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Estimation and Evaluation of a Segmented Markets Monetary Model

John Landon-Lane Filippo Occhino*

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Abstract

This paper develops a heterogeneous agents segmented markets model with endogenous production and a monetary authority that follows a Taylor-type interest rate rule. The model is estimated using Markov chain Monte Carlo techniques and is evaluated as a framework suitable for empirical monetary analysis. We find that the segmented markets friction significantly improves the statistical out-of-sample prediction performance of the model, and generates delayed and realistic impulse response functions to monetary policy shocks. In addition, we find that the estimates of the Taylor rule are stable across the pre-1979 and post-1982 periods in our sample, while the volatilities of the structural shocks faced in the pre-1979 period are substantially higher than in the post-1982 period.

Keywords: Segmented markets, Markov chain Monte Carlo, Taylor rule, Monetary policy shocks.

JEL Classification Number: C11, C52, E52.

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1 Introduction

Segmented markets models, where a subset of households do not participate in financial markets, have proven to provide important theoretical insights into the short-run interaction of money, prices, interest rates and exchange rates¹. Still a segmented markets model suitable for empirical monetary analysis has yet to be developed. To that end we propose a segmented markets model with endogenous production and a monetary authority that follows a Taylor-type interest rate rule.

The model introduces features of standard limited participation models into the heterogeneous agents segmented markets framework. The key feature is that a subset of households, the traders, receive lump-sum monetary transfers from the monetary authority, and firms borrow money from the traders to finance production. Monetary policy shocks and technology shocks are introduced as sources of uncertainty.

The model is evaluated from two perspectives. First, the model is evaluated statistically based on its predictive performance. We estimate the model using Markov chain Monte Carlo methods, bringing non-sample and sample information to bear on the statistical evaluation, and then formally compare the model with the alternative of full participation. Second, the model is evaluated from an economics perspective by comparing the model's impulse response function to the responses to monetary policy shocks documented in the empirical literature.

We find that the segmented markets friction significantly improves the statistical out-of-sample prediction performance of the model, and generates delayed and realistic impulse response functions to monetary policy shocks. In addition, we find that the estimates of the Taylor rule are stable across the pre-1979 and post-1982 periods in our sample. Our evidence suggests that the greater macroeconomic instability in the pre-1979

¹Among the most recent studies adopting various types of market segmentation are Alvarez, Lucas and Weber (2001), Alvarez, Atkeson and Kehoe (2002), Alvarez, Atkeson and Edmond (2003), Lahiri, Singh and Vegh (2003), Gali, Lopez-Salido and Valles (2004), Occhino (2004), and Bilbie (2005). Other contributions to the segmented markets literature will be presented at the session "Monetary Economies with Segmented Markets" of the 2005 Meeting of the Society for Economic Dynamics.

period is more likely to be due to larger volatilities of the structural shocks, especially the technology shock, rather than to differences in the adopted monetary policy rule.

The paper is organized as follows. Section 2 describes the economy and defines the competitive equilibrium. Section 3 explains the solution and estimation methods. Section 4 details the data and justifies the prior. Section 5 comments on the estimation results and on the impulse response analysis. Section 6 concludes.

2 Model

The segmented markets model that we propose is a cash-in-advance production economy, with a large number of households, a large number of firms owned by households, and a monetary authority. The number of firms is normalized to one. Time is discrete and indexed by t . There is a single non-durable consumption good produced by labor, one-period bonds issued by firms, and money. The sources of uncertainty in the economy are monetary policy shocks and technology shocks.

There are two types of households, traders and non-traders. Let $\lambda \in (0, 1]$ and $\lambda^* \equiv 1 - \lambda$ be the proportion of traders and non-traders respectively. Households of the same type are identical in all respects. The two types of households differ because only traders receive lump-sum transfers of money from the monetary authority, and only traders participate in the bond market, purchasing bonds sold by firms. We refer to the case where $\lambda = 1$ and $\lambda < 1$ respectively as the full participation model and the segmented markets model. To help interpretability, we anticipate that the predictions of the model as to money, prices, interest rates and output would not change if we replaced the assumption that traders receive monetary transfers with the assumption that they purchase bonds issued by the monetary authority and that the monetary authority returns the revenue from seigniorage to the traders in a lump-sum fashion.

We now describe three key features of the segmented markets friction, and the

role they play in the mechanics of the model. The first two features are in common with the standard limited participation friction, the third is what makes the two frictions different.

First, only traders receive lump-sum transfers of money from the monetary authority. As in Grossman and Weiss (1983) and Lucas (1990), this assumption is introduced to model the liquidity effects of monetary injections, namely the positive response of the nominal interest rate together with the negative response of the money supply to a contractionary monetary policy shock.

Second, firms need cash-in-advance to produce goods, and borrow money by selling bonds to the traders. Notice that the agents who lend to firms are the same ones who receive the lump-sum transfers of money from the monetary authority. This assumption, which follows Fuerst (1992), Christiano and Eichenbaum (1992a) and the limited participation literature, is introduced to model the real effects of monetary injections, namely the negative response of production to a contractionary monetary policy shock.

Third, traders and non-traders belong to separate households. In the standard limited participation framework, all agents belong to a representative household, which bounds the effects of monetary policy to be short-lived. In segmented markets models, however, traders and non-traders belong to different households, which allows monetary policy to have distributional and, hence, more persistent and delayed effects. We show below that both the liquidity effect and the real effect of monetary injections last for several periods, and their peaks may occur with delay.

The timing of the events within each period is as follows. At the beginning of each period, all cash balances are held by households. Let a_t and a_t^* be respectively the cash balances held traders and non-traders at the beginning of period t . Within the period, three markets meet in sequence, the bond market, the labor market and the goods market. The three markets are monetary; that is bonds, labor and goods are all traded in exchange of money.

In the bond market, traders receive lump-sum transfers of money τ_t from the monetary authority, and purchase one-period bonds from the firms at the nominal interest rate $i_t > 0$. Then, the labor market meets where firms rent labor from households with the money received in exchange of the bond sale. The wage rate is $w_t > 0$. After that, firms produce goods. Aggregate production

$$y_t \equiv h_t n_t \tag{1}$$

is the product of the stock of technology $h_t > 0$ and labor demand $n_t \geq 0$. After producing goods firms then enter the goods market, selling consumption goods to households at the goods price $p_t > 0$.

Households cannot use the money earned by selling labor to purchase consumption goods in the same period. The money supply is defined as the amount of dollars $m_t \equiv p_t y_t$ spent in the goods market. The inflation rate π_t is defined by

$$\pi_{t+1} \equiv \log(p_{t+1}) - \log(p_t) \tag{2}$$

and the money growth rate μ is similarly defined as the first difference of log-money.

Finally, households consume, and the firms redeem their bonds and distribute profits to the households. Since the production technology is linear, equilibrium profits are zero, and the equilibrium does not depend on the firms' ownership. For notational convenience, then, we assume that profits are destroyed rather than distributed to households.

