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The Effect of Central Bank Credibility on Forward Guidance in an Estimated New Keynesian Model*

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Abstract

This paper examines the effectiveness of forward guidance in an estimated New Keynesian model with imperfect central bank credibility. Forward guidance and the credibility of the central bank are uniquely modeled by utilizing a game-theoretic evolutionary framework. We estimate credibility for the U.S. Federal Reserve with Bayesian methods exploiting survey data on interest rate expectations from the Survey of Professional Forecasters (SPF). The results provide important takeaways: (1) The estimate of Federal Reserve credibility in terms of forward guidance announcements is relatively high, which indicates a degree of forward guidance effectiveness, but still one that is below the fully credible case. (2) If a central bank is perceived as less credible, anticipation effects are attenuated and, accordingly, output and inflation do not respond as favorably to forward guidance announcements. (3) Imperfect credibility and forward guidance are an important aspect to resolve the so-called "forward guidance puzzle," which the literature shows arises from the unrealistically large responses of macroeconomic variables to forward guidance statements in structural models with perfect credibility. (4) Imperfect central bank credibility can also explain the evidence of forecasting error predictability based on forecasting disagreement found in the SPF data. Thus, accounting for imperfect credibility is important to model the formation of expectations in the economy and to understand the transmission mechanism of forward guidance announcements.

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1 Introduction

Since the $2008 - 2009$ Great Recession, central bank forward guidance has been an essential monetary policy tool. For instance, when interest rate reached the zero lower bound (ZLB) in the aftermath of the Great Recession, the U.S. Federal Reserve provided guidance on the future course of interest rates. The Federal Open Market Committee (FOMC) first implemented forward guidance in their December 2008 statement: "the Committee anticipates that weak economic conditions are likely to warrant exceptionally low levels of the federal funds rate for some time." This type of lower-for-longer policy is predicted to have beneficial effects on the economy as described by Eggertsson and Woodford (2003) and Woodford (2003). In addition, when interest rates are away from the ZLB, forward guidance can provide clarification and transparency about future monetary policy. As explained by Williams (2013), greater clarity from forward guidance about the future policy path can help households and businesses make better investment decisions and boost the economy.

The effectiveness of forward guidance, however, rests on the perceived credibility of the central bank to follow through with its statements. Standard macroeconomic models often consider the case of a fully credible monetary authority. However, this assumption ignores a key channel through which forward guidance can affect the economy. If the central bank is perceived as trustworthy, agents are likely to internalize how future statements about policy will affect their decisions today. If not, the effect on the economy from forward guidance will be not as strong. Indeed, Goodfriend and King (2016) recognize this stating that "forecasts, and policy, should not be based solely on forecasts from a model that assumes full credibility in the stated policy path." Thus, it is important to examine how the effectiveness of forward guidance depends on the credibility of the central bank.

This paper studies the effects of forward guidance with imperfect central bank credibility. A standard New Keynesian model augmented with standard macroeconomic persistence features (that is, with price stickiness, price indexation, habit formation, and interest rate inertia) is employed. Following Del Negro et al. (2012) and Laséen and Svensson (2011), forward guidance is implemented by adding anticipated or forward guidance shocks to the monetary policy rule. The model is estimated using Bayesian methods with data on expectations of the interest rate from the Survey of Professional Forecasters (SPF).

A novelty of our framework regards employing an evolutionary game-theoretic setup when incorporating central bank credibility and forward guidance into aggregate expectations. In the model, based on the axiomatic approach of Branch and McGough (2009), expectations are a weighted sum of central bank and private sector forecasts. Private agents that believe the central bank announcements about forward are assumed to follow the full-information rational expectations (FIRE) typically employed in the literature. Those agents who do not believe central bank announcements about forward guidance, instead, form forecasts based on a data-driven VAR(1) in output, inflation, and interest rates which effectively disregards all forward guidance announcements and only responds to the policy announced when it materializes. A key parameter in our analysis is $0 \leq \tau \leq 1$, which defines the weight assigned by private agents to the belief that the monetary authority forward guidance commitments are credible and would be honored. If $\tau \rightarrow 1$, private agents believe the central bank to be perfectly credible and all announcements about forward guidance to be honored. Thus, in that limiting case, aggregate expectations follow FIRE and we are back in the standard setup in the literature (e.g., Del Negro et al. (2012)). If $\tau \rightarrow 0$, agents do not perceive the monetary authority to be credible and ignore forward guidance statements altogether. Aggregate expectations then do not contain forward guidance information.

The results from our estimated model show essential takeaways. First, a distinctive contribution of our paper regards our use of Bayesian estimation procedures and the SPF dataset. We utilize expectations of the interest rate from the SPF to help identify forward guidance shocks. Bayesian estimation procedures then show that the estimate of the credibility parameter (i.e., τ) in terms of forward guidance announcements hovers around 0.8 with 1 being the case of a fully credible commitment. Since the U.S. central bank is perceived as less than fully credible in its forward guidance announcements, there exists less immediate and overall anticipation effects on the economy from forward guidance than under the perfectly credible case. The impulse response functions and variance decomposition results in this paper show that the responses of output and inflation to forward guidance shocks do not respond as favorably relative to the scenario of a perfectly credible central bank.

Second, we also establish that imperfect credibility is another important aspect to resolve the so-called "forward guidance puzzle". Del Negro et al. (2012) explain that the forward guidance puzzle arises because standard New Keynesian models produce unusually large responses to forward guidance news. The credibility estimate indeed is below the fully credible case and this dampens the power of forward guidance. Our evidence suggests that the attenuation of the anticipation effects that results from a forward guidance policy that is imperfectly credible can go a long ways in reconciling the standard New Keynesian workhorse model with the empirical evidence on the more modest efficacy of forward guidance.

Finally, our model cross-validates well with other important features of the SPF data—in particular, with the predictability of forecasting errors based on forecasting disagreements. In both simulated data from our model and in the SPF data, we compare the empirical relationship between forecasts errors and forecast disagreements with a standard regression. Our model of imperfect credibility can display comovements between the previously mentioned variables at different horizons that are broadly consistent to the comovements implied by the SPF dataset.

The key implication we derive from our estimated model is, therefore, that accounting for imperfect credibility is important to model the formation of expectations in the economy and the transmission mechanism of monetary policy (particularly for policy announcements or forward guidance). We then examine four robustness scenarios. First, the main results do not substantially change if the model is estimated over our full sample ($1981 : Q3 - 2018 : Q4$), the non-ZLB subsample ($1981 : Q3 - 2008 : Q4$), and the Great Moderation period ($1985 : Q1 - 2007 : Q3$). In particular, the estimate of τ is high indicating a high level of trust in the central bank, but still below the fully credible case and similar to our baseline estimate for the full sample.

Second, the structure of the forecasting model of private sector agents also does not affect the estimate of the credibility parameter τ. This prior result provides more evidence that τ captures central bank credibility in terms of forward guidance. Third, our results are largely robust to a more agnostic prior belief about τ. The prior distribution in the baseline exercise was centered around a high degree of central bank credibility. When a more agnostic prior belief is assumed, our estimate of τ does not noticeably change in relation to the benchmark case. Finally, the results are robust if $t + 1$ expectations correspond to the one-period ahead forecasts in the SPF instead of corresponding to the nowcast.

In summary, by using Bayesian estimation procedures and interest rate expectations data, the estimate of Federal Reserve credibility in terms of forward guidance is at a high level. However, our estimated value is below the fully credible case. Consequently, since the central bank is perceived as less than fully credible, there exists less immediate and overall effects of forward guidance on the economy. Our model of central bank credibility offers a novel take on the formation of expectations which highlights the importance of non-cooperative games between the central bank and the private sector in our understanding of expectations. In addition, our evidence on forward guidance under imperfect credibility cross-validates well with the evidence of forecastability of the SPF forecasting errors. Finally, we argue that incorporating monetary authority credibility into standard macroeconomic models can be another aspect to solve the "forward guidance puzzle". Thus, accounting for imperfect credibility is important to model the formation of expectations in the economy and the transmission mechanism of forward guidance announcements.

1.1 Contribution to the Literature

There exists a growing strand of the monetary policy literature focused on the transmission mechanism through which forward guidance is thought to operate. This transmission channel relies on anticipation effects driven by a credible commitment to future policy. The evidence suggests that forward guidance moves expectations but only partially (Ferrero and Secchi (2009); Ferrero and Secchi (2010); Hubert (2014); Hubert (2015a); Hubert (2015b)). Mainstream theory suggests that the anticipation effects are simply too strong within the standard class of general equilibrium models to be consistent with the empirical evidence (the so-called "forward guidance puzzle" of Del Negro et al. (2012)).[1] Some authors have argued that misspecification can be part of the story—like capital market imperfections in McKay et al. (2016).

Other papers have analyzed the expectations formation process of agents. Gauss (2015) and Andrade et al. (2019) show that heterogenous expectations in an economy can influence the power of forward guidance. Cole (2020a) and Cole (2020b) explain that the rational expectations assumption can overstate the benefits of forward guidance relative to a more realistic adaptive learning rule. The effectiveness of forward guidance has also been analyzed via the communications channel. Campbell et al. (2019) find that FOMC forward guidance information has limited power at long horizons. As explained by De Graeve et al. (2014), the effects of forward guidance on the economy can have more positive effects if its length is tied to the future condition of the economy (threshold-based forward guidance).[2]

The present paper also fits into prior research exploring the conduct of monetary policy when agents have imperfect information about the economy. Under an adaptive learning framework in which agents are uncertain about the true structure of the economy, Eusepi and Preston (2010) analyze different monetary policy communication strategies to ensure stable macroeconomic dynamics. Honkapohja and Mitra (2019) study central bank credibility in an adaptive learning framework when the monetary authority implements a price-level targeting policy. Ferrero and Secchi (2009) and Ferrero and Secchi (2010) show that if the central bank communicates to the public its projections of the output gap and inflation, more desirable and stable outcomes can occur in the economy. Orphanides and Williams (2004), Orphanides and Williams (2007), Gaspar et al. (2006), and Gaspar et al. (2010) study central bank behavior when agents have imperfect information about the parameters in the central bank's

[1] Carlstrom et al. (2015) also show unusually large responses of the macroeconomic variables to interest rate pegs under a perfectly credible central bank.

[2] Campbell et al. (2012) also examine Odyssean and Delphic forward guidance in the U.S and find that the FOMC has achieved some success in communicating Odyssean forward guidance.

policy rule function or optimal monetary policy with adaptive learning. However, none of these papers explicitly model forward guidance and credibility in an estimated model as is done in our study.

Our paper is closest to Goy et al. (2018) and Haberis et al. (2014) which have looked at the role of monetary policy credibility.[3] The former shows that forward guidance can help escape the liquidity trap when central bank credibility is endogenous while the latter explains that interest rate pegs can produce more muted responses of the macroeconomic variables if agents in their model are allowed to perceive the central bank as not credible.[4] However, our paper differs in the following ways: (1) we motivate the credibility and forward guidance framework with an evolutionary game-theoretic setup; (2) by using Bayesian methods, we exploit survey data on interest rate expectations to infer the credibility of forward guidance shocks; (3) we estimate credibility of the central bank in terms of forward guidance to show that a less credible central bank reduces the effectiveness of forward guidance; and (4) we cross-validate our model with data from the SPF. To the best of our knowledge, none of the prior literature has established and provided evidence to support these previous points.

Altogether we see our paper adding to the literature along the following dimensions. First, we explicitly model the credibility of the policy commitment on the part of the private agents and the willingness to implement those commitments in a game-theoretic context which is tied to the formation of expectations. Second, we exploit SPF data and Bayesian estimation techniques to analyze the effects of central bank credibility on forward guidance. Bayesian estimation procedures and survey data are employed to recover an estimate of central bank credibility in terms of forward guidance, which other studies have not estimated. Third, the resulting outcomes from our estimation show a high but imperfectly credible central bank in the U.S. This result implies that credibility has dampens the effects of forward guidance on the economy relative to the perfectly credible central bank case. Finally, to the best of our knowledge, we are also the first paper to cross-validate a macroeconomic model of central bank credibility and forward guidance on the forecastability of SPF forecasting errors. In short, we argue that deviations from FIRE behavior can arise endogenously in a setting where policy commitments about the future path of the interest rate can be reneged by the central bank. Therefore, we conclude that the anticipation effects of forward guidance are attenuated when the central bank is perceived as unable to fully commit to honor the

[3] Other papers related to ours include Eggertsson and Woodford (2003) who also discuss the importance of the management of expectations when the interest rate is constrained by the ZLB, and also Kiley (2016) and Swanson (2018) who explore forward guidance at the ZLB.

[4] Nakata and Sunakawa (2019) and Dong and Young (2019) examine time consistent policy in a model with forward guidance and credibility.

announced future path.

The remainder of the paper goes as follows: In Section 2 we discuss our baseline model including the game-theoretic motivation of our notion of central bank credibility. In Section 3 we introduce our Bayesian estimation approach which is based on an expectations-augmented linearized version of the general equilibrium model. In Section 4 we present our main findings, while in Section 5 we provide additional robustness checks on our key estimate of central bank credibility. In Section 6 we conclude. A detailed discussion of the evolutionary games of credibility as well as all listed tables and figures are provided in the Appendix.

2 Benchmark Model

We employ a standard New Keynesian model that follows from the workhorse framework laid out by Woodford (2003), Giannoni and Woodford (2004), Milani (2007), Cúrdia et al. (2015), and Cole and Milani (2017). The log-linear approximation that we bring to the data is derived from the optimizing behavior of households and firms. Our variant of the model includes four conventional sources of macroeconomic persistence—habit formation in consumption, price stickiness, price indexation, and interest rate inertia—to capture the dynamics of the macroeconomic data. The model is completed with a Taylor (1993) interest rate feedback rule with inertia which describes the response of monetary policy to domestic economic conditions. We augment the standard monetary policy rule in one important dimension by explicitly distinguishing between unanticipated (surprises) and anticipated (forward guidance) shocks to monetary policy—a distinction that allows us to investigate the central bank's commitment to a future path of the nominal policy rate (forward guidance) through the lens of a general equilibrium model and which we describe in greater detail in Subsection 2.2.

We depart from the full-information rational expectations (FIRE), homogeneous-beliefs paradigm embedded in the workhorse New Keynesian model allowing heterogeneous-beliefs to emerge in a game-theoretic context where private agents and the central bank have to decide whether to belief the central bank's promises (the private agents) and whether to honor the forward guidance commitments made (the central bank). However, unlike Goy et al. (2018), we maintain the assumption that the central bank's own forecasts are based on full-information and are formed under fully-rational expectations. Our reasoning here is similar to Park (2018) who argues that monetary authorities typically employ macroeconomic models with rational expectations to forecast future economic activity as well as the future path of inflation and the policy rate. Private agents, in turn, are modeled as heterogeneous-beliefs rational households-firms. Private agents and the central bank play a mixed-strategy equilibrium whereby odds are assigned to the rational expectations forecasts under full commitment but also to expectations that are formed on the basis of standard VAR techniques used to fit the data. VAR techniques are fairly easy to implement, yet are immune to attempts to "manage expectations" through forward guidance announcements on the part of the central bank.

In this economic environment, apart from the conventional New Keynesian distortions—monopolistic competition and price rigidities—we also recognize the informational distortions that arise when in equilibrium the central bank's forward guidance emerges as not fully credible. These informational distortions are reflected in forecasting disagreements between competing forecasting models. For those private agents that do not believe the central bank's forecasts, their VAR-based forecasts would represent a departure from rational expectations. We interpret, therefore, forecasting discrepancies as indicating an informational friction that at its core is tied to the inability of the central bank to fully commit to honor its forward guidance announcements.

2.1 Main Structural Relationships

As derived in Cúrdia et al. (2015), the workhorse New Keynesian model of the economy can be described by the following pair of log-linearized equations:

$$\tilde{x}_t = \mathbb{E}_t \tilde{x}_{t+1} - (1-\beta\eta)(1-\eta)(i_t - \mathbb{E}_t \pi_{t+1} - r_t^n), \quad (1)$$

$$\tilde{\pi}_t = \beta \mathbb{E}_t \tilde{\pi}_{t+1} + \xi_p \left(\omega x_t + ((1-\beta\eta)(1-\eta))^{-1} \tilde{x}_t \right) + \mu_t, \quad (2)$$

where

$$\tilde{y}_t \equiv y_t - \eta y_{t-1} - \beta\eta \mathbb{E}_t (y_{t+1} - \eta y_t), \quad (3)$$

$$\tilde{y}_t^n \equiv y_t^n - \eta y_{t-1}^n - \beta\eta \mathbb{E}_t \left(y_{t+1}^n - \eta y_t^n \right), \quad (4)$$

$$\tilde{x}_t \equiv \tilde{y}_t - \tilde{y}_t^n = x_t - \eta x_{t-1} - \beta\eta \mathbb{E}_t (x_{t+1} - \eta x_t), \quad (5)$$

$$\tilde{\pi}_t \equiv \pi_t - \iota_p \pi_{t-1}. \quad (6)$$

Here, the one-period nominal interest rate (i_t) is the policy rate, inflation (π_t) is the first-difference on the consumption price level in logs and the output gap (x_t) is defined as $x_t \equiv y_t - y_t^n$, i.e., as the log-deviation of actual output (y_t) from its potential level absent all nominal rigidities (y_t^n).

