Kinked Demand Curves and Inflation Persistence in a Low-Inflation Economy*

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Abstract

Models of the monetary transmission mechanism often have difficulty accounting for the observed inertia of inflation without assuming such inertia is intrinsic. This paper shows that a staggered price model with low trend inflation can generate considerable inflation persistence, if demand curves are characterized by a smoothed-off kink. Inflation displays a hump-shaped response to a monetary policy shock absent a source of intrinsic inertia. Moreover, following a permanent credible disinflation, the kink can lead to a gradual adjustment of inflation and a recession.

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Keywords: Inflation persistence; Trend inflation, Smoothed-off kink in demand curve; Staggered price setting

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1 Introduction

Empirical evidence shows that inflation responds sluggishly to a monetary policy shock, peaking one to two years after the shock, but staggered price models of the monetary transmission mechanism often have difficulty generating the hump-shaped response in the data. The observed persistence of inflation has led a large literature in macroeconomics and monetary economics to adopt the view that inflation is intrinsically inertial. Specifically, this literature reconciles staggered price models with the empirical evidence by adding lags of inflation to otherwise forward-looking specifications of inflation. Two popular sources of such intrinsic inertia are rule-of-thumb price setting (Galí and Gertler, 1999) and price indexation to past inflation (Christiano et al., 2005).[1] The literature notwithstanding, hard-wiring inflation inertia into the structure of the economy remains controversial. Benati (2008) compares monetary policy regimes across countries and shows that the degree of inflation persistence varies with the monetary policy regime, indicating that inflation persistence may not be intrinsic. Moreover, theoretical explanations for intrinsic inflation inertia do not always seem plausible. As Woodford (2007) points out, price indexation to lagged inflation is at odds with the micro evidence that many individual prices remain unchanged for several months or longer.

This paper examines inflation persistence in a Calvo (1983) staggered price model with low, but positive, trend inflation and no intrinsic inflation inertia. While there are multiple ways to evaluate persistence, the paper uses the response of inflation to a monetary policy shock. A staggered price model with trend inflation may generate inflation persistence because the dynamics of real marginal cost depend on the relative price distortion, which is an endogenous state variable. The real marginal cost in turn influences inflation dynamics in a generalized New Keynesian Phillips Curve (NKPC).[2] However, we find that the staggered price model shows only limited persistence in the inflation response. We reach this conclusion by using a realistic calibration of the model parameters and by estimating those parameters using minimum distance estimation. In both the quantitative analysis and the estimation inflation peaks

[1] Fuhrer (2011) and Woodford (2007) review different theories of intrinsic inflation persistence.

[2] See Ascari and Sbordone (2014) for a review of the empirical evidence about inflation persistence and the generalized NKPC.

immediately following a policy shock, lacking the hump-shaped response that is suggested by the empirical evidence.

We proceed by introducing a "smoothed-off" kink in demand curves in the staggered price model with trend inflation. This kink in demand curves has been analyzed by Kimball (1995), Dotsey and King (2005), and Levin et al. (2008), and generates strategic complementarity in price setting.[3] In the presence of such a kink, a measure of price dispersion distinct from the relative price distortion becomes a relevant state variable. Higher inflation increases price dispersion, as it leads price-adjusting firms to choose a higher relative price and erodes the relative price of non-adjusting firms. Under staggered price setting, price dispersion today depends on prices set in the current and in past periods; as a result, current price dispersion depends on past price dispersion. The lagged price dispersion can have a pronounced influence on inflation dynamics because it enters directly in the generalized NKPC, such that the dynamics of inflation can inherit the persistence of price dispersion. We find with both the quantitative analysis of the calibrated model and the estimation of the model parameters that a monetary policy shock generates a persistent and hump-shaped response of inflation, despite price-adjusters being purely forward-looking.

In addition to increasing inflation persistence, the kink in demand curves can bring the response of output per hour to a policy shock in line with the empirical evidence. VAR evidence indicates output per hour rises after an expansionary policy shock. However, in the case of no kink in demand curves a large increase in the relative price distortion can give rise to a counterfactual negative response. In the quantitative analysis of the model output per hour declines following an expansionary shock, because the negative effect of the relative price distortion dominates the positive effect from increasing returns to scale in the model. A kink in demand curves dampens the response of the relative price distortion to a policy shock substantially, as even a large increase in price dispersion is associated with only a small increase in the relative price distortion. The reason is that the kink reduces the demand elasticity of

[3] See also Levin et al. (2007), Shirota (2007), and Kurozumi and Van Zandweghe (2015). Dossche et al. (2010) estimate the curvature of demand curves and find evidence of a kink, albeit a smaller one than used in many macroeconomic studies.

goods with a low relative price, thus limiting the rise in *demand* dispersion associated with an increase in *price* dispersion. By mitigating the increase in the relative price distortion the kink prevents a counterfactual decline of output per hour in the model.

Inflation persistence plays a central role in the literature concerning credible disinflation.[4] In a canonical New Keynesian model, with no intrinsic inflation inertia, a credible permanent reduction in the trend inflation rate causes the inflation rate to adjust immediately and fully, while output never deviates from its steady-state level. However, once intrinsic inflation inertia is introduced, inflation adjusts gradually to its new trend rate, while output declines temporarily (Fuhrer, 2011). The latter dynamics align more closely with the historical experience; for instance, they are reminiscent of the U.S. economy's behavior during the Volcker disinflation. Our calibrated model with low trend inflation and a kink in demand curves generates similar dynamics even without intrinsic inflation inertia: a permanent credible disinflation leads to a gradual decline in inflation and can cause a recession. Habit formation in consumption preferences plays a role for this result, as a high degree of habit persistence prevents a recession by smoothing out the response of output. In contrast, in the case of no kink in demand curves, a credible disinflation in the model with low trend inflation leads to a rapid decline in inflation and no recession, regardless of the degree of habit persistence.

Our paper is related to a recent strand of literature that examines the role of trend inflation for inflation persistence. Cogley and Sbordone (2008) stress the role of time-variation in trend inflation for understanding inflation persistence, and argue that intrinsic inflation inertia is not needed once drift in trend inflation is taken into account. Our paper offers a complementary explanation of inflation persistence based on the interaction between trend inflation and a kink in demand curves. Moreover, evidence of Benati (2008), Pivetta and Reis (2007), and others indicates that inflation persistence in the U.S. has not changed significantly in the post-World War II period, although the possibility of a decline in inflation persistence remains the subject of debate.[5] Consistent with this evidence, our analysis focuses on a long time period beginning

[4]For prominent examples see Ball (1994), Fuhrer and Moore (1995) and Mankiw and Reis (2002).

[5]Cogley and Sargent (2002) argue that inflation persistence has declined, but Sims (2002) and Stock (2002) challenge that view. Cogley, Primiceri and Sargent (2010) show that inflation-*gap* persistence declined after the Volcker disinflation and attribute the decline primarily to a reduced innovation variance for trend inflation

in the 1960s.

The paper proceeds as follows. Section 2 presents the Calvo model of staggered price setting with trend inflation and a smoothed-off kink in demand curves. Section 3 uses a calibration to study model impulse responses to a monetary policy shock and permanent credible disinflation. Section 4 uses minimum distance estimation to fit the model impulse responses to their empirical counterparts. Section 5 concludes.

2 Model

The model economy is populated by a representative household, a representative final-good firm, a continuum of intermediate-good firms, and a monetary authority. Key features of the model are that each period a fraction of intermediate-good firms keeps prices of their differentiated products unchanged, while the remaining fraction reoptimizes its prices in the face of the final-good firm's demand curves in which a smoothed-off kink is introduced. The model economy is the same as that of Kurozumi and Van Zandweghe (2015), except for the addition of habit persistence in consumption preferences and a fixed cost of production. The behavior of each economic agent is described in turn.

2.1 Household

The representative household consumes C_t final goods, supplies N_t homogeneous labor, and purchases B_t one-period riskless bonds to maximize the utility function $E_0 \sum_{t=0}^{\infty} \beta^t [\log(C_t - bC_{t-1}) - N_t^{1+\sigma_n}/(1+\sigma_n)]$ subject to the budget constraint $P_t C_t + B_t = P_t W_t N_t + i_{t-1} B_{t-1} + T_t$, where E_t denotes the expectation operator conditional on information available in period t, $\beta \in (0,1)$ is the subjective discount factor, $b \in [0,1)$ is the degree of (internal) habit formation, $\sigma_n \geq 0$ is the inverse of the elasticity of labor supply, P_t is the price of final goods, W_t is the real wage, i_t is the gross interest rate on the bonds, and T_t consists of lump-sum public transfers and firm profits.