Monetary policy is set in terms of the one-period nominal interest rate. The monetary authority sets the monetary transfers τ_t to target the nominal interest rate i_t . The monetary policy rule is a Taylor interest rate rule. The deviation \hat{i}_t of the interest

rate from its non-stochastic steady state value follows the process

$$\hat{i}_{t+1} = \rho_i \hat{i}_t + (1 - \rho_i) [\kappa_\pi \hat{\pi}_t + \kappa_y \hat{y}_t] + \sigma_i \epsilon_{i,t+1} \quad (3)$$

where $\hat{\pi}_t$ and \hat{y}_t are respectively the deviation of the inflation rate and the percentage deviation of output from their non-stochastic steady state values, which are determined endogenously, $\rho_i \in [0, 1)$ is the conditional first-order autocorrelation of the interest rate, $\kappa_\pi \geq 0$ is the response coefficient to inflation deviations, $\kappa_y \geq 0$ is the response coefficient to output percentage deviations, $\sigma_i > 0$ is the volatility of the monetary policy shock, and $\epsilon_{i,t+1}$ is the normalized monetary policy shock independently and identically distributed as standard normal.

The stock of technology follows the exogenous process

$$\hat{h}_{t+1} = \rho_h \hat{h}_t + \sigma_h \epsilon_{h,t+1} \quad (4)$$

where \hat{h}_t , is the percentage deviation of the stock of technology from its non-stochastic steady state value, $\rho_h \in [0, 1)$ is the conditional first-order autocorrelation, $\sigma_h > 0$ is the volatility of the technology shock and $\epsilon_{h,t+1}$ is the normalized technology shock independently and identically distributed as standard normal. Monetary policy shocks and technology shocks are independent.

Histories consist of the past realizations of the two shocks. Let a_{t+1} , a_{t+1}^* and all the other variables dated at t be contingent on the history up to period t . Each trader chooses contingent sequences of consumption demand c_t , labor supply l_t , bond demand b_t and next-period cash balances a_{t+1} , to solve

$$\max_{\{b_t, c_t > 0, l_t > 0, a_{t+1} > 0\}_{t=0}^{\infty}} \left\{ E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log(c_t) - \phi \frac{l_t^{1+\varphi}}{1+\varphi} \right) \right] \right\}$$

subject to:

$$\begin{aligned} b_t + p_t c_t &= a_t + \tau_t \\ a_{t+1} &= w_t l_t + (1 + i_t) b_t \end{aligned} \tag{5}$$

given the trader's initial cash balances $a_0 > 0$ in period zero, where E_0 is the expectation conditional on information available after the shocks $\epsilon_{i,0}$, $\epsilon_{h,0}$ have been revealed, $\beta \in (0, 1)$, $\phi > 0$ and $\varphi > 0$.

The necessary first-order conditions for the traders' optimization problem are

$$\begin{aligned} -\nu_t^1 + \nu_t^2(1 + i_t) &= 0 \\ \beta^t c_t^{-1} - \nu_t^1 p_t &= 0 \\ -\beta^t \phi l_t^\varphi + \nu_t^2 w_t &= 0 \\ -\nu_t^2 + E_t[\nu_{t+1}^1] &= 0 \end{aligned} \tag{6}$$

where ν_t^1 and ν_t^2 are the Lagrange multipliers associated with the two constraints (5).

Non-traders solve the same problem except that they do not purchase bonds and they do not receive monetary transfers. Their problem is then

$$\max_{\{c_t^* > 0, l_t^* > 0, a_{t+1}^* > 0\}_{t=0}^\infty} \left\{ E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log(c_t^*) - \phi \frac{l_t^{*1+\varphi}}{1+\varphi} \right) \right] \right\}$$

subject to:

$$\begin{aligned} p_t c_t^* &= a_t^* \\ a_{t+1}^* &= w_t l_t^* \end{aligned} \tag{7}$$

given the non-trader' initial cash balances $a_0^* > 0$ in period zero.

The necessary first-order conditions for the non-traders' optimization problem are

$$\begin{aligned}
\beta^t c_t^{*-1} - \nu_t^{1*} p_t &= 0 \\
-\beta^t \phi l_t^{*\varphi} + \nu_t^{2*} w_t &= 0 \\
-\nu_t^{2*} + E_t[\nu_{t+1}^{1*}] &= 0
\end{aligned} \tag{8}$$

where ν_t^{1*} and ν_t^{2*} are the Lagrange multipliers associated with the two constraints (7).

Firms choose labor demand n_t and bond supply d_t to solve the static profits maximization problem

$$\max_{\{n_t \geq 0, d_t\}} \{p_t h_t n_t - w_t n_t - i_t d_t\}$$

subject to:

$$d_t = w_t n_t \tag{9}$$

The equilibrium zero-profit condition is

$$p_t h_t - w_t - i_t w_t = 0 \tag{10}$$

The bond market, labor market and goods market equilibrium conditions are

$$\begin{aligned}
\lambda b_t &= d_t \\
\lambda l_t + \lambda^* l_t^* &= n_t \\
\lambda c_t + \lambda^* c_t^* &= h_t n_t
\end{aligned} \tag{11}$$

Let the traders' initial assets a_0 , the non-traders initial assets a_0^* as well as the values of all variables dated at periods earlier than zero be given. An equilibrium is a set of contingent sequences satisfying the definitions (1) and (2), the processes (3) and (4), the agents' constraints and first-order conditions, (5)–(10), and the equilibrium

conditions (11).

3 Methodology

In this section, we describe the methodology used to solve, estimate and evaluate the segmented markets monetary model described in Section 2.

First, we normalize nominal variables by the aggregate cash balances available at the beginning of the period equal to $\lambda a_t + \lambda^* a_t^*$. Then, we compute the non-stochastic steady state, and we log-linearize the system around it. Finally, we define the state vector, s_t , as the 8×1 vector consisting of \hat{i}_t , \hat{h}_t , \hat{a}_t , their lags and the lags of two Lagrange multipliers. Using the invariant subspace method², we derive the linear system of equations describing the equilibrium evolution of the state vector, which we represent as

$$s_t = M_s s_{t-1} + R_s \epsilon_t, \quad (12a)$$

where $\epsilon_t \equiv [\epsilon_{i,t}, \epsilon_{h,t}]'$ is the 2×1 vector of structural shocks, and M_s and R_s are conformable matrices.

The variables of interest in our model are the interest rate that the monetary authority uses as a target for monetary policy, real output, the growth rate of money, and inflation. Therefore, let the data vector x_t be defined as

$$x_t \equiv [\hat{i}_t, \hat{y}_t, \hat{\mu}_t, \hat{\pi}_t]'$$

where \hat{i}_t , $\hat{\mu}_t$ and $\hat{\pi}_t$ are the deviations of the interest rate, the money growth rate and the inflation rate from steady state, while \hat{y}_t is the percentage deviation of output from steady state. The segmented markets model described above imposes restrictions on the relationship between the data vector, x_t , and the state vector, s_t . We represent the linear

²We use MatLab files written by Chris Sims and Paul Klein. We thank them for making the files available at the web address <http://www.ssc.uwo.ca/economics/faculty/klein/>.

system relating the data vector to the state vector as

$$x_t = M_x s_t + R_x \eta_t, \quad (12b)$$

where $\eta_t = [\eta_{\mu,t}, \eta_{\pi,t}]'$ is a 2×1 vector of additional data shocks independent of each other and independent of the structural shocks, and M_x and R_x are conformable matrices. In particular, $\eta_{\mu,t}$ is a shock to the growth rate of money with standard deviation σ_μ , and $\eta_{\pi,t}$ is a shock to the inflation rate with standard deviation σ_π . The matrices M_s and M_x are functions of the structural parameters of the model, and the matrices R_s and R_x are functions of the standard deviations of the structural shocks and the data shocks respectively. The data equation, (12b), and the state equation, (12a), together form the linear state-space (approximate) representation of the model that we use to estimate and evaluate the model.

