Sticky Information and Disagreement about Economic Activity*

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Abstract

This paper estimates a dynamic stochastic general equilibrium (DSGE) model that features agents' information stickiness as well as nominal rigidities. Based on the estimated DSGE model, the article studies how (in)consistent survey disagreement on output is with the prediction of sticky information models, as well as the importance of inattentive agents in accounting for macroeconomic aggregates. Two main findings emerge. First, firms update information quite frequently, while consumers and workers are subject to a substantial amount of information rigidity. Inattentive consumers and workers turn out to be crucial modeling features in enhancing the model's fit to the data. Second, we establish a U-shape relationship of professional forecasters' disagreement against output growth, coherent with the prediction of sticky information models. Survey disagreement tends to rise both in booms and recessions, rather than being countercyclical. We also document evidence that the arrival of new information measured by forecast revision, regardless of its sign, drives up disagreement due to inattentive forecasters. These findings have an implication that survey disagreement may be an inappropriate measure for macroeconomic uncertainty.

Keywords: Sticky Information; Disagreement; Uncertainty
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1 INTRODUCTION

Ever since the pioneer work of Mankiw and Reis (2002), a recent empirical literature has examined the presence of "sticky information" on survey data. A series of papers by Coibion and Gorodnichenko (2012a, 2012b) explore the critical contribution of sticky information in explaining forecast errors and disagreement in the survey-measured time series. In a similar vein, Andrade and Le Bihan (2013) and Dovern et al. (2014) inspect whether the inflation or output predictions from sticky information models are consistent with survey forecasts.

In recent years, disagreement from the Survey of Professional Forecasters (SPF) has received more attention in understanding business cycle dynamics. A prominent exercise is to use the survey disagreement as a proxy for macroeconomic uncertainty [see, for example, Bachmann et al. (2013)], which impacts crucially on the business cycle [Bloom (2009)]. One of the justifications for these applications is that survey-measured disagreement about GDP exhibits a countercyclical pattern. This, however, seems at odds with a perspective of sticky information models, in which the model-implied measure of disagreement about output, σ_t^y's, has a form of

$$\sigma_t^y = \sqrt{(1-\gamma^{si})\sum_{k=0}^{\infty}(\gamma^{si})^k \left[E_{t-k}\left(Y_t - f_t^Y\right)\right]^2} \tag{1}$$

where $\gamma^{si} \in [0,1]$ is the degree of information stickiness and f_t^Y denotes the model-based average forecast of current output defined as $f_t^Y = (1-\gamma^{si})\sum_{k=0}^{\infty}(\gamma^{si})^k E_{t-k}Y_t$.[1] By construction, the measure in (1) is perfectly symmetric with respect to the performance of the economy. If positive and negative economic outcomes are equally plausible with similar magnitude, disagreement is unlikely to be countercyclical as it rises both in booms and recessions.

The article uses Bayesian methods to estimate and evaluate an extended New Keynesian DSGE model that incorporates inattentive private agents and nominal rigidities. Based on the estimated DSGE model, we study how (in)consistent survey disagreement on output is with the prediction of sticky information models, as well as the importance of inattentive agents in accounting for macroeconomic aggregates. In the model, consumers, workers, and firms update their information sets in a sluggish manner á la Mankiw and Reis (2002), while only a fraction of firms and workers are allowed to adjust their prices and wages in a given period under the monopolistically competitive goods and labor markets, respectively. The dynamics of the model variables are driven by technology, preference, wage markup, and monetary policy shocks. We estimate the model using U.S. quarterly data ranged from 1954:Q3 to 2008:Q4. To the best of our knowledge, this article is the first that estimates a DSGE model associated with both information and nominal rigidities, based on full-information maximum likelihood methods.[2]

This paper comprises two parts. In the first part, we estimate the DSGE model to assess the practical consequences of information and nominal rigidities for the dynamics of the model. Several findings emerge. Above all, the degree of information stickiness varies considerably across the agents. Firms update information quite frequently, while consumers and workers are subject to a substantial amount of information rigidity. Consequently, inattentive consumers and workers turn out to be crucial modeling features in enhancing the goodness-of-fit of the model, while the

[1] See Mankiw et al. (2004) for the derivation in detail.

[2] Carrillo (2012) estimates a DSGE model with the both rigidities by employing a minimum distance estimator, but reports that the key parameters for nominal and information rigidities are not identified by the estimation technique.

contribution of inattentive firms to inflation dynamics is relatively limited. Notice that the estimated degrees of sticky information of consumers and firms are broadly consistent with the exiting survey and microeconomic evidence as in Carroll (2003) and Anderson et al. (2013). Regarding price and wage inflation dynamics, our finding emphasizes the role of price and wage rigidities over information stickiness of firms and workers.

In the second, more substantive part, we evaluate empirically how survey disagreement is related to business cycles through the lens of the sticky information framework. Interestingly, our results demonstrate that the cyclical property of survey disagreement is consistent with the prediction of sticky information models. The model-implied disagreements of each agent exhibit a U-shaped pattern against output growth, which approximates the current economic performance. This pattern is confirmed by the Nadaraya-Watson kernel regression as well as by the quadratic regression. The U-shaped is also observed in the SPF disagreement on current output, characterizing a nonlinearity between survey disagreement and business cycles. In particular, the U-shape relationship emerged from the quadratic regression illustrates that survey disagreement is associated negatively with output growth, but positively with its squared term. This implies that the negative correlation between survey disagreement and output growth can be viewed as a consequence of information rigidity rather than advocating its countercyclical nature.

This finding has an implication on the ongoing debate about whether survey disagreement is a good proxy for macroeconomic uncertainty along with the volatility of stock market returns, as well as with the dispersion of stock returns and firms' earnings [Lahiri and Sheng (2010), Jurado et al. (2015)]. Our empirical results suggest that survey disagreement may be an inappropriate measure for uncertainty due to two reasons. First, the observed U-shape attenuates the countercyclical pattern in disagreement. In a sharp contrast, the two uncertainty measures often employed in the existing literature—the stock market volatility series in Bloom (2009) and uncertainty measure by Jurado et al. (2015)—tend to be negatively related to output growth, as the U-shape is not observed with these measures. This finding indicates that the uncertainty measures entail an evident degree of countercyclicality, while survey disagreement does not.

Second, high disagreement observed from the SPF can often be a consequence of agents' infrequent information updating rather than an increase in uncertainty. To be robust, we additionally investigate whether survey disagreement can be predicted by agents' forecast revision associated with the arrival of new information. If only a fraction of agents update their information set at every period, disagreement can be elevated due to the ones with outdated information. Therefore, agents' forecast revision on the economic activity has an explanatory power for the fluctuations in disagreement. We find that forecast revision is a substantial driver of survey disagreement, whereas its role for the fluctuations in the Bloom's stock market volatility series and uncertainty measure by Jurado et al. (2015) is rather insignificant.

2 THE MODEL ECONOMY

In the article, we employ a model in which firms and workers are subject to information rigidity and set prices/wages infrequently in the monopolistically competitive goods and labor markets, respectively. Households often choose the optimal level of consumption and bond holding with outdated information due to costs of updating information. The production sector consists of two parts: a representative final goods producer and intermediate goods producers. The labor sector also has two types of agents: the labor aggregator and workers. The labor aggregator purchases and combines differentiated labor services provided by workers, and sell each unit of labor to intermediate goods producers.

2.1 HOUSEHOLDS The economy is endowed with a continuum of households, and each household consists of a consumer $k \in [0,1]$ and a worker $j \in [0,1]$, as in Carrillo (2012). Each worker supplies a differentiated labor service and sets its wage in a monopolistically competitive labor market. The consumer maximizes its objective function defined as

$$\sum_{s=0}^{\infty} \beta^k E_t \left[\frac{1}{1-\sigma} C_{kt}^{1-\sigma} - \frac{1}{1+\eta} N_{jt}^{1+\eta} \right] \tag{2}$$

subject to the budget constraint

$$s.t.\ C_{kt+s} + \frac{J_{t+s} B_{kt+s}}{P_{t+s}} = \frac{W_{jt+s} N_{jt+s}}{P_{t+s}} + \frac{B_{kt-1}}{P_t} + \Pi_{t+s} \tag{3}$$

where C_{kt}, J_t, B_{kt}, P_t, and Π_t denote the level of consumption, bond price, amount of bonds purchased, aggregate price level, and real profit form intermediate goods producers, respectively. The price of bond is defined as $J_t \equiv \frac{1}{\exp(-\epsilon_t^y)(1+i_t)}$ where $-\epsilon_t^y$ denotes a risk premium shock and i_t is the risk-free interest rate. We interpret ϵ_t^y as a demand shock given that the price of bond has an inverse relationship with the risk premium shock, $-\epsilon_t^y$. N_{jt} is the amount of labor supplied to the labor aggregator at the wage rate W_{jt}.

The households' optimality conditions imply

$$\frac{1}{\exp(-\epsilon_t^y)(1+i_t)} = \beta E_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_t}{P_{t+1}} \right] \tag{4}$$

where Λ_t is the marginal utility of consumption. Log-linearizing (4) yields the standard IS curve given by

$$\hat{\Lambda}_t = E_t \hat{\Lambda}_{t+1} + \left(\hat{i}_t - E_t \hat{\pi}_{t+1} - \epsilon_t^y \right) \tag{5}$$

where a hat ($\hat{}$) denotes log deviation from steady state and $\hat{\Lambda}_t = -\sigma \hat{C}_t^*$. $\hat{\pi}_t$ and $\hat{C}_t^*$ denote the inflation rate and the optimal level of consumption conditional on information available at time t, respectively. The demand shock follows an AR(1) process, $\epsilon_t^y = \rho_y \epsilon_{t-1}^y + e_t^y$, with $e_t^y \sim N(0, \sigma_y^2)$.

We assume that only a fraction of consumers, $1 - \gamma_h^{si}$, are able to update their information set, following Mankiw and Reis (2007). Then the aggregate level of consumption is determined by conditional expectations of the optimal plan of each consumer, $\hat{C}_t^*$, given the information set in period $t{-}k$ where $k \in [0\ \infty]$ as follows:

$$\hat{C}_t = (1 - \gamma_h^{si}) \sum_{k=0}^{\infty} (\gamma_h^{si})^k E_{t-k} \hat{C}_t^* \tag{6}$$

The aggregate level of consumption is determined by the predicted optimal level of consumption based on information in period $t{-}k$, where an integer $k \in [0, \infty]$.[3] It always holds that $\hat{C}_t = \hat{C}_t^*$ under full information, but not under the presence of sticky information. Equation (6) shows that, due

[3]Theoretically $k \in [0, K]$ where $K \to \infty$. In practice, however, we choose $K = 15$ given that this value is large enough for the weight on $E_{t-k}\hat{C}_t^*$ to converge to zero. We maintain this emprical strategy for the other agents' sticky information parameters.

to infrequent information acquisition, consumers often fail to respond to macroeconomic shocks immediately. The delayed response of consumers to macroeconomic shocks produces persistent dynamics of aggregate consumption. In this regard, sticky information models have the ability to generate output persistence without relying on *ad-hoc* propagation mechanisms, such as habit formation in consumption.

2.2 THE LABOR SECTOR The representative labor aggregator purchases N_{jt} at a given wage $W_{j,t}$ and combines a continuum of differentiated labor services using a CES technology:

$$\int_0^1 L\left(\frac{N_{jt}}{N_t};\theta_t^w\right)dj = 1 \tag{7}$$

where $L\left(N_{jt}/N_t\right) = \left(N_{jt}/N_t\right)^{(\theta_t^w-1)/\theta_t^w}$ and θ_t^w is the time-varying elasticity of substitution across differentiated labor services. The labor aggregator sells each unit of labor to firm $i \in [0,1]$ at the wage rate W_t. Each worker provides a differentiated labor service and sets its wage in a monopolistically competitive labor market. The optimal wage rate is derived by solving the following objective function

$$E_t\sum_{s=0}^{\infty}(\alpha_w\beta)^s\varphi_{t+s}\left[W_{jt}X_s^w/P_{t+s} - \text{MRS}_{jt+s}\right]N_{jt+s} \tag{8}$$

subject to the labor demand curve, $N_{jt+s} = N_{t+s}L'^{-1}\left(\frac{W_{jt}X_s^w}{W_{t+s}}\right)$, which is obtained from the zero profit condition of the labor aggregator. MRS_{jt} denotes the marginal rate of substitution between consumption and labor hours in period t. Workers receive a random signal of wage adjustment with probability α_w every period. Workers who fail to receive the signal update their wages according to

$$W_{jt+s} = X_s^w W_{jt} \tag{9}$$

where $X_s^w = \pi^s$. The steady state inflation rate is assumed to be one. The optimal rate of wage then can be written as

$$W_{jt}^* = \frac{E_t\sum_{s=0}^{\infty}(\alpha_w\beta)^s\varphi_{t+s}N_{jt+s}\left(\mu_t^w\right)\text{MRS}_{jt+s}}{E_t\sum_{s=0}^{\infty}(\alpha_w\beta)^s\varphi_{t+s}N_{jt+s}X_s^w/P_{t+s}} \tag{10}$$

where $\mu_t^w \equiv \frac{\theta_{t+s}^w}{\theta_{t+s}^w-1}$ is the time-varying wage markup.

