J. Japanese Int. Economies 24 (2010) 236–258

Contents lists available at ScienceDirect

Journal of The Japanese and International Economies

journal homepage: www.elsevier.com/locate/jjie

Deep habits and the dynamic effects of monetary policy shocks ☆

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ARTICLE INFO

Article history:
Received 2 January 2009
Revised 24 November 2009
Available online 23 December 2009

JEL classification:
E21
E31
E32
E52

Keywords:
Deep habits
Monetary policy
Price puzzle
Inflation persistence
Countercyclical markups

ABSTRACT

Ravn, Morten O., Schmitt-Grohė, Stephanie, Uribe, Martín, and Uuskula, Lenno—Deep habits and the dynamic effects of monetary policy shocks

We introduce deep habits into a sticky-price sticky-wage economy and examine the resulting models ability to account for the impact of monetary policy shocks. The deep habits mechanism gives rise to countercyclical markup movements even when prices are flexible and interacts with nominal rigidities in interesting ways. Key parameters are estimated using a limited information approach. The deep habits model can account very precisely for the persistent impact of monetary policy shocks on aggregate consumption and for both the price puzzle and inflation persistence. A key insight is 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. The results are shown to be stable over time and not caused by monetary policy changes. *J. Japanese Int. Economies* **24** (2) (2010) 236–258. Department of Economics, University College London, Drayton House, Gordon Street, London SW1E 6BT, UK; Department of Economics, Columbia University, 1109A International Affairs Building,

☆ This paper was prepared for the 2008 CEPR/NBER/TCER TRIO conference in Tokyo. We are grateful for comments from the editor, an anonymous referee, Alexander Kriwoluzky, and from seminar participants at the TRIO conference and at the European University Institute.

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doi:10.1016/j.jjie.2009.12.002

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1. Introduction

A substantial body of research has studied the dynamic impact of monetary policy shocks using vector autoregression based methods. This literature has demonstrated that monetary policy shocks identified with timing assumptions give rise to persistent effects on output and its components but also that the dynamic effects on prices 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 two findings are termed 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 impact of monetary policy shocks. We extend a standard sticky-price sticky-wage model with goods-specific ("deep") habits which gives rise to a theory of time-varying markups even in the absence of nominal rigidities. We demonstrate that this mechanism gives rise to a model that can provide a very precise account of the dynamic effects of monetary policy shocks and which can address both of price puzzle and the inflation persistence puzzle.

According to the standard "New Keynesian Phillips curve" inflation is determined by current marginal costs and by expected future inflation. The purely forward looking feature of this relationship implies a lack inflation persistence.[1] A large number of papers have addressed this issue by studying mechanisms that either give rise to persistent movements in marginal costs or that introduce backward looking features into the New Keynesian Phillips curve. Galí and Gertler (1999) allow for the coexistence of forward looking and backward looking price setters. The presence of backward looking price setters introduces a lagged inflation term in the Phillips curve and therefore helps explaining the sluggish adjustment of inflation to monetary policy shocks. Fuhrer and Moore (1995) study a relative contracting model in which workers care about other workers' past real wages and they show that this feature may help explain sluggish inflation adjustments to monetary policy shocks.[2] Erceg et al. (2000) assume that nominal wages as well as prices adjust sluggishly. Christiano et al. (2005), Rabanal and Rubio-Ramirez (2003) and Smets and Wouters (2003) have shown that the combination of sticky prices and sticky wages is helpful for accounting for inflation persistence. There has been less theoretical work on the price puzzle an exception being Castelnuovo and Surico (2006) who study a model in which passive policy gives rise to indeterminacy. When the equilibrium is indeterminate, inflation expectations become very persistent and this has the consequence that a structural VAR can erroneously 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 et al. (2006). The deep habits model assumes that households are subject to keeping up with the Joneses effects at the level of *individual* goods varieties. This feature implies that the demand function facing individual producers depends not only on relative prices and on the level of aggregate demand but also on the firm's past sales. The impact of past sales on current demand, often referred to as state dependence, captures empirically relevant aspects of goods demand functions. Houthakker and Taylor (1970) studied goods level demand functions and found that past sales are key for determining current consumption of goods.

[1] This result holds in Calvo style sticky price models and in models where there are costs of changing prices. Chari et al. (2000) show that it 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 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.

Guadagni and Little's (1983) seminal scanner data study of ground coffee purchases documented a large predictive power of past brand choices on current brand choices, a finding reproduced by many researchers when studying brand demand functions, see Chintagunta et al., 2001 for a recent discussion and survey. Browning and Collado (2007) study goods level consumption demand functions controlling for unobserved consumer heterogeneity and for goods-level habits at the household level and find significant habit effects for a substantial number of goods.

According to the deep habits model, markups are time-varying even when prices are flexible. The non-constancy of the optimal markup derives from an elasticity effect and an intertemporal effect. The elasticity effect is induced by variations in aggregate demand that affect the price elasticity of demand facing producers. In our model, an increase in current aggregate demand increases the price elasticity and therefore leads producers to lower markups. The intertemporal effect arises because a producer who expects high future demand will have an incentive to lower the current markup in order to attract more future demand. Ravn et al. (2006, 2007) have shown that these mechanisms are helpful for understanding the impact of technology shocks and of government spending shocks. In the current paper we argue that deep habits is also an interesting mechanism when accounting for the impact of monetary policy shocks and that it interacts in an intriguing manner with nominal rigidities to produce a model that leads to substantial price inertia even when nominal rigidities are moderate.

We first estimate a VAR on post-war US data and derive the impact of a timing-based identified monetary policy shock. We study a small scale 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 in order not to bias our results towards the existence of a price puzzle.[3] The VAR measurements of the dynamic effects of a monetary policy shock conform with the conventional wisdom regarding inflation persistence and the price puzzle: the price level drops for two quarters after an expansionary monetary policy shock and the maximum increase in inflation appears as late as 3 years after the initial expansion of monetary policy. We also find that aggregate consumption increases persistently 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 deep habits model with the predictions of a standard New Keynesian model and a New Keynesian model that allows for habits in aggregate consumption. This latter economy differs from the deep habits model in that aggregate habits do not lead to time-variation in markups when prices are flexible. 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.

We show that the model implies a complementarity between nominal rigidities and deep habits. 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 itself gives rise to a smaller inflation impact of an expansionary monetary policy shock in the deep habits economy than in models that assume either no habits or 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.

