A Myopic Friction in US Business Cycles*

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Abstract

This paper studies the empirical fit of a standard dynamic stochastic general equilibrium (DSGE) model to US macroeconomic data altered by a bounded rationality assumption in agents' expectation formation. Bounded rationality is in the form of cognitive discounting, or "myopia", which quantifies how people pay less attention to events occurring further in the future. I use a Bayesian likelihood approach to compare the distribution of model parameters for when people are fully rational (i.e. rational expectations) and for when they are myopic. The behavioral model finds evidence of mild myopia in the US economy between 1966 and 2004 evidenced by a general decrease of posterior parameter distributions. However, the marginal likelihood criterion is modestly higher without myopia and thereby implies a better fit. The decrease in posterior distributions shows that the model is sensitive to expectations formations while the marginal like- lihood suggests that myopic behavior can be modeled differently to match the data.

Keywords: Expectations formation, cognitive discounting, Bayesian likelihood

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1 Introduction

People's expectations about the future are key drivers of the economy and understanding how people form these expectations is of interest to policymakers and academics alike. Many macroeconomic models based on assumptions of optimizing rational-expectations behavior have faced difficulties explaining key real world observations such as the lack of inertia in inflation and contradictions of aggregate supply to the NAIRU (Juillard, Kamenik, Kumhof, & Laxton, 2008). In the last 25 years, there has been a growing interest in how a more behavioral approach to macroeconomic modeling may provide new insights [De Grauwe (2012), Kagel and Roth (2016), see Driscoll and Holden (2014) for an extensive review]. An alternative to rational-expectations and reviewed since Conlisk (1996) has been bounded rationality and recent advancements in this topic have created a mathematical framework to quantify a form of bounded rationality via cognitive discounting, or "myopia". In this framework, people poorly understand events further into the future, which means there is an objective true value of the future and a perceived subjective value. One of the prominent tools in macroeconomic modeling is the dynamic stochastic general equilibrium (DSGE) model used for policy analysis and forecasting. Does incorporating cognitive discounting affect the empirical conclusions and properties of DSGE models?

A recent survey of macroeconomists revealed that the profession has generally agreed upon modifying the assumptions used in DSGE modeling, one of them being to relax the rational-expectations hypothesis.[1] This does not come without cause. Since the financial crisis of 2008, there has been a burgeoning literature reviewing how macroeconomics could predict and handle such an event. Equally as large has been the criticism that DSGE models have faced including their rational-expectations assumption [e.g. Blanchard (2016); Krugman (2018); Stiglitz (2018)]. DSGE models have been increasingly used ever since the seminal work done by Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). The latter, also referred to as SW07, is cited as the *proof of concept* that medium-scale DSGE models could be useful for policy analysis, forecasting, and story telling, due to their explicit assumptions about the optimizing behavior held by households, firms, and policymakers. SW07 create an economic model to match the behavior of seven

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[1] See Vines and Wills (2018) for the recent "Rebuilding Macroeconomic Theory" project.

macroeconomic variables for the US economy between 1966 and 2004. Each of the agent classes interact in markets that clear each period, thus are in "general equilibrium". In this paper, I use the standard DSGE model of SW07, given its influence, and how larger, operational DSGE models based off it are prominently used in central banks around the world.[2]

To test the sensitivity of DSGE models with respect to expectations formations, I follow a framework for cognitive discounting by Gabaix (2019), where people are not entirely forward-looking and shrink events happening in the future according to some level of myopia. The impact innovations, or events, happening k steps into the future have on people's expectations are shrunk by a factor $\bar{m}^k$ relative to the rational response. Consider a fully rational agent that would have no myopia; this could be considered as $\bar{m} = 1$. In this world, myopia is mathematically captured in $\bar{m} \in [0, 1]$; then, the closer to 0 (the more myopic), the less that events in the future matter. In a canonical, two-equation New Keynesian model, Gabaix shows that this cognitive discounting parameter solves a few of the puzzles that are inherent to the rational-expectations version, such as the forward guidance puzzle detailed in Del Negro, Giannoni, and Patterson (2012). Given how insightful cognitive discounting is in the context of that model, a natural next step is to bring that assumption into a larger context, such as a DSGE model.

The concept entails merging the myopia parameter into the DSGE framework of SW07 and estimating the behavioral and structural parameters jointly. I follow the Bayesian likelihood approach in SW07, using the Metropolis-Hastings algorithm to approximate the distribution of parameters in the model. By comparing the distributions between the standard model that replicates SW07 and the case with myopia, I find evidence of mild myopia in the US economy that changes some of the conclusions from the standard case. For instance, steady state labor and the elasticity of labor with respect to wage both fall, implying a smaller marginal rate of substitution between working and consuming. Monetary policy and price mark-up shocks also seem to be less persistent than the standard case. Despite this, the marginal likelihood of the myopic model, which captures the out-of-sample prediction performance of the model, is of a worse fit to the data than the

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[2] Including the Federal Reserve's EDO (Chung, Kiley, & Laforte, 2010), the European Central Bank's NAWN (Warne, Coenen, & Christoffel, 2008), and the Swedish Riksbank's RAMSES (Adolfson, Laséen, Lindé, & Svensson, 2011).

standard case. Together, these results suggest that a different way of accounting for myopic behavior may be more appropriate. In the context of the model, myopia is solved under a general equilibrium approach incorporating all of the nominal frictions and shock processes of the SW07 model; the approach taken here assumes that myopia occurs alongside all of these dynamic components, though a worthwhile extension of this would be to estimate myopic behavior in settings without many frictions.

The role of expectations. Figure 1 illustrates the importance of expectations in a basic DSGE framework. The three main building blocks can be labeled Demand, Supply, and Monetary Policy. Demand determines real activity (Y_t) as a function of the expectations about future real activity (Y_{t+1}) and the ex ante real interest rate. Real activity and the expectations of future inflation (π_{t+1}) are used in determining present inflation (π_t) in the aggregate Supply block. Higher expected inflation due to increased output in the future will raise prices and contribute to rising inflation in the present. Demand and Supply feed into Monetary Policy which determines the nominal interest rate (i_t). When the economy overheats (i.e. inflation rises), the central bank will tend to raise this interest rate in order to bring inflation down.

