CARF-F-151

Business Cycle Implications of Internal Consumption Habit for New Keynesian Models

Takashi Kano
The University of Tokyo
James M. Nason
Federal Reserve Bank of Atlanta

June 2009

BUSINESS CYCLE IMPLICATIONS OF INTERNAL CONSUMPTION HABIT FOR NEW KEYNESIAN MODELS

Takashi Kano[†]
Faculty of Economics
Graduate School of Economics
The University of Tokyo
7–3–1 Hongo
Tokyo, JAPAN
email: tkano@e.u-tokyo.ac.jp

James M. Nason
Research Department
Federal Reserve Bank of Atlanta
1000 Peachtree Street, NE
Atlanta, GA
U.S.A. 30309–4470
email: jim.nason@atl.frb.org

Current Draft: June 9, 2009

Abstract

This paper studies the implications of internal consumption habit for propagation and monetary transmission in new Keynesian dynamic stochastic general equilibrium (NKDSGE) models. Bayesian methods are employed to evaluate the role of internal consumption habit in NKDSGE model propagation and monetary transmission. Simulation experiments show that internal consumption habit often improves NKDSGE model fit to output and consumption growth spectra by dampening business cycle periodicity. Nonetheless, habit NKDSGE model fit is vulnerable to the nominal rigidity, to the choice of monetary policy rule, to the frequencies used for evaluation, and to spectra identified by permanent productivity shocks.

Key Words: Habit; New Keynesian; Propagation; Monetary Transmission; 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, Martin Fukač, John Geweke, Tasos Karantounias, Thomas Lubik, Christian Matthes, Ricardo Nunes, Adrian Pagan, B. Ravikumar, Pedro Silos, Larry Schembri, 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, and System Macro Committee Meeting at the Federal Reserve Bank of San Francisco (May 2009) 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 Atlanta or the Federal Reserve System.

1. INTRODUCTION

It is a 'folk-theorem' of macroeconomics that, "All models are false." A sufficiently rich set of stylized facts will reject a dynamic stochastic general equilibrium (DSGE) model. One response finds optimal moments to evaluate a DSGE model, which follows from Hansen (1982). Another approach focuses on sample moments relevant for students of the business cycle.

This paper takes the latter tack to study the business cycle implications of consumption habit for new Keynesian (NK)DSGE models. These models often rely on the real rigidity of internal consumption habit to obtain a better fit to sample moments.[1] Typical is the NKDSGE model analyzed by Del Negro, Schorfheide, Smets, and Wouters (2007).[2] They find that *external* consumption habit is important for matching the hump-shaped output response to a monetary policy shock. This result contrasts with estimates of NKDSGE models reported by Christiano, Eichenbaum, and Evans (2005). In their NKDSGE models, eliminating *internal* consumption habit matters little for replicating the transmission of monetary policy shocks to output.

Lettau and Uhlig (2000) and Otrok, Ravikumar, and Whiteman (2002) also study consumption habit in DSGE models.[3] Instead of the effect on model fit of habit, their focus is on its unintended consequences. According to Lettau and Uhlig consumption habit may solve asset pricing puzzles, but in real business cycle (RBC) models it creates excess consumption smoothness compared to U.S. data. The reason is that habit drives down the local elasticity of substitution. Otrok, Ravikumar, and Whiteman examine habit with spectral utility functions that break consumption volatility down frequency by frequency. A spectral utility decomposition reveals that households are averse to high-frequency consumption movements under

---

[1] Consumption habit is first adapted to 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. However, Pollak (1976) shows that long-run utility with linear habit describes long-run behavior rather than long-run preferences. Rozen (2008) gives an axiomatic treatment of linear intrinsic habit.

[2] Schmitt-Grohé and Uribe (2007) is an excellent survey of habit in macro and finance; also see Nason (1997).

[3] Other critiques of consumption habit are Dynan (2000) and Kano (2009). Dynan rejects estimated moment conditions restricted by consumption habit on U.S.household panel data. Kano develops an observationally equivalence for current account dynamics for consumption habit and a world interest rate shock in a small open economy model. See Ravina (2007) and Gruber (2004) for evidence that supports consumption habit.

habit which explains its ability to solve risk-free rate and equity premium puzzles.

This paper is inspired by Lettau and Uhlig and Otrok, Ravikumar, and Whiteman to explore the role consumption habit has in NKDSGE model propagation and monetary transmission. We frame NKDSGE model propagation and monetary transmission with output and consumption growth spectral densities (SDs). These moments direct attention to the impact habit has on output and consumption growth periodicity. Our choice of these SDs is also guided by business cycle theory and the permanent income hypothesis (PIH). The PIH predicts a flat consumption growth SD, which Galí (1991) notes is at odds with U.S. data. Cogley and Nason (1995b) observe that DSGE models often cannot match the U.S. output growth SD because it peaks between seven and two years per cycle. They and Nason and Cogley (1994) find many DSGE models fail to replicate output's response to permanent and transitory shocks.

The NKDSGE models are borrowed from Christiano, Eichenbaum, and Evans (CEE). Their NKDSGE models have households whose preferences include (additive) internal consumption habit. This paper ties propagation and monetary transmission driven by internal consumption habit to intertemporal complementarity in future near-dated consumption. Our evidence about propagation and monetary transmission offers a resolution to the conflicting evidence of Del Negro, Schorfheide, Smets, and Wouters and CEE by gauging the fit of habit and non-habit NKDSGE models to output and consumption growth SDs.[4]

In the CEE model, the only disturbance is a transitory monetary policy shock. Besides monetary transmission, this paper also studies propagation in NKDSGE models given a random walk total factor productivity (TFP) shock. With these TFP and monetary policy shocks, a NKDSGE model satisfies long-run monetary neutrality (LRMN).

We invoke LRMN to identify *permanent* and *transitory* output and consumption growth SDs. These moments are computed using structural vector moving averages (SVMAs) of output (or consumption) growth and inflation that are just-identified by LRMN. The NKDSGE models

---

[4] The appendix shows that focusing on internal consumption habit sacrifices little generality because it and external habit can produce observationally equivalent linear approximate consumption growth dynamics.

predict that SVMAs are driven by current and lagged TFP and monetary policy shocks. Since these shocks are orthogonal at all leads and lags, SVMAs serve to parameterize permanent and transitory output and consumption growth SDs.

We examine a problem presented by Del Negro and Schorfheide (2008) conditional on LRMN. They find that priors can make it difficult to settle on which if any nominal rigidity is key for NKDSGE model fit using aggregate time series and Bayesian estimation methods. Rather than rely on Bayesian estimation of NKDSGE models, this paper explores the match between permanent and transitory output and consumption growth SDs using Bayesian calibrated habit and non-habit NKDSGE models that contain sticky prices and wages, only sticky prices, or just sticky wages. The fit of these NKDSGE models provides evidence about which, if any, of these rigidities matter for propagation and monetary transmission.

The permanent-transitory decomposition also gives us the opportunity to address an issue raised by Dupor, Han, and Tsai (2009). They obtain estimates of NKDSGE model parameters that are sensitive to whether technology or monetary policy shocks are used for identification. This paper explores this issue by asking if Bayesian calibrated NKDSGE models with different combinations of sticky prices and wages fit better to permanent or transitory output and consumption growth SDs.

This paper employs Bayesian calibration and simulation methods to study NKDSGE model propagation and monetary transmission. We adapt the Bayesian approach of DeJong, Ingram, and Whiteman (1996) and Geweke (2007) to conduct model evaluation. Geweke calls this the minimal econometric approach because it relies neither on likelihood-based tools nor arbitrarily focuses on a few moments while ignoring the rest of the predictive density of a NKDSGE model. Instead, the minimal econometric approach uses distributions of moments computed from atheoretic econometric models to link NKDSGE models to observable data.

We apply the minimal econometric approach by using SVMAs to tie NKDSGE models to sample permanent and transitory output and consumption growth SDs. Sample data, a SVMA, its priors, and Markov chain Monte Carlo (MCMC) simulators create posteriors that yield *empir-*

ical distributions of population SDs. *Theoretical* distributions of population SDs are garnered from SVMAs estimated on synthetic data that are simulated from calibrated NKDSGE models whose parameters are drawn from priors. We study propagation and monetary transmission with means of empirical and theoretical SD distributions. NKDSGE model fit is evaluated with the Kolmogorov-Smirnov (*KS*) statistic because it distills a multi-dimensional SD into a scalar. A NKDSGE model earns a good fit if its theoretical *KS* statistic distributions intersect empirical *KS* statistic distributions. This measure of fit constitutes a 'joint test' of NKDSGE model fit because theoretical SDs must match empirical SDs at several frequencies to achieve substantial overlap of empirical and theoretical *KS* statistic distributions.

The rest of the paper is constructed as follows. Section 2 discusses internal consumption habit and NKDSGE models. The Bayesian minimal econometric approach to DSGE model evaluation is reviewed 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 outlines a NKDSGE model.

2.1 Internal consumption habit

Consumption habit is often superinduced in NKDSGE models to improve fit. 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. We assume that household preferences are intertemporally separable as well as separable across (net) consumption flow, labor disutility, and real balances

$$\mathcal{U}\left(c_t,\, c_{t-1},\, n_t,\, \frac{H_t}{P_t}\right) \;=\; \ln[c_t - hc_{t-1}] - \frac{n_t^{1+\frac{1}{\gamma}}}{1+\frac{1}{\gamma}} + \ln\left[\frac{H_t}{P_t}\right], \quad 0 < \gamma, \tag{1}$$

where c_t, n_t, H_t, P_t, and H_t/P_t, are household consumption, labor supply, the household's stock of cash at the end of date $t-1$, the aggregate price level, and real balances, respectively. We also maintain that $h \in (0, 1)$ and $0 < c_t - hc_{t-1}$, $\forall\ t$. Since internal habit ties current household consumption choice to its past consumption, the marginal utility of consumption is forward-looking, $\lambda_t = \dfrac{1}{c_t - hc_{t-1}} - \mathbf{E}_t\Big\{\dfrac{\beta h}{c_{t+1} - hc_t}\Big\}$, where $\beta \in (0, 1)$ is the household discount factor and $\mathbf{E}_t\{\cdot\}$ is the mathematical expectation operator given date t information.[5]

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 equation $\lambda_t = \mathbf{E}_t\Big\{\lambda_{t+1}R_{t+1}/(1+\pi_{t+1})\Big\}$, 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.[6]

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 $[\beta\ \ \alpha^*]' = [0.993\ \ \exp(0.004)]'$, $h = [0.15\ 0.35\ 0.50\ 0.65\ 0.85]$, and $\tilde{q}_t$ to a quarterly first-order autoregression, AR(1), with a AR1 coefficient of 0.869.[7] Figure 1 shows that at impact $\widetilde{\Delta c}_t$ is driven higher. However, its

---

[5] Dunn and Singleton (1986), 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, habit appears in the data if local substitutability operates at lower frequencies than the sampling frequency of consumption.

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

[7] 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.