Parts of the literature has pursued the idea that the inflation persistence puzzle is not "structural" but caused by changes over time in monetary policy and by 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). We repeat our analysis for two

[3] A common argument is that the price puzzle is reflects misspecification of VAR models in the sense that it is important to include variables that are forward looking. Following Sims (1992) much of the literature has addressed this point by augmenting VARs with the commodity price index.

sub-samples breaking the data in the third quarter of 1979 when Volcker became the chairman of the Fed. We find that the early sub-sample is associated with more pronounced price and inflation puzzles than the late sample. We 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.

The remainder of the paper is structured as follows. Section 2 describes the model. Section 3 contains the details of the structural estimation approach and also applies a structural VAR estimator to US quarterly data. Section 4 analyses the results. Finally, Section 5 concludes.

2. The model

We consider an economy with monopolistically competitive firms and households that act as monopolistically competitive suppliers of labor. Firms and households face costs of changing nominal prices and wages, respectively. The key contribution of the paper is the introduction of the deep habits model of Ravn et al. (2006) into the monetary economy.

2.1. Households

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

Households are subject to good-specific habits as in the external deep habits model of Ravn et al. (2006). Specifically, the marginal utility of the consumption of *individual* goods varieties is subject to a consumption externality specified as catching up with the Joneses. Household j consumes a basket of goods, c^j_{it}, $i \in [0, 1]$ and supplies labor to the firms. Preferences are given as[4]:

$$V^j_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} (x^j_t)^{1-\sigma} - \frac{\gamma}{1+\kappa} (h^j_t)^{1+\kappa} \right] \tag{1}$$

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

$$c_{it} = \int_0^1 c^j_{it}\, dj \tag{3}$$

where $\mathbb{E}_t$ 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, and h^j_t denotes the household j's labor supply in period t.

x^j_t is the consumption basket from which the household derives utility. According to Eq. (2), the consumption basket is a CES-aggregate of "habit adjusted" consumption levels of a continuum of differentiated goods. We model the habit relating to the consumption of *variety i* as the past *aggregate* consumption of this *variety*. The household take c_{it}, as given. The parameter $0 \leqslant \theta^d < 1$ 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.[5]

[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.

[5] Ravn et al. (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. Steinsson and Nakamura (2008) examine pricing implications of this specification.

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

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

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 defined as:

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

According to the demand function in Eq. (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 past aggregate demand for the good.

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 demand of household j, 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:

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

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

and subject to a no-Ponzi game restriction.

The household budget constraint assumes that the household has access to a nominal risk free bond which allows it to smooth 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.[6]

The last term on the right-hand side of the budget constraint denotes nominal costs of adjusting nominal wages. $\zeta_w \geqslant 0$ 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 $\widetilde{\pi}_{wt}$ 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 degree of wage indexation. When $\vartheta_w = 1$ households can costlessly adjust 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, $\pi_{wt-1} = W_{t-1}/W_{t-2}$.

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

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) and (7) taking as given $P_t,\ \vartheta_t, W_0^j,\ R_t$, and Φ_t^j. The first-order conditions are:

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

$$\psi\lambda_{j,t}^h h_t^j\left(x_t^j\right)^{\sigma} = h_t^j\frac{W_t^j}{P_t} - \zeta_w\frac{W_t^j}{W_{t-1}^j}\left(\frac{W_t^j}{W_{t-1}^j} - \widetilde{\pi}_{wt}\right) + \beta\zeta_w\mathbb{E}_t\frac{W_{t+1}^j}{W_t^j}\left(\frac{W_{t+1}^j}{W_t^j} - \widetilde{\pi}_{wt+1}\right)\left(\frac{x_{t+1}^j}{x_t^j}\right)^{-\sigma} \tag{9}$$

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

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

We note from (8)–(10) that the labor supply decision and the intertemporal consumption allocation are affected by the presence of habits in the consumption aggregator. Eq. (9) is a forward looking "wage setting curve". When wages are flexible ($\xi_w = 0$), Eqs. (8) and (9) imply that the household sets the real wage as a fixed markup over the marginal rate of substitution between labor and consumption. The markup is given as $\psi/(\psi-1) \geqslant 1$.[7] Eq. (10) is the intertemporal Euler equation.

2.2. Firms

Firms produce differentiated goods and are 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:

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

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. 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 defined as:

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

Aggregating (12) across firms gives (6).

The demand for firm i's product is found by aggregating Eq. (4) across consumers:

$$c_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta}x_t + \theta^d c_{it-1} \tag{13}$$

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

$$x_t = \int_0^1 x_t^j\,dj$$

The demand function facing firm i at date t depends on the firm's past sales of its product whenever $\theta^d > 0$. This feature of the demand function implies that firms will set non-constant markups even in the absence of nominal rigidities.[8] An increase in current demand, x_t, over habitual demand (c_{it-1}),

[7] 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 does not affect our results.

[8] 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.

increases the price elasticity of the demand facing the firm and this gives firms an incentive to lower the mark-up. Moreover, firms will lower markups when they anticipate high value of future market share.

Firm i sets the price of its product, P_{it}, by maximizing profits 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. $c_{it} \geqslant y_{it}$. Following Rotemberg (1982), we assume that there are quadratic adjustment costs associated with changing nominal prices. Firms face the following profit maximization problem:

$$\max_{P_{it}} \mathbb{E}_0 \sum_{t=0}^{\infty} q_t \Phi_{it} \tag{14}$$

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

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 (the households) discount the stream of nominal profits. This discount factor is given as[9]:

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

$\zeta_p \geqslant 0$ parametrizes the extent of nominal rigidities. When $\zeta \to 0$ prices are flexible while positive values of ζ implies that firms have an incentive to smooth price changes over time. The term $\widetilde{\pi}_t$ is assumed to 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:

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

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

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

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 ($\zeta_p = 0$), Eqs. (17) and (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. Consider the two special cases when either prices are flexible or there are no deep habits. In these special cases, Eqs. (17) and (18) can be expressed as:

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

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

When there are deep habits but prices are flexible, firms will vary the markup in response to changes in current aggregate demand and in response to expected changes in future consumption growth. When prices are sticky but there are no deep habits, firms smooth price increases over time in response to changes in marginal costs or in aggregate demand. When these two mechanisms are com-

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

bined, firms will vary markups in order to smooth price increases but taking into account that the optimal (flexible price) markup is affected by changes in aggregate demand and in expected future consumption growth.