Combining first-order conditions for utility maximization with respect to consumption,

during the Volcker-Greenspan era.

labor supply, and bond holdings yields

$$W_t = \frac{N_t^{\sigma_n}}{\Lambda_t}, \tag{1}$$

$$\Lambda_t = \frac{1}{C_t - bC_{t-1}} - \beta E_t \left(\frac{b}{C_{t+1} - bC_t} \right), \tag{2}$$

$$1 = E_t \left(\frac{\beta \Lambda_{t+1}}{\Lambda_t} \frac{i_t}{\pi_{t+1}} \right), \tag{3}$$

where Λ_t denotes marginal utility and $\pi_t = P_t/P_{t-1}$ is the gross inflation rate.

2.2 Final-good firm

As in Kimball (1995), the representative final-good firm produces Y_t homogeneous goods under perfect competition by choosing a combination of intermediate inputs $\{Y_t(f)\}$ so as to maximize profit $P_t Y_t - \int_0^1 P_t(f) Y_t(f) df$ subject to the production technology

$$\int_0^1 F\left(\frac{Y_t(f)}{Y_t}\right) df = 1, \tag{4}$$

where $P_t(f)$ is the price of intermediate good $f \in [0, 1]$. Following Dotsey and King (2005) and Levin et al. (2008), the production technology is assumed to be of the form

$$F\left(\frac{Y_t(f)}{Y_t}\right) = \frac{\gamma}{(1+\epsilon)(\gamma-1)} \left[(1+\epsilon)\frac{Y_t(f)}{Y_t} - \epsilon \right]^{\frac{\gamma-1}{\gamma}} + 1 - \frac{\gamma}{(1+\epsilon)(\gamma-1)},$$

where $\gamma = \theta(1+\epsilon)$. The parameter $\epsilon \leq 0$ governs the curvature of the demand curve for each intermediate good. In the special case of $\epsilon = 0$, the production technology (4) is reduced to the CES one $Y_t = [\int_0^1 (Y_t(f))^{(\theta-1)/\theta} df]^{\theta/(\theta-1)}$, where the parameter $\theta > 1$ represents the price elasticity of demand for each intermediate good.

The first-order conditions for profit maximization yield the final-good firm's relative demand curve for intermediate good f,

$$\frac{Y_t(f)}{Y_t} = \frac{1}{1+\epsilon} \left[\left(\frac{P_t(f)}{P_t d_{1t}} \right)^{-\gamma} + \epsilon \right], \tag{5}$$

where d_{1t} is the Lagrange multiplier on the production technology (4) in profit maximization, given by

$$d_{1t} = \left[\int_0^1 \left(\frac{P_t(f)}{P_t} \right)^{1-\gamma} df \right]^{\frac{1}{1-\gamma}}. \tag{6}$$

Fig. 1 illustrates the demand curve (5) with various values of the curvature parameter ϵ. As can be seen in this figure, the price elasticity of demand for each intermediate good f, given by $\eta_t = \gamma - \theta\epsilon(Y_t(f)/Y_t)^{-1}$, varies inversely with the relative demand for the good. Therefore, in the presence of the kink in demand curves, the relative demand for an intermediate good becomes more price-elastic for an increase in the relative price of the good, while it becomes less price-elastic for a decline in the relative price of the good.

The final-good firm's zero-profit condition implies that its product's price P_t satisfies

$$1 = \frac{1}{1+\epsilon} d_{1t} + \frac{\epsilon}{1+\epsilon} d_{2t}, \tag{7}$$

where

$$d_{2t} = \int_0^1 \frac{P_t(f)}{P_t} df. \tag{8}$$

Note that in the special case of $\epsilon = 0$, where the production technology (4) becomes the CES one, Eqs. (5)–(7) can be reduced to $Y_t(f) = Y_t(P_t(f)/P_t)^{-\theta}$, $P_t = [\int_0^1 (P_t(f))^{1-\theta} df]^{1/(1-\theta)}$, and $d_{1t} = 1$, respectively.

The final-good market clearing condition is given by

$$Y_t = C_t. \tag{9}$$

2.3 Intermediate-good firms

Each intermediate-good firm f produces one kind of differentiated good $Y_t(f)$ under monopolistic competition. Firm f uses the following production technology:

$$Y_t(f) = \begin{cases} N_t(f) - \phi & \text{if } N_t(f) \geq \phi \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

where $\phi > 0$ denotes the fixed cost of production. Given the real wage W_t, the first-order condition for minimization of the production cost shows that real marginal cost is identical among all intermediate-good firms and equal to the real wage. Thus, Eq. (1) implies that the real marginal cost equals

$$mc_t = \frac{N_t^{\sigma_n}}{\Lambda_t}. \tag{11}$$

The labor market clearing condition is given by

$$N_t = \int_0^1 N_t(f)df. \tag{12}$$

Combining this equation with Eqs. (5) and (10) yields

$$Y_t \left(\frac{s_t + \epsilon}{1 + \epsilon} \right) = N_t - \phi, \tag{13}$$

where $(s_t + \epsilon)/(1 + \epsilon)$ is the relative price distortion and

$$s_t = \int_0^1 \left(\frac{P_t(f)}{P_t d_{1t}} \right)^{-\gamma} df. \tag{14}$$

In the face of the final-good firm's demand curve (5) and the real marginal cost, intermediate-good firms set prices of their products on a staggered basis as in Calvo (1983). Each period a fraction $\xi \in (0, 1)$ of firms keeps previous-period prices unchanged, while the remaining fraction $1 - \xi$ of firms sets the price $P_t(f)$ to maximize the profit function

$$E_t \sum_{j=0}^{\infty} \xi^j q_{t,t+j} \left(\frac{P_t(f)}{P_{t+j}} - mc_{t+j} \right) \frac{1}{1+\epsilon} \left[\left(\frac{P_t(f)}{P_{t+j} d_{1t+j}} \right)^{-\gamma} + \epsilon \right] Y_{t+j},$$

where $q_{t,t+j} = \beta^j C_t / C_{t+j}$ is the stochastic discount factor between period t and period $t + j$. For this profit function to be well-defined, the following assumption is imposed.

Assumption 1 *The three inequalities $\xi\beta\pi^{\gamma-1} < 1$, $\xi\beta\pi^{\gamma} < 1$, and $\xi\beta\pi^{-1} < 1$ hold, where π denotes gross trend inflation.*

Using the final-good market clearing condition (9), the first-order condition for Calvo staggered price setting leads to

$$E_t \sum_{j=0}^{\infty} (\xi\beta)^j \prod_{k=1}^{j} \pi_{t+k}^{\gamma} \left[\left(p_t^* \prod_{k=1}^{j} \frac{1}{\pi_{t+k}} - \frac{\gamma}{\gamma - 1} mc_{t+j} \right) d_{1t+j}^{-\gamma} - \frac{\epsilon}{\gamma - 1} \left(p_t^* \prod_{k=1}^{j} \frac{1}{\pi_{t+k}} \right)^{1+\gamma} \right] = 0, \tag{15}$$

where p_t^* is the relative price set by firms that reoptimize prices in period t.

Moreover, under the Calvo staggered price setting, the price dispersion equations (6), (8), and (14) can be reduced to, respectively,

$$(d_{1t})^{1-\gamma} = (1 - \xi) (p_t^*)^{1-\gamma} + \xi \left(\frac{d_{1t-1}}{\pi_t} \right)^{1-\gamma}, \tag{16}$$

$$d_{2t} = (1 - \xi) p_t^* + \xi \left(\frac{d_{2t-1}}{\pi_t} \right), \tag{17}$$

$$(d_{1t})^{-\gamma} s_t = (1 - \xi) (p_t^*)^{-\gamma} + \xi \left(\frac{d_{1t-1}}{\pi_t} \right)^{-\gamma} s_{t-1}. \tag{18}$$

These equations show that staggered price setting gives rise to persistence in price dispersion.

2.4 Monetary authority and equilibrium

The monetary authority follows a Taylor (1993)-type policy rule. This rule adjusts the interest rate i_t in response to deviations of inflation from trend inflation, output and output growth from their steady-state values, and allows for policy inertia

$$\begin{aligned}\log\left(\frac{i_t}{i}\right) &= \rho_1 \log\left(\frac{i_{t-1}}{i}\right) + \rho_2 \log\left(\frac{i_{t-2}}{i}\right) + (1-\rho_1-\rho_2)\phi_\pi \log\left(\frac{\pi_t}{\pi}\right) \\ &\quad + (1-\rho_1-\rho_2)\phi_y \log\left(\frac{Y_t}{Y}\right) + (1-\rho_1-\rho_2)\phi_g \log\left(\frac{Y_t}{Y_{t-1}}\right) + \varepsilon_{it}, \end{aligned} \tag{19}$$

where i and Y are steady-state values of the interest rate and output, $\phi_\pi, \phi_y, \phi_g \geq 0$ are the policy responses to inflation, output, and output growth, ρ_1, ρ_2 capture the degree of policy inertia, and ε_{it} is an iid shock to monetary policy.

