# INTEGRATING STICKY PRICES AND STICKY INFORMATION*

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**Abstract**

Understanding the relationship between nominal and real variables, most notably inflation and cyclical output, is one of economics' fundamental questions. Towards this understanding, we develop a model that integrates sticky prices and sticky information, i.e. a dual stickiness model. We find that both rigidities are present in U.S. data. We also show that the dual stickiness model's closest competitor is the hybrid New Keynesian model. For both models, current inflation depends in part on last period's inflation. The former model achieves this dependence endogenously through the interaction of the two rigidities, rather than through backward-looking behavior. U.S. data supports the dual stickiness over the hybrid model because lagged expectations terms appear in the former's inflation Euler equation. Finally, we show that it is quantitatively important to

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distinguish between the two by simulating a dynamic equilibrium model under each of the two inflation equations.

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# I. Introduction

The interaction of real activity and inflation is a cornerstone issue of macroeconomics. As with every major macro question, it has been placed under the lens of rational expectations and micro-founded dynamics in recent decades. Approximately ten years ago, efforts to estimate then existing models of price rigidity intensified.[1] These efforts center on the aggregate Euler equation from a rational expectations sticky price model, often called the New Keynesian Phillips Curve (NKPC). A number of authors have argued that the NKPC is empirically deficient. Fuhrer and Moore (1995) find that inflation is more persistent than the models imply. Mankiw (2001) points out that the NKPC is inconsistent with the stylized fact of inflation inertia. Broadly speaking, experts have fallen into one of two camps in explaining the observed inflation inertia.

The first group contends that the original mechanism is largely successful once minor adjustments are made. Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2001) state that the so-called hybrid NKPC, which assumes the presence of backward-looking firms, match U.S. and European data very well. Another adjustment toward improvement of the NKPC is to introduce real rigidities to reduce the sensitivity of prices to real marginal cost.[2] While real rigidities are useful in obtaining estimated frequencies of price changes consistent with micro evidence, most empirical studies continue to find that backward-looking firms play an important role in accounting for the observed inflation inertia. Thus, the hybrid NKPC has been strongly supported by the data, even though the assumption of backward-looking

[1] The existing models at that time included Calvo (1983), Rotemberg (1982), and Taylor (1980).

[2] Sbordone (2002) assumes firm-specific marginal cost under the assumption of inflexible capital movement. Christiano, Eichenbaum and Evans (2005) and Tsuruga (2007) emphasize the importance of variable capital utilization (and nominal wage rigidities) in reducing the sensitivity of prices to real marginal cost.

firms might be unappealing from the theoretical viewpoint.

The second group advocates a major overhaul of the NKPC to account for inflation inertia. A few of the alternatives include imperfect common knowledge (Woodford 2003) and sticky information (Mankiw and Reis 2002, Reis 2006). In Mankiw and Reis, only a fraction of firms choose prices attentively with currently available information. Their sticky information economy replicates inflation inertia extremely well from the theoretical viewpoint. As such, they propose to replace sticky prices with sticky information. Unfortunately, however, recent empirical studies find that empirical comparisons favor the sticky price model rather than the sticky information model.[3]

This paper proposes an alternative model for explaining inflation inertia. We develop a 'dual stickiness' model which integrates price stickiness and information stickiness. In our model, each firm has two adjustment probabilities every period: a chance to reset its price and an independently distributed chance to update its information. Among firms that reset their prices, a fraction of the firms choose their nominal prices with new information and the remaining determine prices with old information.

Remarkably, the dual stickiness model's log-linearized inflation equation has a lagged inflation term. It endogenously arises through the integration of the two types of stickiness. First, price stickiness makes current inflation proportional to the average of newly set relative prices. Then, information stickiness makes some of today's price setting firms behave similarly to some of the last period's price setting firms, creating dependence of the average of newly set relative prices on its own lag. The interaction of the two generates a lagged inflation term. In this sense, we argue that our dual stickiness model provides a more plausible microfoundation for inflation inertia than the hybrid model which obtains a lagged inflation term from exogenously assumed backward-looking firms.

The model's log-linearized inflation equation also has current and lagged expectations terms: forecasts of current and future marginal cost based on current information and fore-

[3]Examples include Coibion (2008), Kiley (2007), and Laforte (2007).

casts of current and future marginal cost growth and inflation based on old information. The lagged expectations term is empirically important in distinguishing the dual stickiness from hybrid model, because only the former has a lagged expectations term.

We take the model to U.S. data and simultaneously estimate the importance of price and information stickiness in a nested framework.[4] We find that both rigidities are present in U.S. data. Hence, our empirical results contravene a wholesale replacement of sticky prices with sticky information. Instead, our results suggest that the integration of price and information stickiness is extremely helpful in accounting for U.S. inflation dynamics.

Our benchmark estimates are that, in each quarter, 14 percent of firms reset prices and 42 percent of firms update information. When we allow for a typical degree of strategic complementarity, these probabilities become 28 percent and 70 percent. We also measure the relative importance of each nominal rigidity and find that sticky prices are more important than sticky information in fitting U.S. inflation dynamics.

We then empirically compare the dual stickiness and hybrid models. To distinguish the dual stickiness from hybrid model, we first focus on the correlations between inflation and lagged expectations, which feature the role of sticky information. While both models account for inflation quite well in terms of goodness of fit, we find that lagged expectations matter for inflation in a statistically significant way. Next, we present a further generalized specification which nests both the dual stickiness and hybrid models. We find that the data supports the dual stickiness model over the hybrid model and thus, we argue that the latter may be misspecified in explaining U.S. inflation dynamics. Finally, using a simple general equilibrium analysis, we show that impulse responses to a cost-push shock can be qualitatively different between the two pricing frictions. This implies that it is important to distinguish the two in understanding macroeconomic dynamics.

The findings of this paper are broadly in line with those of recent papers by Klenow and Willis (2007) and Knotek (2006). They introduce sticky information into a state-dependent

[4] Note that our nested framework contrasts with the previous model selection studies by Kiley (2007), Korenok (2008) and Laforte (2007).

pricing model in general equilibrium and show calibrations and estimation results emphasizing the role of sticky information. Our time-dependent approach has an advantage over the state-dependent approach in that we can easily include dual stickiness pricing into a wide class of dynamic general equilibrium models with many state variables.

An outline of the rest of the paper is as follows. Section II describes the dual stickiness and hybrid models. Section III and IV present our empirical method and findings. Section V shows general equilibrium comparisons between the two models. The final section concludes.

# II. Two Pricing Problems

This section describes a firm's problem under two different sets of frictions. After aggregation, we characterize two inflation equations, one for each set of frictions. The dual stickiness model has both sticky prices and sticky information. This model also nests both the pure sticky price and pure sticky information cases. Our second set of frictions is sticky prices and backward looking firms, i.e. the hybrid model. This latter model has become a workhorse in empirical monetary economics.

## A. The Dual Stickiness Model

Consider a firm which is the monopolist producer and seller of a particular good. The firm infrequently changes its nominal price and also infrequently updates its information. With probability $1-\gamma$, the firm may change its price; otherwise, its current period price equals its previous period price. With probability $1-\phi$, the firm updates its information set to include all current variables; otherwise, the firm's information is the same as its previous period's information. For tractability, these two random events, the opportunities to change a price and to update information, are uncorrelated over time and with each other.

The economy is made up of measure one of the above types of firms, each producing and selling a distinct good. Each faces the above probabilities of price changes and information updates.

We are interested in the behavior of inflation in this economy. Let us define two nominal price indices. First, $p_t$ denotes the log aggregate nominal price level in period $t$. Second, $q_t$ is a nominal price index for all newly set prices in period $t$. We will say more about $q_t$ below.

Because a measure $1-\gamma$ of firms resets its price in each period,

$$p_t = \gamma p_{t-1} + (1-\gamma)\, q_t.$$

Or equivalently, subtracting $p_t$ from both sides and rearranging yield

$$\pi_t = \frac{1-\gamma}{\gamma}\left(q_t - p_t\right), \tag{1}$$

where $\pi_t$ is inflation rate. Intuitively, (1) states that inflation is positive when the newly set prices are higher than the overall price level. It also states that inflation is proportional to newly set relative prices $q_t - p_t$. Figure 1 shows this proportionality diagrammatically. Note that $p_{t-1} - p_t$ is the average relative prices for firms that are not allowed to change prices. Because the weighted sum of all log relative prices must be zero by definition, the two shaded areas in the figure must be equal.

Due to the sticky price assumption, a firm with zero period old information (i.e. current information) and the ability to change its price chooses

$$p_t^f = (1-\gamma)\sum_{j=0}^{\infty}\gamma^j E_t\left(mc_{t+j}^n\right), \tag{2}$$

where $p_t^f$ is the full information optimal price and $mc_t^n$ is nominal marginal cost in period $t$.[5] Intuitively, (2) states that the firm sets its nominal price to the weighted average of current and future nominal marginal costs. This decision is forward-looking because of infrequent opportunities for price changes.

[5] We set the discount factor to unity for simplicity.