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 $h \longrightarrow 1$. Thus, as internal habit becomes stronger, it dictates greater utility costs that persuades the household to move longer sequences of future near-dated consumption in tandem.

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 real rate shock. Figure 1 reveals a similar internal consumption habit propagation mechanism for equation (2) that relies on $h \geq 0.5$ to produce a humped-shaped IRF with a peak at or beyond two quarters. This 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 $\mathbf{E}_t\left\{\widetilde{\Delta c}_{t+1} - \tilde{q}_{t+1}\right\} = 0$. In these cases, figure 1 suggests 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 utility costs on intertemporal consumption choice. For example, as h rises from zero toward one, the household comes to view near-dated consumption as complements rather than substitutes. According to figure 1, this switch creates an economically important internal consumption habit propagation mechanism as h moves past 0.5 and closes in on one.

This paper studies the business cycle 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).[8] Given this, there is little lost by focusing on internal consumption habit. Also, the appendix finds that the impact response of $\widetilde{\Delta c}_t$ becomes large under external consumption habit as $h \longrightarrow 1$.

---

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

2.3 *A new Keynesian DSGE model*

We adapt the NKDSGE model of CEE. The 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 heterogenous 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 $t+1$, x_t is investment, k_t is household capital at the end of date t, 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, $u^* = 1$, $a(1) = 0$ and to achieve a determinate solution $\frac{a''(1)}{a'(1)} = 1.174$. Note that u_t forces household ℓ to forgo $a(\cdot)$ units of consumption per unit of capital. The CCE adjustment costs specification is placed into the law of motion of household capital

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

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

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

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.

Monopolistically competitive firms produce the 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 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 a $P_t = \left[\int_0^1 P_t(j)^{1-\xi}\right]^{1/(1-\xi)}$.

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) with labor-augmenting TFP, A_t, in the constant returns to scale technology, $[u_t K_t(j)]^{\psi}\,[(N_t(j) - N_0)A_t]^{1-\psi}$, $\psi \in (0, 1)$, to create output, $y_t(j)$. TFP is a random walk with drift, $A_t = A_{t-1}\exp\{\alpha + \varepsilon_t\}$, and ε_t its Gaussian innovation, $\varepsilon_t \sim \mathcal{N}(0, \sigma_\varepsilon^2)$.

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 gives 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

$$\frac{P_{c,t}}{P_{t-1}} = \left(\frac{\xi}{\xi-1}\right)\frac{\mathbf{E}_t \sum_{i=0}^{\infty} (\beta\mu_P)^i\, \lambda_{t+i}\phi_{t+i} Y_{D,t+i}\pi_{t+i}^{\xi}}{\mathbf{E}_t \sum_{i=0}^{\infty} (\beta\mu_P)^i\, \lambda_{t+i} Y_{D,t+i}\pi_{t+i}^{\xi-1}} \tag{6}$$

of a firm able to update its price.

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 $N_t(j) = \left[\int_0^1 n_t(\ell)^{(\theta-1)/\theta} d\ell\right]^{\theta/(\theta-1)}$, where θ is the wage elasticity. Labor market monopoly force firms to face downward sloping labor demand schedules for differentiated labor services, $n_t(\ell) = \left[W_t/W_t(\ell)\right]^{\theta} N_t(j)$, 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 $W_t = \left[(1-\mu_W)W_{c,t}^{1-\theta} + \mu_W\,(\alpha^* \pi_{t-1} W_{t-1})^{1-\theta}\right]^{1/(1-\theta)}$, 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, $\alpha^* = \exp(\alpha)$, and lagged inflation. In this case, the optimal nominal wage condition is

$$\left[\frac{W_{c,t}}{P_{t-1}}\right]^{1+\theta/\gamma} = \left(\frac{\theta}{\theta - 1}\right) \frac{\mathbf{E}_t \sum_{i=0}^{\infty} \left[\beta\mu_W \alpha^{*-\theta(1+1/\gamma)}\right]^i \left[\left[\frac{W_{t+i}}{P_{t+i-1}}\right]^{\theta} N_{t+i}\right]^{1+1/\gamma}}{\mathbf{E}_t \sum_{i=0}^{\infty} \left[\beta\mu_W \alpha^{*(1-\theta)}\right]^i \lambda_{t+i} \left[\frac{W_{t+i}}{P_{t+i-1}}\right]^{\theta} \left[\frac{P_{t+i}}{P_{t+i-1}}\right]^{-1} N_{t+i}}, \tag{7}$$

because households solve a fully indexed Calvo-pricing problem.

We close the NKDSGE model with one of two monetary policy rules. CEE identify monetary policy with a money growth process that is a structural infinite-order moving average, SMA(∞). As CEE note, the SMA(∞) is equivalent to the AR(1) money growth supply rule

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

where m^* is mean money growth and the money growth innovation is μ_t. NKDSGE-AR defines models with the money growth rule (8). Monetary policy is described with the Taylor rule

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

in NKDSGE-TR models, 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 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 $P_t \tau_t = [M_{t+1} - M_t] + [B_{t+1} - (1 + R_t)B_t]$. 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 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 Bayesian Monte Carlo methods of DeJong, Ingram, and Whiteman (1996) and Geweke (2007) that we use to assess NKDSGE model fit. DeJong, Ingram, and Whiteman (DIW) and Geweke eschew standard calibration and likelihood-based tools because, in their view, a NKDSGE model lacks predictions for all but population moments. We follow their approach and evaluate NKDSGE models with atheoretic econometric models that tie observed sample data to population moments.

3.1 Solution methods and Bayesian calibration of the DSGE models

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. 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 TFP and monetary policy shocks 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, which endow population SDs with theoretical distributions; see Geweke (2007). Table 1 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 1. The uninformative prior reflects a belief that any $h \in \left[0.05, 0.95\right]$ is as likely as another. Non-habit NKDSGE models are defined by the degenerate prior $h = 0$.

Priors are also taken from earlier DSGE model studies. We place degenerate priors on $\left[\beta\ \gamma\ \delta\ \alpha\ \psi\right]' = \left[0.9930\ \ 1.3088\ \ 0.0200\ \ 0.0040\ \ 0.3500\right]'$ that are consistent with the Cogley and Nason (1995b) calibration. 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). An uninformative prior is imposed on the standard deviation of TFP shock innovations, σ_{ϵ}. The RBC literature suggests that any $\sigma_{\epsilon} \in [0.0070, 0.0140]$ is equally fair, which motivates our choice of this prior.

There are four sticky price and wage parameters to calibrate. The relevant prior means are $[\xi\ \mu_P\ \theta\ \mu_w]' = \left[8.0\ 0.55\ 15.0\ 0.7\right]'$. The mean of ξ implies a steady state price markup, $\xi/(\xi - 1)$, of 14 percent with a 95 percent coverage interval that runs from 11 to 19 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. For example, 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, $\theta/(\theta - 1)$. However, the degenerate mean of μ_w and its 95 percent coverage interval reveals stickier nominal wages than prices, as found for example by CEE, but with the same degree of uncertainty.

The money growth rule (8) is calibrated to estimates from a $1954Q1$–$2002Q4$ sample of M1. The estimates are degenerate priors for $\left[m^{*}\ \rho_m\ \sigma_{\mu}\right]' = \left[0.015\ 0.627\ 0.006\right]'$. Precision of these estimates yield narrow 95 percent coverage intervals. For ρ_m, the lower end of its interval is near 0.5. CEE note that $\rho_m \approx 0.5$ implies the money growth rule (8) mimics their identified monetary policy shock process.

The calibration of the interest rate rule (9) obeys the Taylor principle and $a_y \in (0, 1)$.

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_y. The 95 percent coverage intervals of a_π and a_y rely on estimates that Smets and Wouters (2007) report. 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]. 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 all leads and lags (*i.e.*, $\mathbf{E}\{\varepsilon_{t+i}\,\upsilon_{t+q}\} = 0$, for all i, q).

3.2 Output and consumption moments

We evaluate NKDSGE model fit with output and consumption growth SDs. The SDs are calculated from just-identified SVMAs, which are identified with a LRMN restriction that is 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. We recover the SVMAs from unrestricted VARs with the Blanchard and Quah (1989) decomposition. The VARs are estimated for $[\Delta \ln Y_t\ \ \Delta \ln P_t]'$ and $[\Delta \ln C_t\ \ \Delta \ln P_t]'$ using 1954Q1–2002Q4 and synthetic samples.[9]

We employ just-identified SVMAs to compute permanent and transitory output and consumption growth SDs. If the Taylor rule (9) is the source of the transitory monetary policy shock (υ_t), the just-identified SVMA is

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

The elements of $\mathbb{B}_j$ are identified by the LRMN restriction $\mathbb{B}_{\Delta Y,\upsilon}(\mathbf{1}) = 0$ (*i.e.*, output is independent of the Taylor rule shock υ_t at the infinite horizon) and that the TFP shock ε_t and υ_t are orthogonal at all leads and lags; see the appendix for details. These restrictions per-

---

[9] VAR lag length is chosen using the sample data and likelihood ratio statistics testing down from a maximum of ten lags. These tests settle on a lag length of five for VARs of $[\Delta \ln Y_t\ \ \Delta \ln P_t]'$ and $[\Delta \ln C_t\ \ \Delta \ln P_t]'$.

mit the SVMA (10) to be decomposed into univariate SMA(∞)s of output growth, $\mathbb{B}_{\Delta Y,\varepsilon}(\mathbf{L})\varepsilon_t$ 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). The SVMA (10) is also a Wold representation of $[\Delta \ln Y_t \quad \Delta \ln P_t]'$ whose spectrum (at frequency ω) is $S_{[\Delta Y \quad \Delta P]}(\omega) = (2\pi)^{-1}\Gamma_{[\Delta Y \quad \Delta P]}\exp(-i\omega)$, where $\Gamma_{[\Delta Y \quad \Delta P]}(l) = \sum_{j=0}^{\infty}\mathbb{B}_j\mathbb{B}'_{j-l}$. Expanding the convolution $\Gamma_{[\Delta Y \quad \Delta P]}(l)$ at horizon j gives

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

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 $\mathbb{B}_{\Delta Y,\varepsilon,j}\mathbb{B}_{\Delta Y,\varepsilon,j-l}$ and $\mathbb{B}_{\Delta Y,\upsilon,j}\mathbb{B}_{\Delta Y,\upsilon,j-l}$. The autocovariances suggest treating the univariate output growth SMAs $\mathbb{B}_{\Delta Y,\varepsilon}(\mathbf{L})\varepsilon_t$ and $\mathbb{B}_{\Delta Y,\upsilon}(\mathbf{L})\upsilon_t$ as objects whose innovations are the permanent TFP shock ε_t and transitory Taylor rule shock υ_t. We employ these SMAs to parameterize permanent and transitory output growth SDs.[10] Given the BQ decomposition assumption $\sigma_\iota^2 = 1$, this gives us the output growth SD at frequency ω

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

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

3.3 Bayesian simulation methods

We use MCMC software of Geweke (1999) and McCausland (2004) to create posteriors of SVMAs given priors and a $1954Q1$–$2002Q4$ sample ($T = 196$) of U.S. output, consumption, and price growth.[11] The posteriors contain $\mathcal{J} = 5000$ SVMA parameter vectors that are the basis of empirical, $\mathcal{E}$, permanent and transitory output and consumption growth SD distributions.