Equation (1), often referred to as the dynamic Investment-Savings (IS) equation, describes the aggregate demand of the economy arising from the optimal decisions (the intertemporal Euler equation) of households. Equation (1) together with (3) − (5) implies that the current output gap (x_t) depends on expected one-period and two-period ahead output gaps, the lagged output gap, the current nominal interest rates (i_t), the expected one-period ahead inflation rate ($\mathbb{E}_t(\pi_{t+1})$), and the natural rate (r_t^n) which corresponds to the real rate of interest that would prevail absent all nominal rigidities. Here, the intertemporal rate of substitution is set to one. There exists habit formation in consumption given by the parameter $0 \leq \eta \leq 1$, and households' intertemporal discount rate is given by the parameter $0 < \beta < 1$.

Equation (2) denotes the New Keynesian Phillips Curve (NKPC) and follows from the optimizing decision of firms. These firms are owned by the households and are operated in a monopolistically competitive environment with Calvo (1983) staggered price-setting behavior and Yun (1996) price indexation, as in Christiano et al. (2005). Consequently, equation (2) shows that inflation (π_t) depends on lagged inflation, the expected one-period ahead inflation ($\mathbb{E}_t(\pi_{t+1})$), the current output gap (x_t), the lagged output gap, the expected one-period ahead output gap, and a cost-push shock (μ_t). A fraction of firms given by the parameter $0 \leq \theta \leq 1$ are assumed not to be able to optimally adjust their prices every period, while the remaining fraction $(1-\theta)$ of firms can. The non-reoptimizing firms index their prices to past inflation with the degree of indexation determined by the parameter $0 \leq \iota_p \leq 1$. Furthermore, the parameter $\omega > 0$ is the inverse of the Frisch elasticity of labor supply, while the composite coefficient ξ_p is defined as $\frac{(1-\theta\beta)(1-\theta)}{\theta}$ with β being the household's intertemporal discount factor and θ the constant fraction of non-reoptimizing firms per period.

We use (5) to re-express the system of equations given by (1) − (2) to describe the dynamics of the economy in terms of actual and potential output as follows:

$$\tilde{y}_t = \mathbb{E}_t(\tilde{y}_{t+1}) - (1-\beta\eta)(1-\eta)(i_t - \mathbb{E}_t\pi_{t+1} - r_t^n) - \mathbb{E}_t\left(\Delta\tilde{y}_{t+1}^n\right), \tag{7}$$

$$\begin{aligned}\tilde{\pi}_t = {} & \xi_p\left(\omega y_t + ((1-\beta\eta)(1-\eta))^{-1}\tilde{y}_t\right) + \beta\mathbb{E}_t\tilde{\pi}_{t+1} + \mu_t \\ & - \xi_p\left(\omega y_t^n + ((1-\beta\eta)(1-\eta))^{-1}\tilde{y}_t^n\right).\end{aligned} \tag{8}$$

Based on the output potential transformation in (4), we can further re-write the system of equations in (1) − (2) as follows:

$$\begin{aligned}\tilde{y}_t &= \mathbb{E}_t\left(\tilde{y}_{t+1}\right) - \left(1-\beta\eta\right)\left(1-\eta\right)\left(i_t - \mathbb{E}_t\pi_{t+1} - r_t^n\right) \\ &\quad - \left(\eta y_{t-1}^n - \left(1+\eta+\beta\eta^2\right)y_t^n + \left(1+\beta\eta+\beta\eta^2\right)\mathbb{E}_t\left(y_{t+1}^n\right) - \beta\eta\mathbb{E}_t\left(y_{t+2}^n\right)\right),\end{aligned} \tag{9}$$

$$\begin{aligned}\tilde{\pi}_t &= \xi_p\left(\omega y_t + \left(\left(1-\beta\eta\right)\left(1-\eta\right)\right)^{-1}\tilde{y}_t\right) + \beta\mathbb{E}_t\tilde{\pi}_{t+1} + \mu_t \\ &\quad - \xi_p\left(\begin{array}{c} -\left(\left(1-\beta\eta\right)\left(1-\eta\right)\right)^{-1}\eta y_{t-1}^n + \left(\omega + \left(\left(1-\beta\eta\right)\left(1-\eta\right)\right)^{-1}\left(1+\beta\eta^2\right)\right)y_t^n \\ -\left(\left(1-\beta\eta\right)\left(1-\eta\right)\right)^{-1}\beta\eta\mathbb{E}_t\left(y_{t+1}^n\right)\end{array}\right),\end{aligned} \tag{10}$$

with the same structural relationships as the system of equations given by (7) − (8). This showcases that the dynamic IS and NKPC equations can be expressed in terms of three observable macro variables, output (y_t), inflation (π_t), and the policy rate (i_t), i.e., in terms of three-variable vector $Y_t = \left[y_t, \pi_t, i_t\right]'$. Moreover, these equations also show that cost-push shocks (μ_t) and exogenously-driven shifts in the output potential (y_t^n) and the natural rate of interest (r_t^n) affect the dynamics of output (y_t) and inflation (π_t).

Frictionless Allocation. The potential output allocation (y_t^n) and the natural real interest rate (r_t^n) are important constructs in our analysis and represent the levels of output and of the real interest rate that would prevail absent all nominal rigidities. In that counterfactual scenario, output potential (y_t^n) evolves according to the following equation:

$$\begin{aligned}\omega y_t^n + \tfrac{1}{(1-\beta\eta)(1-\eta)}\left(y_t^n - \eta y_{t-1}^n\right) - \tfrac{\beta\eta}{(1-\beta\eta)(1-\eta)}\left(\mathbb{E}_t\left(y_{t+1}^n\right) - \eta y_t^n\right) \\ = \tfrac{\eta}{(1-\beta\eta)(1-\eta)}\left(\beta\mathbb{E}_t\left(\gamma_{t+1}\right) - \gamma_t\right).\end{aligned} \tag{11}$$

This relationship implies that output potential is a linear combination of current, lagged, and future expected values of output potential as well as current and future expected values of exogenous productivity growth, $\gamma_t \equiv \Delta\ln\left(A_t\right)$ where A_t denotes total factor productivity (TFP). Given the efficient output allocation (or output potential, y_t^n) in (11), the household's intertemporal Euler equation implies that the natural rate of interest (r_t^n) can be expressed as:

$$r_t^n = \mathbb{E}_t\left(\gamma_{t+1}\right) - \omega\mathbb{E}_t\left(\Delta y_{t+1}^n\right). \tag{12}$$

Equations (11) and (12) highlight the close connection between output potential and the natural rate of interest both of which respond to a common shock—the exogenous shock to productivity growth (γ_t).

Here, we observe that the natural rate of interest depends: (a) positively on the forecastable components of next period's exogenous productivity growth (γ_t), and (b) negatively on the forecastable component of next period's growth rate of output potential (Δy_{t+1}^n) which itself depends on the exogenous productivity growth (γ_t) through equation (11). Intuitively, point (b) captures the negative effect on the real interest rate of a higher expected growth rate of marginal utility which, under standard market clearing conditions, directly influences potential hours worked and in turn potential output.

Exogenous (Non-Monetary) Shock Processes. The exogenous shock to productivity growth (γ_t) and the cost-push shock (μ_t) are assumed to follow standard AR(1) processes:

$$\gamma_t = \rho_\gamma \gamma_{t-1} + \varepsilon_t^\gamma, \tag{13}$$

$$\mu_t = \rho_\mu \mu_{t-1} + \varepsilon_t^\mu, \tag{14}$$

where $\varepsilon_t^\gamma \overset{iid}{\sim} N\left(0, \sigma_\gamma^2\right)$ and $\varepsilon_t^\mu \overset{iid}{\sim} N\left(0, \sigma_\mu^2\right)$.[5] The persistence of the productivity growth and cost-push shocks is given by the parameters $0 < \rho_\gamma < 1$ and $0 < \rho_\mu < 1$, respectively. Similarly, the volatility of the productivity growth and cost-push shocks is given by $\sigma_\gamma^2 > 0$ and $\sigma_\mu^2 > 0$, respectively. We do not consider spillovers between productivity growth and cost-push shocks and we also assume that their respective innovations are uncorrelated at all leads and lags.

2.2 Monetary Policy

The monetary policy framework relies on the short-term nominal interest rate (i_t) as its key policy instrument. A Taylor (1993)-type monetary policy rule is generally viewed as a simple and practical guide for the conduct of monetary policy that appears to describe U.S. data well with very little loss of performance relative to an optimal discretionary rule (Dennis (2004)). Henceforth, we assume that the central bank follows a variant of the Taylor (1993) rule whereby the nominal interest rate responds to inflation deviations from its zero-inflation target (π_t) and possibly also to fluctuations in the output gap ($x_t \equiv (y_t - y_t^n)$), i.e.,

$$i_t = \rho i_{t-1} + (1-\rho)\left(\chi_\pi \pi_t + \chi_x \left(y_t - y_t^n\right)\right) + \varepsilon_t^{MP}. \tag{15}$$

This monetary policy framework supported by a Taylor (1993) rule ensures the determinacy of the equilibrium whenever the policy parameters satisfy that $\chi_\pi > 1$ and $\chi_x \geq 0$—that is,

[5] In regards to equation (13), we have also considered a specification with a constant term. The results were largely robust and did not qualitatively change the main conclusions of this paper.

whenever the policy parameters satisfy the Taylor principle. The rule also includes lagged interest rates with a smoothing parameter given by $0 \leq \rho < 1$ and a monetary policy shock term (ε_t^{MP}). The policy rule in equation (15) in general does not achieve the optimal discretionary allocation, but it facilitates the central bank's monetary policy conduct under discretion and its policy communication with private agents.[6]

We deviate from this discretionary policy framework by introducing time-contingent forward guidance in the Taylor (1993) rule in the form of anticipated monetary policy shocks (news) following the approach of Del Negro et al. (2012), Cole (2020a), and Cole (2020b). Specifically, the monetary policy rule in (15) is augmented as follows:

$$i_t = \rho i_{t-1} + (1-\rho)\left[\chi_\pi \pi_t + \chi_x \left(y_t - y_t^n\right)\right] + \varepsilon_t^{MP} + \sum\nolimits_{l=1}^{L} \varepsilon_{l,t-l}^{FG}, \tag{16}$$

where the unanticipated (surprise) monetary policy shocks (ε_t^{MP}) are combined with forward guidance (news) shocks ($\varepsilon_{l,t-l}^{FG}$ for all $l = 1, ..., L$). The length of the forward guidance horizon provided by the news shocks is defined by the horizon $1 \leq L < +\infty$ implying that there is a finite number of L forward guidance shocks in the summation term in equation (16).

Monetary policy surprises and forward guidance shocks are assumed to be purely transitory or *i.i.d.*, i.e.,[7]

$$\varepsilon_t^{MP} \overset{iid}{\sim} N\left(0, \sigma_{MP}^2\right), \tag{17}$$

$$\varepsilon_{l,t-l}^{FG} \overset{iid}{\sim} N\left(0, \sigma_l^{2,FG}\right), \ \forall l = 1, ..., L, \ \text{and } 1 \leq L < +\infty. \tag{18}$$

Each $\varepsilon_{l,t-l}^{FG}$ in equation (16) represents anticipated or news shocks that private agents know about in period $t-l$ but do not affect the interest rate until l periods later, that is, until period t. The volatility of the unanticipated and anticipated monetary policy shocks is given by $\sigma_{MP}^2 > 0$ and $\sigma_l^{2,FG} > 0$ for all $l = 1, ..., L$, respectively. The innovations of anticipated and unanticipated monetary policy shocks are uncorrelated with each other and with the cost-push shock and productivity growth shock innovations at all leads and lags.

Following Laséen and Svensson (2011) and Del Negro et al. (2012), the following recursive

[6] In this setting, following the policy rule in (15) requires that inflation (π_t), actual output (y_t), and the ouput potential (y_t^n) be observed in real time in order to determine the output gap (x_t). Potential output in this economy is independent of monetary policy and of monetary policy shocks and, implied by (11), a function of the productivity growth (γ_t) which is assumed to be known to all private agents and the central bank in real time.

[7] Schmitt-Grohé and Uribe (2012) utilize anticipated shocks and describe them as "news". However, they do not explicitly study forward guidance via monetary policy news shocks and its economic effects.

representation is added to the model's system of equations to describe the news shocks:[8]

$$v_{1,t} = v_{2,t-1} + \varepsilon_{1,t}^{FG}, \tag{19}$$

$$v_{2,t} = v_{3,t-1} + \varepsilon_{2,t}^{FG}, \tag{20}$$

$$\vdots$$

$$v_{L,t} = \varepsilon_{L,t}^{FG}. \tag{21}$$

Each component of the vector $v_t = [v_{1,t}, v_{2,t}, \ldots, v_{L,t}]'$ represents all past and present central bank announcements to change the interest rate $1, 2, \ldots, L$ periods later that private agents know in period t. In addition, we define $\psi_t = \left[\varepsilon_{1,t}^{FG}, \varepsilon_{2,t}^{FG}, \ldots, \varepsilon_{L,t}^{FG}\right]'$ as the vector containing all current-period forward guidance shocks known today that will affect the monetary policy rule $1, 2, \ldots, L$ periods later. Equations (19) − (21) can be simplified to show that $v_{1,t-1}$ corresponds to the last term in equation (16), i.e., the summation of all anticipated monetary policy shocks realized at time t, $v_{1,t-1} = \sum_{l=1}^{L} \varepsilon_{l,t-l}^{FG}$.

Accordingly, the policy rule in (16) can be re-expressed more compactly as:

$$i_t = \rho i_{t-1} + (1 - \rho) \left[\chi_\pi \pi_t + \chi_x (y_t - y_t^n)\right] + \varepsilon_t^{MP} + v_{1,t-1}. \tag{22}$$

The method of using equations (22) together with (17) − (21) provides a tractable way to incorporate a commitment to honor anticipated monetary policy shocks as well as conventional unanticipated monetary policy shocks into the policy framework. This monetary policy regime, therefore, involves a policy commitment tied to the use of forward guidance as an additional tool aimed to communicate (announce) the time-contingent path of future policy rates (i_{t+j}, for some $j \geq 1$). This, in turn, hinges on whether the central bank's announcements will be honored when the time comes. The credibility of the forward guidance commitments is precisely the salient point that we investigate in this paper.

Expectations Augmented Vector of Observable Variables. The state equations that describe the dynamics of the economy in (9) − (10), together with (3) − (4) and (6), pin down the solution to the vector of three observable macro variables given by $Y_t = [y_t, \pi_t, i_t]'$ which

[8] Laséen and Svensson (2011) argue that standard solution techniques apply when forward guidance is modeled as described here rather than as a peg on the future path of the policy rate. Moreover, this implementation also helps us avoid the indeterminacy issues which can arise when modeling central bank forward guidance as pegging the future path of interest rates to a certain value (see Honkapohja and Mitra (2005) and Woodford (2005)). Indeed, the method used here based on anticipated monetary policy shocks (news) alleviates this concern.

includes actual output (y_t), inflation (π_t), and the policy rate (i_t). However, with monetary policy shocks split into unanticipated (surprise) and anticipated (news) shocks, the vector of observable variables Y_t lacks fundamentalness in the sense of Hansen and Sargent (1980) and Martínez-García (2018). In other words, these three observable macro variables do not contain enough information to pin down the vector of unobserved structural shocks $\varepsilon_t = \left(\gamma_t, \mu_t, \varepsilon_t^{MP}, \{\varepsilon_{l,t-l}^{FG}\}_{l=1}^{L}\right)'$. Without additional observable variables, we can only recover residuals that are linear combinations of the underlying structural shocks.

