophocles N., and Nicolas S. Magginas, 2006, "Forward-looking Information in VAR Models and the Price Puzzle", **Journal of Monetary Economics** 53(6), 1225-34.

Castelnuovo, Efrem, and Paolo Surico, 2006, "The Price Puzzle: Fact or Artefact", Bank of England Working Paper no. 288.

Chari, Varadarajan V., Ellen McGrattan and Patrick J. Kehoe, 2000, "Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem?", **Econometrica** 68(5), 1151-80.

Christiano, Lawrence J, Martin Eichenbaum and Charles Evans, 2005, "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy", **Journal of Political Economy** 113, 1-45.

Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin, 2000, "Optimal Monetary Policy with Staggered Wage and Price Contracts", **Journal of Monetary Economics** 46(2), 281-313.

Fuhrer, Jeffrey and Gerald Moore, 1995, "Inflation Persistence", **Quarterly Journal of Economics** 110, 127-160.

Galí, Jordi and Mark Gertler, 1999, "Inflation Dynamics: A Structural Econometric Analysis", **Journal of Monetary Economics** 44, 195-222.

Hall, Alastair, Atsushi Inoue, James N. Nason, and Barbara Rossi, 2007, "Information Criteria for Impulse Response Function Matching Estimation of DSGE Models", manuscript, Duke University.

Hanson, Michael S., 2004, "The "Price Puzzle" Reconsidered", **Journal of Monetary Economics** 51(7), 1385-1413.

Holden, Steinar, and John C. Driscoll, 2003, "Inflation Persistence and Relative Contracting", **American Economic Review** 93(4), 1369-72.

Ireland, Peter N., 2001, "Money's Role in the Monetary Transmission Mechanism", NBER working paper no. 8115.

Levin, Andrew T., and Jeremy Piger, 2003, "Is Inflation Persistence Intrinsic in Industrial Economies?", working paper no.2002-023, Federal Reserve Bank of st. Louis.

Rabanal, Pau, and Juan F. Rubio-Ramirez, 2003, "Inflation Persistence: How Much Can We Explain?", **Federal Reserve Bank of Atlanta Economic Review**, Second Quarter, 43-55.

Ravn, Morten O., Stephanie Schmitt-Grohe and Martin Uribe, 2006, "Deep Habits", **Review of Economic Studies** 73(1), 195-218.

Ravn, Morten O., Stephanie Schmitt-Grohe and Martin Uribe, 2008, "Explaining the Effects of Government Spending on Consumption and the Real Exchange Rate", manuscript, EUI and Columbia University.

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

Sims, Christopher A., 1992, "Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy", **European Economic Review** 36, 2-16.

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

Steinsson, Jon, and Emi Nakamura, 2008, "Price Setting in Forward Looking Customer Markets", manuscript, Columbia University.

Table 1: Calibrated Parameters

Parameter	Meaning	Calibration
γ	Weight on distuility of work	Calibrated to imply $\overline{h} = 0.3$
β	subjective discount factor	Calibrated to imply quarterly real interest rate of 1 percent
π^*	Steady-state gross inflation rate	1
ψ	Labor demand elasticity	4
κ	Inverse of labor supply elasticity	0.5
σ	Inverse of intertemporal elasticity of substitution	3

Table 2: Estimated Parameters

Parameter	Deep Habits		Aggregate Habit		No Habit	
	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error
η	2.48	0.27	5.18	0.03	10134	281.22
ζ_p	14.47	1.82	31.00	0.003	476040	378.33
ϑ_p	0	0.04	0	0.01	0	0.03
ζ_w	40.89	81.83	102.94	0.001	2.25	0.12
ϑ_w	0.96	1.72	0	0.01	0.14	0.01
θ^d	0.85	0.002	-		-	
θ^a	-		0.83	0.001		
ρ_R	0.74	0.01	0.85	0.002	0.86	0.02
α_y	0.04	0.01	0.48	0.02	1	0.34
α_π	1.26	0.02	1.01	0.01	1.01	0.08
υ	0.96	0.09	0.51	0.05	0.40	0.04
Value of quadratic form	79.16		127.81		249.04	