The decision of a price resetting firm in period $t$ with one period old information is similar, except that this firm is restricted to conditioning its optimal price on $E_{t-1}(\cdot)$, instead of $E_t(\cdot)$. Newly set prices based on older vintages of information are similarly restricted.

Next, consider $q_t$, the nominal price index for newly set prices. There will be newly set prices in period $t$ based on information sets of various vintages: current, one period old, two period old, etc. Thus, given the probability of information updating $1 - \phi$, $q_t$ is given by

$$q_t = (1 - \phi) \sum_{k=0}^{\infty} \phi^k E_{t-k}(p_t^f). \tag{3}$$

Thus, the formulation of the price index is identical to the sticky information model by Mankiw and Reis (2002, p.1300), except that each individual price is determined in a forward-looking manner.

This equation can be rewritten as a first-order difference equation. Using the fact that $p_t^f = \Delta p_t^f + p_{t-1}^f$,

$$q_t = \phi q_{t-1} + (1 - \phi) p_t^f + \phi(1 - \phi) \sum_{k=0}^{\infty} \phi^k E_{t-k-1}(\Delta p_t^f). \tag{4}$$

The intuition behind this structure is that some firms continue to hold the same information between periods due to information stickiness and thus a similarity arises in the prices between two periods. To further explore the intuition, suppose that prices were initially stabilized at zero and that a positive shock occurs at period 0. The left diagram of Figure 2 depicts a hypothetical path of $q_t$ as a thick line. In period $t-1$, some firms are inattentive to the shock. They set prices to zero since they do not know that the shock occurred. In this sense, they stick to the initial state, and this 'stickiness' is depicted in the diagram as an arrow moving from $q_{t-1}$ to $q_{-1}$. In the next period $t$, some firms remain inattentive to the shock (with a probability). They set their prices to zero by sticking to the initial state as the arrow moving from $q_t$ to $q_{-1}$ indicates. As a result of the common 'stickiness' to the initial state, persistence of $q_t$ arises endogenously, as the dotted arrow in the diagram shows.

The persistence is carried over to its *relative* level $q_t - p_t$. Namely, using an identity $p_t = \phi p_{t-1} + \phi \pi_t + (1-\phi) p_t$, we can express $q_t - p_t$ as a first-order difference equation of the form:

$$q_t - p_t = \phi(q_{t-1} - p_{t-1}) - \phi \pi_t + (1-\phi)(p_t^f - p_t) + \phi(1-\phi) \sum_{k=0}^{\infty} \phi^k E_{t-k-1}(\Delta p_t^f). \qquad (5)$$

Note that $q_t - p_t$ is more persistent as $\phi$ increases.

Combining (2) and (5) with (1), we can derive

$$\begin{aligned} \pi_t = \rho^D \pi_{t-1} + \zeta_1^D (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_t(mc_{t+j}^n - p_t) \\ + \zeta_2^D (1-\phi) \sum_{k=0}^{\infty} \phi^k (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_{t-k-1}(\Delta mc_{t+j} + \pi_{t+j}), \end{aligned} \qquad (6)$$

where $\rho^D = \gamma\phi/(\phi+\gamma-\gamma\phi)$, $\zeta_1^D = (1-\phi)(1-\gamma)/(\phi+\gamma-\gamma\phi)$ and $\zeta_2^D = \phi(1-\gamma)/(\phi+\gamma-\gamma\phi)$. Also, $mc_t$ is real marginal cost given by $mc_t = mc_t^n - p_t$.

In the inflation equation (6), lagged inflation appears endogenously. As (1) suggests, the sticky price assumption generates a one-to-one relationship between $\pi_t$ and $q_t - p_t$. As (5) suggests, the sticky information assumption generates persistent dynamics of $q_t - p_t$. This newly reset relative price persistence is transformed into inflation persistence through the one-to-one relationship. Therefore, the combination of price and information stickiness endogenously generates lagged inflation in the inflation equation.

Besides the lagged inflation, there are two other terms in (6). The second term of the right hand side represents the present discounted value of future nominal marginal costs deflated by the current price level. This term captures the price-setting behavior of attentive firms. Also, the third term contributes to inflation through lagged expectations on future nominal marginal cost growth. It captures the price-setting behavior of inattentive firms.

## B. The Hybrid Model

Galí and Gertler (1999) depart from the pure sticky price model by assuming the presence of two types of firms. A fraction $\omega$ of firms are backward-looking and use a simple rule of thumb, whenever they reset prices. The remaining firms are forward-looking and set their prices according to (2). Then, the newly reset price index $q_t$ is redefined as a linear combination of the price set by backward-looking firms ($p_t^b$) and the price set by forward-looking firms ($p_t^f$):

$$q_t = \omega p_t^b + (1-\omega)p_t^f, \tag{7}$$

where $p_t^b$ are given by

$$p_t^b = q_{t-1} + \pi_{t-1}. \tag{8}$$

Instead of following the standard derivation of the hybrid NKPC, we derive a similar equation to (6). To derive this, we first substitute (8) into (7):

$$q_t = \omega q_{t-1} + (1-\omega)p_t^f + \omega\pi_{t-1}.$$

Substituting (2) into this equation, subtracting $p_t$ from both sides, and then using (1), we obtain[6]

$$\pi_t = \rho^H \pi_{t-1} + \zeta_1^H (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_t(mc_{t+j}^n - p_t), \tag{9}$$

where $\rho^H = \omega/(\omega+\gamma-\gamma\omega)$ and $\zeta_1^H = (1-\omega)(1-\gamma)/(\omega+\gamma-\gamma\omega)$.

The lagged inflation appears again in the inflation equation (9) of the hybrid model. This appearance stems from the assumption that some of price-setters follow a backward-looking rule-of-thumb. The right panel of Figure 2 diagrammatically depicts the dependence of $q_t$ on its own lag with an arrow directly moving from $q_t$ to $q_{t-1}$.

We argue that the dual stickiness model has more plausible microfoundations for explaining inflation inertia than the hybrid model. Under the dual stickiness model, lagged

[6] Above, we use the fact that $q_{t-1} - p_t = (q_{t-1} - p_{t-1}) - \pi_t = \gamma/(1-\gamma)\pi_{t-1} - \pi_t$.

inflation endogenously arises from the presence of inattentive firms that charge sub-optimal price $E_{t-k}p_t^f$ in a forward-looking manner. In contrast, under the hybrid model, lagged inflation arises from the presence of backward-looking firms. Another advantage of the dual stickiness model is that, while the hybrid model only nests the pure sticky price model ($\omega = 0$), the dual stickiness model nests the pure sticky information model ($\gamma = 0$) as well as the pure sticky price model ($\phi = 0$). In the following sections, we provide evidence that our dual stickiness model is not only theoretically but also empirically more plausible than the hybrid model.

# III. Empirical Implementation

We estimate (6) and (9) using the two step approach proposed by Sbordone (2002), Woodford (2001), and Rudd and Whelan (2005). In the first step, we run a vector-autoregression (VAR) to obtain the predicted series of a real marginal cost measure and inflation. Given the VAR process, the second step minimizes the variance of a distance between the model's and actual inflation. Our estimated parameters are the probability of no price change $\gamma$, the probability of no information update $\phi$, and the fraction of backward looking firms $\omega$. Furthermore, we can estimate the pure sticky price and pure sticky information models by putting restrictions on (6): $\phi = 0$ for the former and $\gamma = 0$ for the latter. For example, if $\gamma = 0$, then (6) reduces to the sticky information Phillips curve:

$$\pi_t = \frac{1-\phi}{\phi} mc_t + (1-\phi)\sum_{k=0}^{\infty} \phi^k E_{t-k-1}(\Delta mc_t + \pi_t). \tag{10}$$

Such a generalization allows us to compare the dual stickiness model to alternative pricing models based on the statistical significance of structural parameters.

Our two step approach differs slightly from the previous studies in that we do not estimate closed form solutions to the aggregate pricing Euler equations.[7] We use the non-closed form

[7] Sbordone (2002) transforms the standard NKPC into a closed form solution for the logarithm of the

equations (6) and (9) to estimate structural parameters.[8] This is because it is generally impossible to derive a closed form solution to the dual stickiness model, due to infinitely many lagged expectations terms in (6).[9]

The details of our estimation procedure are as follows. First, we specify the forecasting model by introducing the vector $X_t$ in the following VAR:

$$X_t = AX_{t-1} + \epsilon_t. \tag{11}$$

The vector $X_t$ should include at least a real marginal cost measure and inflation for estimation. The vector $X_t$ may include lags of variables. In general, for VAR($p$) process, $X_t$ is given by a $(3p \times 1)$ vector of $[x'_t, x'_{t-1}, \cdots, x'_{t-p+1}]'$, where $x_t$ is a vector of a set of variables in period $t$.

Next, we calculate a series of theoretical inflation given the forecasting process (11). Ordinary least squares produces a consistent estimate of the coefficient matrix $\hat{A}$. Let $e_{mc}$ and $e_\pi$ denote the selection vectors with $3p$ elements. All elements are zero except the first element of $e_{mc}$ and the second element of $e_\pi$, which are unity. Given the definitions, we express real marginal cost and inflation as $e'_{mc}X_t$ and $e'_\pi X_t$, respectively.