The green block in the middle are the expectations about the future that are formed by consumers and firms, which are an essential determinant to today's outcomes. In modeling the economy, this central role played by the expectations influences the way the future plays out. For instance, central banks would like to ensure expectations are well anchored so that they can pursue active stabilization policy in the short run without setting off panics or changing people's expectations such that the policy is ineffective. The rational-expectations approach assumes that the economy is well behaved, that expectations take into account all information into the future, and that fluctuations are driven by exogenous disturbances (i.e. the different shocks in the chart). In this manner, the traditional DSGE models test which disturbances (and frictions) are important. However, this is a joint test on the bigger assumption of rational-expectations, and, by changing the expectations assumptions, the interpretations of which shocks are important may greatly differ as is documented in Milani and Rajbhandari (2012) and De Grauwe (2012). Bounded rationality allows for an exploration into a scenario where the economy is not inherently well behaved without the need for exogenous shocks to explain fluctuations.

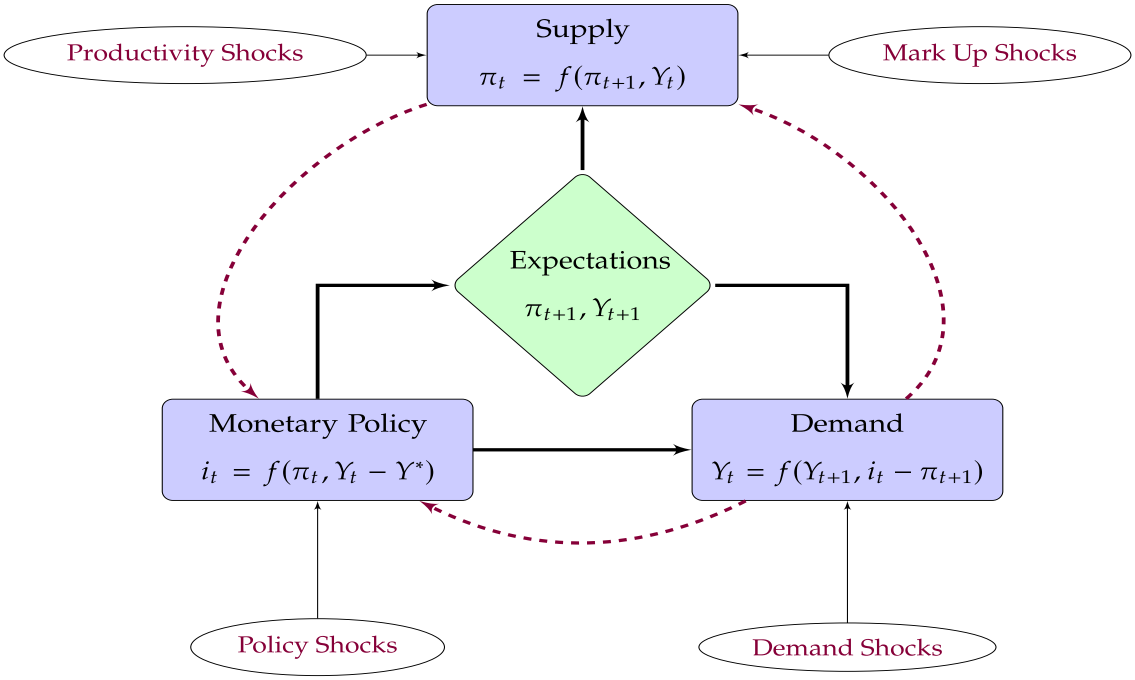

FIGURE 1: Basic DSGE modeling flowchart with Demand, Supply, and a Monetary Policy block determining real activity, inflation, and the interest rate, respectively. Expectations about the future play a central role in determining today's outcomes.

Links with the literature. This paper is related to the growing behavioral macroeconomics literature. The contributions of behavioral economics to macro are reviewed in Driscoll and Holden (2014), and there are many ways to model bounded rationality using different specifications. This particular way with cognitive discounting is an applied macro follow-up to the "sparsity" theory approach developed extensively in Gabaix (2014) and research in behavioral inattention (Gabaix, 2017; Caplin, Csaba, Leahy, & Nov, 2018). The sparsity approach is one that is also applicable for macro contexts in dynamic programming (Gabaix, 2016), as well as in public economics literature dealing with taxes (Farhi & Gabaix, 2020).

This paper most closely aligns with the macro literature that drops the rational expectations hypothesis [see Woodford (2013) for a review]. Popular deviations include a large learning literature (Evans & Honkapohja, 2001; Branch & McGough, 2009; Massaro, 2012; Eusepi & Preston, 2018), incomplete information and higher order beliefs [reviewed in (Angeletos & Lian, 2016)], and experimental economics using household surveys to build theories on expectations formations (Assenza, Heemeijer, Hommes, & Massaro, 2011; Ormeño & Molnár, 2015; Kuchler & Zafar, 2015). Fully forward-looking agents as prescribed in DSGE models have been found to be viable only if the disturbances to the main blocks of the economy are transitory and recurrent enough so that people learn the serial correlation of the shocks from experience. Additionally, were fully forward-looking agents the case, there would be no volatility in macroeconomic variables once the shocks have been partitioned out of the data (Woodford, 2019). Instead, research by De Grauwe (2012) and Jump and Levine (2019) suggests that there is excess volatility even without the shocks. Additionally, Ascari, Magnusson, and Mavroeidis (2019) find that the traditional forward-looking household Euler equation poorly fits aggregate US consumption time series without the need for shocks, further implying the existence of an endogenous source of volatility.

Cognitive discounting has been part of the limited information discussion [e.g. Angeletos and Huo (2018)] and most recently has been incorporated into research determining its existence in the US economy. Andrade, Cordeiro, and Lambais (2019) use the same set-up for the two-equation New Keynesian model as in Gabaix (2019) to estimate behavioral versions of the New Keynesian Phillips Curve and the IS curve using robust maximum likelihood inference. They use the Effective Federal Funds Rate, the output gap, and the inflation rate, using detrended data available from the period 1962:Q2 – 2016:Q4, and find that myopia is located somewhere between 0.8 and 1 for the behavioral IS curve and between 0.14 and 0.95 for the New Keynesian Phillips Curve. While they did not conclude on where the parameter exists in the model, their results strongly suggest the existence of myopia under robust identification techniques. Ilabaca, Meggiorini, and Milani (2020) find substantial degrees of myopia between 1954 and 2007 using Bayesian estimation of a Behavioral three-equation New Keynesian model. Their findings suggest that the presence of myopia prevents the economy from falling into indeterminacy during periods of volatile inflation targeting. In short, these papers not only suggest that the cognitive discounting parameter exists, but that it also fundamentally changes determinacy and equilibrium of a model. Building off these advancements, this paper is the first, to my knowledge, to apply this particular cognitive discounting framework to a medium-scale DSGE model as in SW07.