Table 3: Estimated Parameters with Constrained Markup

Parameter	Deep Habits Estimate	Deep Habits Std. error	Aggregate Habit Estimate	Aggregate Habit Std. error	No Habit Estimate	No Habit Std. error
η	3.19		3		3	
ζ_p	10.18	0.30	24.23	0.28	33.72	135.5
ϑ_p	0	0.01	0	0.003	0	0.01
ζ_w	31.29	8.65	188.3	0.04	34.20	137.25
ϑ_w	0.99	0.25	0	0.01	0	0.01
θ^d	0.86	0.001	-		-	
θ^a	-		0.88	0.001	-	
ρ_R	0.74	0.004	0.77	0.004	0.76	0.02
α_y	0	0.01	0	0.005	0	0.09
α_π	1.49	0.02	1.01	0.01	1.01	0.13
υ	0.90	0.09	0.93	0.09	0.61	0.06
Value of quadratic form	81.95		158.32		261.83	

	Model					
	Deep Habits		Aggregate Habit		No Habit	
Parameter	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error

Table 4: Sub-Sample Stability

Parameter	Sample			
	1954:2-1979:2		1979:3-2008:2	
	Estimate	Std. error	Estimate	Std. error
η	3.91	0.84	5.76	1.42
ζ_p	6.36	4.99	10.53	14.06
ϑ_p	0.00	0.75	0.00	0.62
ζ_w	7.73	75.08	3.47	9.15
ϑ_w	1.00	0.83	0.95	1.77
θ^d	0.89	0.003	0.90	0.003
ρ_R	0.74	0.02	0.66	0.01
α_y	1.00	0.12	0	0.01
α_π	1.01	0.04	2.14	0.11
υ	0.74	0.07	0.93	0.09

