Efficiency Wages and Aggregate Fluctuations: A Non-Walrasian Labor Market Model for Monetary Policy

Christopher Otrok
Department of Economics
University of Virginia

Eric R. Young
Department of Economics
University of Virginia

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Abstract

This paper introduces efficiency wages into a sticky price dynamic general equilibrium model. The model is used to assess the efficacy of particular monetary policy rules, such as inflation targeting, when labor markets are not Walrasian. In particular, we consider efficiency wage constructs where the markup of wages over the marginal product of labor is incentive-based rather than based on monopsony power.

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1. Introduction

It has become common in the monetary policy literature to use estimated medium-scale dynamic general equilibrium models to guide monetary policy, as these models are now competitive with unrestricted VARs in terms of forecasting ability (Smets and Wouters 2007 and Del Negro *et al.* 2004). These models typically rely on households or unions having labor market power to set nominal wages and induce rigidity in those nominal wages through a Calvo mechanism. Real wages are equal to a constant markup over the marginal product of labor (although some models permit the markup to vary exogenously). The decline in unionization in the US suggests an alternative model of the labor market is more appropriate, provided that model can fit the data as well. We provide one perspective on that question here: we examine moral hazard-based efficiency wages in the spirit of Shapiro and Stiglitz (1984).

Our argument for abandoning the market power over nominal wages story in favor of efficiency wages is not simply one of aesthetics. While we would prefer a model that fits the data for the "right reasons" from a purely academic standpoint, the nominal wage rigidity story also has an important side effect: it implies monetary policy has a lot of influence over the labor market. This means that the central bank can strongly influence the real side of the economy through variations in real wages. It is therefore important to assess whether alternative models, such as our efficiency wage model can also fit the data. Given that these models imply much more limited power for monetary policy, it is important to compare the fit of these models before relying too heavily on models with more traditional labor markets. Our efficiency wage model generates a *real* wage rigidity, rather than a nominal one, limiting the power of monetary policy to influence the economy through variations in real wages.[1] Of course, the most useful model may turn out to have both efficiency wage contracts and monopsony power over nominal wages, since there may be reasons for market power unrelated to formal unionization, but the point would still stand: a model that does not rely on nominal wage rigidity alone will likely imply that monetary policy has less power to affect the real economy.

Our efficiency wage construct involves one-period contracts between workers and firms that specify an unobservable effort level; workers who do not supply the recommended effort level are detected with an exogenous probability that varies randomly over time.[2] This shock turns out to drive a wedge between the real wage and the marginal product of labor, producing a theory of the "labor wedge" or "Hall's x" shock that seems to be quite important for labor market fluctuations (Hall 1997, Chari, Kehoe, and McGrattan 2006) without relying on large aggregate movements in the marginal utility of leisure relative to consumption. When the detection probability is high, the wedge is small and employment is high, matching the correlation between the wedge and total hours observed in the cited papers. We also consider different punishments for shirking, from denial of bonuses to nominal wage freezes, since these off-equilibrium considerations affect the equilibrium path but are not directly observable.[3]

Our model is related to the recent literature that introduces non-standard labor markets into

[1] Alexopoulos (2006,2007) and Felices (2006) also introduce efficiency wages into monetary models and find that they improve the ability of the model to capture the dynamics of real wages and inflation; however, their models are not estimated using full information methods.

[2] Following the literature we call these workers shirkers, since it will be optimal to either supply the recommended level of effort or zero

[3] An alternative model of efficiency wages is based on gift exchange and fair wages (Danthine and Kurmann 2004); it lies outside the scope of this paper to examine which of these models is better supported by the data.

monetary DSGE models (such as Blanchard and Galí 2005, Krause and Lubik 2006, and Faia 2007). Models with non-standard labor markets have stronger internal propagation mechanisms, leaving less persistence to be attributed to exogenous shocks and increasing the ability of policy to affect the economy (if all persistence is driven by shocks, changes in policy can only affect the size of the initial impulse). Furthermore, models which make clear predictions about unemployment (such as a search and matching model or our model) can generate a tradeoff between unemployment and inflation (a true Phillips curve), instead of a tradeoff between total hours and inflation.

Nominal price rigidities in our model take the quadratic adjustment costs for nominal prices, as in Rotemberg (1982). Because we locate capital investment with firms and not households, a Calvo adjustment mechanism would imply an infnite number of different capital stocks in equilibrium. Our argument for having firms make the investment decisions is that the wage contract offered a household is not independent of the capital stock of the firm; with efficiency wages, our setup therefore endogenously determines the distribution of wages in the population. Furthermore, as shown in Jermann (1998), capital adjustment costs improve the asset pricing performance of the model, and these costs are more naturally viewed as being paid by the firm.[4]

Since our questions are empirical in nature, we undertake a formal estimation of the model parameters and then evaluate the fit of the model. We employ a Bayesian approach to estimation following the work of Dejong, Ingram and Whiteman (2000)[5] Our model contains features that are fundamentally nonlinear. Therefore it is natural to use 2nd-order solutions to the model coupled with non-linear likelihood methods, as in Fernández-Villaverde and Rubio-Ramírez (2007). For comparison, we also report results from first-order solution around the deterministic steady state and estimate the structural parameters as in Otrok (2001). We view these results as contributing to the debate about the usefulness of nonlinear estimation methods – is the cost of usiing them justified by additional economic insights?

Our model features stochastic shocks to neutral technical change, investment-specific technical change, the detection probability, a shock to the fixed cost of production, and three fiscal policy instruments: the average marginal personal income tax rate, the corporate income tax rate, and the level of government consumption (the technology shocks have unit roots, while the other shocks are stationary). We also have a shock to the interest rate rule that captures unanticipated policy

[4]Under complete markets this arrangement does not generate a different allocation from one where households own the capital stock directly. While our individual members do not face complete insurance markets, the family does; it is not clear whether allocations are identical in our model.

[5]For further arguments for a Bayesian perspective see Fernández-Villaverde and Rubio-Ramírez (2004).

changes. These eight shocks permit us to use eight observables in our estimation procedure: private consumption of nondurables and services, investment, government consumption, average income and corporate tax rates, the unemployment rate, total labor compensation, and the short-term nominal interest rate. Note that many of our shocks are directly observed; this observability puts more pressure on our model to match the data by not permitting shocks to make up the difference as easily.

After establishing the fit of our model, we investigate an alternative rules exercise using our estimated model. Specifically, we first consider the optimal settings for the parameters of the Taylor rule used to set nominal interest rates, where we permit the central bank to respond to lagged deviations of the interest rate, output, and inflation from their steady state values using a linear rule. Our interest here is in assessing the performance of pure inflation targeting (the coefficient on output is zero) versus a flexible targeting scheme that permits some adjustment to output. We compare these rules to rules that permit responses directly to unemployment, capacity utilization, and nominal wage inflation, common variables that are used as indicators of economic conditions.

We then generalize this approach to permit nonlinear rules by solving the model up to the second-order (using the coefficients estimated from the first-order solution); as shown in Benigno *et al.* (2007), nonlinear responses to inflation can be beneficial in emerging market economies that are subject to Sudden Stops. The interpretation of a nonlinear interest rate rule depends on the signs of the linear and quadratic terms. If both terms are positive, the rule specifies a more aggressive increase in rates when the targeted variable increases and a less aggressive decrease when the targeted variable decreases. If the linear term is positive and the quadratic term is negative, the response to decreases is more aggressive while the response to increases is muted. If the linear term is close to zero and the quadratic term is relatively large, the rule specifies a response only to large shocks (those whose squared deviation from the steady state is very big); the direction of the response is depends only on the sign of the quadratic term and not the sign of the deviation.

2. Model

The model economy is populated by a continuum of identical final goods firms, a continuum of differentiated production firms, a continuum of households combined into large families, a continuum of identical construction firms, and fiscal and monetary authorities.