Section 2 introduces the linearized DSGE model with cognitive discounting and is followed by the estimation procedure in section 3 and results in section 4. Section 5 concludes.

2 A Myopic DSGE Model

This section outlines the basic model setup as in Smets and Wouters (2007) and then merges cognitive discounting in expectations formation following the framework in Gabaix (2019). Conceptually, the model incorporates the three basic blocks of the DSGE flowchart previously detailed.[3]

On the Demand side, the model includes households who choose between consumption and investment decisions. Households maximize their non-separable utility over preferences on consumption (with time-varying habits) and hours worked over an infinite time horizon. Households further rent capital services to firms and accumulate capital based on the amount of capital adjustment costs. On the Supply side, the model includes intermediate and final goods producers, as well as an intermediate labor union. Firms produce differentiated goods and decide on the amount of capital and labor to use as well as the amount of capital services to obtain from the households. Firms also show some degree of monopoly power and set prices according to a staggered Calvo pricing scheme to allow for sticky nominal prices, making them a function of current and expected marginal costs (which are, in turn, functions of wages and the rental rate of capital). Labor from the households is supplied to an intermediate labor union that sets wages according to a staggered Calvo wage scheme to allow for sticky nominal wages.[4] In effect, this assures some degree of monopoly power over wages as it makes them a function of past and expected wages. For both prices and wages, there is a partial indexation to past inflation when either the firms or union do not re-optimize their price/wage decisions in a given period. The Monetary Policy in this model is outlined by a central bank that sets the nominal interest rate according to changes in inflation and the output gap. This output gap is the difference between actual output and potential output that would occur in the

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[3] For a detailed description of the decisions faced by each set of agents in this model, please see the Model Appendix of Smets and Wouters (2007) available at `https://assets.aeaweb.org/asset-server/articles-attachments/aer/data/june07/20041254_app.pdf`.

[4] This follows the seminal work done by Calvo (1983).

absence of any stickiness (i.e. under a flexible price and wage scheme).

At equilibrium (steady-state), the model is consistent with a growth path driven by a deterministic, or already established, labor-augmenting technological progress. This implies that the technology makes each worker more productive over time. The model is log-linearized around this steady-state growth path and presented below, again in sections following Demand, Supply, and Monetary Policy. A brief description of parameters is included after each respective section.

Aggregate Demand. The model first includes an aggregate resource constraint that details how output (y_t) is absorbed by consumption (c_t), investment (i_t), capital utilization costs (z_t), and exogenous spending (ε_t^g):

$$y_t = c_y c_t + i_y i_t + z_y z_t + \varepsilon_t^g \tag{1}$$

with

$$c_y = 1 - g_y - i_y \qquad \text{and} \qquad i_y = (\gamma - 1 + \delta) k_y$$

The steady state share of output from consumption, exogenous spending, investment, and capital is given by c_y, g_y, i_y, k_y respectively. Exogenous spending is assumed to follow an AR(1) process with an IID-Normal error term and is affected by a productivity shock. This latter shock is motivated by the fact that exogenous spending includes net exports which may be affected by domestic productivity developments; the process follows: $\varepsilon_t^g = \rho_g \varepsilon_{t-1}^g + \eta_t^g + \rho_{ga} \eta_t^a$.

From the household's maximization of utility, the consumption Euler equation is solved to give the dynamics of current consumption which depends on a weighted average of past and expected future consumption ($c_{t-1}, \mathrm{E}_t(c_{t+1})$), the growth in hours worked ($l_t - \mathrm{E}_t(l_{t+1})$), the ex ante interest rate ($r_t - \mathrm{E}_t(\pi_{t+1})$), and a disturbance term that can be likened to an external finance premium (ε_t^b) :

$$c_t = \left(\frac{\lambda}{\gamma+\lambda}\right) c_{t-1} + \left(\frac{\gamma}{\gamma+\lambda}\right) \mathrm{E}_t(c_{t+1}) + \left[\frac{(\sigma_c - 1)\left(\frac{W_*^h L_*}{C_*}\right)}{\sigma_c\left(1+\frac{\lambda}{\gamma}\right)}\right] [l_t - \mathrm{E}_t(l_{t+1})] - \left[\frac{1-\frac{\lambda}{\gamma}}{\sigma_c\left(1+\frac{\lambda}{\gamma}\right)}\right] \left[r_t - \mathrm{E}_t(\pi_{t+1}) + \varepsilon_t^b\right] \quad (2)$$

The starred variables refer to the steady state actual (non-logged) values for wages, labor, and consumption. The external finance premium is designed to act like a wedge between the central bank interest rate and the return on assets held by the households; it also follows an AR(1) process with an IID-Normal error term: $\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b$.

Similar to consumption, the investment Euler equation is solved to give the dynamics of current investment. The current investment dynamics are dependent on past and future investment (i_{t-1}, i_{t+1}), the value of existing capital stock (q_t), and a disturbance to the investment specific technology process (ε_t^i):

$$i_t = \left(\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right) i_{t-1} + \left(\frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}\right) \mathrm{E}_t(i_{t+1}) + \left(\frac{1}{(1+\beta\gamma^{1-\sigma_c})\gamma^2\varphi}\right) q_t + \varepsilon_t^i \quad (3)$$

The technology process follows an AR(1) process with an IID-Normal error term such that $\varepsilon_t^i = \rho_i \varepsilon_{t-1}^i + \eta_t^i$.

The value of capital stock follows an arbitrage condition dependent on its expected future value (q_{t+1}), the expected future rental rate of capital (r_{t+1}^k), the ex ante interest rate as was seen in the dynamics for consumption, and the external finance premium that was also seen in the dynamics for consumption:

$$q_t = \beta\gamma^{1-\sigma_c}(1-\delta)\mathrm{E}_t(q_{t+1}) + \left[1-\beta\gamma^{1-\sigma_c}(1-\delta)\right] \mathrm{E}_t(r_{t+1}^k) - \left[r_t - \mathrm{E}_t(\pi_{t+1}) + \varepsilon_t^b\right] \quad (4)$$

Aggregate Supply. The Supply side first begins with aggregate production that determines output as a function of current capital services (k_t^s) and hours worked (l_t), as

Structural Parameters for Demand

γ	steady-state growth rate	δ	rate of depreciation on capital
ρ_g	AR coefficient (persistence of last period exog. spending disturbance)	ρ_{ga}	persistence of total factor productivity shock
λ	degree of habit persistence in consumption	σ_c	inverse of Intertemporal Elasticity of Substitution for constant labor
ρ_b	AR coefficient (persistence of last period premium disturbance)	ρ_i	AR coefficient (persistence of last period disturbance to investment)
φ	steady-state elasticity of capital adjustment	β	household discount factor

well as total factor productivity disturbance (ε_t^a):

$$y_t = \phi_p(\alpha k_t^s + (1-\alpha)l_t + \varepsilon_t^a) \tag{5}$$

Total factor productivity follows an AR(1) process with an IID-Normal error term: $\varepsilon_t^a = \rho_a \varepsilon_{t-1}^a + \eta_t^a$.