2.5 Log-linearized equilibrium conditions

The equilibrium conditions (2), (3), (7), (9), (11), (13), (15)–(18), and (19) are log-linearized under Assumption 1 for the analysis in the next sections. Rearranging the resulting equations leads to

$$\hat{Y}_t = \left[1 + \left(\frac{1+\epsilon}{s+\epsilon}\right)\frac{\phi}{Y}\right]\hat{N}_t - \left(\frac{s}{s+\epsilon}\right)\hat{s}_t, \tag{20}$$

$$\hat{mc}_t = \sigma_n \hat{N}_t - \hat{\Lambda}_t, \tag{21}$$

$$\hat{\Lambda}_t = -\frac{1+\beta b^2}{(1-\beta b)(1-b)}\hat{Y}_t + \frac{\beta b}{(1-\beta b)(1-b)}E_t\hat{Y}_{t+1} + \frac{b}{(1-\beta b)(1-b)}\hat{Y}_{t-1}, \tag{22}$$

$$\hat{\Lambda}_t = E_t\hat{\Lambda}_{t+1} + \left(\hat{i}_t - E_t\hat{\pi}_{t+1}\right), \tag{23}$$

$$\begin{aligned}\hat{\pi}_t &= \beta E_t\hat{\pi}_{t+1} + \frac{(1-\xi\pi^{\gamma-1})(1-\xi\beta\pi^\gamma)}{\xi\pi^{\gamma-1}[1-\tilde{\epsilon}\gamma/(\gamma-1-\tilde{\epsilon})]}\hat{mc}_t - \frac{1}{\xi\pi^{\gamma-1}}\left(\hat{d}_{1t} - \xi\beta\pi^{\gamma-1}E_t\hat{d}_{1t+1}\right) \\ &\quad - \frac{(1-\xi\pi^{\gamma-1})[(\pi-1)(\gamma-1)+\tilde{\epsilon}(1-\pi^{1+\gamma})]}{\xi\pi^\gamma[\gamma-1-\tilde{\epsilon}(\gamma+1)]}\left(\hat{\Lambda}_t + \hat{Y}_t\right) + \hat{d}_{1t-1} - \xi\beta\pi^{\gamma-1}\hat{d}_{1t} \\ &\quad - \frac{\gamma(1-\xi\pi^{\gamma-1})[\xi\beta\pi^{\gamma-1}(\pi-1)(\gamma-1)+\tilde{\epsilon}(1-\xi\beta\pi^\gamma)]}{\xi\pi^{\gamma-1}[\gamma-1-\tilde{\epsilon}(\gamma+1)]}\hat{d}_{1t} + \psi_{1t} + \psi_{2t}, \end{aligned} \tag{24}$$

$$\hat{s}_t = \frac{\xi\gamma\pi^{\gamma-1}(\pi-1)}{1-\xi\pi^{\gamma-1}}\left(\hat{\pi}_t + \hat{d}_{1t} - \hat{d}_{1t-1}\right) + \xi\pi^\gamma\hat{s}_{t-1}, \tag{25}$$

$$\hat{d}_{1t} = -\frac{\tilde{\epsilon}\xi\pi^{-1}(\pi^{\gamma}-1)(1-\xi\beta\pi^{-1})}{(1-\xi\pi^{-1})[1-\xi\beta\pi^{\tilde{\theta}-1}+\tilde{\epsilon}(1-\xi\beta\pi^{-1})]}\hat{\pi}_t + \frac{\xi\pi^{-1}[1-\xi\beta\pi^{\gamma-1}+\tilde{\epsilon}\pi^{\gamma}(1-\xi\beta\pi^{-1})]}{1-\xi\beta\pi^{\gamma-1}+\tilde{\epsilon}(1-\xi\beta\pi^{-1})}\hat{d}_{1t-1}, \tag{26}$$

$$\psi_{1t} = \xi\beta\pi^{\gamma}E_t\psi_{1,t+1} + \frac{\beta(\pi-1)(1-\xi\pi^{\gamma-1})}{1-\tilde{\epsilon}\gamma/(\gamma-1-\tilde{\epsilon})}\begin{bmatrix}\gamma E_t\hat{\pi}_{t+1} + (1-\xi\beta\pi^{\gamma})\Big(E_t\hat{mc}_{t+1} + \gamma E_t\hat{d}_{1,t+1}\Big) \\ +(1-\xi\beta\pi^{\gamma})\left(\hat{\Lambda}_t + \hat{Y}_t\right)\end{bmatrix}, \tag{27}$$

$$\psi_{2t} = \xi\beta\pi^{-1}E_t\psi_{2,t+1} + \frac{\tilde{\epsilon}\beta(\pi^{\gamma}-1)(1-\xi\pi^{\gamma-1})}{\pi^{\gamma}\left[\gamma-1-\tilde{\epsilon}(\gamma+1)\right]}\left[E_t\hat{\pi}_{t+1} - (1-\xi\beta\pi^{-1})\left(\hat{\Lambda}_t + \hat{Y}_t\right)\right], \tag{28}$$

$$\hat{i}_t = \rho_1\hat{i}_{t-1} + \rho_2\hat{i}_{t-2} + (1-\rho_1-\rho_2)\left[\phi_\pi\hat{\pi}_t + \phi_y\hat{Y}_t + \phi_g\left(\hat{Y}_t - \hat{Y}_{t-1}\right)\right] + \varepsilon_{it}, \tag{29}$$

where hatted variables denote log-deviations from steady-state values, ψ_{1t} and ψ_{2t} are auxiliary variables, $\tilde{\epsilon} = \epsilon(1-\xi\beta\pi^{\gamma-1})/(1-\xi\beta\pi^{-1})[(1-\xi\pi^{\gamma-1})/(1-\xi)]^{-\gamma/(\gamma-1)}$, and $s = (1-\xi)/(1-\xi\pi^{\gamma})[(1-\xi)/(1-\xi\pi^{\gamma-1})]^{-\gamma/(\gamma-1)}$.

The strategic complementarity arising from the kink in demand curves reduces the slope of the generalized NKPC (24) by $1-\tilde{\epsilon}\gamma/(\gamma-1-\tilde{\epsilon})$. At the zero trend inflation rate (that is, $\pi = 1$), Eqs. (24)−(28) imply that $\hat{s}_t = 0$, $\hat{d}_{1t} = 0$, $\hat{\psi}_{1t} = 0$, and $\hat{\psi}_{2t} = 0$, so these equations can be reduced to

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \frac{(1-\xi)(1-\xi\beta)}{\xi[1-\varepsilon\theta/(\theta-1)]}\hat{mc}_t. \tag{30}$$

Eq. (30) shows that Eq. (24) is a generalized formulation of the familiar NKPC.

Alternatively, if there is no kink in demand curves (that is, $\varepsilon = 0$), Eqs. (24)−(28) imply that $\hat{d}_{1t} = 0$ and $\hat{\psi}_{2t} = 0$, so the five equations can be reduced to the following three

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \frac{(1-\xi\pi^{\theta-1})(1-\xi\beta\pi^{\theta})}{\xi\pi^{\theta-1}}\hat{mc}_t - \frac{(1-\xi\pi^{\theta-1})(\pi-1)}{\xi\pi^{\theta}}\left(\hat{\Lambda}_t + \hat{Y}_t\right) + \psi_{1t}, \tag{31}$$

$$\hat{s}_t = \frac{\xi\theta\pi^{\theta-1}(\pi-1)}{1-\xi\pi^{\theta-1}}\hat{\pi}_t + \xi\pi^{\theta}\hat{s}_{t-1}, \tag{32}$$

$$\begin{aligned}\psi_{1t} &= \xi\beta\pi^{\theta}E_t\psi_{1,t+1} \\ &\quad + \beta(\pi-1)(1-\xi\pi^{\theta-1})\left[\theta E_t\hat{\pi}_{t+1} + (1-\xi\beta\pi^{\theta})E_t\hat{mc}_{t+1} + (1-\xi\beta\pi^{\theta})\left(\hat{\Lambda}_t + \hat{Y}_t\right)\right],\end{aligned} \tag{33}$$

Comparing Eqs. (31)−(33) with Eqs. (24)−(28) shows that the kink introduces a law of motion for price dispersion d_{1t}, and causes the current, the expected future, and the lagged price dispersion to influence inflation directly in the generalized NKPC and indirectly via the law of motion of the relative price distortion. Consequently, persistence in price dispersion is inherited by the dynamics of inflation.

3 Quantitative results

This section uses a realistic calibration of the model to illustrate its key features. First, the effects of the kink in demand curves on the impulse responses to a monetary policy shock are studied. Next, a credible disinflation is examined with and without the kink.

3.1 Calibration

The quarterly calibration is summarized in Table 1. As is common in the monetary policy literature, the subjective discount factor is set at $\beta = 0.99$, the inverse of the labor supply elasticity at $\sigma_n = 1$, the degree of habit persistence at $b = 0.8$, the parameter governing the price elasticity of demand at $\theta = 10$, which implies a markup of 11 percent at the zero trend inflation rate, and the probability of no price change is set to $\xi = 0.75$, which implies that prices change on average every four quarters.