Combining the log-linearized equation of (10) and $\widehat{MRS}_{jt+s} - \widehat{MRS}_{t+s} = -\eta\theta^w\left(\hat{W}_{jt} - \hat{W}_{t+s}\right)$ leads to

$$\hat{W}_t^* \equiv \sum_{k=0}^{\infty}(\alpha_w\beta)^k E_t\left[(1-\alpha_w\beta)\left(\xi_w\left(M\hat{R}S_{t+k} - \hat{w}_{t+k}^r + \epsilon_{t+k}^w\right) + \hat{W}_{t+k}\right)\right] \tag{11}$$

where $\hat{W}_{jt}^* = \hat{W}_t^*$, $\hat{w}_t^r = \hat{W}_t - \hat{P}_t$, and $\xi_w \equiv \frac{1}{1+\eta\theta^w}$. Note that workers choose the same wage rate in equilibrium. The log-deviation of μ_t^w from its steady state is defined as a wage markup shock, ϵ_t^w, which follows an AR(1) process given by $\epsilon_t^w = \rho_w\epsilon_{t-1}^w + e_t^w$ with $e_t^w \sim N(0,\ \sigma_w^2)$. The Calvo scheme applied to both staggered price contracts as well as information updating implies that the dynamics of the aggregate wage rate evolve according to the law of motion

$$\hat{W}_t = (1-\alpha_w)\hat{W}_t^{si} + \alpha_w(\hat{W}_{t-1}) \tag{12}$$

where $\hat{W}_t^{si} \equiv (1-\gamma_w^{si})\sum_{k=0}^{\infty}(\gamma_w^{si})^k E_{t-k}\hat{W}_t^*$. We assume that workers get a random signal of updating information with probability γ_w^{si} in a given period. We further assume that the event of updating information is independent of the timing of price adjustment. In this setting, the weighted average of newly set wages based on information sets of various time periods plays a crucial role in determining wage inflation. To confirm this point, rearranging (12) results in

$$\hat{\pi}_t^w = \frac{1-\alpha_w}{\alpha_w}\left(\hat{W}_t^{si} - \hat{W}_t\right) \tag{13}$$

Using $\hat{W}_t^{si} = (1-\gamma_w^{si})\sum_{k=0}^{\infty}(\gamma_w^{si})^k E_{t-k}\hat{W}_t^*$ and an identity equation, $\hat{W}_t \equiv \gamma_w^{si}\hat{W}_{t-1} + (1-\gamma_w^{si})\hat{W}_t + \gamma_w^{si}(\hat{W}_t - \hat{W}_{t-1})$, we demonstrate that the deviation of the average forecast of the optimal wage rate, $\hat{W}_t^{si}$, from the aggregate wage rate evolves according to the following law of motion

$$\begin{aligned}\hat{W}_t^{si} - \hat{W}_t =& (1-\gamma_w^{si})\left(\hat{W}_t^* - \hat{W}_t\right) + \gamma_w^{si}\left(\hat{W}_{t-1}^{si} - \hat{W}_{t-1}\right)\\ &+ \gamma_w^{si}(1-\gamma_w^{si})\sum_{k=0}^{\infty}(\gamma_w^{si})^k E_{t-k-1}\left(\Delta\hat{W}_t^*\right) - \gamma_w^{si}\left(\hat{W}_t - \hat{W}_{t-1}\right)\end{aligned} \tag{14}$$

Combining and rearranging (11), (13), and (14) yield

$$J_t^w = \frac{(1-\alpha_w)(1-\gamma_w^{si})}{\alpha_w + \gamma_w^{si}(1-\alpha_w)}\left\{\sum_{k=0}^{\infty}(\alpha_w\beta)^k E_t\left[(1-\alpha_w\beta)\xi_w\left(\widehat{\text{MRS}}_{t+k} - \hat{w}_{t+k}^r + \epsilon_{t+k}^w\right) + \alpha_w\beta\hat{\pi}_{t+k+1}^w\right]\right\} \tag{15}$$

where $J_t^w \equiv \hat{\pi}_t^w - \frac{\alpha_w\gamma_w^{si}}{\alpha_w+\gamma_w^{si}(1-\alpha_w)}\hat{\pi}_{t-1}^w - \frac{1-\alpha_w}{\alpha_w+\gamma_w^{si}(1-\alpha_w)}G_t^w$, $G_t^w \equiv \gamma_w^{si}(1-\gamma_w^{si})\sum_{k=0}^{\infty}(\gamma_w^{si})^k E_{t-k-1}\left(H_t^w\right)$, and $H_t^w = \alpha_w\beta E_t H_{t+1}^w + (1-\alpha_w\beta)\left[\xi_w\Delta\left(\widehat{\text{MRS}}_t - \hat{w}_t^r + \epsilon_t^w\right) + \hat{\pi}_t^w\right]$. This equation reveals that a quasi-change in wage inflation is determined by current and future values of wage inflation, the wage markup shock, and the gap between $\widehat{\text{MRS}}_t$ and $\hat{w}_t^r$. The law of motion of J_t^w can be written as

$$J_t^w = \alpha_w\beta E_t J_{t+1}^w + \frac{(1-\alpha_w)(1-\gamma_w^{si})}{\alpha_w+\gamma_w^{si}(1-\alpha_w)}\left[(1-\alpha_w\beta)\xi_w\left(\widehat{\text{MRS}}_t - \hat{w}_t^r + \epsilon_t^w\right) + \alpha_w\beta E_t\hat{\pi}_{t+1}^w\right] \tag{16}$$

Rearranging (16) yields an analytical expression that governs wage inflation dynamics, which is given by

$$\begin{aligned}\hat{\pi}_t^w =& \left[\frac{\alpha_w\beta}{\alpha_w+\gamma_w^{si}(1-\alpha_w+\alpha_w^2\beta)}\right]E_t\hat{\pi}_{t+1}^w + \frac{\alpha_w\gamma_w^{si}}{\alpha_w+\gamma_w^{si}(1-\alpha_w+\alpha_w^2\beta)}\hat{\pi}_{t-1}^w\\ &+ \frac{(1-\gamma_w^{si})(1-\alpha_w)(1-\alpha_w\beta)\xi_w}{\alpha_w+\gamma_w^{si}(1-\alpha_w+\alpha_w^2\beta)}\left(\widehat{\text{MRS}}_t - \hat{w}_t^r + \epsilon_t^w\right)\\ &+ \frac{1-\alpha_w}{\alpha_w+\gamma_w^{si}(1-\alpha_w+\alpha_w^2\beta)}\left(G_t^w - \alpha_w\beta E_t G_{t+1}^w\right)\end{aligned} \tag{17}$$

Equation (17) shows that wage inflation is determined by expected wage inflation and lagged wage inflation. Staggered wage contracts and information updating together generate the lagged wage inflation term. Wage inflation expectations appear as a consequence of infrequent wage adjustment and it plays a crucial role in determining the dynamics of inflation. The absence of one of those frictions eliminates the lagged wage inflation term from the wage Phillips curve. The present discounted value of the gap between $\widehat{\mathrm{MRS}}_t$ and $\hat{w}_t^r$ as well as future wage inflation conditional on information sets of various vintages account for wage inflation dynamics.

Before proceeding, it is worth mentioning that the model nests both the standard New Keynesian wage Phillips curve and sticky information Phillips curve as a special case. Restricting the parameter γ_w^{si} to zero leads to the standard wage Phillips curve given by

$$\hat{\pi}_t^w = \beta E_t \hat{\pi}_{t+1}^w + \frac{(1-\alpha_w)(1-\alpha_w\beta)}{\alpha_w}\xi_w\left(\widehat{\mathrm{MRS}}_t - \hat{w}_t^r + \epsilon_t^w\right) \tag{18}$$

When $\alpha_w = 0$, the model collapses into the sticky information wage Phillips curve described by

$$\hat{\pi}_t^w = \frac{1-\gamma_w^{si}}{\gamma_w^{si}}\xi_w(\widehat{\mathrm{MRS}}_t - \hat{w}_t^r + \epsilon_t^w) + (1-\gamma_w^{si})\sum_{k=0}^{\infty}(\gamma_w^{si})^k E_{t-k-1}\left\{\xi_w\left[\Delta\left(\widehat{\mathrm{MRS}}_t - \hat{w}_t^r + \epsilon_t^w\right)\right] + \hat{\pi}_t^w\right\} \tag{19}$$

Nesting the two competing models as a special case, a salient feature of models combining wage and information rigidities is to facilitate evaluations of the relative importance of each friction in a general equilibrium setup.

2.3 FINAL GOODS PRODUCING FIRM The representative final-goods producer purchases intermediate goods, Y_{it}, and transforms it into a final good, Y_t, using the production function proposed by Kimball (1995)

$$\int_0^1 G\left(\frac{Y_{it}}{Y_t}; \theta^p, \psi\right) di = 1 \tag{20}$$

where the production function G has the form established in Dotsey and King (2005) and Levin et al. (2008) as

$$G\left(\frac{Y_{it}}{Y_t}\right) = \frac{\phi}{1+\psi}\left[(1+\psi)\frac{Y_{it}}{Y_t} - \psi\right]^{\frac{1}{\phi}} - \left[\frac{\phi}{1+\psi} - 1\right] \tag{21}$$

where $\phi = \left[\frac{\theta^p(1+\psi)}{\theta^p(1+\psi)-1}\right]$ and $G(1) = 1$. The parameter θ^p governs the price elasticity of demand, whereas the parameter ψ determines the degree of curvature of the demand curve faced by intermediate goods producers. When $\psi = 0$, the demand curve collapses into a standard Dixit-Stiglitz aggregator that has the constant price elasticity of demand. The final goods producer solves the following problem

$$P_t Y_t - \int_0^1 P_{it} Y_{it} di + \lambda_t \left[1 - \int_0^1 G\left(\frac{Y_{it}}{Y_t}; \theta^p, \psi\right) di\right] \tag{22}$$

where λ_t is the Lagrange Multiplier associated with the Kimball aggregator. The zero profit condition of the final goods producer leads to

$$Y_{it} = Y_t G'^{-1}\left[\frac{P_{it}}{P_t}\tau_t\right] \tag{23}$$

where $\tau_t \equiv \int_0^1 \frac{Y_{it}}{Y_t} G'\left(\frac{Y_{it}}{Y_t}; \theta^p, \psi\right) di$ and G'^{-1} is the inverse function of G'.

2.4 INTERMEDIATE GOODS PRODUCING FIRMS The intermediate goods producer maximizes its profit given by

$$E_t(\alpha_p\beta)^s\varphi_{t+s}\left[P_{it}X_s^p - MC_{it+s}\right]Y_{it+s} \tag{24}$$

subject to the demand curve, $Y_{it+s} = Y_{t+s}G'^{-1}\left(\frac{P_{it}X_s}{P_{t+s}}\tau_{t+s}\right)$. The Calvo parameter α_p determines the probability of the firms' receiving a random signal of price adjustment. And $\beta^s\varphi_{t+s}$ is the stochastic discount factor. Firms that cannot optimally adjust prices index their prices to the steady state inflation rate according to

$$P_{it+s} = P_{it}X_s^p, \tag{25}$$

where $X_s^p = \pi^s$. The optimality condition for the intermediate goods-producing firms is given by

$$E_t\sum_{s=0}^{\infty}(\alpha_p\beta)^s\varphi_{t+s}Y_{it+s}\left[P_{it}X_s^p + \left(P_{it}X_s^p - MC_{it+s}\right)\frac{G'}{G'^{-1}G''}\right] = 0 \tag{26}$$

The optimal price can be written as

$$P_{it}^* = \frac{E_t\sum_{s=0}^{\infty}(\alpha_p\beta)^s\varphi_{t+s}Y_{it+s}\left[(\epsilon_{t+s})\,MC_{it+s}\right]}{E_t\sum_{s=0}^{\infty}(\alpha_p\beta)^s\varphi_{t+s}Y_{it+s}\left[(\epsilon_{t+s}-1)\,X_s^p\right]} \tag{27}$$

where $\epsilon_t \equiv -\frac{P_{it}}{Y_{it}}\frac{\partial Y_{it}}{\partial P_{it}} = -\frac{G'}{G'^{-1}G''}$. Notice that $\epsilon = -\frac{G'}{G''} = -\frac{\phi}{(1-\phi)(1+\psi)} = \theta^p$ at the steady state. Firms that have a chance to adjust prices choose the same price, $P_{it}^* = P_t^*$. Intermediate goods are produced using a production function that takes the form of $Y_{it} = \exp(a_t)N_{it}^{\alpha}$, where a_t is a technology shock that follows an AR(1) process, $a_t = \rho_a a_{t-1} + e_t^a$, with $e_t^a \sim N(0,\ \sigma_a^2)$.

