CIRJE-F-623

Business Cycle Implications of Internal Consumption Habit for New Keynesian Models

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June 2009; Revised in August 2010

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Current Draft: August 12, 2010

Abstract

This paper studies the implications of internal consumption habit for new Keynesian dynamic stochastic general equilibrium (NKDSGE) models. Bayesian Monte Carlo methods are employed to evaluate NKDSGE model fit. Simulation experiments show that consumption habit often improves the ability of NKDSGE models to match output and consumption growth spectra. Nonetheless, the fit of NKDSGE models with consumption habit is susceptible to the source of the nominal rigidity, to spectra identified by permanent productivity shocks, to the frequencies used for evaluation, and to the choice of monetary policy rule. These vulnerabilities suggest that NKDSGE model specification is fragile.

Key Words: Habit; New Keynesian; Propagation; Monetary Transmission; Model Evaluation, Bayesian Monte Carlo.

JEL Classification Number: $E10$, $E20$, $E32$.

†We thank Evan Anderson, Heather Anderson, Jeannine Bailliu, Hafedh Bouakez, Toni Braun, Fabio Canova, Youngsung Chang, Richard Dennis, Mick Devereux, Mike Dotsey, Bill Dupor, Jon Faust, Martin Fukač, John Geweke, Pablo Guerron-Quintana, Tasos Karantounias, Keith Kuester, Thomas Lubik, Christian Matthes, Ricardo Nunes, Adrian Pagan, B. Ravikumar, Pedro Silos, Larry Schembri, Frank Schorfheide, Tan Wang, Tao Zha, and seminar and session participants at the Bank of Japan, Bank of Canada, 2004 Far Eastern Meetings of the Econometric Society, 10th International Conference on Computing in Economics and Finance (July 2004), 2007 Summer Meetings of the Econometric Society, HEC Montréal, Hitotsubashi University, University of Tokyo, Kobe University, Federal Reserve Bank of Atlanta's macro lunch workshop, Yonsei University, Workshop on Methods and Applications for DSGE Models at the Federal Reserve Bank of Cleveland (October 2008), 2008 Reserve Bank of Australia Research Workshop, "Monetary Policy in Open Economies", Federal Reserve Bank of Philadelphia, Northern Illinois University, System Macro Committee Meeting at the Federal Reserve Bank of San Francisco (May 2009), Hong Kong University of Science and Technology, Keio University, Tohoku University, Osaka University, and Johns Hopkins University for useful discussions. An early version of this paper circulated as, "Business Cycle Implications of Internal Habit Formation". The first author wishes to thank the Ministry of Education, Culture, Sports, Science and Technology of the Government of Japan for support from a grant-in-aid for scientific research (number 20730205). The views in this paper represent those of the authors and are not those of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

1. Introduction

It is a folk theorem of macroeconomics that dynamic stochastic general equilibrium (DSGE) models are refuted by a sufficiently rich description of aggregate fluctuations. This widely held belief stands in contrast to evaluation strategies that rely on the entire predictive density of a DSGE model. The tension between econometric evaluation of DSGE models and the folk theorem is that the latter implies the former is bound to fail. The issue remains that progress on DSGE models requires methods that evaluate fit on actual data.

This paper contributes to DSGE model research by evaluating the impact of consumption habit on propagation and monetary transmission in new Keynesian (NK)DSGE model using Bayesian Monte Carlo tools. Consumption habit is known to be successful at closing the distance between real business cycle models and aggregate quantity and asset price moments since Boldrin, Christiano, and Fisher (2001). Analysis by Eichenbaum and Hansen (1990) and Heaton (1995) suggest that habit achieves this success because it imposes costs on household utility that induces intertemporal complementarity in consumption. Given intertemporal complementarity and a positive consumption shock, households respond by substituting from current to future consumption. The stronger is habit the further consumption is pushed into the future and spread across more future dates given the shock.

We quantify this intuition by linearizing a one-period bond Euler equation in which consumption habit drives marginal utility. Solving the linearized Euler equation yields a first-order stochastic difference equation that generates a hump-shaped consumption growth response to a real rate shock that has a higher peak and is more persistent the stronger is habit.

A goal of this paper is to assess the extent to which this consumption habit mechanism affects propagation and monetary transmission in and the fit of NKDSGE models. The role of consumption habit in NKDSGE model propagation and monetary transmission is not settled. For example, Del Negro, Schorfheide, Smets, and Wouters (2007) find that consumption habit contributes to a NKDSGE model matching the hump-shaped output response to an interest rate rule shock, but Christiano, Eichenbaum, and Evans (2005) do not using a money growth shock. Christiano, Eichenbaum, and Evans (CEE) also report that their monetary policy shock is transmitted by sticky wages, but is not by sticky prices. In contrast, Del Negro and Schorfheide (2008) argue that Bayesian methods and aggregate data cannot discern whether sticky prices or sticky wages matter more for the fit of a NKDSGE model with consumption habit. However Dupor, Han, and Tsai (2009) obtain results that point to flexible prices and durability in consumption, instead of habit, by applying the CEE impulse response matching estimator to a NKDSGE model identified by productivity shocks in place of monetary policy shocks. Finally, little attention is paid to the disparate effects money growth and interest rate rules have on monetary transmission and the fit of NKDSGE models.

This paper reports that consumption habit matters for the fit of NKDSGE models. The evidence is garnered by evaluating 12 NKDSGE models with a Bayesian approach, advocated by Geweke (2010), that shuns estimation. He builds on methods pioneered by DeJong, Ingram, and Whiteman (1996) that employ Bayesian Monte Carlo simulations to gauge the fit of DSGE models to population moments.[1] This approach is labeled the minimal econometric interpretation (MEI) by Geweke to indicate neither an explicit dependence on likelihood-based estimators nor on estimators that focus on a subset of the potential universe of sample moments. A problem for these estimators is that confronting the predictive density of a DSGE model with a sufficiently large vector of sample moments, negates the model according to the folk theorem.[2] The MEI acknowledges that because a NKDSGE model is a partial depiction of economic behavior it has no predictive implications for sample moments.[3] Rather a NKDSGE model can only be judged on its population moments. The tie between prior distributions of population moments generated

[1]Kano (2009) and Nason and Rogers (2006) use Bayesian Monte Carlo simulation methods to examine the fit of small open economy-DSGE models on current account moments.

[2]The MEI differs from the limited information approach of CEE and the Smets and Wouters (2007) application of Bayesian likelihood methods. These estimators are proven useful, but do not guarantee problem free evaluation of NKDSGE models as noted by Del Negro and Schorfheide (2008), Schorfheide (2008), Canova and Sala (2009), Dupor, Han, and Tsai (2009), Iskrev (2010), and Guerron-Quintana (2010) among others.

[3]Geweke (2010) also distinguishes the MEI from prior predictive analysis. Prior predictive analysis relies on economic models having testable implications for sample moments.

by a NKDSGE model and observable data are econometric models that are also partial depictions of economic behavior and yield posterior distributions of population moments.[4]

We adapt the MEI and Bayesian Monte Carlo tools to gauge the fit of NKDSGE models with and without consumption habit on permanent and transitory output and consumption growth spectral densities. Our choice of these moments is guided by the permanent income hypothesis (PIH) and previous business cycle studies. The PIH predicts consumption growth has a flat spectral density, which Galí (1991) notes is at odds with U.S. data. Cogley and Nason (1995b) observe that DSGE models often cannot reproduce the spectral density of U.S. output growth because it peaks in the business cycle frequencies. Also they find, along with Nason and Cogley (1994), that many DSGE models fail to duplicate output's response to permanent and transitory shocks. Thus this paper confronts NKDSGE models with moments other DSGE models have problems replicating, but are necessary for NKDSGE models to match to be counted empirically relevant.

This paper addresses these issues by evaluating the fit of 12 NKDSGE models. We start with a baseline NKDSGE model that has sticky prices and wages similar to those studied by CEE and Smets and Wouters (2007). From this baseline, two NKDSGE models are created by stripping out one or the other nominal rigidity. Baseline, sticky price, and sticky wage NKDSGE models are endowed with household preferences that have either no consumption habit or internal consumption habit. These six NKDSGE models are doubled by defining monetary policy with either a money growth or an interest rate rule.

Judging fit on population permanent and transitory output and consumption growth spectral densities generates evidence about propagation and monetary transmission in NKDSGE models. We gather this evidence by studying the interplay of consumption habit with sticky prices, sticky wages, permanent total factor productivity (TFP) shocks, and transitory money

[4] Although a virtue of the MEI is that it avoids the problems Guerron-Quintana (2010) encounters about choosing the observables on which a NKDSGE model is estimated, intrinsic to Bayesian estimation is a step to update model parameters that is absent from and is a weakness of the MEI. The lack of parameter updating can bias MEI measures of model fit if priors are badly constructed, but poorly formed priors are also an issue when posteriors are used to compare the fit of models.

growth or interest rate rule shocks. These structural shocks meet the requirements of long-run monetary neutrality (LRMN) and the Blanchard and Quah (1989) decomposition. We invoke LRMN and the Blanchard and Quah (BQ) decomposition to map from a VAR of output growth-inflation or consumption growth-inflation to a structural vector moving average (SVMA) in actual and synthetic data. Under LRMN, an output growth-inflation (consumption growth-inflation) SVMA predicts a vertical long-run supply curve (PIH-consumption function). According to the BQ decomposition, these mappings also impose orthogonal shock innovations on the SVMAs that the NKDSGE models identify as TFP and monetary policy shocks. Thus, we assign to the SVMAs the task of computing permanent and transitory output and consumption growth spectral densities because the MEI recognizes that these econometric models connect observed data to population versions of these moments predicted by the NKDSGE models.

The Bayesian Monte Carlo experiments show that the fit of NKDSGE models to permanent and transitory output and consumption growth spectral densities is improved by including consumption habit. Thus, propagation and monetary transmission in NKDSGE models is more empirically relevant when consumption habit is combined with nominal rigidities. However, we find that NKDSGE model fit is sensitive to: (1) changes in the mix of nominal rigidities, (2) switching from a money growth rule to an interest rate rule, (3) identifying spectral densities on permanent TFP shocks instead of transitory monetary policy shocks, and (4) conducting evaluation on the entire spectrum rather than limiting it to the business cycle frequencies.

The rest of the paper is constructed as follows. Section 2 discusses internal consumption habit and NKDSGE models. Our application of the MEI to NKDSGE model evaluation is outlined in section 3. Results appear in section 4. Section 5 concludes.

2. Internal Consumption Habit and NKDSGE Models

This section describes household preferences with internal consumption habit, studies internal consumption habit propagation, connects it to intertemporal complementarity in future near-dated consumption, and sketches the baseline NKDSGE model.

2.1 Internal consumption habit

Consumption habit is often superinduced in DSGE models to improve fit.[5] This paper adopts additive internal consumption habit. Internal habit operates on lagged household consumption, unlike external habit which assume lags of aggregate consumption appear in utility, of which the (multiplicative) 'catching-up-with-the-Joneses' specification of Abel (1990) is typical. The model assumes that household preferences are intertemporally separable as well as separable across (net) consumption flow, labor disutility, and real balances

$$\mathcal{U}\left(c_t,\, c_{t-1},\, n_t,\, \frac{H_t}{P_t}\right) \;=\; \ln[c_t \,-\, hc_{t-1}] \,-\, \frac{\gamma}{1+\gamma} n_t^{1+\frac{1}{\gamma}} \,+\, \ln\left[\frac{H_t}{P_t}\right], \tag{1}$$

where c_t, n_t, γ, H_t, and P_t are household consumption, household labor supply, the strictly positive Frisch labor supply elasticity, household cash at the end of date $t-1$, and the aggregate price level, respectively. Since internal habit ties current consumption choice to date $t-1$ consumption for a household, the marginal utility of consumption is forward-looking,

$$\lambda_t \,=\, \frac{1}{c_t - hc_{t-1}} - \mathbf{E}_t\left\{\frac{\beta h}{c_{t+1} - hc_t}\right\},$$

assuming $0 < c_t - hc_{t-1}$ for all t, where the habit parameter $h \in (0,\, 1)$, the household discount factor $\beta \in (0,\, 1)$, and $\mathbf{E}_t\{\cdot\}$ is the mathematical expectation operator given date t information.[6]

2.2 The internal consumption habit propagation mechanism

Forward-looking marginal utility suggests internal habit acts as propagation mechanism for consumption. We study this mechanism with a log linear approximation of the Euler equa-

[5]Consumption habit is first grafted into a growth model by Ryder and Heal (1973). Nason (1988), Sundaresan (1989), and Constantinides (1990) are early attempts at solving risk-free rate and equity premium puzzles with consumption habit. Pollak (1976) shows that long-run utility with linear habit describes long-run behavior rather than long-run preferences. Rozen (2010) gives an axiomatic treatment of linear intrinsic habit. An excellent survey of habit in macro and finance is Schmitt-Grohé and Uribe (2007); also see Nason (1997).