Current capital services (k_t^s) used in production are themselves a function of the capital that was installed last period (k_{t-1}) and a degree of capital utilization (z_t). The latter is a function of the rental rate of capital given that capital utilization is derived from the household's cost minimizing problem:

$$k_t^s = k_{t-1} + z_t \tag{6}$$

$$z_t = \left(\frac{1-\psi}{\psi}\right) r_t^k \tag{7}$$

Conversely, cost minimization by the firms will imply a rental rate of capital determined by the capital-labor ratio and real wage (w_t):

$$r_t^k = w_t + l_t - k_t \tag{8}$$

The accumulation of installed capital is a function of investment (i_t), past capital (k_{t-1}), and the investment specific technology process disturbance to capture the efficiency of investment:

$$k_t = \left(\frac{1-\delta}{\gamma}\right) k_{t-1} + \left(\frac{\gamma - 1 + \delta}{\gamma}\right) i_t + \left[(\gamma - 1 + \delta)(1 + \beta\gamma^{1-\gamma_c})\gamma\varphi\right] \varepsilon_t^i \tag{9}$$

In the monopolistically competitive goods market that the firms exist in, their cost minimization will result in a price mark-up (μ_t^p) equal to the difference between their marginal product of labor (mpl_t) and the real wage paid to that labor:

$$\mu_t^p = mpl_t - w_t = \alpha(k_t^s - l_t) + \varepsilon_t^a - w_t \tag{10}$$

In turn, profit maximization happens through the Calvo price stickiness framework and subject to partial indexation to past inflation for when prices cannot be re-optimized. This ensures that prices adjust slowly to their mark-up as defined above. Solving for the optimal pricing decisions and accounting for this stickiness gives the New Keynesian Phillips Curve as a function of past and expected future inflation ($\pi_{t-1}, \mathrm{E}_t(\pi_{t+1})$), the price mark-up, and a price mark-up disturbance (ε_t^p):

$$\begin{aligned}\pi_t = &\left(\frac{\iota_p}{1 + \beta\gamma^{1-\gamma_c}\iota_p}\right)\pi_{t-1} + \left(\frac{\beta\gamma^{1-\gamma_c}}{1 + \beta\gamma^{1-\gamma_c}\iota_p}\right)\mathrm{E}_t(\pi_{t+1}) \\ &- \left[\left(\frac{1}{1 + \beta\gamma^{1-\gamma_c}\iota_p}\right)\left(\frac{(1 - \beta\gamma^{1-\gamma_c}\xi_p)(1 - \xi_p)}{\xi_p[(\phi_p - 1)\varepsilon_p + 1]}\right)\right]\mu_t^p + \varepsilon_t^p\end{aligned} \tag{11}$$

Without inflation indexation, the Phillips curve becomes purely forward-looking; with indexation, the curve is assured to become vertical in the long run. The speed of price adjustment to the mark-up depends, in part, on price stickiness, the Kimball goods market aggregator (ε_p), and the steady-state price mark-up. The price mark-up disturbance follows an ARMA(1,1) process with an IID-Normal error term and a moving average component to capture high frequency fluctuations in inflation: $\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \eta_t^p - \mu_p \eta_{t-1}^p$.

Analogous to the monopolistic goods market is the monopolistic labor market where the union will set a wage mark-up equal to the difference between the real wage and the marginal rate of substitution between working and consuming:

$$\mu_t^w = w_t - mrs_t = w_t - \left[\sigma_l l_t + \frac{\gamma}{\gamma - \lambda}\left(c_t - \frac{\lambda}{\gamma c_{t-1}}\right)\right] \tag{12}$$

Similar to firm prices, real wages will also adjust slowly to their mark-up as defined above. Solving for real wages, we find that it is a function of past and expected future wages (w_{t-1}, w_{t+1}), past, present and expected future inflation, the wage mark-up, as well as a wage mark-up disturbance:

$$\begin{aligned} w_t = \left(\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right) w_{t-1} + \left(\frac{\beta\gamma^{1-\sigma_c}}{1+\beta\gamma^{1-\sigma_c}}\right)\left[\mathrm{E}_t(w_{t+1}) + \mathrm{E}_t(\pi_{t+1})\right] \\ - \left(\frac{1+\beta\gamma^{1-\sigma_c}\iota_w}{1+\beta\gamma^{1-\sigma_c}}\right)\pi_t + \left(\frac{\iota_w}{1+\beta\gamma^{1-\sigma_c}}\right)\pi_{t-1} \\ - \left[\left(\frac{1}{1+\beta\gamma^{1-\sigma_c}}\right)\left(\frac{(1-\beta\gamma^{1-\sigma_c}\xi_w)(1-\xi_w)}{\xi_w[(\phi_w - 1)\varepsilon_w + 1]}\right)\right]\mu_t^w + \varepsilon_t^w \end{aligned} \tag{13}$$

Without inflation indexation, real wages are not dependent on lagged inflation. The speed of wage adjustment to the mark-up depends, in part, on wage stickiness, the Kimball labor market aggregator (ε_w), and the steady-state wage mark-up. The wage mark-up disturbance also follows an ARMA(1,1) process with an IID-Normal error term and a moving average term capturing high frequency fluctuations in wages: $\varepsilon_t^w = \rho_w \varepsilon_{t-1}^w + \eta_t^w - \mu_w \eta_{t-1}^w$.