Log-linearizing (27) and combining it with $\hat{MC}_{it+s} = \hat{MC}_{t+s} + \frac{(\alpha-1)\epsilon}{\alpha}\left[\hat{P}_{it} - \hat{P}_{t+s}\right]$ give rise to the dynamics of the optimal price that has the form of

$$\hat{P}_t^* \equiv (1-\alpha_p\beta)\sum_{k=0}^{\infty}(\alpha_p\beta)^k E_t\left(\xi_p\hat{mc}_{t+k} + \hat{P}_{t+k}\right) \tag{28}$$

where $\hat{P}_{it}^* = \hat{P}_t$, $\hat{mc}_{t+s} = \hat{MC}_{t+s} - \hat{P}_{t+s}$, $\xi_p \equiv \frac{1}{1+\omega_p\epsilon+\epsilon\epsilon_\mu}$, $\epsilon_\mu = -\frac{\psi}{\epsilon-1}$, and $\omega_p \equiv -\frac{\alpha-1}{\alpha}$. Once information is updated according to the Calvo scheme, the aggregate price level is described by

$$\hat{P}_t = (1-\alpha_p)\hat{P}_t^{si} + \alpha_p\hat{P}_{t-1} \tag{29}$$

where $\hat{P}_t^{si} = (1-\gamma_p^{si})\sum_{k=0}^{\infty}(\gamma_p^{si})^k E_{t-k}\hat{P}_t^*$. The aggregate price level is determined by the optimal price conditional on the information set in period $t-k$ where an integer $k \in [0,\infty]$.

Analogously to the derivation of the wage Phillips curve, rearranging (28) and (29) with the term J_t^p defined below yields

$$J_t^p = \alpha_p\beta E_tJ_{t+1}^p + \frac{(1-\alpha_p)(1-\gamma_p^{si})}{\alpha_p+\gamma_p^{si}(1-\alpha_p)}\left[(1-\alpha_p\beta)\xi_p\hat{mc}_t + \alpha_p\beta E_t\hat{\pi}_{t+1}\right] \tag{30}$$

where $J_t^p \equiv \hat{\pi}_t - \frac{\alpha_p\gamma_p^{si}}{\alpha_p+\gamma_p^{si}(1-\alpha_p)}\hat{\pi}_{t-1} - \frac{1-\alpha_p}{\alpha_p+\gamma_p^{si}(1-\alpha_p)}G_t^p$, $G_t^p \equiv \gamma_p^{si}(1-\gamma_p^{si})\sum_{k=0}^{\infty}(\gamma_p^{si})^k E_{t-k-1}\left(H_t^p\right)$, and $H_t^p = \alpha_p \beta E_t H_{t+1}^p + (1-\alpha_p\beta)\left[\xi_p \Delta \hat{mc}_t + \hat{\pi}_t\right]$. The Phillips curve can be written as

$$\begin{aligned}\hat{\pi}_t = &\left[\frac{\alpha_p\beta}{\alpha_p + \gamma_p^{si}(1-\alpha_p+\alpha_p^2\beta)}\right] E_t\hat{\pi}_{t+1} + \frac{\alpha_p\gamma_p^{si}}{\alpha_p + \gamma_p^{si}(1-\alpha_p+\alpha_p^2\beta)}\hat{\pi}_{t-1} \\ &+ \frac{(1-\gamma_p^{si})(1-\alpha_p)(1-\alpha_p\beta)\xi_p}{\alpha_p + \gamma_p^{si}(1-\alpha_p+\alpha_p^2\beta)}(\hat{mc}_t) + \frac{1-\alpha_p}{\alpha_p + \gamma_p^{si}(1-\alpha_p+\alpha_p^2\beta)}\left(G_t^p - \alpha_p\beta E_t G_{t+1}^p\right)\end{aligned} \tag{31}$$

The model implies that inflation is determined by expected inflation, lagged inflation, and real marginal cost, as in the hybrid New Keynesian Phillips curve. The dynamics of inflation also depends on predictions of a change in real marginal cost and inflation based on past information sets. The term G_t^p shows that, in contrast to the purely sticky information model proposed by Mankiw and Reis (2002), predicted future inflation and real marginal costs based on past information sets play a crucial role in determining inflation due to the presence of price rigidity.

The model nests both the New Keynesian Phillips curve and the sticky information Phillips curve proposed by Mankiw and Reis (2002) as a special case. When $\gamma_p^{si} = 0$, the model collapses into the New Keynesian Phillips curve

$$\hat{\pi}_t = \beta E_t\hat{\pi}_{t+1} + \frac{(1-\alpha_p)(1-\alpha_p\beta)}{\alpha_p}\xi_p\hat{mc}_t \tag{32}$$

When $\alpha_p = 0$, the dynamics of inflation is described by the sticky information Phillips curve proposed by Mankiw and Reis (2002) as follows

$$\hat{\pi}_t = \frac{1-\gamma_p^{si}}{\gamma_p^{si}}\xi_p\hat{mc}_t + (1-\gamma_p^{si})\sum_{k=0}^{\infty}(\gamma_p^{si})^k E_{t-k-1}\left(\xi_p\Delta\hat{mc}_t + \hat{\pi}_t\right) \tag{33}$$

Figure 1 shows the properties of the price Phillips curve described by (31). It displays that the introduction of sticky information into the Calvo economy leads to a decline in the coefficient on inflation expectations and an increase in the one on lagged inflation. Both information and price rigidities reduce the coefficient on real marginal cost since price and information rigidities make firms less responsive to a change in real marginal cost. These properties of the price Phillips curve also appear in the IS curve as well as the wage Phillips curve. The presence of information stickiness reduces the role of expectations in determining model variables and makes each variable less sensitive to changes in its driving force.

2.5 MONETARY POLICY The monetary authority sets the interest rate in response to a change in inflation and output gap with interest rate smoothing, summarized by

$$\hat{i}_t = \rho\hat{i}_{t-1} + (1-\rho)\left[a_\pi\hat{\pi}_t + a_y(\hat{Y}_t - \hat{Y}_t^f)\right] + \epsilon_t^m \tag{34}$$

where $\epsilon_t^m = \rho_m\epsilon_{t-1}^m + e^m$ with $e_t^m \sim N(0,\ \sigma_m^2)$. The output gap is defined as the deviation of actual output from the level of output, $\hat{Y}_t^f$, that would prevail when prices and wage are flexible and agents have full information about macroeconomic variables.

3 INFERENCE

3.1 PRIOR DISTRIBUTIONS We calibrate several parameters that are difficult to identify from the data. The discount factor, β, is set to 0.99, which implies an annual steady-state real interest rate of 4 percent. We assume that the parameter α equals 0.75. The steady state price and wage markups, $\theta^p/(\theta^p-1)$ and $\theta^w/(\theta^w-1)$, are set to 0.20 and 0.05, implying that θ^p is 6 and θ^w is 21. These are the values used in Christiano et al. (2005). The parameter ψ that determines the degree of curvature of the demand curve is set to be -5, following Woodford (2003).

The rest of the model parameters are estimated using Bayesian inference methods to construct the parameters' posterior distribution, which integrates the likelihood function with prior information (see An and Schorfheide (2007) for a survey). In doing so, our priors are set to be similar to those in Smets and Wouters (2007), as summarized in Columns 3 through 4 in Table 1. The prior distribution of risk aversion, σ, is a Gamma distribution with mean 1.5 and standard deviation 0.38, whereas that of the inverse of the Frisch elasticity of labor, η, follows a Gamma distribution with mean 2 and standard deviation 0.75. We assume Beta distributions for the information, price, and wage stickiness parameters (γ_h^{si}, γ_w^{si}, γ_p^{si}, α_p, and α_w) with a mean of 0.5 and standard deviation of 0.1. The monetary policy rule AR(1) parameter, ρ, is assumed to have a Beta prior of mean 0.75 and standard deviation 0.1. The monetary policy reaction to inflation, a_π, follows a Normal distribution with a mean of 1.5 and standard deviation of 0.25, while its output gap parameter, a_y, is assumed to have a Gamma distribution of mean 0.13 and standard deviation 0.1.

The remaining prior distributions are identical to those in Smets and Wouters (2007). The AR(1) parameters for the shocks are assumed to follow a Beta distribution with a mean of 0.5 and standard deviation of 0.2. An inverse gamma distribution with a mean of 0.1 and standard deviation of 2 is given to the shock standard deviation parameters.

3.2 ESTIMATION PROCEDURE This paper uses U.S. quarterly data on output, price inflation rate, wage inflation rate, and nominal interest rate from 1954:Q3 to 2008:Q4 as observable variables. We take the first-difference of logarithms of real per capita output, while nominal variables (price inflation, wage inflation, and interest rate) are treated as deviations from their sample mean. Appendix A provides a detailed description of the data.

As a first step for the estimation procedure, the log-linearized system of the DSGE model presented in Section 2 is solved by Sims's (2002) *gensys* algorithm.[4] We then use the Sims optimization routine *csminwel* to maximize the log posterior function, which combines the priors and the likelihood of the data. Finally, the random walk Metropolis-Hastings (MH) algorithm simulates 11,000 draws, with the first 1,000 used as a burn-in period and every 20th thinned, leaving a sample size of 500.

4 ESTIMATION RESULTS

4.1 POSTERIOR ESTIMATES The last two columns of Table 1 report the mean and 90th percentiles from the posterior distributions. Overall, the data seems to be informative in identifying the parameters of the baseline model as the difference between the prior and posterior densities exhibits. Our estimates of both the risk aversion (σ) and inverse of the Frisch elasticity of labor

[4] The companion estimation appendix details the description of the entire log-linearized system.

supply (η) parameters have the means of 2.62 and 2.22, respectively. These estimates are slightly larger than the values provided in Smets and Wouters (2007).

The posterior estimates indicate that information stickiness is present across all agents as the sticky information parameters are estimated to be away from zero. The sticky information parameter of consumers, γ_h^{si}, is estimated to be 0.74, implying that households update their information sets about once a year on average. This estimate is consistent with Carroll (2003), who demonstrates that households update their expectations roughly once a year on average using survey inflation and unemployment expectations from Michigan's Survey Research Center. The posterior mean estimate of the sticky information parameter of workers, γ_w^{si}, is 0.55, indicating that workers update their information about every 6 months. The degree of firms' information stickiness is relatively lower than that of the other agents. The posterior mean of the sticky information parameter of firms, γ_p^{si}, is estimated to be 0.13, which implies that firms update their information sets every 3.4 months.[5] Although being significant different from zero, our estimates of the firms' sticky information parameter are relatively lower than those of consumers and workers. This indicates that firms are less inattentive to macroeconomic shocks than the other agents, which can be closely linked to the finding by Anderson et al. (2013). They document evidence that regular prices that exhibit nominal rigidity are strongly responsive to economic shocks, whereas temporary sale prices are unresponsive since they follow "sticky plans." Kehoe and Midrigan (2012) show that price changes associated with temporary sales are less important than changes in regular price for the monetary transmission mechanism.

Regarding the price and wage stickiness parameters, the model estimates are consistent with those in the existing literature. The posterior mean estimate of the price stickiness parameter, α_p, is 0.72, which indicate that firms reset their prices approximately every 11 months. This model-implied frequency of price adjustment is compatible with the values obtained from retailer-level data, as in Eichenbaum et al. (2011). They document that reference prices, defined as "the most often quoted price within a given time period," are adjusted roughly once a year on average. It is worth mentioning that the estimated degree of price rigidity is much higher than firms' information stickiness. This result is consistent with the finding by Fabiani et al. (2006), who conclude that firms review their prices more frequently than their actual price changes based on surveys of more than 11,000 euro zone companies. The Calvo parameter for staggered wage contracts, α_w, is estimated to be 0.95 with the 90% interval that ranges from 0.93 to 0.96. Barattieri et al. (2010) study the frequency of nominal wage change using data from the Survey of Income and Program Participation. They find that the probability of individual wage being adjusted every quarter is between 5 and 18 percent on average. Our estimates are broadly consistent with their microeconomic evidence.