For expositional purposes, consider a special case with $\gamma = 0$ (i.e. (10)). Given the definitions of selection vectors, $E_{t-k-1}(\Delta mc_t + \pi_t) = (e'_{mc}(A - I) + e'_\pi A)\, A^k X_{t-k-1}$. Then, (10) can be written as

$$\pi_t^m(\theta, A) = \frac{1-\phi}{\phi} e'_{mc} X_t + (1-\phi)(e'_{mc}(A-I) + e'_\pi A) \sum_{k=0}^{\infty} \phi^k A^k X_{t-k-1}, \tag{12}$$

price-unit labor cost ratio, taking nominal marginal cost growth as given. Woodford (2001) and Rudd and Whelan (2005) rewrite the NKPC as a forward-looking solution for inflation and estimate parameters by minimizing a distance between the models' and actual inflation.

[8] Our estimation equation is not a closed form solution for $\pi_t$. Note that $E_t(mc^n_{t+j} - p_t)$ in (6) can be written as $E_t(mc_{t+j} + \pi_{t+j} + \pi_{t+j-1} + \cdots + \pi_{t+1})$. Because these terms include the expectations of future inflation, (6) and (9) are 'non-closed'.

[9] While it is straightforward to derive a closed form under $\phi = 0$, transforming the pure sticky price model alone to a closed form changes the estimation equation under $\phi = 0$ to a form incomparable to the dual stickiness model. As such, we also use a non-closed form to estimate the pure sticky price model. Otherwise, comparisons between the dual stickiness model and its alternatives could be unfair.

where $\pi_t^m(\theta, A)$ denotes the inflation predicted by the model and $\theta$ denotes the unknown parameter vector. In this particular case, $\theta = \phi$. By introducing an arbitrary large truncation value of $K$, we approximate this equation by

$$\pi_t^m(\theta, A) = \frac{1-\phi}{\phi} e'_{mc} X_t + (1-\phi)(e'_{mc}(A-I) + e'_\pi A) \sum_{k=0}^{K-1} \phi^k A^k X_{t-k-1}. \tag{13}$$

When the model explains the data well, $\pi_t^m(\theta, A)$ is close to actual inflation. Using a consistent estimate $\hat{A}$, we choose the parameter $\theta$ by

$$\hat{\theta} = \underset{\theta}{\text{Argmin}} \quad var(\pi_t - \pi_t^m(\theta, \hat{A})). \tag{14}$$

We use the same procedure to estimate (6) and (9). Given the VAR process, the series of $\{X_{t-k}\}_{k=0}^{\infty}$ suffices to express all discounted sums in (6) and (9). The Web Appendix A shows that (6) can be expressed as[10]

$$\pi_t^m(\theta, A) = \rho^D \pi_{t-1} + \zeta_1^D b' X_t + \zeta_2^D c' \sum_{k=0}^{\infty} \phi^k A^k X_{t-k-1}, \tag{15}$$

where $b' = [(1-\gamma)e'_{mc} + \gamma e'_\pi A] [I - \gamma A]^{-1}$ and $c' = (1-\gamma)(1-\phi) [e'_{mc} (A-I) + e'_\pi A] [I - \gamma A]^{-1}$. Similarly, (9) can be rewritten as

$$\pi_t^m (\theta, A) = \rho^H \pi_{t-1} + \zeta_1^H b' X_t. \tag{16}$$

The parameter vector here is $\theta = [\gamma, \phi]'$ for (15) and $\theta = [\gamma, \omega]'$ for (16). Once again, we choose an arbitrary truncation parameter $K$ and minimize the variance of the distance between the model's and actual inflation.

To make statistical inferences, we use a bootstrap method because the forecasted variables in the second step are 'generated regressors' and thus the usual asymptotic standard errors

[10] This Web Appendix is available at http://www.mitpressjournals.org/xxxxxxxxxxxxxxx.

are incorrect. A bootstrap method is more useful for making statistical inferences than corrected asymptotic standard errors because of the complicated estimation equation (15).

To conduct the bootstrap, we first generate 9999 bootstrapped series of $X^*_{i,t}$ from the empirical distribution of the residual $\hat{\epsilon}_t$ and the coefficient estimate $\hat{A}$ in (11). Using the resampled $X^*_{i,t}$, we estimate structural parameters $\theta_i$ by minimizing the variance of $\pi^*_{i,t} - \pi^{*m}_{i,t}(\theta_i, \hat{A})$ for $i = 1, 2, ..., 9999$, where $\pi^*_{i,t}$ is the inflation from the resampled unconstrained VAR and $\pi^{*m}_{i,t}(\theta_i, \hat{A})$ is the resampled inflation predicted by the model. We compute the confidence intervals of $\hat{\theta}$ from the bootstrapped distribution of $\hat{\theta}_i$.[11]

In our benchmark estimation, we use quarterly U.S. data between 1960:Q1 and 2007:Q2. Inflation is measured as the log difference of the NFB price deflator. Labor share, which is a proxy for real marginal cost, is the log of (NFB unit labor cost/NFB price deflator). In our estimation, forecasting power of the VAR is important in measuring the effect of expectations on inflation. Rudd and Whelan (2005) find that the output gap has strong forecasting power for labor share and inflation and that its inclusion into the VAR has a non-negligible effect on empirical performance of the NKPC. For this reason, we also include quadratically detrended real GDP as an output gap measure $y_t$. The VAR coefficients $\hat{A}$ are reported in Table A1 in the Web Appendix for a VAR(3), where we choose the VAR with three lags according to the BIC. The table also reports that the inclusion of output gap is helpful in forecasting labor share and inflation. Finally, we choose a truncation parameter of $K = 12$.

# IV. Findings

Our two key findings are: first, both types of stickiness are present in the data, and second, the data favors the dual stickiness model over the hybrid model.

[11]MacKinnon (2002) gives detailed explanations for the bias-corrected bootstrap intervals. To obtain 95 percent confidence intervals of estimates, we compute the bias-corrected bootstrap interval $[2\hat{\theta} - \bar{\theta}^* - 1.96s^*_{\theta}, 2\hat{\theta} - \bar{\theta}^* + 1.96s^*_{\theta}]$ , where $\hat{\theta}$, $\bar{\theta}^*$, and $s^*_{\theta}$ denote the original estimate from the actual data, the sample mean of the bootstrap estimates $\hat{\theta}^*_i$, and the standard deviation of $\hat{\theta}^*_i$, respectively.

## A. The Dual Stickiness Model and Its Alternatives

Table 1 reports the estimates from four models: i) dual stickiness (Dual); ii) hybrid; iii) pure sticky price (SP); and iv) pure sticky information (SI). The 95 percent confidence intervals appear in brackets. For convenience, we restate the dual stickiness and hybrid model equations in Table 1(a). The other two models are special cases of the dual stickiness model.

### Are both types of stickiness present?

First, both probabilities ($\gamma$ and $\phi$) differ from zero significantly under the dual stickiness model (Row 1 of Table 1(b)). Thus, both types of stickiness matter in accounting for aggregate U.S. inflation. The 95 percent confidence intervals for $\gamma$ and $\phi$ imply that 9-19 percent of firms change prices every quarter but 19-60 percent of these firms use the latest information to determine prices. Evaluated at the point estimates, the former is 14 percent and the latter is 42 percent, suggesting that only 5.9 percent in the economy choose the full information optimal price.[12]

Our estimate of the probability of information updating as 42 percent under dual stickiness is somewhat high relative to our SI model's estimate and those in previous studies (where individual prices are completely flexible). The probability of information updating ranges between 7 and 14 percent under the SI model (Row 4 of Table 1(b)). In comparison with ours, Khan and Zhu (2006) estimate the probability in the range of 12 and 35 percent, using VAR forecasts. Using different estimation strategies from ours, Andrés, López-Salido, and Nelson (2005) and Korenok (2008) find the probability is 15 and 30 percent, respectively.[13]

[12] Our estimates of probabilities of price changes are smaller than those found in micro empirical studies, for example, Bils and Klenow (2004), Nakamura and Steinsson (2008) and Klenow and Kryvtsov (2008). We will briefly explore this difference with their results in our robustness analysis.

[13] There are several reasons why our estimates from the sticky information Phillips curve differ from those discovered by the previous studies, especially Khan and Zhu (2006) whose estimation strategy is the closest to ours. First, we use different specifications of VARs. Second, we use labor share rather than the output gap. Third, we use in-sample forecasts of inflation and labor share rather than out-of-sample forecasts of inflation and the output gap.

Given the statistical significance of price stickiness, our findings contravene the wholesale replacement of sticky prices with sticky information. However, it does not imply that information stickiness should be ignored. The estimate of the corresponding structural parameter $\phi$ is statistically and economically significant.

**Can we distinguish between the dual stickiness and hybrid models?**

Next, we compare the dual stickiness and hybrid models.[14] The estimation equation of the hybrid model (9) has the same terms as the dual stickiness model (6), labeled 'lag $\pi$' and 'attentive firms' in Table 1 (a). However, the dual stickiness model has an additional term, labeled 'inattentive firms.' Therefore, whether the lagged expectations of nominal marginal cost growth are correlated with inflation distinguishes the dual stickiness from hybrid model. The statistical significance of the corresponding parameter $\zeta_2^D$ is the decisive factor in distinguishing the two.