[6]Eichenbaum and Hansen (1990) and Heaton (1995) estimate consumption-based asset pricing models with habit and local substitution through service flows. The adjustment cost hypothesis is rejected in favor of services flows according to their estimates. However, the data support habit if local substitutability operates at lower frequencies than the sampling frequency of consumption.

tion $\lambda_t = \beta\mathbf{E}_t\left\{\lambda_{t+1}R_{t+1}/(1+\pi_{t+1})\right\}$, where R_t is the nominal rate and $1+\pi_{t+1}$ $(= P_{t+1}/P_t)$ is date $t+1$ inflation. The log linear approximation gives a second order stochastic difference equation for demeaned consumption growth, $\widetilde{\Delta c}_t$, whose solution is

$$\widetilde{\Delta c}_t \;=\; \varphi_1\widetilde{\Delta c}_{t-1} \;+\; \frac{\Psi}{\varphi_2}\sum_{j=0}^{\infty}\varphi_2^{-j}\mathbf{E}_t\tilde{q}_{t+j}, \tag{2}$$

where the stable and unstable roots are $\varphi_1 = h\alpha^{*-1}$ and $\varphi_2 = \alpha^*(\beta h)^{-1}$, α^* is the steady state growth rate of the economy, the demeaned real rate is $\tilde{q}_t = \tilde{R}_t - \dfrac{\pi^*}{1+\pi^*}\tilde{\pi}_t$, π^* is mean inflation, and Ψ is a constant that is nonlinear in model parameters.[7]

We analyze internal consumption habit propagation using the solved linearized Euler equation (2). This is depicted in figure 1 with impulse response functions (IRFs) generated by equation (2) and a one percent shock to $\tilde{q}_t$. The calibration sets $[\beta\ \ \alpha^*]' = [0.993\ \ \exp(0.004)]'$ and $\tilde{q}_t$ to a quarterly first-order autoregression, AR(1), with a AR1 coefficient of 0.87.[8] We compute IRFs on the grid $h = [0.15\ 0.35\ 0.50\ 0.65\ 0.85]$. The IRFs drive $\widetilde{\Delta c}_t$ higher at impact as shown in Figure 1. However, its response falls from about one to 0.11 percent as h rises from 0.15 to 0.85. Figure 1 also displays IRFs that are shifted to the right with higher peaks and slower decay rates as h increases. Thus, as internal habit becomes stronger, it dictates greater intertemporal complimentarity that persuades the household to move in tandem long and longer sequences of future near-dated consumption.

The internal consumption habit propagation mechanism is also discussed by CEE. They note that in their NKDSGE model, in which h is estimated to be about 0.65, internal consumption habit generates a hump-shaped consumption response to a nominal shock. Figure 1 reveals a similar internal consumption habit propagation mechanism for equation (2). When $h \geq 0.5$, equation (2) produces a humped-shaped IRF with a peak at or beyond two quarters. This

[7]The appendix constructs equation (2), which assumes a unit root TFP shock drives trend consumption.

[8]The real demeaned federal funds rate $\tilde{q}_t$ equals the quarterly nominal federal funds rate net of implicit GDP deflator inflation multiplied by the ratio of its mean to one plus its mean. The SIC selects a AR(1) for $\tilde{q}_t$ over any lag length up to ten on a $1954Q1$–$2002Q4$ sample. The appendix has details.

mechanism contrasts with $h \in (0, 0.5)$ or the non-habit model, $h = 0$, in which a linear approximation of the Euler equation sets $\mathbf{E}_t\left\{\widetilde{\Delta c}_{t+1} - \tilde{q}_{t+1}\right\} = 0$. Given $h \leq 0.5$, figure 1 indicates that consumption growth dynamics are dominated by the time series properties of $\tilde{q}_t$.

Greater risk aversion is often cited as the reason that consumption habit is a useful real rigidity to improve model fit. This explanation is bound up with consumption habit lowering the (local) elasticity of substitution. An equivalent notion is that consumption habit imposes costs on utility when consumption is substituted intertemporally. As h rises, a household views changes in current consumption as costly for future utility. These costs induce the household to treat near-dated consumption as complements rather than substitutes. According to figure 1, habit switches consumption from an intertemporal substitute to complement which creates an economically important propagation mechanism given $h \in (0.5, 1)$.

This paper studies the implications of internal consumption habit for NKDSGE models. Nonetheless, the results of this paper should extend beyond internal consumption habit to external habit. In the appendix, we show that internal and external habit produce equivalent consumption growth IRFs after impact given $\tilde{q}_t$ is a AR(1).[9] This indicates little generality is lost by focusing on internal consumption habit.

2.3 A new Keynesian DSGE model

The baseline NKDSGE model contains (a) internal consumption habit, (b) capital adjustment costs, (c) variable capital utilization, (d) fully indexed Calvo-staggered price setting by monopolistic final goods firms, and (e) fully indexed Calvo-staggered wage setting by monopolistic households with heterogeneous labor supply. Households reside on the unit circle with addresses $\ell \in [0, 1]$. The budget constraint of household ℓ is

$$\frac{H_{t+1}}{P_t} + \frac{B_{t+1}}{P_t} + c_t + x_t + a(u_t)k_t + \tau_t \ = \ r_t u_t k_t + \frac{W_t(\ell)}{P_t} n_t(\ell) + \frac{H_t}{P_t} + R_t \frac{B_t}{P_t} + \frac{D_t}{P_t}, \qquad (3)$$

where B_{t+1} is the stock of government bonds the household carries from date t into date $t+1$,

[9]The observational equivalence extends to multiplicative internal and external consumption habit using the onto mapping from additive to multiplicative consumption habit parameters that Dennis (2009) constructs.

x_t is investment, k_t is capital owned by the household at the end of date $t-1$, τ_t is a lump sum government transfer, r_t is the real rental rate of k_t, $W_t(\ell)$ is the nominal wage paid to household ℓ, R_t is the nominal return on B_t, D_t is dividends received from firms, $u_t \in (0, 1)$ is the capital utilization rate, and $a(u_t)$ is its cost function. At the steady state, $u^* = 1$, $a(1) = 0$. To achieve determinate solutions, we set $\frac{a''(1)}{a'(1)} = 1.174$. Note that u_t forces household ℓ to forgo $a(\cdot)$ units of consumption per unit of capital. The adjustment costs specification is adapted from CEE, which places it into the law of motion of household capital

$$k_{t+1} \;=\; (1-\delta)k_t \;+\; \left[1 - S\left(\frac{1}{\alpha}\frac{x_t}{x_{t-1}}\right)\right]x_t, \quad \delta \in (0, 1), \quad 0 < \alpha, \tag{4}$$

where δ is the capital depreciation rate and α (= $\ln \alpha^*$) is deterministic TFP growth. The cost function $S(\cdot)$ is strictly convex, where $S(1) = S'(1) = 0$ and $S''(1) \equiv \varpi > 0$. In this case, the steady state is independent of the adjustment cost function $S(\cdot)$.

Given k_0, B_0, and c_{-1}, the expected discounted lifetime utility function of household ℓ

$$\mathbf{E}_t\left\{\sum_{i=0}^{\infty}\beta^i \mathcal{U}\left(c_{t+i},\, c_{t+i-1},\, n_{t+i}(\ell),\, \frac{H_t}{P_t}\right)\right\} \tag{5}$$

is maximized by choosing c_t, k_{t+1}, H_{t+1}, B_{t+1}, and $W_t(\ell)$ subject to period utility (1), budget constraint (3), the law of motion of capital (4), and downward sloping labor demand.

Households offer differentiated labor services to firms in a monopolistic market in which a Calvo staggered nominal wage mechanism operates. We assume the labor supply aggregator is $N_t = \left[\int_0^1 n_t(\ell)^{(\theta-1)/\theta} d\ell\right]^{\theta/(\theta-1)}$, where θ is the wage elasticity. Labor market monopoly imposes downward sloping labor demand schedules for differentiated labor services, $n_t(\ell) = \left[W_t/W_t(\ell)\right]^{\theta} N_t$, on firms, where the nominal wage index is $W_t = \left[\int_0^1 W_t(\ell)^{1-\theta} d\ell\right]^{1/(1-\theta)}$. The nominal wage aggregator is $W_t = \left[(1-\mu_W)W_{c,t}^{1-\theta} + \mu_W\left(\alpha^*\pi_{t-1}W_{t-1}\right)^{1-\theta}\right]^{1/(1-\theta)}$, which has households updating their desired nominal wage $W_{c,t}$ at probability $1-\mu_W$. With probability μ_W, households receive the date $t-1$ nominal wage indexed by steady state TFP growth, α^*, and π_{t-1}. In this case, the optimal nominal wage condition is

$$\left[\frac{W_{c,t}}{P_{t-1}}\right]^{1+\theta/\gamma} = \left(\frac{\theta}{\theta-1}\right)\frac{\mathbf{E}_t\sum_{i=0}^{\infty}\left[\beta\mu_W\alpha^{*-\theta(1+1/\gamma)}\right]^i\left[\left[\frac{W_{t+i}}{P_{t+i-1}}\right]^{\theta}N_{t+i}\right]^{1+1/\gamma}}{\mathbf{E}_t\sum_{i=0}^{\infty}\left[\beta\mu_W\alpha^{*(1-\theta)}\right]^i\lambda_{t+i}\left[\frac{W_{t+i}}{P_{t+i-1}}\right]^{\theta}\left[\frac{P_{t+i}}{P_{t+i-1}}\right]^{-1}N_{t+i}}, \tag{6}$$

because household ℓ solves a fully indexed Calvo-pricing problem. Equation (6) smooths nominal wage growth which forces labor supply to absorb TFP and monetary policy shocks conditional on the Frisch elasticity γ. Output and consumption respond because changes in labor supply alter production and the intra- and intertemporal margins of NKDSGE models.

Monopolistically competitive firms produce final goods that households consume. The consumption aggregator is $c_t = \left[\int_0^1 y_{D,t}(j)^{(\xi-1)/\xi}dj\right]^{\xi/(\xi-1)}$, where $y_{D,t}(j)$ is household final good demand for the output of a firm with address j on the unit interval. Final good firm j maximizes its profits by setting its price $P_t(j)$, subject to $y_{D,t}(j) = [P_t/P_t(j)]^{\xi}\, Y_{D,t}$, where ξ is the price elasticity, $Y_{D,t}$ is aggregate demand, and the price index is $P_t = \left[\int_0^1 P_t(j)^{1-\xi}\right]^{1/(1-\xi)}$.

The jth final good firm mixes capital, $K_t(j)$, rented and labor, $N_t(j)$, hired from households net of fixed cost N_0 given labor-augmenting TFP, A_t, in the constant returns to scale technology, $\left[u_tK_t(j)\right]^{\psi}\left[[N_t(j)-N_0]\,A_t\right]^{1-\psi}$, $\psi \in (0, 1)$, to create output, $y_t(j)$. Fixed labor cost N_0 is included to satisfy the needs of monopolistic competition in the final goods market. TFP is a random walk with drift, $A_t = A_{t-1}\exp\{\alpha + \varepsilon_t\}$, with its Gaussian innovation, $\varepsilon_t \sim \mathcal{N}(0, \sigma_\varepsilon^2)$, for the NKDSGE models to have a permanent shock.

Calvo-staggered price setting restricts a firm to update to optimal price $P_{c,t}$ at probability $1-\mu_P$. Or with probability μ_P, firms are stuck with date $t-1$ prices scaled by inflation of the same date, π_{t-1}. This fixes the price aggregator $P_t = \left[(1-\mu_P)P_{c,t}^{1-\xi} + \mu_P\,(\pi_{t-1}P_{t-1})^{1-\xi}\right]^{1/(1-\xi)}$. Under full price indexation, Calvo-pricing yields the optimal forward-looking price

$$\frac{P_{c,t}}{P_{t-1}} = \left(\frac{\xi}{\xi-1}\right)\frac{\mathbf{E}_t\sum_{i=0}^{\infty}\left(\beta\mu_P\right)^i\lambda_{t+i}\phi_{t+i}Y_{D,t+i}\pi_{t+i}^{\xi}}{\mathbf{E}_t\sum_{i=0}^{\infty}\left(\beta\mu_P\right)^i\lambda_{t+i}Y_{D,t+i}\pi_{t+i}^{\xi-1}} \tag{7}$$

of a firm able to update its price. Under full price indexation, equation (7) implies restrictions that smooth inflation. Inflation smoothing forces the economy's response to shocks onto output and consumption, among other quantity variables. Along with habit inducing intertemporal complementarity in consumption, inflation and nominal wage growth smoothing are potential sources of propagation and monetary transmission in NKDSGE models.

We close the NKDSGE model with one of two monetary policy rules. CEE identify monetary policy with a money growth process that is a MA(∞). As they note, this MA(∞) is equivalent to the AR(1) money growth $\left(\ln M_{t+1}/M_t = m_{t+1}\right)$ supply rule

$$m_{t+1} = (1-\rho_m)m^* + \rho_m m_t + \mu_t, \quad \left|\rho_m\right| < 1, \quad \mu_t \sim \mathcal{N}\left(0, \sigma_\mu^2\right), \tag{8}$$

where m^* is mean money growth and μ_t is the money growth innovation. We use NKDSGE-MG to label models with the money growth rule (8). The mnemonic NKDSGE-TR refers to models in which monetary policy is described with the Taylor rule

$$(1-\rho_R\mathbf{L})R_t = (1-\rho_R)\left(R^* + a_\pi\mathbf{E}_t\pi_{t+1} + a_{\tilde{Y}}\tilde{Y}_t\right) + \upsilon_t, \quad \left|\rho_R\right| < 1, \quad \upsilon_t \sim \mathcal{N}\left(0, \sigma_\upsilon^2\right), \tag{9}$$

where $R^* = \pi^*/\beta$ and $\pi^* = \exp(m^* - \alpha)$. Under the interest rate rule (9), the monetary authority obeys the 'Taylor' principle, $1 < a_\pi$, and sets $a_{\tilde{Y}} \in (0, 1)$. This policy regime assumes the monetary authority computes private sector inflationary expectations, $\mathbf{E}_t\pi_{t+1}$, and mean zero transitory output, $\tilde{Y}_t$, without inducing measurement errors.

The government finances B_t, interest on B_t, and a lump-sum transfer τ_t with new bond issuance $B_{t+1} - B_t$, lump-sum taxes τ_t, and money creation, $M_{t+1} - M_t$. Under either monetary policy rule, the government budget constraint is $P_t\tau_t = [M_{t+1} - M_t] + [B_{t+1} - (1 + R_t)B_t]$. We assume government debt is in zero net supply, $B_{t+1} = 0$ and the nominal lump-sum transfer equals the monetary transfer, $P_t\tau_t = M_{t+1} - M_t$, along the equilibrium path at all dates t.