Forward guidance generates persistent effects on the economy from anticipated—yet transitory—future deviations from the systematic component of the policy rule operating through expectations. Given the monetary policy rule in equation (16), we can show that the expected future path of the policy rate at time t can be written as follows:

$$\mathbb{E}_t\left(i_{t+s}\right) = \begin{cases} \rho i_{t-1} + (1-\rho)\left[\chi_\pi \pi_t + \chi_x\left(y_t - y_t^n\right)\right] + \varepsilon_t^{MP} + \upsilon_{1,t-1}, \text{ for } s=0, \\ \rho i_{t-1+s} + (1-\rho)\left[\chi_\pi \mathbb{E}_t\left(\pi_{t+s}\right) + \chi_x \mathbb{E}_t\left(y_{t+s} - y_{t+s}^n\right)\right] + \upsilon_{s+1,t-1} + \varepsilon_{s,t}^{FG}, \ \forall s \in \{1,2,...,L-1\}, \\ \rho i_{t-1+s} + (1-\rho)\left[\chi_\pi \mathbb{E}_t\left(\pi_{t+s}\right) + \chi_x \mathbb{E}_t\left(y_{t+s} - y_{t+s}^n\right)\right] + \varepsilon_{s,t}^{FG}, \text{ for } s=L, \\ \rho i_{t-1+s} + (1-\rho)\left[\chi_\pi \mathbb{E}_t\left(\pi_{t+s}\right) + \chi_x \mathbb{E}_t\left(y_{t+s} - y_{t+s}^n\right)\right], \ \forall s > L. \end{cases} \tag{23}$$

Hence, the expression in (23) shows that expectations on the future path of the interest rate consistent with expectations about inflation and economic activity should shift in response to announcements of anticipated (forward guidance) monetary policy shocks helping us tease them apart from unanticipated (surprise) monetary policy shocks. Given this, we adopt the identification strategy explored by Doehr and Martínez-García (2015) in a VAR setting and employed by Cole and Milani (2017) within a DSGE model which consists in augmenting the vector of observables $Y_t = [y_t, \pi_t, i_t]'$ with expectations with which to disentangle anticipated from unanticipated monetary policy shocks.[9]

We expand the vector of observables Y_t with expectations as follows:

$$\overline{Y}_t = \left[y_t, \pi_t, i_t, \mathbb{E}_t\left(\Delta y_{t+1}\right), \mathbb{E}_t\left(\Delta y_{t+2}\right), \mathbb{E}_t\left(\pi_{t+1}\right), \mathbb{E}_t\left(i_{t+1}\right), ..., \mathbb{E}_t\left(i_{t+L}\right)\right]', \tag{24}$$

where $\Delta y_{t+j} = \Delta x_{t+j} + \Delta y_{t+j}^n$ denotes the growth rate of actual output in time period $t+j$ (for $j=1,2$) and, by analogy, we define $\Delta y_{t+j}^n = \left(y_{t+j}^n - y_{t+j-1}^n\right)$ to be the corresponding growth rate of output potential in time period $t+j$.[10] Given the structure of the economy described

[9] In Subsection 2.3, we show how to model aggregate expectations that mixes full-information rational expectations (FIRE) and VAR-based expectations that treat the monetary authority's forward guidance announcements as not believable.

[10] In estimations, we use up to five periods ahead of the interest rate forecasts as part of our observables (i.e., up to $\mathbb{E}_t\left(i_{t+5}\right)$) given the data available in the SPF dataset. The corresponding observation equations

by equations (9) − (10), the non-monetary shock processes in (11) − (14), the Taylor (1993) rule in (22), and the unanticipated and anticipated monetary policy shocks given by (17) − (21), the vector of observables augmented with expectations $\overline{Y}_t$ satisfies the fundamentalness property that ensures we can identify all structural shocks $\varepsilon_t = \left(\gamma_t, \mu_t, \varepsilon_t^{MP}, \left\{\varepsilon_{l,t-l}^{FG}\right\}_{l=1}^{L}\right)'$.[11]

2.3 Central Bank Credibility

Monetary policy news shocks open up the possibility of managing expectations as an additional tool for policymakers. However, this implies rational private agents have to factor the credibility of the central bank's forward guidance commitment in forming their own expectations about the future. Indeed, this is the case because forward guidance announcements are inherently time-inconsistent—such news are promises about future monetary policy that the central bank may find beneficial to renege from unless future policymakers could be bound somehow to credible honor those commitments when the time comes. Simply put, private agents realize that there is neither a verification mechanism nor a way to enforce those promise to ensure that the central bank delivers on the future policy path that has been announced and must form expectations accordingly.

This is partly because, while the vector of observables $Y_t = [y_t, \pi_t, i_t]'$ can be monitored with observable data, neither announcements about the expected future path of the policy rate (news shocks) nor the central bank's own public forecasts—if used to communicate the forward guidance policy—can be confirmed and validated with the observed data Y_t in real time. It is also partly because central banks have incentives to consider deviating from the fully credible commitment case. In this paper, we describe the credibility problem as it relates to the central bank's attempts at forward guidance in a game-theoretic framework between rational-expectations private agents and the central bank through the lens of an evolutionary-type "game of chicken" (Osborne and Rubinstein (1994) and the Appendix for

will be described in more detail in Subsection 2.3.

[11] Alternatively, we could also use the yield curve to help us identify the news shocks. Assuming the expectations hypothesis of the terms structure of interest rates holds, it follows from equations (16) and (23) that the long-term nominal interest at any given maturity $n \geq L+1$ (i_t^n) can be expressed as:

$$i_t^n = \rho\left(\frac{1}{n}\sum_{z=0}^{n-1}\mathbb{E}_t i_{t-1+z}\right) + (1-\rho)\left[\chi_\pi\left(\frac{1}{n}\sum_{z=0}^{n-1}\mathbb{E}_t\pi_{t+z}\right) + \chi_x\left(\frac{1}{n}\sum_{z=0}^{n-1}\mathbb{E}_t x_{t+z}\right)\right] + \frac{1}{n}\left(\varepsilon_t^{MP} + v_{1,t-1} + \sum_{l=1}^{L} v_{l,t}^{FG}\right).$$

Working directly with the expected path of the policy rate, as we do in this paper, lessens the concern that using longer maturity rates along the yield curve means that we are jointly testing the validity of our model and that of the expectations hypothesis of the term structure of interest rates too.

further details on the structure and solution of this game).[12]

Strategies. Private agents choose between two different pure-strategies to form their expectations about the future—either they believe the central bank will honor its forward guidance commitments (C) or they disregard the promises that come from announcements about the future path of monetary policy and make forecasts solely on the basis of the observed dynamics of the economy (D). Similarly, the central bank concerns itself with two pure strategies—either to honor its commitments and deliver on the announced policy (C) or to renege from the existing commitments (D). Conventionally, the literature on forward guidance has assumed the strategy pair (C, C) holds accepting that such an outcome could be sustained in equilibrium. As shown in the Appendix, there are conditions on the payoffs of each player that would indeed support such an outcome as an evolutionarily stable strategy (ESS). However, without a payoff-based disciplining mechanism that enforces the strategy pair (C, C), we must consider the broad range of plausible strategic implications of the non-cooperative evolutionary game that arises between the central bank and private agents.[13]

Here, $\mathbb{E}_t^C(Y_{t+1})$ represents the private sector's forecasts when the private sector follows strategy C. These forecasts are model-implied, full-information rational expectations (FIRE) ones.[14] We denote $\mathbb{E}_t^D(Y_{t+1})$ the private sector's forecasts when forward guidance announcements are viewed as not credible and the private agents follow strategy D. Our interpretation is that, under strategy D, private agents simply dismiss the announcements as "cheap talk" and accordingly there are no anticipation effects to be achieved from forward guid-

[12] We assume households own the firms and we often refer to the firm-owning households as private agents. This implies that, in our benchmark economy, the expectations of households will not differ from those of firms that enter into the aggregate demand and price-setting behavior equations in equilibrium. We leave for future research the exploration of richer environments where firms' expectations may differ from those of households.

[13] The Appendix discusses the notion of an evolutionarily stable strategy (ESS) in a general form of the game betweent the central bank and the private sector laid out here. An ESS is defined as a strategy (or set of strategies) that supports a refinement of a Nash equilibrium where the ESS supports a stable solution (which is a set of strategies that cannot be displaced by any available alternative strategy). The Appendix provides a more formal derivation of the general structure of the evolutionary game between the central bank and the private agents. Yet the conclusion is the same that we indicate here: there are payoffs (like in the well-known "game of chicken") where a mixed strategy equilibrium in which imperfect central bank credibility exists and is evolutionarily stable.

[14] In a manner similar to Park (2018), we assume that central banks are always fully-informed about the conditions and structure of the economy in this game and form their own expectations according to FIRE. Park (2018) reasons that monetary authorities typically employ macroeconomic models with rational expectations to forecast future economic activity as well as the future path of inflation and the policy rate. However, it should be noted that Park (2018) did not explicitly incorporate forward guidance (anticipated monetary policy shocks) together with central bank credibility as done in the present paper.

ance. Conceivably, the central bank could engineer a forward guidance policy where some announcements are honored to build up a reservoir of credibility that may steer rational-expectations private agents to believe into future promises that the central bank may wish to renege from. We consider instead that private agents that have no faith in the central bank follow a Hernán-Cortés-type "burning your ship" plan of action that denies policymakers the chance to rebuild their reputation when they have no intent to honor all their policy commitments. For this, we rely on the key result of Martínez-García (2018) that shows that, under quite general conditions, the reduced-form solution of a linear rational expectations model such as the one described in this paper can be cast in a finite-order VAR form.

Hence, we assume that private agents that find the central bank's forward guidance not to be credible form their expectations based on a VAR model for the vector of observables $Y_t = [y_t, \pi_t, i_t]'$ committing themselves to forecast the future path of the economy in that way. Private agents are sophisticated enough to handle standard time series techniques with which to inform their views about the future path of the economy. Hence, we simply assume that private agents forecast the vector of observables Y_t (i.e., private agents infer $\mathbb{E}_t^D(Y_{t+1})$) assuming $Y_t = [y_t, \pi_t, i_t]'$ follows a parsimonious structural VAR(1) process of the following form:

$$Y_t = A + BY_{t-1} + u_t, \tag{25}$$

which we show later in our empirical examination of the evidence that describes well the historical dynamics of Y_t in our sample. Here, A and B are reduced-form matrices of conforming dimensions and u_t is a vector of (non-structural) residuals.[15] This essentially implies that private agents that do not believe the policy commitments of the central bank are set to ignore all news shocks until they materialize—if at all—at a later time.

[15] In here, we assume that private agents have access to an arbitrarily large dataset with all current and lagged values of Y_t so that A and B are the corresponding population matrices for the process and there is no need to re-estimate the process in (25) with each new observation because the impact it would have on the estimates is negligible. If the data available is limited, learning over time might be important as well as every new observation allows the private agents to re-estimate and update the coefficients in matrices A and B. We leave the issue of learning on shorter subsamples (when private agents do not have access to an arbitrarily large dataset of the observables) for future research.

Payoff Matrix. We posit a symmetric payoff matrix for the game between the central bank and private agents that can be represented as follows:

		Private Agents	
		C	**D**
Central Bank	**C**	R, R	L, T
	D	T, L	P, P

Here, R denotes the welfare level achieved in (C, C) when private agents form expectations according to the FIRE assumption believing forward guidance to be credible (C) and the central bank honors its forward guidance announcements (C). Standard macroeconomic models typically assume and analyze the (C, C) scenario. When the private agents and the central bank coalesce on (C, C), news about future monetary policy propagate over time. The propagation of news shocks occurs because private agents immediately anticipate the change in the future path and adjust their own choices from that point in time onwards in order to intertemporally smooth over the equilibrium path along which the economy moves. This case can occur as an ESS if the payoffs satisfy that $R > T > L > P$.

However, there are plausible scenarios whereby the monetary authority might find it beneficial to renege on its promises, which would lead private agents to take into account the credibility of the monetary authority. Thus, there could be a mixed equilibrium where the central bank and private agents play strategy C with a probability strictly lower than one. This equilibrium arises if the inequalities in the payoff matrix satisfy that $T > R > L > P$ (the "game of chicken") while in the polar case where $T > R > P > L$ ("Prisoner's dilemma") both players would coalesce instead around the (D, D) scenario. Hence, the plausibility of a mixed strategy ESS equilibrium is what motivates our idea of monetary authority credibility in the game between the central bank and the private sector.

The intuition for the inequalities that describe the "game of chicken," which motivates our central bank credibility framework, is described as follows. The time-inconsistency of forward guidance is incorporated in the payoff matrix of this game with $T > R$, where T represents the gains from temptation that can be achieved when either the central bank reneges on its forward guidance commitment or private agents believe them not to be credible (D) while the other player sticks with C and gets penalized with the payoff L such that $R > L$. The logic is that reneging from a policy announcement deemed credible by private agents means the central bank can twist the expectations of the private sector influencing economic conditions over a period of time without actually shifting the policy stance at all. This, in turn, allows the central bank to influence the economy with what essentially amounts to "sweet talk" (strategy D) and achieve outcomes that would be at least as good and possibly better than with forward guidance and full commitment (strategy C).[16] In turn, the private sector can ignore announcements that are deemed to be detrimental to their interests (D) even when the central bank is bound by its commitments. If central banks make an announcement that they intend to keep but private agents do not believe the forward guidance, then that negates the anticipation effects of news shocks—news shocks only can impact the economy when the news shock is actually realized. In other words, this allows the private agents to "cherry pick" only the most beneficial or profitable policy announcements to anticipate their gains while rejecting any others.

In these scenarios, the player that sticks with strategy C while the other player opts for strategy D ends up worse off than in the (C, C) scenario given. This is so because reneging on a policy announcement for private agents or cutting off the anticipation channel of forward guidance for the central bank would significantly limit the desired effectiveness of this tool and lead to potentially worse welfare outcomes for the complaint player (the player that follows strategy C). Finally, the last inequality implies that $L > P$ where P is the punishment payoff that each player can secure if both end up playing strategy D. We interpret this to mean that both sides would not find beneficial to play the cheater's strategy simultaneously. Forward guidance benefits would not exist through the anticipation channel in that case and would not be realized on the economy as the central bank reneges from its statements. The difference between this "game of chicken" or game of central bank credibility and the payoffs of the "Prisoner's dilemma" is that in the "Prisoner's dilemma" this inequality is reversed, i.e., $P > L$, implying that both the central bank and private agents would be worse playing C than playing D when the other player goes for strategy D.

[16] An additional comment regarding central bank credibility is warranted. As described in Subsection 2.2, the forward guidance news shocks that are modeled in the monetary policy rule influence the interest rate l periods later. For instance, $\varepsilon_{1,t}$ will be realized upon the economy one period later. However, how to interpret the central bank reneging on its promises in this game-theoretic setting? If the monetary authority does not follow through with its forward guidance announcements, the effects of forward guidance shocks failing to be realized upon the economy would be picked up by the contemporaneous monetary policy shock. In other words, in the set-up of Del Negro et al. (2012) that we adopt here, reneging on a forward guidance announcement would be represented as an increase in the contemporaneous (surprise) monetary policy shock of the same magnitude but opposite sign as the news shock at the time when it is supposed to materialize.

Mixed Strategy Equilibrium. In the evolutionary "game of chicken", the private sector and the central bank evolve towards a stable mixed-strategy equilibrium as shown in the Appendix. The dynamics of the symmetric evolutionary game for both the central bank and private agents and the corresponding mixed strategy ESS are illustrated in the vector field in Figure 1. At the intersection point $0 < \tau < 1$, which defines the equilibrium probability that the central bank plays strategy C, the strategies are best against each other and the economy reaches an ESS equilibrium—any deviation from the mixed-strategy at that point will be self-correcting. The implicit payoffs given by (T, R, L, P) will determine the intersection point τ, and thus, the degree of endogenous credibility τ that the private sector and the central bank attach to forward guidance. This game is one where a player can only out-do the other player by "cheating" (choosing strategy D) if the other player behaves cooperatively (choosing strategy C). Any attempt to get the best possible payoff (T) then involves a necessary risk of the worst possible payoff (P). The interpretation of credibility and the value of forward guidance commitments seems natural to us in this framework. We do not model explicitly the payoff matrix explicitly here. Instead, we take as given that a general form of the solution—including the mixed-strategy ESS equilibrium outcome of the "game of chicken"—where $0 \leq \tau \leq 1$ is plausible and incorporate it into our characterization of the way expectations are formed in the economy (for both private agents and the central bank).

Following on the footsteps of the axiomatic approach to incorporate heterogenous beliefs of Branch and McGough (2009), expectations in the economy are a weighted sum of private agents who believe the central bank to be credible and those who do not. Specifically, we define aggregate expectations on macroeconomic variables ($\mathbb{E}_t (Y_{t+1})$) with the following expression:[17]

$$\mathbb{E}_t (Y_{t+1}) = \tau \mathbb{E}_t^C (Y_{t+1}) + (1 - \tau) \mathbb{E}_t^D (Y_{t+1}), \tag{26}$$

where $Y_t = [y_t, \pi_t, i_t]'$ is the vector of macro observables. $\mathbb{E}_t^C (Y_{t+1})$ represents the model-implied FIRE forecasts whenever central bank's commitments are fully credible and $\mathbb{E}_t^D (Y_{t+1})$ denotes the expectations of private sector agents who believe the monetary authority's commitment to be not credible. As stated above, the latter form expectations based on equation (25).

[17] A small caveat here is necessary—while this characterization of the expectations is adopted for the vector of observables $Y_t = [y_t, \pi_t, i_t]'$, we should note that the expectations on the frictionless allocation given by (11) and (12) are simply the FIRE expectations corresponding to $\mathbb{E}_t^c (\cdot)$. The reason for this is simply that neither monetary policy nor monetary policy shocks (surprises or news) affect frictionless allocation so whether private agents believe the forward guidance announcements or not should not matter for how agents view and forecast the dynamics of the frictionless economy.