2.3. Monetary policy

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

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

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:

$$x_t = c_t - \theta^d c_{t-1} \tag{20}$$
$$\gamma h_t^\kappa = x_t^{-\sigma} w_t - \lambda_t^h \tag{21}$$
$$\psi \lambda_t^h h_t x_t^\sigma + \zeta_w \pi_{wt}(\pi_{wt} - \widetilde{\pi}_{wt}) = h_t w_t + \beta \zeta_w \mathbb{E}_t \pi_{wt+1}(\pi_{wt+1} - \widetilde{\pi}_{wt+1}) \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \tag{22}$$
$$x_t^{-\sigma} = \beta R_t \mathbb{E}_t x_{t+1}^{-\sigma} \frac{1}{\pi_{t+1}} \tag{23}$$
$$c_t = h_t - \frac{\zeta_p}{2}(\pi_t - \widetilde{\pi}_t)^2 - \frac{\zeta_w}{2}(\pi_{wt} - \widetilde{\pi}_{wt})^2 \tag{24}$$
$$\lambda_t^y = w_t \tag{25}$$
$$\lambda_t^y + \lambda_t^c = 1 + \theta^d \beta \mathbb{E}_t \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \lambda_{t+1}^c \tag{26}$$
$$\eta \lambda_t^c x_t + \zeta_p \pi_t(\pi_t - \widetilde{\pi}_t) = c_t + \beta \zeta_p \mathbb{E}_t \frac{x_{t+1}^{-\sigma}}{x_t^{-\sigma}} \pi_{t+1}(\pi_{t+1} - \widetilde{\pi}_{t+1}) \tag{27}$$
$$R_t - R^* = \rho_R(R_{t-1} - R^*) + (1-\rho_R)\left[\alpha_\pi(\pi_t - \pi^*) + \alpha_y\left(\frac{y_t - y^*}{y^*}\right)\right] + \varepsilon_t \tag{28}$$
$$\widetilde{\pi}_t = \vartheta_p \pi^* + (1 - \vartheta_p)\pi_{t-1} \tag{29}$$
$$\widetilde{\pi}_{wt} = \vartheta_w \pi_w^* + (1 - \vartheta_w)\pi_{wt-1} \tag{30}$$
$$w_t = w_{t-1} + \pi_{wt} - \pi_t \tag{31}$$

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 Eq. (27). The log-linearized version of this equation can be expressed as:

$$\widehat{\pi}_t = \frac{(1-\vartheta_p)}{1+\beta(1-\vartheta_p)}\widehat{\pi}_{t-1} + \frac{\beta}{1+\beta(1-\vartheta_p)}\mathbb{E}_t\widehat{\pi}_{t+1} + \psi_1\widehat{mc}_t + \psi_2(\mathbb{E}_t\widehat{c}_{t+1} - \widehat{c}_t) - \psi_3(\widehat{c}_t - \widehat{c}_{t-1}) - \psi_4\mathbb{E}_t\widehat{\lambda}^c_{t+1} \tag{32}$$

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

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

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

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

$$\psi_4 = \theta^d\beta/\left(\zeta_p\frac{\overline{\pi}^2}{\overline{c}}(1+\beta(1-\vartheta_p))\right)$$

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

In the absence of deep habits and when prices are not indexed ($\theta^d = 1-\vartheta_p = 0$), Eq. (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 moderates 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 $\mathbb{E}_t\widehat{\lambda}^c_{t+1}$ and $(\mathbb{E}_t\widehat{c}_{t+1} - \widehat{c}_t)$. Particularly interesting is the implication that an increasing in the expected marginal value of future demand $(\mathbb{E}_t\widehat{\lambda}^c_{t+1})$ has a negative impact on current inflation as it gives firms an incentive to lower the markup in order to capture a higher future market share.

3. Estimation

In this section we provide empirical evidence on the dynamic effects of a monetary policy shock and we discuss our approach to estimating the key parameters of the model presented in the preceding section.

3.1. SVAR estimates of the impact of monetary policy shocks

We study US quarterly data for the sample period 1954:2–2008:2. The dynamic effects of monetary policy shocks are estimated using a structural VAR estimator. Consider the following reduced form VAR:

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

where x_t is a vector of observables, $B(L)$ 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 logarithm of the commodity price index divided by the CPI, 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 deseasonalized.

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 et al. (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 $A_i,\ i = 0, \ldots, p$, 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). We allow for constant terms and trends when estimating the VAR and we assume that $p = 8$ (but shorter lag structures give almost identical results).

The impulse responses to the identified monetary policy shock are illustrated in Fig. 1. 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% (bootstrapped, non-centered) confidence intervals for a forecast horizon of 20 quarters. According to our estimates, an expansionary monetary policy shock corresponds to a decline in the nominal interest rate which remains low for around six quarters before eventually returning to its long-run value.

We find that a monetary policy loosening gives rise to a bell shaped persistent increase in aggregate consumption which peaks at 4% above trend around six quarters after the initial one standard error expansionary monetary policy shock. The increase in consumption persists until approximately 3.5 years after the initial decline in the interest rate. The response of inflation confirms conventional wisdom. We find that the inflation rate declines for the first two quarters after the expansionary monetary policy shock (recall that the impact response is by definition equal to zero). Inflation 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 about 3 years after monetary policy shock. Thus, the small-scale VAR confirms the presence of the price puzzle and the inflation persistence puzzle.

The impact of monetary policy shocks on the vector of observables is very similar to the estimates that derive from much larger scale VARs, see e.g. Christiano et al. (2005). This is reassuring since omitted variables bias could potentially be important for both the price puzzle and the inflation persistence puzzle. Indeed, excluding the commodity price index from the VAR leads to much more significant price puzzle indicating the relevance of introducing forward looking indicators in the VAR. Nonetheless, even after controlling for the informational content of the commodity price index, we find that there is a small price puzzle and that inflation persistence is abundant. Moreover, as we will discuss later, these results are robust in a qualitative sense to allow for a structural change in 1979 when Volcker took over as the chairman of the Fed. For that reason, we will interpret the inflation and price puzzles as empirical regularities.

3.2. Estimation of the structural parameters

The model introduces quite a large number of parameters some of which we do not have strong priors about realistic values. 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 calibrate while the parameters in Θ_2 are estimated by matching the identified impulse responses discussed above. We make this distinction between the structural parameters because not all of them are easily identifiable from our estimation approach as they have little impact on the dynamics of the model but instead matter for the model's steady-state. 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 $\Theta_2 = [\eta, \zeta_p, \vartheta_p, \zeta_w, \vartheta_w, \theta^d, \rho_R, \alpha_y, \alpha_\pi, \upsilon]$.