2.1. Households

The households are organized into a giant family that makes asset market decisions and provides some consumption insurance against unemployment risk. We assume that the family cannot affect the probability of employment for its members (no costly search effort). The dynamic problem of the family is

$$\max_{\left\{c_{t+s}^{f},s_{t+s},b_{t+s},m_{t+s},c_{t+s}^{e},c_{t+s}^{s},c_{t+s}^{u}\right\}_{s=0}^{\infty}} E_t \sum\nolimits_{s=0}^{\infty} \beta^s U_{t+s}$$

subject to

$$\begin{aligned}
U_t &= \sum\nolimits_{j=1}^{4} \left[\left(n_{j,t} - \exp\left(\upsilon_t\right) \Upsilon n_{j,t}^{s}\right) u_t^e + \exp\left(\upsilon_t\right) \Upsilon n_{j,t}^{s} \log\left(c_{j,t}^{s}\right)\right] + \left(1 - \sum\nolimits_{j=1}^{4} n_{j,t}\right) \log\left(c_t^u\right) + \varphi \log\left(\frac{m_{t-1}}{P_t}\right) && (2.1)\\
u_t^e &= \log\left(c_{j,t}^{e}\right) + \frac{\mu}{1+\varsigma}\left(1 - he_{j,t} - f\right)^{1+\varsigma} && (2.2)\\
P_t c_t^f &\leq i_{t-1} b_{t-1} + m_{t-1} + P_t\left(p_t^e + \left(1-\tau_t\right)\left(1-\tau_t^c\right) d_t\right) s_{t-1} + P_t T_t - b_t - m_t - P_t p_t^e s_t && (2.3)\\
c_{j,t}^{e} &\leq \left(1 - \tau_t - \tau_t^u\right) w_{j,t} h + c_t^f && (2.4)\\
c_{j,t}^{s} &\leq \theta\left(1 - \tau_t - \tau_t^u\right) w_{j,t} h + c_t^f && (2.5)\\
c_t^u &\leq c_t^f + \nu w h. && (2.6)
\end{aligned}$$

The government taxes aggregate dividends using the corporate income tax rate τ_t^c and the personal income tax rate τ_t; the tax rate τ_t^u is used to fund the government unemployment insurance system which provides benefits at replacement rate ν (relative to the steady state wage w); we ignore any intrafamily transfers to the unemployed and assume that any individual who declines a job opportunity is denied benefits. The first-order conditions (ordered b_t, m_t, s_t, c_t^f) are

$$\begin{aligned}
\lambda_t &= \beta E_t\left[i_t \lambda_{t+1}\right] && (2.7)\\
\lambda_t &= \frac{\beta\varphi}{m_t} + \beta E_t\left[\lambda_{t+1}\right] && (2.8)\\
\lambda_t P_t p_t^e &= \beta E_t\left[\lambda_{t+1} P_{t+1}\left(p_{t+1}^e + \left(1-\tau_{t+1}\right)\left(1-\tau_{t+1}^c\right) d_{t+1}\right)\right] && (2.9)\\
P_t \lambda_t &= \sum_{j=1}^{4}\left(\frac{n_{j,t} - \exp\left(\upsilon_t\right)\Upsilon n_{j,t}^{s}}{c_{j,t}^{e}} + \frac{\exp\left(\upsilon_t\right)\Upsilon n_{j,t}^{s}}{c_{j,t}^{s}}\right) + \frac{1 - \sum_{j=1}^{4} n_{j,t}}{c_t^u} && (2.10)
\end{aligned}$$

plus the budget constraint that determines the multiplier λ_t. Note the timing convention: objects dated t are known in period t, so that the nominal return on bonds chosen in period t is risk-free. The real return is not, as it is subject to inflation risk.

In the above expressions, $\beta \in (0,1)$ is the discount factor, $\varphi \geq 0$ is the relative weight on real

money balances, $\mu \geq 0$ is the relative weight on leisure, $\varsigma \leq 0$ governs the Frisch elasticity of labor supply, and $f \geq 0$ is the fixed cost of supplying labor. Two other parameters, Υ and θ, will be detailed more completely in a subsequent section; for now, we simply note that they measure the probability of detecting a shirker and the pecuniary cost paid by that shirker upon detection. υ_t is a shock to the detection probability, p_t^e is the price of equity shares s_t with dividend d_t, and $(\tau_t, \tau_t^c, \tau_t^u)$ are personal income taxes, corporate income taxes, and payroll taxes, respectively. P_t is the aggregate price level.

Family consumption can be viewed as insurance against wage and unemployment risk (wage risk comes from the random matching between workers and firms of different type). It is imperfect, however, as the family is assumed not to increase the share of family consumption received by either detected shirkers or the unemployed. The UI system provides some insurance against unemployment; however, shirkers do not receive any such insurance (and must make the payroll tax contribution that funds this system). Because individuals who turn down a job opportunity do not receive UI benefits, in equilibrium all job offers are accepted.

2.2. Final Goods Firms

The final goods firm solves the maximization problem

$$\max_{\{y_{i,t}\}_i, Y_t} \left\{ P_t Y_t - \int_0^1 p_t^i y_t^i di \right\}$$

subject to the technological constraint

$$\left(\int_0^1 \left(y_t^i\right)^{\frac{\gamma-1}{\gamma}} di \right)^{\frac{\gamma}{\gamma-1}} - Y_t \geq 0. \tag{2.11}$$

The first-order conditions are

$$P_t = \Omega_t \tag{2.12}$$

$$p_t^i = \Omega_t \left(\int_0^1 \left(y_t^i\right)^{\frac{\gamma-1}{\gamma}} di \right)^{\frac{1}{\gamma-1}} \left(y_t^i\right)^{-\frac{1}{\gamma}} \tag{2.13}$$

plus the constraint (Ω_t is the multiplier). The individual demand for the input produced by firm i is therefore

$$y_{i,t} = \left(\frac{p_t^i}{P_t} \right)^{-\gamma} Y_t \tag{2.14}$$

The price index is

$$P_t = \left(\int_0^1 \left(p_t^i\right)^{1-\gamma} di \right)^{\frac{1}{1-\gamma}} . \tag{2.15}$$

The parameter $\gamma \geq 1$ is the elasticity of the demand for individual good i with respect to the relative price of good i; in equilibrium it measures the markup over marginal cost.

2.3. Production Firms

There exist a continuum of firms that produce a differentiated product; each firm is therefore a local monopoly and is permitted to choose its own price. Furthermore, each firm interacts with individual workers and offers contracts that specify the wage to be paid and the recommended level of effort. Each contract must respect the incentive constraint for effort, since it cannot be observed. Shirking is exogenously and stochastically observable only with probability $\exp(\upsilon_t)\,\Upsilon \in [0,1]$.[6] The discount factor of the firm will equal the ratio of the marginal value of wealth in period $t+1$ to the value in period t for the family, $\frac{\beta\lambda_{t+1}}{\lambda_t}$ Each firm faces a quadratic cost of adjusting its nominal price, as in Rotemberg (1982); we assume that this cost is permanently heterogeneous over 4 different types in order to generate meaningful price dispersion.[7]

We denote a firm with a superscript i and a subscript j that identifies the type; by assumption each type is 25 percent of the total population. The dynamic firm problem for a firm is

$$\max_{\left\{d_{j,t+s}^i, y_{j,t+s}^i, p_{j,t+s}^i, k_{j,t+s}^i, w_{j,t+s}^i, n_{j,t+s}^i, u_{j,t+s}^i, e_{j,t+s}^i\right\}_{s=0}^{\infty}} E_t \sum\nolimits_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t} P_{t+s} d_{j,t+s}^i$$

[6] Our model follows Alexopoulos (2006,2007) fairly closely in this respect.

[7] Ultimately we are interested in price dispersion because it generates heterogeneity across firms – family members may get assigned to firms paying currently low wages. Furthermore, price dispersion creates an output inefficiency that may be important. Standard menu cost models (like Ireland 1997) do not have price dispersion.

subject to

$$\left(\frac{p_{j,t}^i}{P_t}\right)^{-\gamma} Y_t \geq y_{j,t}^i \tag{2.16}$$

$$\exp\left(a_t\right)\left(u_{j,t}^i k_{j,t-1}^i\right)^{\alpha}\left(e_{j,t}^i n_{j,t}^i h\right)^{1-\alpha} - \exp\left(x_t\right)\Phi \geq y_{j,t}^i \tag{2.17}$$

$$p_{j,t}^i y_{j,t}^i + P_t q_t^o\left(1 - \frac{\delta}{1+\zeta}\left(u_{j,t}^i\right)^{1+\zeta}\right) k_{j,t-1}^i \geq P_t w_{j,t}^i n_{j,t}^i h + P_t q_t^n k_{j,t}^i + P_t d_{j,t}^i + \frac{\phi_j}{2}\left(\frac{p_{j,t}^i}{\pi p_{j,t-1}^i} - 1\right)^2 y_{j,t}^i \tag{2.18}$$

$$\frac{\mu}{1+\varsigma}\left(1 - h e_{j,t}^i - f\right)^{1+\varsigma} \geq \exp\left(\upsilon_t\right)\Upsilon \log\left(\frac{\theta\left(1-\tau_t-\tau_t^u\right) w_{j,t}^i h + c_t^f}{\left(1-\tau_t-\tau_t^u\right) w_{j,t}^i h + c_t^f}\right). \tag{2.19}$$