The parameter $0 < \tau < 1$ determines the equilibrium weight implied by the evolutionary "chicken game" between the private sector and the central bank. In the limiting case where $\tau \to 1$, all private agents in the economy believe the central bank to be perfectly credible and $\mathbb{E}_t Y_{t+1}$ simplifies to the (homogeneous beliefs) fully rational expectations solution implied by $\mathbb{E}_t \left(Y_{t+1}^C \right)$. In the opposite polar case where $\tau \to 0$, the monetary authority is considered not credible and private agents choose to ignore the central bank's forward guidance announcements in the way they form their expectations. In general, aggregate expectations of private agents in this evolutionary game-theoretic setup between private agents and the central bank would be a convex combination of the fully credible forward guidance and not credible forward guidance weighed by any plausible τ that lies within the unit interval (i.e., $0 \leq \tau \leq 1$). Hence, τ is interpreted as the weight assigned by private agents to the belief that the forward guidance commitments are credible and would be honored while $1 - \tau$ represents the fraction of private agents that form expectations obtained from the reduced-form VAR model in (25). This is the benchmark we estimate in this paper and inevitably leads to an economy where forward guidance loses some of its power if τ is strictly less than one—it is in this sense that our model can contribute to address the well-known "forward guidance puzzle" in the literature, which is unrealistically large responses of macroeconomic variables to forward guidance statements.

3 Bayesian Estimation Methods

Overall, the workhorse New Keynesian model with forward guidance and central bank credibility that we have laid out here includes equations for aggregate demand (the dynamic IS curve), the New Keynesian Phillips curve (NKPC), potential output, the efficient real interest rate (or natural rate), and the AR(1) shock processes for productivity growth and cost-push shock. Moreover, the model is completed with a Taylor (1993) monetary policy rule with inertia and forward guidance (transitory news shocks) as well as surprise shocks, a recursive representation of the central bank's promises regarding changes to future interest rates (announcements), private sector expectations who do not believe the central bank to be credible, and heterogenous-beliefs aggregate expectations weighted by the central bank's credibility. In other words, the benchmark model that we aim to estimate includes equations (9), (10), (11), (12), (13), (14), (16), (19) – (21), (25), and (26). We implement our estimation strategy and approach using Dynare codes (Adjemian et al. (2011)).

3.1 Data Sources

We utilize Bayesian estimation techniques with U.S. macroeconomic time series variables. Data for output, inflation, and interest rates correspond to U.S. real GDP, growth rate in the GDP deflator, and the Federal Funds rate. The relevant acronyms are GDPC1, GDPDEF, and FEDFUNDS with the data retrieved from the FRED database of the Federal Reserve Bank of St. Louis. We also employ observations for expectations of future macroeconomic variables. Specifically, we utilize expectations regarding one-period and two-period ahead output growth, one-period ahead inflation, and one-period to five-period ahead interest rates. These forecast series are retrieved from the Survey of Professional Forecasters (SPF) database of the Federal Reserve Bank of Philadelphia (FRB of Philadelphia (2019)).[18] The relevant acronyms are RGDP, PGDP, and TBILL. In addition, our dataset spans $1981 : Q3$ through $2017 : Q3$.[19]

[18] We use the mean value across respondents.

[19] Forward guidance outside the explicit forward guidance statements that emanated from the aftermath of the Great Recession can still be found in our dataset. Indeed, Campbell et al. (2012) explain that the FOMC has issued implicit and explicit forward guidance long before the Great Recession. Lindsey (2003) also discusses types of central bank communication in the 1980s in the U.S. Wynne (2013) explains how FOMC statements to the public have evolved from vague text in the early 1990s to more specific and clarifying statements post-Great Recession. Contessi and Li (2013) also discuss FOMC statements containing elements of forward guidance in the early 2000s. BIS (2019) provides a detailed description an assessment of forward guidance and other unconventional monetary policy tools since the $2008 - 09$ financial recession for the U.S. and across other countries with related experiences. Furthermore, in Subsection 5.2, we perform a robustness check that provides more evidence that τ captures central bank credibility in terms of forward guidance.

3.2 Estimation Strategy

3.2.1 Observation Equations

The observation equations mapping the model variables into the data are given by the following system of equations:

$$\begin{bmatrix} g_t^{obs} \\ \pi_t^{obs} \\ i_t^{obs} \\ \mathbb{E}_t^{obs}(g_{t+1}) \\ \mathbb{E}_t^{obs}(g_{t+2}) \\ \mathbb{E}_t^{obs}(\pi_{t+1}) \\ \mathbb{E}_t^{obs}(i_{t+1}) \\ \mathbb{E}_t^{obs}(i_{t+2}) \\ \mathbb{E}_t^{obs}(i_{t+3}) \\ \mathbb{E}_t^{obs}(i_{t+4}) \\ \mathbb{E}_t^{obs}(i_{t+5}) \end{bmatrix} = \begin{bmatrix} \Delta y_t \\ \pi_t \\ i_t \\ \mathbb{E}_t(\Delta y_{t+1}) \\ \mathbb{E}_t(\Delta y_{t+2}) \\ \mathbb{E}_t(\pi_{t+1}) \\ \mathbb{E}_t(i_{t+1}) \\ \mathbb{E}_t(i_{t+2}) \\ \mathbb{E}_t(i_{t+3}) \\ \mathbb{E}_t(i_{t+4}) \\ \mathbb{E}_t(i_{t+5}) \end{bmatrix} + \begin{bmatrix} \bar{\gamma}^g + \gamma_t \\ \bar{\gamma}^\pi \\ \bar{\gamma}^r \\ \bar{\gamma}^{g^1} + \mathbb{E}_t\left(\gamma_{t+1}\right) \\ \bar{\gamma}^{g^2} + \mathbb{E}_t\left(\gamma_{t+2}\right) \\ \bar{\gamma}^\pi \\ \bar{\gamma}^{r^1} \\ \bar{\gamma}^{r^2} \\ \bar{\gamma}^{r^3} \\ \bar{\gamma}^{r^4} \\ \bar{\gamma}^{r^5} \end{bmatrix} + \begin{bmatrix} \mathbf{0}_{3\times 8} \\ \mathbf{I}_{8\times 8} \end{bmatrix} \begin{bmatrix} o_t^{g_{t+1}} \\ o_t^{g_{t+2}} \\ o_t^{\pi_{t+1}} \\ o_t^{i_{t+1}} \\ o_t^{i_{t+2}} \\ o_t^{i_{t+3}} \\ o_t^{i_{t+4}} \\ o_t^{i_{t+5}} \end{bmatrix}, \tag{27}$$

where $g_t \equiv \Delta y_t$ represents the growth rate of output in time period t. Observations for expectations include an *i.i.d.* measurement error term (i.e., $o_t^{g_{t+1}}$, $o_t^{g_{t+2}}$, $o_t^{\pi_{t+1}}$, $o_t^{i_{t+1}}$, $o_t^{i_{t+2}}$, $o_t^{i_{t+3}}$, $o_t^{i_{t+4}}$, and $o_t^{i_{t+5}}$). This mapping is similar to that of Cole and Milani (2017) and consistent with the expectations-augmented approach to disentangle between news and surprises about monetary policy proposed by Doehr and Martínez-García (2015).

It is also important to clarify how the SPF expectations align with model implied expectations. We treat the nowcast of the forecasted variables of the SPF as the $t+1$ timing in our analysis as is done in other papers (e.g., Cole and Milani (2017)). The reason is as follows. From the SPF documentation (FRB of Philadelphia (2019)), the respondents of the SPF usually have to report their forecasts before the middle of the current quarter. For instance, in regards to forecasts for $Q1$, the deadline submission date is the second to third week of February. The nowcast is approximately a $2-$month ahead forecast while the one-period ahead is a $5-$month ahead forecast. Therefore, we believe it makes more sense to treat the SPF nowcast as $t+1$ forecasts in our model. However, as a robustness check in Subsection 5.4, we analyze the baseline results using one-period ahead SPF forecasts as $t+1$ expectations in our model instead.[20]

[20] Equation (27) also includes up to five periods ahead interest rate expectations (i.e., $\mathbb{E}_t^{obs}(i_{t+1})$, $\mathbb{E}_t^{obs}(i_{t+2})$, $\mathbb{E}_t^{obs}(i_{t+3})$, $\mathbb{E}_t^{obs}(i_{t+4})$, and $\mathbb{E}_t^{obs}(i_{t+5})$). As we utilize the nowcast for $t+1$ expectations, we

3.2.2 Choice of Priors

The choice of prior distributions on the structural parameters largely follows Cole and Milani (2017) and Smets and Wouters (2007). The price indexation parameter ι_p is assumed to have a prior distribution of Beta. We select a Normal distribution centered over 1 for the prior distribution of ω. We also assume persistence in the productivity growth and cost-push shocks as these both have Beta prior distributions with mean of 0.50. To ensure positive values, the prior distributions on the standard deviations of the shocks are chosen to be Inverse Gamma.[21]

The prior distribution of the policy parameters are also standard from prior studies. The priors on the χ_π and χ_x are both Normal centered over 1.5 and 0.125, respectively. There is assumed to exist high degree of persistence *a priori* when the central bank adjusts the interest rate as ρ follows a Beta with mean 0.75. The prior assumptions on the previous three parameters follow from Smets and Wouters (2007). In addition, the value of the forward guidance horizon is chosen to be twelve periods, that is, $L = 12$. This assumption is based on the FOMC statement utilizing time-contingent forward guidance. Specifically, in September 2012, the FOMC stated "the Committee also ... anticipates that exceptionally low levels for the federal funds rate are likely to be warranted at least through mid-2015." Thus, there are twelve quarters from September 2012 and "mid-2015" if the latter date is taken to be the end of quarter three of 2015.

The central parameter in our model is τ, which measures the degree of central bank credibility in the economy. As described above, all agents in the economy believe central bank statements to be perfectly credible whenever $\tau \to 1$. If $\tau \to 0$, the central bank is not perceived to be credible and agents do not factor forward guidance statements into their forecasts. In our benchmark estimation, we choose an informative prior distribution, a beta with mean 0.8. However, as this parameter is central to our analysis, we will conduct a robustness check in Subsection 5.3. Specifically, we will compare the baseline results to the case if one is more agnostic about the true value of τ and adopts a uniform distribution. Moreover, when we estimate τ, we will refer to this case as the not perfectly credible central bank scenario, denoted $\widehat{\tau}$. When we do not estimate τ and assume agents perceive the monetary authority to be perfectly credible, we will indicate this case as $\tau = 0.98$.

have SPF data for the nowcast and up to four-quarters ahead for the estimation (which we exploit to its fullest).

[21] The following parameters are also fixed: the household's intertemporal discount factor β is set to 0.99, habit persistence η is fixed at 0.50, and the composite coefficient ξ_p is set to 0.0015. The latter two values roughly follow Cúrdia et al. (2015) and Giannoni and Woodford (2004), respectively. The constants in the observation equations in (27) are fixed to the historical mean of their respective series.

3.2.3 Reduced-Form Forecasting Model

The current paper assumes that expectations for the entire economy are composed of a weighted sum of FIRE expectations under perfect credibility and VAR-based expectations that simply ignore the forward guidance statements. As stated in equation (25), the latter type of agents form expectations via a VAR(1) process. However, it is important to justify the lag length of this forecasting model. To accomplish this task, we calculate the Bayes Information Criterion (BIC) for a VAR(1), VAR(2), and VAR(3) models on the vector of observables $Y_t^{obs} = \left[g_t^{obs}, \pi_t^{obs}, i_t^{obs}\right]$.[22] The BIC values for the three models are -31.16, -20.05, and 4.56, respectively. Thus, we utilize the VAR(1) as it has the lowest BIC.

4 Main Results

4.1 Estimates of Central Bank Credibility

We now proceed with our main exercise to investigate the effects central bank credibility has on the efficacy of forward guidance. The results are shown via three channels: posterior point estimates, variance decomposition, and impulse response functions under both a perfectly credible and imperfectly credible central bank. In regards to the former, we utilize $\tau = 0.98$ in the estimation. For the imperfectly credible central bank, we will estimate τ and denote this case as $\widehat{\tau}$. Table 1 and Table 2 display the posterior mean and 90% highest posterior density interval estimates. Table 3 shows the variance decomposition with parameter values at their posterior mean. The last line calculates the sum of all the variation in the macroeconomic variable due to the forward guidance shocks. Figure 2, Figure 3, and Figure 4 display the impulse response functions. Each panel shows the mean response of the model-implied output and observables (inflation and interest rate). The solid line represents $\tau = 0.98$, while the dashed line denotes $\widehat{\tau}$.

We first examine the case in which the monetary authority is perceived to be perfectly credible. In Table 1 and Table 2, the first three columns under "Posterior Distribution" show that the estimates of the main structural parameters largely align with prior literature. The value of interest rate smoothing is high at 0.9365 which roughly follows the FIRE model found in Milani (2007). The amount of inflation indexation is 0.5076 and the estimated value of $\omega = 0.9716$. The previous estimates follows closely Cúrdia et al. (2015). There exists a medium degree of productivity growth inertia (ρ_γ) which is slightly less than that

[22] We use data spanning $1985:Q1$ through $2007:Q3$. This period corresponds to the Great Moderation era in the U.S.

found in Cúrdia et al. (2015) especially the results under their "T" rule. In the last line under the "Perfectly Credible C.B." column, Table 3 also displays that the total amount of variation in output and inflation explained by all of the forward guidance shocks is 69.24% and 1.19%, respectively. Finally, the solid lines in Figure 2, Figure 3, and Figure 4 show the mean impulse response under $\tau = 0.98$ to a one standard deviation increase in a shock. Specifically, given that agents are forward looking, news that the interest rate will increase 1, 4, 8, or 12 periods ahead affects agents' intertemporal decisions by lowering output and inflation on impact. When the shock is realized on the economy, output decreases again. Since those who perceive the monetary authority to be perfectly credible follow the FIRE, these agents completely understand the shock left the economy, and thus, output, inflation, and interest rates proceed to return back to steady state.

What are the predicted effects if the central bank is not assumed to be perfectly credible? To answer this question, we first analyze the posterior estimates in the last three columns in Table 1 and Table 2. Overall, the values of the main structural parameters do not drastically differ from the perfectly credible case, but do display a few slight differences. For instance, in the last three columns under "Not Perfectly Credible C.B.," the estimated value of the autoregressive parameter on the cost-push shock is relatively lower than in the $\tau = 0.98$ scenario. However, this lack of persistence could instead be picked up in the higher estimates for inflation indexation parameter relative to the perfectly credible central bank case. More importantly, when allowing agents the option of not fully believing forward guidance statements about the path of interest rates, the estimate of τ is 0.7699. This value indicates a certain level of trust in the U.S. central bank (i.e., Federal Reserve) implying effectiveness of forward guidance on the economy.[23] However, the fact that this estimated value is not close to $\tau \approx 1$ suggests that agents do not believe the monetary authority to be perfectly credible.

The ramifications of this result are a dampening of the power of forward guidance on the economy. Figure 2 and Figure 3 display this reasoning. The impulse responses under $\widehat{\tau}$ (dashed line) follow similar paths as under $\tau = 0.98$ (solid line). However, the dashed line is not as reactive to central bank forward guidance as the solid line. Specifically, the initial impact of output and inflation to forward guidance news is larger under the perfectly credible case than the imperfectly credible scenario. When the shock is realized on the economy l periods later, the responses of output and inflation are also overall larger under $\tau = 0.98$ than $\widehat{\tau}$. The reason for the discrepancies is that agents believe central bank statements about

[23] This result does agree with Swanson (2018) who finds that forward guidance has a degree of effectiveness when the economy is constrained by ZLB.

future interest rates under the $\tau = 0.98$ scenario, and thus, fully internalize the effects of forward guidance. In contrast, agents who do not fully believe forward guidance commitments do not incorporate the full effects of forward guidance, and thus, macroeconomic variables are not as responsive.

Variance decomposition results also display the reduced effects of forward guidance on the economy under an imperfectly credible monetary authority. In Table 3, we compute the variance decomposition with parameter values at their posterior mean. The combined contribution of the forward guidance shocks to output and inflation is less under $\widehat{\tau}$ than $\tau \approx 1$. Under a central bank that is perceived as imperfectly credible, the total contribution of $\varepsilon_{1,t}^{FG}$, $\varepsilon_{2,t}^{FG}$,..., $\varepsilon_{12,t}^{FG}$ to output and inflation is 51.34% and 0.21%, respectively. Under a monetary authority perceived as perfectly credible, the combined contribution is 69.24% and 1.19%.[24] Thus, if a central bank is perceived as more credible, there exist greater immediate and overall effects on the economy from forward guidance. To put it another way, if a central bank is less credible, the immediate and overall effects on output and inflation are not as great relative to the perfectly credible scenario.

The results show that modeling forward guidance credibility can be another approach to address the "forward guidance puzzle" of Del Negro et al. (2012). In the previously mentioned paper, the authors explain that standard New Keynesian models similar to the one presented in Section 2 produce unusually large responses of the macroeconomic variables to forward guidance shocks. Specifically, real GDP growth and inflation show unrealistically large reactions to forward guidance news. The extreme responses do not seem to reconcile with the data. In addition, a notable feature of their model is the assumption of a perfectly credible central bank. In contrast, our paper allows for agents to not perceive the monetary authority as perfectly credible. As discussed in the previous paragraphs, the results show that the reaction of macroeconomic variables to forward guidance shocks is dampened and not as large under $\widehat{\tau}$ relative to $\tau \approx 1$.