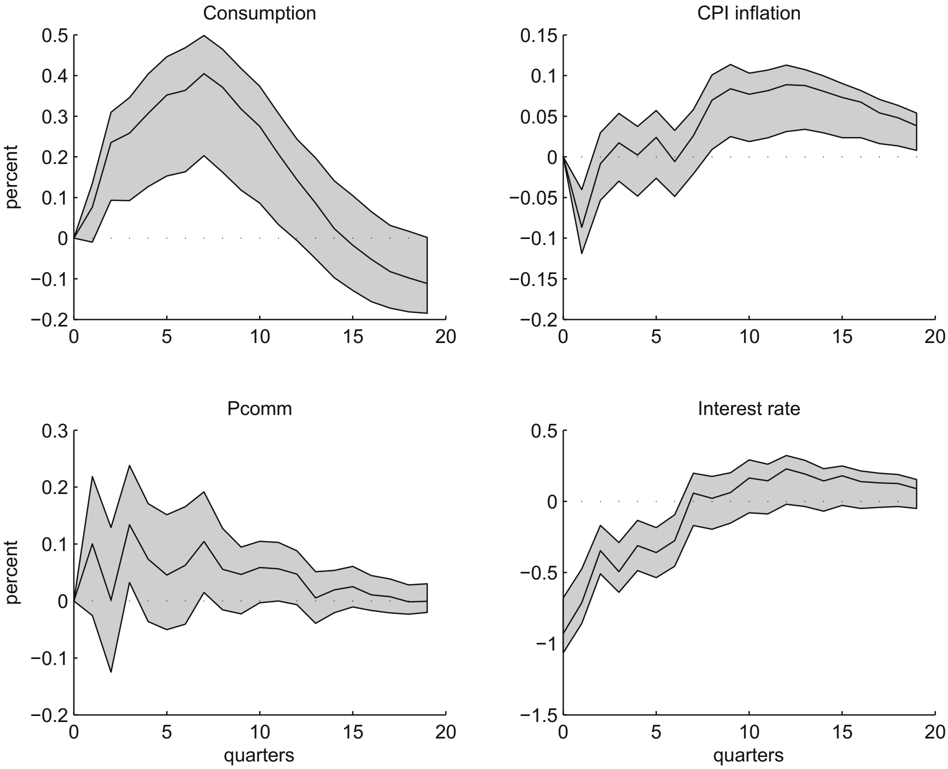

Fig. 1. The impact of an identified monetary policy shock. Notes: The figure illustrates the impact of a 1 standard error decline in the federal funds rate in the U.S. Grey areas show the 95% confidence intervals.

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% annual real interest rate in the non-stochastic steady-state. π^* is normalized to 1 while γ is calibrated so that it is consistent with a steady-state level of hours work equal to 30%.

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% 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. 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".

3.2.2. Estimation of Θ_2

We estimate Θ_2 using a limited information approach. The idea is to derive estimates of Θ_2 by matching as closely the theoretical impact of a monetary policy shock with the empirical VAR estimates. We do this the following way. 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 $(3R-2) \times 1$ vector $\widehat{\Phi}^{data}$ and let W be a $(3R-2)$ square diagonal matrix with the inverses of the standard errors of $\widehat{\Phi}^{data}$ along its diagonal (R denotes the forecast horizon).[10] The structural parameters are then estimated from the following minimization problem:

[10] This vector is of dimension $(3R-2)$ because the impact responses of consumption and inflation to the monetary policy shock are constrained to be zero.

Table 1
Calibrated parameters.

Parameter	Meaning	Calibration
γ	Weight on disutility of work	Calibrated to imply $\bar{h} = 0.3$
β	Subjective discount factor	Calibrated to imply quarterly real interest rate of 1%
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

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

where $\Phi(\Theta_2|\Theta_1)^{theory}$ denotes the impulse response of the observables in the model economy given Θ_2, conditional upon the calibration of Θ_1.

When estimating Θ_2 we need to take into account one subtle issue. Recall that $\widehat{\Phi}^{data}$ is estimated assuming that consumption and inflation do not respond within a quarter to a monetary policy shock. In our model this identifying assumption is not satisfied. To address this issue we introduce a simulation step in which we measure the model's impulse responses subject to the empirical identification strategy.[11,12] Thus, $\widehat{\Phi}(\Theta_2|\Theta_1)^{theory}$ 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 **measured** monetary policy shock on the model equivalents of the observables. That is, we derive the measure $\widehat{\Phi}(\Theta_2|\Theta_1)^{theory}$ 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 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 $\widehat{\Phi}_i(\Theta_2|\Theta_1)^{theory}$ of the ith simulation from the impulse responses assuming that consumption and inflation do not respond contemporaneously to the monetary policy shock.
Step 4: Calculate $\widehat{\Phi}(\Theta_2|\Theta_1)^{theory}$ as the mean of $\widehat{\Phi}_i(\Theta_2|\Theta_1)^{theory}$ for $i = 1, 2, \ldots, N$.

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. This procedure is then continued until we find the solution to the minimization problem in Eq. (35). We calculate the standard errors of $\widehat{\Theta}_2$ following Hall et al. (2007) as:

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

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

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

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

[11] Christiano et al. (2005) address this issue instead by introducing timing assumptions in the model economy that renders it consistent with the identifying assumption in the data.

[12] Strictly speaking, there is another difference between the empirical VAR and the model since the empirical VAR includes the commodity price index. If this variable is excluded from the empirical VAR we find a much more pronounced price puzzle, see Sims (1992). In principle the model can be extended to include commodities but we believe that this would not generate many more insights but would certainly complicate the analysis very significantly.