Turning to the parameters appeared in the monetary policy rule, the interest rate smoothing parameter, ρ, is estimated to be 0.83. The mean estimate for the policy responsiveness to inflation, a_π, is slightly lower than 1.0 with the 90% interval that ranges from 0.76 to 1.21. These estimates quite smaller than those reported in the conventional New Keynesian DSGE literature endowed with no sticky information assumption. Instead, our estimates are relatively close to Orphanides (2001) and Rabanal (2007). Orphanides (2001) finds that the coefficient on current inflation in the

[5]Khan and Zhu (2006) estimate a sticky information model and report that the fraction of firms updating their information set in a given quarter ranges from one thirds to one seventh. However, the estimated degree of information rigidity can be altered substantially once nominal rigidity is introduced into the sticky information model.

Taylor rule is about 0.8 using real-time data. Within an estimated DSGE model framework, Rabanal (2007) also obtains the estimated mean of 1.04 based on the same set of observable variables as this article. Finally, the parameter a_y, that measures policy responsiveness to output gap, has a posterior mean of 0.02.

4.2 IMPULSE RESPONSES This section explores the properties of the baseline model presented in Section 2. In particular, we investigate how the introduction of information stickiness into the standard New Keynesian DSGE model alters the dynamics of the model variables.

The solid lines in Figure 2 report the mean impulse responses to one standard deviation shocks obtained from the baseline model. In order to demonstrate how information rigidity affects the dynamics of the model variables, we also calculate impulse responses from the same model, but with some (or all) agents' sticky information setups turned off. To this end, we resolve the model by restricting the corresponding sticky information parameters to zero, while keeping all of the other parameter estimates from the model. We consider four different combinations. The dash-dot lines with asterisks in the figure represent the impulse responses for the no-sticky-information counterpart (i.e., $\gamma_h^{si} = \gamma_w^{si} = \gamma_p^{si} = 0$). The remaining three combinations assume no sticky information of each agent at a time. The dash-dot lines, dash-dot lines with circles, and solid lines with diamonds correspond to impulse responses under no sticky information of consumers ($\gamma_h^{si} = 0$), firms ($\gamma_p^{si} = 0$), and workers ($\gamma_w^{si} = 0$), respectively.

Several findings emerge regarding the effects of a monetary policy shock. The baseline model with inattentive consumers has the ability to generate a delayed and hump-shaped response of output in the face of a contractionary monetary policy shock. The underlying mechanism of this phenomenon is straightforward. The presence of inattentive consumers, who cannot adjust their consumption plans frequently, prevents output from responding immediately to the shock. In contrast, allowing consumers to process full-information leads to an immediate drop in output in response to the identical shock, as displayed in the impulse response generated under no sticky information of consumers (dash-dot line). These findings suggest that the presence of inattentive consumers serves as an internal propagation mechanism that can account for the persistent and gradual response of output to the shock, often captured by habit formation in consumption.

The baseline model fails to generate a hump-shaped response of inflation to a monetary policy shock, despite the presence of the lagged inflation term in the Phillips Curve. This result arises from the fact that the estimated sticky information parameter for firms is quite low.[6] When consumers have full information (dash-dot lines with asterisks and dash-dot lines), the monetary policy shock leads to a sharp decline in inflation, as opposed to the cases with inattentive consumers. Our results indicate that inattentive consumers play an important role in accounting for inflation persistence, whereas inattentive firms have a relatively limited contribution to the dynamics of inflation. The baseline model yields a hump-shaped response of wage inflation in the face of a monetary policy shock. When workers are attentive (dash-dot lines with asterisks and solid lines with diamonds), however, the model is unable to generate a delayed and gradual response of wage inflation to the shock. This finding suggests that the presence of inattentive workers is crucial in accounting for

[6]The finding casts doubt on the class of models integrating sticky price and information as an alternative to the hybrid New Keynesian Phillips curve. Coibion (2006) and Keen (2007) show that flexible price models with sticky information also fail to generate a hump-shaped response of inflation to a monetary policy shock using a DSGE model framework.

inertia in wage inflation.[7]

Turning to the consequences of a technology shock, we find that the presence of inattentive consumers and workers makes the equilibrium dynamics of output and wage inflation more persistent. On the contrary, inflation always declines immediately in the face of a positive technology shock, regardless of the presence of information stickiness. The immediate response of inflation to the shock is consistent with the empirical evidence demonstrated in Altig et al. (2011).[8]

A common feature of a positive demand shock is to raise key macroeconomic variables. The presence of sticky information reduces the magnitude of the impulse responses to the shock. The muted responses of output and price inflation jointly cause a decrease in fluctuations of the interest rate, transmitted via the monetary policy rule as in (34).

Finally, a negative wage markup shock drives down output with a delay. The impulse responses display that inattentiveness of workers plays a crucial role in producing the persistence of the model variables. By contrast, the contribution of inattentive firms and consumers for a more persistent equilibrium is relatively limited, in the wake of the wage markup shock.

Overall, our results illuminate that information stickiness of consumers and workers significantly alters the dynamics of the model variables. On the other hand, we find a relatively limited contribution of firms' information stickiness to the model's equilibrium dynamics. This finding is mainly attributable to the different degree of information stickiness across the agents, captured by the posterior estimates for these parameters.

4.3 MODEL COMPARISONS ACROSS VARIOUS STICKY INFORMATION SETUPS Having delineated the effects of each information friction on the model's equilibrium, we now access the importance of sticky information in terms of model fit. To do so, we re-estimate the model under the four different assumptions regarding agents' (in)attentiveness considered in the previous subsection.

Table 2 summarizes the posterior mean estimates of the model parameters and marginal likelihoods for each combination of information stickiness.[9] Note that the baseline model collapses to a standard New Keynesian DSGE model if all agents are allowed to be attentive to macroeconomic shocks. Overall, a notable feature in model fit is that the baseline model outperforms the full information model with price and wage rigidities with respect to the marginal likelihood. Assuming no sticky information of all the agents causes a substantial decline in the marginal likelihood from −850.73 to −969.23. This finding reveals the importance of information stickiness in enhancing the goodness-of-fit of the model.

The individual effects of each information friction are reported in the last three columns of Table 2. Regarding model fit, our findings indicate that information friction of consumers plays the most significant role in enhancing the model's fit to the data.[10] Setting $\gamma_h^{si} = 0$ leads to a substantial deterioration of the marginal likelihood from −850.73 to −920.61. The reduction in the marginal likelihood is less profound for the cases in which the assumption that either firms or

[7] Measures of wage inflation appear to be very volatile in U.S. data, which might attribute to a considerable amount of measurement errors as documented in Justiniano et al. (2013).

[8] In contrast, the hybrid New Keynesian Phillips curve generates a delayed response of inflation to a technology shock within a DSGE model, as highlighted by Dupor et al. (2009).

[9] The average log marginal density is calculated by using the Geweke's (1999) modified harmonic mean estimator.

[10] Although we do not report here, introducing noisy information and habit formation in consumption into the extended DSGE model does not substantially change our results.

workers are attentive is abolished.

Our posterior estimates display that most of the structural parameters are insensitive to the choice of the sticky information setups. Nevertheless, there are two notable exceptions, both of which are associated with the presence of inattentive consumers. First, the assumption regarding consumers' (in)attentiveness matters for the estimates of the risk aversion parameter, σ. The parameter estimates are relatively lower when the model is endowed with inattentive consumers, compared to the specifications assuming attentive ones. The sticky information parameter of consumers governs the response of output to the real interest rate as the risk aversion parameter does. Note that an increase in either the sticky information or the risk aversion parameter reduces the response of output to the interest rate. Since the parameters play the same role in determining the responsiveness of output to the interest rate, the risk aversion parameter is estimated to be low if the model is endowed with inattentive consumers. Second, the presence of inattentive consumers significantly alters the demand shock process. When consumers are inattentive, the estimates of the AR(1) coefficient for the demand shock (ρ_y) diminish, whereas the standard deviation estimates (σ_y) surge. This phenomenon is in line with one of the earlier findings of this article, the model-generated persistence induced by sticky information of consumers. Abandoning the sticky information assumption of consumers makes the equilibrium output dynamics less persistent, which is corrected through higher estimates for the autocorrelation parameter. As the demand shock becomes more persistent, an innovation of smaller magnitude is required to explain the output dynamics.

5 STICKY INFORMATION AND DISAGREEMENT

One of interesting features of sticky information models is associated with their ability to generate time-varying disagreement about macroeconomic variables, often observed in survey data. In recent years, disagreement has received more attention in understanding business cycle dynamics. A prominent exercise is to use disagreement as a proxy for macroeconomic uncertainty [see, for example, Bachmann et al. (2013)], which impacts crucially on the business cycle [Bloom (2009)]. Similarly, survey disagreement is also considered as a proxy for ambiguity (Knightian uncertainty) as in Ilut and Schneider (2014). One of the justifications for these applications is that survey-measured disagreement about GDP exhibits a countercyclical pattern. By analyzing survey data of G7 countries, for instance, Dovern et al. (2012) demonstrate that disagreement about GDP growth significantly expands during recessions, and is negatively related to output growth as well as output gap.

Sticky information models, however, provide a slightly different prediction: an arrival of a shock, no matter whether it is positive or negative, tends to increase disagreement on economic activity. If positive and negative shocks are equally plausible with similar magnitude, output growth is not likely to be negatively related to disagreement since disagreement rises both in booms and recessions. Based on a comparison between the survey-measured and model-implied disagreements, this section examines how (in)consistent survey disagreement is with the prediction of sticky information models.

5.1 DISAGREEMENT AND BUSINESS CYCLES The model-implied measure of disagreement about output, σ_t^y's, has a form of

$$\sigma_{t,i}^y = \sqrt{(1-\gamma_i^{si})\sum_{k=0}^{K}(\gamma_i^{si})^k \left[E_{t-k}\left(\hat{Y}_t - f_t^Y\right)\right]^2} \tag{35}$$

where $i \in [h, w, p]$ and f_t^Y denotes the model-based average forecast of current output defined as $f_t^Y = (1-\gamma_i^{si})\sum_{k=0}^{K}(\gamma_i^{si})^k E_{t-k}\hat{Y}_t$. As in the previous section, we set $K = 15$. The measure of disagreement defined as above displays several properties. First of all, the degree of disagreement on economic activity is determined by the sticky information parameters, γ_i^{si}'s, in the model economy. Second, the absence of sticky information eliminates the model-implied disagreement so that the measures, σ_t^y, equal zero. Third, disagreement is serially correlated and its persistence is positively associated with the sticky information parameter. Finally, conditioning on a γ_i^{si} value, the measure is perfectly symmetric with respect to the sign of shocks perturbing the economy: the impact of a shock raising $\hat{Y}_t$ by 1% on σ_t^y is identical to the one lowering it by the same percentage.

The upper panel of Figure 3 displays the time series of the SPF disagreement about current output as well as the mean estimates for the model-implied disagreements.[11] The figure gives an insight on how the survey-measured and model-implied disagreements interact with business cycles. The overall movements of the disagreement series share a similar pattern: they tend to rise prior to or during recessions, and there are frequent spikes observed during booms. Focusing on the model-implied disagreements, their level is different across agents endowed with different degrees of information rigidity. The highest disagreement in level is associated with consumers who face the most severe degree of information rigidity. Firms that are subject to the least information stickiness entail the lowest disagreement in level. With agents' more frequent information updating in a given period, the level of disagreement across agents tends to decline since the fraction of agents who agree about current economic activity rises.

The lower panel of Figure 3 depicts the scatter plots of the model-implied disagreements among firms, workers, and consumers against the survey disagreement about current output. Based on the correlation coefficient, the survey disagreement is more tightly related to the model-implied disagreement among firms than the other model-implied disagreements. In spite of the evidence of comovement, however, the model-implied series are not perfectly correlated with the survey-measured one. The discrepancy may emerge from the fact that in reality current economic activity is not fully observed by the survey respondents, whereas agents who update information perfectly specify the status of the economy in the model.[12]

To examine formally the countercyclical feature in the disagreement series, we begin by considering two versions of regressions. The first group of regression equations relates disagreement to the probability of recession as follows:

$$\sigma_t^y = \beta_0 + \beta_1 p_t^{rec} + u_t \tag{36}$$

[11] The SPF disagreement is available at the Federal Reserve Bank of Philadelphia's website. Unlike to the theoretical measure, however, the SPF disagreement is defined as the dispersion of the 75th and 25th percentile survey responses.