---

[10] The idea of parameterizing permanent and transitory output and consumption growth SDs with a SMA extends ideas found in Akaike (1969) and Parzen (1974).

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

The SVMAs are also engaged to create theoretical, $\mathcal{T}$, distributions of population permanent and transitory output and consumption growth SDs. The $\mathcal{T}$ SD distributions are computed using SVMAs estimated on $\mathcal{J}$ synthetic samples of length $\mathcal{M} \times T$, $\mathcal{M} = 5$, that are simulated from a linearized NKDSGE model conditional on priors placed on its parameters.[12] NKDSGE models are judged on the overlap of $\mathcal{T}$ and $\mathcal{E}$ moment distributions.

3.4 Measures of fit

Our metric for judging the fit of a NKDSGE model begins with Cogley and Nason (1995a). They measure the fit of DSGE models to sample moments using Kolmogorov-Smirnov (*KS*) and Cramer-von Mises (*CvM*) goodness of fit statistics.

This paper employs *KS* statistics, but in the context of Bayesian calibration experiments. The *KS* statistics are centered on the sample output (or consumption) growth SD, $\widehat{I_T}(\omega)$, which is constructed from SVMAs estimated on the actual data. At frequency ω, the jth draw from the ensemble of $\mathcal{E}$ SDs of output growth (or consumption growth) is $I_{\mathcal{E},T,j}(\omega)$. The associated draw from a $\mathcal{T}$ distribution is $I_{\mathcal{T},T,j}(\omega)$. Define the ratio $\mathcal{R}_{\mathcal{D},T,j}(\omega) = \widehat{I_T}(\omega) \;/\; I_{\mathcal{D},T,j}(\omega)$ at replication j, as well as its partial sum $\mathcal{V}_{\mathcal{D},T,j}\left(2\pi q/T\right) = 2\pi \sum_{\ell=1}^{q} \mathcal{R}_{\mathcal{D},T,j}\left(2\pi\ell/T\right)/T$, where $\mathcal{D} = \mathcal{E}$, $\mathcal{T}$. The partial sum serves to construct $\mathcal{B}_{T,\mathcal{D},j}(\kappa) = 0.5\sqrt{2T}\Big[\mathcal{V}_{T,\mathcal{D},j}(\kappa\pi) - \kappa\mathcal{V}_{T,\mathcal{D},j}(\pi)\Big]/\pi$, $\kappa \in [0, 1]$. If the 'partial' differences $\mathcal{B}_{T,\mathcal{D},j}(\cdot)$, $j = 1, \ldots, \mathcal{J}$, are small, the sample and $\mathcal{D}$ spectra are close.[13] Vectors of 'partial' differences $\left\{\mathcal{B}_{T,\mathcal{D},j}(\cdot)\right\}_{j=1}^{J}$ are collected to form $KS_{\mathcal{D},j} = Max\left|\mathcal{B}_{T,\mathcal{D},j}(\kappa)\right|$. Although *KS* statistics measure the distance between sample and $\mathcal{E}$ or $\mathcal{T}$ spectra, we employ distributions of $\mathcal{E}$ and $\mathcal{T}$ *KS* statistics to gauge the fit of the NKDSGE models. NKDSGE model fit is judged on the overlap of $\mathcal{E}$ and $\mathcal{T}$ distributions of *KS* statistics. Substantial overlap of these distributions indicate a good fit for a NKDSGE model.

The *KS* statistic is useful because it collapses a multidimensional SD into a scalar. Thus, NKDSGE model fit is gauged jointly on several frequencies. However, we also include mean $\mathcal{E}$ and $\mathcal{T}$ permanent and transitory output and consumption growth SDs to study NKDSGE

---

[12] NKDSGE models generate mean theoretical SDs nearly identical to population SDs at $\mathcal{M} = 5$.

[13] Since $\mathcal{V}_T(\omega)$ is the sum of the ratio $\mathcal{R}_T(\omega)$, a linear filter applied to the actual and synthetic data has no effect on $\mathcal{B}_{T,\mathcal{D},j}(\kappa)$. Hence, linear filtering will not alter the *KS* statistics and NKDSGE model evaluation.

model propagation and monetary transmission frequency by frequency.

DIW advocate using the confidence interval criterion (*CIC*) to quantify the intersection of $\mathcal{E}$ and $\mathcal{T}$ distributions. The *CIC* measures the fraction of a $\mathcal{T}$ *KS* distribution that occupies an interval defined by lower and upper quantiles of the relevant $\mathcal{E}$ *KS* distribution, given a $1 - p$ percent confidence level.[14] 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 SD and the non-habit model's $CIC \leq 0.3$, the data view habit as more plausible for this moment. We also report densities of $\mathcal{E}$ and $\mathcal{T}$ *KS* statistic distributions to examine visually NKDSGE model fit.

We calculate SDs on the entire spectrum and on business cycle horizons from eight to two years per cycle. By restricting attention to business cycle fluctuations, we build on an approach to model evaluation of Diebold, Ohanian, and Berkowitz (1998). Their insight is that a focus on business cycle frequencies matters for DSGE model evaluation when model misspecification (*i.e.*, 'all models are false') corrupts measurement of short- and long-run fluctuations. We address these problems by judging NKDSGE model fit on the business cycle frequencies, which ignores low and high frequency output and consumption growth amplitude and periodicity.

4. Habit and Non-Habit NKDSGE Model Evaluation

This section presents evidence about habit and non-habit NKDSGE model fit to $\mathcal{E}$ permanent and transitory output and consumption growth SDs. Mean $\mathcal{E}$ SDs appear in figure 2. We report *CIC* in table 2. Figures 3–8 give visual evidence about NKDSGE model fit.

4.1 Business cycle moments: Output and consumption growth SDs

Figure 2 contains mean $\mathcal{E}$ permanent and transitory output and consumption growth SDs. The top (bottom) panel of figure 2 contains mean $\mathcal{E}$ permanent (transitory) output and consumption growth SDs. Mean $\mathcal{E}$ output growth SDs appear as solid (blue) lines in figure 2, while consumption growth SDs plots are thicker with '♦' symbols.

---

[14] DIW set the *CIC* of $\mathcal{Q}$ to $\frac{1}{1-p}\int_a^b \mathcal{T}(\mathcal{Q}_j)d\,\mathcal{Q}_j$ 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 $\int_a^b \mathcal{E}(\mathcal{Q}_j)d\,\mathcal{Q}_j$.

The SDs decompose variation in output and consumption growth frequency by frequency in response to permanent and transitory shocks. The former shock yields mean $\mathcal{E}$ permanent output and consumption growth SDs that display greatest power at frequency zero as shown in the top panel of figure 2. However, the consumption growth SD exhibits only about a third of the amplitude (*i.e.*, volatility) that is found in output growth at the long run. The permanent shock also produces smaller peaks around four years per cycle in output and consumption growth SDs that reveal periodicity in the business cycle frequencies.

The lower panel of figure 2 presents mean transitory $\mathcal{E}$ output and consumption growth SDs. The mean $\mathcal{E}$ transitory output (consumption) growth SD peaks at less than four (eight) years per cycle. At the mean peaks, output growth is almost four times more volatile than consumption growth. However, output and consumption growth display periodicity at the business cycle frequencies with mean peaks between eight and two years per cycle.

We view the mean permanent and transitory $\mathcal{E}$ output and consumption growth SDs as challenges to NKDSGE models.[15] Mean $\mathcal{E}$ consumption growth SDs appear to vary enough at growth and business cycle frequencies to reject the PIH. Thus, NKDSGE models must violate the PIH to match these moments. Output growth SDs confront NKDSGE models with periodicity at low and business cycle frequencies that show these models need economically meaningful propagation and monetary transmission to achieve a good fit.

4.2 *Habit and non-habit NKDSGE model fit: Evaluation by CIC*

Table 2 reports *CIC* that evaluate NKDSGE model fit. The top panel has *CIC* of habit and non-habit sticky price and wage (baseline), sticky price only (SPrice), and sticky wage only (SWage) NKDSGE-AR models (the money growth rule (8) defines monetary policy).[16] The lower panel includes *CIC* of NKDSGE-TR models (the Taylor rule (9) replaces the money growth rule). Columns headed $\infty : 0$ and $8 : 2$ contain *CIC* that measure the overlap of $\mathcal{E}$ and $\mathcal{T}$ *KS* statistic

---

[15] When the SVMAs are calculated from VAR(2)s rather than VAR(5)s, $\mathcal{E}$ permanent and transitory output and consumption growth SDs are qualitatively unchanged.

[16] 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. The markup in the labor market is fixed at $(\theta - 1)/\theta$, which equals $n^{-1/\gamma}$, given $\mu_W = 0$.

distributions based on the entire spectrum and eight to two years per cycle, respectively.

The lower panel of table 2 includes *CIC* of $\mathcal{E}$ and $\mathcal{T}$ *KS* statistic distributions of output and consumption growth SDs that are tied to NKDSGE-TR models. Habit NKDSGE-TR models yield *CIC* of 0.3 or more in 14 of 24 simulation experiments, but non-habit NKDSGE-TR models are responsible for only seven *CIC* ≥ 0.3. When habit and non-habit NKDSGE-TR models generate these *CIC* on the same SD, non-habit model *CIC* are larger only in two of seven cases. We view these results as evidence that internal consumption habit improves NKDSGE-TR model fit.[17] It also worth noting that it is difficult to choose between the fit of baseline, SPrice, and SWage habit NKDSGE-TR models to $\mathcal{E}$ transitory SDs using the *CIC*.

The NKDSGE-AR models are less successful at replicating the $\mathcal{E}$ *KS* statistic distributions. The upper panel of table 2 contains only five *CIC* ≥ 0.3 of the 48 entries. The SPrice habit NKDSGE-AR model is responsible for four of these *CIC*.

A striking feature of table 2 is that the fit of the baseline habit NKDSGE-AR model is dominated by the baseline habit NKDSGE-TR model. The baseline habit NKDSGE-TR model better replicates $\mathcal{E}$ transitory SDs compared to the baseline habit NKDSGE-AR model. Nevertheless, baseline NKDSGE models fail to propagate TFP innovations into output and consumption growth amplitude and periodicity that match $\mathcal{E}$ permanent SD distributions. The relevant *CIC* are less than 0.3 in the first two rows of the top and bottom panels of table 2.

Table 2 also provides information about the impact of sticky prices on NKDSGE model fit. Only SPrice habit NKDSGE models yield *CIC* > 0.3 for *KS* statistic distributions of the permanent output and consumption growth SDs. However, the comparisons must be limited to eight to two years per cycle for these models to generate *CIC* of this size. Thus there is evidence that internal consumption habit and fully indexed Calvo staggered pricing combine to propagate TFP shocks into economically meaningful output and consumption growth periodicity, but only at the business cycle frequencies.