We find that $\zeta_2^D$ is significantly different from zero in Table 1(c). The point estimate is 0.087 and the lower bound on the 95 percent confidence interval is 0.039. Later, we estimate the dual stickiness model using alternative measures of marginal cost, detrending method and subsamples. For all but two specifications, the unique feature of that model, lagged expectations, enter the inflation equation in a statistically significant way.

## B. Comparing Goodness of Fit

Let us assess the models' goodnesses of fit with the (uncentered) adjusted $R$-squareds.[15] It is not surprising that the dual stickiness model dominates the SP and SI models in terms of goodness of fit, because the dual stickiness model generalizes the other two. Still, the

[14]Our hybrid model results are in line with Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2005). They emphasize that the key parameters for assessing the importance of forward- versus backward-looking behavior are $\gamma_f$ and $\gamma_b$, which are functions of $\gamma$ and $\omega$. (Specifically, $\gamma_f = \gamma/(\gamma+\omega)$ and $\gamma_b = \omega/(\gamma+\omega)$ when the discounted factor equals unity.) While they conclude $\gamma_f = 0.65$ and $\gamma_b = 0.35$, our estimates imply $\gamma_f = 0.63$ and $\gamma_b = 0.37$ under the benchmark case even with our different estimation strategy.

[15]Since the regressors in our estimation equation do not include a constant, we use the 'uncentered' adjusted $R$-squared instead of the standard 'centered' one.

magnitude of improvement is impressive, and it occurs because the dual stickiness model has lagged inflation. In terms of comparisons between the SP and SI models, the SP model is comparable to or somewhat better than the SI model, which is consistent with Korenok (2008) and Coibion (2008). The assessment can be done visually by looking at the path of the models' inflation. Figures 3-6 plot actual inflation and inflation predicted by the four models between 1960:Q1 and 2007:Q2. The figures demonstrate that the inflation series generated by the dual stickiness models tracks actual inflation closely while those generated by the SP and SI models do so only roughly. Thus, the dual stickiness model is successful in fitting inflation due to the presence of lagged inflation.

Using estimates of the variance of the distance between the model's and actual inflation, we can quantify the relative importance of price and information stickiness. We compute the percentage reduction in the variance of the distance between the model's and actual inflation when we add another type of stickiness into either the SP or SI model. First, we can see from Table 1(b) that the variance of the SP model is 0.18. If one adds sticky information to the SP model, it becomes the dual stickiness model, with variance equal to 0.11. Hence, the percentage reduction in the variance is $-(0.11-0.18)/0.18 \simeq 38$ percent. In other words, adding sticky information contributes to 38 percent reduction in the variance of residuals in the SP model. Next, a similar calculation shows that adding price stickiness into the SI model reduces the variance of the SI model by about 45 percent. Therefore, adding sticky prices beats adding sticky information in terms of the percentage reduction in the variance of residuals.

Next, Table 1(b) also compares the dual stickiness and hybrid models in terms of goodness of fit. Both models explain inflation almost equally well. The $\bar{R}^2$ of the dual stickiness and the hybrid models are the same up to the third digit. The estimate of $\gamma$ under the dual stickiness model is slightly different from that under the hybrid model. More interestingly, whereas the structural parameters $\phi$ and $\omega$ have different interpretations, the estimates of $\phi$ and $\omega$ are quite close each other ($\phi = 0.58$ vs. $\omega = 0.52$). Why do the two models perform equally well? Why do the estimates of the different structural parameters take similar values?

To see why, rewrite (4) such that $q_t$ is decomposed into the prices set by attentive and inattentive firms:

$$q_t = \phi \tilde{p}_t^b + (1-\phi) p_t^f,$$

where $\tilde{p}_t^b$ is given by

$$\tilde{p}_t^b = q_{t-1} + (1-\phi) \sum_{k=0}^{\infty} \phi^k E_{t-k-1}(\Delta p_t^f). \tag{17}$$

Comparing (8) and (17), the difference comes from the second term of the right hand side of the equations. While the second term of (8) is lagged inflation, that of (17) is the conditional expectations on the change in the full information optimal price. Because there is no reason that $p_t^b$ is equal to $\tilde{p}_t^b$, the estimated parameters are, in general, different. However, if the lagged expectations term in (17) happens to be very close to $\pi_{t-1}$, the empirical results of the two models become similar.

## C. Robustness

This subsection establishes the robustness of our two main findings. Specifically, both types of stickiness are present in the data and $\zeta_2^D$ is significant.

In the first step VAR, our benchmark estimation used the quadratically detrended output gap. Since an HP filtered output gap has been considered as an alternative measure of output gap in the literature, we also use an HP filtered output gap to check robustness. Row 1 of Table 2 (HPY in VAR) shows the results when the first step VAR replaces the quadratically detrended output gap with an HP filtered output gap. Comparing this with the benchmark results in Table 1, our results remain robust to different measures of the output gap on the whole.[16]

Next, we may also use the output gap as a proxy for real marginal cost in the second step

[16] We also did robustness analysis to alternative specifications of the VAR such as the lag length and the inclusion of the federal funds rate or 3-month Treasury bill rate in the benchmark VAR. These robustness checks revealed that parameter estimates and the goodness of fit remain essentially unaltered.

estimation. Rows 2 and 3 of Table 2 contain results under the assumption that $mc_t = y_t$.[17] That said, we replace labor share with alternative output gap measures in the second step estimation. Again, our main findings are robust to the alternative marginal cost measures.[18]

We also estimate our dual stickiness model over different sub-samples. Our estimation strategy implicitly assumes that the unrestricted forecasting process of $X_t$ (i.e. the coefficient matrix $A$) is invariant over the whole sample. This assumption could be questionable if a shift in policy alters the dynamic path of a macroeconomic variable in its reduced form and affects the economic agents' forecasts. Clarida, Galí, and Gertler (2000) and Orphanides (2004) argue that U.S. monetary policy stance shifted after 1979. As such, we split samples to estimate the dual stickiness model: 1960:Q1 - 1979:Q2 and 1984:Q1 - 2007:Q2. The first sub-sample reflects Paul Volcker's appointment as Federal Reserve Chairman in 1979. These results are shown in Row 4-7 of Table 2. As the table shows, our results are, on the whole, robust to splitting samples. The parameters $\gamma$ and $\phi$ are statistically different from zero and $\zeta_2^D$ is statistically significant at least in the first sub-sample.

Finally, we can consider the presence of strategic complementarity. The presence of firm specific capital or decreasing returns to labor allows us to introduce strategic complementarity, which reduces the sensitivity of prices to the average marginal cost in the economy. Galí, Gertler, and López-Salido (2001) and Walsh (2003) consider a continuum of firms indexed by $i$ facing the production function with decreasing returns to labor, $Y_t(i) = L_t(i)^{1-a}$, where $a < 1$. In this case, the full information optimal price is

$$p_t^f = (1-\gamma)\sum_{j=0}^{\infty}\gamma^j E_t(\alpha mc_{t+j} + p_{t+j}),$$

where $\alpha$ is a function of returns to labor $1-a$ and the elasticity of substitution among

[17]Suppose that household instantaneous utility function takes a simple form of $\log C_t - \chi L_t$ and the production function is linear $Y_t = L_t$, where $C_t$, $L_t$ and $Y_t$ denotes the aggregate consumption, labor and output. Also suppose that the market clearing condition is given by $C_t = Y_t$. Then, we can express the marginal cost as $mc_t = y_t$ in terms of the log-deviation from the steady state.

[18]We also varied the value of the truncation parameter $K$ in the second step estimation. The estimates changed very little.

differentiated goods $\nu$. In particular, $\alpha = (1-a)/(1+a(\nu-1))$. Galí, Gertler, and López-Salido (2003) parameterize $a = 0.27$ and $\nu = 11$, resulting in $\alpha = 0.197 < 1$. Thus, the parameter $\alpha$ reduces the sensitivity of prices to aggregate real marginal cost compared to our benchmark case due to strategic complementarity in price setting.

The bottom row of Table 2 gives results under strategic complementarity of $\alpha = 0.2$. Assuming strategic complementarities shortens the average duration between price changes to approximately 10.8 months and such a result is broadly in line with micro empirical findings of Nakamura and Steinsson (2008).[19] On the other hand, strategic complementarity also reduces the degree of information stickiness. Our estimate of $\phi$ becomes 0.30, implying the reduction of the average duration between information updates up to approximately 4.3 months. However, even when we allow for strategic complementarity, $\zeta_2^D$ remains significant. Therefore, the importance of sticky information in the dual stickiness model remains robust to introducing strategic pricing complementarity.

## D. Dual Stickiness Versus Hybrid Pricing in a Nested Model

In this section, we show further evidence that the data supports the dual stickiness over hybrid model. To do so, we extend the dual stickiness model to allow for some backward-looking firms.