4.2 Predictability of Forecasting Errors

Our benchmark model assumed that expectations in the economy are a weighted sum of agents who believe the central bank to be perfectly credible (i.e., those who follow FIRE) and private sector agents who believe the monetary authority to not be credible. However,

[24] The combined contribution of the forward guidance shocks to interest rates is slightly higher under the imperfectly credible case relative to the perfectly credible scenario. This result may be due to forward guidance shocks having a slightly greater effect on the interest rate once they are realized as some agents do not fully believe forward guidance statements when they are announced.

a natural question regards whether this approach or the perfectly credible case is the more appropriate method to model expectations? Standard macroeconomic models often consider *only* the $\tau \approx 1$ case, that is, FIRE. However, if the forecasts of private sector agents only followed the rational expectations hypothesis, their forecast errors should be random, and thus, not dependent or correlated with forecasting disagreement among agents.[25] Thus, a useful cross validation of our model is to examine this idea with our model and compare it to what the data postulate.

We proceed in the following manner. We define forecasting errors of the interest rate at the one-period ahead horizon as $FE_t^1 = \mathbb{E}_{t-1}(i_t) - i_t$. Forecasting disagreement (DEV_t^1) at the one-period ahead horizon is specified as the difference between the 75^{th} and 25^{th} percentile (i.e., interquartile range) between $\mathbb{E}_{t-1}^C(i_t)$ and $\mathbb{E}_{t-1}^D(i_t)$. The remaining forecast errors are defined as $FE_t^2 = \mathbb{E}_{t-2}(i_t) - i_t$, $FE_t^3 = \mathbb{E}_{t-3}(i_t) - i_t$, $FE_t^4 = \mathbb{E}_{t-4}(i_t) - i_t$, and $FE_t^5 = \mathbb{E}_{t-5}(i_t) - i_t$ at the two, three, four, and five-period ahead horizons, respectively. The remaining forecasting disagreements are given by DEV_t^2, DEV_t^3, DEV_t^4, and DEV_t^5 at the two, three, four, and five-period ahead horizons, respectively. We collect data from the U.S. economy. Forecasting errors are computed with respect to the mean forecast with SPF data. The relevant acronym is TBILL. Forecasting disagreements are measured with the interquartile range of the cross-sectional distribution of individual forecasts in order to make the empirical results less sensitive to outliers.[26] The data span $1981 : Q3 - 2018 : Q4$ for the baseline case implying 150 observations.

We run separate regressions of FE_t^h on DEV_t^h at the one, two, three, four, and five periods ahead horizons $(h = 1, 2, 3, 4, 5)$:

$$FE_t^1 = \delta_0^1 + \delta_1^1 DEV_t^1 + e_t^1, \tag{28}$$

$$FE_t^2 = \delta_0^2 + \delta_1^2 DEV_t^2 + e_t^2, \tag{29}$$

$$FE_t^3 = \delta_0^3 + \delta_1^3 DEV_t^3 + e_t^3, \tag{30}$$

$$FE_t^4 = \delta_0^4 + \delta_1^4 DEV_t^4 + e_t^4, \tag{31}$$

$$FE_t^5 = \delta_0^5 + \delta_1^5 DEV_t^5 + e_t^5. \tag{32}$$

[25] Indeed, non-random forecast errors have been found in other settings. Andrade and Le Bihan (2013) examine the ECB Survey of Professional Forecasters and Czudaj and Beckmann (2018) study expectations for the G7 countries. Both papers find that nonrandom forecasts errors in the data. Coibion et al. (2012) and Coibion et al. (2015) also test FIRE and show that information rigidities exist in the forecasts of agents. This result displays evidence against FIRE.

[26] We have considered the same exercise DEV specified as the difference between the 90^{th} and 10^{th} percentile and similar results occurred.

The usual regression error terms are described by e_t^1, e_t^2, e_t^3, e_t^4, and e_t^5 at the one, two, three, four, and five-period ahead horizons, respectively. Furthermore, we perform the same exercise using the simulated counterparts from our model. Specifically, we simulate the model at the posterior mean for a time period of $2,000$ discarding the first 100 simulated observations. We average across $10,000$ replications. We then perform the same regressions given by equations (28) − (32) on a rolling window of 150 observations. The full range of rolling window estimates are represented in Figure 5, which shows a box-and-whisker plot that display their min, max, median, and interquartile range. The point estimates from the data are also shown in Figure 5. The orange circles denote estimates of δ_1^1, δ_1^2, δ_1^3, δ_1^4, and δ_1^5 from the benchmark dataset (i.e., $1981 : Q3 - 2018 : Q4$). The red diamonds represent estimates from the non-ZLB period of our dataset, that is, $1981 : Q3 - 2008 : Q4$.

The results suggest that the approach of modeling expectations with central bank credibility and forward guidance aligns well with the data. By using SPF data, estimates of δ_1^1, δ_1^2, δ_1^3, δ_1^4, and δ_1^5 show that forecasting errors are positively correlated with forecasting disagreement. Figure 5 displays that the orange circles and red diamonds have positive values. This challenges the assumption that forecasting errors ought to be unpredictable and follow FIRE and points at the fact that there is information in the recorded disagreements. In our model disagreements arise fundamentally because of the credibility or lack thereof of policy commitments on the part of the central bank. Through simulated data obtained from our benchmark model where central bank credibility is estimated to be imperfect, we show that this environment can produce a range of values that encompasses those we find in the data. For instance, the estimates of δ_1^1, δ_1^2, δ_1^3, δ_1^4, and δ_1^5 using SPF data lie towards the median of their respective box-and-whisker plots. In addition, under *both* SPF and simulated data, estimates of δ_1^1, δ_1^2, δ_1^3, δ_1^4, and δ_1^5 display an upward trend the longer the forecasting horizon. This result provides further external validation for our underlying theory that disagreements partly reflect incomplete credibility of the central bank's policies and that such disagreements can in part explain the sample estimates suggesting they have some forecasting predictability.

Overall, the results of our main exercise suggest a number of takeaways. Our estimate of Federal Reserve credibility is high at $\widehat{\tau} = 0.7699$. However, this estimated value is below the fully credible case indicating a dampening of the power of forward guidance. If the central bank is perceived as less credible, there exist less immediate and overall effects on the economy from forward guidance. Our model also matches the data well when utilizing SPF data to seek external cross-validation for our model's expectations framework. In addition, the integration of imperfect central bank credibility into a standard macroeconomic model can be another approach to solve the forward guidance puzzle. Thus, accounting for imperfect credibility is important to model the formation of expectations in the economy and the transmission mechanism of forward guidance announcements.

5 Robustness

A main result of our paper displayed that the higher the value of our central bank credibility parameter, τ, the greater the effects of forward guidance on the economy. In particular, τ is estimated to be 0.7699 for the U.S. economy. This high value implies a higher degree of Federal Reserve credibility perceived by agents in the economy, and thus, a level of effectiveness from forward guidance. However, the estimated value of τ is still below the fully credible case (i.e., $\tau \approx 1$). In the following subsections, we analyze the robustness of these results. Specifically, we examine the sensitivity of the benchmark outcomes to the time period used in the estimation, forecasting model used by private sector agents, prior beliefs about τ, and the timing assumption matching SPF forecasts to our model's expectations.

5.1 Subsamples

5.1.1 Non-ZLB

Central bank forward guidance was implemented in response to short-term interest rates hitting their ZLB during the Great Recession. A consequence was that the nominal interest rate exhibited a nonlinear feature during this time period. For simplicity, we do not explicitly model a nonlinear monetary policy rule in Section 2. However, it is important to compare the effect of central bank credibility on forward guidance during ZLB and non-ZLB time periods. Thus, in this subsection, we reestimate the model over the subsample $1981 : Q3 - 2008 : Q4$ and compare the results to our benchmark outcomes.

The "Non-ZLB" column in Table 4 and Table 5 displays the results. Even during an era where the interest rate does not bind at zero, our baseline result still holds. Specifically, the value of τ is estimated to be 0.7770, which is about the same as our benchmark estimate of 0.7699. The values of the other parameters do not considerably change either. Therefore, noticeable effects of forward guidance on the economy exist even during a non-ZLB time period as a high degree of Federal Reserve credibility is estimated to exist. However, the estimate of τ is still below the fully credible central bank scenario.

5.1.2 Great Moderation

Our full sample includes periods of relatively high volatility in the macroeconomic variables (i.e., pre-1985) and the Great Recession onward. However, it is important to examine the effect of central bank credibility on forward guidance during a stable time period. Thus, this subsection compares the benchmark estimation to the case in which we reestimate the model over the subsample $1985 : Q1 - 2007 : Q3$. This period has been called the "Great Moderation" in which the volatility in macroeconomic variables was relatively low (see Clark (2009)).

The estimates of the structural and measurement error parameters of this exercise are displayed in the "Great Moderation" column of Table 4 and Table 5. The results show that the benchmark takeaway from Section 4 does not change. The estimate of our central bank credibility parameter is 0.7802, which is the same as our baseline value. Thus, there exists a high degree of central bank credibility in the U.S. during a stable economic era, which implies an apparent effect of forward guidance during this time period. However, $\widehat{\tau}$ is still below the fully credible central bank case as is comparable to the baseline case of Subsection 4.1.

5.2 Alternative Reduced-Form Forecasting Model

A way to further ensure that τ captures central bank credibility in terms of forward guidance regards examining the forecasting model of the private sector. The benchmark case in Section 4 assumed private sector agents, who believe the monetary authority to be not credible, formed expectations from a VAR(1). However, central bank expectations followed FIRE. The results displayed that the effects of forward guidance varied depending on the perceived credibility of the central bank by the private sector and that the estimate of τ was 0.7699. However, a natural question arises. Specifically, would the value of τ depend on other non-forward guidance elements in the forecasting model of private sector agents?

This section examines the case when private sector agents know more about the true structure of the economy, that is, not credible expectations ($\mathbb{E}_t\left(Y_{t+1}^D\right)$) become more rational. Agents are assumed to know the AR(1) shocks, that is, $w_t = [a_t, \mu_t]'$, when formulating their expectations of future macroeconomic variables. Thus, equation (25) is rewritten as:

$$Y_t = A + BY_{t-1} + Cw_t + e_t, \tag{33}$$

where the A, B, and C are coefficient matrices of appropriate dimensions and e_t is a vector of white noise error terms.

Table 6 and Table 7 produce two main takeaways. First, additional knowledgeable about the true structure of the economy seems to have minimal effect on the posterior estimates of the parameters. In Table 6, the estimate of our central bank credibility parameter is 0.7731 which is approximately the same as our baseline estimate of 0.7699. Altogether Table 6 and Table 7 display that the estimates of the other parameters in the model do not appreciably change. Thus, even if agents utilize a forecasting model that follows more closely FIRE, the results do not substantially change. In particular, there exists noticeable effects of forward guidance on the economy as agents are estimated to believe the Fed to be highly credible, but still below the fully credible case of $\tau \approx 1$. The second takeaway regards further evidence that τ captures credibility of the central bank in terms of forward guidance. Since the estimate of τ does not significantly change when agents are more rational, τ does not seem to be capturing agents' lack of knowledge about the true structure of the economy, that is, not knowing productivity growth and cost-push shocks. Thus, because the value of τ does not seem to depend on these other non-forward guidance elements, this latter result provides additional evidence that τ captures central bank credibility.

5.3 Alternative Priors on the Credibility Parameter

The central parameter is our analysis is τ, which measures the degree of central bank credibility regarding forward guidance. If $\tau \to 1$, the central bank in the economy is assumed to be perfectly credible and agents incorporate forward guidance announcements into their expectations. If $\tau \to 0$, the monetary authority is considered not credible and agents do not incorporate central bank forward guidance statements into their expectations. Our baseline prior assumption for τ assumed a high degree central bank credibility. This value seems reasonable as our paper and dataset deals exclusively with the U.S. economy and Federal Reserve. However, it is also important to examine the results if a more agnostic view about the value of τ is believed.

This section examines the results when the prior distribution for τ changes to a Uniform distribution on the unit interval. The outcomes of this section are displayed in Table 8 and Table 9. The results show that the estimate for τ is 0.6046, which is somewhat smaller than our benchmark of 0.7699.[27] However, the former estimate of τ is still relatively high and within range of our benchmark estimate. Therefore, if one is agnostic about the true value of τ and adopts a $U(0,1)$ prior distribution, there exists apparent effects of forward guidance

[27] The estimates of the other parameters also do not substantially change.

on the U.S. economy as the public believes the US central bank to be credible. However, similar to the benchmark results of Subsection 4.1, the estimated value of τ is still below the fully credible case (i.e., $\tau \approx 1$).[28]

5.4 Alternative Mapping of SPF Forecasts

Section 3 described our data and observables we included for estimation of our model. In our benchmark analysis, we utilized the SPF nowcast for our model's $t+1$ timing of expectations. As explained in Subsection 3.2.1, we believe this assumption made sense given the actual submission dates and timing of SPF forecasters. However, a natural question can emerge. Specifically, what if SPF one-period ahead forecasts were used for our model's $t+1$ timing of expectations instead of the nowcast?

This section performs a robustness check to analyze the results when the above question is taken into account. The model's observation equations are modified as follows:

$$\begin{bmatrix} g_t^{obs} \\ \pi_t^{obs} \\ i_t^{obs} \\ \mathbb{E}_t^{obs}(g_{t+1}) \\ \mathbb{E}_t^{obs}(g_{t+2}) \\ \mathbb{E}_t^{obs}(\pi_{t+1}) \\ \mathbb{E}_t^{obs}(i_{t+1}) \\ \mathbb{E}_t^{obs}(i_{t+2}) \\ \mathbb{E}_t^{obs}(i_{t+3}) \\ \mathbb{E}_t^{obs}(i_{t+4}) \end{bmatrix} = \begin{bmatrix} \Delta y_t \\ \pi_t \\ i_t \\ \mathbb{E}_t(\Delta y_{t+1}) \\ \mathbb{E}_t(\Delta y_{t+2}) \\ \mathbb{E}_t(\pi_{t+1}) \\ \mathbb{E}_t(i_{t+1}) \\ \mathbb{E}_t(i_{t+2}) \\ \mathbb{E}_t(i_{t+3}) \\ \mathbb{E}_t(i_{t+4}) \end{bmatrix} + \begin{bmatrix} \bar{\gamma}^g + \gamma_t \\ \bar{\gamma}^\pi \\ \bar{\gamma}^r \\ \bar{\gamma}^{g^1} + \mathbb{E}_t\left(\gamma_{t+1}\right) \\ \bar{\gamma}^{g^2} + \mathbb{E}_t\left(\gamma_{t+2}\right) \\ \bar{\gamma}^\pi \\ \bar{\gamma}^{r^1} \\ \bar{\gamma}^{r^2} \\ \bar{\gamma}^{r^3} \\ \bar{\gamma}^{r^4} \end{bmatrix} + \begin{bmatrix} \mathbf{0}_{3\times 7} \\ \mathbf{I}_{7\times 7} \end{bmatrix} \begin{bmatrix} o_t^{g_{t+1}} \\ o_t^{g_{t+2}} \\ o_t^{\pi_{t+1}} \\ o_t^{i_{t+1}} \\ o_t^{i_{t+2}} \\ o_t^{i_{t+3}} \\ o_t^{i_{t+4}} \end{bmatrix}. \tag{34}$$

Two differences are apparent between the observation equations in this section (i.e., equation (34)) and the baseline observation equations (i.e., equation (27)). First, $t+1$ timing in our model now corresponds to one-period ahead expectations in the SPF dataset. In addition, $\mathbb{E}_t^{obs}(i_{t+5})$ is not in equation (34). Since this section utilizes one-period ahead SPF expectations (and not the nowcast) for $t+1$ expectations in our model, we only have data up to four periods ahead from the SPF.

[28] A noticeable feature displayed in Tables Table 8 and Table 9 is that the marginal likelihood is also higher under a uniform prior distribution on τ than under the beta prior distribution assumed in our benchmark (in Table 1 and Table 2). However, the estimate of the main parameter of interest, τ, is only somewhat smaller than the benchmark indicating a still high degree of central bank credibility. Thus, the main results do not qualitatively change when utilizing an uninformative prior.

Table 10 and Table 11 display the estimated values of the structural and measurement error parameters of this subsection. The main takeaway is that the benchmark results are robust to the timing assumption matching SPF forecasts to our model's expectations. The estimated value of our parameter of interest, τ, is 0.7760, which does not notably change relative to Section 4. In addition, the estimates of the other parameters do not considerably change. However, the value of the marginal likelihood is lower at 633.5083 compared to 902.1554 from the baseline case. Since the marginal likelihood depends on the data, the discrepancy could be due to this subsection using one less observable than Section 4 as described in previous paragraph.

6 Conclusion

The aftermath of the $2008-2009$ Great Recession caused central banks around the world to utilize the unconventional monetary policy of forward guidance. However, its effectiveness rests on the credibility channel of the central bank. Thus, this paper examines the effectiveness of forward guidance in an estimated New Keynesian model with imperfect central bank credibility. We uniquely model forward guidance and credibility by utilizing a game-theoretic framework, exploiting interest rate expectations data from the SPF, estimating credibility using Bayesian methods, and cross-validating with the SPF dataset.