The inferential problem is twofold: First we want to estimate the structural parameters of the model, and second we want to evaluate various functions of interest, such as the impulse response functions generated by the model. We follow authors such as DeJong, Ingram and Whiteman (1996, 2000), Geweke (1999), Landon-Lane (1998), Schorfheide (2000), and more recently Fernandez-Villaverde and Rubio-Ramirez (2004) and Smets and Wouters (2003), and use Bayesian likelihood methods to answer the inferential problem. The use of likelihood methods brings all the information contained in the observed data to bear on the inferential problem.

We now describe in detail our estimation methodology. Suppose that we observe T observations on our data vector x_t . Let this sample be denoted as $X_T = \{x_t\}_{t=1}^T$. Let θ be a $p \times 1$ parameter vector that includes all the parameters that determine the system matrices in the state-space representation (12). Then, using the Kalman Filter (Harvey 1989, page 104), we can, for any particular value of the parameter vector θ , calculate the value likelihood function for the model given by (12)³. Let $p(X_T|\theta, \mathcal{M})$

³In order to calculate the likelihood function for a state-space model using the Kalman Filter we need

represent that likelihood function of model \mathcal{M} indexed by parameter vector θ .

Let $p(\theta|\mathcal{M})$ represent the prior density that we, the investigators, place over the parameter vector θ that indexes model \mathcal{M} . The prior distribution over the parameters θ represents our beliefs regarding the true values of the parameters of the model, and this acts as a way of imposing non-sample information onto our inferential problem. The information on θ contained in the data is combined with the non-sample information on θ via Bayes' Theorem,

$$p(\theta|X_T, \mathcal{M}) \propto p(\theta|\mathcal{M})p(X_T|\theta, \mathcal{M}). \quad (13)$$

The posterior distribution, $p(\theta|X_T, \mathcal{M})$, contains all information on the value of θ contained in the observed data and all non-sample information on θ supplied by the prior. The inferential problem, described above, boils down to estimating the following expected value:

$$E(g(\theta)|X_T, \mathcal{M}) = \int_{\Theta} g(\theta)p(\theta|X_T, \mathcal{M})d\theta, \quad (14)$$

where $g : \mathbb{R}^p \rightarrow \mathbb{R}^q$ is some well-defined (potentially) vector valued function of θ , and Θ is the domain of θ . In all but very special cases the integral defined in (14) cannot be calculated analytically or, because of the 'curse of dimensionality', cannot be calculated using numerical integration techniques. In these cases we use Markov chain Monte Carlo (MCMC) methods (see Tierney 1994) to simulate N serially correlated draws from $p(\theta|X_T, \mathcal{M})$, $\{\theta_1, \dots, \theta_N\}$. Then as long as $E(g(\theta)|X_T, \mathcal{M}) = \bar{g} < \infty$ and

to make an assumption about the initial value of the state vector, s_0 . In what follows we treat the initial value of the state vector as a parameter of the model rather than using the steady state values of the state vector and the covariance matrix of the state vector as the initial conditions of the filter.

$E(g(\theta) - E(g(\theta))^2 | X_T, \mathcal{M}) = \sigma_g^2 < \infty$ then

$$\begin{aligned}\bar{g}(N) &= \frac{1}{N} \sum_{j=1}^N g(\theta_j) \xrightarrow{a.s.} \bar{g} \\ \sigma_g^2(N) &= \frac{1}{N} \sum_{j=1}^N (g(\theta_j) - \bar{g}(N))^2 \xrightarrow{a.s.} \sigma_g^2.\end{aligned}\tag{15}$$

Examples of functions that we use in this paper are the indicator function that selects one of the elements of θ and the impulse response function of an element of the data vector to a structural shock.

4 Data and Prior Distributions

The data are obtained from the FRED II database⁴. All series are seasonally adjusted quarterly data for the period 1982:IV–2003:IV. During that period, it is commonly agreed that the monetary authority followed a Taylor interest rate rule, although not necessarily the benchmark specification (3) that we adopt. The four data series that we use to estimate the model are the federal funds rate, real GDP, M1, and the GDP deflator. The interest rate, the money growth rate and the inflation rate are all expressed in annualized percentage points.

The state-space representation (12) makes predictions over the deviations from the non-stochastic steady state. To convert the data into deviations, we detrend the data using a linear trend with endogenously chosen breaks. The break points are chosen using the Quandt (1960) likelihood ratio test with the critical values reported in Andrews (1993). We choose this detrending method instead of using the Hodrick-Prescott or the Baxter-King filters in order to maintain the high frequency information of the data. An alternative to our method of using a linear trend with endogenous breaks is using a high-pass Butterworth-type filter, which only eliminates the low frequency components

⁴<http://research.stlouisfed.org/fred2/>

of the data. When we use this alternative detrending method, our estimates are only slightly affected and our main conclusions remain. We report the results obtained with the linear detrending method since it is somewhat more transparent.

With regard to our choices for the prior distributions, we distinguish three types of “free” parameters: the structural (or deep) parameters, the standard deviations of the shocks, and the initial values for the state s_0 . The prior distributions for the first two types are reported in Table 1.

Table 1: Prior Distribution for Structural Parameters

Parameter	Distribution	Mean	Std. dev.	95 % IQR
λ	Beta	0.350	0.1438	[0.102 0.661]
β	Beta	0.990	0.0044	[0.980 0.997]
φ	Log-Normal	1.057	0.8636	[0.205 3.302]
γ	Normal	2.000	0.4000	[1.196 2.783]
ρ_i	Beta	0.850	0.0355	[0.773 0.913]
κ_π	Log-normal ^a	1.758	0.1536	[1.500 2.101]
κ_y	Log-Normal	0.502	0.0758	[0.370 0.665]
ρ_h	Beta	0.900	0.0655	[0.738 0.987]
σ_i	Log-Normal	2.000	2.7024	[0.169 8.668]
σ_h	Log-Normal	2.000	2.7024	[0.169 8.668]
σ_μ	Log-Normal	2.000	2.7024	[0.169 8.668]
σ_π	Log-Normal	2.000	2.7024	[0.169 8.668]

^adefined on $[1, \infty]$

The key structural parameter is λ , the proportion of traders. To choose a prior for λ , we consider evidence from the Survey of Consumer Finances of 1992, which is the mid-year in the sample period. Kennickell and Starr-McCluer (1994) report the following data: The percentage of households having transaction accounts is 87.5%, having retirement accounts is 39.3%. The percentage investing in CD’s is 16.6%, in mutual funds 11.2%, in stocks 17.8%, in bonds 4.7%. It is arguable what set of financial assets should be considered as the empirical counterparts of the model’s bonds. Transaction accounts, however, such as checking and savings accounts, are usually considered money, not bonds.