---

[17] The *CIC* of table 2 are nearly unchanged either using the *CvM* statistic instead of the *KS* statistic or replacing the uniform prior of h with a prior drawn from a beta distribution with mean, standard deviation, and 95 percent coverage interval of 0.65, 0.15, and [0.38, 0.88]. These *CIC* are found in the appendix.

The SWage NKDSGE models only duplicate the $\mathcal{E}$ transitory output and consumption growth SDs if monetary policy is defined by the Taylor rule (9). The last two rows of table 2 contain *CIC* that imply a good fit for the SWage habit NKDSGE-TR model to $\mathcal{E}$ transitory SDs on the entire spectrum. The relevant $CIC \geq 0.36$. When internal consumption habit is missing from the SWage NKDSGE-TR model and the match to $\mathcal{E}$ transitory SDs is constrained to eight to two years per cycle, the $CIC \geq 0.45$. The same NKDSGE model cannot replicate these moments over the entire spectrum with $CIC \leq 0.13$. The SWage NKDSGE-AR models also produce $\mathcal{T}$ *KS* statistic densities of transitory SDs that have little overlap with their $\mathcal{E}$ counterparts (*i.e.*, $CIC \leq 0.22$). These results indicate that sticky wages combined with the Taylor rule (9) create monetary transmission in the habit NKDSGE model.

4.3 Baseline habit NKDSGE model fit: The role of monetary policy rules

This section expands on the *CIC* of table 2 by presenting additional evidence about the fit of baseline NKDSGE models to $\mathcal{E}$ permanent and transitory output and consumption growth SDs. We plot mean $\mathcal{E}$ and $\mathcal{T}$ permanent and transitory SDs and *KS* statistic densities of the baseline NKDSGE models in the first column of figures 3 and 4. The second (third) column contains densities of *KS* statistics that are constructed over the entire spectrum (constrained to eight to two years per cycle). The *KS* statistic densities also appear with the relevant *CIC*. From top to bottom, the rows of figures 3 and 4 present results for permanent output, transitory output, permanent consumption, and transitory consumption growth SDs. We denote mean $\mathcal{E}$ SDs and *KS* statistic densities with (blue) solid lines, mean $\mathcal{T}$ non-habit SDs and *KS* statistic densities with (green) dashed lines, and mean $\mathcal{T}$ habit SDs and *KS* statistic densities with (red) dot-dash lines in figures 3 and 4. The four remaining figures employ the same layout.

Baseline NKDSGE models fail to match $\mathcal{E}$ permanent output and consumption growth SDs. The poor fit is reflected in $\mathcal{T}$ *KS* statistic densities that are flat or far to the right of the relevant $\mathcal{E}$ densities as seen in the second and third columns of the odd numbered rows of figures 3 and 4. The lack of overlap of these $\mathcal{E}$ and $\mathcal{T}$ *KS* densities are consistent with mean $\mathcal{T}$ permanent SDs that often peak between eight and four years per cycle while mean $\mathcal{E}$

permanent SDs slowly decay from the low to business cycle frequencies in the odd numbered windows of the first column of figures 3 and 4. Thus, the combination of internal consumption habit or not, sticky prices and wages, and either monetary policy rule fails to propagate TFP shocks into the low and business cycle frequencies to match $\mathcal{E}$ permanent SDs.

The choice of monetary policy rule matters for baseline NKDSGE model fit to the $\mathcal{E}$ transitory SDs. The baseline habit NKDSGE-TR model responds to a monetary policy shock by dampening output and consumption growth volatility between eight and two years a cycle by a factor of four or more as shown in the first column of the even numbered rows of figure 4. This moves mean $\mathcal{T}$ transitory SDs of the baseline habit NKDSGE-TR model closer to mean $\mathcal{E}$ transitory SDs within the business cycle frequencies. These moments are not matched by the habit baseline NKDGSE-AR model because it yields mean $\mathcal{T}$ transitory SDs with business cycle periodicity in the first column of figure 3 that are far from mean $\mathcal{E}$ transitory SDs. As a consequence, the habit baseline NKDGSE-AR model produce $\mathcal{T}$ KS statistic densities of transitory SDs that fail to overlap $\mathcal{E}$ KS statistic densities in the second and third columns of the even numbered rows of figure 3. The same plots in figure 4 display greater overlap of $\mathcal{E}$ and $\mathcal{T}$ KS statistic densities. Thus, combining internal consumption habit and the Taylor rule (9) pushes the baseline NKDSGE model closer to $\mathcal{E}$ transitory output and consumption growth SDs.

In summary, internal consumption habit works with the Taylor rule (9) to improve the fit of the baseline NKDGSE model to $\mathcal{E}$ transitory SDs by generating business cycle periodicity and flattening $\mathcal{T}$ high frequency amplitude. Poole (1970) obtains a similar result by showing that an interest rate rule damps output fluctuations in a sticky price Keynesian macro model when monetary shocks are less volatile than real shocks. Thus, we have a resolution of the disparate NKDSGE model estimates of Del Negro, Schorfheide, Smets, and Wouters (2007) and CEE. It is the Del Negro, Schorfheide, Smets, and Wouters combination of consumption habit and a Taylor rule that helps the baseline NKDSGE model better match $\mathcal{E}$ transitory SDs compared to the baseline habit NKDSGE-AR model. These results also can be interpreted in light of Otrok, Ravikumar, and Whiteman (2002). They show that habit creates a distaste by households for high frequency consumption fluctuations. This distaste is consistent with internal consumption habit creating intertemporal complementarity that operates in the business cycle frequencies and, in conjunction with the Taylor rule (9), is a source of monetary transmission in the baseline habit NKDSGE-TR model.

4.4 NKDSGE model propagation and transmission: Habit and nominal rigidities

This section studies the role of internal consumption habit and the nominal rigidities of sticky prices and wages in propagation and monetary transmission. Erceg, Henderson, and Levin (2000) recognize that sticky prices and wages matter for monetary policy evaluation. However, sticky prices and wages must propagate TFP shocks and transmit monetary shocks to the real economy in this case. This suggests we judge the fit of habit NKDSGE models with and without sticky prices and sticky wages while remembering that these models also include capacity utilization and investment adjustment costs.

Table 2 shows that stripping out sticky nominal wages ($\mu_W = 0$) or sticky prices ($\mu_P = 0$) have disparate effects on NKDSGE models. Retaining sticky prices as the only nominal rigidity leads habit SPrice NKDSGE models to match better to $\mathcal{E}$ permanent output and consumption growth SDs than either baseline or SWage NKDSGE models. However, the improved fit is achieved only on business cycle frequencies. The SWage NKDSGE models have difficulties matching these moments, but not $\mathcal{E}$ transitory output and consumption growth SDs.

Removing nominal wage stickiness conveys a propagation mechanism to SPrice NKDSGE models. The propagation mechanism pushes SPrice NKDSGE models closer to $\mathcal{E}$ permanent output and consumption growth SDs in the business cycle frequencies. Figures 5 and 6 present visual evidence about the ability of SPrice NKDSGE-AR and NKDSGE-TR models to propagate TFP shocks from eight to two years per cycle. This evidence appears in the first and third rows of the third column of figures 5 and 6 as $\mathcal{E}$ and $\mathcal{T}$ KS statistic densities that display substantial overlap. When the fit is extended to the entire spectrum, $\mathcal{T}$ KS statistic densities have smaller peaks with tails far to the right relative to the associated $\mathcal{E}$ KS statistic densities. Note that when limited to eight to two years per cycle, SPrice non-habit NKDSGE models also are able to match the $\mathcal{E}$ permanent output growth SD.

The monetary policy rules contribute different propagation mechanisms to the SPrice habit NKDSGE model. The first column of figure 5 displays the mean $\mathcal{T}$ permanent output and consumption growth SDs of the SPrice habit NKDSGE-AR model. These $\mathcal{T}$ SDs fall from frequency zero into a lesser peak around three years per cycle before a sharp loss of power at two years per cycle. Compare this to the slow decay from the low into the business cycle frequencies of mean $\mathcal{T}$ permanent SDs generated by the SPrice habit NKDSGE-TR model in the first column of figure 6. In either case, mean $\mathcal{T}$ permanent SDs are always above mean $\mathcal{E}$ permanent SDs, except at low and high frequencies which signals excess theoretical output and consumption growth volatility at the business cycle frequencies. However, the Taylor rule (9) yields relatively less volatility at these frequencies in the SPrice habit NKDSGE model while the SPrice habit NKDSGE-AR model creates business cycle periodicity in mean $\mathcal{T}$ permanent SDs resembling that found in mean $\mathcal{E}$ permanent SDs.

There are also differences in monetary transmission across SPrice habit NKDSGE-AR and NKDSGE-TR models. The latter model matches $\mathcal{E}$ transitory output and consumption growth SDs over the entire spectrum given the overlap of $\mathcal{E}$ and $\mathcal{T}$ KS statistic densities in the even numbered rows of the second column of figure 6. The SPrice habit NKDSGE-AR model is also successful at duplicating transitory $\mathcal{E}$ SDs if limited to eight to two years per cycle. This evidence is provided by the third column of the second and fourth rows of figure 5 that depict substantial overlap of $\mathcal{E}$ and $\mathcal{T}$ KS densities. The third column of these rows in figure 6 shows that the SPrice habit NKDSGE-TR model fits at least as well to the transitory $\mathcal{E}$ SDs when the comparison is only at the business cycle frequencies. Nonetheless, only the Taylor rule shock υ_t is transmitted by the SPrice non-habit NKDSGE model into fluctuations that match the $\mathcal{E}$ transitory SDs across the entire spectrum.

The SPrice habit NKDSGE models generate mean $\mathcal{T}$ transitory output and consumption growth SDs that reflect the good match to $\mathcal{E}$ transitory SDs found in figures 5 and 6. The first column of figure 6 shows that the SPrice habit NKDSGE-TR model damps mean $\mathcal{T}$ transitory

SDs at the business cycle frequencies. Thus, these moments are near mean $\mathcal{E}$ transitory SDs. Since the SPrice habit NKDSGE-AR model generates amplitude that is expressed as periodicity around two years per cycle in its mean $\mathcal{T}$ transitory SDs, as seen in the first column of figure 5, these moments and mean $\mathcal{E}$ transitory SDs are not as close.

Next, we study the implications of nominal sticky wages for permanent and transitory output and consumption growth fluctuations. Figures 7 and 8 report results for the SWage NKDSGE-AR and NKDSGE-TR models. The evidence is that these models have problems matching $\mathcal{E}$ permanent output and consumption growth SDs, but that the SWage habit NKDSGE-TR model produces a good match to $\mathcal{E}$ transitory SDs.