[12] More specifically, the discrepancy can attribute to the two information rigidities, not considered in this work. As the studies by Coibion and Gorodnichenko (2012a, 2012b) make explicit, noisy information is likely to be another source of information rigidity. Another explanation for the discrepancy may be time-varying information stickiness. Using the ECB SPF data, Andrade and Le Bihan (2013) show that the fraction of survey respondents who update information in a given period is state-dependent.

where σ_t^y denotes either the survey-measured or the model-implied disagreement about current output and p_t^{rec} is the recession probability.[13] The use of the recession probability, instead of a NBER recession dummy, is guided by a better fit of the regression equation to the data. This is partly because the recession probability tends to capture the severity of recessions, whereas a NBER recession dummy simply indicates the binary status of the economy. In addition, we also consider an extension of (36) given as

$$\sigma_t^y = \beta_0 + \beta_1 p_t^{rec} + \beta_2 \sigma_{t-1}^y + u_t. \tag{37}$$

Since the sticky information mechanism allows only a fraction of agents to update their information set, disagreement depends on its own lag. For example, if most of economic agents are inattentive at time t, disagreement tends not to fluctuate significantly between $t-1$ and t, which increases the persistence of the disagreement series. The inertial feature stands out even more sharply with serially correlated shocks. Accordingly, the autoregressive term is designed to capture the persistence in disagreement generated by sticky information.

The second group of regression equations posit that disagreement depends both on levels and squares of output growth:

$$\sigma_t^y = \beta_0 + \beta_1 (\Delta y_t)^2 + \beta_2 \Delta y_t + u_t \tag{38}$$

$$\sigma_t^y = \beta_0 + \beta_1 (\Delta y_t)^2 + \beta_2 \Delta y_t + \beta_3 \sigma_{t-1}^y + u_t \tag{39}$$

where Δy_t is output growth. Fluctuations in disagreement are driven by the agents who update information about the contemporaneous state of the economy, approximated by output growth in period t. Therefore, information about a change in output is expected to be a significant driver of disagreement about current output. The inclusion of the squared output growth is motivated by the implication of sticky information models, in that the size of shocks hitting the economy substantially governs the cross-sectional dispersion of forecasts. In a similar vein, Andrade and Le Bihan (2013) employ the squared term to study the role of sticky information in understanding disagreement in the ECB SPF data.

Table 3 reports the estimation results of the regression equations (36) and (37).[14] Regarding the recessions without the autoregressive term (upper panel), the coefficient on the recession probability is signed positive and statistically significant at 5% or below, regardless of the dependent variable. Disagreement grows with increasing probability of recession, which is commonly observed across the survey-measured and model-implied disagreements. This may be interpreted as an evidence for the countercyclical disagreement.

The countercyclical pattern carries over to the case in which the autoregressive term is present, as in the lower panel of Table 3. The estimates of β_1 are all positive with statistical significance at 5% or below. The autoregressive parameter (β_2) for the model-implied disagreement regression is estimated to be 0.826 for consumers, 0.730 for workers, and 0.463 for firms, respectively. This indicates that the persistence of the model-implied disagreement is positively related to the degree of inattentiveness. The estimates of β_2 for the SPF-based regression are 0.677 and 0.654 for current and future output respectively, which are inbetween the model-based estimates associated with the information stickiness of firms and workers.

[13] The recession probability is drawn from the Federal Reserve Economic Data (FRED) website.

[14] In order to explore the sensitivity of the results, we also provide the estimates of the regressions using the SPF disagreement about one-period-ahead output, instead of current output, as the regressand.

The conclusion is almost unaltered with the second group of regressions (38) and (39), summarized in Table 4. Regardless of the presence of the autoregressive component, the estimates of the output growth coefficient (β_2) are all negative and statistically significant at 10% level or below, characterizing an inverse relationship between disagreement and output growth. The estimates of the autoregressive coefficient (β_3) are quite similar to their recession probability regression counterpart. A more notable finding, however, emerges from the coefficients on the squared output growth term (β_1): they are all signed positive and significant at 10% level or below. This suggests a potential nonlinearity between disagreement and business cycles, which is consistent with the prediction of sticky information models. Notice that Mankiw et al. (2004) document evidence on a nonlinear relationship between disagreement about inflation and changes in inflation from survey data, which is coherent with sticky information models. Unlike to this study, however, they report the countercyclicality in the observed disagreement about output, incompatible to the presence of sticky information. The subsequent part of this section focuses on how the baseline model with inattentive agents helps account for the observed negative relationship between output growth and disagreement.

Figure 4 depicts the scatter plots of the survey-measured and model-implied disagreements against output growth. In each panel, we additionally plot the fitted values of the Nadaraya-Watson kernel regression (thick solid lines) and regression equation (38) (dashed lines), together with the mean and 1.5 standard deviation bounds of output growth (solid and dashed vertical lines, respectively). The kernel regression is designed to explore the nature of the relationship between disagreement measures and output growth with no *a priori* restriction on the functional form. As the fitted values of the kernel regression (upper left panel) demonstrates, the relationship between the SPF disagreement and output growth is characterized by a U-shaped curve. The same U-shaped pattern is observed in the model-implied disagreements for consumers, workers, and firms. This finding indicates that the U-shape pattern from the SPF disagreement provides evidence in favor of sticky information—shocks that cause a deviation of output growth from its steady state *either positively or negatively* drive up disagreement. Notice that the tendency is also evident from the lower envelope of the observations in each panel.

Another notable finding is that the kernel fits are well approximated by the quadratic lines associated with the regression (38), which invokes a careful interpretation of the countercyclical disagreement in survey data. An equivalent equation form of (38) is $\sigma_t^y = b_1 + b_2(\Delta y_t - b_3)^2 + u_t$ where b_1, b_2, and b_3 are linear combinations of β_0, β_1, and β_2, and all positive. Since a combination of the positive values of b_2 and b_3 results in a negative value for β_2, the quadratic pattern in disagreement suggests that the negative coefficient on output growth is likely to be a consequence of the *presence* of sticky information. This demonstrates that the observation of the countercyclical disagreement can be reconciled with sticky information models.

As displayed in the model-implied disagreements in Figure 4, the quadratic pattern varies across the agents. The U-shape is most evident for the model-implied disagreement of firms (lower right panel), and becomes more obscure as the workers' and consumers' disagreement series (lower left and upper right panels, respectively) are considered. The less evident U-shape is attributed to the fact that disagreement is often high even when output growth is around its historical mean, which emphasizes the *degree* of sticky information in shaping disagreement. In order to explore this issue, we start from how the model-based disagreement is measured, as in (35). The equation makes explicit that there are two sources of the persistence of disagreement—the degree of information stickiness and persistence of shocks conveyed in $\hat{Y}_t$. What matters for the different degree of disagreements across agents is the former source, whereas the effects of the latter are automatically controlled for by fitting in the identical shock sequences regardless of agents. Then suppose an economy endowed with agents' inattentiveness is hit by a large transitory shock at t, which raises disagreement as the sticky information framework predicts. The dynamic effects of the shock on disagreement hinge upon how quickly information is disseminated among agents. Under the assumption of infrequent information updating, the elevated disagreement is likely to remain high over time even though the economy gets back to normal, compared to the case in which agents update information more often.

In our estimated model, consumers and workers are subject to higher degree of inattentiveness than firms. Together with these estimates, the model-implied disagreements in Figure 5 confirm the reasoning by displaying the actual (circles) and regression (39) predicted (diamonds) values: a more severe degree of agents' inattentiveness leads to high disagreement even when the economy operates at its historical average. In contrast, when the lagged term σ^y_{t-1} is absent, the fitted values degenerate to the quadratic lines in Figure 4. In this case, low disagreement always corresponds to output growth around the historical mean. The results make clear that the lagged disagreement term is the source of high disagreement during normal times. Notice that a similar pattern is observed from the survey-measured disagreement (first panel), which is compelling given the estimated degree of survey respondents' inattentiveness in the existing literature. Coibion and Gorodnichenko (2012a), for example, estimate the degree of information stickiness for the US survey respondents to be 0.55, comparable to the workers' information stickiness in our model.

5.2 IS SURVEY DISAGREEMENT AN APPROPRIATE MEASURE OF UNCERTAINTY? The empirical literature has discussed whether survey disagreement is a good proxy for macroeconomic uncertainty along with the volatility of stock market returns, as well as with the dispersion of stock returns and firms' earnings [Lahiri and Sheng (2010), Jurado et al. (2015)].

From a sticky information perspective, our empirical results suggest that survey disagreement may be an inappropriate measure for uncertainty due to two reasons. First, as the observed U-shape in Figure 4 conveys, an increase in output growth above its mean can also drive up disagreement. It suggests that uncertainty tends to rise when the economy performs beyond the historical average. This attenuates the countercyclical pattern in disagreement, which is a necessary condition for a variable to be a good proxy for macroeconomic uncertainty. To make the comparison explicit, Figure 6 plots the two uncertainty measures frequently employed in the existing literature—the stock market volatility series in Bloom (2009) and uncertainty measure by Jurado et al. (2015 hereafter JLN)—against output growth, together with their fitted values of the Nadaraya-Watson kernel regression. In a sharp contrast to the SPF disagreement series, these uncertainty measures do not display a U-shaped pattern as they tend to be negatively related to output growth. This finding indicates that the Bloom and JNL measures of uncertainty entail an evident degree of countercyclicality, while survey disagreement does not.

Second, high disagreement observed from the SPF can often be a consequence of agents' infrequent information updating rather than an increase in uncertainty. In order to make the exposition more precise, here we investigate whether survey disagreement can be predicted by agents' forecast revision associated with the arrival of new information. If only a fraction of agents update their information set at every period, disagreement can be elevated due to the ones with outdated information. Therefore, agents' forecast revision on the economic activity has an explanatory power for the fluctuations in disagreement. We test the hypothesis by setting up the regressions as:

$$\sigma_t^y = \beta_0 + \beta_1\sigma_{t-1}^y + \beta_2\Delta y_t + \beta_3(F_t\Delta y_t - F_{t-1}\Delta y_t)^2 + u_t \tag{40}$$

$$\sigma_t^y = \beta_0 + \beta_1\sigma_{t-1}^y + \beta_2\Delta y_t + \beta_3(F_t\Delta y_{t+1} - F_{t-1}\Delta y_{t+1})^2 + u_t \tag{41}$$

where F_t denotes the operator averaging survey forecasts at t so that $F_t\Delta y_t$ becomes the average survey forecast of output growth. By construction, $F_t\Delta y_t - F_{t-1}\Delta y_t$ is the forecast revision on current output growth between $t-1$ and t. The magnitude of forecast revision is gauged by its squared term. We consider the survey and model-implied disagreements as well as the Bloom and JLN measures of uncertainty for σ_t^y.

Table 5 summarizes the estimation results for the regressions (40) and (41). The table demonstrates that the statistical significance of β_3 hinges critically upon whether the regressand is a disagreement series. The squared forecast revision term has a statistically significant contribution, at 5% level or below, to survey or model-implied disagreements about current and one-period-ahead output. By contrast, the Bloom's stock market volatility series and JLN uncertainty measure do not respond to the forecast revision, implying that newly updated information has no explanatory power to the uncertainty measures.

Another perspective on whether disagreements are influenced by forecast revisions can be gleaned from a vector autoregression (VAR) analysis. To this end, we consider a VAR(2) specification with three variables such as output growth, squared forecast revision, and disagreement (or uncertainty measures). The structural innovations are identified via a recursive ordering, assuming that a change in output growth leads to a revision on output growth forecast (i.e., $F_t\Delta y_t - F_{t-1}\Delta y_t$) and in turn the latter affects disagreement.[15] Figure 7 plots the impulse responses with their 95 percent confidence intervals of the survey disagreements, model-implied disagreements, stock market volatility, and JLN measure of uncertainty to an innovation to the forecast revision. The survey disagreements jump up in response to a rise in forecast revision and remain statistically different from zero for more than 5 quarters. A similar pattern is observed for the model-implied disagreement of consumers and workers, who display a significant degree of information stickiness. Meanwhile, the response of the firms' disagreement to forecast revision is rather short-lived due to their relatively frequent information updating. The figure shows even more conspicuously that the stock market volatility and JLN's uncertainty measure do not respond significantly to forecast revision that is induced by information updating, as their 95% confidence intervals always include zero.

6 CONCLUDING REMARKS

This paper has shown the importance of information stickiness of consumers, workers, and firms in accounting for the dynamics of macro aggregates as well as its implications in understanding the cyclical property of survey disagreements about economic activity, based on an estimated DSGE model. The analytical solution exhibits that endowing conventional models with sticky information alters the dynamic properties of the model variables by reallocating the relative importance of forward-looking components. In addition, the estimated DSGE model reveals a substantial degree

[15] Although not included herein, we find that the results are affected neither by incorporating additional variables such as inflation and the federal funds rate into the VAR(2) model nor by changing the lags of the VAR specification. Also, considering $F_t\Delta y_{t+1} - F_{t-1}\Delta y_{t+1}$ instead of $F_t\Delta y_t - F_{t-1}\Delta y_t$ in the VAR system yields very similar estimates.

of information stickiness of consumers and workers, which is an important modeling feature in improving the goodness of fit.