In addition, we notice that in the model the traders are the households *actively* trading in financial markets, adjusting their portfolios of money and bonds in response to monetary policy shocks and technology shocks. Households which simply invest in financial assets without frequently adjusting their portfolios should not be considered as traders. Hence, the fraction λ of traders should be much lower than the fraction of households investing in financial assets, to which the above data from the Survey of Consumer Finances refer. With these considerations in mind, we choose a substantially loose prior for λ with a mean of 0.35 and a 95% prior coverage interval of $[0.1, 0.65]$.

Proceeding with the other structural parameters, the prior for β , the quarterly preferences discount factor, has a mean equal to 0.99 and a 95% prior coverage interval of $[0.98, 0.997]$, consistently with common values used in macroeconomic studies. Notice that, in the non-stochastic steady state, the real interest rate is equal to the preferences discount rate, so this prior reflects a range of annualized real interest rates from 1.2% to 8% with a mean interest rate of 4%.

The parameter φ is the inverse of the elasticity of labor supply to the real wage. There is a wide range of evidence about this elasticity in the literature. The microeconomic evidence tends to suggest that the elasticity is lower than 1, implying a large value for φ . The theoretical contributions of Hansen (1985) and Rogerson (1988), however, show that very large values for the elasticity of the aggregate labor supply, and hence small values for φ , are consistent with a small or unitary value for the elasticity of the individual labor supply. For these reasons, we choose a relatively loose prior for φ with a mean approximately equal to 1, and a 95% prior coverage interval of $[0.2, 3.4]$.

The parameter γ is the common annualized growth rate of all nominal variables in the non-stochastic steady state, including money and prices. Since the monetary transfers $\lambda\tau_t$ represent the only changes in the money supply, the steady state money growth rate γ is equal to the steady state ratio of the monetary transfers to the beginning-of-period aggregate cash balances times 400. Also, by the Fisher equation, the sum of the steady

state inflation rate γ and the steady state real interest rate is equal to the steady state nominal interest rate. The mean of the prior for γ is set to be 2%, which is the value commonly considered as the target level of the monetary authority for the inflation rate. The 95% prior coverage interval runs from 1.2% to 2.8%.

We set the priors for the parameters of the Taylor interest rate rule, (3), based on other empirical studies which use substantially different methodologies. In his original contribution, Taylor (1993) argues that the behavior of the monetary authority after 1987 is well characterized by an interest rate rule with $\rho_i = 0$, $\kappa_\pi = 1.5$ and $\kappa_y = 0.5$. In a very influential recent study, Clarida, Gali and Gertler (2000) estimate a forward-looking Taylor interest rate rule for the period 1982:IV–1996:IV, and obtain a large interest rate autocorrelation $\rho_i = 0.79$, a large response to inflation deviations $\kappa_\pi = 2.15$, and a large response to output percentage deviations $\kappa_y = 0.93$. We then choose a prior for the quarterly first-order autocorrelation ρ_i with a 95% prior coverage interval of $[0.77, 0.91]$, a prior for the response coefficient to inflation deviations κ_π with a 95% prior coverage interval of $[1.5, 2.1]$, and a prior for the response coefficient to output percentage deviations κ_y with a 95% prior coverage interval of $[0.37, 0.67]$.

The last structural parameter is the quarterly first-order autocorrelation of the technology ρ_h , for which we choose a prior with mean equal to 0.9 and a 95% prior coverage interval running from 0.75 to 0.99. The prior is consistent with common values used in the real business cycle literature.

The second set of parameters are the standard deviations of the two structural shocks σ_i and σ_h and the standard deviations of the two data shocks σ_μ and σ_π . We choose a prior relatively flat and uninformative for all standard deviations. The prior has mean equal to 2 and a 95% prior coverage interval of $[0.169, 8.668]$.

The last set of parameters are the initial values for the state s_0 . These are treated as parameters of the system to be estimated. The priors for these parameters are independent Normal with mean 0 and variance 1. The very large variance has been chosen

to reflect prior uncertainty over the initial values for the state.

5 Results

In this section, we report the results from estimating the state-space representation (12) using Bayesian methods with the priors described in Section 4. We then comment on the ability of the model to replicate the impulse response functions to monetary policy shocks documented in the empirical literature, and we show that the model performance improves as the length of a period in the model increases. We finally compare the estimation results for the periods 1960:I–1979:II and 1982:IV–2003:IV with the aim of contributing to the research over the likely reasons for the different macroeconomic performances during the two periods.

5.1 Estimation Results

Table 2 reports the results of the estimation for the period 1982:IV–2003:IV. The model is estimated using a random-walk Hastings-Metropolis (RWHM) chain⁵. The results reported were obtained using 100,000 draws from a RWHM chain and in all cases the numerical standard error of all our estimates were less than 5% of the reported posterior standard errors.

Our first result is that a likelihood comparison strongly favors the segmented markets model over the full participation model. The difference between the log marginal likelihoods is approximately 9 in favor of the segmented markets model, implying a ratio between the marginal likelihoods in the order of e^9 .

Turning to the estimates of some key parameters, the point estimate of λ , the fraction of traders, is 16%. Recalling that the traders are the households that not only invest but also actively trade in bonds in response to the economy's shocks, the estimate

⁵See Tierney (1993) for a discussion on how to implement this particular Markov chain Monte Carlo procedure, and Landon-Lane (1998) for its application to DSGE models.

Table 2: Posterior moments (Quarterly data 1982:IV–2003:IV)

Parameter	Segmented Markets			Full Participation		
	Mean	Std. dev.	95% IQR	Mean	Std. dev.	95% IQR
λ	0.162	0.0383	[0.091 0.239]	—	—	—
β	0.993	0.0036	[0.984 0.998]	0.992	0.0040	[0.983 0.998]
φ	0.024	0.0066	[0.013 0.038]	0.046	0.0169	[0.020 0.085]
γ	1.876	0.4109	[1.068 2.677]	1.931	0.3966	[1.148 2.694]
ρ_i	0.599	0.0350	[0.527 0.664]	0.571	0.0347	[0.503 0.637]
κ_π	3.469	0.3903	[2.784 4.313]	3.456	0.3995	[2.770 4.326]
κ_y	0.309	0.0418	[0.236 0.402]	0.303	0.0396	[0.233 0.388]
ρ_h	0.998	0.0017	[0.994 1.000]	0.998	0.0015	[0.994 1.000]
σ_i	1.162	0.0018	[1.006 1.353]	1.164	0.0020	[1.010 1.346]
σ_h	0.755	0.0068	[0.635 0.900]	0.767	0.0058	[0.664 0.892]
σ_μ	5.148	0.0211	[4.466 5.955]	5.241	0.0389	[4.547 6.079]
σ_π	0.997	0.1533	[0.842 1.197]	0.999	0.1459	[0.848 1.179]
log ML	-693.99 (0.160)			-703.12 (0.088)		

seems consistent with the previously cited data from the Survey of Consumer Finances, which refer to the percentage of households investing, not necessarily trading, in each category of assets.

The point estimate of φ is 0.024, implying a very large elasticity of the aggregate labor supply to the real wage rate. Several studies find that models where the elasticity of the aggregate labor supply is large better match macroeconomic data. Indeed, the real models of Hansen (1985) and Christiano and Eichenbaum (1992b) and the monetary model of Cooley and Hansen (1989) adopt the indivisible-labor assumption which implies a utility function linear in labor, and so infinite elasticity.