Equilibrium requires goods, labor, and money markets to clear in the decentralized economy. This occurs when $K_t = k_t$ given $0 < r_t$, $N_t = n_t$ given $0 < W_t$, $M_t = H_t$, and also requires P_t, and R_t are strictly positive and finite. This leads to the aggregate resource constraint, $Y_t = C_t + I_t + a(u_t)K_t$, where aggregate consumption $C_t = c_t$ and aggregate investment $I_t = x_t$. A rational expectations equilibrium equates, on average, firm and household subjective forecasts of r_t and A_t to the objective outcomes generated by the decentralized economy. We add to this list μ_t and R_t, υ_t, P_t, or W_t under the money growth rule (8), the interest rate rule (9), a flexible price regime, or a competitive labor market, respectively.

3. Bayesian Monte Carlo Strategy

This section outlines the Bayesian Monte Carlo methods of DeJong, Ingram, and Whiteman (1996) and Geweke (2010). We adapt their procedures to assess the fit of 12 NKDGSE models on permanent and transitory output and consumption growth spectral densities. DeJong, Ingram, and Whiteman (DIW) and Geweke eschew standard calibration and estimation tools because, in their view, a DSGE model lacks predictions except for population moments. Geweke calls this the minimal econometric interpretation (MEI). We engage the MEI to evaluate NKDSGE models on population spectral densities generated from Bayesian Monte Carlo experiments. One set of experiments apply sample data, a structural vector moving average (SVMA), its priors, and a Markov chain Monte Carlo (MCMC) simulator to create posterior distributions of population spectral densities. Prior distributions of population spectral densities are approximated using a SVMA estimated on synthetic data that are simulated from a calibrated NKDSGE model whose parameters are drawn from independent priors.[10] The SVMAs are the econometric models that connect posterior and prior population moments to sample data. Posterior and prior population spectral densities are labeled empirical and theoretical spectral densities, $SD_{\mathcal{E}}$ and $SD_{\mathcal{T}}$, in the rest of the paper. The MEI gauges NKDSGE model fit on the overlap of distributions of permanent and transitory output and consumption growth $SD_{\mathcal{E}}$ and $SD_{\mathcal{T}}$.[11] Kolmogorov-Smirnov goodness of fit statistics give a concise measure of this overlap. Table 1 summarizes our implementation of the MEI to evaluate 12 NKDSGE models.

3.1 Output and consumption moments

We evaluate NKDSGE model fit with a vector of moments consisting of permanent and transitory output and consumption growth spectral densities. The spectral densities are calculated from SVMAs that are just-identified by the orthogonality of shock innovations along with a LRMN restriction embedded in the NKDSGE model of section 2. In this model, LRMN ties the TFP innovation ε_t to the permanent shock. The transitory shock is identified with the money growth innovation μ_t or Taylor rule innovation υ_t. Under LRMN, we recover SVMAs from unrestricted second-order VARs, VAR(2)s, of $[\Delta \ln Y_t \;\; \Delta \ln P_t]'$ and $[\Delta \ln C_t \;\; \Delta \ln P_t]'$ subsequent to applying the Blanchard and Quah (1989) decomposition.[12] A vertical long-run aggregate supply curve results from applying LRMN to the $\Delta \ln Y_t$–$\Delta \ln P_t$ system. The $\Delta \ln C_t$–$\Delta \ln P_t$ system represents a serially correlated demand-consumption function system giving rise to a vertical long-run PIH-consumption function assuming LRMN.

[10]Geweke (2010) develops the MEI by conditioning prior distributions of moments just on an economic model and its priors. Since LRMN and the assumptions of the BQ decomposition are built into the NKDSGE models, a SVMA(∞) can be recovered from the approximate linearized solution of a NKDSGE model. We choose instead to construct distributions of $SD_{\mathcal{T}}$s from SVMA(∞)s estimated on data simulated from linearized NKDSGE models. This approach is consistent with the MEI because population SVMA(∞)s are recovered with sufficiently long synthetic samples.

[11]The overlap of $SD_{\mathcal{E}}$ and $SD_{\mathcal{T}}$ distributions expresses the posterior odds, say, of a NKDSGE model with consumption habit against a NKDSGE model that lacks it. The favored NKDSGE model generates a prior distribution of a $SD_{\mathcal{T}}$ that better covers the posterior distribution of the relevant $SD_{\mathcal{E}}$.

[12]Blanchard and Quah (1989) include an appendix with a theorem that establishes necessary and sufficient conditions under which bivariate ARs identify the correct responses to a permanent shock and a transitory shock when truth is there are several permanent and transitory shocks. The theorem states that the BQ decomposition is satisfied when responses, say, of output growth and inflation to either permanent or transitory shocks are equivalent up to a scalar lag operator. Since the shocks that often appear in NKDSGE models are AR(1)s, adding these shocks to a NKDSGE model will not create spurious identification according to the theorem.

As an example consider the SVMA

$$\begin{bmatrix} \Delta \ln Y_t \\ \Delta \ln P_t \end{bmatrix} = \sum_{j=0}^{\infty} \mathbb{B}_j \begin{bmatrix} \varepsilon_{t-j} \\ \upsilon_{t-j} \end{bmatrix}, \quad \text{where} \quad \mathbb{B}_j = \begin{bmatrix} \mathbb{B}_{\Delta Y,\varepsilon,j} & \mathbb{B}_{\Delta Y,\upsilon,j} \\ \mathbb{B}_{\Delta P,\varepsilon,j} & \mathbb{B}_{\Delta P,\upsilon,j} \end{bmatrix}, \tag{10}$$

that equates the monetary policy shock with the Taylor rule innovation υ_t. Elements of $\mathbb{B}_j$ are just-identified (i) by the orthogonality of the TFP shock innovation ε_t and υ_t and (ii) by the LRMN restriction $\mathbb{B}_{\Delta Y,\upsilon}(\mathbf{1}) = 0$ (*i.e.*, output is independent of υ_t at the infinite horizon); see the appendix for details. These restrictions permit the SVMA (10) to be decomposed for output growth into univariate SMA(∞)s, $\mathbb{B}_{\Delta Y,\varepsilon}(\mathbf{L})\varepsilon_t$ and $\mathbb{B}_{\Delta Y,\upsilon}(\mathbf{L})\upsilon_t$. The former (latter) SMA(∞) is the IRF of output growth with respect to the permanent shock ε_t (transitory shock υ_t).

We grab the SMA(∞) of $\mathbb{B}_{\Delta Y,\varepsilon}(\mathbf{L})\varepsilon_t$ and $\mathbb{B}_{\Delta Y,\upsilon}(\mathbf{L})\upsilon_t$ from the SVMA (10) to calculate permanent and transitory output growth spectral densities. Since the SVMA (10) is also a Wold representation of $[\Delta \ln Y_t \quad \Delta \ln P_t]'$, its spectrum (at frequency ω) is computed as $SD_{[\Delta Y \quad \Delta P]}(\omega) = (2\pi)^{-1}\Gamma_{[\Delta Y \quad \Delta P]}\exp(-i\omega)$, where $\Gamma_{[\Delta Y \quad \Delta P]}(l) = \sum_{j=0}^{\infty} \mathbb{B}_j \mathbb{B}'_{j-l}$. The convolution $\Gamma_{[\Delta Y \quad \Delta P]}(l)$ is expanded at horizon j to obtain

$$\mathbb{B}_j \mathbb{B}'_{j-l} = \begin{bmatrix} \mathbb{B}_{\Delta Y,\varepsilon,j}\mathbb{B}_{\Delta Y,\varepsilon,j-l} + \mathbb{B}_{\Delta Y,\upsilon,j}\mathbb{B}_{\Delta Y,\upsilon,j-l} & \mathbb{B}_{\Delta Y,\varepsilon,j}\mathbb{B}_{\Delta P,\varepsilon,j-l} + \mathbb{B}_{\Delta Y,\upsilon,j}\mathbb{B}_{\Delta P,\upsilon,j-l} \\ \mathbb{B}_{\Delta P,\varepsilon,j}\mathbb{B}_{\Delta Y,\varepsilon,j-l} + \mathbb{B}_{\Delta P,\upsilon,j}\mathbb{B}_{\Delta Y,\upsilon,j-l} & \mathbb{B}_{\Delta P,\varepsilon,j}\mathbb{B}_{\Delta P,\varepsilon,j-1} + \mathbb{B}_{\Delta P,\upsilon,j}\mathbb{B}_{\Delta P,\upsilon,j-l} \end{bmatrix},$$

whose off-diagonal elements imply output growth and employment cross-covariances and, therefore, co- and quad-spectra, while the upper left diagonal elements contain output growth autocovariances $\mathbb{B}_{\Delta Y,\varepsilon,j}\mathbb{B}_{\Delta Y,\varepsilon,j-l}$ ($\mathbb{B}_{\Delta Y,\upsilon,j}\mathbb{B}_{\Delta Y,\upsilon,j-l}$) with respect to ε_t (υ_t), the identified permanent (transitory) shock.[13] We exploit the SMAs $\mathbb{B}_{\Delta Y,\varepsilon}(\mathbf{L})\varepsilon_t$ and $\mathbb{B}_{\Delta Y,\upsilon}(\mathbf{L})\upsilon_t$, that are along the diagonal, to parameterize permanent and transitory output growth spectral densities, which extends ideas of Akaike (1969) and Parzen (1974). Given the BQ decomposition assumption

[13] The appendix constructs SVMAs from structural VARs and also reports that across all Bayesian Monte Carlo simulation the 12 NKDSGE models satisfy the invertibility condition of Fernández-Villaverde, Rubio-Ramírez, Sargent, and Watson (2007).

that the structural shock innovations have unit variances, the output growth spectral density at frequency ω is

$$SD_{\Delta Y,\iota}(\omega) \;=\; \frac{1}{2\pi}\left|\mathbb{B}_{\Delta Y,\iota,0} + \mathbb{B}_{\Delta Y,\iota,1}e^{-i\omega} + \mathbb{B}_{\Delta Y,\iota,2}e^{-i2\omega} + \ldots + \mathbb{B}_{\Delta Y,\iota,j}e^{-ij\omega} + \ldots\right|^2, \quad \iota \;=\; \varepsilon,\, \upsilon.$$

Before computing $SD_{\Delta Y,\iota}(\omega)$, we truncate its polynomial at $j = 40$, a ten year horizon.

3.2 Bayesian simulation methods I: Empirical Distributions

We engage MCMC software of Geweke (1999) and McCausland (2004) to create posterior distributions of SVMAs. These posterior distributions consist of $\mathcal{J} = 5000$ SVMA parameter vectors that are grounded on unrestricted VAR(2)s, LRMN, the BQ decomposition, priors, and a $1954Q1$–$2002Q4$ sample ($T = 196$) of U.S. output, consumption, and price growth.[14] These $\mathcal{J}$ vectors are used to calculate distributions of posterior or empirical permanent and transitory output and consumption growth spectral densities, $SD_{\mathcal{E},\Delta C}$ and $SD_{\mathcal{E},\Delta C}$.

3.3 Bayesian simulation methods II: Theoretical Distributions

Several steps are needed to solve and simulate NKDSGE models. The models have a permanent TFP shock, which requires stochastic detrending of optimality and equilibrium conditions before log-linearizing around deterministic steady states that is described in the appendix. We engage an algorithm of Sims (2002), sketched in the appendix, to solve for linear approximate equilibrium laws of motion of a NKDSGE model. Synthetic samples result from feeding sequences of TFP and monetary policy shock innovations into these equilibrium laws of motion given initial conditions and draws from priors of NKDSGE model parameters.

Priors embed our uncertainty about NKDSGE model parameters that is reflected in distributions of prior or theoretical population permanent and transitory output and consumption growth spectral densities, $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$. Table 2 lists these priors. For example, h has an uninformative prior that is drawn from an uniform distribution with end points 0.05 and 0.95 in table 2. The uninformative prior reflects a belief that any $h \in \left[0.05,\, 0.95\right]$ is as likely

[14] The software is found at `http://www2.cirano.qc.ac/~bacc`, while the appendix describes the data.

as another. Non-habit NKDSGE models are defined by the degenerate prior $h = 0$.

Priors are also taken from earlier DSGE model studies.[15] We place degenerate priors on $\left[\beta\ \delta\ \alpha\ \psi\right]' = \left[0.9930\ \ 0.0200\ \ 0.0040\ \ 0.3500\right]'$ that are consistent with the Cogley and Nason (1995b) calibration. However, the micro estimates of Kimmel and Kniesner (1998) supply the mean of the prior of the Frisch labor supply elasticity, $\gamma = 1.55$. Uncertainty about $\left[\beta\ \gamma\ \delta\ \alpha\ \psi\right]'$ is captured by 95 percent coverage intervals, which include values in Nason and Cogley (1994), Hall (1996), and Chang, Gomes, and Shorfheide (2002). We set the prior of the investment cost of adjustment parameter ϖ to estimates reported by Bouakez, Cardia, and Ruge–Murcia (2005). The standard deviation of TFP shock innovations, σ_ϵ, is given an uniform prior because the DSGE literature suggests that any draw of σ_ϵ from $[0.0070,\ 0.0140]$ is equally likely.