The first-order conditions (ordered $d_t, y_t, p_t, k_t, w_t, n_t, u_t, e_t$) are

$$P_t = \Lambda_{3,t}^i P_t \tag{2.20}$$

$$\Lambda_{1,3,t}^i p_{1,t}^i = \Lambda_{1,1,t}^i + \Lambda_{1,2,t}^i \tag{2.21}$$

$$\gamma \Lambda_{j,1,t}^i p_{j,t}^{-\gamma-1} P_t^{\gamma} Y_t - \Lambda_{j,3,t}^i y_{j,t} = \phi_j\left(\frac{p_{j,t}}{\pi p_{j,t-1}} - 1\right)\frac{y_{j,t}}{\pi p_{j,t-1}} - \phi_j \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{p_{j,t+1}}{\pi p_{j,t}} - 1\right)\frac{p_{j,t+1}}{\pi p_{j,t}}\frac{y_{j,t}}{p_{j,t}}\right] \tag{2.22}$$

$$\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\begin{array}{c}\Lambda_{j,2,t+1}^i \alpha \exp\left(a_{t+1}\right)\left(u_{j,t+1}^i\right)^{\alpha}\left(k_{j,t}^i\right)^{\alpha-1}\left(e_{j,t+1}^i n_{j,t+1}^i h\right)^{1-\alpha} + \\ \Lambda_{j,3,t+1}^i P_{t+1} q_{t+1}^o\left(1 - \frac{\delta}{1+\zeta}\left(u_{j,t+1}^i\right)^{1+\zeta}\right)\end{array}\right)\right] = \Lambda_{j,3,t}^i P_t q_t^n$$

$$\Lambda_{j,3,t}^i P_t n_{j,t}^i h + \Lambda_{j,4,t}^i \frac{\exp\left(\upsilon_t\right)\Upsilon\theta\left(1-\tau_t-\tau_t^u\right) h}{\theta\left(1-\tau_t-\tau_t^u\right) w_{j,t}^i h + c_t^f} = \Lambda_{j,4,t}^i \frac{\exp\left(\upsilon_t\right)\Upsilon\left(1-\tau_t-\tau_t^u\right) h}{\left(1-\tau_t-\tau_t^u\right) w_{j,t}^i h + c_t^f} \tag{2.23}$$

$$\Lambda_{j,2,t}^i\left(1-\alpha\right)\exp\left(a_t\right)\left(u_{j,t}^i k_{j,t-1}^i\right)^{\alpha}\left(e_{j,t}^i\right)^{1-\alpha} h^{1-\alpha}\left(n_{j,t}^i\right)^{-\alpha} = \Lambda_{j,3,t}^i P_t w_{j,t}^i h \tag{2.24}$$

$$\Lambda_{j,2,t}^i \alpha \exp\left(a_t\right)\left(u_{j,t}^i\right)^{\alpha-1}\left(k_{j,t-1}^i\right)^{\alpha}\left(h e_{j,t}^i n_{j,t}^i\right)^{1-\alpha} = \Lambda_{j,3,t}^i P_t q_t^o \delta\left(u_{j,t}^i\right)^{\zeta} k_{j,t-1}^i \tag{2.25}$$

$$\Lambda_{j,2,t}^i\left(1-\alpha\right)\exp\left(a_t\right)\left(u_{j,t}^i k_{j,t-1}^i\right)^{\alpha}\left(n_{j,t}^i\right)^{1-\alpha} h^{1-\alpha}\left(e_{j,t}^i\right)^{-\alpha} = \Lambda_{j,4,t}^i \mu\left(1 - h e_{j,t}^i - f\right)^{\varsigma} h \tag{2.26}$$

plus the constraints which determine the multipliers $(\Lambda_{1,1,t}, \Lambda_{1,2,t}, \Lambda_{1,3,t}, \Lambda_{1,4,t})$. a_t is an aggregate shock to total factor productivity, x_t is an aggregate shock to the fixed cost, and υ_t is an aggregate shock to the detection probability. In a symmetric equilibrium all firms of a given type choose the same price and output. Given these expressions the other choices of the firms are also identical, so that we need only keep track of the behavior of one stand-in firm for each type. The resulting

price index is

$$P_t = \left(\frac{1}{4} p_{1,t}^{\frac{\gamma}{\gamma-1}} + \frac{1}{4} p_{2,t}^{\frac{\gamma}{\gamma-1}} + \frac{1}{4} p_{3,t}^{\frac{\gamma}{\gamma-1}} + \frac{1}{4} p_{4,t}^{\frac{\gamma}{\gamma-1}} \right)^{\frac{\gamma-1}{\gamma}}$$

and aggregate output is

$$P_t Y_t = \frac{1}{4} p_{1,t} y_{1,t} + \frac{1}{4} p_{2,t} y_{2,t} + \frac{1}{4} p_{3,t} y_{3,t} + \frac{1}{4} p_{4,t} y_{4,t}.$$

The nominal wage index is

$$P_t w_t = \frac{1}{4} w_{1,t} + \frac{1}{4} w_{2,t} + \frac{1}{4} w_{3,t} + \frac{1}{4} w_{4,t}.$$

Some useful intuition about the effects of efficiency wages can be obtained by combining some of the first-order conditions. Normalizing $P_t = 1$ for convenience, we obtain the following expression:

$$(1 - \tau_t - \tau_t^u)\, w_{j,t} = \frac{1}{\exp(\upsilon_t)\, \Upsilon} \frac{\mu\, (1 - h e_{j,t} - f)^{\varsigma}\, e_{j,t}}{\left(\frac{1}{c_{j,t}^e} - \frac{\theta}{c_{j,t}^s} \right)}. \tag{2.27}$$

A model with a competitive labor market equates the after-tax wage to the marginal rate of substitution between consumption and leisure.[8] The detection probability therefore looks like a 'labor wedge,' creating a gap between the MRS and the wage; as noted in Hall (1997) and Chari, Kehoe, and McGrattan (2006), labor wedges play an important role in generating observed business cycles, and our model provides one microfoundation for them.[9] If υ_t increases, the RHS of (2.27) falls, requiring either a decline in after-tax wages or a rise in the second term to restore balance; with concave utility both adjustments will take place. To increase the second term, which has the form of a marginal rate of substitution between leisure and consumption, there are two options: increase required effort or increase consumption of nonshirkers relative to shirkers. Increasing relative consumption for nonshirkers can be accomplished by raising wages, since shirkers only receive $\theta < 1$ of any wage increase; thus, the decline in wages is reduced. Thus, we expect higher detection probabilities to generate higher effort and lower wages; intuitively, a higher detection probability is associated with a smaller moral hazard problem, leading to less distortion in the labor market.

[8] Monopolistic competition introduces a wedge between the wage and the marginal product of capital.

[9] Business cycle frequency variation in the gap between the marginal product of labor and the MRS is largely due to movements in the wedge between the MRS and the wage, not to movements in the wedge between the wage and the MPN. Our model is consistent with that evidence.

Alternative punishments can be introduced, as in Felices (2006). One particularly appealing punishment is a nominal freeze on wages, implying that consumption for shirkers is

$$c_{j,t}^{s} = \left(1 - \tau_t - \tau_t^u\right) \frac{P_{t-1}}{P_t} w_{j,t-1} h + c_t^f$$

where $P_{t-1} w_{j,t-1}$ is the nominal wage at firm j from the previous quarter. The first-order conditions are

$$P_t = \Lambda_{j,3,t}^i P_t \tag{2.28}$$

$$\Lambda_{j,3,t}^i p_{j,t}^i = \Lambda_{j,1,t}^i + \Lambda_{j,2,t}^i \tag{2.29}$$

$$\gamma \Lambda_{j,1,t}^i p_{j,t}^{-\gamma-1} P_t^{\gamma} Y_t - \Lambda_{j,3,t}^i y_{j,t} = \phi_j \left(\frac{p_{j,t}}{\pi p_{j,t-1}} - 1 \right) \frac{y_{j,t}}{\pi p_{j,t-1}} - \phi_j \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\frac{p_{j,t+1}}{\pi p_{j,t}} - 1 \right) \frac{p_{j,t+1}}{\pi p_{j,t}} \frac{y_{j,t}}{p_{j,t}} \right] \tag{2.30}$$

$$\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \left(\begin{array}{c} \Lambda_{j,2,t+1}^i \alpha \exp\left(a_{t+1}\right) \left(u_{j,t+1}^i\right)^{\alpha} \left(k_{j,t}^i\right)^{\alpha-1} \left(e_{j,t+1}^i n_{j,t+1}^i h\right)^{1-\alpha} + \\ \Lambda_{j,3,t+1}^i P_{t+1} q_{t+1}^o \left(1 - \frac{\delta}{1+\zeta} \left(u_{j,t+1}^i\right)^{1+\zeta}\right) \end{array} \right) \right] = \Lambda_{j,3,t}^i P_t q_t^n$$

$$\Lambda_{j,3,t}^i P_t n_{j,t}^i h + \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \Lambda_{j,4,t+1}^i \frac{\exp\left(\upsilon_{t+1}\right) \Upsilon \left(1 - \tau_{t+1} - \tau_{t+1}^u\right) \frac{P_t}{P_{t+1}} h}{\left(1 - \tau_{t+1} - \tau_{t+1}^u\right) \frac{P_t}{P_{t+1}} w_{j,t+1}^i h + c_{t+1}^f} \right) = \Lambda_{j,4,t}^i \frac{\exp\left(\upsilon_t\right) \Upsilon \left(1 - \tau_t - \tau_t^u\right) h}{\left(1 - \tau_t - \tau_t^u\right) w_{j,t}^i h + c_t^f} \tag{2.31}$$