The SWage NKDSGE models yield a poor match to $\mathcal{E}$ permanent SDs. Figures 7 and 8 reveal, in the first and third windows of their first column, that mean $\mathcal{T}$ permanent output and consumption growth SDs have peaks in the business cycle frequencies not observed in mean $\mathcal{E}$ permanent SDs. Without sticky prices, habit NKDSGE models produce excess business cycle volatility and periodicity in response to permanent TFP shocks. The distance between mean $\mathcal{E}$ and $\mathcal{T}$ permanent SDs is mirrored by the lack of overlap of $\mathcal{T}$ and $\mathcal{E}$ KS statistic densities in the second and third columns of the odd number rows of figures 7 and 8.

The even number rows of figure 8 testify to the good fit the SWage habit NKDSGE-TR model has to $\mathcal{E}$ transitory output and consumption growth SDs. This model produces mean $\mathcal{T}$ transitory SDs with maximum power at business cycle frequencies consistent with that found for mean $\mathcal{E}$ transitory SDs, as seen in the second and fourth windows of the first column of figure 8. The $\mathcal{E}$ and $\mathcal{T}$ transitory SD distributions map into $\mathcal{E}$ and $\mathcal{T}$ KS statistic densities that display substantial overlap over the entire spectrum or when constrained to eight to two years per cycle. The SWage habit NKDSGE-AR model is unable to match mean $\mathcal{E}$ transitory SDs either on the entire spectrum or when limited to eight to two years per cycle as shown in the second and third columns of the even numbered rows of figure 7.

This section reports that SPrice and SWage habit NKDSGE models have propagation and monetary transmission mechanisms that are economically meaningful. We find that $\mathcal{E}$ transitory output and consumption growth SDs are duplicated over the entire spectrum by SPrice and SWage habit NKDSGE-TR models. Only SPrice habit NKDSGE-AR and NKDSGE-TR models propagate TFP shock innovations into $\mathcal{T}$ permanent output and consumption growth SD distributions that replicate $\mathcal{E}$ permanent SDs distributions. However, this match occurs only at the business cycle frequencies.

Internal consumption habit contributes to propagation and monetary transmission in NKDSGE models by inducing intertemporal consumption complementarity. Propagation and monetary transmission in habit NKDSGE models produce $\mathcal{T}$ output and consumption growth SD that match $\mathcal{E}$ output and consumption growth SD, but there are subtleties to this fit. The fit is vulnerable to the specification of nominal rigidities in the habit NKDSGE models. Baseline, SPrice, and SWage habit NKDSGE models duplicate $\mathcal{E}$ transitory output and consumption growth SDs. However, the baseline and SWage habit NKDSGE models require the Taylor rule (9) to achieve this match while the SPrice habit NKDSGE models replicate $\mathcal{E}$ transitory SDs with either monetary policy rule. Nonetheless, we find that it is difficult to choose which combination of sticky prices and wages in the habit NKDSGE models best replicate $\mathcal{E}$ transitory SDs. These results affirm Del Negro and Schorfheide (2008). On the other hand when output and consumption growth SDs are identified by a permanent TFP shock, only the SPrice habit NKDSGE models duplicate $\mathcal{E}$ permanent SDs. It is worth mentioning again that the match between $\mathcal{E}$ and $\mathcal{T}$ permanent SDs only arises on the business cycle frequencies. Our results about the disparate fit of the habit NKDSGE models to the $\mathcal{E}$ and $\mathcal{T}$ permanent and transitory SDs are in the spirit of Dupor, Han, and Tsai (2009). They report estimates of NKDSGE model that differ across identifications tied to permanent TFP or transitory monetary policy shocks. Although their estimates indicate little habit persistence and a lack of price stickiness under the TFP shock identification, our evidence indicates that habit NKDSGE model fit is sensitive to the shock that drives output and consumption growth fluctuations.

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 output and consumption growth spectral densities (SDs) identified by permanent productivity and transitory monetary shocks.

The fit of habit and non-habit NKDSGE models is explored using Bayesian calibration and Monte Carlo methods. The evidence favors retaining internal consumption habit in NKDSGE models because this real rigidity often pushes theoretical permanent and transitory output growth SDs closer to the associated empirical SDs. This confirms Del Negro, Schorfheide, Smets, and Wouters (2007) who argue that consumption habit moves NKDSGE models closer to output dynamics, but is not consistent with Christiano, Eichenbaum, and Evans (2005).

Nonetheless, the Bayesian simulation experiments reveal that internal consumption habit has subtle effects on NKDSGE model fit. We find a poor fit for NKDSGE models to output and consumption growth SDs identified by the permanent productivity shock with one exception. These moments are replicated by habit NKDSGE models that have been stripped of sticky wages if the evaluation is limited to the business cycle frequencies. The habit NKDSGE models have more success at matching SDs identified by a Taylor rule shock than by a money growth rule shock. This fit is about the same whether the habit NKDSGE model with a Taylor rule combines sticky prices and wages or strips out one of these nominal rigidities.

Our results raise issues about the manner in which consumption habit is often handled within NKDSGE models. Internal consumption habit is often treated as if it is deeply founded in household preferences rather than as a reduced-form real friction that improves model fit. Alternatives to this view are found in Chetty and Sziedl (2005) and Ravn, Schmitt-Grohé, and Uribe (2006) who develop micro foundations for consumption habit. Also, Rozen (2008) provides valuable insights with axioms for intrinsic habit. We suspect that including these ideas in NKDSGE models will become an important part of business cycle research.

This paper reports that there are vulnerabilities in NKDSGE model fit. The fit is compromised by focusing on permanent output and consumption growth SDs instead of transitory SDs. This issue is explored by Dupor, Han, and Tsai (2009) and Del Negro and Schorfheide (2008). Dupor, Han, and Tsai obtain limited information NKDSGE model estimates that show how the moments used for identification affect inference about sticky prices and wages. In contrast, Del Negro and Schorfheide argue that Bayesian likelihood methods and aggregate data cannot distinguish between competing nominal rigidities in NKDSGE models. Our results suggest that both views have merit as explanations for NKDSGE model fit. Along with their work, we hope this paper inspires research about the role real and nominal rigidities play in NKDSGE model propagation and monetary transmission.

References

Abel, A.B., 1990. Asset prices under habit formation and catching up with the Joneses. American Economic Review Paper and Proceedings 80, 38–42.

Akaike, H., 1969. Power spectrum estimation through autoregressive model fitting. Annals of the Institute of Statistical Mathematics 21, 407–419.

Basu, S., Fernald, J.G., 1997. Returns to scale in U.S. production: Estimates and implications. Journal of Political Economy 105, 249–283.

Blanchard, O.J., Quah, D., 1989. The dynamic effects of aggregate demand and supply disturbances. American Economic Review 79, 655–673.

Bouakez, H., Cardia, E., Ruge-Murcia, F., 2005. Habit formation and the persistence of monetary policy shocks. Journal of Monetary Economics 52, 1073–1088.

Chang, Y., Gomes, J.F., Schorfheide, F., 2002. Leaning-by-doing as a propagation mechanism. American Economic Review 92, 1498–1520.

Chetty, R., Szeidl, A., 2005. Consumption commitments: Neoclassical foundations for habit formation. Manuscript, Department of Economics, University of California, Berkeley.

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, 1–45.

Cogley, T., Nason, J.M., 1995a. Effects of the Hodrick-Prescott filter on trend and difference stationary time series: implications for business cycle research. Journal of Economic Dynamics and Control 19, 253–278.

Cogley, T., Nason, J.M., 1995b. Output dynamics in real-business-cycle models. American Economic Review 85, 492–511.

Constantinides, G.M., 1990. Habit formation: a resolution of the equity premium puzzle", Journal of Political Economy 98, 519–543.

Diebold, F.X., Ohanian, L.E., Berkowitz, J., 1998. Dynamic equilbrium economies: A framework for comparing models and data. Review of Economic Studies 65, 433–451.

DeJong, D.N., Ingram, B.F., Whiteman, C.H., 1996. A Bayesian approach to calibration. Journal of Business and Economic Statistics 14, 1–9.

Del Negro, M., Schorfheide, F., 2008. Forming priors for DSGE models (and how it affects the assessment of nominal rigidities). Journal of Monetary Economics 55, 1191–1208.

Del Negro, M., Schorfheide, F., Smets, F. Wouters, R. 2007. On the Fit of New Keynesian Models. Journal of Business & Economic Statistics 25, 123–143.

Dennis, R., 2009. Consumption-habits in a new Keynesian business cycle model. Journal of Money, Credit, and Banking, forthcoming.

Dunn, K.B., Singleton, K.J., 1986. Modelling the term structure of interest rates under non-separable utility and durability of goods. Journal of Financial Economics 178, 27–55.

Dupor, B. Han, J., Tsai, Y.C., 2009. What do technology shocks tell us about the new Keynesian paradigm? Journal of Monetary Economics 56, 560–569.

Dynan, K.E., 2000. Habit formation in consumer preference: Evidence from panel data. American Economic Review 90, 391–405.

Eichenbaum, E., Hansen, L.P., 1990. Estimating models with intertemporal substitution using aggregate time series data. Journal of Business and Economic Statistics 8, 53–69.

Erceg, C.J., Henderson D.W., Levin A.T., 2000. Optimal monetary policy with staggered wage and price contracts. Journal of Monetary Economics 46, 281–313.

Fernández-Villaverde, J., Rubio-Ramírez, J.F., Sargent T.J., Watson M.W., 2007. ABC's (and D)'s for understanding VARS. American Economic Review 97, 1021–1026.

Galí, J., 1991. Budget constraints and time-series evidence on consumption, American Economic Review 81, 1238–1253.

Geweke, J., 1999. Using simulation methods for Bayesian econometric models: Inference, development, communication. Econometric Reviews 18, 1–73.

Geweke, J., 2007. Models, computational experiments and reality. Manuscript. Department of Economics, University of Iowa.

Gruber, J.W., 2004. A present value test of habit and the current account. Journal of Monetary Economics 51, 1495–1507.

Hall, G.J., 1996. Overtime, effort, and the propagation of business cycle shocks. Journal of Monetary Economics 38, 139–160.

Hansen, L.P., 1982. Large sample properties of generalized methods of moments estimators. Econometrica 50, 1029–1054.

Heaton, J., 1995. An empirical investigation of asset pricing with temporary dependent preference specifications. Econometrica 63, 681–717.

Ireland, P.N., 2001. Sticky-price models of the business cycle: Specification and stability. Journal of Monetary Economics 47, 3–18.

Kano, T., 2009. Habit formation, and the present-value model of the current account: Yet another suspect. Journal of International Economics, forthcoming.

Lettau, M., Uhlig, H., 2000. Can habit formation be reconciled with business cycle facts? Review of Economic Dynamics 3, 79–99.

Lindé, J., 2005. Estimating New-Keynesian Phillips curves: A full information maximum likelihood approach. Journal of Monetary Economics 52, 1135–1149.

McCausland, W., 2004. Using the BACC Software for Bayesian Inference. Journal of Computational Economics 23, 201–218.