This estimator is applied subject to various parameter restrictions. We assume that $\xi_p,\ \xi_w,\ \alpha_y,\ \upsilon \geqslant 0,\ 0 \leqslant \vartheta_p,\ \vartheta_w \leqslant 1,\ \eta,\ \alpha_\pi > 1,\ 0 \leqslant \theta^d < 1$, and $-1 < \rho_R < 1$. 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 order to examine the impact of the deep habits mechanism we compare the results with the estimation results for two alternative models. The first alternative model is a standard "aggregate" habit New Keynesian model. In this model preferences are given by:

$$V_0 = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} \left(c_t^j - \theta^a c_{t-1} \right)^{1-\sigma} - \frac{\gamma}{1+\kappa} \left(h_t^j \right)^{1+\kappa} \right] \tag{36}$$

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

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

which is the aggregate habit model studied 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 Figs. 2–4 which illustrate the VAR based impulse responses of the observables to a monetary policy shock for the three alternative models along with their empirical counterparts. The deep habits model clearly provides a superior fit to the empirical estimates of the impact of a monetary policy shock. The deep habits model captures very precisely the bell shaped response of aggregate consumption and the interest rate path is also matched extremely well. Importantly, the model can account simultaneously for the price puzzle and for inflation persistence. Note that 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.

Table 2
Estimated parameters.

Parameter	Model					
	(1) Deep habits		(2) Aggregate habit		(3) 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*	–	0*	–
ζ_w	40.89	81.83	102.94	0.001	2.25	0.12
ϑ_w	0.96	1.72	0*	–	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*	–	1.01*	–
υ	0.96	0.09	0.51	0.05	0.40	0.04
Value of quadratic form	79.16		127.81		249.04	

* This parameter was up against the boundary condition.

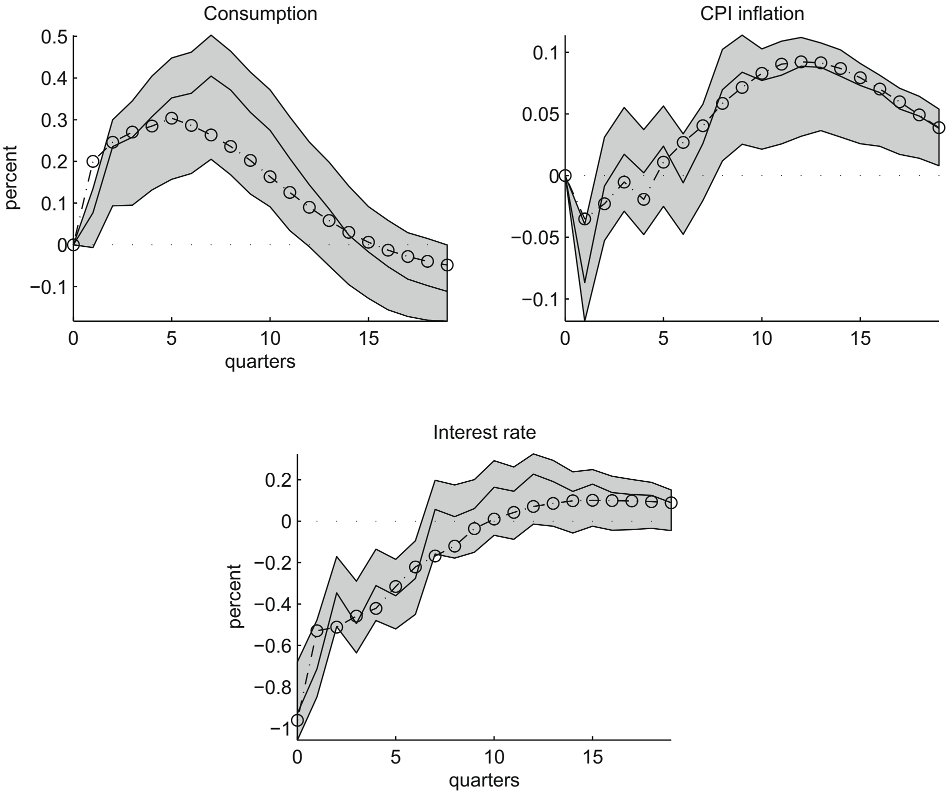

Fig. 2. The VAR-based impact of a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1% point decrease in the interest rate in the deep habits economy when measured with a VAR filter.

The aggregate habit model gives rise to a consumption response to the monetary policy shock that is very similar to the deep habits model. However, the aggregate habits model provides a worse fit to both the interest rate path and, in particular, 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% lower than the aggregate habits model and 70% 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 echoes 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

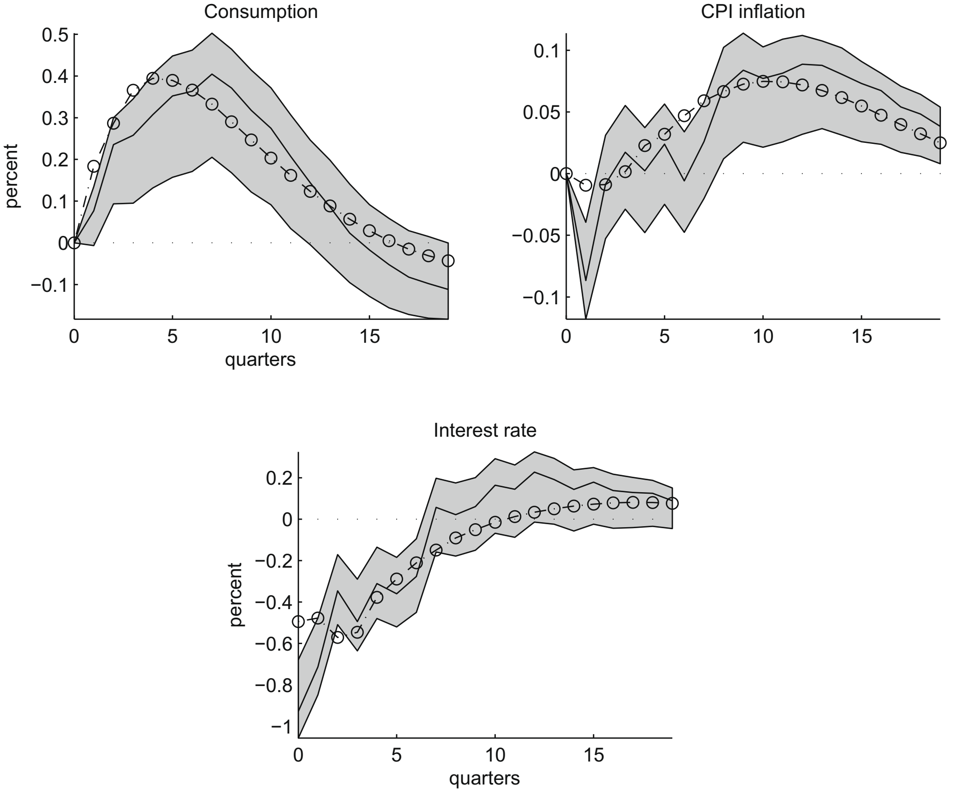

Fig. 3. The VAR-based impact of a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1% point decrease in the interest rate in the aggregate habits economy when measured with a VAR filter.