Figure 1: The impact of a 1 standard error decline in the federal funds rate in the US
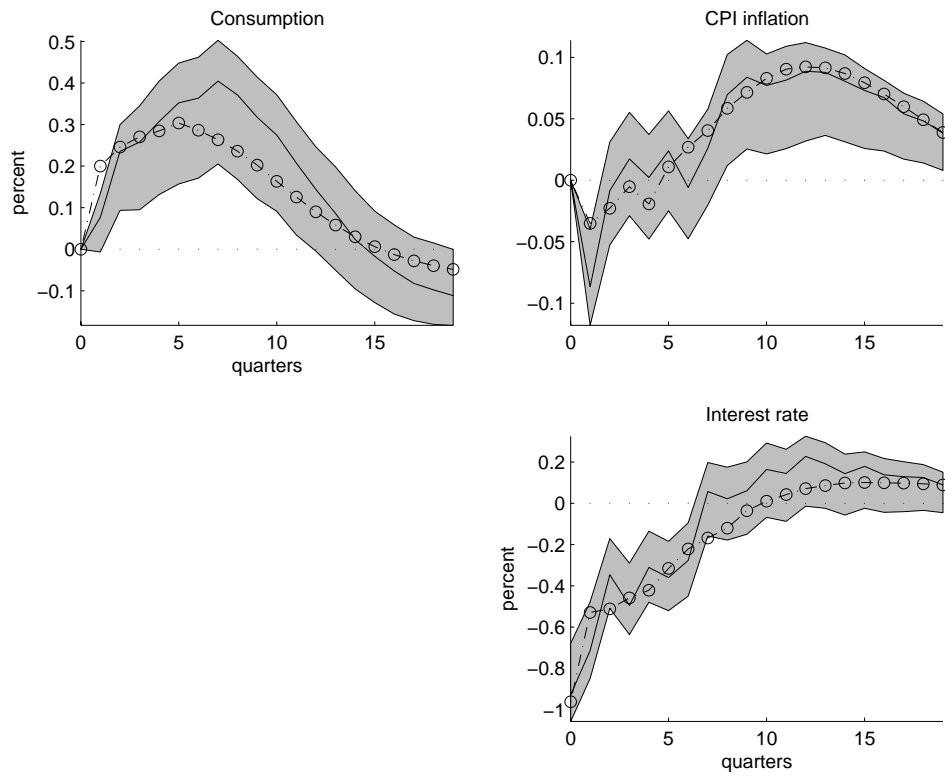
Figure 2: The VAR based impulse responses to a monetary policy shock in the deep habits model.
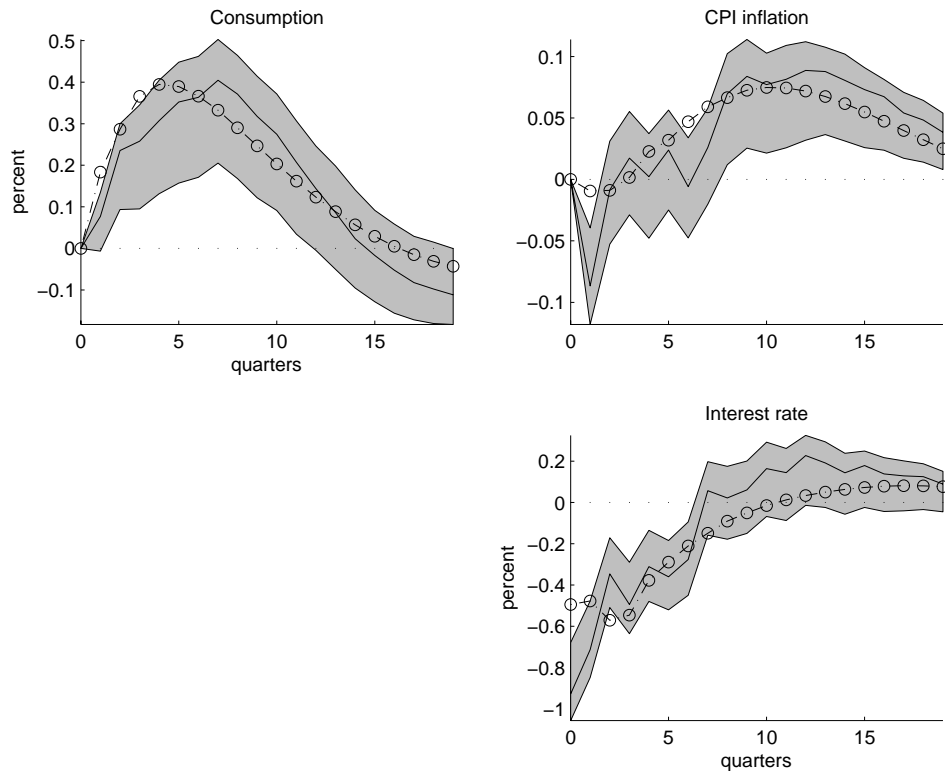