With regard to the interest rate rule, it is helpful to compare the results of our estimation with the ones of Clarida, Gali and Gertler (2000), although this comparison should be treated with caution primarily because their Taylor rule is forward-looking while ours is not. The results are qualitatively similar, but quantitatively we find a smaller autocorrelation for the interest rate $\rho_i = 0.6$, a larger response coefficient to

inflation deviations $\kappa_\pi = 3.47$, and a smaller response coefficient to output deviations $\kappa_y = 0.31$.

The estimate of the first-order autocorrelation ρ_h of the percentage deviation of the technology shock is very close to 1, suggesting that the technology shock has a permanent impact on the economy.

5.2 Response to monetary policy shocks

The above likelihood comparison suggests that there is strong statistical evidence that the segmented markets model is a better model at explaining the observed data than the full participation model. An important question, however, is whether the segmented markets model makes reliable economic, or qualitative, predictions, and is a suitable framework for empirical monetary analysis. Christiano, Eichenbaum and Evans (1999) argue that comparing the model response to monetary policy shocks with the empirical response is an important criterion for selecting a framework for monetary analysis. Following their argument, we compare the model impulse response function with the empirical impulse responses documented in their article. We anticipate that referring to the empirical impulse responses documented in other VAR studies, like Leeper, Sims and Zha (1996), and Bernanke and Mihov (1998) would lead us to similar conclusions.

Figure 2 in Christiano, Eichenbaum and Evans (1999) documents the empirical impulse responses to a contractionary monetary policy shock. The shock has a positive impact effect on the federal funds rate of about 75 basis points, and the effect vanishes within 1 year. The response of output is ‘hump-shaped’: Output decreases over time with a trough after six quarters of -0.5%, and then increases back to its steady state. The impact effect on M1 is slightly less (in absolute values) than -0.1%. The response of prices is not statistically significant. Stated differently, the impact effect on the annualized M1 growth rate is less than -0.4%, while the impact effect on the inflation rate is approximately zero. The M1 growth rate is negative for three quarters.

The two columns of figure 1 show respectively the impulse response functions to a contractionary monetary policy shock for the segmented markets model and the full participation model.

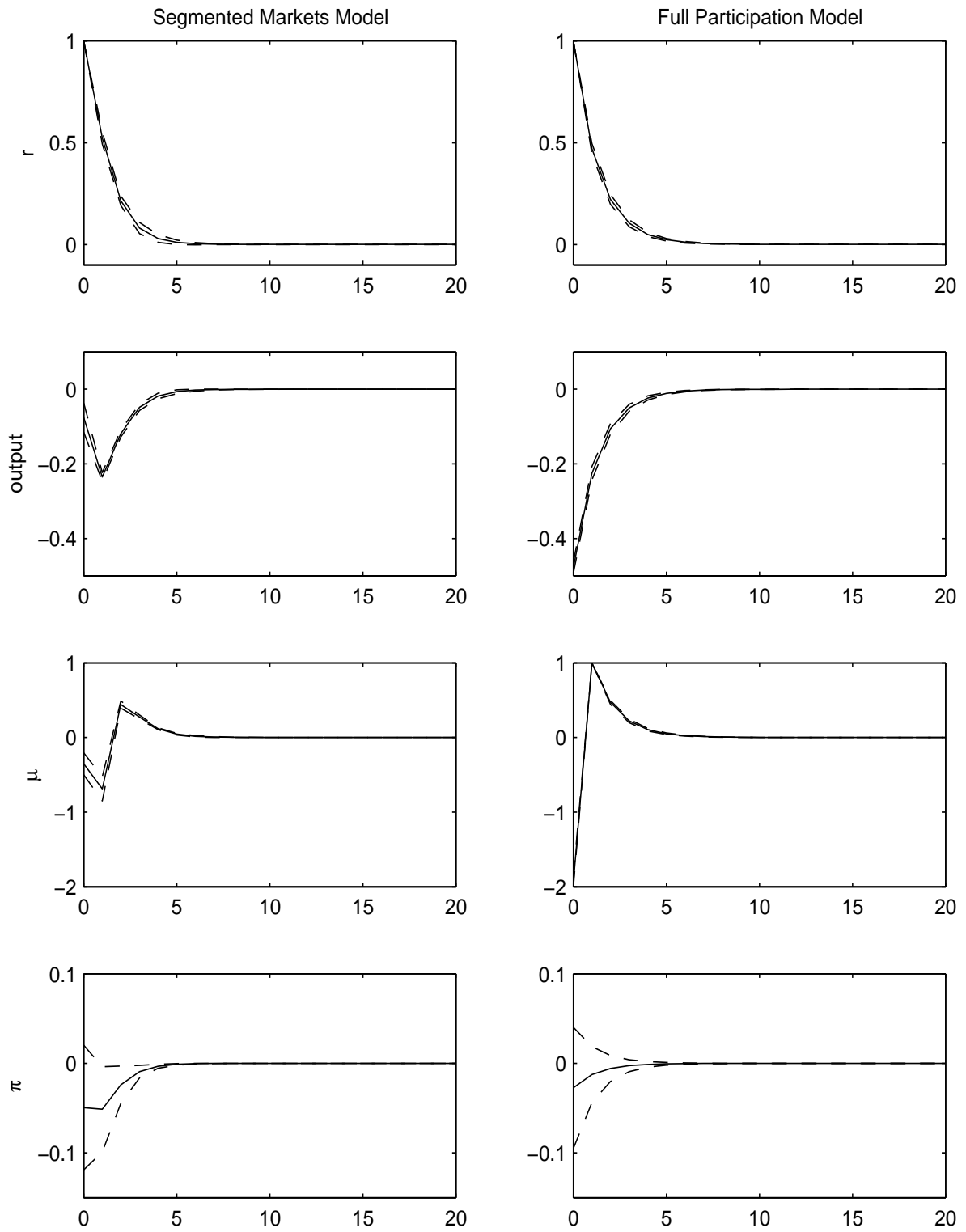
The response of the interest rate is similar in the two models. The interest rate increases by 1% in the impact period and returns to steady state within 1 year.

With regard to output, while in the full participation model output decreases immediately by -0.45% and returns monotonically to steady state, in the segmented markets model output decreases immediately by -0.1%, reaches a trough of -0.25% in the second period, and then returns monotonically to steady state. The segmented markets model is able to replicate the ‘hump-shaped’ response of output to monetary policy shocks without other assumptions or frictions that are able to enhance the persistence and the delay of the model response, like sticky behavior or information, adjustment costs, habit persistence or dynamic capital accumulation (time to build). Even though the trough occurs after only one period, the ability of the benchmark segmented markets model to replicate the delayed response of output has to be regarded as an important point in favor of the segmented markets framework relative to other monetary frameworks like sticky prices and limited participation. The magnitude of the output response is smaller than in the data but we show below that the magnitude increases substantially as the length a period in the model increases.

Turning to the responses of the other variables, while in the full participation model the response of the money growth rate is negative for only one period, in the segmented markets model it is negative for two periods, closer to the data. In the segmented markets model, the trough of the response occurs in the second period, and the magnitude of the response is smaller and more realistic. For both models, the response of the inflation rate is negative but small and not statistically significant.

Having regard to the sign, the magnitude and the persistence, the impulse response function generated by the segmented markets model is consistent with data.