Structural Parameters for Supply

ϕ_p	reflects fixed costs in production	ρ_a	AR coefficient (persistence of last period total factor productivity disturbance)
ψ	elasticity of cap. utilization adjust. cost (↑ ψ → more costly to change)	ι_p	degree of inflation indexation for prices
ξ_p	degree of price stickiness	ρ_p	AR coefficient (persistence of last price mark-up)
μ_p	MA coefficient to capture high fluctuations in inflation	σ_l	elasticity of labor with respect to wage
ι_w	degree of inflation indexation for wages	ξ_p	degree of wage stickiness
ρ_w	AR coefficient (persistence of last wage mark-up)	μ_w	MA coefficient to capture high fluctuations in wages
α	the share of capital used in production	$\bar{l}$	steady-state labor hours worked, normalized to equal zero

Monetary Policy. The model gets closed with a monetary policy reaction function that captures changes in inflation and the output gap, as well as a monetary policy disturbance (ε_t^r):

$$r_t = \rho r_{t-1} + (1-\rho)\left[r_\pi \pi_t + r_y(y_t - y_t^p)\right] + r_{\Delta y}\left[(y_t - y_t^p) - (y_{t-1} - y_{t-1}^p)\right] + \varepsilon_t^r \tag{14}$$

The output gap is the difference between actual output and potential output (y^p) that would occur in the absence of any stickiness (i.e. under a flexible price and wage scheme). The policy disturbance follows an AR(1) process with an IID-Normal error term: $\varepsilon_t^r = \rho_r \varepsilon_{t-1}^r + \eta_t^r$.

Structural Parameters for Monetary Policy

ρ	last period interest rate smoothing parameter	r_π	persistence of inflation on monetary policy
r_y	persistence of output gap on monetary policy	$r_{\Delta y}$	persistence of short-run feedback in output gap on monetary policy
ρ_r	AR coefficient (persistence of last policy disturbance)		

The model thus far has 14 equations and 14 endogenous variables (y_t, c_t, i_t, q_t, k_t^s, k_t, z_t, r_t^k, μ_t^p, π_t, μ_t^w, w_t, l_t, r_t). Additionally, there are 29 structural parameters and seven exogenous disturbances which include the exogenous spending, the total factor productivity, the external finance premium, the investment specific technology, the price mark-up, the wage mark-up, and the monetary policy shocks (ε_t^g, ε_t^a, ε_t^b, ε_t^i, ε_t^p, ε_t^w, ε_t^r).

Cognitive Discounting. Under cognitive discounting, people do not fully understand the world they are in, especially when events are far off into the future. People receive noisy signals about the true objective value of the steady-state through a subjective view dampened by myopia. This dampening can be thought mathematically as a shrinkage from the true steady-state. Theory wise, this is presented in the following lemma by Gabaix (2019):

Lemma 2.2: *For any variable* $z(X_t)$ *with* $z(0) = 0$*, the beliefs of the behavioral agent satisfy, for all* $k \geq 0$*, the following linearized relationship*:

$$\mathrm{E}_t^{BR}[z(X_{t+k})] = \bar{m}^k \mathrm{E}_t[z(X_{t+k})] \tag{15}$$

Cognitive discounting, or myopia, is captured by an $\bar{m}$ parameter between 0 and 1. The k refers to the number of steps into the future such that a higher k will be discounted far more relative to the fully rational response if the person is more myopic. Consider the lemma using the following thought experiment which involves any state variable Φ such that it has an expected value of 0.[5] Then, at time zero, a person who receives a noisy signal S_1 about tomorrow can either get the true value presented to them (Φ_1) with a probability q or an incorrect idea (Φ_1') with probability $1 - q$. Then,

$$S_1 = \begin{cases} \Phi_1, & \text{w.p. } q \\ \Phi_1', & \text{w.p. } 1 - q \end{cases}$$

Under rational-expectations, we assume that the correct value of the future is known such that the expected value of the noisy signal is $\mathrm{E}[S_1|\Phi_1] = q\Phi_1 + (1-q)\mathrm{E}[\Phi_1'] = q\Phi_1$, given that $\bar{\Phi} = 0$. This establishes that the perceived value given the true value will be dependent on the probability that the true value occurs. On average, however, the expected perceived true value will be

$$\mathrm{E}[\Phi_1^e(S_1)|\Phi_1] = \mathrm{E}[qS_1|\Phi_1] = q\mathrm{E}[S_1|\Phi_1] = q^2\Phi_1 \implies \bar{m}\Phi_1 \implies \bar{m}F(\Phi_0, \varepsilon_1)$$

where the perceived true value of the state variable is a function F using the initial value given and some disturbance. People shrink tomorrow's expectation about the future to some degree of the probability that they will know the true value of tomorrow, but in this case we think about this probability to reflect myopia. If we were to always know the truth, then we would not be myopic and fall back into rational-expectations.

Using this framework, we can incorporate cognitive discounting into the dynamics of consumption (for the output gap) and inflation giving myopically behavioral versions of 2 and 11:

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[5] A similar exposition is found in Gabaix's paper, Appendix 9.1.

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\begin{aligned}
c_t = \left(\frac{\lambda}{\gamma+\lambda}\right) c_{t-1} + \left(\frac{\gamma\bar{m}}{\gamma+\lambda}\right) \mathrm{E}_t(c_{t+1}) + \left[\frac{(\sigma_c - 1)\left(\frac{W_*^h L_*}{C_*}\right)}{\sigma_c\left(1+\frac{\lambda}{\gamma}\right)}\right] [l_t - \mathrm{E}_t(l_{t+1})] \\
- \left[\frac{1-\frac{\lambda}{\gamma}}{\sigma_c\left(1+\frac{\lambda}{\gamma}\right)}\right] \left[r_t - \mathrm{E}_t(\pi_{t+1}) + \varepsilon_t^b\right] \quad (16)
\end{aligned}
$$

$$
\begin{aligned}
\pi_t = \left(\frac{\iota_p}{1+\beta\gamma^{1-\gamma_c}\iota_p}\right) \pi_{t-1} + \left(\frac{\beta\gamma^{1-\gamma_c} M^f}{1+\beta\gamma^{1-\gamma_c}\iota_p}\right) \mathrm{E}_t(\pi_{t+1}) \\
- \left[\left(\frac{1}{1+\beta\gamma^{1-\gamma_c}\iota_p}\right)\left(\frac{(1-\beta\gamma^{1-\gamma_c}\xi_p)(1-\xi_p)}{\xi_p[(\phi_p - 1)\varepsilon_p + 1]}\right)\right] \mu_t^p + \varepsilon_t^p \quad (17)
\end{aligned}
$$

where inflation takes accounts for the Calvo pricing scheme and incorporates an M^f parameter that is a function of $\bar{m}$ and price stickiness.[6]

3 Estimation Method

The model presented in the previous section is estimated using observable quarterly U.S. time series data ranging from 1966Q1 – 2004Q4. The data was collected from the U.S. Department of Commerce, Department of Labor, and the Board of Governors of the Federal Reserve System.[7] Using 1996 as a base year, the data for real output, real consumption, real investment, real wages, and the GDP deflator (inflation) is log differenced. Labor hours are taken as 100 times log, and the Federal Funds Rate is divided into quarters to capture the

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[6] Define $M^f = \bar{m}\left[\xi_p + \frac{(1-\beta\xi_p)(1-\xi_p)}{1-\beta\xi_p\bar{m}}\right]$ as the added component to the myopic equation for inflation. Were $\bar{m} = 1$, the equations become the standard purely forward-looking ones from the original model.