Suppose that a fraction $\omega$ of firms are backward-looking, i.e. charge prices according to (8). The remaining firms are forward-looking but have two constant probabilities of price and information adjustment as in the dual stickiness model. In this case, the newly reset price index $q_t$ becomes

$$q_t = (1-\omega)\left[(1-\phi)\sum_{k=0}^{\infty}\phi^k E_{t-k}(p_t^f)\right] + \omega p_t^b. \tag{18}$$

[19] Bils and Klenow (2004) first discovered the median durations between U.S. micro price changes are about 4.3 months. Nakamura and Steinsson (2008) argue that removing the effect of sales and product substitutions lengthens the median durations of ‘regular price’ changes up to 8-11 months, while Klenow and Kryvtsov (2008) continue to argue for frequent regular price changes of 7.2 months.

The new definition of $q_t$ nests all models presented in the paper. To see this, suppose that $\omega = 0$. Then, this model becomes the dual stickiness model because (18) reduces to (3). Since the dual stickiness model nests the SP and SI models, this generalized $q_t$ nests the SP and SI model. Also, if $\phi = 0$, (18) reduces to (7), implying the hybrid model.

The Web Appendix B derives the following:

$$\begin{aligned}\pi_t = \rho_1 \pi_{t-1} - \rho_2 \pi_{t-2} + \zeta_1^G (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_t(mc_{t+j}^n - p_t) \\ + \zeta_2^G (1-\phi) \sum_{k=0}^{\infty} \phi^k (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_{t-k-1}(\Delta mc_{t+j} + \pi_{t+j}),\end{aligned} \tag{19}$$

where $\rho_1 = [\omega + \phi\gamma + \phi\omega(1-\gamma)]/\tau$, $\rho_2 = \phi\omega/\tau$, $\zeta_1^G = (1-\phi)(1-\omega)(1-\gamma)/\tau$, $\zeta_2^G = \phi(1-\omega)(1-\gamma)/\tau$ and $\tau = \gamma + (1-\gamma)[\phi + (1-\phi)\omega]$. The resulting equation adds only one additional lag of inflation. Hence, we can apply the same empirical procedure as before.

Table 3 shows estimates of (19). Our preliminary estimates revealed that structural parameter $\omega$ takes an economically nonsensical negative value. To avoid such a difficulty, we estimate the model with the restrictions that $\gamma \in (0,1)$, $\phi \in (0,1)$, and $\omega \in (0,1)$.[20] Then, the obtained point estimates are the same up to the third digit as those of the dual stickiness model in Table 1. That said, the data chooses the dual stickiness model over the hybrid model under the generalized framework.

Summing up our empirical findings, we conclude that the dual stickiness model is empirically more plausible than the hybrid model in two aspects. First, the lagged expectations of nominal marginal cost growth are significantly correlated with current inflation, which the hybrid model does not predict. Second, under the generalized framework which nests the dual stickiness and hybrid model, the data chooses the dual stickiness model over the hybrid model. These findings suggest that the hybrid model may be misspecified in accounting for U.S. inflation. Nevertheless, researchers might want to use the simpler hybrid model for

[20] In particular, we put the following restrictions. In estimating $\gamma$ such that $\gamma \in (0,1)$, we estimate $\tilde{\gamma}$ defined as $\gamma = 1/(1+\exp(\tilde{\gamma}))$. Under this restriction, the estimated $\tilde{\gamma}$ always generate $\gamma \in (0,1)$. We impose the same restrictions on $\phi$ and $\omega$ to obtain economically plausible structural estimates.

their general equilibrium analysis because the goodness of fit of the hybrid model is as good as the dual stickiness model and the hybrid model looks a good approximation to the dual stickiness model. In the next section, we will show that this simplifying approximation is treacherous for understanding macroeconomic dynamics.

# V. General Equilibrium Comparisons

This section compares the dual stickiness and hybrid models by placing each inflation equation in an otherwise identical dynamic stochastic general equilibrium (DSGE) model. We then simulate impulse responses to a 'cost-push' shock to understand the differences between the effects of the two estimated inflation equations on macroeconomic dynamics.

## A. Setup

We consider the following simple log-linearized model:

$$i_t = \varphi_y y_t + \varphi_\pi \pi_t \tag{20}$$

$$y_t = E_t (y_{t+1}) - \sigma [i_t - E_t (\pi_{t+1})], \tag{21}$$

where $i_t$ is the nominal interest rate between period $t$ and $t+1$, and $y_t$ is the output gap. Equation (20) is an interest rate rule followed by the central bank. Equation (21) is a standard consumption Euler equation, which can be derived from a representative household's optimization problem.

We use inflation equations (6) and (9), from the dual stickiness and hybrid models respectively appending a cost-push shock $u_t$ to each. A positive cost-push shock causes an exogenous rise in inflation. Holding everything other than current inflation constant, a one percent cost-push shock raises current inflation by one percent. Finally, we assume real marginal cost equals the output gap, i.e. $mc_t = y_t$.[21]

[21]See Footnote 17 for an example of set of assumptions that justifies this equation. Note that we assume

Next, we let $\varphi_y = 0.5/4$ and $\varphi_\pi = 1.5$ following Taylor (1993), and $\sigma$, the intertemporal elasticity of substitution, equal one. For the two inflation equations, we use the point estimates from the benchmark case in Table 1. The results are qualitatively similar for a wide range of parameter values for $\varphi_y$, $\varphi_\pi$, and $\sigma$.

## B. Impulse Responses

Figure 7 plots each model's impulse response of inflation, the price level and output to a one-percent i.i.d. cost-push shock that occurs at $t = 0$. We measure responses as percentage deviations from the steady state.

Dynamic responses of the three variables are qualitatively different between the dual stickiness and hybrid models. The inflation and output responses are less persistent under the dual stickiness model than the hybrid model. The price level increases in the impact period and monotonically decreases until it reaches to a new steady state level. In contrast, the price level under the hybrid model monotonically rises and converges to a substantially higher steady state level.

To understand the differences, we decompose firms in both models into three types as shown in Table 4. In the dual stickiness model, a fraction $\gamma$ of firms are not allowed to change prices (Type I), a fraction $(1-\gamma)(1-\phi^{t+1})$ of firms know the shock and set prices to $p_t^f$ (Type II) and the remaining fraction $(1-\gamma)\phi^{t+1}$ of firms do not know the shock and set prices to the initial steady state level of zero (Type III). On the other hand, in the hybrid model, a fraction $\gamma$ of firms are not allowed to change prices (Type I), a fraction $(1-\gamma)(1-\omega)$ of firms set prices to $p_t^f$ (Type II), and the remaining $(1-\gamma)\omega$ set prices according to the backward-looking rule of thumb (Type III). Because the estimates of $(\gamma, \phi)$ and $(\gamma, \omega)$ for the two models are close, the causes of the different responses lie in the difference in Type III's price-setting behavior and the time-varying fractions of Type II and III in the dual stickiness model.

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neither strategic complementarity nor strategic substitutability.

Now, we show how dynamics of variables are explained. Let us first focus on inflation. The inflation responses are not very different between the two models at the impact period, because Type III firms set prices to zero in both models. Under the dual stickiness model, they do so because they think that the economy remains in the initial steady state. Under the hybrid model, they do so because both the last period's newly set price and inflation are zero. Meanwhile, facing a shock of the same size, Type II firms in both models raise prices by approximately the same amount.[22] Consequently, inflation responses in this impact period are approximately the same.

By the i.i.d. assumption, the shock to the economy disappears afterwards. It follows that the optimal price $p_1^f$ is much lower than $p_0^f$, reducing Type II's reset price. In the dual stickiness model, Type III firms continue to believe that the economy is unchanged and to choose prices of zero. The composite effect of the reduction in the optimal price for Type II and inattentive pricing for Type III reduces the price level and changes inflation to a slightly negative level. On the other hand, backward-looking Type III firms in the hybrid model raise prices based on the previous period's positive inflation. It causes inflation to remain high.

The same mechanism continues to work after $t = 1$. Type III firms in the dual stickiness model remain inattentive to the shock and continue to set zero price. As a result, inflation shows negative responses until it converges to zero. On the other hand, Type III firms in the hybrid model continue to raise prices as long as a positive last period inflation is observed, causing inflation to be persistent. Therefore, after the impact period, inflation under the dual stickiness model shows quantitatively and qualitatively different dynamics from the hybrid model.

Output responses are almost mirror images of the inflation responses. Under our calibrated interest rate rule, the central bank responds strongly to inflation. Therefore, the nominal interest rate moves almost proportionally to the inflation response. Then, the nominal

[22] This is only approximate because, due to the forward-looking behavior, Type II firms in the hybrid model set slightly higher prices taking into account the higher future inflation rates.

interest rate movement is translated negatively into output dynamics via the consumption Euler equation.

Before closing this section, it should be noted that the dynamics of the two models are not necessarily different. For instance, Figure 8 plots the impulse responses of the two models where we use an AR(1) cost-push shock with coefficient of 0.9. In this case, the impulse responses are relatively similar between the two models. In both models, the inflation responses are fairly persistent, because Type II firms in both models have a strong incentive to raise their prices, anticipating the cost-push shock will remain positive over many periods.