Nason, J.M., 1988. The equity premium and time-varying risk behavior. FEDS Paper no. 11, Board of Governors of the Federal Reserve System, Washington, DC.

Nason, J.M., 1997. Taste Shocks. in Glaser, D. (ed.), BUSINESS CYCLES AND DEPRESSIONS: AN ENCYCLOPEDIA, 673–676, Garland Publishing, Inc., New York, NY.

Nason, J.M., Cogley, T., 1994. Testing the implications of long-run neutrality for monetary business cycle models. Journal of Applied Econometrics 9, S37–S70.

Nason, J.M., Slotsve, G.A., 2004. Along the New Keynesian Phillips Curve with Nominal and Real Rigidities. Working Paper 2004–09, Federal Reserve Bank of Atlanta.

Otrok, C., Ravikumar, B., Whiteman, C.H., 2002. Habit formation: a resolution of the equity premium puzzle? Journal of Monetary Economics 49, 1261–1288.

Parzen, E., 1974. Some recent advances in time series modelling. I.E.E.E. Transactions on Automatic Control AC-19, 723–729.

Pollak, R.A., 1976. Habit formation and long-run utility functions. Journal of Economic Theory 13, 272–297.

Poole, W., 1970. Optimal choice of monetary policy instruments in a simple stochastic macro model. Quarterly Journal of Economics 84, 197–218.

Ravina, E., 2007. Habit persistence and keeping up with the Joneses: Evidence from micro data. Manuscript, Columbia Business School, Columbia University, New York, NY.

Ravn, M., Schmitt-Grohé, S., Uribe, M., 2006. Deep habits. Review of Economic Studies 73, 1–24.

Rozen, K., 2008. Foundations of intrinsic habit formation. Cowles Foundation Discussion Paper no. 1642. Yale University.

Ryder, H.E., Jr., Heal, G.M., 1973. Optimal growth with intertemporally dependent preferences. Review of Economic Studies 40, 1–31.

Sbordone, A.M., 2002. Prices and Unit Costs: A New Test of Price Stickiness. Journal of Monetary Economics 49, 235–456.

Sims, C., 2002. Solving linear rational expectations models. Computational Economics 20, 1–20.

Schmitt-Grohé, S., Uribe, M., 2007. Habit persistence. in Durlauf, S.N., Blume, L.E., (eds.) THE NEW PALGRAVE DICTIONARY OF ECONOMICS, SECOND EDITION, Palgrave Macmillan, NY, NY.

Smets, F., Wouters, R., 2007. Shocks and frictions in US business cycles: A Bayesian DSGE approach. American Economic Review 97, 1123–1175.

Sundaresan, S.M., 1989. Intertemporally dependent preferences and the volatility of consumption and wealth. Review of Financial Studies 2, 73–89.

TABLE 1: 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	1.3088	0.3196	[0.7831, 1.8345]
δ	Depreciation Rate	Beta	0.0200	0.0045	[0.0122, 0.0297]
α	Deterministic Growth Rate	Normal	0.0040	0.0015	[0.0015, 0.0065]
ϖ	Capital Adjustment Costs	Normal	4.7710	1.0260	[3.0834, 6.4586]
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	8.0000	1.1000	[6.1907, 9.8093]
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	Normal	0.0152	0.0006	[0.0142, 0.0162]
ρ_m	$\Delta \ln M$ AR1 Coef.	Beta	0.6278	0.0549	[0.5355, 0.7162]
σ_μ	$\Delta \ln M$ Shock Std.	Normal	0.0064	0.0008	[0.0048, 0.0080]
a_π	Taylor Rule $\mathbf{E}_t\pi_{t+1}$ Coef.	Normal	1.8000	0.2000	[1.4710, 2.1290]
$a_{\hat{Y}}$	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	[0.5512, 0.7417]
σ_υ	Taylor Rule Shock Std.	Normal	0.0051	0.0013	[0.0031, 0.0072]

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 2: *CIC* OF KOLMOGOROV-SMIRNOV STATISTICS

	ΔY w/r/t Trend Sh'k		ΔY w/r/t Transitory Sh'k		ΔC w/r/t Trend Sh'k		ΔC w/r/t Transitory Sh'k	
Model	$\infty : 0$	$8 : 2$	$\infty : 0$	$8 : 2$	$\infty : 0$	$8 : 2$	$\infty : 0$	$8 : 2$
NKDSGE-AR								
Baseline								
Non-Habit	0.01	0.03	0.00	0.01	0.00	0.04	0.00	0.00
Habit	0.01	0.07	0.11	0.11	0.05	0.26	0.15	0.21
SPrice								
Non-Habit	0.03	0.30	0.00	0.21	0.01	0.23	0.00	0.05
Habit	0.06	0.42	0.18	0.62	0.15	0.55	0.26	0.54
SWage								
Non-Habit	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.01
Habit	0.00	0.02	0.19	0.22	0.03	0.14	0.16	0.24
NKDSGE-TR								
Baseline								
Non-Habit	0.00	0.00	0.13	0.73	0.00	0.00	0.02	0.41
Habit	0.00	0.04	0.54	0.75	0.05	0.19	0.37	0.73
SPrice								
Non-Habit	0.02	0.52	0.01	0.79	0.00	0.24	0.00	0.54
Habit	0.10	0.67	0.30	0.77	0.15	0.57	0.35	0.81
SWage								
Non-Habit	0.00	0.00	0.13	0.74	0.00	0.00	0.01	0.45
Habit	0.00	0.04	0.44	0.66	0.04	0.16	0.36	0.74

NKDSGE-AR 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* measure the intersection of distributions of *KS* statistics computed over the entire spectrum (from eight to two years per cycle).