The empirical implications of sticky information are crucial for understanding how survey disagreement evolves conditional on business cycles. We establish a quadratic pattern between the SPF disagreement and output growth, which can be well rationalized by sticky information models. The data suggests only a tenuous tendency for the countercyclicality of survey disagreement, raising skepticism about whether survey disagreement on output is an appropriate measure of macroeconomic uncertainty.

We conclude by noting that, in this paper, we have mainly considered the sticky information framework as in Mankiw and Reis (2002, 2007). Sticky information models typically posit that the degree of information rigidity of agents is time-invariant. As Coibion and Gorodnichenko (2012a) emphasize, however, state-dependent information rigidity could be another viable hypothesis, supported by the survey forecasts on economic activity. This fact has important implications for understanding how information rigidity interacts with fluctuations in macroeconomic aggregates, which can be crucial in accounting for the behavior of survey-measured time series. Investigating these implications would be a valuable future research agenda.

A DATA

The model is estimated using U.S. quarterly data from 1954:Q3 to 2008:Q4. As in Rabanal (2007), output and the corresponding price and wage indexes use the Nonfarm Business Sector data. Detailed data descriptions are as follows.

$$\begin{aligned}
\text{Output Growth} &= \log(\text{Per Capita Real GDP/Per Capita Real GDP(-1)}) \times 100, \\
\text{Price Inflation} &= \log(\text{Price Deflator/Price Deflator(-1)}) \times 100, \\
\text{Wage Inflation} &= \log(\text{Real Wage/Real Wage(-1)}) \times 100, \\
\text{Nominal Interest Rate} &= \text{Federal Funds Rate}/4,
\end{aligned}$$

where sources of the original data are:

- Real GDP: Nonfarm Business Sector Real Output, Index 2009=100, Quarterly, Seasonally Adjusted (Source: Federal Reserve Economic Data–FRED, Series ID "OUTNFB")
- Pop Index: Civilian Noninstitutional Population, Ages 16 Years and Over, Seasonally Adjusted (Source: U.S. Department of Labor, Bureau of Labor Statistics)
- Price Deflator: Nonfarm Business Sector Implicit Price Deflator, Index 2009=100, Quarterly, Seasonally Adjusted (Source: Federal Reserve Economic Data–FRED, Series ID "IPDNBS")
- Real Wage: Nonfarm Business Sector Real Compensation Per Hour, Index 2009=100, Quarterly, Seasonally Adjusted (Source: Federal Reserve Economic Data–FRED, Series ID "COMPRNFB")
- Federal Funds Rate: Averages of Daily Figures, Percent (Source: Board of Governors of the Federal Reserve System)

B TABLES

Parameter		Prior		Posterior	
		Dist.	Mean (Std)	Mean	[5%, 95%]
σ	Risk Aversion	G	1.5 (0.38)	2.62	[1.91, 3.37]
η	Inverse Frisch Elasticity	G	2.0 (0.75)	2.22	[1.15, 3.62]
γ_h^{si}	Sticky Info. Consumers	B	0.5 (0.1)	0.74	[0.64, 0.84]
γ_w^{si}	Sticky Info. Workers	B	0.5 (0.1)	0.55	[0.39, 0.72]
γ_p^{si}	Sticky Info. Firms	B	0.5 (0.1)	0.13	[0.08, 0.20]
α_p	Price Stickiness	B	0.5 (0.1)	0.72	[0.65, 0.78]
α_w	Wage Stickiness	B	0.5 (0.1)	0.95	[0.93, 0.96]
ρ	MP Rule AR(1)	B	0.75 (0.1)	0.83	[0.78, 0.87]
a_π	MP Rule Inflation	N	1.5 (0.25)	0.97	[0.76, 1.21]
a_y	MP Rule Output Gap	G	0.13 (0.1)	0.02	[0.01, 0.04]
ρ_a	Technology Shock AR(1)	B	0.5 (0.2)	0.95	[0.92, 0.97]
ρ_m	MP Shock AR(1)	B	0.5 (0.2)	0.25	[0.16, 0.35]
ρ_y	Demand Shock AR(1)	B	0.5 (0.2)	0.81	[0.74, 0.87]
ρ_w	Wage Markup Shock AR(1)	B	0.5 (0.2)	0.15	[0.07, 0.25]
σ_a	Technology Shock Std.	IG	0.1 (2)	5.45	[3.62, 7.69]
σ_m	MP Shock Std.	IG	0.1 (2)	0.22	[0.21, 0.24]
σ_y	Demand Shock Std.	IG	0.1 (2)	2.52	[1.31, 4.86]
σ_w	Wage Markup Shock Std.	IG	0.1 (2)	0.77	[0.70, 0.83]

Table 1: Prior and posterior distributions of each estimated parameter for the baseline model.

Parameter		Prior		Posterior Mean				
		Dist.	Mean (Std)	Baseline	No Sticky Info. (Full Info.)	$\gamma_h^{si}=0$	$\gamma_w^{si}=0$	$\gamma_p^{si}=0$
σ	Risk Aversion	G	1.5 (0.38)	2.62	4.18	4.14	2.61	2.69
η	Inverse Frisch Elasticity	G	2.0 (0.75)	2.22	1.84	1.73	2.23	1.93
γ_h^{si}	Sticky Info. Consumers	B	0.5 (0.1)	0.74	–	–	0.73	0.67
γ_w^{si}	Sticky Info. Workers	B	0.5 (0.1)	0.55	–	0.54	–	0.53
γ_p^{si}	Sticky Info. Firms	B	0.5 (0.1)	0.13	–	0.12	0.12	–
α_p	Price Stickiness	B	0.5 (0.1)	0.72	0.71	0.71	0.72	0.76
α_w	Wage Stickiness	B	0.5 (0.1)	0.95	0.96	0.95	0.95	0.95
ρ	MP Rule AR(1)	B	0.75 (0.1)	0.95	0.96	0.95	0.95	0.95
a_π	MP Rule Inflation	N	1.5 (0.25)	0.97	0.79	0.75	0.98	0.92
a_y	MP Rule Output Gap	G	0.13 (0.1)	0.02	0.03	0.03	0.03	0.02
ρ_a	Technology Shock AR(1)	B	0.5 (0.2)	0.95	0.96	0.94	0.95	0.95
ρ_m	MP Shock AR(1)	B	0.5 (0.2)	0.25	0.28	0.30	0.25	0.25
ρ_y	Demand Shock AR(1)	B	0.5 (0.2)	0.81	0.95	0.95	0.82	0.84
ρ_w	Wage Markup Shock AR(1)	B	0.5 (0.2)	0.15	0.12	0.14	0.14	0.14
σ_a	Technology Shock Std.	IG	0.1 (2)	5.45	3.89	5.51	5.56	5.47
σ_m	MP Shock Std.	IG	0.1 (2)	0.22	0.23	0.23	0.22	0.22
σ_y	Demand Shock Std.	IG	0.1 (2)	2.52	0.31	0.31	2.34	1.68
σ_w	Wage Markup Shock Std.	IG	0.1 (2)	0.77	0.74	0.77	0.75	0.77
Average Log Marginal Densities				– 850.73	–969.23	–920.61	–886.02	–865.27

Table 2: Average log marginal densities and mean posterior estimates of each estimated parameter for the various specifications with distinct sticky information setups.

$$\sigma_t^y = \beta_0 + \beta_1\, p_t^{rec} + u_t$$

	Survey-measured Disagreement		Model-implied Disagreement		
	SPF about y_t	SPF about y_{t+1}	Consumers	Workers	Firms
β_1	0.271** (0.106)	0.450*** (0.118)	0.729** (0.288)	0.572*** (0.178)	0.214*** (0.044)
R^2	0.10	0.13	0.10	0.12	0.17

$$\sigma_t^y = \beta_0 + \beta_1\, p_t^{rec} + \beta_2 \sigma_{t-1}^y + u_t$$

	Survey-measured Disagreement		Model-implied Disagreement		
	SPF about y_t	SPF about y_{t+1}	Consumers	Workers	Firms
β_1	0.112** (0.047)	0.226*** (0.051)	0.537*** (0.125)	0.433*** (0.094)	0.152*** (0.038)
β_2	0.677*** (0.056)	0.654*** (0.049)	0.826*** (0.037)	0.730*** (0.041)	0.463*** (0.073)
R^2	0.53	0.53	0.74	0.60	0.36

Table 3: Estimation results for the recession probability regressions. σ_t^y denotes either survey-measured or model-implied disagreement about output at t; p_t^{rec} denotes the recession probability at t. The numbers in parenthesis indicate standard errors for the corresponding coefficient. Statistical significance at * 10%, ** 5%, and *** 1%.

$$\sigma_t^y = \beta_0 + \beta_1\,(\Delta y_t)^2 + \beta_2 \Delta y_t + u_t$$

	Survey-measured Disagreement		Model-implied Disagreement		
	SPF about y_t	SPF about y_{t+1}	Consumers	Workers	Firms
β_1	0.003*** (0.001)	0.004*** (0.001)	0.013*** (0.002)	0.012*** (0.001)	0.005*** (0.000)
β_2	−0.024** (0.009)	−0.039*** (0.012)	−0.069*** (0.017)	−0.062*** (0.011)	−0.028*** (0.003)
R^2	0.11	0.11	0.22	0.38	0.60

$$\sigma_t^y = \beta_0 + \beta_1\,(\Delta y_t)^2 + \beta_2 \Delta y_t + \beta_3 \sigma_{t-1}^y + u_t$$

	Survey-measured Disagreement		Model-implied Disagreement		
	SPF about y_t	SPF about y_{t+1}	Consumers	Workers	Firms
β_1	0.002* (0.0001)	0.002** (0.0001)	0.011*** (0.001)	0.011*** (0.001)	0.004*** (0.000)
β_2	−0.010* (0.006)	−0.016*** (0.005)	−0.063*** (0.011)	−0.055*** (0.008)	−0.024*** (0.002)
β_3	0.669*** (0.053)	0.663*** (0.055)	0.822*** (0.027)	0.714*** (0.031)	0.413*** (0.055)
R^2	0.53	0.51	0.87	0.85	0.75

Table 4: Estimation results for the quadratic output growth regressions. σ_t^y denotes either survey-measured or model-implied disagreement about output at t; Δy_t denotes output growth at t. The numbers in parenthesis indicate standard errors for the corresponding coefficient. Statistical significance at * 10%, ** 5%, and *** 1%.

	$\sigma_t^y = \beta_0 + \beta_1\sigma_{t-1}^y + \beta_2\Delta y_t + \beta_3(F_t\Delta y_t - F_{t-1}\Delta y_t)^2 + u_t$						
	Actual Series				Model-implied Disagreement		
	SPF about y_t	SPF about y_{t+1}	Stock market vol.	JLN series	Consumers	Workers	Firms
β_1	0.678*** (0.058)	0.666*** (0.054)	0.735*** (0.066)	0.948*** (0.044)	0.833*** (0.039)	0.741*** (0.042)	0.501*** (0.073)
β_2	0.002 (0.004)	–0.003 (0.006)	–0.229 (0.229)	–0.005*** (0.001)	0.000 (0.021)	0.005 (0.018)	–0.002 (0.006)
β_3	0.0114** (0.0051)	0.0154*** (0.0036)	0.0651 (0.0906)	–0.0004 (0.0005)	0.0237*** (0.0091)	0.0209*** (0.0084)	0.0069*** (0.0034)
R^2	0.56	0.54	0.47	0.91	0.71	0.57	0.33
	$\sigma_t^y = \beta_0 + \beta_1\sigma_{t-1}^y + \beta_2\Delta y_t + \beta_3(F_t\Delta y_{t+1} - F_{t-1}\Delta y_{t+1})^2 + u_t$						
	Actual Series				Model-implied Disagreement		
	SPF about y_t	SPF about y_{t+1}	Stock market vol.	JLN series	Consumers	Workers	Firms
β_1	0.675*** (0.058)	0.658*** (0.060)	0.724*** (0.066)	0.938*** (0.044)	0.832*** (0.041)	0.740*** (0.044)	0.494*** (0.076)
β_2	0.001 (0.005)	–0.003 (0.006)	–0.186 (0.223)	–0.005*** (0.001)	0.000 (0.022)	0.006 (0.019)	–0.002 (0.006)
β_3	0.0154** (0.0076)	0.0238*** (0.0075)	0.3020 (0.2401)	–0.0006 (0.0010)	0.0463*** (0.0162)	0.0399** (0.0164)	0.0135*** (0.0070)
R^2	0.53	0.52	0.47	0.91	0.71	0.56	0.32

Table 5: Estimation results for the recession of various macroeconomic uncertainty measures (σ_t^y) on forecast revisions ($F_t\Delta y_t - F_{t-1}\Delta y_t$ or $F_t\Delta y_{t+1} - F_{t-1}\Delta y_{t+1}$). The numbers in parenthesis indicate standard errors for the corresponding coefficient. Statistical significance at * 10%, ** 5%, and *** 1%.