Figure 3: The VAR based impulse responses to a monetary policy shock in the aggregate habits model
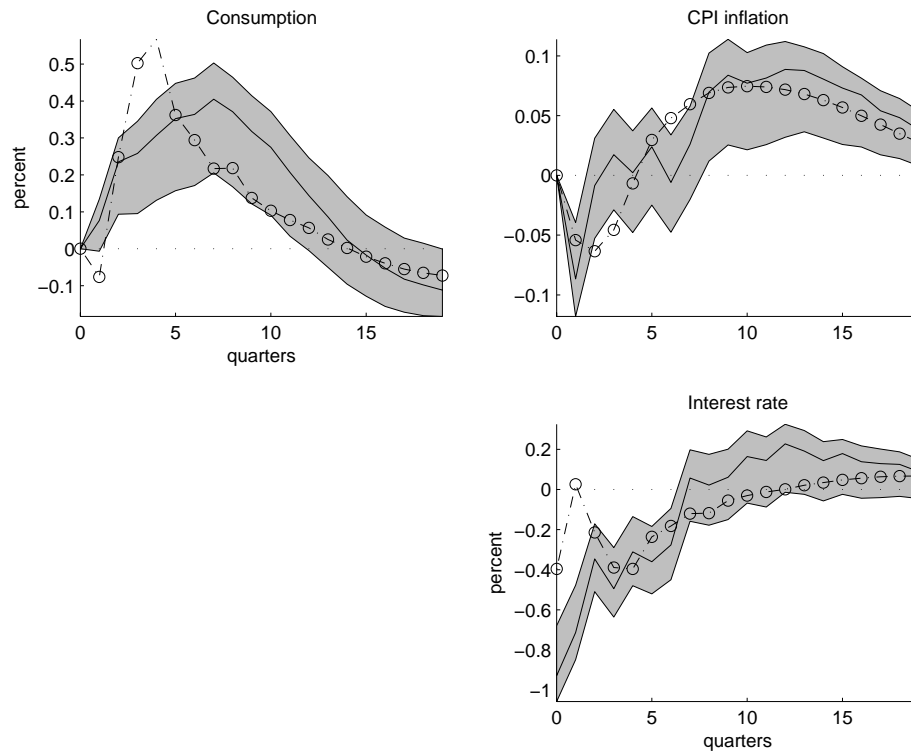
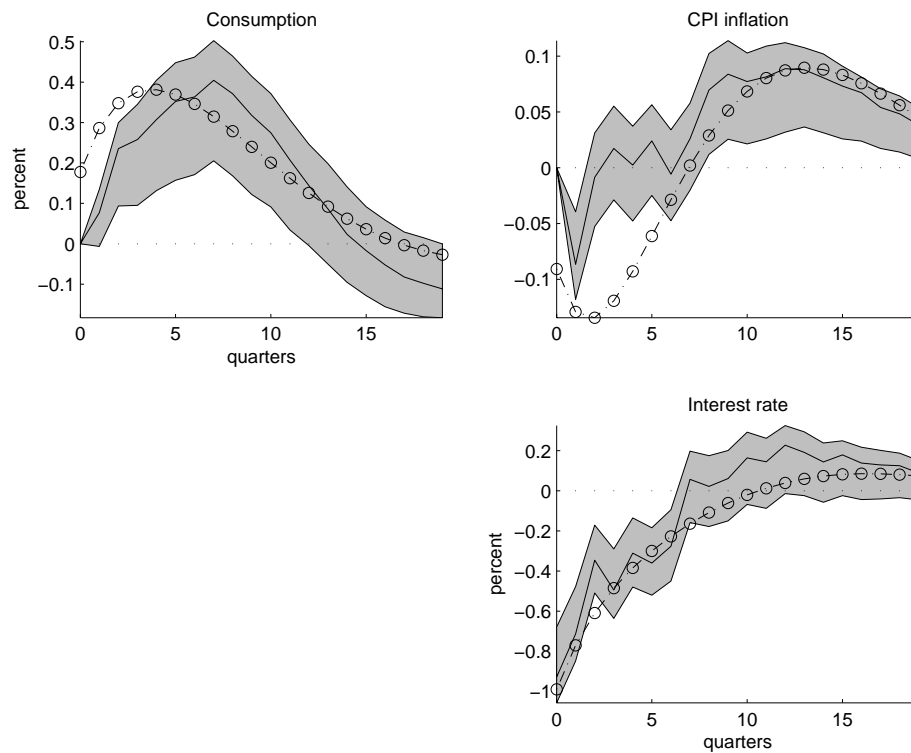Figure 4: The VAR based impulse responses to a monetary policy shock in the model with no habits