$$\Lambda_{j,2,t}^i \left(1 - \alpha\right) \exp\left(a_t\right) \left(u_{j,t}^i k_{j,t-1}^i\right)^{\alpha} \left(e_{j,t}^i\right)^{1-\alpha} h^{1-\alpha} \left(n_{j,t}^i\right)^{-\alpha} = \Lambda_{j,3,t}^i P_t w_{j,t}^i h \tag{2.32}$$

$$\Lambda_{j,2,t}^i \alpha \exp\left(a_t\right) \left(u_{j,t}^i\right)^{\alpha-1} \left(k_{j,t-1}^i\right)^{\alpha} \left(h e_{j,t}^i n_{j,t}^i\right)^{1-\alpha} = \Lambda_{j,3,t}^i P_t q_t^o \delta \left(u_{j,t}^i\right)^{\varsigma} k_{j,t-1}^i \tag{2.33}$$

$$\Lambda_{j,2,t}^i \left(1 - \alpha\right) \exp\left(a_t\right) \left(u_{j,t}^i k_{j,t-1}^i\right)^{\alpha} \left(n_{j,t}^i\right)^{1-\alpha} h^{1-\alpha} \left(e_{j,t}^i\right)^{-\alpha} = \Lambda_{j,4,t}^i \mu \left(1 - h e_{j,t}^i - f\right)^{\varsigma} h \tag{2.34}$$

note that the wage decision is now dynamic. A similar (although more complicated) expression for the labor wedge can be obtained in this setup, with the same intuition – an increase in the detection probability will decrease wages and increase effort.

2.4. Construction Firms

Construction firms combine old capital and investment to produce new capital. The problem of these firms is static:

$$\max_{K^d, I, K_t^s} \left\{ q_t^n K_t^s - q_t^o K_t^d - I_t \right\}$$

subject to the technological constraint

$$K_t^s = (1 + a_2) K_t^d + \frac{a_1 \exp(z_t)}{1 - \omega} I_t^{1-\omega} \left(K_t^d\right)^{\omega}; \tag{2.35}$$

(a_1, a_2) are constants and $\omega^{-1} \geq 0$ is the elasticity of Tobin's $q = q^n/q^o$ with respect to I/K.[10] The first-order conditions are

$$q_t^n a_1 \exp(z_t) \left(\frac{I_t}{K_t^d}\right)^{-\omega} = 1 \tag{2.36}$$

$$q_t^n \left(1 + a_2 + \frac{a_1 \exp(z_t)\, \omega}{1 - \omega} \left(\frac{I_t}{K_t^d}\right)^{1-\omega}\right) = q_t^o \tag{2.37}$$

plus the constraint. z_t is a shock to the production of new capital. The parameters (a_1, a_2) are chosen such that the total and marginal costs of adjustment are zero and one in the steady state:

$$\begin{aligned} d &= \frac{\delta \overline{u}^{1+\zeta}}{1+\zeta} \\ a_1 &= \left(\frac{d}{1-d}\right)^{\omega} \\ a_2 &= -\frac{\omega}{1-\omega} \frac{d}{1-d} \end{aligned}$$

where $\overline{u}$ is the steady state utilization rate common to all types. Because the production technology is constant returns to scale, we need consider only the behavior of the stand-in construction firm.

2.5. Government

There are three branches of the government in the model. The monetary authority operates a nominal interest rate rule that sets current yields on nominal bonds by looking at the ratio of three variables to their steady state values: current real output, the past nominal interest rate, and current realized CPI inflation. The rule also incorporates an error term:

$$\frac{i_t}{i} = \left(\left(\frac{Y_t}{Y}\right)^{F_1} \left(\frac{\pi_t}{\pi}\right)^{F_2}\right)^{1-F_3} \left(\frac{i_{t-1}}{i}\right)^{F_3} \exp(\kappa_t) \tag{2.38}$$

$$\pi_t = \frac{P_t}{P_{t-1}}. \tag{2.39}$$

[10] Adjustment costs of this form are common in the asset pricing literature (Jermann 1998). The type of adjustment cost commonly used in the estimated DSGE literature involves penalizing the change in investment across periods; it is not clear how to interpret or decentralize adjustment costs of that form.

For simplicity we assume that the monetary authority can respond to current inflation and output, although it is certainly debatable whether that is possible in practice.

The fiscal authority sets taxes and borrowing to satisfy the government budget constraint

$$P_t\tau_t w_t h n_t + P_t\left(\tau_t + \tau_t^c - \tau_t\tau_t^c\right) d_t S_t + M_t - M_{t-1} = P_t \exp\left(g_t\right) G + P_t T_t - B_t + i_{t-1}B_{t-1}; \quad (2.40)$$

all seigniorage revenue is rebated to the fiscal authority. The current stock of nominal money M_t is endogenously set to ensure the interest rate target is achieved; the ex post real rate of return on bonds chosen in period t is then

$$R_{t+1} = \frac{i_t}{\pi_{t+1}} \quad (2.41)$$

where π_{t+1} is realized inflation from t to $t+1$. Variations in T_t clear the fiscal constraint and (g_t, τ_t, τ_t^c) are assumed to vary stochastically.

Finally, the unemployment insurance system also balances its budget by setting the appropriate tax rate:

$$\nu w h\left(1 - \sum\nolimits_{j=1}^{4} n_{j,t}\right) = \tau_t^u \sum\nolimits_{j=1}^{4} w_{j,t} h n_{j,t}. \quad (2.42)$$

Note that unemployment benefits are fixed per person relative to average wages, implying that taxes vary over the cycle to ensure the agency balances its budget. We assume that UI revenues are not part of the general budget.

In our alternative rules exercise we consider interest rate specifications that permit responses to other variables: the unemployment rate, the aggregate index of capacity utilization, and the wage inflation rate are three variables that we particularly focus on.

2.6. Market Clearing

The following market clearing conditions must hold. First, the total amount of production must equal that consumed by employed members, shirkers, unemployed members, and the family plus investment plus government consumption. Second, the family must hold 1 equity. Third, the number of nominal government bonds purchased by the family must equal the number issued by the fiscal authority. Fourth, the number of nominal monetary claims held by the family must equal the number issued by the monetary authority. Fifth, the number of employed agents plus the number of shirkers must equal the number of workers hired by the firm. And finally, the markets for old and new capital must clear. These conditions imply the following additional

equations must be satisfied:

$$
\begin{aligned}
Y_t &= (n_t - \upsilon_t n_t^s)\, c_t^e + \upsilon_t n_t^s c_t^s + (1 - n_t)\, c_t^u + c_t^f + I_t + \exp(g_t)\, G && (2.43)\\
S_t &= 1 && (2.44)\\
b_t &= 0 && (2.45)\\
m_t &= M_t && (2.46)\\
K_t^s &= \sum\nolimits_{j=1}^{4} k_{j,t} && (2.47)\\
K_t^d &= \sum\nolimits_{j=1}^{4} \left(1 - \frac{\delta}{1+\zeta} u_{j,t}^{1+\zeta}\right) k_{j,t-1}. && (2.48)
\end{aligned}
$$

In equilibrium $n_{j,t}^s = 0\ \forall j$, so the labor market condition is given by

$$n_t = \sum\nolimits_{j=1}^{4} n_{j,t}.$$

For future reference, we define

$$C_t = \sum\nolimits_{j=1}^{4} n_{j,t} c_{j,t}^e + \left(1 - \sum\nolimits_{j=1}^{4} n_{j,t}\right) c_t^u + c_t^f$$

as aggregate consumption.

2.7. Shocks

We assume that z_t and a_t have unit roots:

$$
\begin{aligned}
z_t &= g_z + z_{t-1} + \eta_{z,t}\\
\eta_{z,t} &= \rho_z \eta_{z,t-1} + \epsilon_{z,t}
\end{aligned}
$$

and

$$
\begin{aligned}
a_t &= g_a + a_{t-1} + \eta_{a,t}\\
\eta_{a,t} &= \rho_a \eta_{a,t-1} + \epsilon_{a,t}.
\end{aligned}
$$

The shocks to government spending and the fixed cost are assumed to vary around the stochastic trend generated by the unit root processes. The tax and detection probability shocks are stationary

AR(1) processes, since they are bounded between 0 and 1, and the interest rate shock κ is white noise.

Due to the stochastic trend we must deflate all variables that inherit the unit root; for convenience we assume that steady state inflation is 1. For estimation purposes we use unnormalized consumption and investment growth.

3. Estimation and Calibration

The model is estimated using Bayesian methods. There is a long history of using Bayesian methods in empirical DSGE estimation beginning with the work of DeJong, Ingram, and Whiteman (2000). We refer the interested reader to the survey of An and Schorfheide (2007) for a thorough review of this literature.

The model has 8 structural shocks. We assume that the fiscal shocks (g_t, τ_t, τ_t^c) are directly observable (we ignore measurement error in these series). We therefore need 5 additional observables to avoid stochastic singularity. We choose aggregate consumption growth, aggregate investment growth, total employment, CPI inflation, and the nominal federal funds rate (compounded quarterly and annualized).