There are four sticky price and wage parameters to calibrate. The relevant prior means are $[\xi\ \ \mu_P\ \ \theta\ \ \mu_w]' = \left[12.0\ 0.55\ 15.0\ 0.7\right]'$. The mean of ξ implies a steady state price markup, $\xi/(\xi - 1)$, of nine percent with a 95 percent coverage interval that runs from five to 33 percent. This coverage interval blankets estimates found in Basu and Fernald (1997) and CEE. More uncertainty surrounds the priors of μ_P, θ, and μ_w. Sbordone (2002), Nason and Slotsve (2004), Lindé (2005), and CEE suggest a 95 percent coverage interval for μ_P of $[0.45,\ 0.65]$. Likewise, a 95 percent coverage interval of $[0.04,\ 0.25]$ suggests substantial uncertainty around the seven percent prior mean household wage markup, $\theta/(\theta - 1)$. The degenerate mean of μ_w and its 95 percent coverage interval reveals stickier nominal wages than prices, as found by CEE and Rabanal and Rubio-Ramírez (2005), but we imbue it with greater uncertainty.

The money growth rule (8) is calibrated to estimates from a $1954Q1$–$2002Q4$ sample of the monetary base. The point estimates are degenerate priors for $\left[m^*\ \ \rho_m\ \ \sigma_\mu\right]' = \left[0.011\ 0.628\ 0.006\right]'$. We give these prior means less precision than found in sample. For example, the lower end of the 95 percent coverage interval of ρ_m is near 0.46. CEE note that $\rho_m \approx 0.5$ implies the money growth rule (8) mimics the persistence of their MA(∞) monetary policy shock process.

[15] The means of several priors match sample means of the consumption-output ratio, labor input, federal funds rate, and inflation on a $1955Q1$–$2002Q4$ sample. We also fix $N_0 = 0.1678$ and $r^* = 1.0050$.

The calibration of the interest rate rule (9) obeys the Taylor principle and $a_{\mathcal{Y}} \in (0,1)$. The degenerate prior of a_π is 1.80. We assign a small role to movements in transitory output, $\widetilde{Y}$, with a prior mean of 0.05 for $a_{\mathcal{Y}}$. The 95 percent coverage intervals of a_π and $a_{\mathcal{Y}}$ rely on estimates reported by Smets and Wouters (2007). The interest rate rule (9) is also calibrated to smooth R_t given a prior mean of 0.65 and a 95 percent coverage interval of [0.55, 0.74] that incorporates estimates found in Guerron-Quintana (2010). Ireland (2001) is the source of the prior mean of the standard deviation of the monetary policy shock, $\sigma_\upsilon = 0.0051$, and its 95 percent coverage interval, [0.0031, 0.0072]. We assume all shock innovations are uncorrelated at leads and lags (*i.e.*, $\mathbf{E}\{\varepsilon_{t+i}\, \upsilon_{t+q}\} = 0$, for all i, q).

Draws from the priors of the parameters of a NKDSGE model are applied to its linearized approximation to generate a synthetic sample of length $\mathcal{M} = \mathcal{W} \times T$. On the $\mathcal{J}$ synthetic samples of length $\mathcal{M}$, SVMAs are estimated subsequent to estimating unrestricted VAR(2)s, invoking LRMN and the assumptions of the BQ decomposition. We set $\mathcal{W} = 5$ to compute prior population permanent and transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$.

3.4 Measures of fit

The fit of NKDSGE models is gauged with a tool that updates one Cogley and Nason (1995a) exploit. They measure the fit of DSGE models to the spectral density of U.S. output growth with the Kolmogorov-Smirnov (*KS*) goodness of fit statistic. The *KS* statistic is useful because it maps a multidimensional *SD* into a scalar statistic that summarizes model fit.

This paper employs the *KS* statistic to gauge NKDSGE model fit, but in the context of Bayesian Monte Carlo experiments. The experiments produce (posterior) empirical and (prior) theoretical distributions of *KS* statistics, $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$, that are normalized on sample output or consumption growth spectral densities, $\widehat{SD}_T$, which is constructed from a SVMA estimated on actual data of length T. Define $\mathcal{R}_{\mathcal{D},j}(\omega) = \widehat{SD}_T(\omega)/SD_{\mathcal{D},j}(\omega)$ at replication j and frequency ω, where $\mathcal{D} = \mathcal{E},\ \mathcal{T}$. Next, compute the partial sum $\mathcal{V}_{\mathcal{D},j}\,(2\pi q/\mathcal{H}) = 2\pi\mathcal{H}^{-1}\sum_{\ell=1}^{q}\mathcal{R}_{\mathcal{D},j}\,(2\pi\ell/\mathcal{H})$, where $\mathcal{H} = T$ when $\mathcal{D} = \mathcal{E}$ and $\mathcal{H} = \mathcal{M}$ otherwise. The partial sums are used to construct the partial difference $\mathcal{B}_{\mathcal{D},j}(\kappa) = 0.5\pi^{-1}\sqrt{2\mathcal{H}}\Big[\mathcal{V}_{\mathcal{D},j}(\kappa\pi) - \kappa\mathcal{V}_{\mathcal{D},j}(\pi)\Big]$, $\kappa \in [0, 1]$. The restriction placing κ on $[0, 1]$ requires that the partial difference $\mathcal{B}_{\mathcal{D},j}(\kappa)$ is evaluated on the entire spectrum. The $KS_{\mathcal{D}}$ statistic at replication j is calculated as the maximal absolute value of $\mathcal{B}_{\mathcal{D},j}(\kappa)$, $KS_{\mathcal{D},j} = Max_{\kappa\in[0,1]}\Big|\mathcal{B}_{\mathcal{D},j}(\kappa)\Big|$. The $KS_{\mathcal{E},j}$s and $KS_{\mathcal{T},j}$s statistics are collected into vectors of length $\mathcal{J}$ to form distributions of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistics. Substantial overlap of these distributions indicate a good fit for a NKDSGE model. This constitutes a 'joint test' of NKDSGE model fit because the distribution of $SD_{\mathcal{T}}$ must match the distribution of $SD_{\mathcal{E}}$ at several frequencies for distributions of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistics to display significant area in common.

DIW advocate using the confidence interval criterion (*CIC*) to quantify the intersection of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ distributions. The *CIC* measures the fraction of $\mathcal{J}$ elements of a $KS_{\mathcal{T}}$ distribution that occupies an interval defined by lower and upper quantiles of the associated $KS_{\mathcal{E}}$ distribution given a $1-p$ percent confidence level.[16] We set $p = 0.05$. If a habit NKDSGE model yields a $CIC > 0.3$ (as DIW imply in their analysis of RBC models), say, for the transitory output growth spectral density and the non-habit model's $CIC \leq 0.3$ on this moment, the former model is viewed as providing a more plausible match in this case.

We calculate $KS_{\mathcal{E},j}$ and $KS_{\mathcal{T},j}$ statistics on the entire spectrum and on business cycle horizons from eight to two years per cycle. By isolating the business cycle fluctuations, we build on an insight of Diebold, Ohanian, and Berkowitz (1998). Their insight is that a focus on the business cycle frequencies matters for NKDSGE model evaluation when model misspecification corrupts measurement of short- and long-run fluctuations. We address these problems by compiling $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ distributions in which κ is limited to frequencies between eight and two years per cycle, or $KS_{\mathcal{D},j} = Max_{\kappa\in[0.064,0.25]}\Big|\mathcal{B}_{T,\mathcal{D},j}(\kappa)\Big|$. This mitigates problems of discounting NKDSGE models that perform well at business cycle horizons, but poorly on the lower growth and higher short-run frequencies.

[16]Following DIW, the *CIC* of a $KS_{\mathcal{T}}$ statistic distribution is set to $\frac{1}{1-p}\int_a^b KS_{\mathcal{T},j}dj$ for a $1-p$ percent confidence level, where a (b) is the lower $0.5p$ (upper $1-0.5p$) quantile. The *CIC* is normalized by $1-p$ to equal $\int_a^b KS_{\mathcal{E},j}dj$.

4. Habit and Non-Habit NKDSGE Model Evaluation

This section judges the fit of 12 NKDGSE models to distributions of permanent and transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$. The evaluation is based on the overlap of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic densities that are plotted in the second and third columns of figures 3–8 and quantified by *CIC* reported in table 3. Along with mean permanent and transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$, mean permanent and transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ are presented in the first column of figures 3–8 to give information about propagation and monetary transmission in NKDSGE models.

4.1 Summary of moments to match: Mean $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$

Figure 2 plots mean permanent and transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$. These *SD*s decompose the average variation frequency by frequency of the response of output and consumption growth to permanent and transitory shocks.[17] The top (bottom) panel of figure 2 contains mean permanent (transitory) $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$. Mean $SD_{\mathcal{E},\Delta Y}$ appear as solid (blue) lines in figure 2, while mean $SD_{\mathcal{E},\Delta C}$ plots are thicker with (blue) '♦' symbols.

Mean permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ display greatest variation or power at frequency zero (*i.e.*, long-run) in the top panel of figure 2. This is followed by immediate decay across the remaining frequencies. However, the mean permanent $SD_{\mathcal{E},\Delta Y}$ has about five times the amplitude (*i.e.*, volatility) at the long-run that is found in the mean permanent $SD_{\mathcal{E},\Delta C}$.

The lower panel of figure 2 presents mean transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ with disparate shapes. The latter *SD* peaks around six years per cycle. Rather than a peak, mean transitory $SD_{\mathcal{E},\Delta C}$ plateaus from the growth frequencies (*i.e.*, more than eight years per cycle) to four years per cycle before decaying in the high frequencies. At the business cycle frequencies, this plateau exhibits about 20 percent of the volatility of mean transitory $SD_{\mathcal{E},\Delta Y}$.

Mean permanent and transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ suggest the underlying empirical distributions pose challenges for NKDSGE models. Sufficient periodicity is displayed by mean $SD_{\mathcal{E},\Delta C}$s in figure 2 at low and business cycle frequencies to reject the PIH. Thus, NKDSGE

[17] A mean *SD* is computed across an ensemble of SD_j, $j = 1, \ldots, \mathcal{J}$ pointwise or frequency by frequency.

models must violate the PIH to generate distributions of permanent and transitory $SD_{\mathcal{T},\Delta C}$ that match distributions of $SD_{\mathcal{E},\Delta C}$s. Economically meaningful propagation and monetary transmission mechanisms are also needed by NKDSGE models to produce distributions of permanent and transitory $SD_{\mathcal{T},\Delta Y}$ that achieve a good fit to distributions of $SD_{\mathcal{E},\Delta Y}$.

4.2 Quantify NKDSGE model fit: CIC

Table 3 presents *CIC* that measure the overlap of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic distributions. The extent of the overlap of these distributions is a gauge of the fit of NKDSGE models to permanent and transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ distributions. The top panel of table 3 lists *CIC* of sticky price and wage (baseline), sticky price only (SPrice), and sticky wage only (SWage) habit and non-habit NKDSGE-MG models in which the money growth rule (8) defines monetary policy.[18] The lower panel contains *CIC* of NKDSGE-TR models that replace equation (8) with the Taylor rule (9). Columns titled $\infty : 0$ ($8 : 2$) include *CIC* quantifying the overlap of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic distributions on the entire frequency domain (business cycle frequencies that run from eight to two years per cycle).

Table 3 shows that placing consumption habit in NKDSGE models produces a superior fit. Of the 27 $CIC \geq 0.3$ listed in table 3, 18 are tied to habit NKDSGE models. This is twice as many as non-habit NKDSGE models produce. The SPrice habit NKDSGE-MG model generates four of the five $CIC \geq 0.3$ in the top panel of table 3. In the bottom panel of table 3, 14 of the 22 $CIC \geq 0.3$ are produced by baseline, SPrice, and SWage habit NKDSGE-TR models. SPrice habit NKDSGE-TR models enjoy six of these 14 *CIC*. The remaining eight $CIC \geq 0.3$ are divided evenly between baseline and SWage habit NKDSGE-TR models in the bottom panel of table 3.

A striking feature of table 3 is the disparate effects habit, sticky prices, and sticky wages have on the fit of NKDSGE models to distributions of permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$. The Bayesian Monte Carlo experiments reveal that on these distributions only SPrice NKDSGE models yield $CIC \geq 0.3$. In the middle of the top panel of table 3, these matches occur for the

[18]The SWage NKDSGE model requires the degenerate prior $\mu_P = 0$ with fixed markup $\phi = (\xi - 1)/\xi$. When the nominal wage is flexible, households set their optimal wage period by period in SPrice NKDSGE models. In this case, the markup in the labor market is fixed at $(\theta - 1)/\theta$, which equals $n^{-1/\gamma}$, given $\mu_W = 0$.

SPrice habit NKDSGE-MG model on permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ distributions exclusively at the business cycle frequencies. The SPrice habit NKDSGE-TR model obtains similar results in the middle of the bottom panel of table 3 with four $CIC \geq 0.3$ in the columns labeled 8 : 2 (years per cycle). An additional $CIC \geq 0.3$ is generated by this model for the permanent $SD_{\mathcal{E},\Delta Y}$ distribution when the evaluation is conducted on the entire spectrum. In comparison, SPrice non-habit NKDSGE-MG and -TR models are responsible for three $CIC \geq 0.3$ that measure the overlap of permanent $SD_{\mathcal{E}}$ and $SD_{\mathcal{T}}$ distributions. Thus, the most empirically relevant propagation mechanisms are attributed to SPrice habit NKDSGE-MG and -TR models.

Several NKDSGE models have empirically credible monetary transmission mechanisms. According to table 3, transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ distributions are replicated by habit NKDSGE models whether sticky prices and wages are combined or used one at a time. Nonetheless, it is evident from table 3 that NKDSGE-TR models fit these distributions better than do NKDSGE-MG models. Baseline and SWage habit NKDSGE-TR models realize transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ distributions that match transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ distributions with $CIC \geq 0.44$ on the entire spectrum and at the business cycle frequencies in the bottom panel of table 3. SPrice habit NKDSGE-MG and -TR models are adept at fitting transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ distributions, but only on the business cycle frequencies. These successes are not duplicated by baseline and SWage habit NKDSGE-MG models given *CIC* in the top panel of table 3.