For the parameter governing the curvature of demand curves two cases are considered. First, $\varepsilon = 0$, which is the case of constant elasticity demand curves. Second, $\varepsilon = -8$, which implies a curvature $-\gamma = 70$, an intermediate value in a wide range found in the literature surveyed by Dossche et al. (2010).[6] Under this calibration, the slope of the generalized NKPC–that is, the elasticity of inflation with respect to real marginal cost in Eq. (24)–is equal to 0.060 if $\varepsilon = 0$ and 0.044 if $\varepsilon = -8$.[7]

In terms of monetary policy, the response to inflation in the Taylor rule is set at $\phi_\pi = 1.5$, the degree of interest rate smoothing at $\rho_1 = 0.9$, and the policy responses to the output gap and output growth are set to zero. The annualized trend inflation rate is set at two percent, which is the Federal Reserve's long-run inflation target.[8] To determine the fixed cost in the

[6] To meet Assumption 1 under the calibration, the annualized trend inflation rate needs to be greater than -1.66 percent if $\varepsilon = -8$ and between -69.61 and $+12.65$ percent if $\varepsilon = 0$.

[7] At the zero trend inflation rate the kink in demand curves reduces the slope of the generalized NKPC by an order of magnitude: The slope is 0.086 if $\varepsilon = 0$ and 0.009 if $\varepsilon = -8$. The positive trend inflation rate thus mitigates the effect of the kink on the slope of the generalized NKPC.

[8] The average annual inflation rate of the PCE price index has been 2.0 percent since 1990 and 3.4 percent

production function, ϕ, it is assumed that steady-state profits are equal to zero.

3.2 Impulse responses to a monetary policy shock

Using the baseline calibration, this subsection examines the impulse responses to a monetary policy shock in the model presented in the previous section. Of particular interest are the dynamic responses of inflation and output per hour, and how the kink in demand curves affects their shape.

A large empirical literature documents that inflation responds sluggishly to a monetary policy shock. Furthermore, output per hour rises after an expansionary policy shock (see Christiano, Eichenbaum and Evans, 2005). The dashed lines in Figure 4 are the dynamic responses of the federal funds rate, inflation, output, and output per hour to an expansionary monetary policy shock, which are obtained from a small structural VAR model that is described in more detail in the next section. The responses show that inflation rises gradually and peaks one to two years after the shock, and output per hour rises for about one year after the shock, confirming the previous evidence.[9] Also, output rises for about one to two years after the shock.

Without a kink in demand curves the model with low trend inflation has difficulty replicating the first two stylized facts from the VAR. The dashed lines in Figure 2 show the impulse responses to a negative 60 basis points policy shock under the baseline calibration with no kink in demand curves (that is, $\varepsilon = 0$). Output displays a hump-shaped response. However, inflation jumps almost one percentage point on impact and the response dies out within about two years. The gradual decline in the response of inflation reflects two sources of inertia, which are inherited by the real marginal cost: the persistence of habits in consumption preferences and the persistence of the relative price distortion. Combining Eqs. (20)−(21), and setting

since 1959.

[9] Van Zandweghe (2015) analyzes the impulse responses of the components of output per hour–total factor productivity, capital per hour, and factor utilization–to a monetary policy shock and concludes that the positive response of output per hour to an expansionary shock is due to a rise in factor utilization.

$\varepsilon = 0$, shows that the real marginal cost depends on output and the relative price distortion:

$$\hat{mc}_t = \frac{\sigma_n}{1 + (1/s)(\phi/Y)} \left(\hat{Y}_t + \hat{s}_t \right) - \hat{\Lambda}_t,$$

where the marginal utility, $\hat{\Lambda}_t$, adds the persistence from the consumption habits.

The positive trend inflation rate strengthens the two sources of inflation persistence compared to the zero trend inflation rate, but the effect is minor under the baseline calibration. Both sources are stronger in the case of low trend inflation–that is, two percent under the baseline calibration–than in the case of zero trend inflation. In the latter $\hat{s} = 0$, so the relative price distortion has no effect on the dynamics of real marginal cost and inflation. Moreover, if the trend inflation rate is positive, the effect of habit persistence affects the generalized NKPC directly, as shown by the third term on the right hand side of Eq. (31). Nevertheless, the response of inflation to the policy shock is similar to that obtained in the case of the zero trend inflation rate, which is shown by the dotted line in the figure. Therefore, under the baseline calibration, the positive trend inflation rate has only a minor influence on the dynamic response of inflation.

In the case of no kink in demand curves, the starkest implication of the positive trend inflation rate is that it changes the sign on the response of output per hour from positive to negative. The sign change stems from the influence of the relative price distortion on output per hour. If $\varepsilon = 0$, Eq. (20) implies that

$$\hat{Y}_t - \hat{N}_t = \left(\frac{1}{s} \frac{\phi}{Y} \right) \hat{N}_t - \hat{s}_t.$$

Output per hour increases with hours worked due to the increasing returns to scale introduced by the fixed cost in production.[10] But if trend inflation is positive, output per hour declines with the relative price distortion, and this effect dominates in the figure. That is, the relative price distortion lowers labor productivity as it reduces the efficiency of labor in generating aggregate output. The negative response of output per hour in the staggered price model is at odds with the positive empirical response in the VAR.[11]

[10] Basu and Fernald (2001) evaluate different explanations of the procyclicality of output per hour.

[11] Damjanovic and Nolan (2010) observe that the relative price distortion can lead a policy rate hike to raise

We now evaluate the effect of a kink in demand curves on the dynamic responses to a monetary policy shock. The solid lines in Figure 2 display the impulse responses obtained in the case of a kink (that is, $\varepsilon = -8$). The top right panel of the figure shows that the kinked demand curves give rise to a persistent and hump-shaped response of inflation, in line with the empirical evidence. The inertial response of inflation allows the policy rate to remain lower for longer and leads to a larger output boom. Thus, the kink in demand curves generates considerable persistence in the inflation response to a policy shock. The bottom right panel shows that the response of price dispersion (that is, d_{1t}) is persistent and hump-shaped. Higher inflation increases price dispersion, as it leads price-adjusting firms to choose a higher relative price and it erodes the relative price of non-adjusting firms. With Calvo staggered price setting, price dispersion today depends on prices set in the current and in past periods; hence price dispersion depends on its own lag. Although price-adjusters are purely forward-looking, the response of inflation is persistent and hump-shaped because it inherits the dynamics of price dispersion.

A second result is that the kink generates a positive response of output per hour to an expansionary policy shock, corresponding to the empirical evidence. Eq. (20) implies that output per hour increases with hours worked and declines with the relative price distortion.[12] However, the kink in demand curves dampens the response of the relative price distortion to a policy shock substantially. As shown in the bottom two panels, the response of the relative price distortion is much smaller than that of price dispersion. This is because, by reducing the demand elasticity of goods with a low relative price, the kink limits the rise in demand dispersion associated with an increase in price dispersion. The muted response of the relative price distortion allows the influence of the increasing returns to scale to dominate and generate a positive response of output per hour.

output in a staggered price model with trend inflation but no habit persistence. They conclude that "further work is required to understand this and reconcile it with how one typically thinks the economy responds to such a shock." The present paper attempts to take up their call.

[12] The relative price distortion is equal to $\Delta_t \equiv (s_t + \varepsilon)/(1+\varepsilon)$, so the log-linearized relative price distortion shown in the bottom panel of Figure 2 is equal to $\hat{\Delta}_t = [s/(s+\varepsilon)]\hat{s}_t$. Under the baseline calibration the coefficient $s/(s+\varepsilon)$ is negative.

3.3 Credible disinflation

This subsection investigates the responses of inflation and output to a permanent credible disinflation, comparing the case of a kink in demand curves and the case of no kink. In the Calvo model with price indexation to the trend inflation rate, as in Yun (1996), and no intrinsic inflation inertia, a credible decline in the trend inflation rate causes inflation to adjust immediately and fully, while output never deviates from its steady-state level. However, once intrinsic inflation inertia is introduced, inflation adjusts gradually to its new trend rate and output declines temporarily.[13]

The experiment is as follows. Assume in period 0 the economy is in steady state with an annualized trend inflation rate of two percent. In period 1, the central bank credibly lowers the annualized trend inflation rate permanently to one percent. Denote the vector of endogenous state variables in the log-linearized model by $\hat{k}_t = \log k_t - \log k(\pi)$; for instance, $k_t = [Y_t,\, s_t,\, d_{1t}]'$ in the model with the kink and $k_t = [Y_t,\, s_t]'$ otherwise.[14] Here $k(\pi)$ denotes the vector of steady-state values of k_t, which emphasizes that these values are functions of the trend inflation rate. Since all variables are in steady state in period 0, in period 1 the lagged endogenous state variables under the new trend inflation rate are given by $\log k(\pi^0) - \log k(\pi^1)$, where $\pi^0 = 1.02^{0.25}$ and $\pi^1 = 1.01^{0.25}$. Then the solution of the log-linearized model at the trend inflation rate of π^1 is used to compute inflation and output in periods $1, 2, 3, \ldots$[15]

Figure 3 displays the inflation and output responses to the disinflation in the two cases with and without a kink in demand curves. In addition, the figure shows the responses from an analogous model with no kink in demand curves and intrinsic inflation inertia. Specifically, in this model firms that do not reoptimize their prices are assumed to fully index their prices

[13]Fuhrer (2011) demonstrates these results in a staggered price model approximated at the zero trend inflation rate and an ad hoc, backward-looking specification for output. Ball (1994) shows that a credible disinflation can even cause an output boom in a staggered price model.