The results show important takeaways. First, the estimate of central bank credibility in terms of forward guidance announcements is high for the Federal Reserve indicating a degree of effectiveness of forward guidance on the U.S. economy. However, the estimated value is still below the fully credible case. Consequently, when the central bank is perceived to be less than perfectly credible, there exist less immediate and overall effects on the economy from forward guidance. Output and inflation do not respond as favorably to forward guidance relative to the fully credible case. In addition, our model's expectations framework that incorporates central bank credibility and forward guidance cross-validates well with data from the SPF. We also demonstrate that imperfect credibility is another method to resolve the forward guidance puzzle. Furthermore, the results do not noticeably change when examining the following robustness scenarios: different sample periods, forecasting model of private sector agents, prior on our credibility parameter τ, and the timing assumption regarding SPF forecasts. Overall, accounting for imperfect credibility is important to model the formation of expectations in the economy and the transmission mechanism of forward guidance announcements.

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8 Appendix. Evolutionary Game of Central Bank Credibility

In this section, we provide further justification that the evolutionary game framework introduced in Subsection 2.3 is appropriate to model central bank credibility. We proceed by describing the credibility game between the central bank and private agents in general terms. The (evolutionary) game between the central bank and private agents consists of:

1. Two players referred as the central bank (cb) and the private sector (pa), i.e., $M = \{cb, pa\}$.

2. A strategy set S_i for each player $i \in M$ with two pure strategies which are to comply (C) or to deviate (D), i.e., $S_i = \{C, D\}$ for each $i \in M$.

3. A linear payoff function $u_i : S_i \to \mathbb{R}$, assigned to each player $i \in M$, which can be written in matrix form as $u_i(s_i) = Z_i s_i \in \mathbb{R}$ for any payoff matrix Z_i and strategy $s_i \in S_i$, for each player $i \in M$.

We define the strategy space of the game as $S = \Pi_{i \in M} S_i$ where each strategy pair is pin down as $s = (s_{pa}, s_{cb}) \in S$. Denoting $s_i \in S_i$ the strategy of player $i \in M$ and the strategy of the other player as $s_{-i} := (s_j) \in S_{-i} = \Pi_{j \in M, j \neq i} S_j$ where $j \neq i$ and $i, j \in M$, it follows that the strategy pair can be rewritten as $s := (s_i, s_{-i}) \in S_i \times S_{-i} = S = \Pi_{i \in M} S_i$ for all $i \in M$. From here, we define a best response for a given player in the following general terms:

Definition 1 *A strategy $\widehat{s}_i \in S_i$ is called a best response to strategy $s_{-i} \in S_{-i}$ iff $u_i(\widehat{s}_i, s_{-i}) \geq u_i(s_i, s_{-i})$, $\forall i \in M$, $\forall s_i \in S_i$.*

If every player chooses its best response, then no other strategy can increase the player's payoff. Hence, all players following their best response strategies constitutes a Nash equilibrium defined as follows:

Definition 2 *A pair of strategies $s^* \in S$ is called a Nash equilibrium iff $u_i(s^*) = u_i\left(s_i^*, s_{-i}^*\right) \geq u_i\left(s_i, s_{-i}^*\right)$, $\forall i \in M$, $\forall s_i \in S_i$.*

A Nash equilibrium is a strategy pair in the game that is a best response for both players simultaneously so no player can benefit from switching to play another alternative strategy. In other words, if an individual player of type $i \in M$ were to choose the alternative strategy $s_i \neq s_i^*$ where $s_i \in S_i$ when all other individual players follow the strategy s_i^* receives a payoff $u_i\left(s_i, s_{-i}^*\right) \leq u_i\left(s_i^*, s_{-i}^*\right)$, i.e., s_i^* does just as good or better than any other alternative strategy. However, a Nash equilibrium allows for the possibility that some alternative strategy may achieve the same payoff, i.e., there may be some $s_i \in S_i$ for which $u_i\left(s_i, s_{-i}^*\right) \leq u_i\left(s_i^*, s_{-i}^*\right)$. In turn, an evolutionary stable strategy (ESS) is a strategy that has the stronger property that, if the strategy is followed, an individual member of the central bank's policymaking committee (the FOMC in the U.S. Federal Reserve) or an individual private agent who adopt a novel strategy cannot hope to successfully displace the ESS strategy. More precisely, a ESS strategy can be defined in the following terms:

Definition 3 *A strategy $s_i^{ESS} \in S_i$ for each $i \in M$ is an evolutionary stable strategy (ESS) if: either (a) $u_i\left(s_i^{ESS}, s_{-i}^{ESS}\right) > u_i\left(s_i, s_{-i}^{ESS}\right), \forall s_i \in S_i$ and $s_i \neq s_i^{ESS}$; or (b) $u_i\left(s_i^{ESS}, s_{-i}^{ESS}\right) = u_i\left(s_i, s_{-i}^{ESS}\right)$ and $u_i\left(s_i^{ESS}, s_{-i}\right) > u_i\left(s_i, s_{-i}\right), \forall\left(s_i, s_{-i}\right) \in S$ and $s_i \neq s_i^{ESS}$ and $s_{-i} \neq s_{-i}^{ESS}$.*

In other words, the ESS concept is an equilibrium refinement to the Nash equilibrium. What this means is that a strategy pair $\left(s_i^{ESS}, s_{-i}^{ESS}\right)$ describes an ESS strategy for each player if: (a) the ESS strategy does strictly better playing against ESS than any alternative would do; or (b) some alternative strategy does as well as ESS playing against ESS but ESS still does strictly better playing against the alternative strategy than the alternative does playing against itself.

The central bank credibility game. The linear payoff function $u_i : \{C, D\} \times \{C, D\} \rightarrow \mathbb{R}$ for both players (the central bank and the private sector) and two strategies (**C**omply or **D**eviate) can be described in normal form with the following payoff matrix:

		Private Agents: **C**	Private Agents: **D**
Central Bank	**C**	R_{cb}, R_{pa}	L_{cb}, T_{pa}
Central Bank	**D**	T_{cb}, L_{pa}	P_{cb}, P_{pa}

We use the following notational conventions: to comply (C) means to commit to honor the policy announcements on the part of the central bank and to accept the credibility of such commitments on the part of the private agents, while to deviate (D) means to renege on the policy announcements and to rely on a forecasting model not containing policy announcements (e.g., equation (25)) to negate any credibility to such announcements respectively.

We assume that the payoff of private agents and the central bank is tied to the social welfare achieved. **R** refers to the reward or social welfare that both players achieve jointly by choosing both C. If the two players deviate then each receives **P** which is the punishment payoff (the sub-optimal social welfare) that they achieve jointly by choosing both D. In our context, the social welfare that can be achieved when both players deviate is lower than if both comply, i.e., $P > R$. When one player complies and the other deviates, **T** is the temptation payoff that the player that deviates (D) receives while **L** is the loser payoff received by the player that complies (C). In our context, the player that deviates (or cheats) in this game benefits at the expense of the player that complies, i.e., the social welfare perceived by the player that is cheated is reduced by a modifier value relative to that of the cheater such that $L_i < T_i$, $\forall i \in M$.

Without loss of generality, we will assume for expositional simplicity that the temptation and loser payoffs are symmetric for both players, i.e. $L_i = L$ and $T_i = T$, $\forall i \in M$. Similarly, the reward and punishment values are also symmetric for both players, i.e., $R_i = R$ and $P_i = P$, $\forall i \in M$. Given the symmetric payoff matrix that we describe here, the linear payoff function can be written in matrix form as $u_i(s_i) = Z_i s_i \in \mathbb{R}$ for any strategy $s_i \in S_i$ and for each player $i \in M$ with $Z_i = Z = \begin{bmatrix} R & L \\ T & P \end{bmatrix}$. Here, depending on the ordering of R, T, L, and P, we can have significantly different games with different properties. A well-known game, the Prisoner's Dilemma, requires the ordering to be $T > R > P > L$. We consider however two other orderings that stand out as most relevant for the interaction between the central bank and the private agents: the Game of Chicken which requires $T > R > L > P$ and the Trust Dilemma that imposes instead that $R > T > L > P$.

Replicator dynamics. Let us consider $p_j(t)$ the frequency with which pure strategy $j = \{C, D\}$ is played and $p(t) = (p_C(t), p_D(t))^T$ the corresponding state vector, where t denotes the t-th replication of the same game. We postulate a law of motion for $p(t)$ that describes how the dynamics of the game evolve as players consider future generations (or replications) of the game at play. If players engage in a symmetric game with the payoff matrix Z, then $(Zp(t))_j$ is the expected payoff for strategy $j = \{C, D\}$ and $\left(p(t)^T Zp(t)\right)$ is the average payoff. Thus, the relative performance of the given frequency vector $p_j(t)$ for each strategy $j = \{C, D\}$ is given by $\frac{(Zp(t))_j}{p(t)^T Zp(t)}$ for $p(t)^T Zp(t) \neq 0$.

We assume that learning from the experience in replication t, the frequency $p_j(t)$ for each strategy $j = \{C, D\}$ would be update in the following generation (or in the subsequent replication) proportionally to its relative performance in the current one, i.e.,

$$\frac{p_j\left(t+\Delta t\right)}{p_j\left(t\right)} = \frac{\left(Zp\left(t\right)\right)_j}{p\left(t\right)^T Zp\left(t\right)}\Delta t, \tag{35}$$

for $\Delta t > 0$ and for all $j = \{C, D\}$. Hence, $p_j\left(t+\Delta t\right) - p_j\left(t\right) = p_j\left(t\right)\frac{\left(Zp(t)\right)_j - p(t)^T Zp(t)}{p(t)^T Zp(t)}\Delta t$. This, in turn, yields the following differential equation as $\Delta t \to 0$:

$$\dot{p_j} = p_j \frac{\left(Zp\right)_j - p^T Zp}{p^T Zp}, \tag{36}$$

for all $j = \{C, D\}$ with $\dot{p_j}$ denoting the derivative of $p_j\left(t\right)$ with respect to t. A solution $q_j\left(t\right)$ to the simplified differential equation:

$$\dot{q_j} = q_j\left[\left(Zq\right)_j - q^T Zq\right], \tag{37}$$

suffices to describe the replicator dynamics of the game as (36) has the same trajectories as (37). That is because, according to the transformation of t given by $t\left(s\right) = \int_{s_0}^{s} p\left(t\right)^T Zp\left(t\right)$ with s_0 being the initial generation (replication), every solution $p_j\left(t\right)$ of (36) delivers a solution $q_j\left(s\right) := p_j\left(t\left(s\right)\right)$ of the simplified differential equation (37).

Evolutionary stable strategies. Let us denote the frequency of strategy D with q and the frequency of strategy C as $1-q$ with $\widetilde{q} = \left(1-q, q\right)^T$. The replicator equation in (37) has two terms that depend on the payoff matrix Z. The first term depends on $Z\widetilde{q}$ which gives us that $\begin{pmatrix} \left(1-q\right)R + qL \\ \left(1-q\right)T + qP \end{pmatrix}$. Since strategy D is ordered after C in the layout of the normal form of the game, we use the second component of $Z\widetilde{q}$ to describe $\left(Z\widetilde{q}\right)_j$ when $j = D$. The second term $\widetilde{q}^T Z\widetilde{q}$ can be expressed as $\left(1-q\right)^2 R + \left(1-q\right)q\left(L+T\right) + q^2 P$. Thus, the replicator equation in (37) for strategy D is given by:

$$\dot{q} = q\left[\left(1-q\right)T + qP - \left(1-q\right)^2 R - \left(1-q\right)q\left(L+T\right) - q^2 P\right]. \tag{38}$$

By setting $\dot{q} = 0$, i.e., solving this equation:

$$q\left[T - R - \left(L - P + 2\left(T - R\right)\right)q + \left(L - P + T - R\right)q^2\right] = 0, \tag{39}$$

we obtain the evolutionary states of the model. This holds trivially true for $q^{ES} = 0$ and for $q^{ES} = 1$. The mixed strategy solution can be pin down by factoring the roots from the quadratic function $q^2 - \left(\frac{L-P+2(T-R)}{L-P+T-R}\right) q + \left(\frac{T-R}{L-P+T-R}\right) = 0$ where we already know that one of the roots is $q^{ES} = 1$. From that, we obtain that that the mixed strategy state of the model is $q^{ES} = \left(\frac{1}{1+\frac{L-P}{T-R}}\right)$. To sum up:

Lemma 1 *The central bank credibility game has generically three states. Two states are in pure strategies where $q^{ES} = 0$ implies playing C and $q^{ES} = 1$ implies playing D. The mixed strategy state, if one exists, involves playing strategy D with a frequency of $q^{ES} = \left(\frac{1}{1+\frac{L-P}{T-R}}\right)$ and strategy C with a frequency of $1 - q^{ES} = \left(\frac{\frac{L-P}{T-R}}{1+\frac{L-P}{T-R}}\right)$.*

The mixed strategy state is well-defined and satisfies $0 \leq \left(\frac{1}{1+\frac{L-P}{T-R}}\right) \leq 1$ whenever $(L-P)+(T-R) \geq 0$ and $\frac{L-P}{T-R} \geq 0$. The Prisoner's Dilemma, as indicated before, requires the ordering to be $T > R > P > L$. Therefore, $T - R > 0$ and $L - P < 0$ violates the condition that $\frac{L-P}{T-R} \geq 0$ and for this case there are only two states in based on pure strategies. Similarly, the Trust Dilemma that imposes instead that $R > T > L > P$ implies that $L - P > 0$ and $T - R < 0$. Therefore, in the case of the Trust Dilemma, there are only two states in pure strategies as well. In turn, the Game of Chicken which we emphasize in the paper requires $T > R > L > P$ which then implies that $L - P > 0$ and $T - R > 0$ and satisfies the conditions that insure a well-defined mixed strategy state exists.

Definition 4 *A strategy pair $\left(1 - q^{ESS}, q^{ESS}\right)^T$ is said to be an evolutionary stable strategy (ESS) if its a locally convergent evolutionary state which is dynamically restored after a disturbance through the learning process implied by the replicator equation in (37), provided the disturbance is not too large. That is, $q^{ES} = 0$ is an ESS if $\dot{q} < 0$ for $q^0 \to 0$ from the right ($q^0 > 0$) and $q^{ES} = 1$ is an ESS if $\dot{q} > 0$ for $q^0 \to 1$ from the left ($q^0 < 1$). In turn, $q^{ES} = \left(\frac{1}{1+\frac{L-P}{T-R}}\right)$ is an ESS if $\dot{q} < 0$ for $q^0 \to \frac{1}{1+\frac{L-P}{T-R}}$ from the right ($q^0 > \frac{1}{1+\frac{L-P}{T-R}}$) and $\dot{q} > 0$ for $q^0 \to \frac{1}{1+\frac{L-P}{T-R}}$ from the left ($q^0 < \frac{1}{1+\frac{L-P}{T-R}}$).*

When we explore the dynamics implied by the replicator equation in (37), it follows that given the orderings of the payoffs R, T, L, and P:

Proposition 1 *The Prisoner's Dilemma game has one ESS only, that is the state $q^{ESS} = q^{ES} = 1$ (which implies the player follows the pure strategy D). Similarly, the Trust Dilemma* *has one ESS only that corresponds to the other pure strategy* $q^{ESS} = q^{ES} = 0$ *(the player follows the pure strategy* C*). In turn, the only ESS of the central bank credibility game (the Game of Chicken between the central bank and the private sector) is the mixed strategy implied by* $q^{ESS} = q^{ES} = \left(\frac{1}{1+\frac{L-P}{T-R}}\right)$.

When we estimate our model with central bank credibility and forward guidance in Section 4, the data favor a mixed strategy equilibrium. Thus, Proposition 1 suggests that the Game of Chicken is better suited than the Prisoner's Dilemma or the Trust Dilemma to describe the central bank credibility game. Finally, we illustrate the dynamics of the symmetric central bank credibility game (the Game of Chicken) for both players (the central bank and the private sector) simultaneously and its corresponding mixed strategy ESS in the vector field in Figure 1.