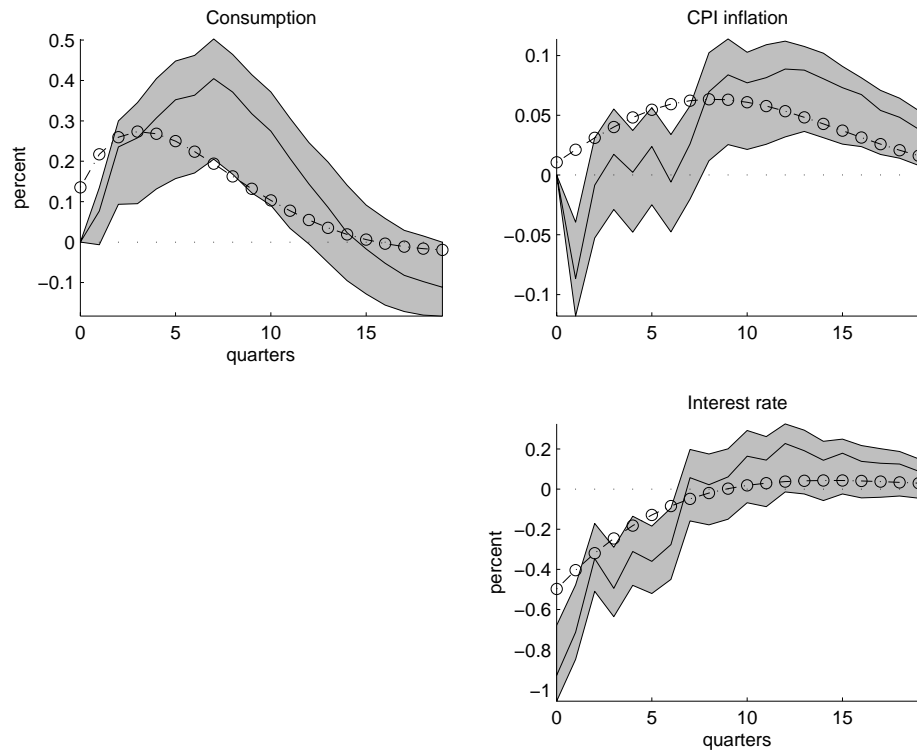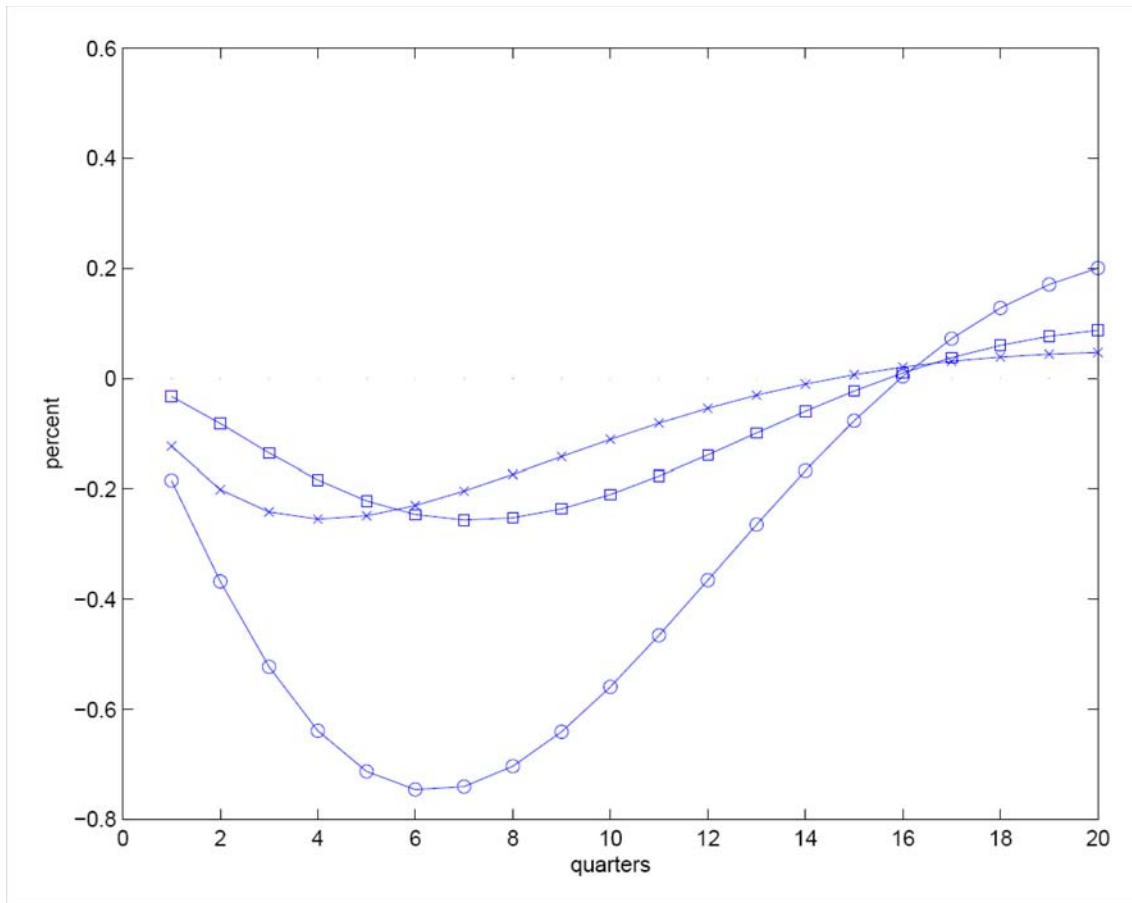Figure 5: The exact impulse responses to a monetary policy shock in the deep habits model.