[14]For the analysis in this subsection it is assumed that there is no policy rate smoothing (that is, $\rho_1 = \rho_2 = 0$), to facilitate comparison with the literature that studies intrinsic inflation inertia discussed earlier.

[15]It is clear from this experiment that the standard NKPC, with price indexation to the trend inflation rate as in Yun (1996), leads inflation to adjust immediately and fully to a shift in the trend inflation rate, and leaves output unchanged regardless of whether habit formation is present. The reason is that the steady-state value of output is independent of the trend inflation rate, so $\log k(\pi^0) - \log k(\pi^1) = 0$. Adding a backward-looking inflation term breaks this result.

to the previous-period inflation rate as in Christiano, Eichenbaum and Evans (2005). The left column shows responses under the baseline calibration summarized in Table 1 (except for no policy rate smoothing). Without curvature in demand curves and with no indexation, inflation drops immediately, slightly overshooting the new trend rate (the dashed line). Adding price indexation ensures that inflation declines gradually toward the new trend rate (the dotted line). Notably, adding the kink in demand curves, instead of indexation, yields a similarly gradual decline in inflation (the solid line). In terms of real activity, in the model with no price indexation the disinflation causes output to converge gradually to its new steady-state level, regardless of whether demand curves are kinked. The new steady-state output level lies below the initial level in the case of the kink, whereas it exceeds the initial level in the case of no kink.[16] In contrast, in the model with price indexation the disinflation generates an output recession, consistent with the dynamics reported by Fuhrer (2011).

The right column shows the effects of disinflation obtained in the absence of habit formation in consumption preferences (that is, $b = 0$). This calibration allows highlighting the dynamics generated by price dispersion and price distortion in the two cases, since now $k_t = [s_t, \, d_{1t}]'$ in the case of the kink in demand curves and $k_t = s_t$ in the case of no kink. Once again, the kink in demand curves induces a gradual adjustment of inflation, in line with the model with price indexation. Moreover, in the presence of the kink, the disinflation causes a recession, as output declines initially and then rebounds gradually to converge to its new steady-state level. Thus, the responses of inflation and output in the absence of habit formation are consistent with the results obtained with the model with price indexation. In contrast, the case of no kink (and no price indexation) induces neither a gradual adjustment of inflation nor a recession.

4 Estimation results

This section evaluates whether the staggered price model with a kink in demand curves can match the empirical impulse responses from a structural VAR model. To this end, the staggered

[16]Kurozumi and Van Zandweghe (2015) show that the kink in demand curves can cause steady-state output to become an increasing function of trend inflation, in contrast with the case of constant-elasticity demand curves. This is because the kink alters the effect of trend inflation on the steady-state markup and the relative price distortion.

price model is augmented by introducing capital formation and a variable capital utilization rate. As shown by Christiano, Eichenbaum and Evans (2005), a variable capital utilization rate can dampen the estimated initial impact of a monetary policy shock on inflation because it subdues real marginal cost. That helps prevent an immediate rise in inflation, which is absent from empirical inflation responses. Furthermore, a variable capital utilization rate contributes to generating a procyclical response of output per hour.[17] The addition of capital and capital utilization introduces four new parameters: $\alpha \in (0, 1)$ is the cost share of capital, $\delta \in (0, 1)$ is the capital depreciation rate, $\sigma_a > 0$ governs the curvature of the cost of capital utilization and $\kappa > 0$ governs the curvature of the investment adjustment cost. The log-linearized equilibrium conditions of the model with capital formation are summarized in Appendix A.

4.1 Econometric methodology

The empirical analysis consists of two steps. First, we estimate a structural VAR model for the sample period from 1959:Q1 to 2007:Q4. The variables are the log of the GDP deflator, the log of real GDP, the log of output per hour in the business sector, and the federal funds rate.[18] The lag length of the VAR is set to six quarters, as determined by the Akaike information criterion. A history of monetary policy shocks is recovered from the error terms under the identifying assumption that no economic variable except the federal funds rate responds contemporaneously to such a shock, following a large literature (see Christiano, Eichenbaum and Evans (1999) and Boivin, Kiley and Mishkin (2011)).

Second, a group of parameters of the staggered price model are estimated by minimum distance estimation. A few of the parameters are calibrated: $\alpha = 0.36$, $\beta = 0.99$, $\delta = 0.025$, and the trend inflation rate is set at the two percent annualized rate. The estimation method then entails finding the vector of parameters $x = [\epsilon, \theta, \xi, \sigma_n, b, \sigma_a, \kappa, \phi_\pi, \phi_y, \phi_g, \rho_1, \rho_2]'$ that minimizes

$$J = (\Psi(x) - \hat{\Psi})' W (\Psi(x) - \hat{\Psi}), \tag{34}$$

[17] We estimated the model presented in Section 2, which abstracts from capital formation, and found that the kink in demand curves causes the estimated response of inflation to the policy shock to be hump-shaped, but with an overly large initial impact.

[18] Also included is a commodity price index, in logs, to limit the extent of a price puzzle.

where $\Psi(x)$ and $\hat{\Psi}$ denote, respectively, the stacked impulse response functions of 20 quarters obtained from the staggered price model and from the VAR model, excluding the initial quarter. Following Christiano, Eichenbaum and Evans (2005), Giannoni and Woodford (2005), and Boivin and Giannoni (2006), the weighting matrix W is a diagonal matrix that contains the inverse variances of the elements of $\hat{\Psi}$.[19] Minimum distance estimation seems a natural choice given our objective of explaining the dynamic effects of a monetary policy shock. Moreover, this method avoids having to add additional shocks to the staggered price model and imposing additional identifying assumptions to estimate those shock processes.

4.2 Dynamic responses to a monetary policy shock

Table 2 shows the estimated parameter values obtained in the case of a kink in demand curves and in the case of no kink. As shown in the left column, in the presence of the kink the estimated parameters of the demand curve are $\epsilon = -1.64$ and $\theta = 11.02$. These values imply a curvature of $-\gamma = -\theta(1+\epsilon) = 7.06$, which is of the same order of magnitude as the estimated value reported by Dossche et al (2010).[20] The estimated probability of no price adjustment $\xi = 0.93$ is high, likely due in part to the absence of sticky wages from the model. Likewise, the estimated degree of habit persistence, $h = 0.96$, is on the high end of values found in the literature. The small estimate for σ_a (0.50) and the moderate value of κ (2.00) are in line with the findings of Christiano et al. (2005). The estimated values of the parameters in the Taylor rule are in the range of estimates found in the literature. The right column gives estimation results obtained with the restricted case, which precludes curvature by setting $\epsilon = 0$. This case yields notable shifts in two of the estimated parameters. The elasticity of demand takes a smaller value of $\theta = 7.39$ and the degree of habit formation declines sharply ($h = 0.07$). The other parameters take similar values as found for the case of a kink.

The estimated model with a kink in demand curves generates a persistent and hump-shaped inflation response to a monetary policy shock. The solid lines in Figure 4 display the impulse

[19]Other papers that use minimum distance estimation include Rotemberg and Woodford (1997) and Amato and Laubach (2003).

[20]These authors argue that "a very sensible value to choose for the curvature would be around 4" (p. 740). Figure 1 illustrates an example of a demand curve with curvature equal to 7.

responses of the staggered price model. The response of inflation peaks nine quarters after the shock. The response of output is also hump-shaped, but the response of output per hour is front loaded. Immediately after the shock the model-based impulse responses lie outside the confidence bands of the empirical impulse responses. Partly this is because the timing assumption in the staggered price model allows an immediate response of inflation, output, and output per hour, whereas the VAR model assumes these variables remain unchanged on impact. Overall, however, the model-based impulse responses align fairly closely with their empirical counterparts.

To gauge the effect of the kink on the dynamic responses in the estimated staggered price model, Figure 5 compares the impulse responses obtained with the two sets of estimation results. The key difference is that the kink causes a monetary policy shock to have a muted impact on inflation and to generate a hump-shaped inflation response. In contrast, inflation peaks on impact in the absence of the kink, even though in this case the model has been reestimated. Therefore, the estimation result confirms the finding of the quantitative analysis in the previous section that the kink can lead to considerable inflation persistence.