3.1. Data

Data on aggregate personal consumption, gross investment and government consumption are from the NIPA accounts. All data are real chained measures. The inflation rate is constructed from the personal consumption deflator, also from the NIPA accounts. Employment is the number of Non-farm workers divided by the population aged 16 and over and the data source is the Bureau of Labor Statistics; the mean employment rate is 45.4 percent. The personal income tax rate is constructed by dividing personal income tax revenues by personal income. Similarly, the corporate tax is constructed by dividing corporate tax revenue by corporate profits. The source series are from the BEA department website. The federal funds rate is from the St. Louis Fed Fred database. The sample period is from 1955:1-2007:1 and all data are quarterly.

3.2. Calibration

Since not all of the model parameters are well identified in the likelihood function and we use a limited number of time series in model estimation it is useful to calibrate some of the model

parameters. We set $\beta = \frac{1}{1+i}$, where i is the mean interest rate observed in our data. We select values for $(\alpha, \mu, \delta, \zeta)$ to match the model steady state to a utilization rate of 82 percent, a depreciation rate of 2.5 percent, an employment rate equal to the detrended mean from our data ($n = 0.454$), and a labor income to total income ratio of 66 percent.[11] We set Φ equal to 1 percent of steady state output. The UI replacement rate is set to $\nu = 0.4$, consistent with estimates in the labor literature, and $\varsigma = -2.0$ matches reasonably well with estimates of the Frisch elasticity of labor supply. $\omega = 1/0.23$ is the value used in Jermann (1998). Finally, we choose $\varphi = 0.2$ and $f = 0.01$; these parameters are fundamentally unidentified and relatively unimportant.

It turns out that we require a relatively harsh punishment for our model to produce a locally determinate equilibrium; we choose $\theta = 0.5$, implying that the punishment for shirking nearly as bad as being unemployed. Alexopoulos (2006,2007) uses $\theta = 0.95$, implying that shirking is nearly costless and involves only the denial of relatively-small bonus payments.

3.3. Estimates using 1st Order Approximation

We provide two sets of model estimates. The first is based on a linear approximation to the model's structural equations. Here we evaluate the model's likelihood using the Kalman filter and then sample from the posterior using a random walk Monte Carlo Markov Chain algorithm. Since these methods are now standard we do not provide extensive details.[12] For the results reported here we used a Markov chain of length $20,000$. The model parameters that are currently being estimated are

$$\left\{F_1, F_2, F_3, \rho_a, \rho_z, \rho_x, \rho_g, \rho_\upsilon, \rho_\tau, \rho_{\tau c}, \sigma_a, \sigma_z, \sigma_x, \sigma_g, \sigma_\upsilon, \sigma_\tau, \sigma_{\tau c}, \sigma_\kappa, \gamma, \phi_1, \phi_2, \phi_3, \phi_4\right\}.$$

(We are somewhat uncertain about the identifiability of the ϕ_i parameters separately; jointly they are determined by the dynamics of inflation. The model makes a connection between price dispersion and aggregate inefficiency, so the relative values of the adjustment cost parameters may also be pinned down, at least in the second-order solution. Which firm type gets assigned which value of ϕ depends on the random draws of the Markov chain).

[11] Our mean employment number seems low, but it lumps unemployed and out of labor force states together and is linearly-detrended due to a significant nonstationary component which the model is incapable of handling.

[12] Otrok (2001) provides complete details on this procedure.

The state space representation of the model is

$$\begin{aligned}\mathcal{S}_t &= \mathcal{A}\mathcal{S}_{t-1} + \mathcal{B}\epsilon_t^s \\ \mathcal{O}_t &= \mathcal{C}\mathcal{S}_{t-1}\end{aligned}$$

where $\mathcal{S}_t$ is the vector of states, $\mathcal{O}_t$ is the vector of observables, ϵ_t^s is the vector of structural shocks, and $(\mathcal{A}, \mathcal{B}, \mathcal{C})$ are matrices. The state variables for the economy are

$$\mathcal{S}_{t-1} = \left\{ \begin{array}{c} k_{1,t-1}, p_{1,t-1}, k_{2,t-1}, p_{2,t-1}, k_{3,t-1}, p_{3,t-1}, k_{4,t-1}, p_{4,t-1}, i_{t-1}, m_{t-1}, P_{t-1}, \\ \eta_{a,t}, \eta_{z,t}, x_t, g_t, \tau_t, \tau_t^c, \upsilon_t, \kappa_t, C_{t-1}, I_{t-1}, Z_{t-1}. \end{array} \right\}$$

Table 1 reports the posterior mean and 95 percent posterior coverage intervals for the model parameters. One important point here is that our markup is very small – just under 1 percent based on the posterior median of γ; Figure 1 shows the posterior distribution. It turns out that our model is locally indeterminate for large values of the markup, preventing the estimation procedure from moving into a region with small γ. Of course, we also have a second markup for wages caused by the binding incentive constraint, so the total gap between wages and marginal products could be quite large.

Figure 2 shows a histogram of the draws for the policy parameters (F_1, F_2, F_3). Both F_1 and F_3 are well-identified, with the model implying a significant amount of interest rate smoothing and little to no output response. The histogram of F_2 shows multiple modes, but a longer run (not yet reported) has resolved this issue; in any case, the posterior is concentrated above 2.5, implying strong response to inflation deviations.

For the shock processes, Figure 3 shows that most of the autoregressive coefficients are well-identified; the government spending and detection probability shocks are essentially unit root processes. For the shock variances we find that the variance of the fixed cost shock σ_x is not clearly identified; it is possible that the linear solution cannot draw clear distinctions between the output lost due to price dispersion and the output lost due to the fixed cost shock; moving to the second order solution may therefore generate economically-meaningful improvements.

3.4. Estimates using 2nd Order Approximation

Fernández-Villaverde and Rubio-Ramírez (2007) develop a nonlinear likelihood-based approach to estimating DSGE models. Part of the motivation for this agenda is that even in well-behaved cases

caution should be used with linear likelihood methods (e.g. Fernández-Villaverde, Rubio-Ramírez, and Santos 2006 show that second-order mistakes in decision rules translate into first-order mistakes in the likelihood). In our case we are interested in estimating the parameters of a model where the underlying propagation mechanism is based on a wage model with inherent nonlinearities (we also intend to include stochastic volatility in a revision of the paper and the insurance component to efficiency wages may be important), so it is natural to want to work directly with the non-linear version of the model. Furthermore, we investigate the role of nonlinear policy rules and naturally want to characterize the extent to which current estimated rules are nonlinear. In other work, we have found that nonlinear policy rules can dominate linear ones for emerging markets (Benigno *et al.* 2007), so we are naturally interested in whether the same is true for developed economies. To investigate whether actual policy rules are nonlinear requires us to abandon the estimation of the linear model, so we are currently trying to estimate the model using the particle filter from Fernández-Villaverde and Rubio-Ramírez (2007) as well as the Gaussian EIS filter from DeJong *et al.* (2007).

<TO BE COMPLETED>

4. Monetary Policy Rules

We first consider the optimal setting for the parameters of the Taylor rule used to set nominal interest rates, where we permit the central bank to respond to lagged deviations of the interest rate, output, and inflation from their steady state values using a linear rule. We compare the performance of pure inflation targeting (the coefficient on output is zero) versus a flexible targeting scheme that permits some adjustment to output. We compare these rules to rules that permit responses directly to unemployment, capacity utilization, and nominal wage inflation, variables that are often used as indicators of economic conditions. Our objective function for efficiency is the welfare of the family:

$$U_t = \sum\nolimits_{j=1}^{4} \left[\left(n_{j,t} - \exp\left(\upsilon_t\right) \Upsilon n_{j,t}^{s} \right) u_t^{e} + \exp\left(\upsilon_t\right) \Upsilon n_{j,t}^{s} \log\left(c_{j,t}^{s}\right) \right] + \left(1 - \sum\nolimits_{j=1}^{4} n_{j,t} \right) \log\left(c_t^{u}\right) + \beta E_t \left[U_{t+1} \right].$$

We compute lifetime utility using a second-order expansion as in Schmitt-Grohé and Uribe (2004); since the rules that we consider have no effect on the steady state, our welfare calculation amounts to comparing the coefficients that multiply the variance scaling terms.[13] That is, the difference in

[13] As is common in the literature, we ignore the utility of real money balances.

welfare between two policies is given by

$$\begin{aligned}\Delta &= U^1 - U^0 \\ &= \frac{1}{2}g_{ss}^1 - \frac{1}{2}g_{ss}^0,\end{aligned}$$

where g_{ss}^i is the vector of coefficients that capture the effect of variance on lifetime utility under each policy scenario.[14] Inspection of the welfare objective shows that price dispersion has a welfare cost here – when firms have different prices they produce different wages, leading to consumption being unequal across households. Under a concave objective inequality is welfare-reducing, so the monetary authority may try to limit price dispersion. We also evaluate our rules according to a simple criterion that penalizes the variance of aggregate income and inflation relative to some targets; we specify the targets as $\pi^* = 1$ and $y^* = Y$, the steady state output level.