9 Tables

Table 1: **Prior & Posterior Estimates of Structural Parameters**

	Prior Distr.	Posterior Distribution					
		Perfectly Credible C.B. ($\tau = 0.98$)			Not Perfectly Credible C.B. ($\hat{\tau}$)		
	Distr.	Mean	5%	95%	Mean	5%	95%
τ	B(0.80, 0.01)	-	-	-	0.7699	0.7529	0.7870
ω	N(1.00, 0.05)	0.9716	0.8869	1.0552	0.9971	0.9117	1.0776
ρ	B(0.75, 0.10)	0.9365	0.9240	0.9498	0.9668	0.9539	0.9798
χ_π	N(1.50, 0.10)	1.4390	1.2741	1.6012	1.4964	1.3323	1.6595
χ_x	N(0.125, 0.05)	0.1734	0.0957	0.2495	0.1314	0.0486	0.2137
ι_p	B(0.50, 0.15)	0.5076	0.0279	0.7140	0.6571	0.5179	0.7972
ρ_γ	B(0.50, 0.20)	0.3483	0.1546	0.5353	0.4978	0.4765	0.5194
ρ_μ	B(0.50, 0.20)	0.1958	0.0043	0.6530	0.0270	0.0032	0.0504
σ_γ	IG(0.30, 2.00)	0.8024	0.5555	1.0459	0.6030	0.5428	0.6618
σ_μ	IG(0.30, 2.00)	0.1209	0.0733	0.1483	0.1319	0.1179	0.1458
σ_{MP}	IG(0.30, 2.00)	0.1852	0.1663	0.2041	0.1917	0.1718	0.2113
σ_1^{FG}	IG(0.30, 2.00)	0.0698	0.0595	0.0798	0.0687	0.0581	0.0795
σ_2^{FG}	IG(0.30, 2.00)	0.0418	0.0360	0.0467	0.0490	0.0415	0.0563
σ_3^{FG}	IG(0.30, 2.00)	0.0377	0.0356	0.0400	0.0412	0.0359	0.0457
σ_4^{FG}	IG(0.30, 2.00)	0.0379	0.0356	0.0403	0.0424	0.0366	0.0477
σ_5^{FG}	IG(0.30, 2.00)	0.0598	0.0471	0.0722	0.0585	0.0461	0.0705
σ_6^{FG}	IG(0.30, 2.00)	0.0593	0.0465	0.0715	0.0583	0.0459	0.0699
σ_7^{FG}	IG(0.30, 2.00)	0.0590	0.0467	0.0712	0.0583	0.0462	0.0703
σ_8^{FG}	IG(0.30, 2.00)	0.0585	0.0462	0.0705	0.0582	0.0460	0.0697
σ_9^{FG}	IG(0.30, 2.00)	0.0584	0.0460	0.0701	0.0582	0.0458	0.0702
σ_{10}^{FG}	IG(0.30, 2.00)	0.0584	0.0461	0.0704	0.0582	0.0460	0.0701
σ_{11}^{FG}	IG(0.30, 2.00)	0.0584	0.0463	0.0707	0.0582	0.0462	0.0700
σ_{12}^{FG}	IG(0.30, 2.00)	0.0584	0.0462	0.0704	0.0584	0.0460	0.0703
	logMargL	782.9432			902.1554		

Note: C.B.: Central Bank, G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 2: **Prior & Posterior Estimates of Measurement Errors**

	Prior Distr.	Posterior Distribution					
		Perfectly Credible C.B. ($\tau = 0.98$)			Not Perfectly Credible C.B. ($\hat{\tau}$)		
	Distr.	Mean	5%	95%	Mean	5%	95%
$\sigma^{me}_{g^1}$	IG(0.10, 2.00)	0.3432	0.3097	0.3755	0.3427	0.3093	0.3763
$\sigma^{me}_{g^2}$	IG(0.10, 2.00)	0.1963	0.1753	0.2174	0.1929	0.1737	0.2118
$\sigma^{me}_{\pi^1}$	IG(0.10, 2.00)	0.1941	0.1743	0.2143	0.1613	0.1453	0.1771
$\sigma^{me}_{i^1}$	IG(0.10, 2.00)	0.0350	0.0279	0.0421	0.0291	0.0233	0.0349
$\sigma^{me}_{i^2}$	IG(0.10, 2.00)	0.0170	0.0139	0.0200	0.0170	0.0140	0.0199
$\sigma^{me}_{i^3}$	IG(0.10, 2.00)	0.0147	0.0123	0.0170	0.0146	0.0123	0.0168
$\sigma^{me}_{i^4}$	IG(0.10, 2.00)	0.0155	0.0129	0.0180	0.0161	0.0133	0.0188
$\sigma^{me}_{i^5}$	IG(0.10, 2.00)	0.0197	0.0156	0.0237	0.0212	0.0165	0.0256
	logMargL	782.9432			902.1554		

Note: C.B.: Central Bank, G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 3: **Variance Decomposition**

	Perfectly Credible C.B. ($\tau = 0.98$)			Not Perfectly Credible C.B. ($\hat{\tau}$)		
	Output	Inflation	Interest Rate	Output	Inflation	Interest Rate
ε_t^{MP}	20.56	0.39	51.74	43.43	0.18	47.37
ε_t^{γ}	8.03	0.00	0.00	0.01	0.01	0.01
ε_t^{μ}	2.16	98.42	3.39	5.22	99.58	4.56
$\varepsilon_{1,t}^{FG}$	3.81	0.06	7.05	6.16	0.02	6.05
$\varepsilon_{2,t}^{FG}$	1.74	0.03	2.43	3.26	0.01	3.07
$\varepsilon_{3,t}^{FG}$	1.74	0.03	1.90	2.33	0.01	2.16
$\varepsilon_{4,t}^{FG}$	2.07	0.03	1.84	2.46	0.01	2.28
$\varepsilon_{5,t}^{FG}$	5.90	0.09	4.45	4.67	0.02	4.34
$\varepsilon_{6,t}^{FG}$	6.46	0.10	4.25	4.64	0.02	4.31
$\varepsilon_{7,t}^{FG}$	6.96	0.11	4.09	4.65	0.02	4.32
$\varepsilon_{8,t}^{FG}$	7.34	0.12	3.92	4.63	0.02	4.30
$\varepsilon_{9,t}^{FG}$	7.75	0.13	3.82	4.63	0.02	4.30
$\varepsilon_{10,t}^{FG}$	8.16	0.15	3.76	4.63	0.02	4.30
$\varepsilon_{11,t}^{FG}$	8.51	0.16	3.71	4.62	0.02	4.29
$\varepsilon_{12,t}^{FG}$	8.80	0.18	3.65	4.66	0.02	4.33
Total FG	69.24	1.19	44.87	51.34	0.21	48.05

Note: This table computes the variance decomposition with parameter values at their posterior mean. Each column displays the percentage contribution of each shock to model-implied output and observables (infl ation and interest rates). Total forward guidance denotes the sum of all of the forward guidance shocks. The measurement errors are not shown as their contribution concerns expected values of observables.

Table 4: **Prior & Posterior Estimates of Structural Parameters under Subsamples**

	Prior Distr.	Posterior Distribution					
		Non-ZLB			Great Moderation		
	Distr.	Mean	5%	95%	Mean	5%	95%
τ	B(0.80, 0.01)	0.7770	0.7597	0.7942	0.7802	0.7623	0.7980
ω	N(1.00, 0.05)	0.9975	0.9154	1.0795	0.9963	0.9139	1.0785
ρ	B(0.75, 0.10)	0.9526	0.9357	0.9700	0.9540	0.9321	0.9763
χ_π	N(1.50, 0.10)	1.4901	1.3268	1.6512	1.4996	1.3367	1.6619
χ_x	N(0.125, 0.05)	0.1351	0.0524	0.2163	0.1337	0.0517	0.2139
ι_p	B(0.50, 0.15)	0.6362	0.4866	0.7879	0.3872	0.2163	0.5600
ρ_γ	B(0.50, 0.20)	0.4933	0.4644	0.5219	0.4195	0.3482	0.4914
ρ_μ	B(0.50, 0.20)	0.0364	0.0039	0.0680	0.0797	0.0076	0.1511
σ_γ	IG(0.30, 2.00)	0.6494	0.5747	0.7239	0.5570	0.4735	0.6393
σ_μ	IG(0.30, 2.00)	0.1296	0.1137	0.1449	0.1238	0.1068	0.1407
σ_{MP}	IG(0.30, 2.00)	0.2190	0.1929	0.2445	0.1444	0.1251	0.1635
σ_1^{FG}	IG(0.30, 2.00)	0.0774	0.0638	0.0910	0.0636	0.0514	0.0759
σ_2^{FG}	IG(0.30, 2.00)	0.0552	0.0456	0.0646	0.0554	0.0456	0.0651
σ_3^{FG}	IG(0.30, 2.00)	0.0456	0.0386	0.0523	0.0446	0.0374	0.0513
σ_4^{FG}	IG(0.30, 2.00)	0.0468	0.0393	0.0540	0.0420	0.0356	0.0471
σ_5^{FG}	IG(0.30, 2.00)	0.0651	0.0499	0.0797	0.0690	0.0521	0.0860
σ_6^{FG}	IG(0.30, 2.00)	0.0653	0.0499	0.0803	0.0690	0.0518	0.0859
σ_7^{FG}	IG(0.30, 2.00)	0.0651	0.0495	0.0798	0.0691	0.0519	0.0859
σ_8^{FG}	IG(0.30, 2.00)	0.0649	0.0493	0.0794	0.0692	0.0519	0.0863
σ_9^{FG}	IG(0.30, 2.00)	0.0654	0.0497	0.0804	0.0688	0.0518	0.0852
σ_{10}^{FG}	IG(0.30, 2.00)	0.0653	0.0499	0.0804	0.0690	0.0524	0.0858
σ_{11}^{FG}	IG(0.30, 2.00)	0.0650	0.0499	0.0798	0.0689	0.0519	0.0857
σ_{12}^{FG}	IG(0.30, 2.00)	0.0652	0.0499	0.0798	0.0690	0.0518	0.0858
	logMargL	588.4758			602.2963		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 5: **Prior & Posterior Estimates of Measurement Errors under Subsamples**

	Prior Distr.	Posterior Distribution					
		Non-ZLB			Great Moderation		
	Distr.	Mean	5%	95%	Mean	5%	95%
$\sigma^{me}_{g^1}$	IG(0.10, 2.00)	0.3332	0.2957	0.3705	0.2891	0.2529	0.3238
$\sigma^{me}_{g^2}$	IG(0.10, 2.00)	0.2022	0.1783	0.2248	0.1761	0.1538	0.1985
$\sigma^{me}_{\pi^1}$	IG(0.10, 2.00)	0.1692	0.1505	0.1881	0.1646	0.1441	0.1845
$\sigma^{me}_{i^1}$	IG(0.10, 2.00)	0.0328	0.0251	0.0403	0.0360	0.0284	0.0433
$\sigma^{me}_{i^2}$	IG(0.10, 2.00)	0.0191	0.0152	0.0228	0.0178	0.0143	0.0212
$\sigma^{me}_{i^3}$	IG(0.10, 2.00)	0.0167	0.0137	0.0196	0.0172	0.0138	0.0204
$\sigma^{me}_{i^4}$	IG(0.10, 2.00)	0.0182	0.0145	0.0217	0.0177	0.0141	0.0211
$\sigma^{me}_{i^5}$	IG(0.10, 2.00)	0.0233	0.0178	0.0287	0.0209	0.0162	0.0255
	logMargL	588.4758			602.2963		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 6: **Prior & Posterior Estimates of Structural Parameters with More Rational Non-Credible Expectations**

	Prior Distr.	Posterior Distribution		
	Distr.	Mean	5%	95%
τ	B(0.80, 0.01)	0.7731	0.7561	0.7903
ω	N(1.00, 0.05)	0.9966	0.9142	1.0777
ρ	B(0.75, 0.10)	0.9683	0.9551	0.9814
χ_π	N(1.50, 0.10)	1.4763	1.3133	1.6357
χ_x	N(0.125, 0.05)	0.1308	0.0481	0.2106
ι_p	B(0.50, 0.15)	0.6785	0.5379	0.8176
ρ_γ	B(0.50, 0.20)	0.4726	0.4379	0.5085
ρ_μ	B(0.50, 0.20)	0.0308	0.0034	0.0577
σ_γ	IG(0.30, 2.00)	0.5930	0.5329	0.6523
σ_μ	IG(0.30, 2.00)	0.1382	0.1215	0.1543
σ_{MP}	IG(0.30, 2.00)	0.1959	0.1759	0.2162
σ_1^{FG}	IG(0.30, 2.00)	0.0759	0.0649	0.0869
σ_2^{FG}	IG(0.30, 2.00)	0.0456	0.0387	0.0524
σ_3^{FG}	IG(0.30, 2.00)	0.0414	0.0361	0.0459
σ_4^{FG}	IG(0.30, 2.00)	0.0424	0.0366	0.0477
σ_5^{FG}	IG(0.30, 2.00)	0.0585	0.0460	0.0704
σ_6^{FG}	IG(0.30, 2.00)	0.0586	0.0464	0.0708
σ_7^{FG}	IG(0.30, 2.00)	0.0583	0.0460	0.0704
σ_8^{FG}	IG(0.30, 2.00)	0.0583	0.0463	0.0704
σ_9^{FG}	IG(0.30, 2.00)	0.0585	0.0460	0.0706
σ_{10}^{FG}	IG(0.30, 2.00)	0.0584	0.0462	0.0706
σ_{11}^{FG}	IG(0.30, 2.00)	0.0584	0.0460	0.0706
σ_{12}^{FG}	IG(0.30, 2.00)	0.0584	0.0463	0.0702
	logMargL	886.5071		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 7: **Prior & Posterior Estimates of Measurement Errors with More Rational Non-Credible Expectations**

	Prior Distr.	Posterior Distribution		
	Distr.	Mean	5%	95%
$\sigma_{g^1}^{me}$	IG(0.10, 2.00)	0.3392	0.3062	0.3727
$\sigma_{g^2}^{me}$	IG(0.10, 2.00)	0.1894	0.1703	0.2081
$\sigma_{\pi^1}^{me}$	IG(0.10, 2.00)	0.1588	0.1427	0.1748
$\sigma_{i^1}^{me}$	IG(0.10, 2.00)	0.0249	0.0193	0.0306
$\sigma_{i^2}^{me}$	IG(0.10, 2.00)	0.0166	0.0137	0.0194
$\sigma_{i^3}^{me}$	IG(0.10, 2.00)	0.0146	0.0123	0.0167
$\sigma_{i^4}^{me}$	IG(0.10, 2.00)	0.0161	0.0133	0.0189
$\sigma_{i^5}^{me}$	IG(0.10, 2.00)	0.0213	0.0166	0.0258
	logMargL	886.5071		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 8: **Prior & Posterior Estimates of Structural Parameters under U(0,1) Prior on τ**

	Prior Distr.	Posterior Distribution		
	Distr.	Mean	5%	95%
τ	U(0, 1)	0.6046	0.5692	0.6398
ω	N(1.00, 0.05)	0.9974	0.9138	1.0797
ρ	B(0.75, 0.10)	0.9758	0.9635	0.9884
χ_π	N(1.50, 0.10)	1.5197	1.3582	1.6830
χ_x	N(0.125, 0.05)	0.1257	0.0436	0.2075
ι_p	B(0.50, 0.15)	0.5664	0.3682	0.7714
ρ_γ	B(0.50, 0.20)	0.4942	0.4790	0.5098
ρ_μ	B(0.50, 0.20)	0.0373	0.0047	0.0690
σ_γ	IG(0.30, 2.00)	0.6018	0.5438	0.6599
σ_μ	IG(0.30, 2.00)	0.1432	0.1266	0.1594
σ_{MP}	IG(0.30, 2.00)	0.2036	0.1813	0.2256
σ_1^{FG}	IG(0.30, 2.00)	0.0831	0.0684	0.0975
σ_2^{FG}	IG(0.30, 2.00)	0.0630	0.0520	0.0738
σ_3^{FG}	IG(0.30, 2.00)	0.0478	0.0403	0.0550
σ_4^{FG}	IG(0.30, 2.00)	0.0506	0.0423	0.0588
σ_5^{FG}	IG(0.30, 2.00)	0.0606	0.0473	0.0736
σ_6^{FG}	IG(0.30, 2.00)	0.0602	0.0473	0.0728
σ_7^{FG}	IG(0.30, 2.00)	0.0604	0.0472	0.0732
σ_8^{FG}	IG(0.30, 2.00)	0.0605	0.0474	0.0733
σ_9^{FG}	IG(0.30, 2.00)	0.0605	0.0472	0.0733
σ_{10}^{FG}	IG(0.30, 2.00)	0.0605	0.0473	0.0731
σ_{11}^{FG}	IG(0.30, 2.00)	0.0603	0.0476	0.0729
σ_{12}^{FG}	IG(0.30, 2.00)	0.0604	0.0474	0.0732
	logMargL	928.9150		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 9: **Prior & Posterior Estimates of Measurement Errors under U(0,1) Prior on τ**

	Prior Distr.	Posterior Distribution		
	Distr.	Mean	5%	95%
$\sigma_{g^1}^{me}$	IG(0.10, 2.00)	0.3406	0.3073	0.3740
$\sigma_{g^2}^{me}$	IG(0.10, 2.00)	0.1924	0.1732	0.2107
$\sigma_{\pi^1}^{me}$	IG(0.10, 2.00)	0.1514	0.1368	0.1660
$\sigma_{i^1}^{me}$	IG(0.10, 2.00)	0.0255	0.0202	0.0307
$\sigma_{i^2}^{me}$	IG(0.10, 2.00)	0.0173	0.0142	0.0203
$\sigma_{i^3}^{me}$	IG(0.10, 2.00)	0.0147	0.0124	0.0169
$\sigma_{i^4}^{me}$	IG(0.10, 2.00)	0.0167	0.0138	0.0196
$\sigma_{i^5}^{me}$	IG(0.10, 2.00)	0.0230	0.0178	0.0281
	logMargL	928.9150		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 10: **Prior & Posterior Estimates of Structural Parameters under Alternative SPF Timing**