C FIGURES

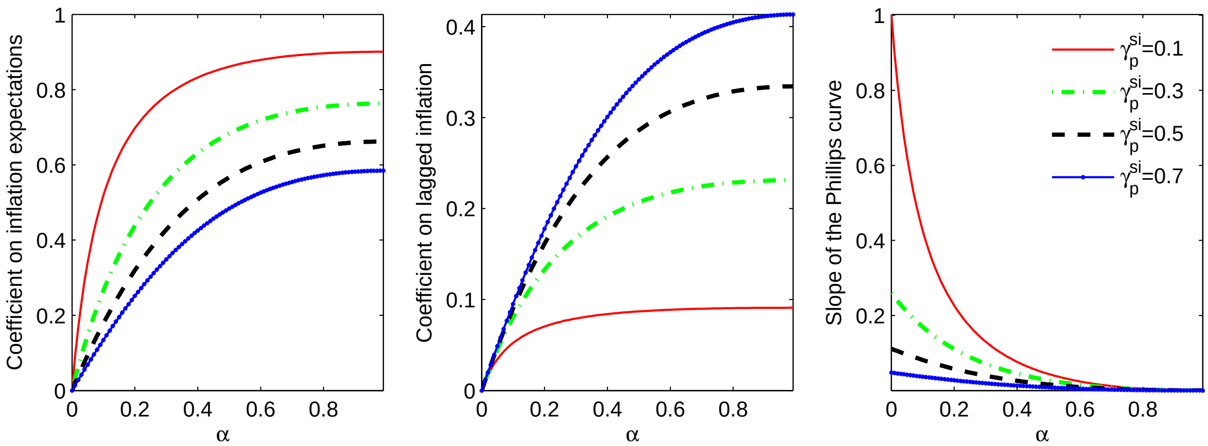

Figure 1: Properties of the price Phillips curve under various degrees of sticky information of firms (γ_p^{si}).

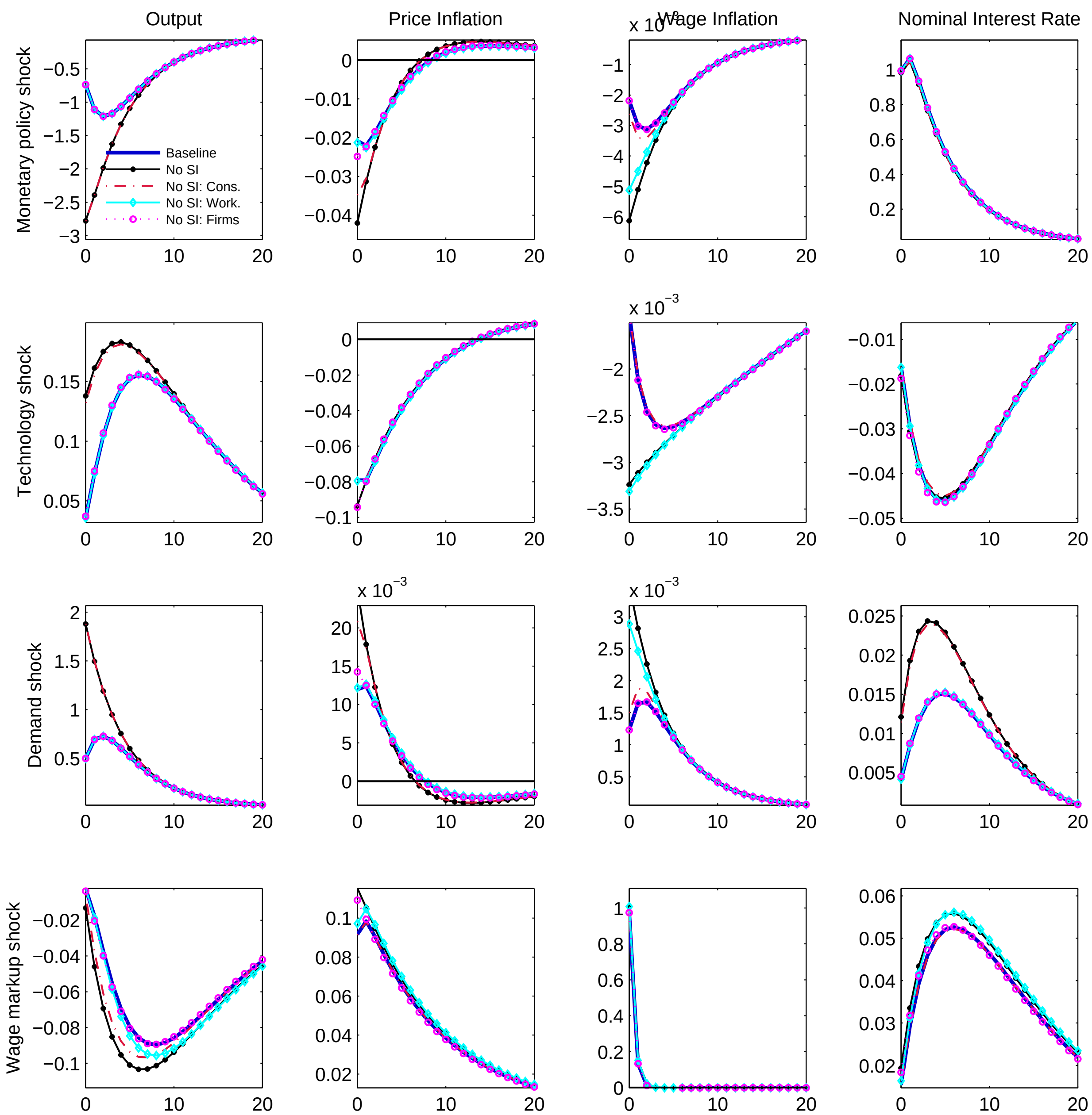

Figure 2: Impulse response functions evaluated at the mean of the posterior parameter distributions. In each panel, the impulse response for the baseline (solid lines), model with no sticky information of all agents (dash-dot lines with asterisks), model with no sticky information of consumers (dash-dot lines), model with no sticky information of workers (solid lines with diamonds), and model with no sticky information of firms (dash-dot lines with circles) are reported. The x-axis measures quarters.

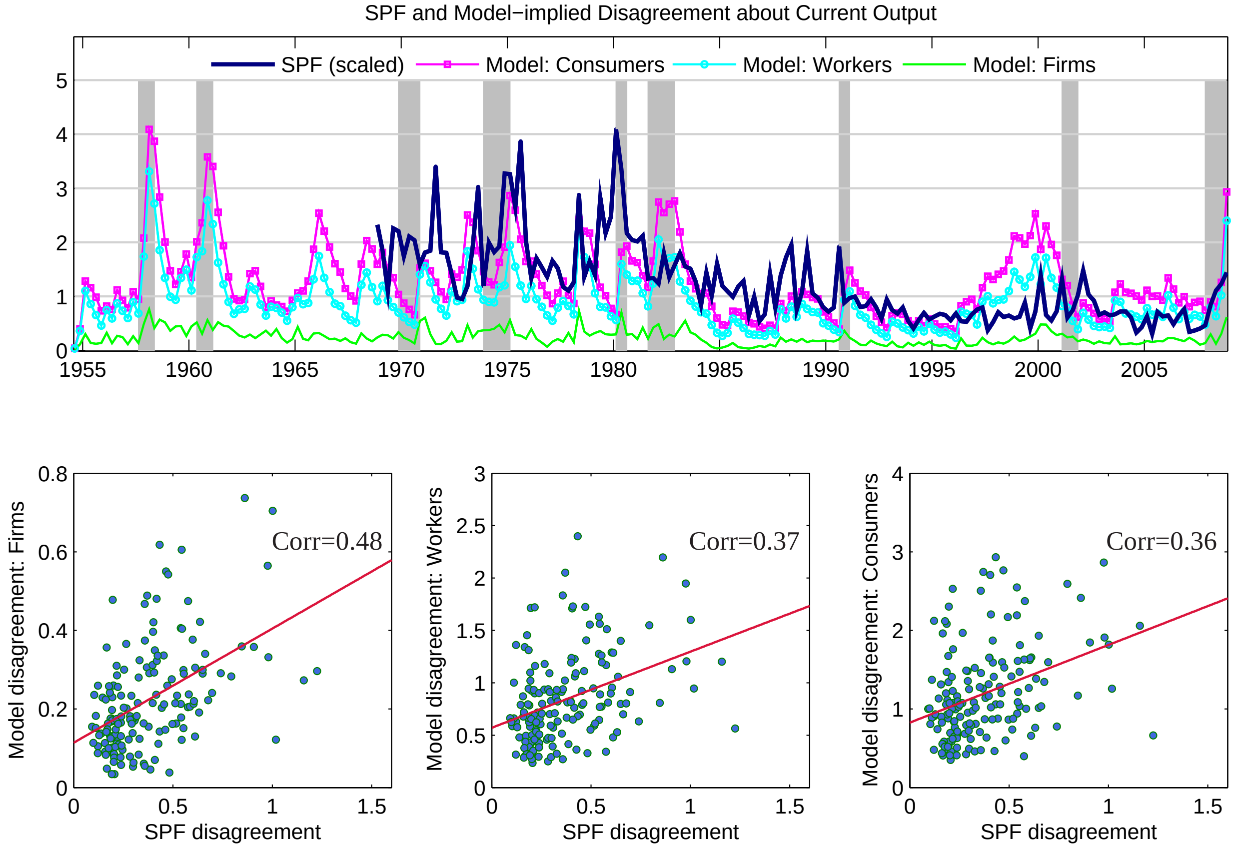

Figure 3: [**Upper panel**] SPF survey-measured disagreement about current output (thick solid line) and mean estimates for the model-implied disagreements by each agent (consumers: solid line with squares; workers: solid line with circles; firms: thin solid line) about current output. The SPF survey-measured disagreement series is scaled so that its maximum value is identical to that of the model-implied disagreement of consumers. Shaded areas indicate NBER recession dates. [**Lower panel**] Scatter plots for SPF survey-measured disagreement about current output (x-axis) and the mean estimates for the model-implied disagreements by each agent (y-axis), together with the OLS predicted values (solid lines).