As for the response of output per hour, it is positive in both cases of the demand curves. The positive response of output per hour in the absence of a kink contrasts with the findings from the calibrated model in the previous section. Moreover, the bottom left panel of Figure 5 shows that the rise in output per hour occurs despite a relatively large response of the relative price distortion. The reason is that in the model with variable capital utilization, output per hour depends positively on the capital utilization rate, in addition to the effects from the fixed cost of production and the relative price distortion discussed in the previous section (see Eq. (39) in Appendix A). The bottom right panel shows that the capital utilization rate responds positively to the policy shock, thus contributing to a procyclical response of output per hour. Moreover, the response of capital utilization is larger in the case of no kink in demand curves. Thus, the positive effect of higher capital utilization, along with the fixed cost, dominates the negative effect of the relative price distortion, preventing a decline in output per hour.

5 Concluding remarks

In a Calvo staggered price model with low trend inflation, this paper examines the implications of a "smoothed-off" kink in demand curves for inflation persistence. A quantitative analysis of the model demonstrates that such a kink can give rise to considerable inflation inertia. Inflation displays a persistent and hump-shaped response to a monetary policy shock, consistent with the empirical evidence. In addition, a kink in demand curves can lead the dynamic response of output per hour to a policy shock to align with the empirical evidence. The paper also shows that following a permanent credible disinflation, the kink can lead to a gradual adjustment of inflation and a recession. Consumption habits play a role for this result: Too much habit persistence smooths out the response of output and prevents a recession.

The conclusion that a kink in demand curves can account for the observed inflation inertia is strengthened by the results from estimation of the model parameters. The estimated curvature is in line with other micro evidence but smaller than the values typically used in macro studies. Despite the relatively small estimated degree of curvature, the response of inflation to a policy shock obtained with the estimated model displays a hump shape. If instead the estimation imposes constant-elasticity demand inflation peaks immediately after the shock.

A Model with capital formation

The introduction of capital formation follows Christiano, Eichenbaum and Evans (2005), and modifies the problems of the representative household and the intermediate-good firms. First, the representative household maximizes utility subject to the budget constraint $P_tC_t + P_tI_t + P_ta(u_t)K_t + B_t = P_tW_tN_t + P_tR_tu_tK_t + i_{t-1}B_{t-1} + T_t$ and the capital accumulation constraint $K_{t+1} = (1-\delta)K_t + [1 - S(I_t/I_{t-1})]I_t$, where K_t denotes the capital stock, I_t is investment, and δ is the capital depreciation rate. Furthermore, $a(\cdot)$ is an adjustment cost for the capital utilization rate u_t with $a(1) = 0$, and $S(\cdot)$ is an investment adjustment cost with $S(1) = S'(1) = 0$. In addition to (1)-(3), there are first order conditions for capital, investment, and the capital utilization rate:

$$\begin{aligned}
q_t &= \beta E_t \frac{\Lambda_{t+1}}{\Lambda_t}\left[a'(u_{t+1})u_{t+1} - a(u_{t+1}) + (1-\delta)q_{t+1}\right], \\
1 &= q_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}}\right] + \beta E_t \frac{\Lambda_{t+1}}{\Lambda_t} q_{t+1} S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2, \\
R_t &= a'(u_t),
\end{aligned} \tag{35}$$

where q_t denotes the marginal rate of substitution between consumption and investment.

Second, intermediate-good firm f uses a Cobb-Douglas production technology:

$$Y_t(f) = \begin{cases} (K_t(f)u_t(f))^\alpha N_t(f)^{1-\alpha} - \phi & \text{if } (K_t(f)u_t(f))^\alpha N_t(f)^{1-\alpha} \geq \phi \\ 0 & \text{otherwise} \end{cases} \tag{36}$$

where $\alpha \in (0,1)$ denotes the cost share of capital. Combining the firm's conditions for cost-minimization with conditions (1) and (35) yields

$$\begin{aligned}
mc_t &= (1-\alpha)^{-1}\left(\frac{N_t}{K_t u_t}\right)^\alpha \frac{N_t^{\sigma_n}}{\Lambda_t}, \qquad (37) \\
a'(u_t) &= \alpha\, mc_t \left(\frac{N_t}{K_t u_t}\right)^{1-\alpha}.
\end{aligned}$$

Eq. (37) shows that a rise in the capital utilization rate dampens real marginal cost. Finally, combining the labor market clearing condition (12) with Eqs. (5) and (36) yields

$$Y_t\left(\frac{s_t + \epsilon}{1+\epsilon}\right) = (K_t u_t)^\alpha N_t^{1-\alpha} - \phi. \tag{38}$$

The log-linearized equilibrium conditions of the model with capital formation consist of (23)–(29), and

$$\begin{aligned}
\hat{\Lambda}_t &= -\frac{1+\beta b^2}{(1-\beta b)(1-b)}\hat{C}_t + \frac{\beta b}{(1-\beta b)(1-b)}E_t\hat{C}_{t+1} + \frac{b}{(1-\beta b)(1-b)}\hat{C}_{t-1}, \\
\hat{K}_{t+1} &= (1-\delta)\hat{K}_t + \delta \hat{I}_t, \\
\hat{q}_t &= E_t\Lambda_{t+1} - \Lambda_t + [1-\beta(1-\delta)]\sigma_a E_t\hat{u}_{t+1} + \beta(1-\delta)E_t\hat{q}_{t+1}, \\
\hat{q}_t &= (1+\beta)\kappa\hat{I}_t - \kappa\beta E_t\hat{I}_{t+1} - \kappa\hat{I}_{t-1}, \\
\sigma_a\hat{u}_t &= \hat{mc}_t + (1-\alpha)\left(\hat{N}_t - \hat{K}_t\right), \\
\hat{mc}_t &= (\alpha+\sigma_n)\hat{N}_t - \hat{\Lambda}_t - \alpha\left(\hat{K}_t + \hat{u}_t\right), \\
\hat{Y}_t &= \left[1 + \left(\frac{1+\epsilon}{s+\epsilon}\right)\frac{\phi}{Y}\right]\left[(1-\alpha)\hat{N}_t + \alpha\hat{K}_t + \alpha\hat{u}_t\right] - \left(\frac{s}{s+\epsilon}\right)\hat{s}_t, \qquad (39) \\
\hat{Y}_t &= \left(1 - \delta\frac{K}{Y}\right)\hat{C}_t + \left(\delta\frac{K}{Y}\right)\hat{I}_t + \left(\frac{1-\beta(1-\delta)}{\beta}\right)\frac{K}{Y}\hat{u}_t.
\end{aligned}$$

The parameter $\sigma_a = a''(1)/a'(1) > 0$ governs the curvature of the cost of capital utilization and $\kappa = S'' > 0$ governs the curvature of investment adjustment costs.

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Table 1: Baseline calibration

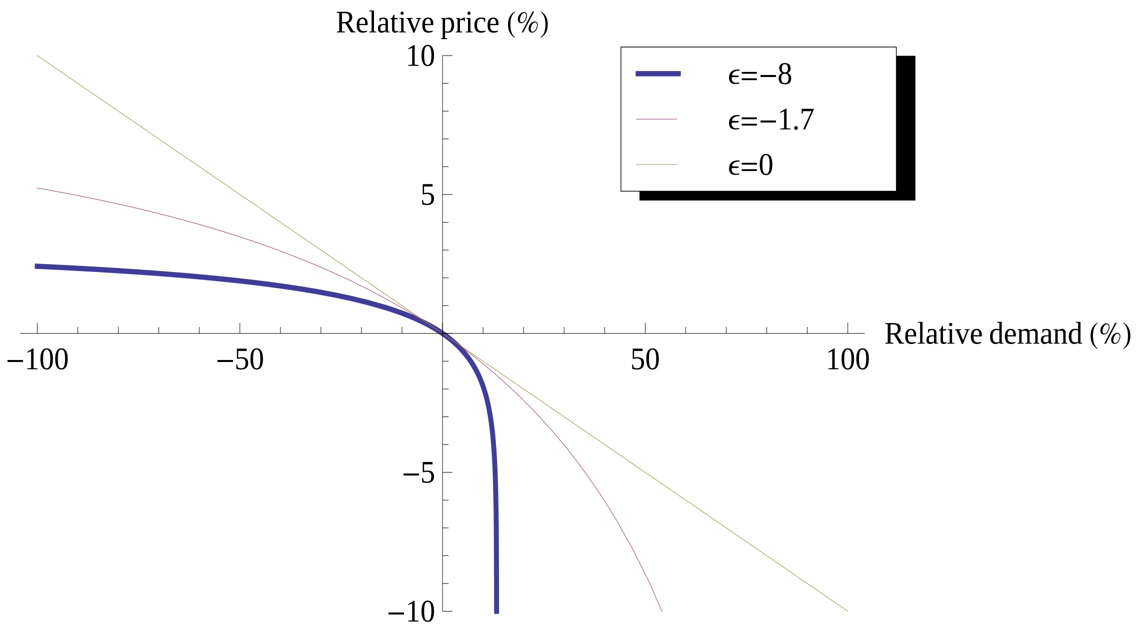
β	Subjective discount factor	0.99
σ_n	Inverse of the elasticity of labor supply	1
b	Degree of habit persistence	0.8
ξ	Probability of no price change	0.75
θ	Parameter governing the price elasticity of demand	10
ϵ	Parameter governing the curvature of demand curves	-8, 0
ϕ_π	Policy response to inflation	1.5
ϕ_y	Policy response to output gap	0
ϕ_g	Policy response to output growth	0
ρ_1	Policy response to first lag of interest rate	0.9
ρ_2	Policy response to second lag of interest rate	0
π	Trend inflation rate	$1.02^{0.25}$