Figure 1: Impulse Response Function to Monetary Policy Shocks (Quarterly data 1982:IV–2003:IV)



5.3 Three effects of a monetary policy shock

To help intuition on the dynamics of the impulse response function, we now distinguish three separate effects that a monetary policy shock has on segmented markets economies.

The first effect, which is present both with markets segmentation and full participation, is the negative effect of an increase in the interest rate on output. The effect is revealed using the the traders' first-order conditions, (6), and the firms' zero-profit condition, (10), to obtain

$$\begin{aligned}\frac{\phi l_t^\varphi}{c_t^{-1}} &= \frac{w_t}{p_t} \frac{1}{1+i_t} \\ \frac{w_t}{p_t} &= \frac{h_t}{1+i_t}\end{aligned}$$

The first equation states that the marginal rate of substitution between consumption and leisure increases with the real wage and decreases with the interest rate. The second equation states that, in turn, the real wage decreases with the interest rate. Hence, an increase in the interest rate increases the relative price of consumption relative to leisure both directly and indirectly through the real wage. The resulting equilibrium levels of consumption and labor decrease. To derive this last conclusion immediately, let us focus on the full participation case, where all households are traders. In this case, since $\lambda = 1$, the labor and goods market equilibrium conditions imply that $c_t = h_t l_t$. Then, the previous equations imply

$$\phi l_t^{1+\varphi} = \frac{1}{(1+i_t)^2} \tag{16}$$

so aggregate labor and output decrease as the interest rate increases.

The second effect that a monetary policy shock has is the limited participation liquidity effect originally described by Grossman and Weiss (1983) and Rotemberg (1984), and then by Lucas (1990), Fuerst (1992), Alvarez and Atkeson (1996), and Occhino (2004). When markets are segmented, after a contractionary monetary policy

shock, the real interest rate increases above fundamentals, possibly leading to an inverse relation between the nominal interest rate and the money supply. The lower the fraction of traders λ , the stronger the liquidity effect. The effect can be best described by focusing on a simple segmented markets model with constant output, exogenous money supply and endogenous nominal interest rate. In the case that the velocity of money is constant, the inflation rate is determined by the exogenous money supply process. Then, a decrease in the aggregate money supply decreases the traders' cash balances and consumption, and increases the expected traders' consumption growth rate. The traders' Euler equation implies that the real interest rate increases above fundamentals. If the real interest rate increase outweighs the expected inflation increase, the Fisher equation implies that the nominal interest rate increases, leading to the inverse relation between the nominal interest rate and the money supply.

The third effect that a monetary policy shock has on segmented markets economies is the 'hump-shape' response of output. From the non-traders' constraints and first-order conditions, (7) and (8), we obtain

$$\begin{aligned}\nu_t^{2*} &= E_t[\nu_{t+1}^{1*}] \\ \phi l_t^{*\varphi} / w_t &= E_t[\beta / (p_{t+1} c_{t+1}^*)] \\ \phi l_t^{*\varphi} / w_t &= \beta / a_{t+1}^* \\ \phi l_t^{*\varphi} / w_t &= \beta / w_t l_t^* \\ \phi l_t^{*1+\varphi} &= \beta\end{aligned}$$

so the non-traders' labor supply is constant, and the aggregate labor supply is determined by the traders' labor supply only. Then, from the traders' first-order conditions, (6), using the firms' zero profit condition, (10), and log-linearizing around the non-stochastic steady

state, we obtain

$$\begin{aligned}
\nu_t^2 &= E_t[\nu_{t+1}^1] \\
\nu_t^2 &= E_t[\nu_{t+1}^2(1 + i_{t+1})] \\
\phi l_t^\varphi / w_t &= E_t[\beta \phi l_{t+1}^\varphi (1 + i_{t+1}) / w_{t+1}] \\
\phi l_t^\varphi (1 + i_t) / p_t h_t &= E_t[\beta \phi l_{t+1}^\varphi (1 + i_{t+1})^2 / p_{t+1} h_{t+1}]
\end{aligned}$$

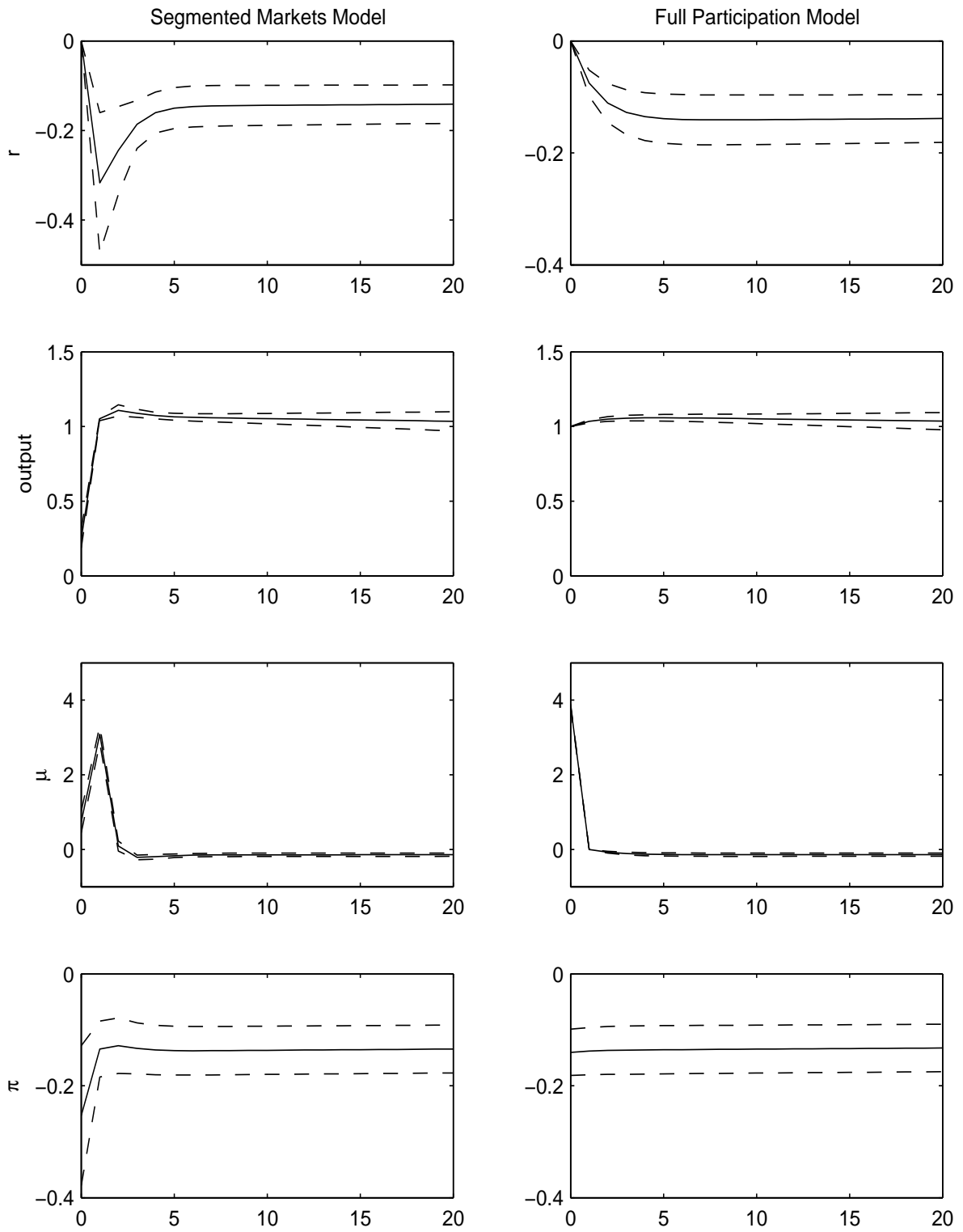
$$\varphi(E_t \hat{l}_{t+1} - \hat{l}_t) + 2(E_t \hat{i}_{t+1} - \hat{i}_t) - (E_t \hat{h}_{t+1} - \hat{h}_t) + (\hat{i}_t - E_t \hat{\pi}_{t+1}) = 0$$