We then generalize this approach to permit nonlinear rules. The interpretation of a nonlinear interest rate rule depends on the signs of the linear and quadratic terms. If both terms are positive, the rule specifies a more aggressive increase in rates when the targeted variable increases and a less aggressive decrease when the targeted variable decreases. If the linear term is positive and the quadratic term is negative, the response to decreases is more aggressive while the response to increases is muted. If the linear term is close to zero and the quadratic term is relatively large, the rule specifies a response only to large shocks (those whose squared deviation from the steady state is very big); the direction of the response is depends only on the sign of the quadratic term and not the sign of the deviation.[15]

[results on policy rules to be added]

5. Conclusion

In a revised version of this paper we plan to introduce stochastic volatility shocks into our model. The Great Moderation – the decline in the volatility of US aggregates observed since 1980 – has received a great deal of attention recently, with two camps emerging regarding its origins. The first camp attributes it to "good luck" (Fernández-Villaverde and Rubio-Ramírez 2007, Arias, Hansen, and Ohanian 2007, Justiniano and Primiceri 2007), where shocks simply got less volatile

[14] This calculation does not imply that the welfare criterion is equivalent to minimizing the volatility of inflation or other endogenous variables.

[15] More general rules cannot be accomodated within a linear-quadratic setup. In particular, without third-order terms we cannot consider different responses to large positive and negative deviations.

(either temporarily or permanently). The second camp attributes it to "good policy," so that the Fed has learned how to conduct monetary policy better; learning dynamics can lead researchers to attribute declines in volatility due to good policy instead to good luck (Bullard and Singh 2007, Milani 2007). The model with stochastic volatility is more challenging to estimate, since conditional heteroskedasticity disappears in first-order approximations; thus, we will need to work with the second-order approximation to the structural equations and nonlinear filters

We also plan to generalize the price rigidity to permit stochastic adjustment of prices with an upward-sloping hazard rate (a parsimonious method for approximating the state-dependent pricing studied in Dotsey, King, and Wolman 1999); this approach keeps the number of different capital stocks finite. Fully state-contingent pricing setups are difficult to estimate because they imply that the number of state variables can change as we move through the parameter space; it is extremely costly to repeatedly solve for the steady states and check that all firms have adjusted within some fixed number of periods. Our approximation would fix the number of periods and then impose an adjustment probability of 1 in the final period while estimating the other adjustment probabilities; outside information about the frequency of price changes could then be brought to bear on this issue.

Our interest in stochastic volatility models has two dimensions beyond the Great Moderation. The first question involves the welfare costs of inflation. It is common to argue that the costs of anticipated inflation may be high because high inflation comes with high inflation volatility; a model with stochastic volatility shocks could produce this outcome through a positive correlation between the innovations in the shocks and the innovations in the stochastic volatility process. It is then possible to assess whether these costs will actually be high when the stochastic volatility process is empirically sound. Second, there has been a movement recently that argues the Fed should use asset prices as a guide for monetary policy – it should prick the "bubbles" in the stock market and the housing market by raising nominal interest rates. Given the evidence that asset prices have show significant evidence of conditional heteroskedasticity (either driven by ARCH/GARCH effects or stochastic volatility), this argument cannot be supported theoretically without a good model of asset prices.[16] Reflecting the issues raised in McGrattan and Prescott (2005), we also intend to incorporate more detail on expensing of intangible investments and other details that have long-run

[16] Casarin and Trecoci (2006) show that asset prices have declined in volatility at the same time as macroeconomic aggregates using a stochastic volatility perspective. Uhlig (2007) advocates real wage rigidities in asset pricing models in order to limit the ability of agents to insure using elastic labor supply.

effects on equity premia and the value of the stock market.

References

[1] Alexopoulos, Michelle (2006), "Shirking in a Monetary Business Cycle Model," *Canadian Journal of Economics* **39(3)**, pp. 689-718.

[2] Alexopoulos, Michelle (2007), "A Monetary Business Cycle Model with Unemployment," forthcoming, *Journal of Economic Dynamics and Control*.

[3] An, Sungbae and Frank Schorfheide (2007), "Bayesian Analysis of DSGE Models," *Econometric Reviews* **26(2-4)**, pp. 113-72.

[4] Arias, Andres, Gary D. Hansen, and Lee E. Ohanian (2007), "Why Have Business Cycle Fluctuations Become Less Volatile?" *Economic Theory* **32(1)**, pp. 43-58.

[5] Benigno, Gianluca, Christopher Otrok, Alessandro Rebucci, and Eric R. Young (2007), "Alternative Monetary Policy Rules in a Model with Endogenous Sudden Stops," forthcoming, *Handbook of Central Banking*.

[6] Blanchard, Olivier and Jordi Galí (2005), "Real Wage Rigidities and the New Keynesian Model," Massachussetts Institute of Technology Working Paper **05-27**.

[7] Bullard, James and Aarti Singh (2007), "Learning and the Great Moderation," Federal Reserve Bank of St. Louis Working Paper **2007-027A**.

[8] Casarin, Roberto and Carmine Trecoci (2006), "Business Cycle and Stock Market Volatility: A Particle Filter Approach," Discussion Paper **0603**, Dipartimento di Scienze Economiche, Università degli Studi di Brescia.

[9] Chari, V.V., Patrick J. Kehoe, and Ellen R. McGrattan (2006), "Business Cycle Accounting," *Econometrica* **75(3)**, pp. 781-836.

[10] Danthine, Jean-Pierre and André Kurmann (2004), "Fair Wages in a New Keynesian Model of the Business Cycle," *Review of Economic Dynamics* **7(1)**, pp. 107-42.

[11] DeJong, David N., Hariharan Dharmarajan, Roman Liesenfeld, and Jean-François Richard (2007), "An Efficient Filtering Approach to Likelihood Approximation for State-Space Representations," manuscript, University of Pittsburgh.

[12] DeJong, David N., Beth F. Ingram, and Charles H. Whiteman (2000), "A Bayesian Approach to Dynamic Macroeconomics," *Journal of Econometrics* **98(2)**, pp. 203-23.

[13] Del Negro, Marco, Frank Schorfheide, Frank Smets, and Rafael Wouters (2007), "On the Fit of New Keynesian Models," *Journal of Business and Economic Statistics* **25(2)**, pp. 143-62.

[14] Dotsey, Michael, Robert G. King, and Alexander L. Wolman (1999), "State-Dependent Pricing and the General Equilibrium Dynamics of Money and Output," *Quarterly Journal of Economics* **114**, pp. 655-90.

[15] Faia, Ester (2007), "Optimal Monetary Policy Rules with Labor Market Frictions," forthcoming, *Journal of Economic Dynamics and Control.*

[16] Felices, Guillermo (2006), "Can Information-Consistent Wages Help Explain the Dynamics of Real Wages and Inflation?" working paper, Bank of England.

[17] Fernández-Villaverde, Jesús and Juan F. Rubio-Ramírez (2004), "Comparing Dynamic Equilibrium Economies to Data," *Journal of Econometrics* **123**, pp. 153-87.

[18] Fernández-Villaverde, Jesús and Juan F. Rubio-Ramírez (2006), "How Structural Are Structural Parameters?" forthcoming, *2007 NBER Macroeconomics Annual.*

[19] Fernández-Villaverde, Jesús and Juan F. Rubio-Ramírez (2007), "Estimating Macroeconomic Models: A Likelihood Approach," forthcoming, *Review of Economic Studies.*

[20] Fernández-Villaverde, Jesús, Juan F. Rubio-Ramírez, and Manuel Santos (2006), "Convergence Properties of the Likelihood of Computed Dynamic Models," *Econometrica* **74**, pp. 93-119.

[21] Hall, Robert E. (1997), "Macroeconomic Fluctuations and the Allocation of Time," *Journal of Labor Economics* **15(1)** Part 2: Essays in Honor of Yoram Ben-Porath, pp. S223-50.

[22] Ireland, Peter N. (1997), "A Small, Structural, Quarterly Model for Monetary Policy Evaluation," *Carnegie-Rochester Conference Series on Public Policy* **47**, pp. 83-108.

[23] Jermann, Urban (1998), "Asset Pricing in Production Economies," *Journal of Monetary Economics* **41(2)**, pp. 257-75.

[24] Justiniano, Alejandro and Giorgio Primiceri (2007), "The Time Varying Volatility of Macroeconomic Fluctuations," forthcoming, *American Economic Review.*

[25] Krause, Michael U. and Thomas A. Lubik (2005), "The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions," forthcoming, *Journal of Monetary Economics*.

[26] McGrattan, Ellen R. and Edward C. Prescott (2005), "Taxes, Regulations, and the Value of U.S. and U.K. Corporations," *Review of Economic Studies* **72**, pp. 767-96.