parameter, $\theta^a = 0.826$. The associated standard errors are in both cases very small. Thus, for a given real interest rate, 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 much 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 Figs. 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 Figs. 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, this model implies that the inflation rate rises

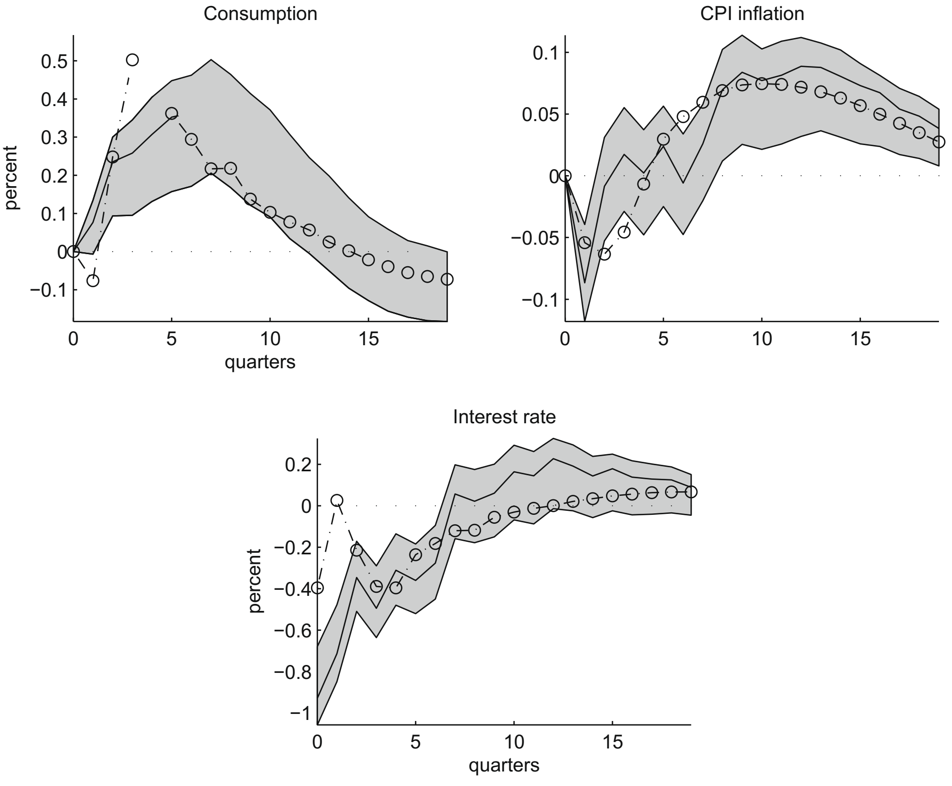

Fig. 4. The VAR-based impact of a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1% point decrease in the interest rate in the economy with no habits economy when measured with a VAR filter.

slightly upon impact and reaches its peak 2 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. Fig. 7 illustrates the paths of the markup in response to a monetary policy shock for three different economies. The first economy is the deep habits economy using the parameter estimates listed in the "Deep Habits" column of Table 2. The second economy is the aggregate habits model using the parameter estimates of the "Aggregate Habits" column of Table 2. The third economy is the aggregate habits economy but using the parameter estimates for the deep habits economy setting $\theta^a = \widehat{\theta}^d$.

Comparing paths of the markup for the first and third of these economies reveals the impact of allowing for deep habits rather than the standard aggregate habit assuming that all other parameters are unchanged. The markup declines much more significantly in response to the monetary policy shock in the deep habits economy than the standard aggregate habit model. The intuition for this result is that 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 high values of future market shares. In the deep habits economy, this leads to a period of declining inflation despite the monetary injection. As time passes, current consumption and habitual consumption become aligned and future consumption growth declines. This reverses producers' incentive to

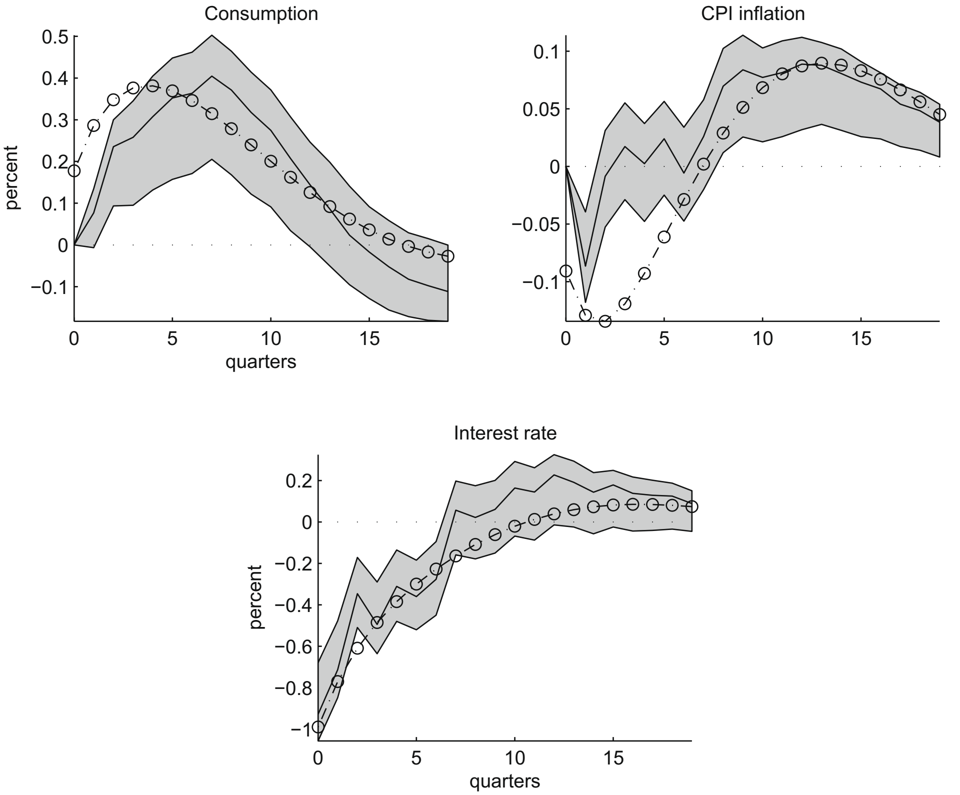

Fig. 5. The exact response to a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1% point decrease in the interest rate in the deep habits economy.

lower the markup in the deep habits economy 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.