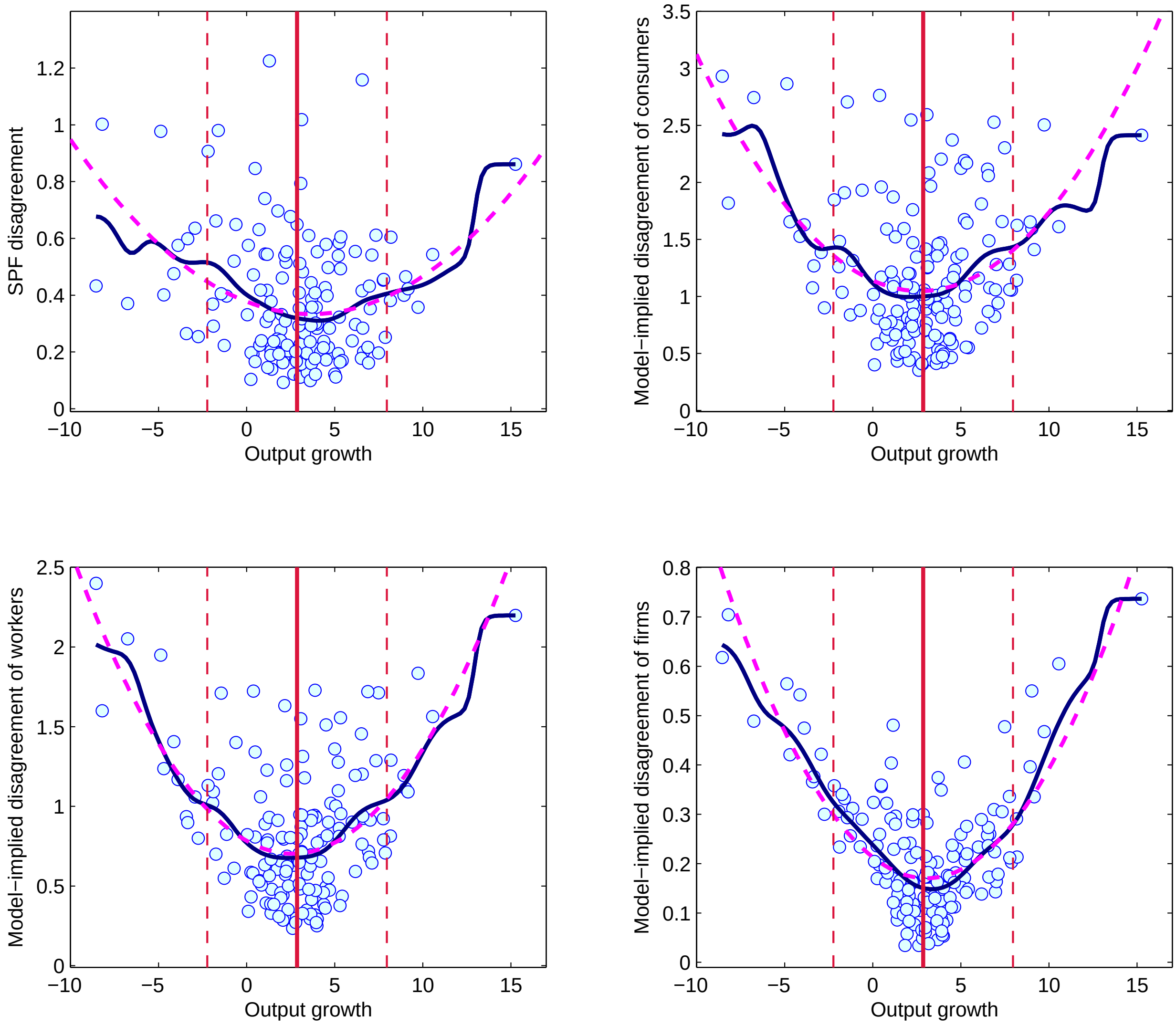

Figure 4: Scatter plots for output growth (x-axis) and either the SPF survey-measured or the model-implied disagreement about current output (y-axis). In each panel, the solid, dashed, vertical solid, and vertical dashed lines indicate the fitted values of the Nadaraya-Watson kernel regression, function values of $\hat{\beta}_0 + \hat{\beta}_1 (\Delta y_t)^2 + \hat{\beta}_2 \Delta y_t$ based on the estimates of the regression equation $\sigma_t^y = \beta_0 + \beta_1 (\Delta y_t)^2 + \beta_2 \Delta y_t + u_t$, mean output growth rate, and 1.5 standard deviation bounds from the mean output growth rate, respectively.

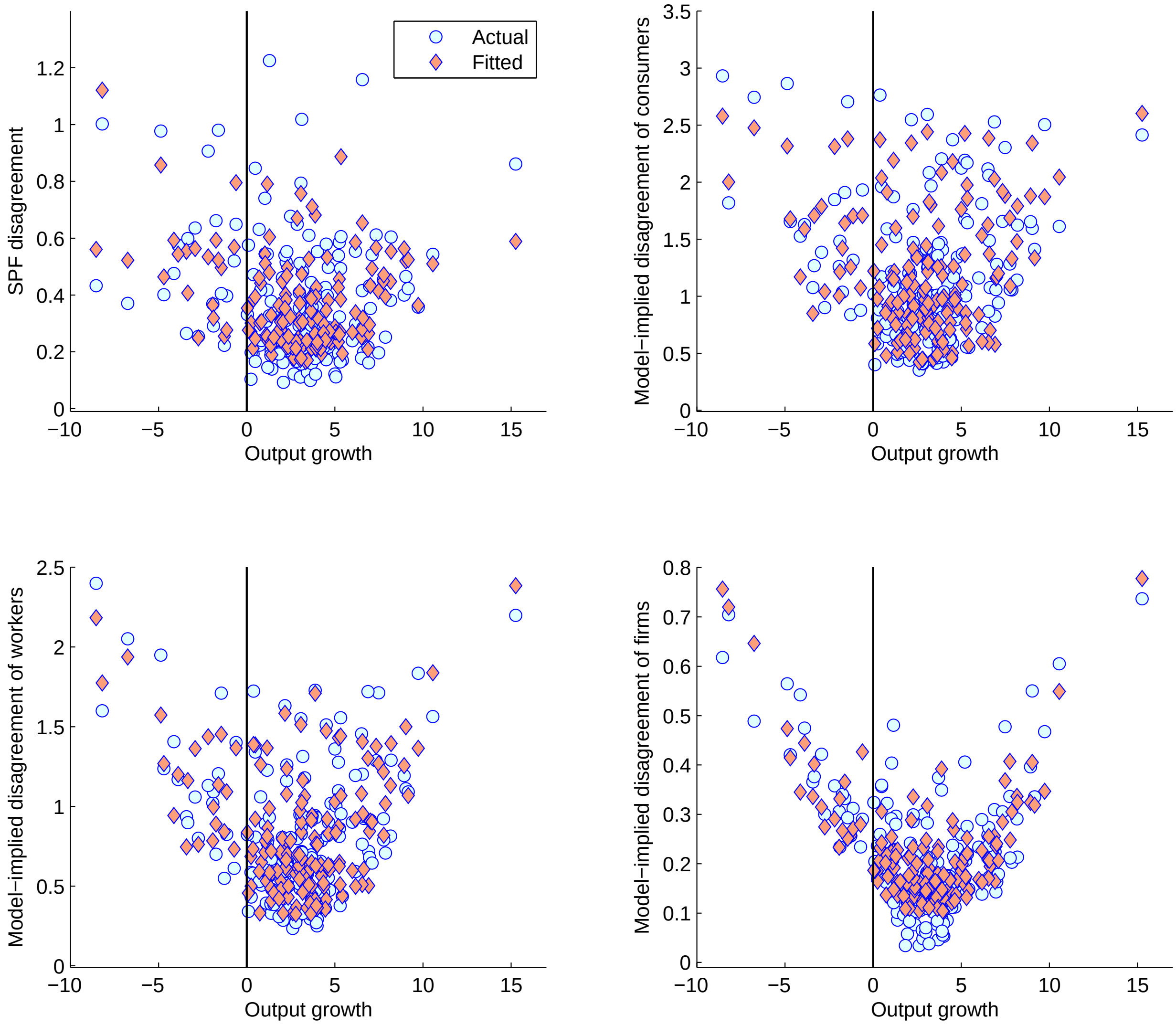

Figure 5: Scatter plots for output growth (x-axis) and either the SPF survey-measured or the model-implied disagreement about current output (y-axis). In each panel, the circle and diamond markers indicate the actual and fitted values of the regression equation $\sigma_t^y = \beta_0 + \beta_1 (\Delta y_t)^2 + \beta_2 \Delta y_t + \beta_3 \sigma_{t-1}^y + u_t$, respectively.

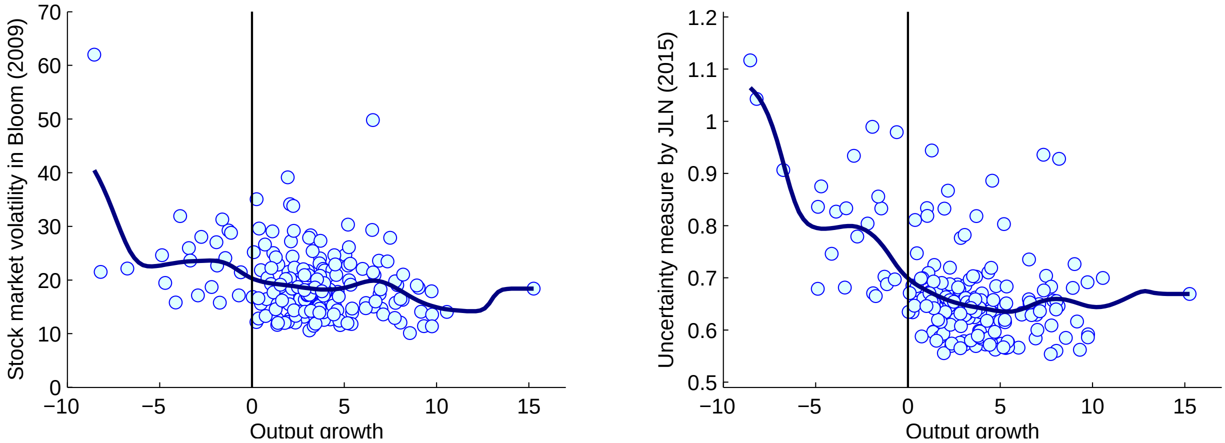

Figure 6: Scatter plots for output growth (x-axis) and the various measures of macroeconomic uncertainty in the existing literature (y-axis). In each panel, the solid line indicates the fitted values of the Nadaraya-Watson kernel regression.

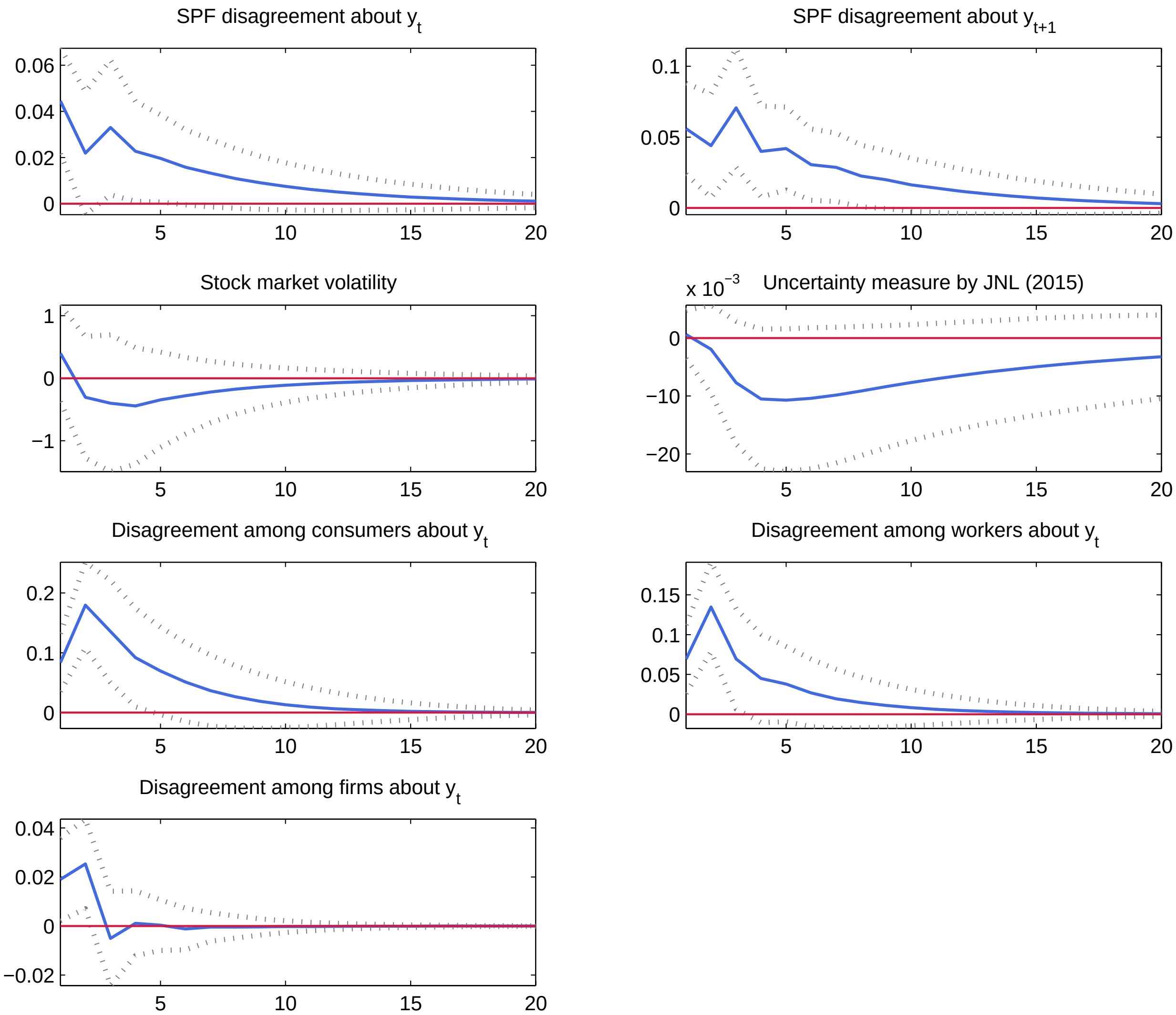

Figure 7: VAR(2) impulse responses (solid lines) with 95% confidence intervals (dashed lines) of the various measures of macroeconomic uncertainty to an innovation on the forecast revision.

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