FIGURE 1: ΔC RESPONSE TO REAL INTEREST RATE SHOCK

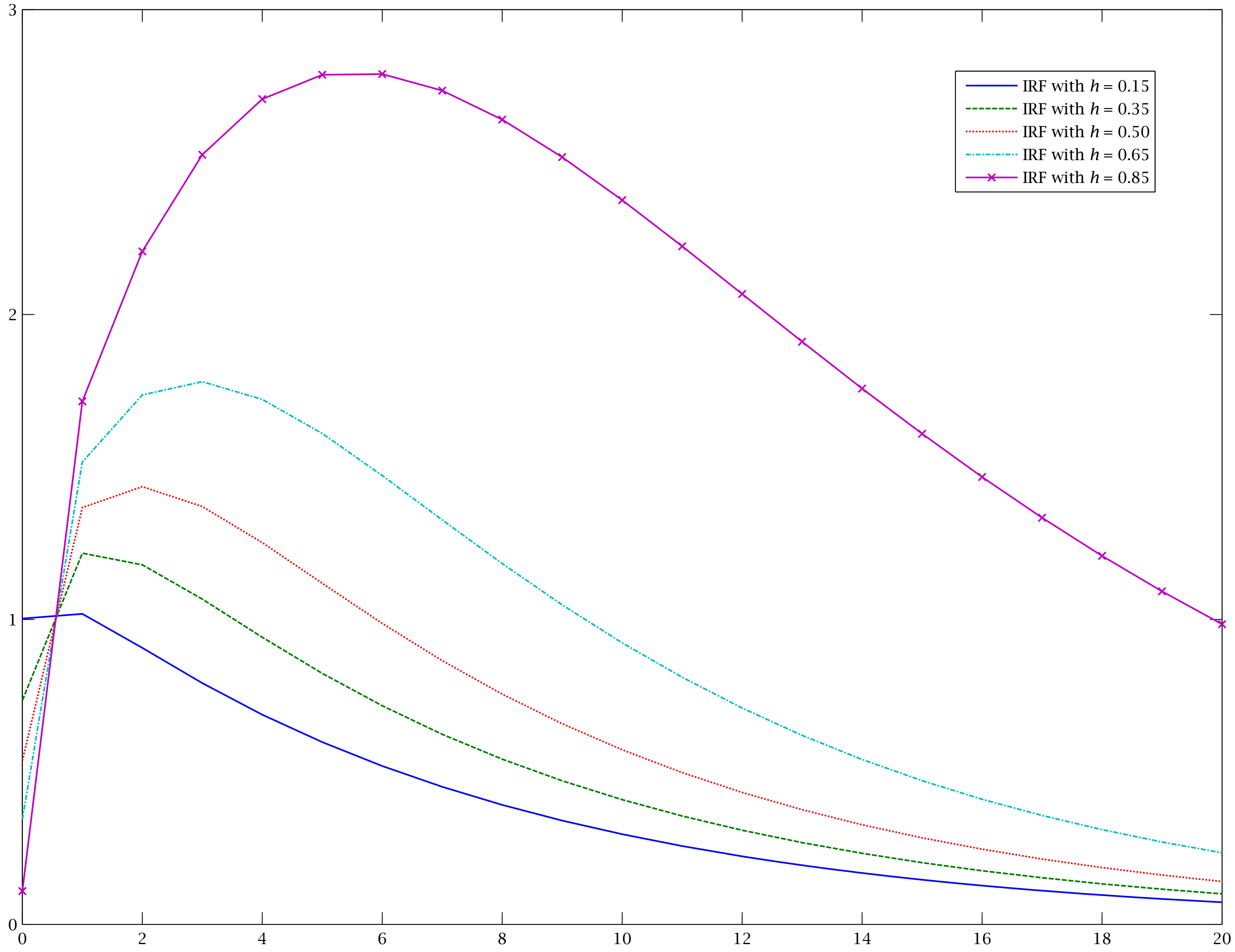


FIGURE 2: MEAN STRUCTURAL $\mathcal{E}$ SPECTRA OF ΔY AND ΔC

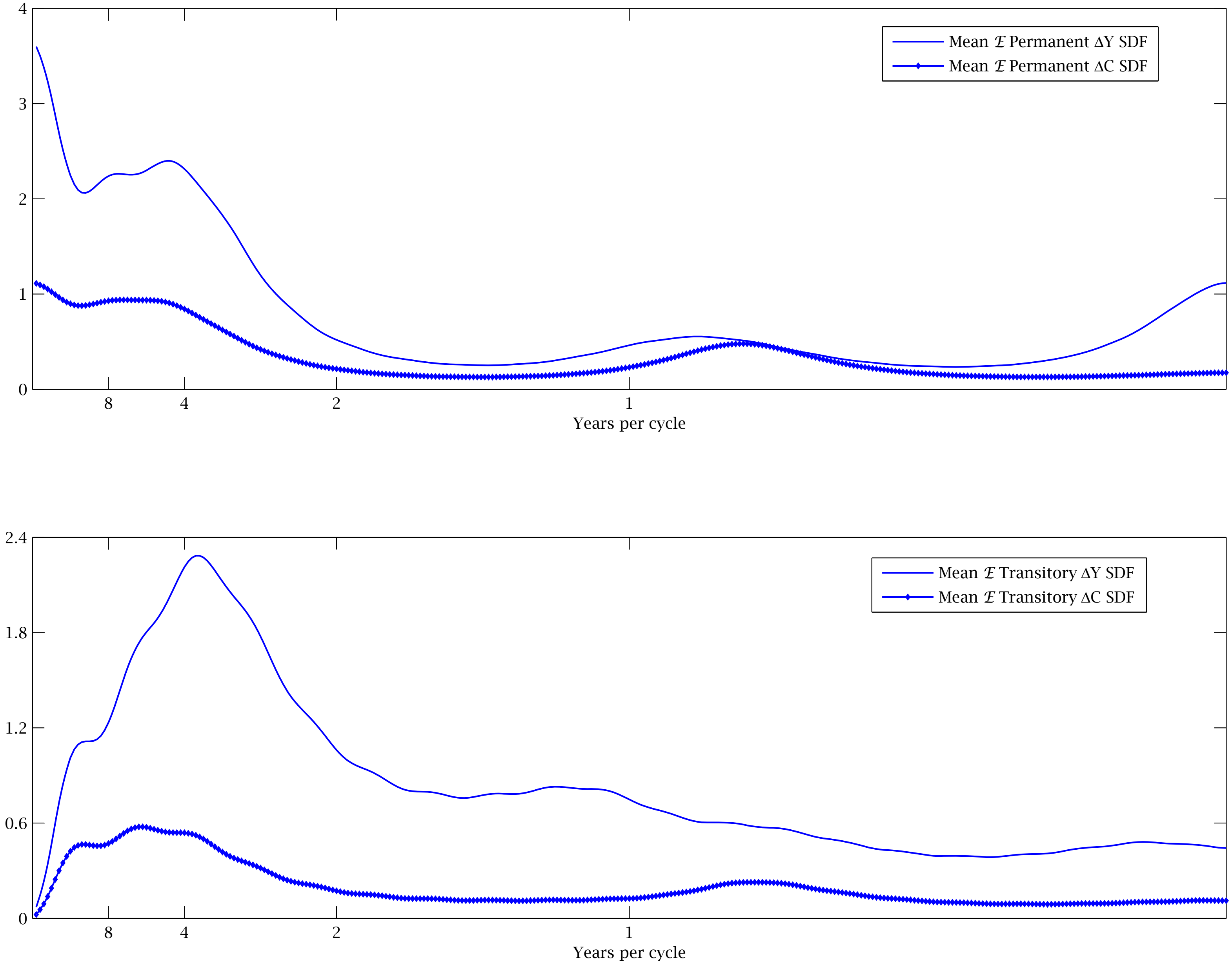


FIGURE 3: MEAN STRUCTURAL $\mathcal{E}$ AND $\mathcal{T}$ SDS AND KS DENSITIES FOR BASELINE NKDSGE MODELS WITH AR(1) MONEY GROWTH RULE

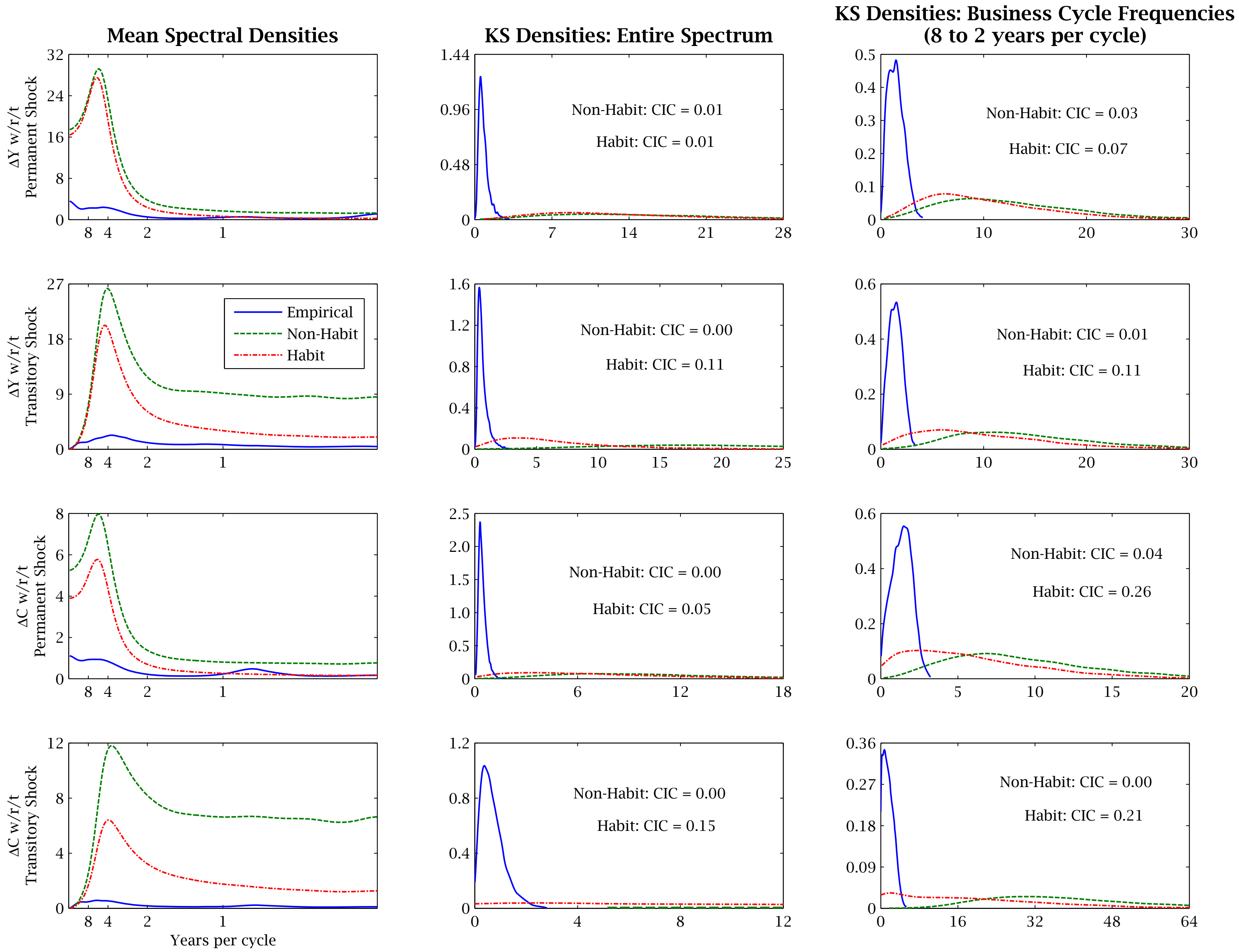


Figure 4: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for Baseline NKDSGE Models with Taylor Rule

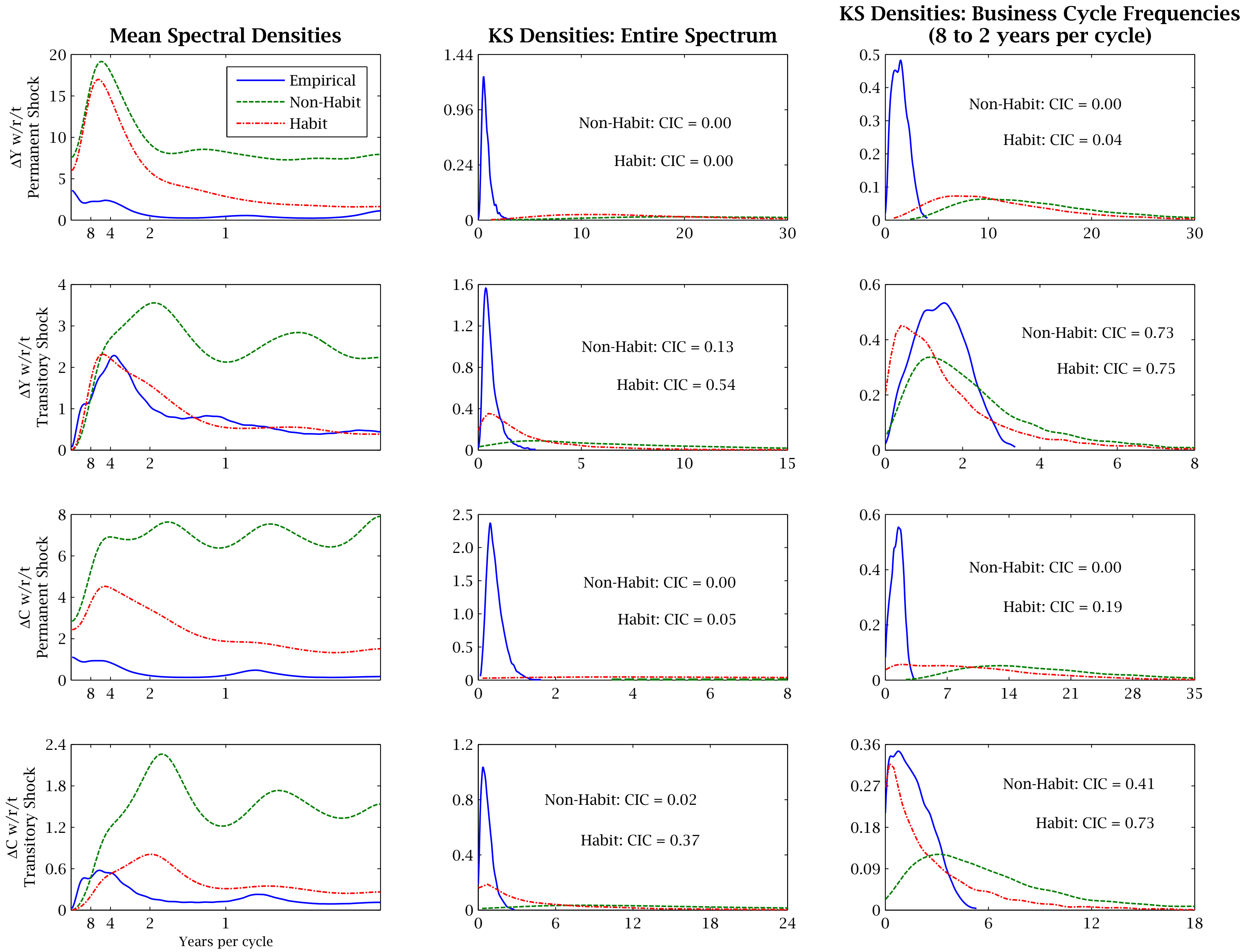


Figure 5: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with AR(1) Money Growth Rule and Only Sticky Prices