Figure 6: The exact impulse responses to a monetary policy shock in the aggregate habits model.

Figure 7: Markup dynamics (line with circles: Deep habits; Line with crosses: Aggregate habit model using deep habit parameter estimates; Line with boxes: Aggregate habit model with aggregate habit parameters)
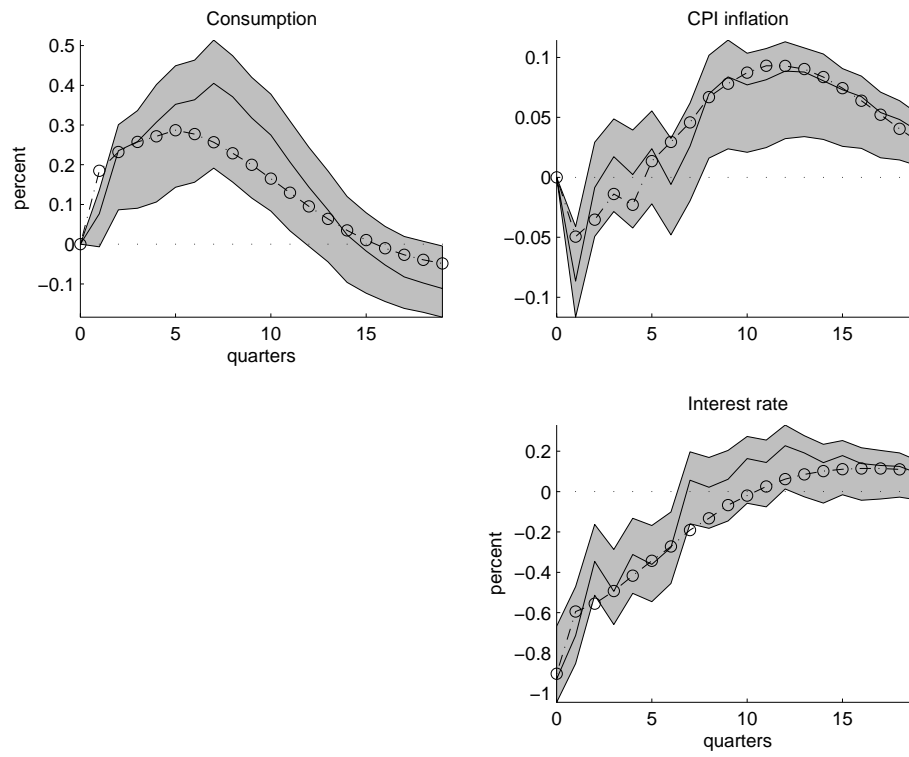
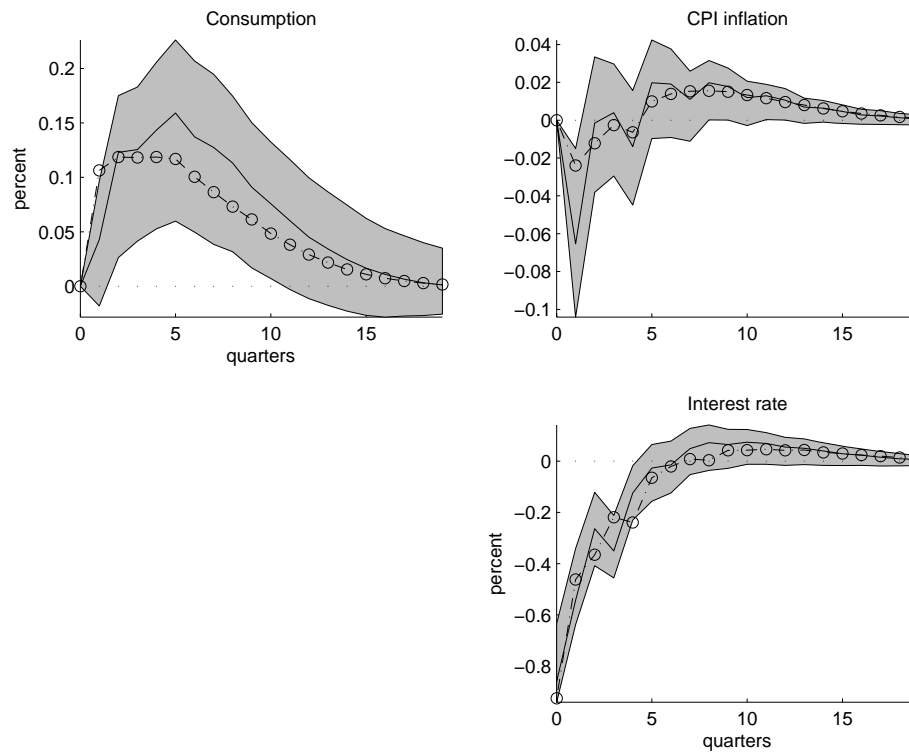Figure 8: The VAR based impact of a monetary policy shock in the deep habits economy with a contrained markup

Figure 9: The VAR based impact of a monetayr policy shock in the deep habits economy: Post 1979:2 sample