In summary, the *CIC* of table 3 show that consumption habit confers a superior fit to NKDSGE models.[19] These results echo the support Del Negro, Schorfheide, Smets, and Wouters (2007) obtain for consumption habit in their NKDSGE model. However, we find that the fit of habit NKDSGE models to $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ distributions is not robust to the mix of nominal rigidities or choice of monetary policy rule. The frequencies on which the habit NKDSGE models are evaluated also matter for judgments about fit.

[19] The appendix presents Bayesian Monte Carlo experiments that estimate VAR(4)s instead of VAR(2)s, substitute the Cramer-von Mises (*CvM*) goodness of fit statistic for the *KS* statistic to quantify NKDSGE model fit, and replace the prior $h \sim U(0.05, 0.95)$ with either the prior $h \sim U(0.05, 0.499)$, $h \sim U(0.50, 0.95)$, or $h \sim \beta(0.65, 0.15)$. The latter prior implies a 95 percent coverage interval for h of $[0.38, 0.88]$. These experiments are reported in the appendix and reinforce the message table 3 has for the impact of consumption habit on NKDSGE model fit.

4.3 *Visualize NKDSGE model dynamics and fit: Figures 3–8*

The content of figures 3–8 is described in this section. Evidence to evaluate the fit of baseline NKDSGE-MG and -TR models is reported in figures 3 and 4, respectively. Figures 5 and 6 contain results for SPrice NKDSGE-MG and -TR models. The final two figures present plots generated by SWage NKDSGE-MG and -TR models.

Figures 3–8 summarize evidence about propagation, monetary transmission, and NKDSGE model fit in 12 windows spread across four rows and three columns. From top to bottom, the four rows report results for permanent $SD_{\Delta Y}$, transitory $SD_{\Delta Y}$, permanent $SD_{\Delta C}$, and transitory $SD_{\Delta Y}$, respectively. The first column of figures 3–8 plots mean SDs, while the second and third columns display densities of KS statistics.

Visual testimony about NKDSGE model propagation and monetary transmission appears in the first column of figures 3–8. This column consists of four windows containing plots of mean permanent $SD_{\mathcal{T},\Delta Y}$, mean transitory $SD_{\mathcal{T},\Delta Y}$, mean permanent $SD_{\mathcal{T},\Delta C}$, and mean transitory $SD_{\mathcal{T},\Delta C}$. Mean $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ are denoted by (red) dot-dash plots for NKDSGE models with consumption habit and (green) dashed plots for NKDSGE models without consumption habit. The solid (blue) plots of these windows are the mean $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ displayed in figure 2 and are included in figures 3–8 for comparison.

The second and third columns of figures 3–8 furnish densities that map from distributions of permanent and transitory $SD_{\mathcal{E}}$s and $SD_{\mathcal{T}}$s to densities of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistics. The overlap of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic densities are a visual depiction of CIC and thus of NKDSGE model fit. Figures 3–8 display this overlap in columns two and three with a scheme similar to that described for the first column. Solid (blue) lines, (green) dashed lines, and (red) dot-dash lines denote $KS_{\mathcal{E}}$ statistic densities, $KS_{\mathcal{T}}$ statistic densities generated by non-habit NKDSGE models, and $KS_{\mathcal{T}}$ statistic densities produced by habit NKDSGE models, respectively. The second (third) column of figures 3–8 evaluates NKDSGE model fit with $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistics computed on the entire spectrum (restricted to the business cycle frequencies).

4.4 NKDSGE model propagation: Habit and nominal rigidities

This section explores the impact of different combinations of consumption habit, sticky prices, and sticky wages on the propagation of TFP shocks in NKDSGE models. For example, the first and third rows of the second and third columns of figures 3, 4, 7, and 8 present $KS_{\mathcal{T}}$ densities whose mass are to the right of $KS_{\mathcal{E}}$ densities. The lack of overlap explains the associated $CIC < 0.3$ for baseline and SWage NKDSGE models in table 3. The inability to match distributions of permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ extends to whether consumption habit is included in or is excluded from baseline and SWage NKDSGE models. Switching from the money growth rule (8) to the Taylor rule (9) also cannot repair the poor fit of these NKDSGE models to distributions of permanent $SD_{\mathcal{E}}$s.

The odd numbered rows of the first column of figures 3, 4, 7, and 8 display mean permanent $SD_{\mathcal{E},\Delta Y}$, $SD_{\mathcal{E},\Delta C}$, $SD_{\mathcal{T},\Delta Y}$, and $SD_{\mathcal{T},\Delta C}$ consistent with $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic densities exhibiting little overlap. These mean permanent $SD_{\mathcal{E}}$s decay slowly from the infinite horizon into the business cycle frequencies. The same charts include mean permanent $SD_{\mathcal{T}}$s that often peak between eight and four years per cycle besides possessing substantial amplitude at the growth frequencies. Thus, the poor fit of baseline and SWage NKDSGE models to distributions of permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ cannot be attributed to weak propagation of TFP shocks.

Nontheless, baseline and SWage NKDSGE models have powerful propagation mechanisms. Fully indexed sticky wages induce these propagation mechanisms, in part, by smoothing nominal wages which forces households to adjust labor supply in response to permanent TFP shocks. This response contributes to an empirically unreasonable propagation mechanism.

Stripping out sticky wages conveys an empirically credible propagation mechanism to habit NKDSGE-MG and -TR models when fit to distributions of permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ is limited to the business cycle frequencies. The first and third rows of the third column of figures 5 and 6 provide this evidence with $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic densities that display considerable overlap. This shows SPrice habit NKDSGE models possess economically meaningful propagation mechanisms at the business cycle frequencies marked by combining intertemporal complementarity in consumption with inflation smoothing.

There are two successes for SPrice habit and non-habit NKDSGE-TR models when asked to replicate the distribution of permanent $SD_{\mathcal{E},\Delta Y}$ on the entire spectrum. In the middle window of the first row of figure 6, these NKDSGE models yield $KS_{\mathcal{T}}$ statistic densities that overlap the $KS_{\mathcal{E}}$ statistic density. This is further evidence of the difficulties NKDSGE models have at matching distributions of permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$, especially on the entire distributions.

SPrice habit NKDSGE-MG and -TR models are responsible for mean permanent $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ that possess less volatility and periodicity compared to those produced by baseline and SWage NKDSGE models. The odd numbered rows of figures 5 and 6 show that removing sticky wages reduces volatility and periodicity in mean permanent $SD_{\mathcal{T}}$s. This moves these SDs closer to mean permanent $SD_{\mathcal{E}}$s on the business cycle frequencies. The most striking example of a SPrice habit NKDSGE model generating empirically relevant mean dynamics is found in the (red) dot-dash plots in the first column of the first and third rows of figure 6. In this figure, plots of mean permanent $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ decay smoothly from the long-run into the business cycle frequencies. This mimics the behavior of mean permanent $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$.

This section reports that consumption habit combines with fully indexed sticky prices to create empirically relevant and economically meaningful propagation of TFP shocks in NKDSGE models at the business cycle frequencies. With this mix of real and nominal rigidities, SPrice habit NKDSGE models tie propagation to intertemporal consumption complementarity and inflation smoothing. Thus, the match between NKDSGE models and distributions of $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ identified by a permanent TFP shock is sensitive to the mix of nominal rigidities, a result in line with Dupor, Han, and Tsai (2009), and to the frequencies used to judge fit.

4.5 NKDSGE model monetary transmission: Habit and monetary policy rules

Erceg, Henderson, and Levin (2000) recognize that implementing optimal monetary policy can be problematic when faced with sticky prices and wages. Nonetheless, their conclusions about monetary policy analysis rests on sticky prices and wages transmitting monetary policy shocks to the real economy in ways that match empirical observation. This section assesses the empirical relevance of different combinations of sticky prices and wages for monetary transmission in NKDSGE models with and without consumption habit. The specification of monetary policy matters for evaluating NKDSGE model fit because monetary transmission is described with transitory $SD_{\mathcal{T},\Delta Y}$s and $SD_{\mathcal{T},\Delta C}$s that are identified with respect to either the money growth rule (8) or Taylor rule (9) shock innovations.

We find that baseline, SPrice, and SWage NKDSGE models achieve greater success in matching distributions of transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ given the Taylor rule (9) defines monetary policy. The Taylor rule contributes to a superior fit, especially when the entire spectrum is used for evaluation, by dampening output and consumption growth fluctuations. These results are anticipated by Poole (1970). In a sticky price Keynesian macro model, he shows that an interest rate rule minimizes the variance of output relative to a money growth rule when real shocks are more volatile than nominal shocks. Since we apply priors to the NKDSGE models that respect this ordering of the relative volatilities of TFP, money growth rule, and Taylor rule shocks, our Bayesian Monte Carlo experiments underline the sensitivity of NKDSGE model fit to the specification of monetary policy rules.

Money growth rule (8) shock innovations are transmitted by baseline and SWage NKDSGE models into fluctuations in output and consumption growth. However, these monetary transmission mechanisms are unable to produce distributions of transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta Y}$ that cover distributions of transitory $SD_{\mathcal{E},\Delta C}$ and $SD_{\mathcal{E},\Delta C}$. The even numbered rows of the second and third columns of figures 3 and 7 depict the poor fit of baseline and SWage NKDSGE-MG models with distributions of transitory $SD_{\mathcal{E}}$ and $SD_{\mathcal{T}}$ that do not overlap. This lack of fit is translated into excessive amplitude and periodicity in mean transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ compared to mean transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ that are found in the even numbered rows of the first column of figures 3 and 7.

An exception to this poor fit is obtained by the SPrice habit NKDSGE-MG model. This NKDSGE model generates distributions of transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ that intersect distributions of transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ on the business cycle frequencies in the second and third rows of the third column of figure 5. The good fit helps explain mean transitory $SD_{\mathcal{T}}$s of the SPrice habit NKDSGE-MG model that cross mean transitory $SD_{\mathcal{E}}$s (from below) at between eight to two years per cycle in the even numbered rows of the first column of figure 5. When the entire spectrum serves to judge fit, the second and fourth rows of the second column of figure 5 display $KS_{\mathcal{T}}$ statistic densities far to the right of the associated $KS_{\mathcal{E}}$ statistic densities.

Baseline, SPrice, and SWage habit NKDGSE-TR models produce mean transitory $SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ that are more similar to mean transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ as shown in the second and fourth rows of the first column of figures 4, 6, and 8. Thus, Taylor rule shock innovations are transmitted into output and consumption growth fluctuations on average in economically relevant ways by baseline, SPrice, and SWage habit NKDGSE-TR models using intertemporal complementarity created by consumption habit and nominal wage growth smoothing engendered by fully indexed sticky wages. Although these NKDSGE-TR models yield mean transitory $SD_{\mathcal{T}}$ that are close to the mean transitory $SD_{\mathcal{E}}$, note that mean transitory $SD_{\mathcal{E}}$s are most nearly realized by the SWage habit NKDSGE-TR model.

Monetary transmission differs across baseline and SPrice habit NKDSGE-TR models. The baseline habit NKDSGE-TR model produces periodicity in its mean transitory $SD_{\mathcal{T},\Delta Y}$ that is close to displayed by the mean transitory $SD_{\mathcal{E},\Delta Y}$ in the second row of the first column of figure 4, but the former mean spectral density lacks the volatility of the latter. The lack of volatility is reversed by the SPrice habit NKDSGE-TR model. The second row of the first column of figure 6 displays mean transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{T},\Delta Y}$ that have about the same amplitude. However, the latter SD has much of its power in the high frequency rather than at the business cycle frequencies.

Mean transitory $SD_{\mathcal{E},\Delta C}$ and $SD_{\mathcal{T},\Delta C}$ expose more disparities in the monetary transmission mechanisms of baseline and SPrice habit NKDSGE-TR models. The baseline NKDSGE-TR model yields a mean transitory $SD_{\mathcal{T},\Delta C}$ in the bottom panel of the first column of figure 4 that is out of phase in the lower frequencies with the mean transitory consumption growth $SD_{\mathcal{E},\Delta C}$, but captures its amplitude. When the lone nominal rigidity is sticky prices, the fourth row of the first column of figure 6 shows that the SPrice habit NKDSGE-TR model produces a mean transitory $SD_{\mathcal{T},\Delta C}$ that is out of phase in the high frequencies, but mimics the amplitude of the mean transitory consumption growth $SD_{\mathcal{E},\Delta C}$.

The Bayesian Monte Carlo experiments reveal that the fit of baseline, SPrice, and SWage NKDSGE-TR models to distributions of transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ is vulnerable to the frequencies used for evaluation. A good fit for these models is affirmed on the business cycle frequencies by the overlap of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic densities in the far right columns of figures 4, 6, and 8. The NKDSGE-TR models match the transitory $SD_{\mathcal{E}}$s on the business cycle frequencies whether or not household preferences include consumption habit. However, only baseline and SWage habit NKDSGE-TR models replicate transitory $SD_{\mathcal{E}}$s on the entire spectrum given the overlap of $KS_{\mathcal{E}}$ and $KS_{\mathcal{T}}$ statistic densities in the even numbered rows of the middle columns of figures 4 and 8.

This section shows there are several combinations of consumption habit, sticky prices, sticky wages, and the money growth rule (8) or Taylor rule (9) that create empirically significant and economically meaningful monetary transmission in NKDSGE models. When fit is measured on the business cycle frequencies, the baseline, SPrice, and SWage NKDGSE-TR and SPrice habit NKDSGE-MG models match transitory output and consumption growth $\mathrm{SD}_{\mathcal{E}}$s. These models face problems when evaluated on these posterior moments using the entire spectrum. This metric limits a satisfactory fit just to the baseline and SWage habit NKDGSE-TR models. Common to these models is fully indexed Calvo nominal wage setting. This nominal rigidity contributes to empirically relevant monetary transmission by trading smoother nominal wage growth for greater variation in labor supply. Nonetheless, our evidence lends support to the contention of Del Negro and Schorfheide (2008) that it is difficult to choose among competing nominal rigidities when evaluating NKDSGE model fit, especially to monetary policy shocks.