[27] Milani, Fabio (2007), "Learning and Time-Varying Macroeconomic Volatility," manuscript, University of California-Irvine.

[28] Otrok, Christopher (2001), "On Measuring the Welfare Cost of Business Cycles," *Journal of Monetary Economics* **47(1)**, pp. 61-92.

[29] Rotemberg, Julio J. (1982), "Monopolistic Price Adjustment and Aggregate Output," *Review of Economic Studies* **49**, pp. 517-31.

[30] Schmitt-Grohé, Stephanie and Martín Uribe (2004), "Solving Dynamic General Equilibrium Models Using a Second-Order Approximation to the Policy Function," *Journal of Economic Dynamics and Control* **28**, pp. 755-75.

[31] Shapiro, Carl and Joseph E. Stiglitz (1984), "Equilibrium Unemployment as a Worker Discipline Device," *American Economic Review* **74(3)**, pp. 433-44.

[32] Smets, Frank and Rafael Wouters (2007), "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review* **97(3)**, pp. 586-606.

[33] Uhlig, Harald (2007), "Explaining Asset Prices with External Habits and Wage Rigidities in a DSGE Model," *American Economic Review* **97(2)**, pp. 239-43.

Table 1a

Posterior Quantiles

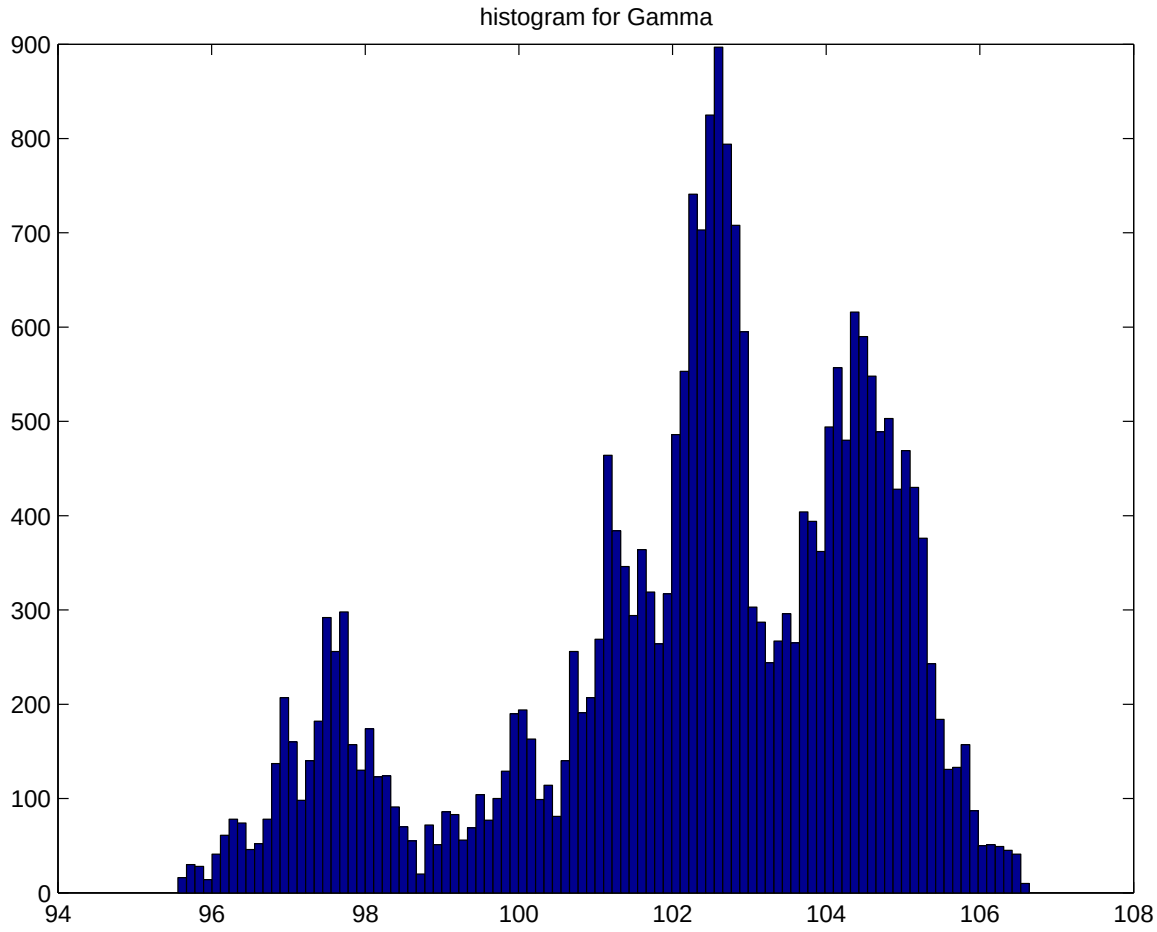
	5%	50%	Mean	95%
F_1	-0.0323	-0.0201	-0.0204	-0.0098
F_2	2.2213	2.8537	2.8631	3.3328
F_3	0.6937	0.7684	0.7652	0.8202
γ_a	0.0023	0.0037	0.0038	0.0056
γ_z	0.0015	0.0046	0.0047	0.0084
γ	97.3272	102.6037	102.2584	105.2951
ϕ_1	0.2074	0.3744	0.3977	0.6385
ϕ_2	0.0200	0.2272	0.2480	0.5199
ϕ_3	0.0368	0.2541	0.2536	0.4394
ϕ_4	0.0349	0.1666	0.1779	0.3597

Table 1b

Posterior Quantiles

	5%	50%	Mean	95%
ρ_a	0.7618	0.7970	0.8004	0.8417
ρ_z	0.6828	0.7136	0.7188	0.7643
ρ_v	0.9889	0.9952	0.9948	0.9991
ρ_g	0.9924	0.9928	0.9928	0.9932
ρ_x	0.9470	0.9707	0.9701	0.9904
ρ_τ	0.8253	0.8788	0.8789	0.9352
$\rho_{\tau,c}$	0.8641	0.9089	0.9073	0.9471
σ_a	0.0274	0.0305	0.0306	0.0340
σ_z	0.2973	0.3259	0.3287	0.3606
σ_v	0.0035	0.0039	0.0039	0.0043
σ_g	0.0100	0.0109	0.0109	0.0118
σ_x	1.9943	2.3391	2.3510	2.6924
σ_τ	0.0042	0.0045	0.0046	0.0049
$\sigma_{\tau,c}$	0.0100	0.0108	0.0108	0.0117
σ_κ	0.0030	0.0035	0.0035	0.0040

Figure 1


histogram for Gamma
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94
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104
106
108