Table 2: Estimated parameters

Parameter	Kink	No kink
ϵ	-1.638	—
	(0.001)	
θ	11.020	7.389
	(0.001)	(0.001)
ξ	0.928	0.935
	(0.101)	(0.002)
σ_n	1.271	1.221
	(0.001)	(0.001)
h	0.958	0.073
	(0.004)	(0.001)
σ_a	0.504	0.520
	(0.002)	(0.001)
κ	2.003	2.004
	(0.002)	(0.001)
ϕ_π	2.000	2.003
	(0.003)	(0.001)
ϕ_y	0.016	0.005
	(0.211)	(0.001)
ϕ_g	0.282	0.251
	(0.006)	(0.002)
ρ_1	0.818	0.821
	(0.030)	(0.009)
ρ_2	-0.175	-0.169
	(0.038)	(0.002)

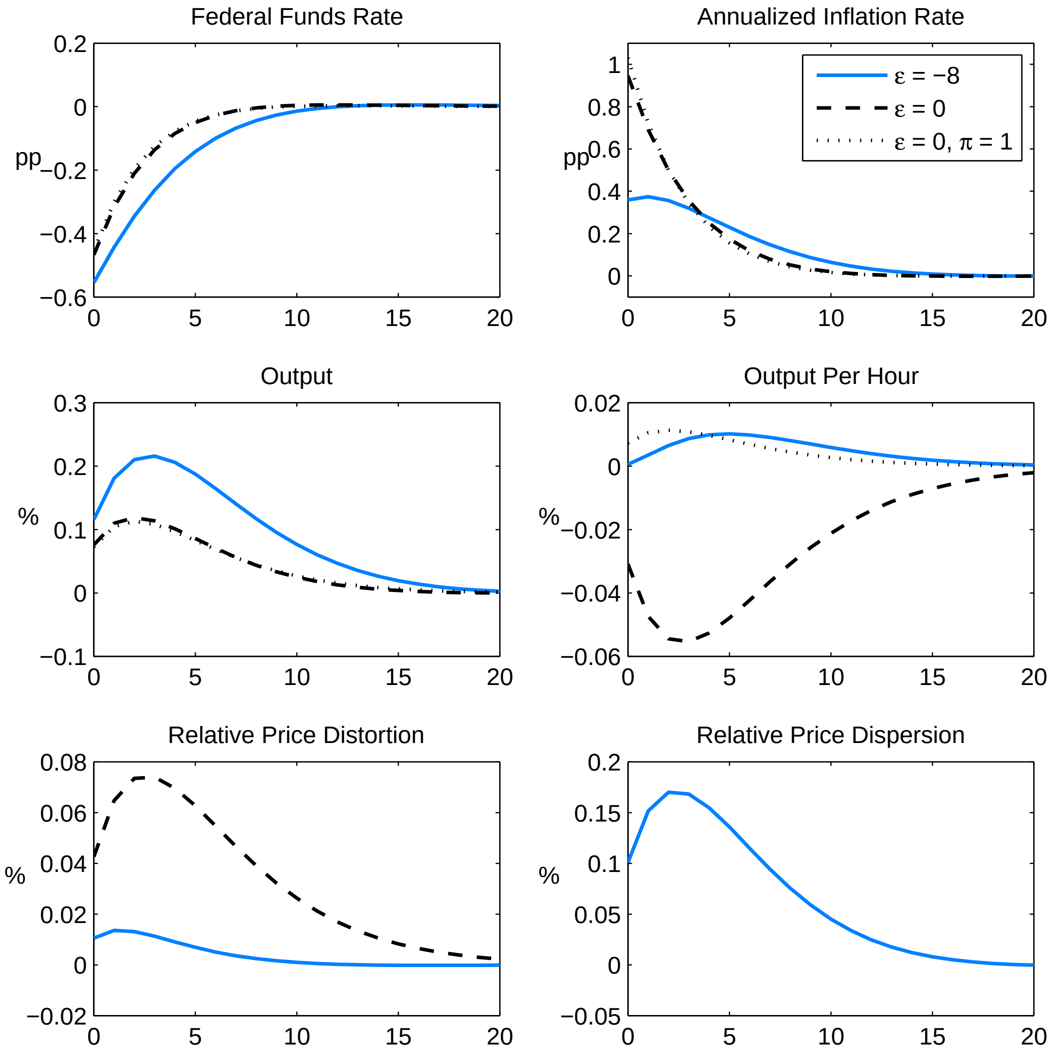
Note: Standard errors are in parentheses.

Figure 1: Smoothed-off kink in demand curve.



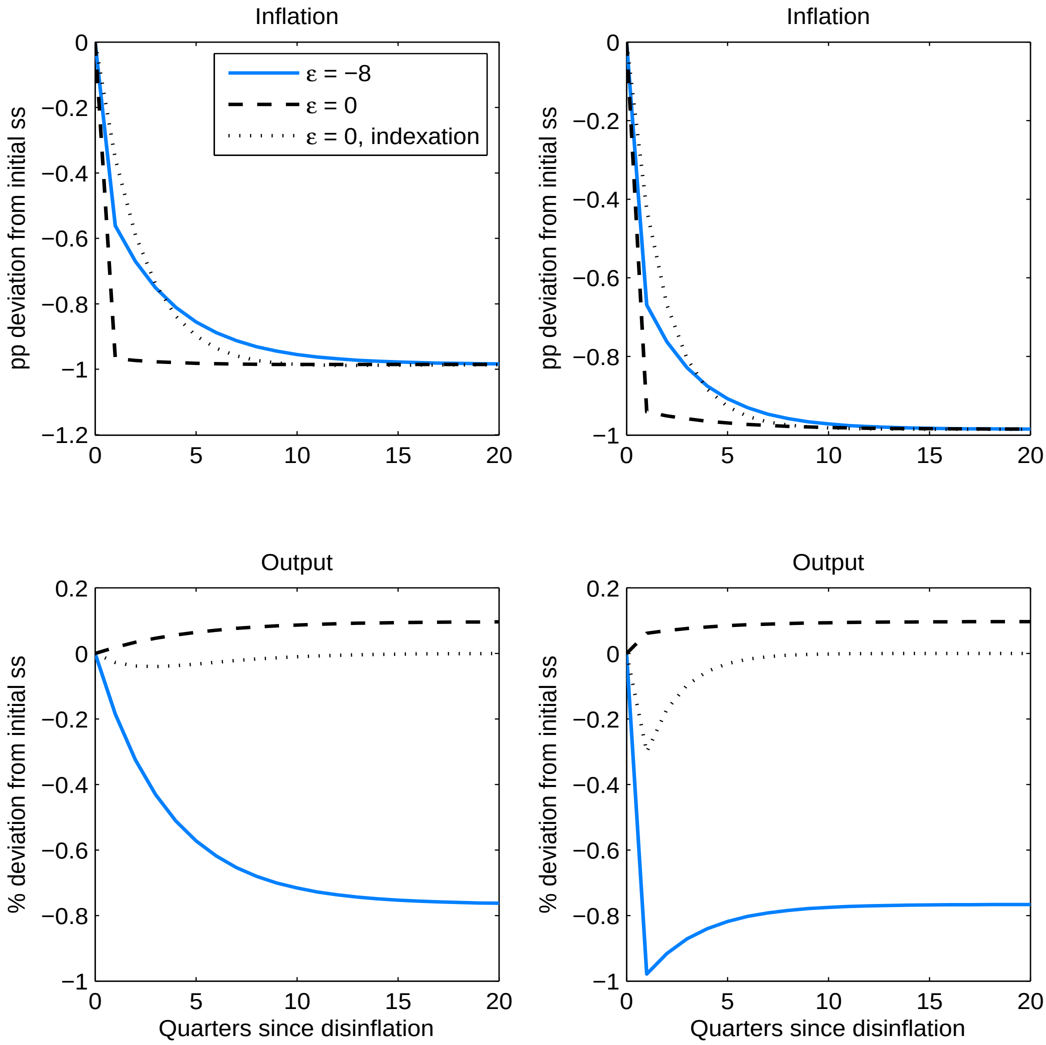
Note: For different values of the parameter governing the curvature of demand curves, ϵ, this figure uses the baseline calibration of the parameter governing the price elasticity of demand ($\theta = 10$).