5. Conclusion

This paper studies the business cycle implications of internal consumption habit for new Keynesian dynamic stochastic general equilibrium (NKDSGE) models. We examine the fit of 12 NKDSGE models that have different combinations of internal consumption habit, Calvo staggered prices and nominal wages, along with several other real rigidities. The NKDSGE models are confronted with population output and consumption growth spectral densities (*SD*s) identified by permanent productivity and transitory monetary shocks.

The fit of NKDSGE models with and without consumption habit is explored using Bayesian Monte Carlo methods that avoid estimation. We view this approach as a low cost way to explore the fit of competing NKDSGE model specifications that complement results obtained from estimation. The evidence produced using these techniques favors retaining consumption habit in NKDSGE models. Nonetheless, the Bayesian Monte Carlo experiments show that the fit of NKDSGE models with consumption habit is susceptible to (1) changing the mix of nominal rigidities, (2) identifying *SD*s on permanent productivity shocks instead of transitory monetary policy shocks, (3) evaluating *SD*s on the entire spectrum rather than the business cycle frequencies, and (4) tying monetary policy to a money growth rule instead of a Taylor rule. These results suggest that there remain ambiguities about the specification of real and nominal rigidities in NKDSGE models. The resolution of these ambiguities should inspire further research into the role real and nominal rigidities play in propagation and monetary transmission.

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Table 1: Summary of MEI and Bayesian Monte Carlo Methods

	Empirical (Posterior)	Theoretical (Prior)
Sample	Actual	Synthetic
Sample Length	$T = 196$	$\mathcal{M} = T \times \mathcal{W}$, $\mathcal{W} = 5$
Number of Replications	$\mathcal{J} = 5000$	$\mathcal{J} = 5000$
Priors	VAR coefficients	NKDSGE model parameters
Simulator	MCMC produce BVAR coefficients	Estimate VARs on synthetic data generated by NKDSGE Models
BQ Decomposition under LRMN	Invert BVAR to obtain SVMA(∞)	Invert estimated VAR to produce SVMA(∞)
Distributions	$SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ mapped into $KS_{\mathcal{E}}$ statistics	$SD_{\mathcal{T},\Delta Y}$ and $SD_{\mathcal{T},\Delta C}$ mapped into $KS_{\mathcal{T}}$ statistics

TABLE 2: BAYESIAN CALIBRATION OF NKDSGE MODELS

		Prior Distribution	Mean	Standard Deviation	95 Percent Cover Interval
h	Internal Consumption Habit	Uniform	—	—	[0.0500, 0.9500]
β	H'hold Subjective Discount	Beta	0.9930	0.0020	[0.9886, 0.9964]
γ	Labor Supply Elasticity	Normal	1.5500	0.5360	[0.4995, 2.6005]
δ	Depreciation Rate	Beta	0.0200	0.0045	[0.0122, 0.0297]
α	Deterministic Growth Rate	Normal	0.0040	0.0015	[0.0011, 0.0064]
ϖ	Capital Adjustment Costs	Normal	4.7710	1.0260	[2.7601, 6.7819]
ψ	Capital's Share of Output	Beta	0.3500	0.0500	[0.2554, 0.4509]
σ_ϵ	TFP Growth Shock Std.	Uniform	—	—	[0.0070, 0.0140]
ξ	Final Good Dmd Elasticity	Normal	12.0000	4.0820	[3.9994, 20.0006]
μ_P	No Price Change Probability	Beta	0.5500	0.0500	[0.4513, 0.6468]
θ	Labor Demand Elasticity	Normal	15.0000	3.0800	[8.9633, 21.0367]
μ_W	No Wage Change Probability	Beta	0.7000	0.0500	[0.5978, 0.7931]
m^*	$\Delta \ln M$ Mean	Beta	0.0114	0.0030	[0.0063, 0.0180]
ρ_m	$\Delta \ln M$ AR1 Coef.	Beta	0.6278	0.0800	[0.4653, 0.7767]
σ_μ	$\Delta \ln M$ Shock Std.	Beta	0.0064	0.0012	[0.0043, 0.0090]
a_π	Taylor Rule $\mathbf{E}_t \pi_{t+1}$ Coef.	Normal	1.8250	0.2300	[1.3742, 2.2758]
$a_{\hat{Y}}$	Taylor Rule $\hat{Y}_t$ Coef.	Normal	0.1000	0.0243	[0.0524, 0.1476]
ρ_R	Taylor Rule AR1 Coef.	Beta	0.6490	0.0579	[0.5317, 0.7578]
σ_υ	Taylor Rule Shock Std.	Beta	0.0051	0.0016	[0.0025, 0.0087]

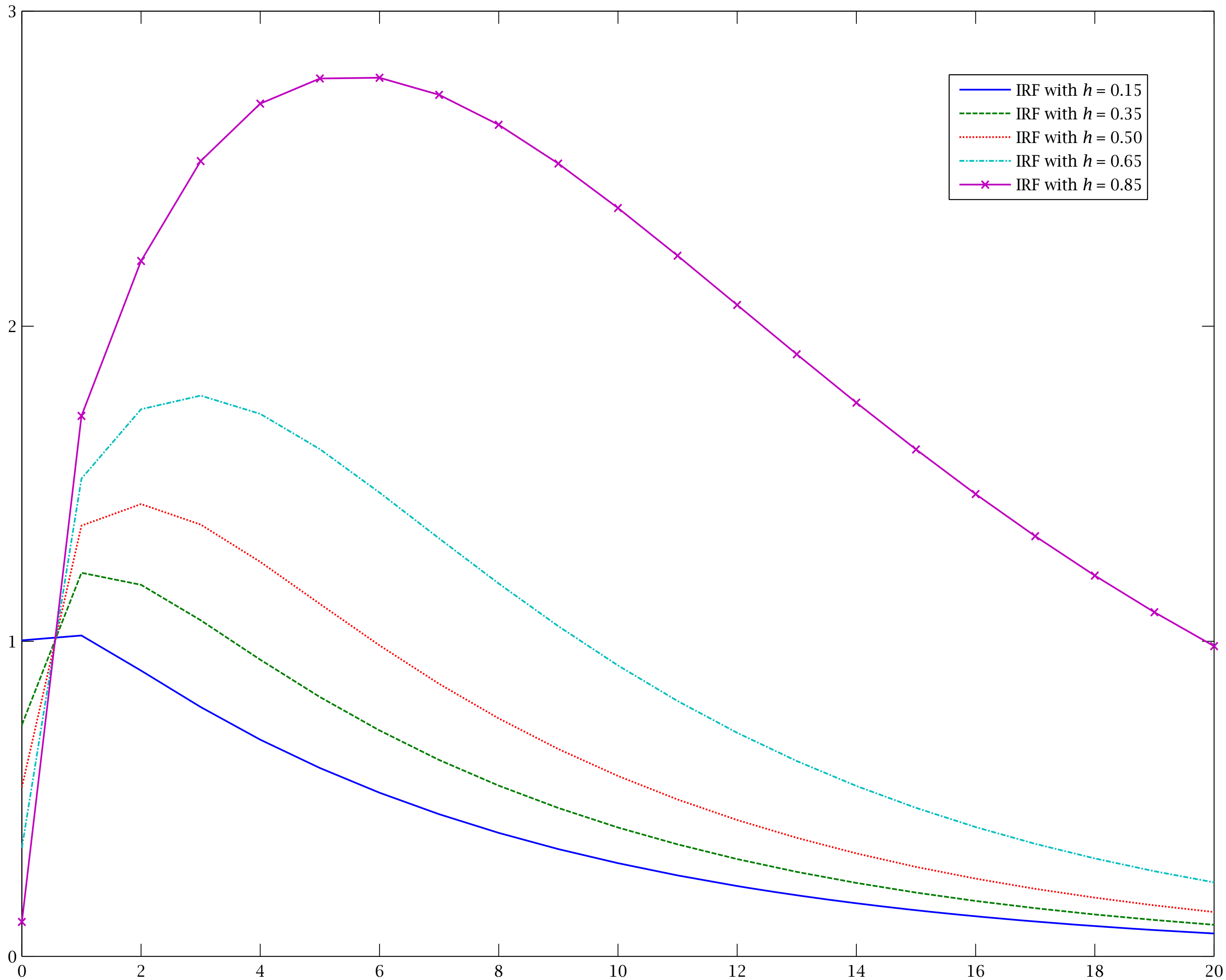
The calibration relies on existing DSGE model literature; see the text for details. For a non-informative prior, the right most column contains the lower and upper end points of the uniform distribution. When the prior is based on the beta distribution, its two parameters are $a = \overline{\Gamma}_{i,n}\left[(1-\overline{\Gamma}_{i,n})\overline{\Gamma}_{i,n}/STD(\Gamma_{i,n})^2 - 1\right]$ and $b = a(1-\overline{\Gamma}_{i,n})/\overline{\Gamma}_{i,n}$, where $\overline{\Gamma}_{i,n}$ is the degenerate prior of the ith element of the parameter vector of model $n = 1, \ldots, 4$, and its standard deviation is $STD(\Gamma_{i,n})$.

Table 3: *CIC* of Kolmogorov-Smirnov Statistics

Model	ΔY w/r/t Trend Sh'k $\infty:0$	ΔY w/r/t Trend Sh'k $8:2$	ΔY w/r/t Transitory Sh'k $\infty:0$	ΔY w/r/t Transitory Sh'k $8:2$	ΔC w/r/t Trend Sh'k $\infty:0$	ΔC w/r/t Trend Sh'k $8:2$	ΔC w/r/t Transitory Sh'k $\infty:0$	ΔC w/r/t Transitory Sh'k $8:2$
NKDSGE-MG								
Baseline								
Non-Habit	0.02	0.03	0.00	0.01	0.00	0.00	0.00	0.00
Habit	0.00	0.04	0.16	0.18	0.02	0.16	0.13	0.18
SPrice								
Non-Habit	0.03	0.47	0.00	0.23	0.01	0.17	0.00	0.04
Habit	0.14	0.64	0.11	0.59	0.09	0.44	0.29	0.49
SWage								
Non-Habit	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.06
Habit	0.00	0.01	0.18	0.23	0.01	0.10	0.13	0.23
NKDSGE-TR								
Baseline								
Non-Habit	0.01	0.00	0.12	0.71	0.00	0.00	0.08	0.68
Habit	0.00	0.03	0.64	0.52	0.03	0.14	0.53	0.85
SPrice								
Non-Habit	0.40	0.57	0.00	0.76	0.01	0.16	0.00	0.49
Habit	0.43	0.74	0.29	0.65	0.15	0.46	0.33	0.76
SWage								
Non-Habit	0.00	0.00	0.21	0.37	0.00	0.00	0.02	0.81
Habit	0.00	0.05	0.55	0.45	0.03	0.13	0.44	0.77

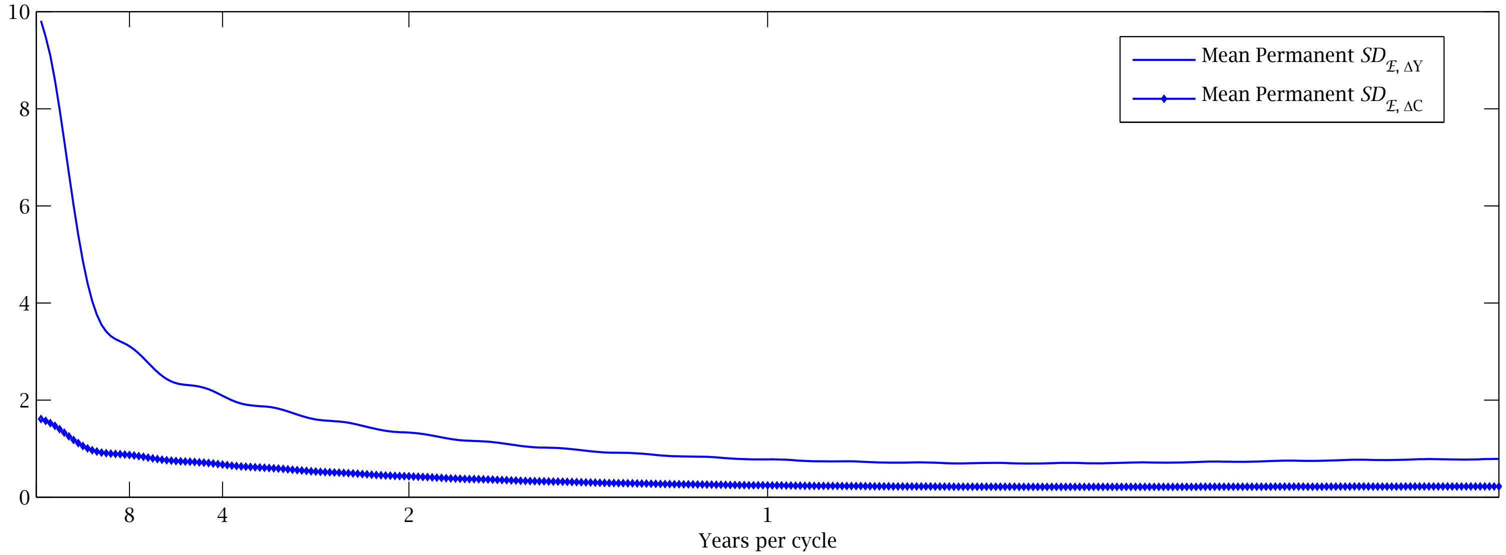
NKDSGE-MG and NKDSGE-TR denote the NKDSGE model with the AR(1) money supply rule (8) and the Taylor rule (9), respectively. Baseline NKDSGE models include sticky prices and sticky wages. The acronyms SPrice and SWage represent NKDSGE models with only sticky prices or sticky nominal wages, respectively. The column heading $\infty:0$ $(8:2)$ indicates that *CIC* quantify the intersection of $\mathcal{E}$ and $\mathcal{T}$ *KS* statistic distributions computed from permanent and transitory output and consumption growth SDs with domains on the entire spectrum (from eight to two years per cycle).