[7] For a full description of the data, see the Model Appendix given by Smets and Wouters (2007).

quarterly interest rate. The measurement equation can then be shown as:

$$Y_t = \begin{bmatrix} dlGDP_t \\ dlC_t \\ dlI_t \\ dlW_t \\ lL_t \\ dlP_t \\ FFR_t \end{bmatrix} = \begin{bmatrix} \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{\gamma} \\ \bar{l} \\ \bar{\pi} \\ \bar{r} \end{bmatrix} + \begin{bmatrix} y_t - y_{t-1} \\ c_t - c_{t-1} \\ i_t - i_{t-1} \\ w_t - w_{t-1} \\ l_t \\ \pi_t \\ r_t \end{bmatrix}$$

where $\bar{\gamma}$ is the steady-state quarterly growth rate of GDP, consumption, investment, and wages; $\bar{l}$ is the steady-state labor hours worked, normalized to zero; $\bar{\pi}$ is the steady-state inflation rate; and $\bar{r}$ is the steady-state nominal interest rate.

Using Bayesian likelihood, the method requires maximizing the log posterior function and then using the Metropolis-Hastings algorithm to derive the full posterior distribution of the parameters and the marginal likelihood of the model which captures its out-of-sample prediction performance. This approach assumes that the true values of the structural parameters and shocks come from the prior probability distributions and means. These priors for the structural parameters are fully detailed in Smets and Wouters (2007), section II.A, and I follow the priors closely. The prior for cognitive discounting is taken from Ilabaca et al. (2020) who find substantial degrees of myopia in the US economy using a sample range from 1954 – 2007. A sample of 250,000 draws by the algorithm are generated with the first 50,000 being neglected. The model is estimated with and without myopia so that there can be a fruitful comparison between the parameters and the shocks.

4 Parameter Estimates & Results

Table 1 gives the posterior results for the model structural parameters. The columns have the prior distributions, the posterior distributions (without myopia and then with myopia), and a column showing the direction change of the means as we go from without myopia to with myopia. The prior column includes the distribution type, the prior mean, and the

Prior and Posterior Distribution of Structural Parameters

		Prior		*Posterior without Myopia*			Posterior with Myopia			Δ
	Distr.	Mean	St. Dev.	*Mean*	5%	95%	Mean	5%	95%	
$\bar{m}$	Beta	0.80	0.15	1	1	1	0.98	0.96	0.99	↓
φ	Normal	4.00	1.50	5.74	3.97	7.42	5.98	4.22	7.65	↑
σ_l	Normal	2.00	0.75	1.83	0.91	2.78	1.59	0.66	2.52	↓
r_π	Normal	1.50	0.25	2.04	1.74	2.33	1.97	1.68	2.26	↓
$\bar{\pi}$	Gamma	0.62	0.10	0.78	0.61	0.96	0.74	0.57	0.91	↓
$\bar{l}$	Normal	0.00	2.00	0.53	-1.30	2.32	0.21	-1.27	1.64	↓
σ_c	Normal	1.50	0.37	1.38	1.16	1.59	1.40	1.18	1.61	–
λ	Beta	0.70	0.10	0.71	0.64	0.78	0.71	0.64	0.77	–
ξ_w	Beta	0.50	0.10	0.70	0.60	0.81	0.70	0.60	0.81	–
ξ_p	Beta	0.50	0.10	0.66	0.56	0.74	0.64	0.56	0.72	–
ι_w	Beta	0.50	0.15	0.58	0.38	0.78	0.56	0.36	0.77	–
ι_p	Beta	0.50	0.15	0.24	0.10	0.38	0.27	0.11	0.41	–
ψ	Beta	0.50	0.15	0.54	0.36	0.72	0.50	0.32	0.68	–
ϕ_p	Normal	1.25	0.12	1.60	1.48	1.73	1.58	1.46	1.71	–
ρ	Beta	0.75	0.10	0.81	0.77	0.85	0.81	0.77	0.85	–
r_y	Normal	0.12	0.05	0.08	0.05	0.12	0.08	0.04	0.12	–
$r_{\Delta y}$	Normal	0.12	0.05	0.22	0.18	0.27	0.23	0.19	0.28	–
$100(\beta^{-1}-1)$	Gamma	0.25	0.10	0.16	0.07	0.26	0.17	0.08	0.27	–
$\bar{\gamma}$	Normal	0.40	0.10	0.43	0.40	0.45	0.42	0.40	0.45	–
α	Normal	0.30	0.05	0.19	0.16	0.21	0.18	0.16	0.21	–

Table 1: Posterior distributions of structural parameters given by the Metropolis-Hastings algorithm.

standard deviation. The posterior distributions without myopia (shown in *italics*) and with myopia include the posterior mean without myopia and the 90% high density interval (HDI) or credible interval. The HDI captures the range of values on the posterior probability distribution that includes 90% of the probability, meaning there is a 90% probability that the population parameter exists in this interval.