Finally, an important insight is that the deep habits mechanism and nominal rigidities are complementary. Recall that our 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. In other words, the movements in markups that arise optimally in the deep habits economy imply a persistent rise in inflation following a monetary policy expansion without relying on extreme degrees of impediments to the adjustment of prices and wages.

4.1. Constrained markup

The steady-state markup in the deep habits model is given as:

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

while the steady-state markup is $\frac{\eta}{\eta-1}$ in the two alternative economies. Thus, given the point estimates in Table 2, the steady-state markup in the standard New Keynesian model is approximately 0%, 24% in

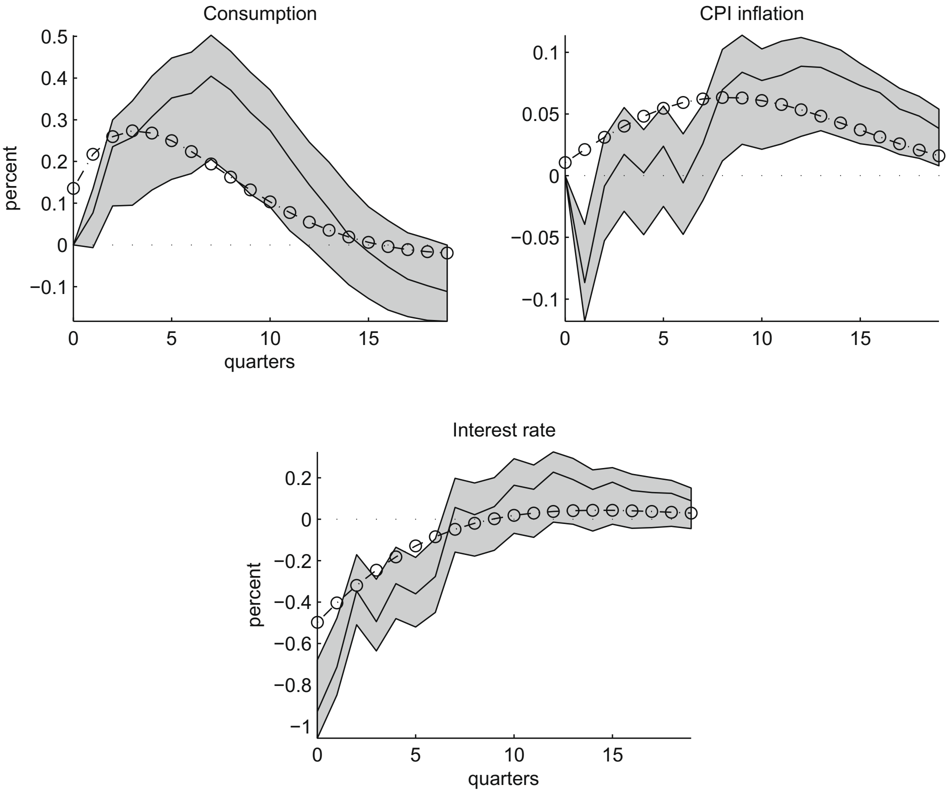

Fig. 6. The exact response to a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show theoretical impact of a 1% point decrease in the interest rate in the aggregate habits economy.

the standard habit model, but as high as 74% in the deep habits model. We now investigate the consequences of constraining the markup during the estimation procedure.

Table 3 reports the parameter estimates when we constrain the markup to be 50%. 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% 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.

Fig. 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 Fig. 3. Thus, our results do not derive from unreasonable assumptions regarding the markup.[13]

[13] We repeated this experiment setting the steady-state markup equal to 25%. We found that the deep habits model still fits the data better than the two alternative models. This restriction leads to higher estimates of the degrees of price and wage inflexibility.

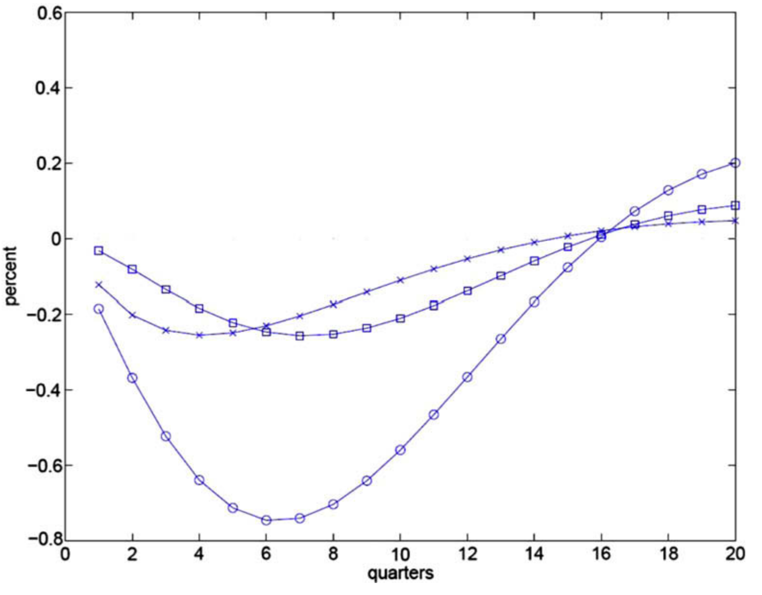

Fig. 7. Markup dynamics in theoretical economies. Notes: The figure shows the dynamics of markups after a 1% drop in the interest rate in three different economies: The line with circles corresponds to the deep habits economy listed in Table 1, column (1). The line with crosses corresponds to the aggregate habit economy using the parameter values listed in Table 1, column (2). The line with boxes corresponds to the aggregate habit economy assuming the parameter values estimated in the deep habits specification listed in Table 1, column (1).

Table 3
Estimated parameters with constrained markup.

Parameter	Model					
	Deep habits		Aggregate habit		No habit	
	Estimate	Std. error	Estimate	Std. error	Estimate	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*	–	0*	–
ζ_w	31.29	8.65	188.3	0.04	34.20	137.25
ϑ_w	0.99	0.25	0*	–	0*	–
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*	–	0*	–
α_π	1.49	0.02	1.01*	–	1.01*	–
υ	0.90	0.09	0.93	0.09	0.61	0.06
Value of quadratic form		81.95		158.32		261.83

* This parameter was up against the boundary condition.