where \hat{l}_t and \hat{h}_t are percentage deviations from steady state, while \hat{i}_t and $\hat{\pi}_t$ are deviations from steady state. For simplicity, consider the case that the interest rate is exogenous ($\kappa_\pi = \kappa_y = 0$). Since both \hat{h}_t and \hat{i}_t are exogenous, the last equation shows that the higher the real interest rate $\hat{i}_t - E_t \hat{\pi}_{t+1}$, the lower the expected traders' labor growth rate $E_t \hat{l}_{t+1} - \hat{l}_t$. Recall that, in segmented markets economies, the liquidity effect of a contractionary monetary policy shock increases the real interest rate above fundamentals. Then, the expected traders' labor growth rate decreases, and so does the expected aggregate labor growth rate. If markets are segmented enough, the liquidity effect is so strong that the expected aggregate labor growth rate is negative, and the trough in the response of aggregate labor and output occurs some periods after the shock.

5.4 Response to technology shocks

The two columns of Figure 2 show respectively the impulse response functions to an expansionary technology shock for the segmented markets model and the full participation model. In both models, the shock has approximately permanent effects since the estimated first-order autocorrelation ρ_h of the percentage deviation of technology is very close to 1.

Figure 2: Impulse Response Function to Technology Shocks (Quarterly data 1982:IV–2003:IV)



The responses of all variables are more delayed in the segmented markets model. After the first five quarters, however, the two impulse response functions are very similar. After an expansionary technology shock, output increases by about 1%, and the inflation rate decreases by about -0.15% per year. Since the velocity of money is identically equal to one, the money growth rate is approximately equal to the sum of the output growth rate and the inflation rate, so the money growth rate sharply increases in the impact period, and rapidly decreases toward the inflation rate level. The estimated Taylor interest rate rule implies that the interest rate decreases, mainly due to the large estimated response coefficient to inflation deviations κ_{π} .

5.5 Semester periods

We have seen earlier that the magnitude of the output response to monetary policy shocks is smaller in the segmented markets model than in the data. In this section, we emphasize that the magnitude increases substantially as the length of a period in the model increases.

As in Cooley and Hansen (1989), the period length plays an important role because of the presence of cash-in-advance constraints. To see why, notice that an increase in the interest rate affects the economy by increasing the cost of holding cash balances. Also, the cash-in-advance constraints imply that the longer the period, the larger the stock of cash balances that households need to hold relative to their consumption flow, and the larger the stock of cash balances that firms need to hold relative to their cost of wages flow. Then, the effect of a given increase in the annualized interest rate on interest costs increases proportionally to the period length. As a result, the longer the period, the larger the impact of a given increase in the annualized interest rate on aggregate labor and output.

For instance, in the full participation case, after log-linearizing the equilibrium

equation (16) around the steady state, we obtain

$$(1 + \varphi)\hat{l}_t = -2\hat{i}_t$$

Notice that \hat{i}_t is the deviation of the period interest rate from steady state. For given deviation of the annualized interest rate, \hat{i}_t is proportional to the period length. Hence, for given deviation of the annualized interest rate, the percentage deviation \hat{l}_t of the labor supply from steady state is proportional to the period length.

To assess the potential of the segmented markets model at replicating the output response to monetary policy shocks, we estimate the model setting the period length equal to one semester, and using semester data for the period 1983–2003, the same as in the previous section. The priors are the same as the ones reported in Table 1, except that the parameters which depend on the period length, β , ρ_i and ρ_h , are modified accordingly.

Table 3 reports the estimation results, while Figures 3 and 4 show the impulse response functions to monetary policy shocks and technology shocks. For comparison with the other figures, the units of the x-axis are still quarters. Both the estimates and the impulse response functions are consistent with most observations made in the previous section. This time, however, the segmented markets model generates a much more realistic output response to monetary policy shocks. After a contractionary monetary policy shock, output decreases by -0.2% in the impact period, and reaches a trough of -0.45% in the second semester. The magnitude of the output response is about right. The output response is still ‘hump-shaped’, and the trough of the response occurs after one semester.

5.6 Pre-1979 period

There is ongoing research over the question whether monetary policy has been different before 1979 and after 1982, and whether the monetary authority has been responsible

Figure 3: Impulse Response Function to Monetary Policy Shocks (Semester Data 1983:1–2003:2)