Summing up, our simple exercises show that the two models can exhibit notably different dynamics in a DSGE framework. We conclude that distinguishing between the two models can be important for understanding macroeconomic dynamics.

# VI. Conclusion

We developed and estimated a dual stickiness model that integrates sticky prices and sticky information. Our estimation results show that both rigidities are present in U.S. data. The model can explain U.S. inflation well, and its goodness of fit is as good as that of the hybrid New Keynesian model. The empirical success of the two models is due to the dependence of current inflation on last period's inflation. While the hybrid model achieves this dependence by assuming backward-looking firms, the dual stickiness model does so through the interaction of the two nominal rigidities. We consider this as an important theoretical appeal of the dual stickiness model. Moreover, our empirical results suggest that the dual stickiness model is more plausible than the hybrid model in two aspects: i) the data supports the prediction of the dual stickiness model that current inflation correlates with lagged expectations on current and future nominal marginal cost growth; ii) the data chooses the dual stickiness over hybrid model when a generalized model that nests the two is estimated. Therefore, we conclude that the dual stickiness model has advantages over the hybrid model both theoretically and empirically. Finally, by simple calibration exercises, we showed that dynamic responses of inflation and output under the dual stickiness model could quantitatively and qualitatively differ from those under the hybrid model. This finding implies that, despite the almost identical goodnesses of fit, distinguishing between the two models is important when one examines the consequences of these pricing models on macroeconomic dynamics.

The analysis of this paper can be extended in a number of directions. First, although this paper adopted a limited-information approach that is relatively less subject to model misspecification errors, it would also be interesting to estimate the model in a full-fledged DSGE framework. Besides efficiency gains, this approach would allow us to explicitly model a variety of real rigidities, which some recent studies consider as an important source of inflation persistence. Second, we focused only on aggregate inflation. Given that recent studies with sector-level data have found that inflation dynamics exhibit significant heterogeneity across sectors, estimating the dual stickiness model using disaggregated data may be fruitful.[23] Finally, this paper did not explore welfare implications of dual stickiness. Examining the normative implications, especially for optimal monetary policy, is also an important step for future research.

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Table 1: ESTIMATES OF THE FOUR INFLATION EQUATIONS

a. Models

| | | lag $\pi$ | attentive firms | inattentive firms |
|---|---|---|---|---|
| Dual | $\pi_t =$ | $\rho^D \pi_{t-1}$ | $+\zeta_1^D (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_t(mc_{t+j}^n - p_t)$ | $+ \zeta_2^D (1-\phi) \sum_{k=0}^{\infty} \phi^k (1-\gamma) \sum_{j=0}^{\infty} \gamma^j \times$ $E_{t-k-1}(\Delta mc_{t+j} + \pi_{t+j})$ |
| Hybrid | $\pi_t =$ | $\rho^H \pi_{t-1}$ | $+\zeta_1^H (1-\gamma) \sum_{j=0}^{\infty} \gamma^j E_t(mc_{t+j}^n - p_t)$ | |

b. Structural parameters, model fit

| | $\gamma$ | $\phi$ | $\omega$ | $\bar{R}^2$ | $\text{Var}(\pi_t - \hat{\pi}_t)$ |
|---|---|---|---|---|---|
| Dual | 0.859 | 0.581 | 0.00 | 0.757 | 0.114 |
| | [0.808, 0.910] | [0.404, 0.814] | - | | |
| Hybrid | 0.875 | 0.00 | 0.516 | 0.757 | 0.114 |
| | [0.837, 0.911] | - | [0.359, 0.725] | | |
| SP | 0.882 | 0.00 | 0.00 | 0.608 | 0.184 |
| | [0.842, 0.920] | - | - | | |
| SI | 0.00 | 0.896 | 0.00 | 0.556 | 0.208 |
| | - | [0.857, 0.931] | - | | |

c. Reduced form parameters

| | $\rho^D$ or $\rho^H$ | $\zeta_1^D$ or $\zeta_1^H$ | $\zeta_2^D$ |
|---|---|---|---|
| Dual | 0.531 | 0.063 | 0.087 |
| | [0.389, 0.724] | [0.027, 0.092] | [0.039, 0.141] |
| Hybrid | 0.550 | 0.065 | 0.00 |
| | [0.392, 0.760] | [0.028, 0.095] | - |

Estimation is from 1960:Q1 to 2007:Q2. SP and SI stand for the pure sticky price and pure sticky information models, respectively. A VAR(3) using $mc_t$, $\pi_t$ and $y_t$ is estimated over 1957:Q2 - 2007:Q2 as the first step VAR estimation. Panel (a) contains estimated equations for the dual stickiness and hybrid models. Parameters $\gamma$, $\phi$ and $\omega$ denote the probability of price fixity and information fixity, and the fraction of backward-looking firms, respectively. The 95 percent bootstrap confidence intervals are in brackets. Definitions of $\rho^D$, $\rho^H$, $\zeta_1^D$, $\zeta_1^H$ and $\zeta_2^D$ are in the main text.

Table 2: THE DUAL STICKINESS MODEL UNDER ALTERNATIVE SPECIFICATIONS

| | $\gamma$ | $\phi$ | $\rho^D$ | $\zeta_1^D$ | $\zeta_2^D$ |
|---|---|---|---|---|---|
| HPY in VAR | 0.877 | 0.443 | 0.417 | 0.073 | 0.058 |
| | [0.829, 0.924] | [0.231, 0.661] | [0.233, 0.610] | [0.040, 0.112] | [0.019, 0.103] |
| mc=QDY | 0.874 | 0.722 | 0.654 | 0.036 | 0.094 |
| | [0.821, 0.911] | [0.580, 0.922] | [0.540, 0.812] | [0.018, 0.054] | [0.058, 0.148] |
| mc=HPY | 0.838 | 0.449 | 0.413 | 0.098 | 0.080 |
| | [0.787, 0.872] | [0.267, 0.637] | [0.263, 0.570] | [0.077, 0.132] | [0.038, 0.130] |
| Benchmark | 0.821 | 0.424 | 0.388 | 0.115 | 0.085 |
| 1960:Q1-1979:Q2 | [0.717, 0.900] | [0.070, 0.689] | [0.092, 0.614] | [0.058, 0.208] | [0.009, 0.155] |
| | 0.924 | 0.494 | 0.475 | 0.040 | 0.039 |
| 1984:Q1-2007:Q2 | [0.797, 1.079] | [0.260, 0.897] | [0.298, 0.831] | [-0.016, 0.075] | [-0.107, 0.176] |
| HPY in VAR | 0.824 | 0.458 | 0.418 | 0.105 | 0.089 |
| 1960:Q1-1979:Q2 | [0.555, 0.994] | [0.100, 0.769] | [0.111, 0.680] | [0.005, 0.284] | [0.004, 0.201] |
| | 0.922 | 0.474 | 0.455 | 0.043 | 0.039 |
| 1984:Q1-2007:Q2 | [0.787, 1.080] | [0.238, 0.887] | [0.278, 0.822] | [-0.010, 0.076] | [-0.115, 0.185] |
| Strategic complementarity | 0.723 | 0.300 | 0.269 | 0.241 | 0.103 |
| ($\alpha = 0.2$) | [0.653, 0.794] | [0.099, 0.512] | [0.110, 0.461] | [0.116, 0.348] | [0.028, 0.187] |

Estimation is from 1960:Q1 to 2007:Q2 in Row 1-3 and 8. Row 1 (HPY in VAR) uses an HP filtered output gap instead of a quadratically detrended output gap in the first step VAR estimation. Row 2 (mc=QDY) and 3 (mc=HPY) use the quadratically detrended output gap and HP filtered output gap as a proxy for marginal cost in the second step estimation, respectively. In Row 4-7, the sub-sample 1960:Q1-1979:Q2 uses a VAR(3) sample over 1957:Q2-1979:Q2, and the sub-sample 1984:Q1-2007:Q2 uses a VAR(3) sample over 1981:Q2-2007:Q2. Benchmark refers to the case where the VAR uses a quadratically detrended output gap. Row 8 shows the estimates assuming that there is strategic complementarity. Other characteristics are explained in the footnote to Table 1.

Table 3: THE NESTED HYBRID-DUAL STICKINESS MODEL

a. Structural parameters, model fit

| | $\gamma$ | $\phi$ | $\omega$ | $R^2$ | $\text{Var}(\pi_t - \hat{\pi}_t)$ |
|---|---|---|---|---|---|
| Benchmark | 0.859 | 0.581 | 0.000 | 0.756 | 0.114 |
| | [0.717, 0.957] | [0.023, 0.988] | [0.000, 0.000] | | |
| HPY in VAR | 0.877 | 0.443 | 0.000 | 0.778 | 0.104 |
| | [0.741, 0.959] | [0.027, 0.950] | [0.000, 0.000] | | |

b. Reduced form parameters

| | $\rho_1$ | $\rho_2$ | $\zeta_1^G$ | $\zeta_2^G$ |
|---|---|---|---|---|
| Benchmark | 0.531 | 0.000 | 0.063 | 0.087 |
| | [0.023, 0.945] | [0.000, 0.000] | [0.001, 0.382] | [0.001, 0.280] |
| HPY in VAR | 0.417 | 0.000 | 0.073 | 0.058 |
| | [0.027, 0.913] | [0.000, 0.000] | [0.002, 0.337] | [0.001, 0.249] |

The first row in each panel shows estimates of the generalized model where the first step VAR estimation is the same as the benchmark case. The second row in each panel shows results of the generalized model where the first step VAR estimation uses an HP filtered output gap instead of a quadratically detrended output gap.