	Prior Distr.	Posterior Distribution		
	Distr.	Mean	5%	95%
τ	B(0.8, 0.01)	0.7760	0.7584	0.7931
ω	N(1.00, 0.05)	0.9906	0.9087	1.0727
ρ	B(0.75, 0.10)	0.9529	0.9364	0.9696
χ_π	N(1.50, 0.10)	1.4866	1.3250	1.6520
χ_x	N(0.125, 0.05)	0.1362	0.0572	0.2168
ι_p	B(0.50, 0.15)	0.6494	0.5133	0.7912
ρ_γ	B(0.50, 0.20)	0.3763	0.3192	0.4354
ρ_μ	B(0.50, 0.20)	0.0320	0.0034	0.0599
σ_γ	IG(0.30, 2.00)	0.7111	0.6233	0.7971
σ_μ	IG(0.30, 2.00)	0.1350	0.1206	0.1490
σ_{MP}	IG(0.30, 2.00)	0.1931	0.1732	0.2131
σ_1^{FG}	IG(0.30, 2.00)	0.0897	0.0783	0.1012
σ_2^{FG}	IG(0.30, 2.00)	0.0446	0.0382	0.0510
σ_3^{FG}	IG(0.30, 2.00)	0.0410	0.0357	0.0453
σ_4^{FG}	IG(0.30, 2.00)	0.0619	0.0480	0.0752
σ_5^{FG}	IG(0.30, 2.00)	0.0618	0.0481	0.0753
σ_6^{FG}	IG(0.30, 2.00)	0.0618	0.0482	0.0753
σ_7^{FG}	IG(0.30, 2.00)	0.0618	0.0482	0.0751
σ_8^{FG}	IG(0.30, 2.00)	0.0617	0.0479	0.0750
σ_9^{FG}	IG(0.30, 2.00)	0.0616	0.0481	0.0748
σ_{10}^{FG}	IG(0.30, 2.00)	0.0619	0.0482	0.0753
σ_{11}^{FG}	IG(0.30, 2.00)	0.0620	0.0483	0.0751
σ_{12}^{FG}	IG(0.30, 2.00)	0.0615	0.0480	0.0747
	logMargL	633.5083		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

Table 11: **Prior & Posterior Estimates of Measurement Errors under Alternative SPF Timing**

	Prior Distr.	Posterior Distribution		
	Distr.	Mean	5%	95%
$\sigma_{g^1}^{me}$	IG(0.10, 2.00)	0.3186	0.2876	0.3498
$\sigma_{g^2}^{me}$	IG(0.10, 2.00)	0.1846	0.1654	0.2035
$\sigma_{\pi^1}^{me}$	IG(0.10, 2.00)	0.1806	0.1627	0.1977
$\sigma_{i^1}^{me}$	IG(0.10, 2.00)	0.0204	0.0160	0.0246
$\sigma_{i^2}^{me}$	IG(0.10, 2.00)	0.0153	0.0128	0.0178
$\sigma_{i^3}^{me}$	IG(0.10, 2.00)	0.0153	0.0128	0.0177
$\sigma_{i^4}^{me}$	IG(0.10, 2.00)	0.0203	0.0161	0.0246
	logMargL	633.5083		

Note: G: Gamma Distribution, N: Normal Distribution, B: Beta Distribution, U: Uniform Distribution, IG: Inverse-Gamma Distribution.

10 Figures

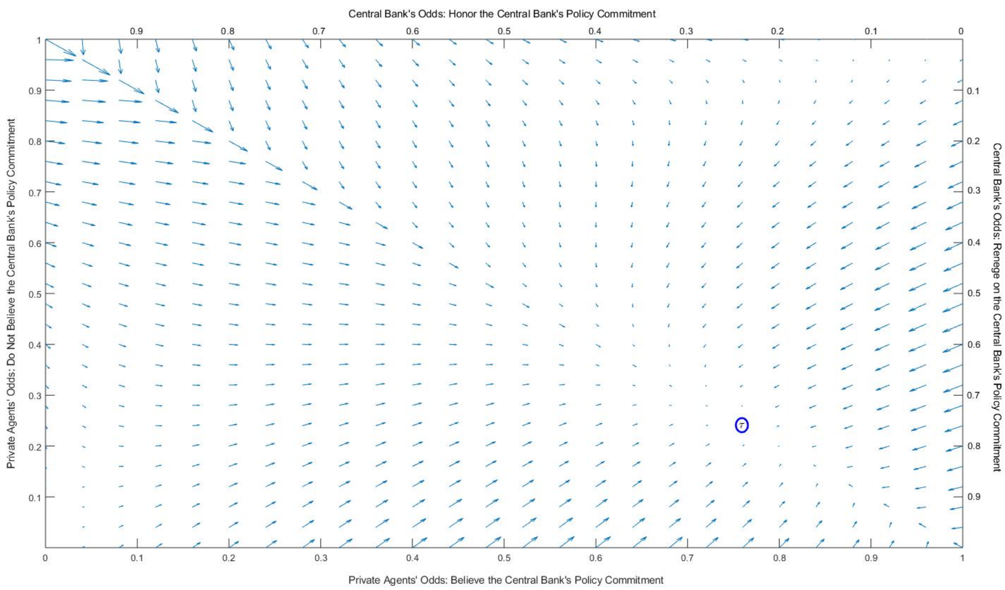

Figure 1: **Stable Mixed Strategy Equilibrium in the Evolutionary Game of Credibility between the Central Bank and Private Agents.**

Sources: Authors' rendering.

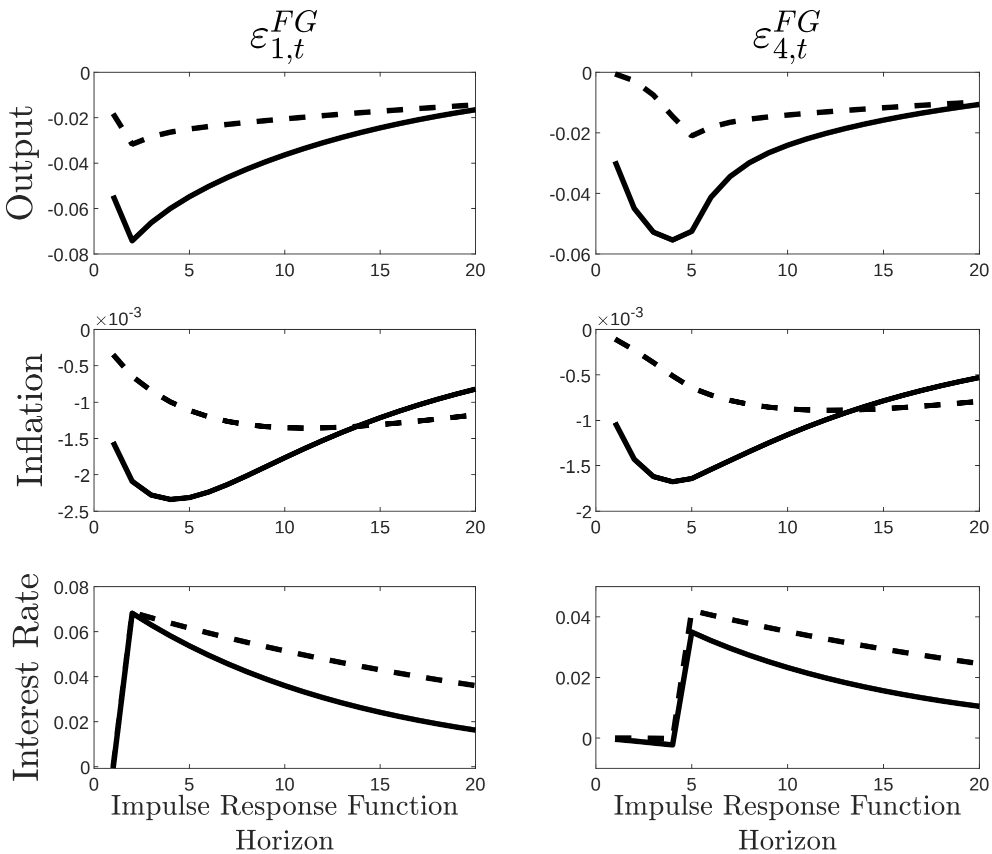

Figure 2: **Impulse Response Functions.**

Note: Mean response of model-implied output and observables (in flation and interest rate) to one-period ahead forward guidance and four-period ahead forward guidance shocks. Solid Line: Perfectly Credible C.B. (i.e., $\tau = 0.98$). Dashed line: Not Perfectly Credible C.B. (i.e., Benchmark $\hat{\tau}$). C.B.: Central Bank.

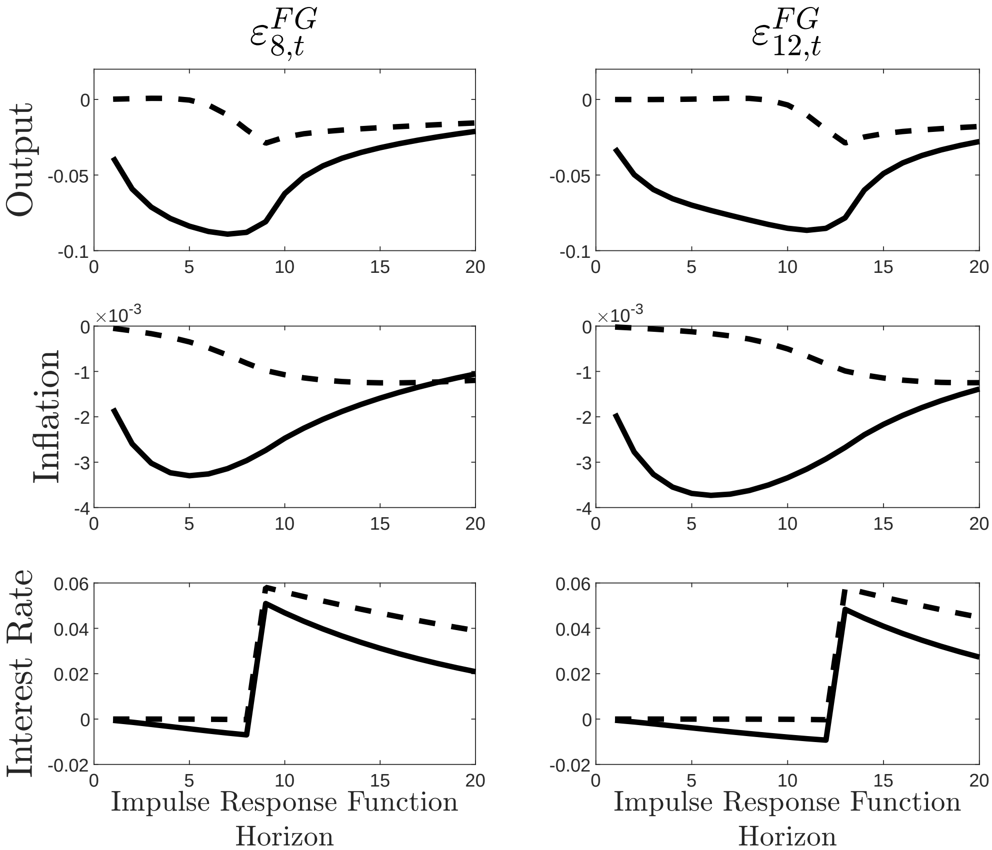

Figure 3: **Impulse Response Functions.**

Note: Mean response of model-implied output and observables (in flation and interest rate) to eight-period ahead forward guidance and twelve-period ahead forward guidance shocks. Solid Line: Perfectly Credible C.B. (i.e., $\tau = 0.98$). Dashed line: Not Perfectly Credible C.B. (i.e., Benchmark $\hat{\tau}$). C.B.: Central Bank.

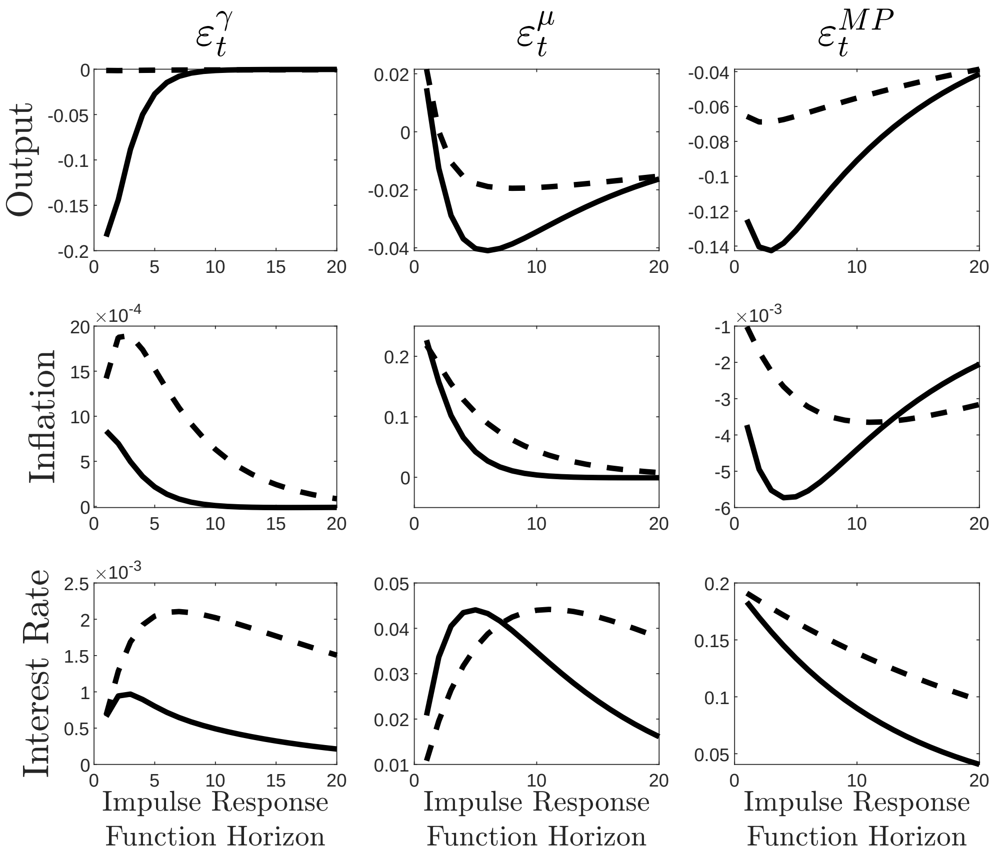

Figure 4: **Impulse Response Functions.**

Note: Mean response of model-implied output and observables (infl ation and interest rate) to productivity growth, cost-push, and unanticipated monetary policy shocks. Solid Line: Perfectly Credible C.B. (i.e., $\tau = 0.98$). Dashed line: Not Perfectly Credible C.B. (i.e., Benchmark $\hat{\tau}$). C.B.: Central Bank.

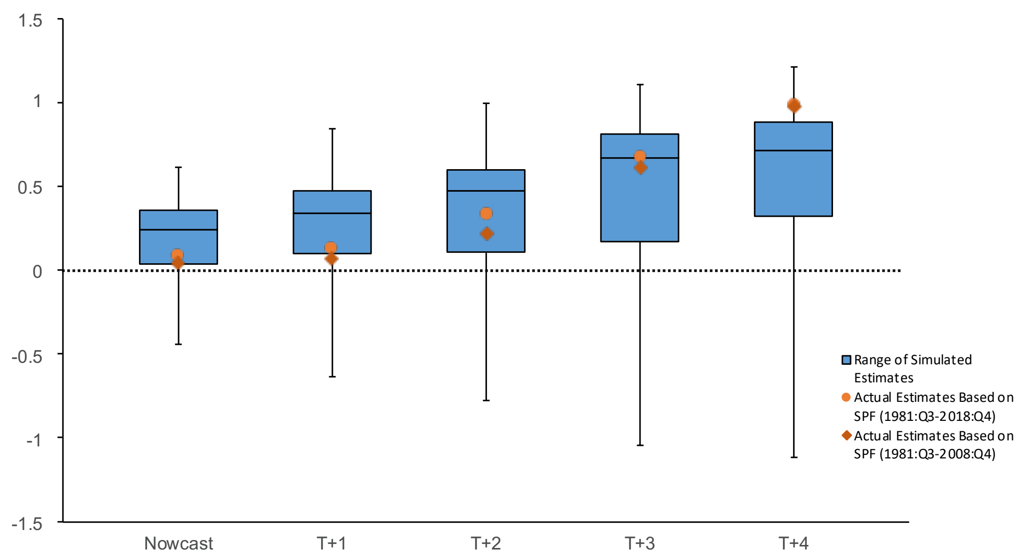

Figure 5: **Estimates of Forecasting Errors Relation to Forecasting Disagreement: Survey of Professional Forecasters (SPF) vs. Simulated Data.**

Sources: Survey of Professional Forecasters (SPF), simulated data based on the estimates of the benchmark model, author's calculations.
Note: Forecasting errors are computed with respect to the mean forecast with SPF data from 1981:Q3 until 2018:Q4 (150 observations). Forecasting disagreements are measured with the interquartile range of the cross-sectional distribution of individual forecasts in order to make the empirical results less sensitive to outliers. We regress forecasting errors on an intercept and this measure of forecasting disagreement for all available time horizons. We perform the same exercise on a rolling window of 150 observations from a simulated sample data of 2,000 observations. We represent the full range of rolling window estimates with a box-and-whisker plot that show their min, max, median, and interquartile range.