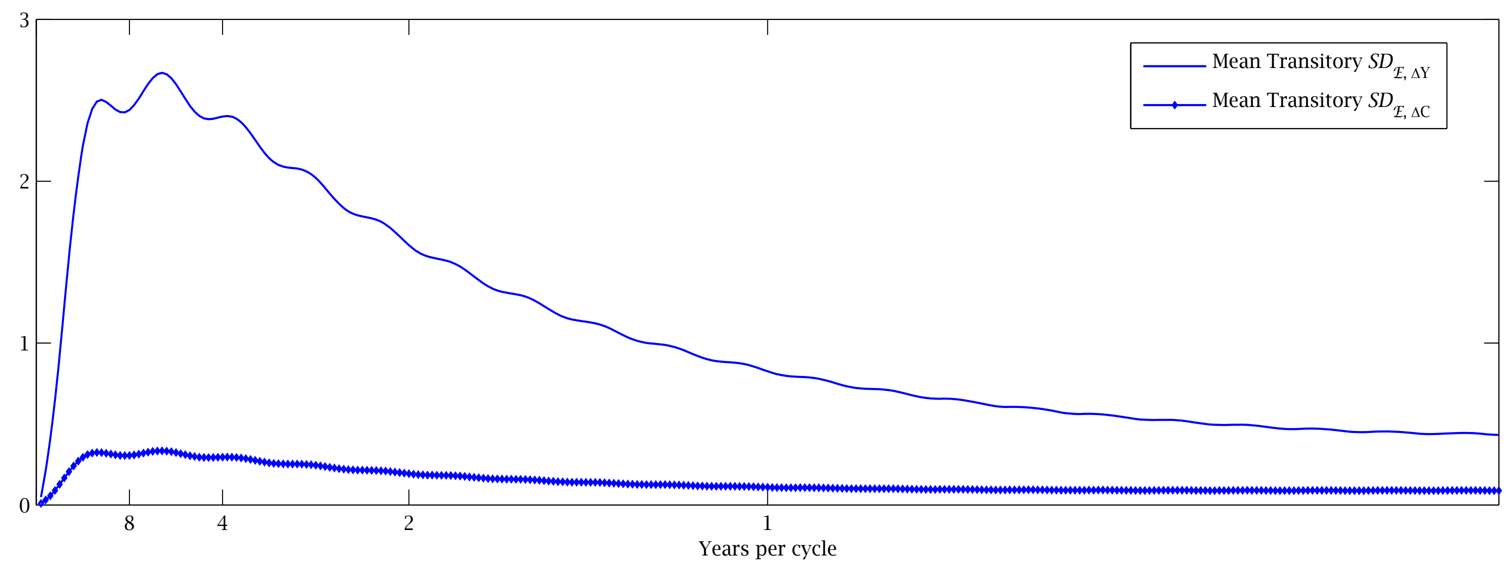
FIGURE 1: ΔC RESPONSE TO REAL INTEREST RATE SHOCK



The plots are the impulse response functions (IRFs) of consumption growth (ΔC) generated from the solved linearized Euler (2) given a one percent shock to the forecast innovation of the AR(1) of the real rate, q_t.

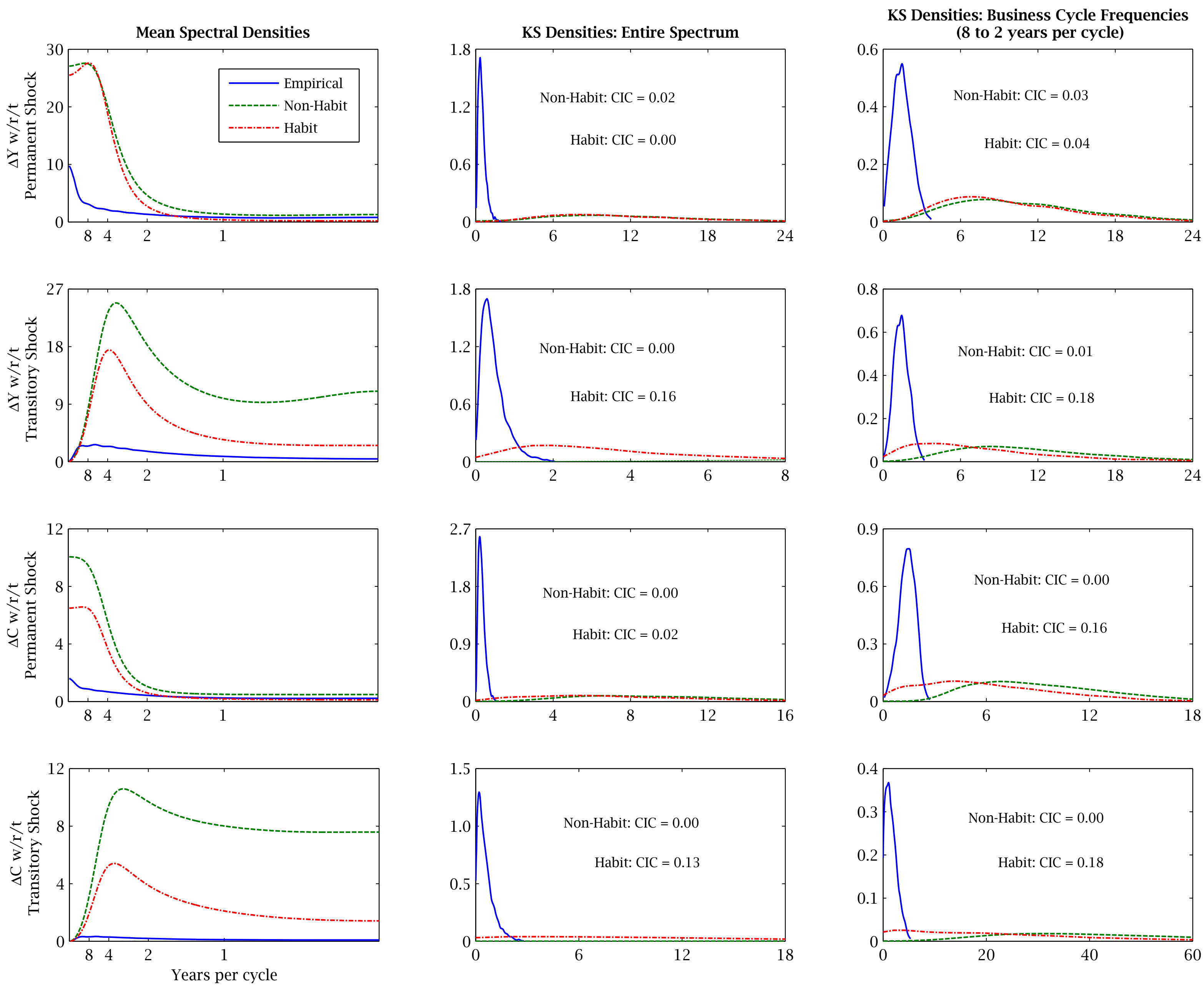
FIGURE 2: MEAN STRUCTURAL $\mathcal{E}$ SPECTRA OF ΔY AND ΔC





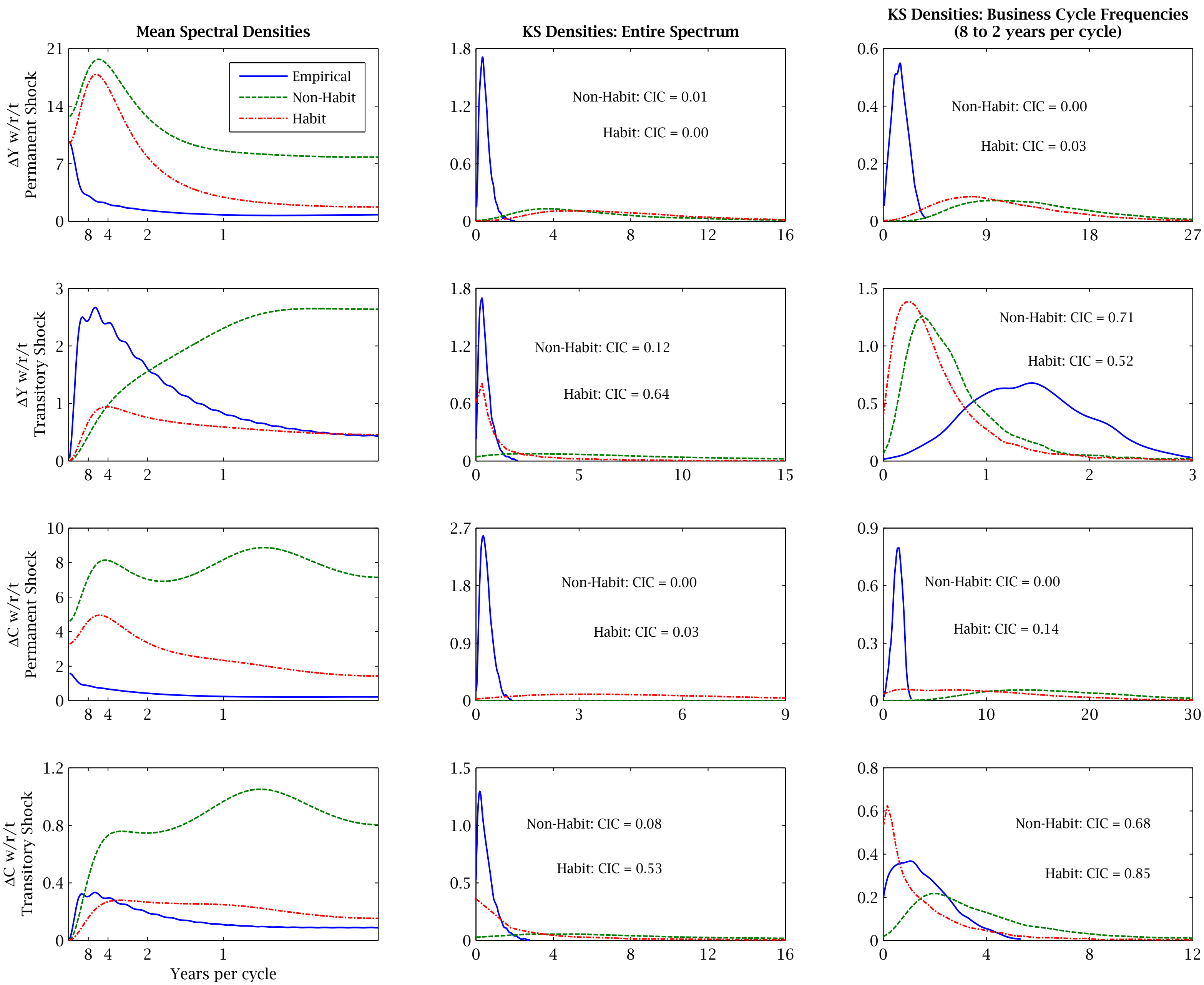
Mean permanent and transitory $SD_{\mathcal{E},\Delta Y}$ and $SD_{\mathcal{E},\Delta C}$ are averaged frequency by frequency across ensembles that consist of $\mathcal{J}$ of these *SD*s. The *SD*s are constructed using SVMA(∞)s that rely on LRMN, the BQ decomposition, unrestricted VAR(2)s.

Figure 3: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for Baseline NKDSGE Models with AR(1) Money Growth Rule



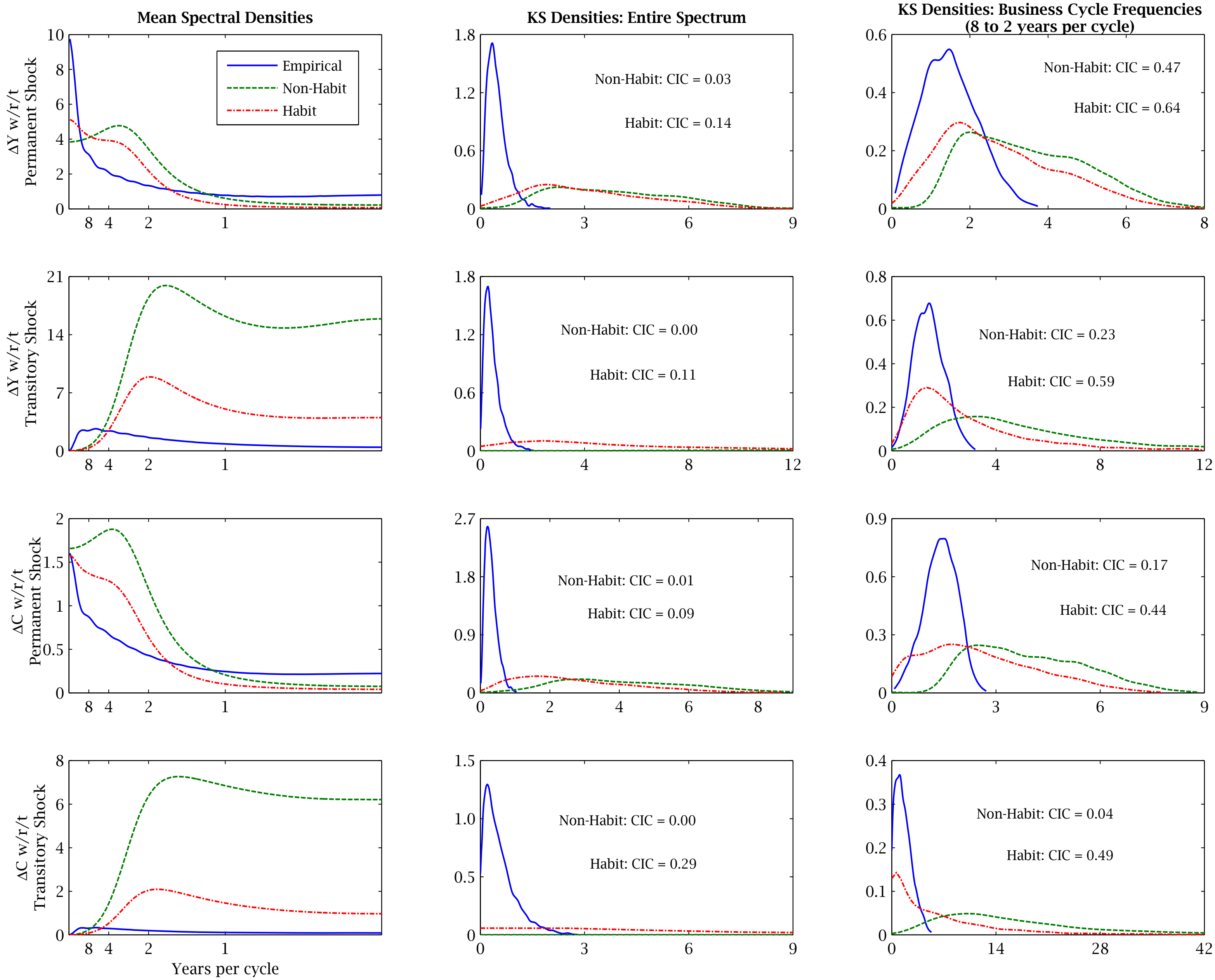
See section 4.3 for details.