Table 4: THREE TYPES OF FIRMS IN THE DUAL STICKINESS AND HYBRID MODELS

| | | Type I | Type II | Type III |
|---|---|---|---|---|
| Dual Stickiness | fraction: | $\gamma$ | $(1-\gamma)\left(1-\phi^{t+1}\right)$ | $(1-\gamma)\,\phi^{t+1}$ |
| | price is: | fixed | set to $p_t^f$ | set to zero |
| Hybrid | fraction: | $\gamma$ | $(1-\gamma)\,(1-\omega)$ | $(1-\gamma)\,\omega$ |
| | price is: | fixed | set to $p_t^f$ | set according to rule-of-thumb |

Figure 1: RELATIONSHIP BETWEEN INFLATION AND RELATIVE RESET PRICES

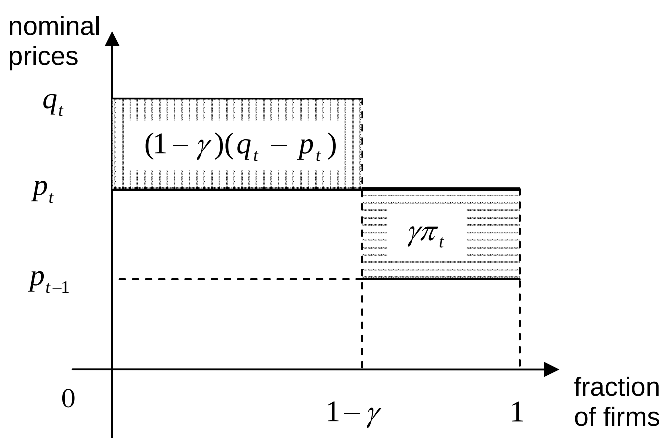


Figure 2: HYPOTHETICAL PATHS OF NEWLY SET PRICES $q_t$ UNDER THE TWO PRICING MODELS

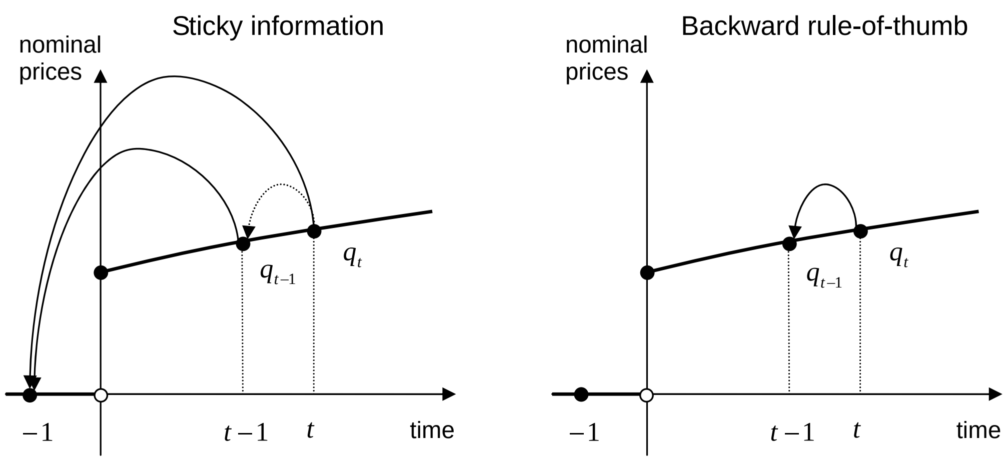


Figure 3: THE INFLATION PREDICTED BY THE DUAL STICKINESS MODEL

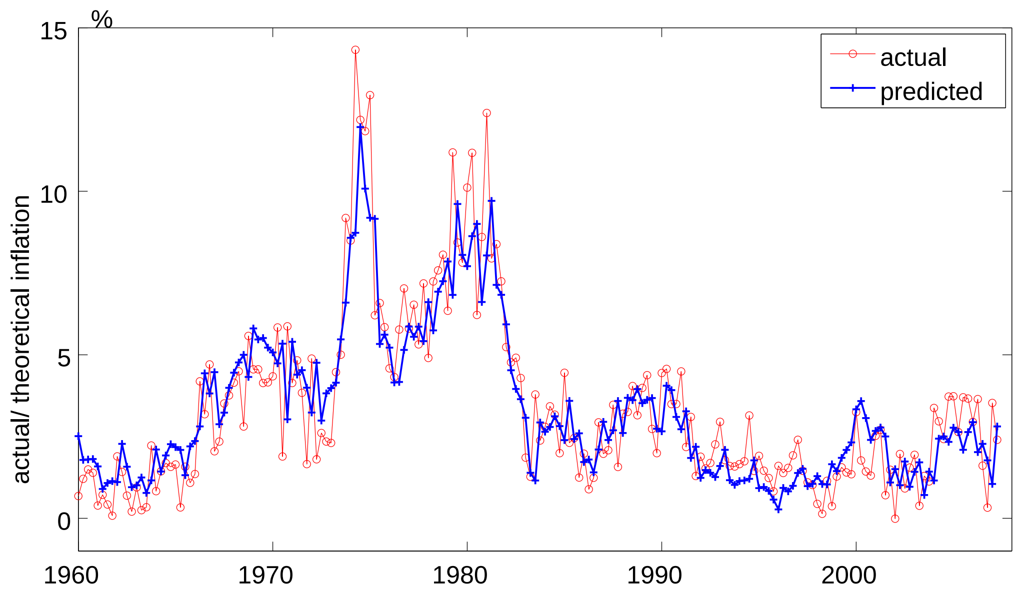


Figure 4: THE INFLATION PREDICTED BY THE HYBRID MODEL

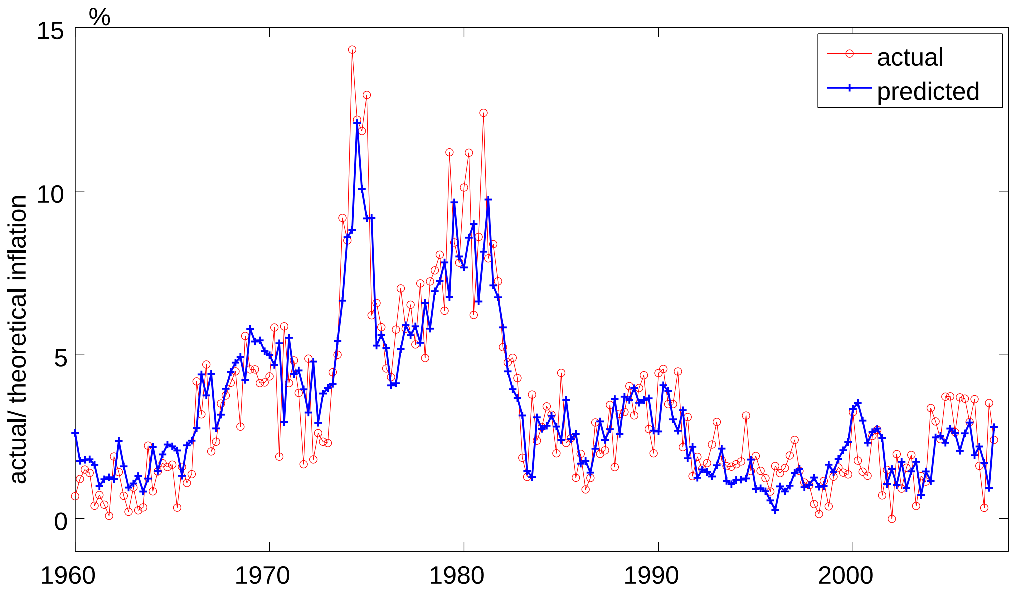