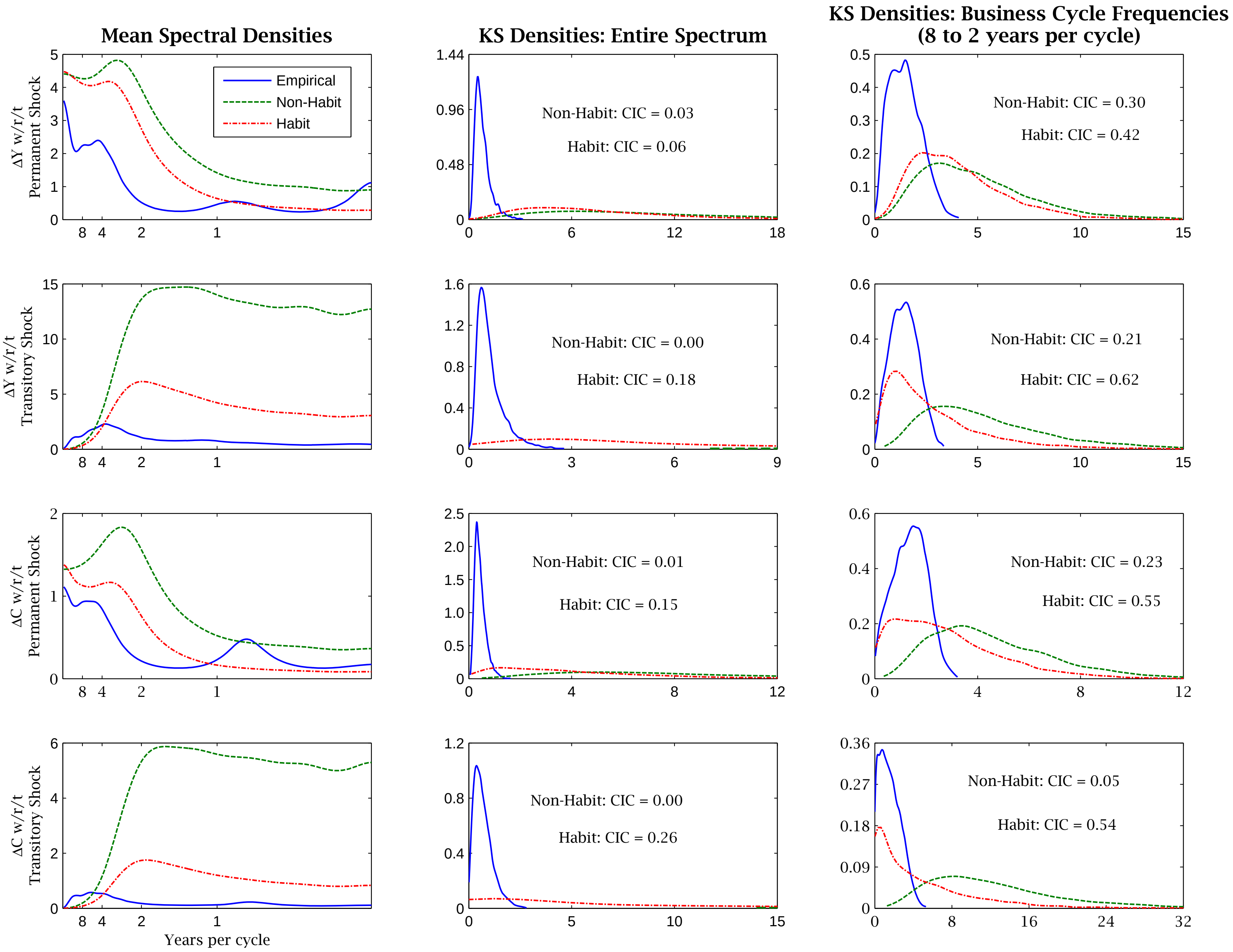
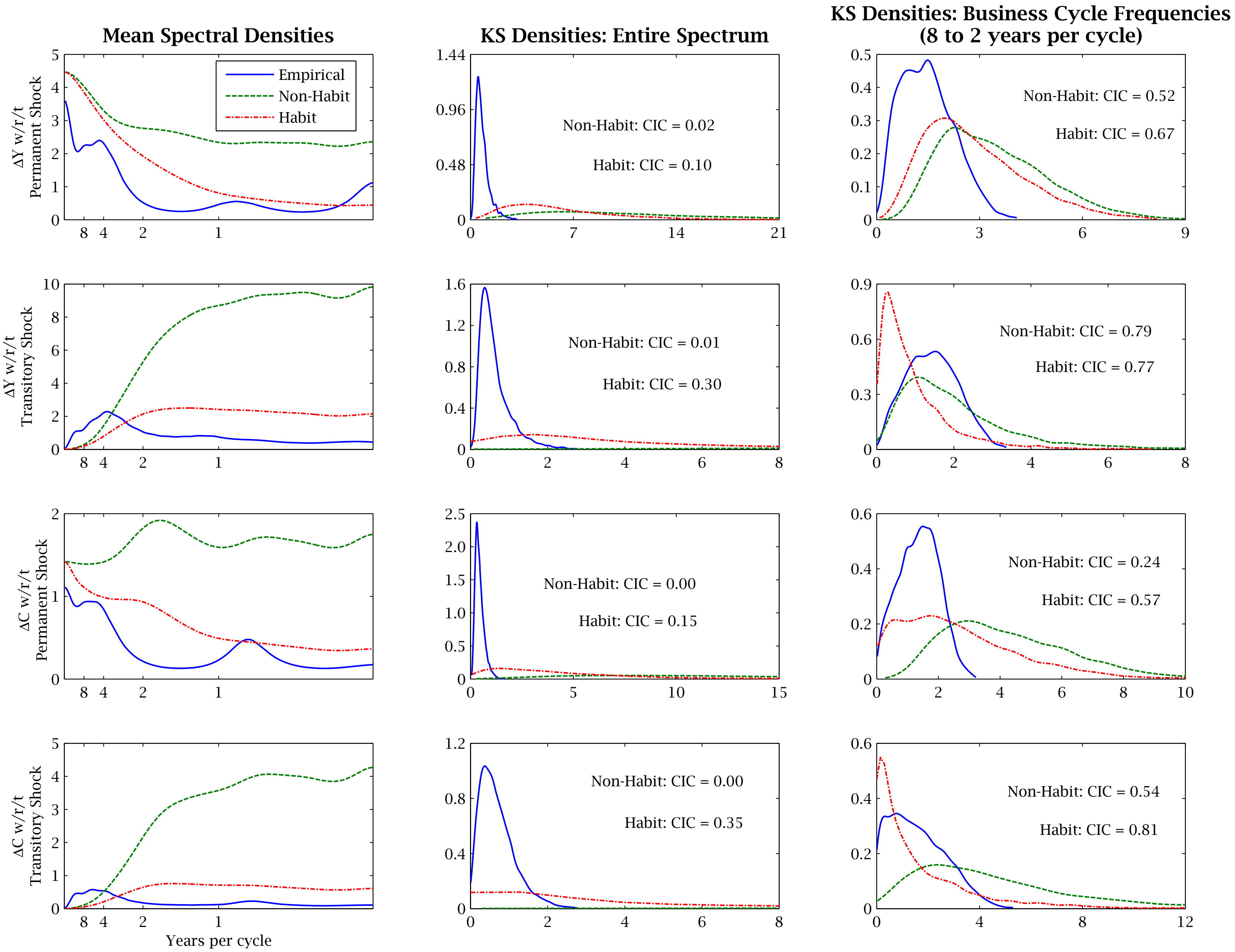


Figure 6: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with Taylor Rule and only Sticky Prices



Mean Spectral Densities

KS Densities: Entire Spectrum

KS Densities: Business Cycle Frequencies (8 to 2 years per cycle)

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

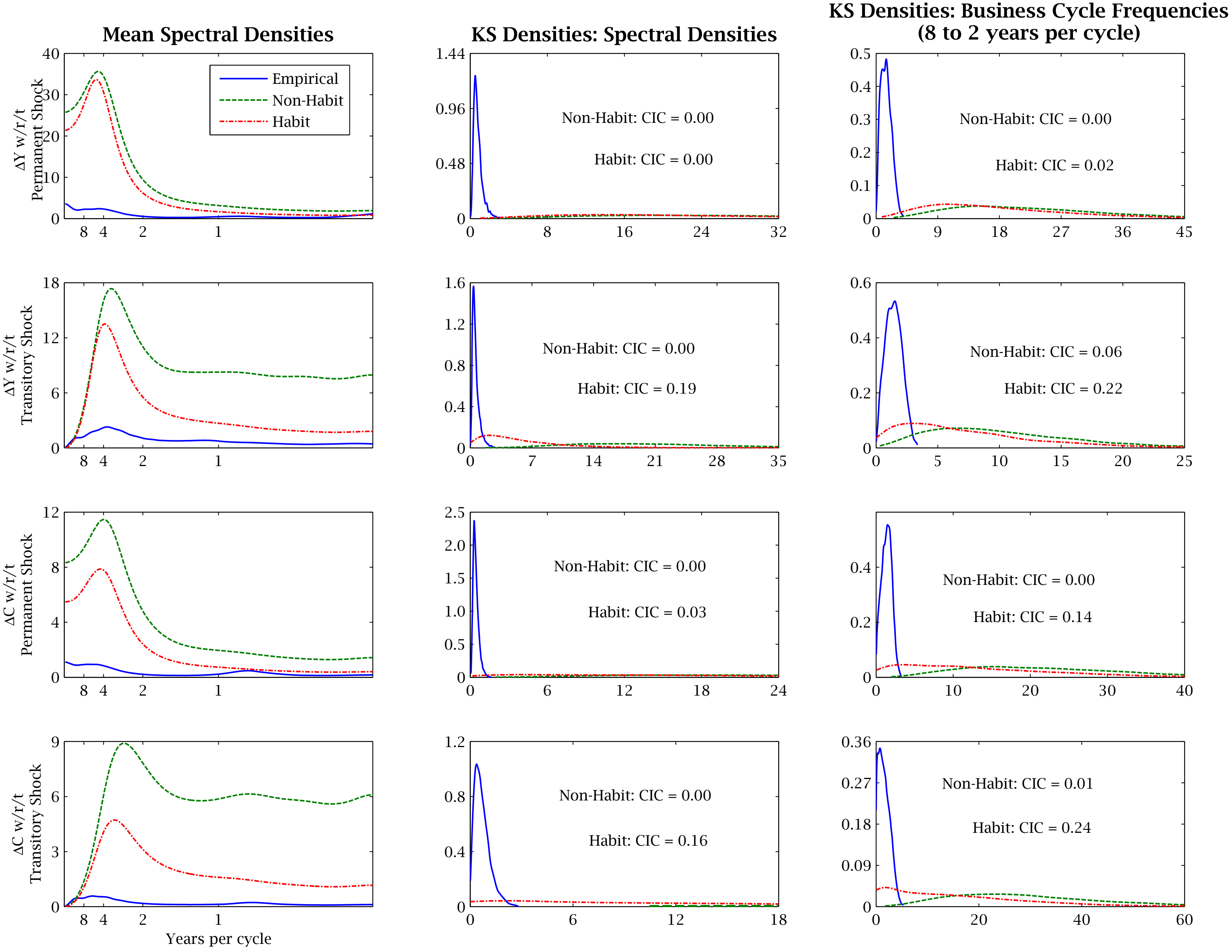


Figure 8: Mean Structural $\mathcal{E}$ and $\mathcal{T}$ SDs and KS Densities for NKDSGE Models with Taylor Rule and only Sticky Wages