Figure 2: Effect of trend inflation and kink in demand curves on shape of impulse responses.



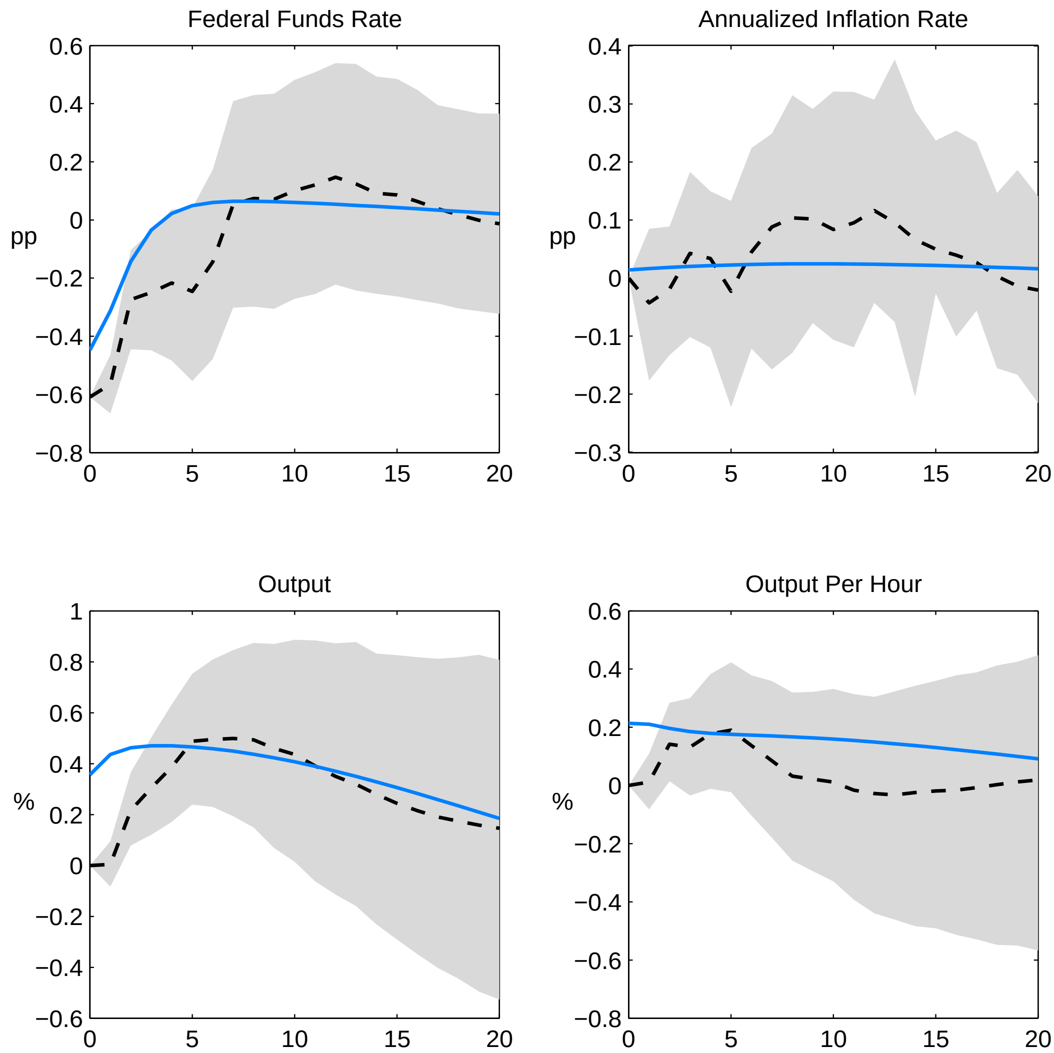
Note: Solid (blue) lines are impulse responses obtained under the baseline calibration in the case of a kink in demand curves (i.e., $\epsilon = -8$). Dashed lines are impulse responses obtained under the baseline calibration in the case of no kink in demand curves (i.e., $\epsilon = 0$). Dotted lines are impulse responses obtained under the baseline calibration in the case of no kink, except for zero trend inflation (i.e., $\varepsilon = 0$, $\pi = 1$). Units on the horizontal axis are quarters.

Figure 3: Credible disinflation in the staggered price model with low trend inflation.



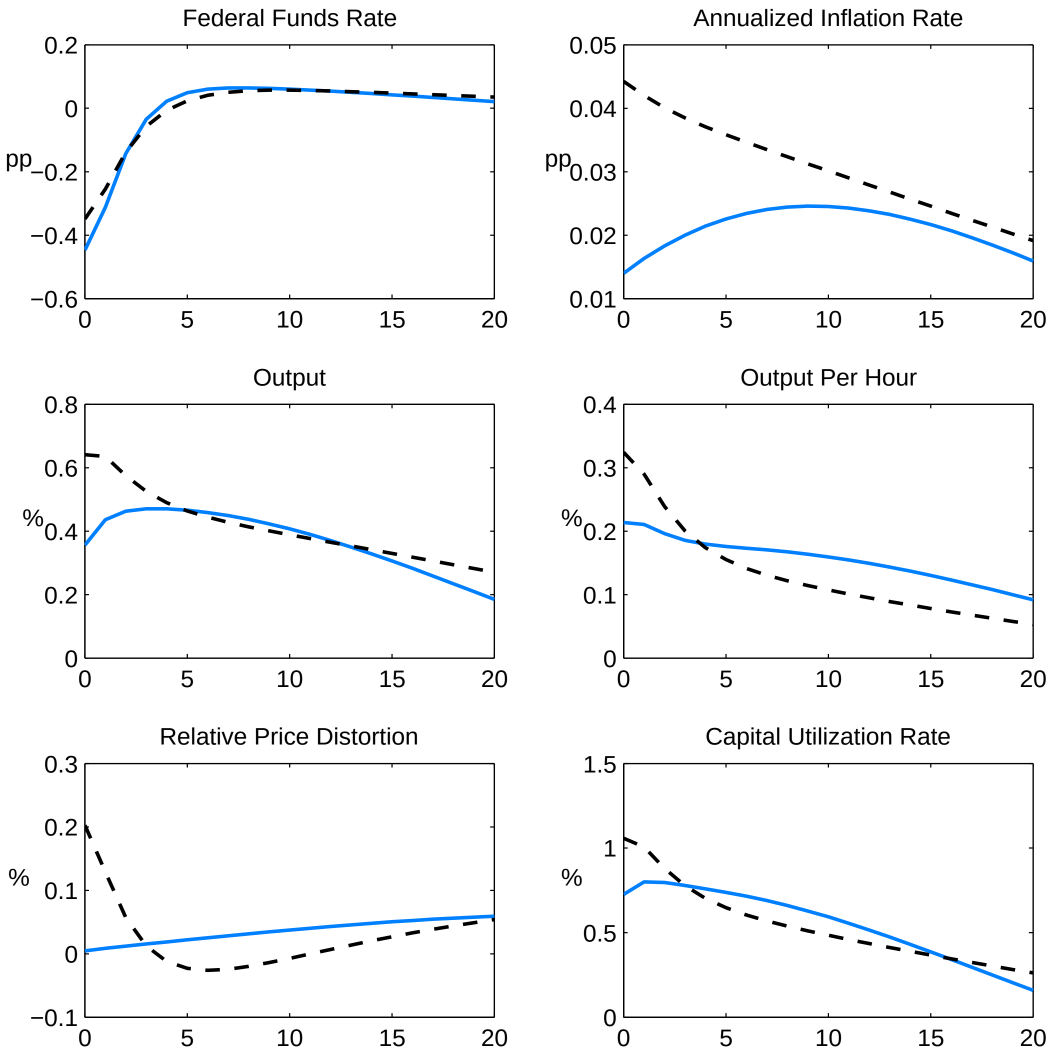
Note: The left column shows the case of habit persistence (i.e., $b = 0.8$) and the right column shows the case of no habit persistence (i.e., $b = 0$). Solid (blue) lines are responses in the case of a kink in demand curves (i.e., $\varepsilon = -8$). Dashed lines are responses in the case of no kink in demand curves (i.e., $\epsilon = 0$). Dotted lines are responses obtained in the case of no kink and full price indexation to past prices. Units on the horizontal axis are quarters.

Figure 4: Model and VAR-based impulse responses.



Note: Dashed lines are impulse responses of the structural VAR model and gray areas are 90 percent confidence intervals obtained using Kilian's (1998) bootstrap procedure. Solid lines are impulse responses of the estimated staggered price model with a kink in demand curves. Units on the horizontal axis are quarters.

Figure 5: Estimated effect of kink in demand curves on the shapes of impulse responses.



Note: Solid lines are impulse responses obtained with the estimated parameters in the case of a kink in demand curves. Dashed lines are impulse responses obtained with the estimated parameters in the case of no kink. Units on the horizontal axis are quarters.