Figure 5: THE INFLATION PREDICTED BY THE PURE STICKY PRICE MODEL

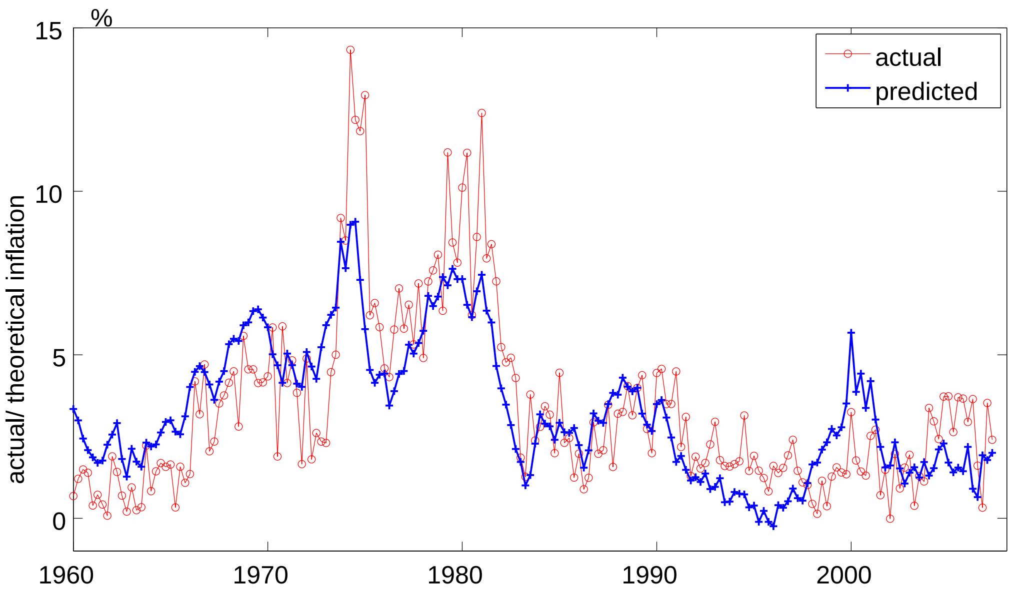


Figure 6: THE INFLATION PREDICTED BY THE PURE STICKY INFORMATION MODEL

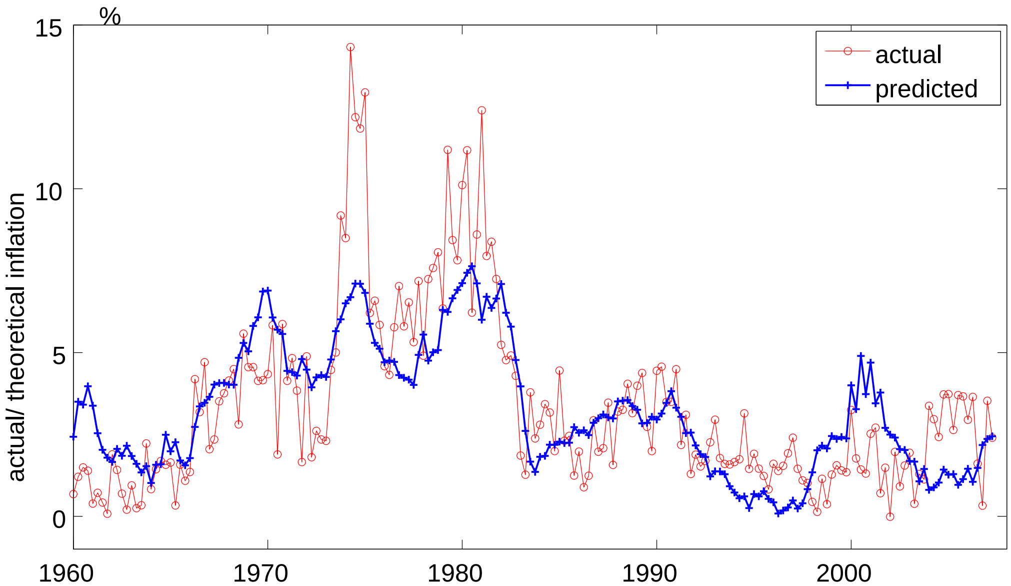
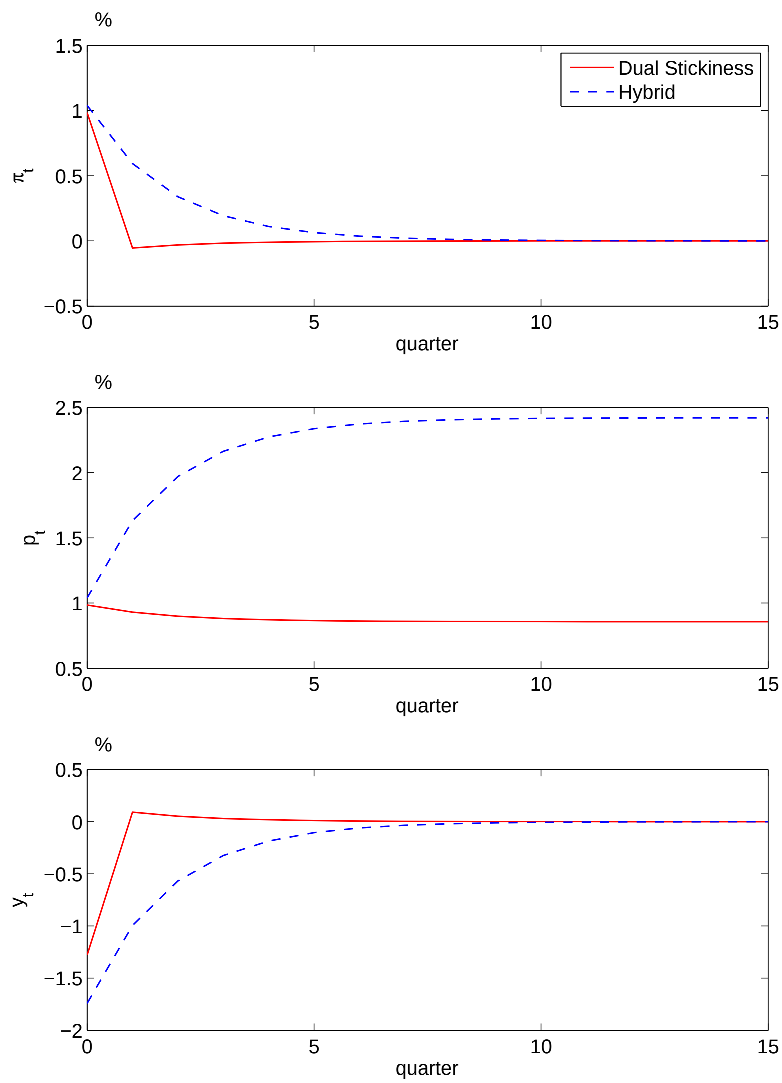
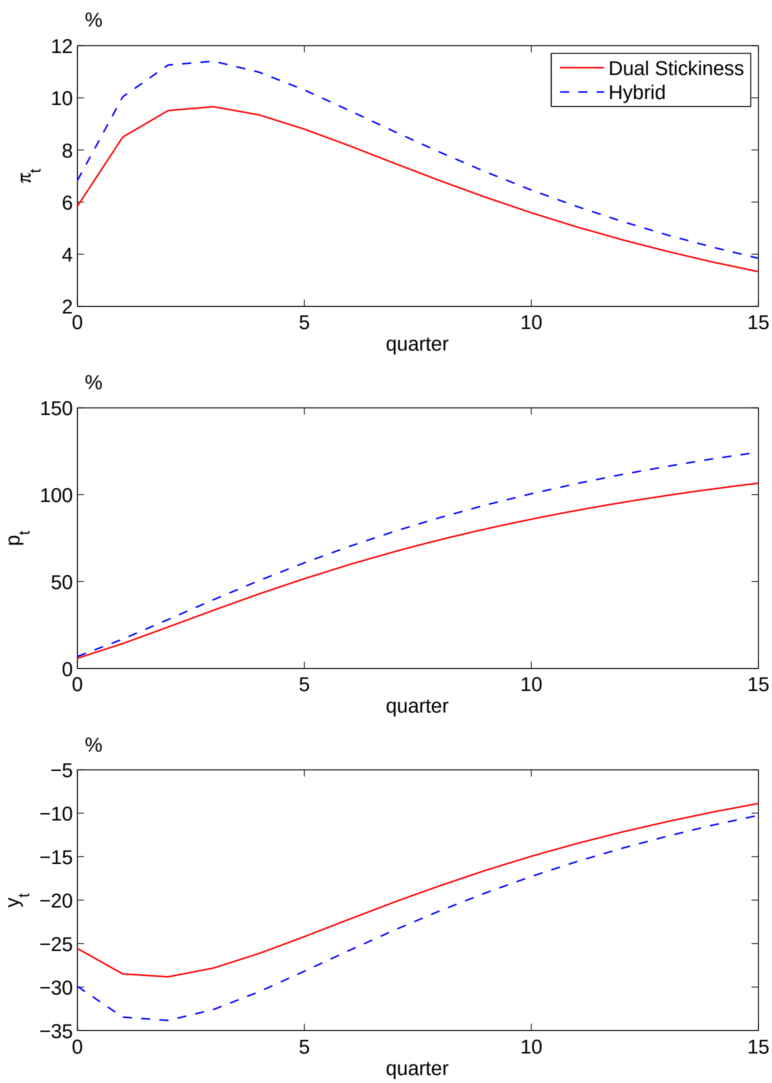


Figure 7: IMPULSE RESPONSES TO AN I.I.D. COST-PUSH SHOCK




The figure displays the impulse responses of inflation $\pi_t$, the price level $p_t$, and the output gap $y_t$ to an i.i.d. cost-push shock. Responses are measured in percentage deviations from the steady state.

Figure 8: IMPULSE RESPONSES TO A PERSISTENT COST-PUSH SHOCK




The figure displays the impulse responses of inflation $\pi_t$, the price level $p_t$, and the output gap $y_t$ to a persistent cost-push shock (with an AR coefficient of 0.9). Responses are measured in percentage deviations from the steady state.