The first row here is the cognitive discounting parameter for myopia. The data permits fairly tight identification of mild myopia with a mean of 0.98 which is very close to the benchmark case of 1. The only other parameter whose identification became substantially tighter under myopia was that of the steady-state labor $\bar{l}$; its posterior mean also fell substantially. With this and a lower elasticity of labor with respect to wage (σ_l), the data suggests that myopia causes labor at the intensive margin to fall. People value leisure more today than they do consumption today given any shocks to both in the future. Other parameters such as the steady-state inflation and the weight monetary policy puts on fluctuations in inflation weakly fell and have only marginally tighter identification than in

PRIOR AND POSTERIOR DISTRIBUTION OF SHOCK PROCESSES

		Prior		*Posterior without Myopia*			Posterior with Myopia			Δ
	Distr.	Mean	St. Dev.	*Mean*	5%	95%	Mean	5%	95%	
ρ_r	Beta	0.50	0.20	0.15	0.04	0.24	0.14	0.04	0.23	↓
ρ_p	Beta	0.50	0.20	0.89	0.80	0.96	0.87	0.78	0.96	↓
σ_a	Invgamma	0.10	2.00	0.45	0.41	0.50	0.46	0.42	0.51	↑
σ_i	Invgamma	0.10	2.00	0.45	0.37	0.53	0.44	0.36	0.52	↓
σ_p	Invgamma	0.10	2.00	0.14	0.11	0.16	0.15	0.12	0.17	↑
ρ_a	Beta	0.50	0.20	0.95	0.94	0.97	0.95	0.93	0.97	–
ρ_b	Beta	0.50	0.20	0.22	0.07	0.36	0.22	0.07	0.36	–
ρ_g	Beta	0.50	0.20	0.97	0.96	0.99	0.97	0.96	0.99	–
ρ_i	Beta	0.50	0.20	0.71	0.61	0.80	0.72	0.62	0.82	–
ρ_w	Beta	0.50	0.20	0.96	0.94	0.99	0.97	0.95	0.99	–
μ_p	Beta	0.50	0.20	0.69	0.54	0.85	0.67	0.52	0.84	–
μ_w	Beta	0.50	0.20	0.84	0.75	0.93	0.84	0.75	0.94	–
ρ_{ga}	Normal	0.50	0.20	0.52	0.37	0.66	0.51	0.37	0.66	–
σ_b	Invgamma	0.10	2.00	0.23	0.19	0.27	0.24	0.20	0.28	–
σ_g	Invgamma	0.10	2.00	0.53	0.48	0.58	0.53	0.48	0.58	–
σ_r	Invgamma	0.10	2.00	0.24	0.22	0.27	0.24	0.22	0.27	–
σ_w	Invgamma	0.10	2.00	0.24	0.20	0.28	0.24	0.20	0.27	–

TABLE 2: Posterior distributions of structural shocks given by the Metropolis-Hastings algorithm.

the case without myopia. The elasticity of capital adjustment costs is the only parameter that increased substantially (though its identification range stayed the same) and its increase implies that there is more sensitivity to cost changes and therefore more sluggishness under myopia. The degree of wage and price stickiness (ξ_w, ξ_p) still seem higher than the prior of 0.50, though without much change between the case with and without myopia. Monetary policy still does not seem to react much to the present output gap (r_y) but does react to short-run changes in the output gap ($r_{\Delta y}$). All other parameters were fairly in line to the benchmark model of no myopia with a steady-state inflation rate of 2.96% annually.

Table 2 is a mixed bag with only modest differences between the case with and without myopia. The AR coefficients for monetary policy and price mark-up shocks decreased, implying less persistence over time for both, and both generated tighter identification. The mild changes to these may be explained by the fact that the model captured mild degrees of myopia. There was little to no change in the distribution to the finance premium, exogenous spending, monetary policy, and wage mark-up shocks. The total factor productivity, exogenous spending, and wage mark-up processes are still the most persistent (ρ_a, ρ_g, ρ_w). The mean of the standard errors to the shocks (σ_a, σ_i, σ_p, σ_l, σ_g, σ_r, σ_w) did not change

Comparison of the Marginal Likelihood

Order of the VAR	No Other Prior	Sims and Zha (1998) prior
VAR(1)	-928.0	-940.9
VAR(2)	-966.6	-915.8
VAR(3)	-1018.1	-908.7
VAR(4)	-1131.2	-906.6
VAR(5)	–	-907.7
DSGE w/o Myopia	-905.8	-905.8
DSGE w/ Myopia	-922.3	–

Table 3: Comparing the Marginal Likelihood of Alternative VAR models and a DSGE model with and without myopia.

from the case without myopia.

Table 3 shows the comparison of the out-of-sample forecast performance of various VARs and the DSGE model with and without myopia captured by the marginal likelihood statistic. The procedure in Smets and Wouters (2007) has the models estimated under the 1966Q1 – 2004Q4 range with a training sample from 1956Q1 – 1965Q4. The two priors used in the paper use the prior outlined in the preceding tables and one set forth in the Bayesian VAR of Sims and Zha (1998) who incorporate degrees of persistence and co-integration of the variables into their prior. The DSGE model with myopia is not trained on this other prior. Comparison of the marginal likelihoods of the VARs and the DSGE models show that the DSGE with myopia does better than all the VARs in fitting the data with a marginal likelihood of -922.3 but does worse than without myopia whose marginal likelihood was -905.8.

5 Conclusion

This paper set out to determine whether cognitive discounting, or myopia, in expectations formation affected the conclusions reached by a standard DSGE model and whether it would provide a better fit to the data than under rational-expectations. It is the first attempt at merging the recent framework for bounded rationality Gabaix (2019) into a medium-scale DSGE model by Smets and Wouters (2007). By estimating the myopic DSGE model using seven US macroeconomic variables between 1966 and 2004, the results suggest that incorporating cognitive discounting generally decreases the posterior distribution means of the structural parameters relative to a case without myopia. This implies that the empirical conclusions of the DSGE model are affected by the assumptions in expectations formation.

Myopia appears to exist in a mild form close to a value of 1, although with a tighter identification than related literature between 0.96 and 0.99. Labor at the intensive margin has fallen with myopia and there is a smaller marginal rate of substitution between working and consuming. With a shrinkage factor of the future, people's time horizon that they use to drive them in satisfying a certain level of consumption becomes smaller and thus are less willing to trade leisure for consumption as implied by the lower steady-state labor hours. Myopia does not seem to improve analysis of the processes for the exogenous shock variables but does imply less persistence of a monetary and price mark-up shocks over time. Despite these conclusions, the marginal likelihood comparison shows that the model with myopia does not produce a better fit to the data than the model without myopia, though its fit is only marginally worse. One possible explanation for this could be that additional steps are required in merging the bounded rationality framework in order to fully incorporate cognitive discounting in the DSGE model.

Asides from a more robust merger of cognitive discounting into the dynamics of the DSGE model, this paper furthers the discussion of how to drop the rational-expectations assumption in macroeconomics. As an additional exercise of this paper, training the myopic DSGE model using different priors and further analyzing the forecast variance decomposition can give a clearer picture of just how far reaching the implications of adding myopia are in the evolution of macroeconomic variables. Beyond this paper, a fruitful exercise may be to modify the assumptions of cognitive discounting and add in other recent work such as anchoring into the behavioral aspects of this approach.