Figure 2

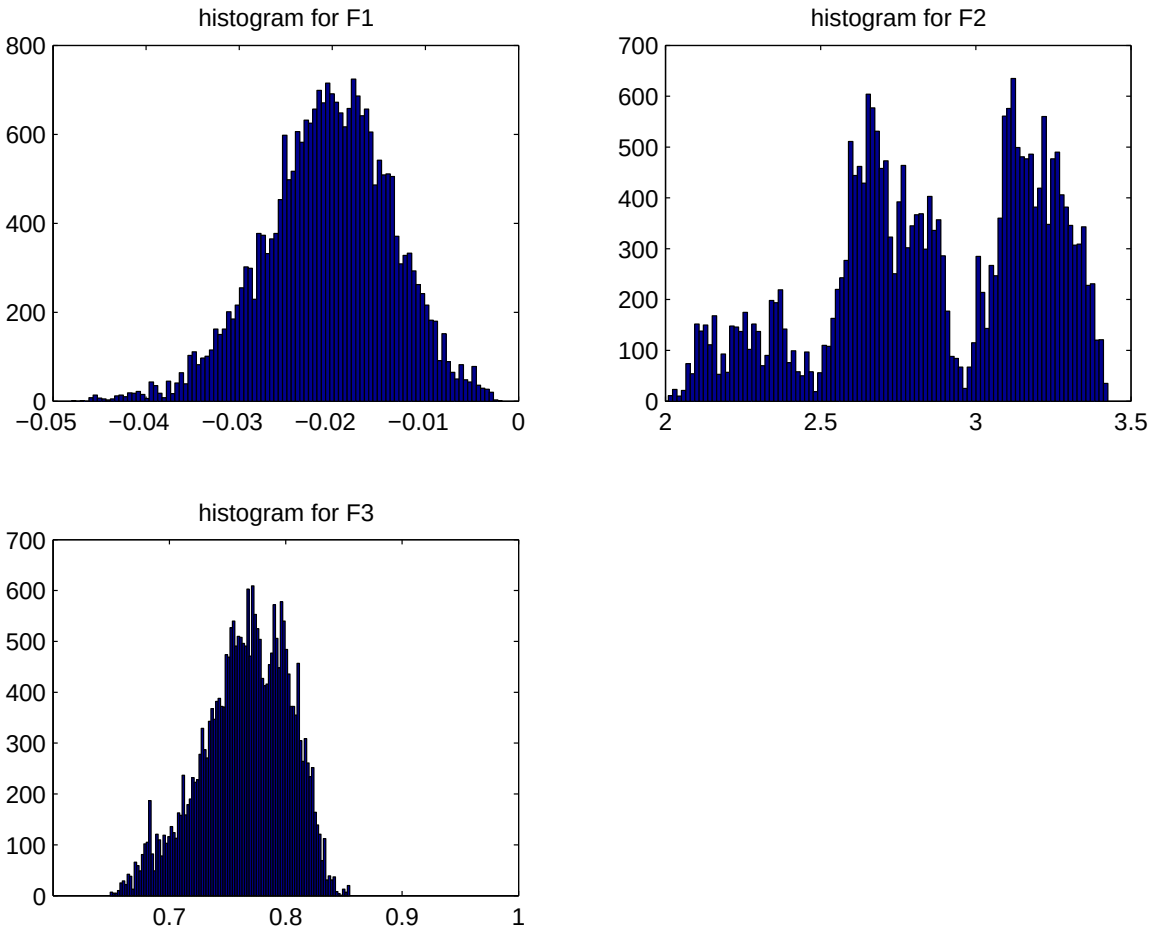

histogram for F1
800
600
400
200
0
−0.05
−0.04
−0.03
−0.02
−0.01
0
histogram for F2
700
600
500
400
300
200
100
0
2
2.5
3
3.5
histogram for F3
700
600
500
400
300
200
100
0
0.7
0.8
0.9
1

Figure 3

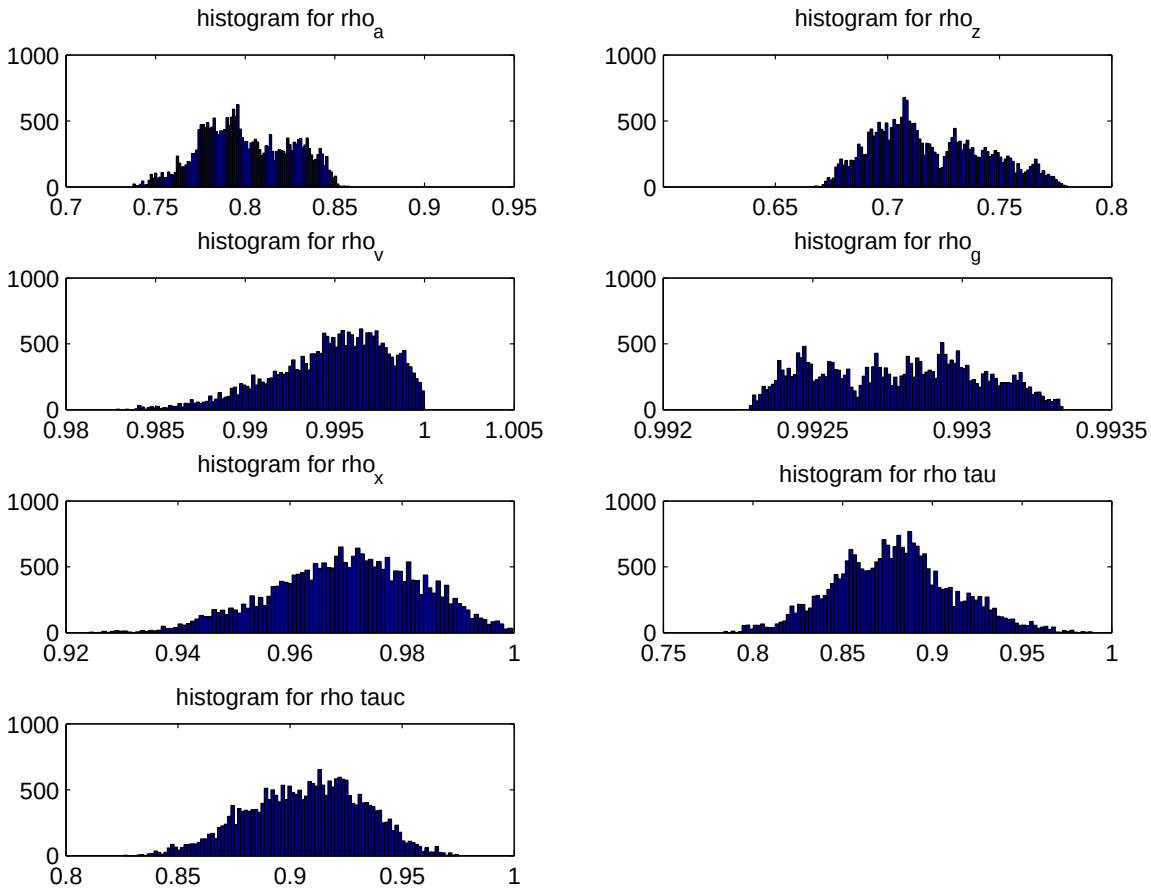
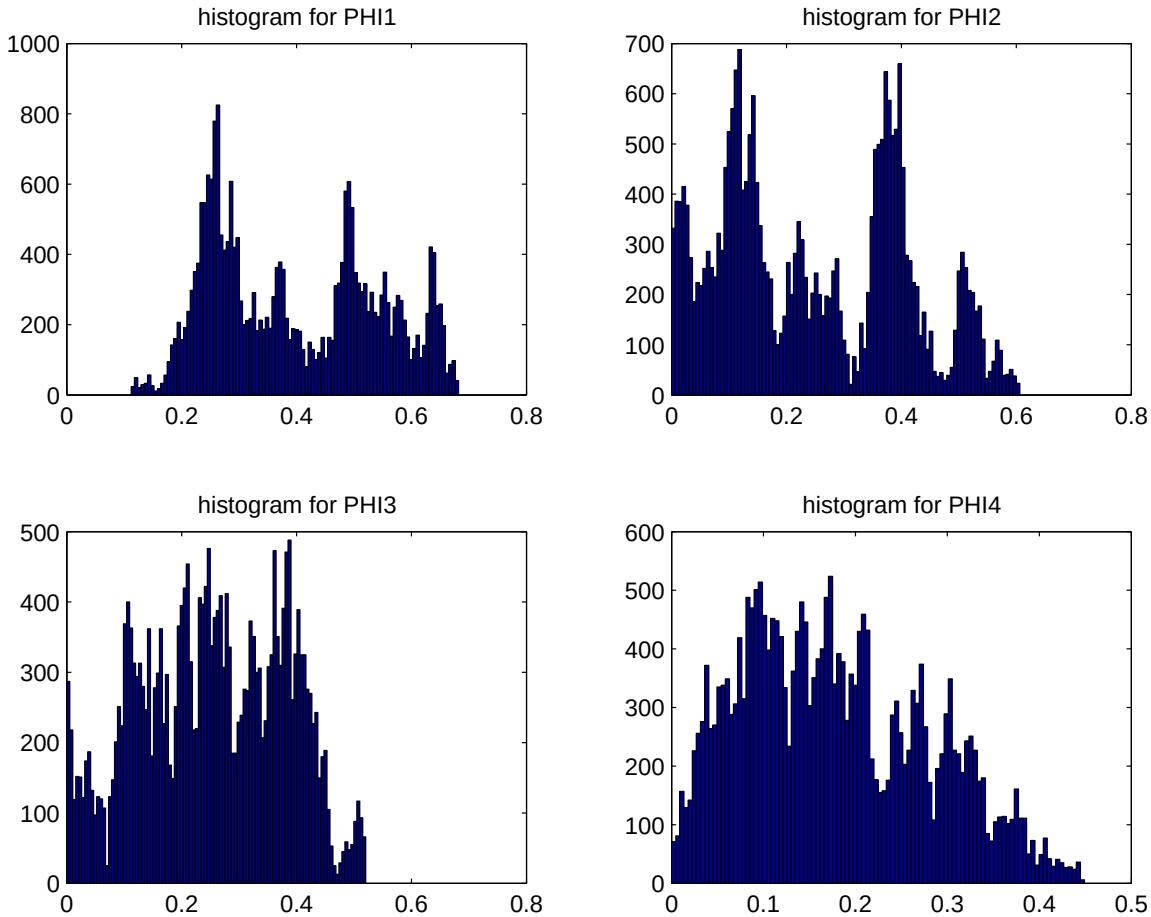

histogram for rho$_a$
1000
500
0
0.7
0.75
0.8
0.85
0.9
0.95
histogram for rho$_z$
1000
500
0
0.65
0.7
0.75
0.8
histogram for rho$_v$
1000
500
0
0.98
0.985
0.99
0.995
1
1.005
histogram for rho$_g$
1000
500
0
0.992
0.9925
0.993
0.9935
histogram for rho$_x$
1000
500
0
0.92
0.94
0.96
0.98
1
histogram for rho tau
1000
500
0
0.75
0.8
0.85
0.9
0.95
1
histogram for rho tauc
1000
500
0
0.8
0.85
0.9
0.95
1

Figure 4


histogram for PHI1
histogram for PHI2
histogram for PHI3
histogram for PHI4