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 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.

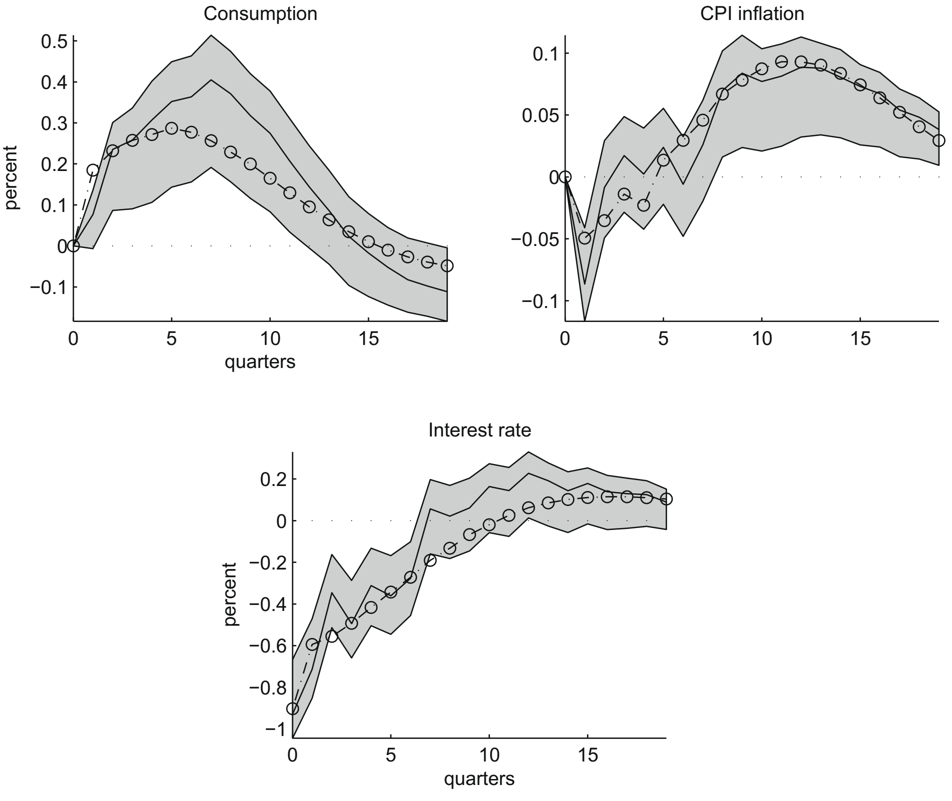

Fig. 8. The impact of a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate. Lines with circles show the VAR-based theoretical impact of a 1% point decrease in the interest rate in the deep habits economy when constraining the steady-state markup.

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. We reestimate the empirical VAR splitting the sample into a pre-1979:3 sample and a post-1979:2 sample. With the sub-sample estimates of the impact of monetary policy shocks at hand, we reestimate the structural parameters and investigate 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 of 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.

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*	–	0.00*	–
ζ_w	7.73	75.08	3.47	9.15
ϑ_w	1.00*	–	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*	–
α_π	1.01*	–	2.14	0.11
υ	0.74	0.07	0.93	0.09

* This parameter was up against the boundary condition.

Fig. 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-sam-

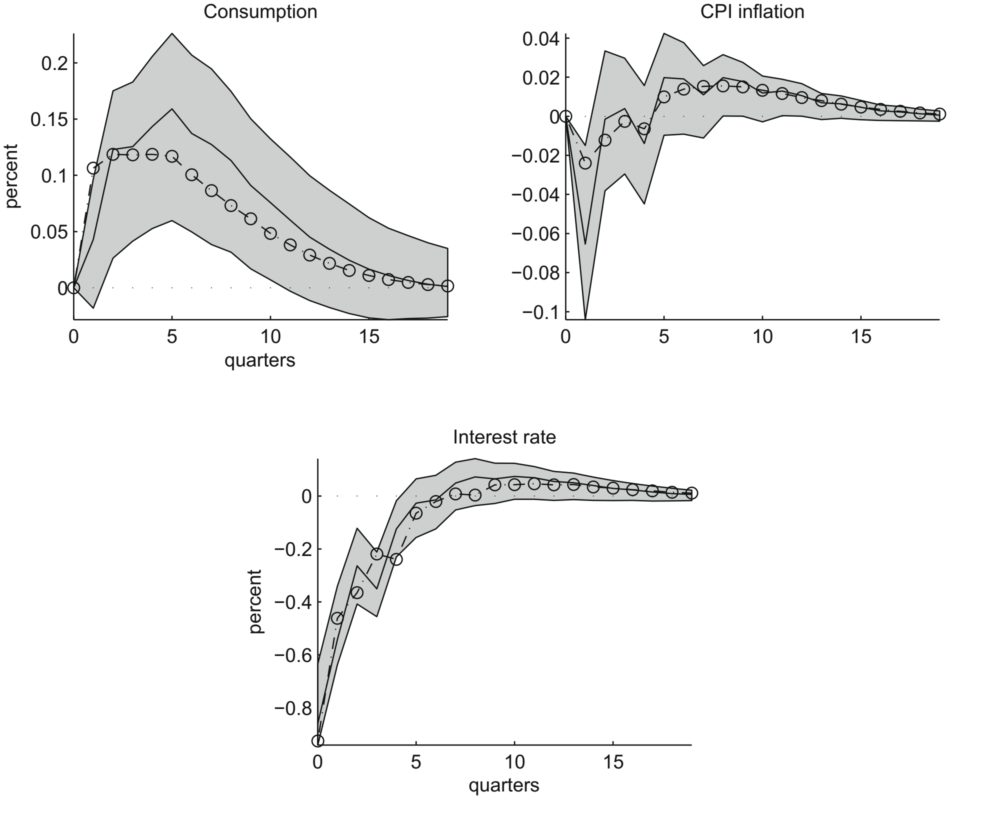

Fig. 9. The VAR-based impact of a monetary policy shock. Notes: Lines without circles show empirical estimates of a 1 standard error decrease in the federal funds rate when estimated for the post 1979:2 sample. Lines with circles show theoretical impact of a 1% point decrease in the interest rate in the deep habits economy when measured with a VAR filter.

ple 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 seven 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.

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