References

Adolfson, M., Laséen, S., Lindé, J., & Svensson, L. E. (2011). Optimal monetary policy in an operational medium-sized DSGE model. *Journal of Money, Credit and Banking*, *43*(7), 1287–1331.

Andrade, J., Cordeiro, P., & Lambais, G. (2019). *Estimating a Behavioral New Keynesian Model* (Papers No. 1912.07601). arXiv.org.

Angeletos, G.-M., & Huo, Z. (2018). *Myopia and Anchoring* (NBER Working Papers No. 24545). National Bureau of Economic Research, Inc.

Angeletos, G.-M., & Lian, C. (2016). *Incomplete Information in Macroeconomics: Accommodating Frictions in Coordination* (NBER Working Papers No. 22297). National Bureau of Economic Research, Inc.

Ascari, G., Magnusson, L. M., & Mavroeidis, S. (2019). Empirical evidence on the Euler equation for consumption in the US. *Journal of Monetary Economics*(4), 1–25.

Assenza, T., Heemeijer, P., Hommes, C., & Massaro, D. (2011). *Individual Expectations and Aggregate Macro Behavior* (CeNDEF Working Papers No. 11-01). Universiteit van Amsterdam, Center for Nonlinear Dynamics in Economics and Finance.

Blanchard, O. (2016). Do DSGE models have a future? *Revista de Economia Institucional*, *18*(35), 39–46.

Branch, W. A., & McGough, B. (2009). A New Keynesian model with heterogeneous expectations. *Journal of Economic Dynamics and Control*, *33*(5), 1036–1051.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, *12*(3), 383-398.

Caplin, A., Csaba, D., Leahy, J., & Nov, O. (2018). *Rational Inattention, Competitive Supply, and Psychometrics* (NBER Working Papers No. 25224). National Bureau of Economic Research, Inc.

Christiano, L. J., Eichenbaum, M., & Evans, C. L. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, *113*(1), 1–45.

Chung, H., Kiley, M. T., & Laforte, J.-P. (2010). *Documentation of the Estimated, Dynamic, Optimization-based (EDO) model of the U.S. economy: 2010 version* (Finance and Economics Discussion Series No. 2010-29). Board of Governors of the Federal Reserve System (U.S.).

Conlisk, J. (1996). Why Bounded Rationality? *Journal of Economic Literature*, *34*(2), 669–700.

De Grauwe, P. (2012). *Lectures on Behavioral Macroeconomics* (1st ed.). Princeton University Press.

Del Negro, M., Giannoni, M., & Patterson, C. (2012). The Forward Guidance Puzzle. *Federal*

Reserve Bank of New York Staff Reports, no. 574.

Driscoll, J. C., & Holden, S. (2014). Behavioral Economics and Macroeconomic Models John. *Finance and Economics Discussion Series*, *43*(1), 1–35.

Eusepi, S., & Preston, B. (2018). The science of monetary policy: An imperfect knowledge perspective. *Journal of Economic Literature*, *56*(1), 3–59.

Evans, G. W., & Honkapohja, S. (2001). *Learning and expectations in macroeconomics*. Princeton University Press.

Farhi, E., & Gabaix, X. (2020). Optimal taxation with behavioral agents. *American Economic Review*, *110*(1), 298–336.

Gabaix, X. (2014). A Sparsity Based Model of Bounded Rationality. *The Quarterly Journal of Economics*, 1661–1710.

Gabaix, X. (2016). *Behavioral Macroeconomics Via Sparse Dynamic Programming* (NBER Working Papers No. 21848). National Bureau of Economic Research, Inc.

Gabaix, X. (2017). *Behavioral Inattention* (NBER Working Papers No. 24096). National Bureau of Economic Research, Inc.

Gabaix, X. (2019). *A Behavioral New Keynesian Model* (Tech. Rep. No. 22954). National Bureau of Economic Research, Inc.

Ilabaca, F., Meggiorini, G., & Milani, F. (2020). Bounded rationality, monetary policy, and macroeconomic stability. *Economics Letters*, *186*, 108522.

Juillard, M., Kamenik, O., Kumhof, M., & Laxton, D. (2008). Optimal price setting and inflation inertia in a rational expectations model. *Journal of Economic Dynamics and Control*, *32*(8), 2584-2621.

Jump, R. C., & Levine, P. (2019). Behavioural New Keynesian models. *Journal of Macroeconomics*, *59*(November 2018), 59–77.

Kagel, J. H., & Roth, A. E. (2016). Macroeconomics: A Survey of Laboratory Research. In *The Handbook of Experimental Economics, Volume 2.* Princeton University Press.

Krugman, P. (2018). Good enough for government work? Macroeconomics since the crisis. *Oxford Review of Economic Policy*, *34*(1-2), 156–168.

Kuchler, T., & Zafar, B. (2015, October). *Personal Experiences and Expectations about Aggregate Outcomes* (IZA Discussion Papers No. 9444). Institute of Labor Economics (IZA).

Massaro, D. (2012). Heterogeneous Expectations in Monetary DSGE Models. *SSRN*

Electronic Journal(225408), 1–31.

Milani, F., & Rajbhandari, A. (2012). Expectation formation and monetary DSGE models: Beyond the rational expectations paradigm. *Advances in Econometrics*, *28*, 253–288.

Ormeño, A., & Molnár, K. (2015). Using Survey Data of Inflation Expectations in the Estimation of Learning and Rational Expectations Models. *Journal of Money, Credit and Banking*, *47*(4), 673–699.

Sims, C., & Zha, T. (1998). Bayesian methods for dynamic multivariate models. *International Economic Review*, *39*(4), 949-68.

Smets, F., & Wouters, R. (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review*, *97*(3), 586–606.

Stiglitz, J. E. (2018). Where modern macroeconomics went wrong. *Oxford Review of Economic Policy*, *34*(1-2), 70–106.

Vines, D., & Wills, S. (2018). The rebuilding macroeconomic theory project: An analytical assessment. *Oxford Review of Economic Policy*, *34*(1-2), 1–42.

Warne, A., Coenen, G., & Christoffel, K. (2008). *The new area-wide model of the euro area: a micro-founded open-economy model for forecasting and policy analysis* (Working Paper Series No. 944). European Central Bank.

Woodford, M. (2013). Macroeconomic Analysis Without the Rational Expectations Hypothesis. *Annual Review of Economics*, *5*(1), 303-346.

Woodford, M. (2019). Monetary policy analysis when planning horizons are finite. *NBER Macroeconomics Annual*, *33*(1), 1–50.