Figure 4: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for Baseline NKDSGE Models with Taylor Rule



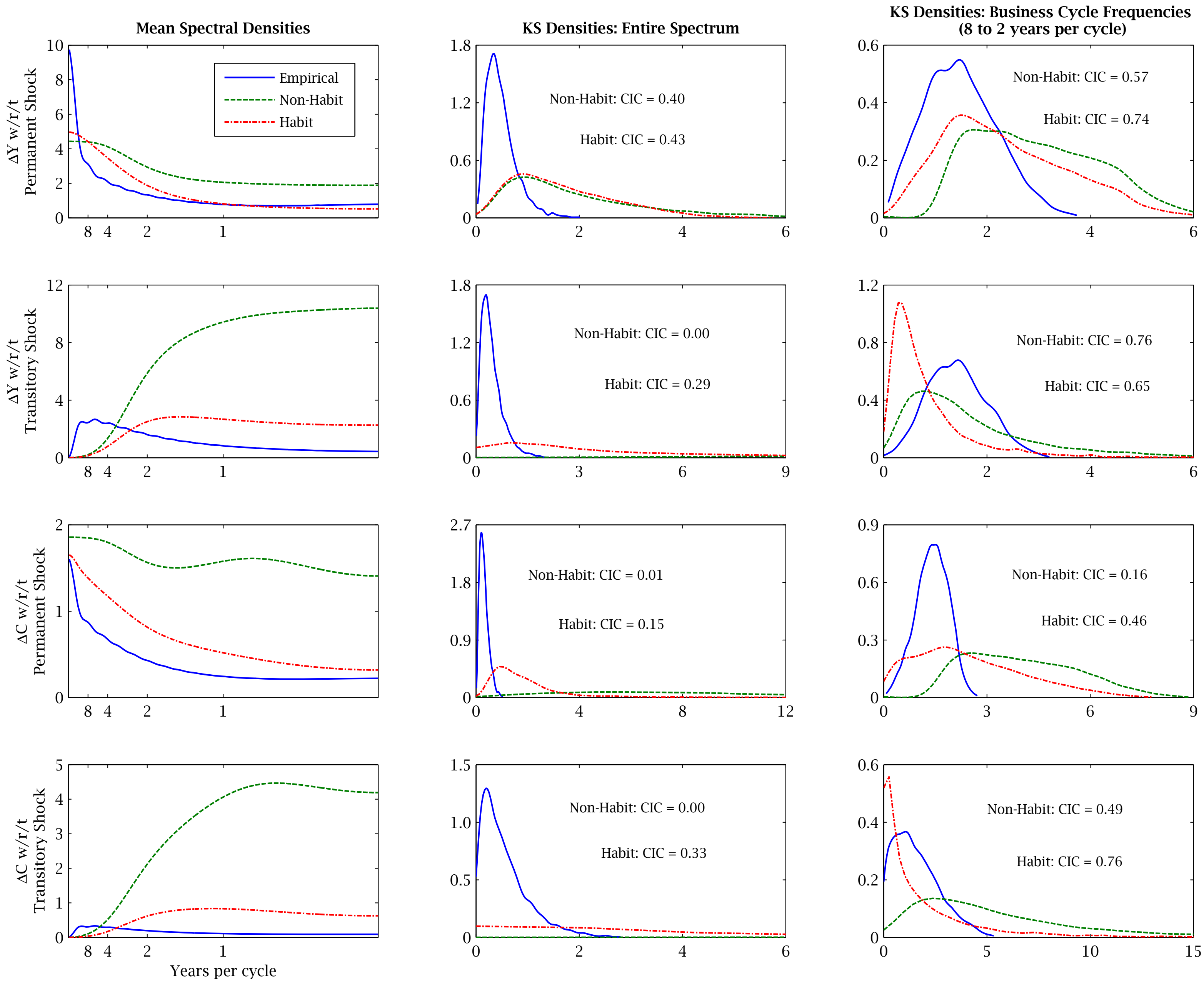
See section 4.3 for details.

Figure 5: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with AR(1) Money Growth Rule and Only Sticky Prices



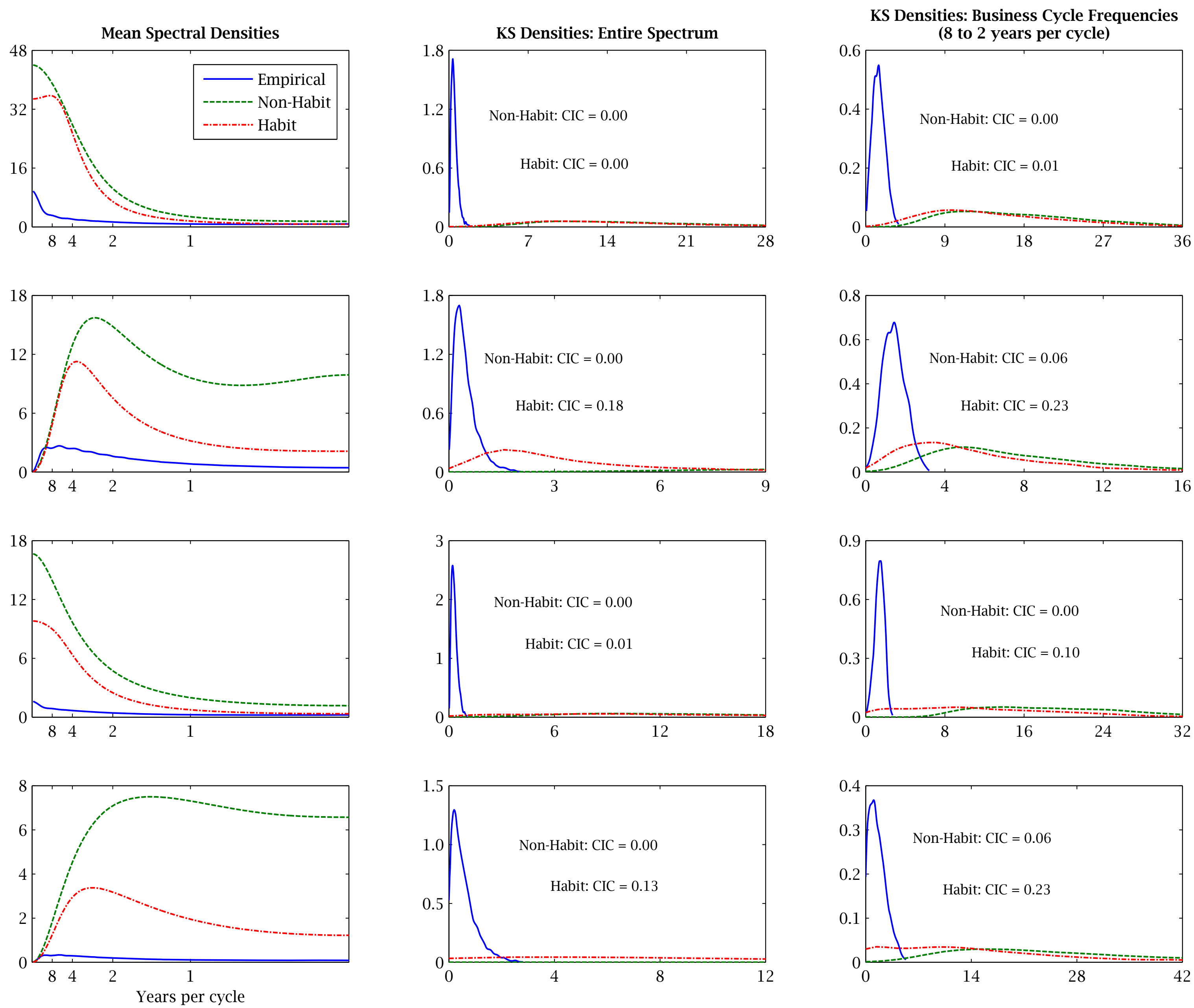
See section 4.3 for details.

Figure 6: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with Taylor Rule and only Sticky Prices



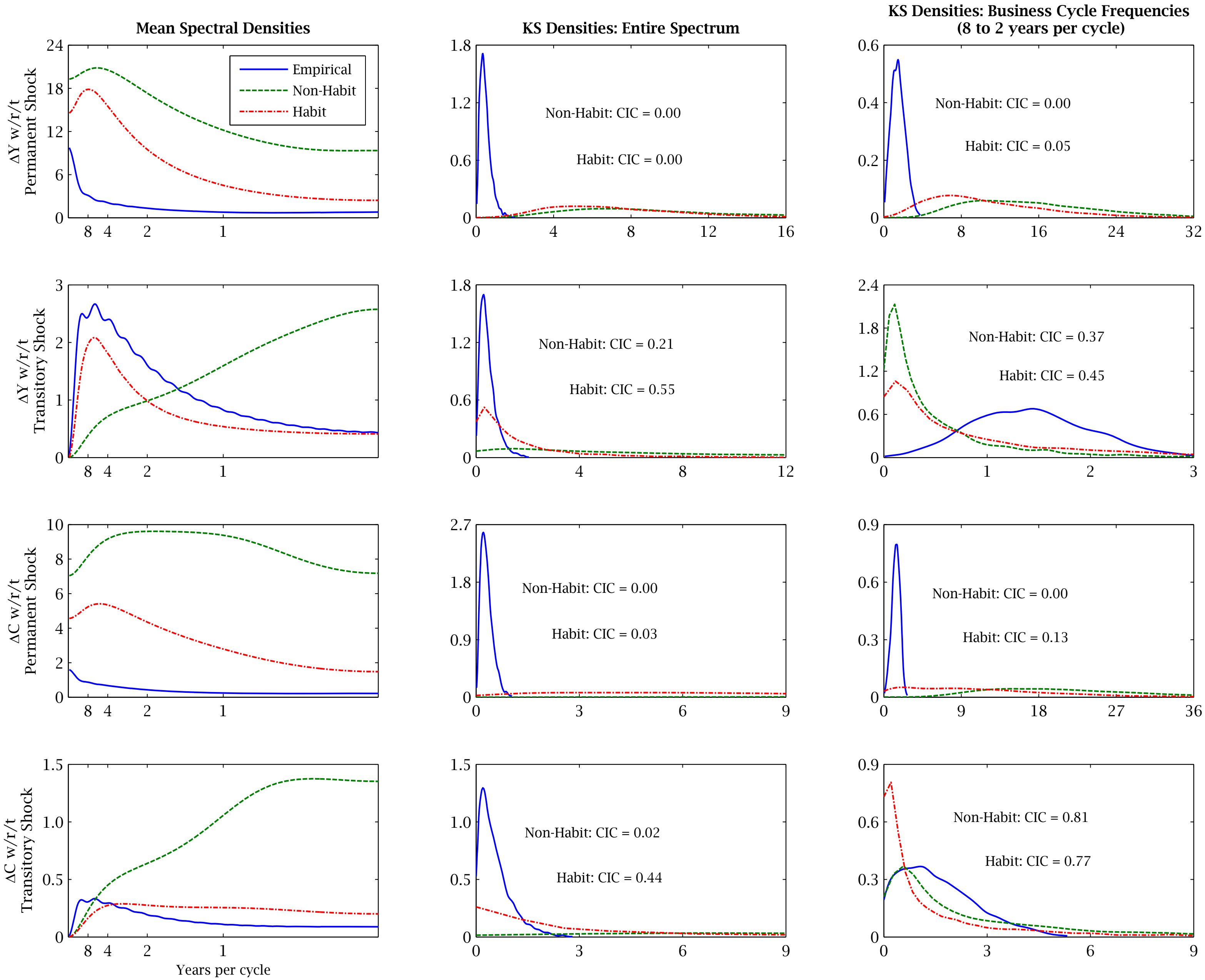
See section 4.3 for details.

Figure 7: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with AR(1) Money Growth Rule and Only Sticky Wages



See section 4.3 for details.

Figure 8: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with Taylor Rule and only Sticky Wages



See section 4.3 for details.