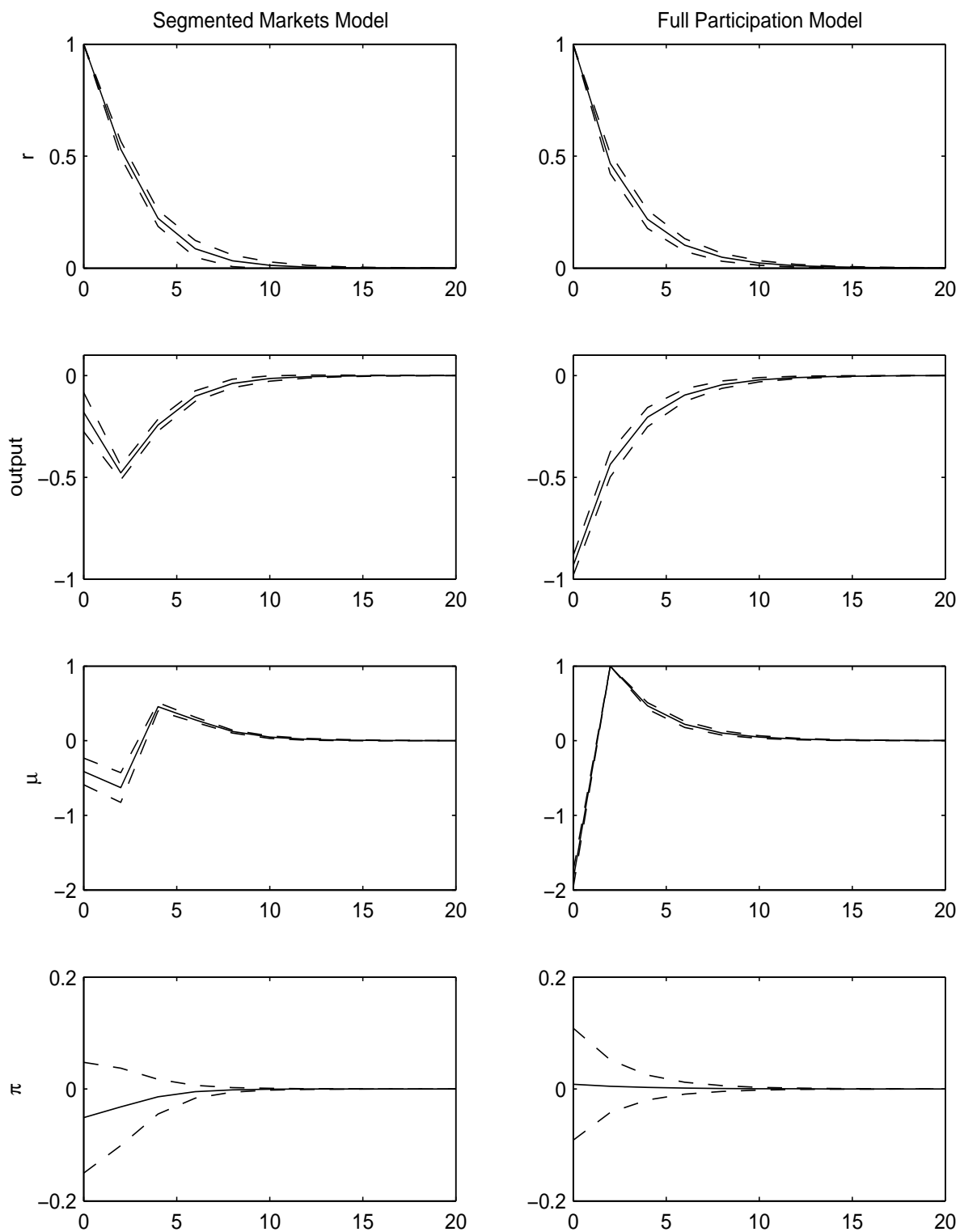


Figure 4: Impulse Response Function to Technology Shocks (Semester Data 1983:1-2003:2)

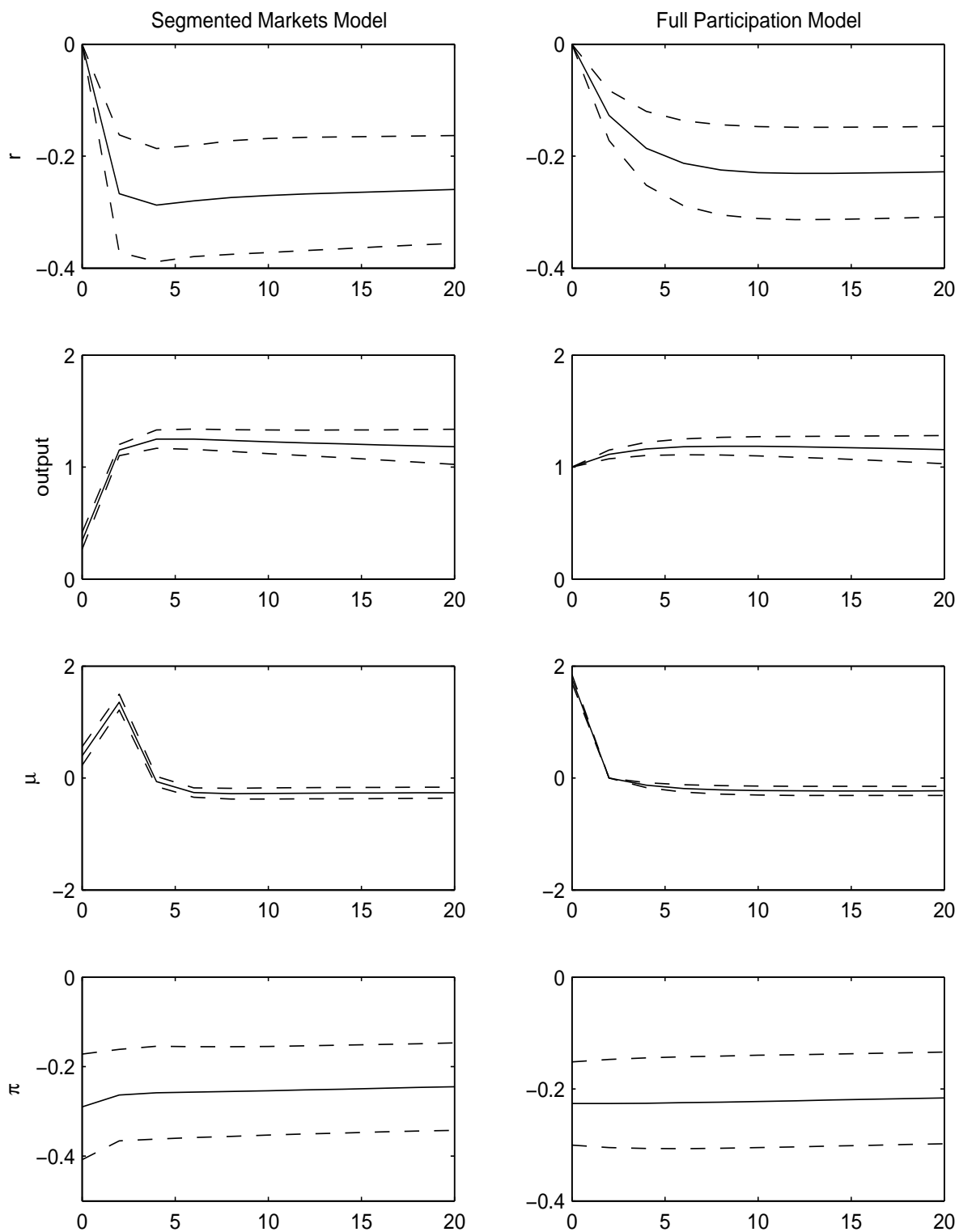


Table 3: Posterior moments (Semester data 1983–2003)

Parameter	Segmented Markets			Full Participation		
	Mean	Std. dev.	95% IQR	Mean	Std. dev.	95% IQR
λ	0.185	0.0465	[0.102 0.281]	—	—	—
β	0.992	0.0037	[0.983 0.998]	0.992	0.0040	[0.982 0.998]
φ	0.028	0.0094	[0.012 0.048]	0.071	0.0295	[0.028 0.143]
γ	1.868	0.4025	[1.076 2.668]	1.899	0.4060	[1.082 2.682]
ρ_i	0.781	0.0204	[0.739 0.820]	0.766	0.0210	[0.724 0.806]
κ_π	2.827	0.2796	[2.351 3.449]	2.934	0.2973	[2.425 3.575]
κ_y	0.362	0.0485	[0.279 0.468]	0.346	0.0468	[0.265 0.452]
ρ_h	0.996	0.0039	[0.986 1.000]	0.997	0.0030	[0.989 1.000]
σ_i	1.424	0.0019	[1.164 1.764]	1.434	0.0020	[1.161 1.784]
σ_h	1.284	0.0166	[1.008 1.655]	1.544	0.0161	[1.267 1.899]
σ_μ	4.489	0.0281	[3.666 5.477]	4.486	0.0535	[3.677 5.501]
σ_π	1.103	0.1503	[0.866 1.431]	1.088	0.1512	[0.853 1.406]
log ML	-391.77 (0.293)			-394.10 (0.084)		

in part for the greater macroeconomic instability of the earlier period. Most recently, Clarida, Gali and Gertler (2000) estimate a forward-looking Taylor interest rate rule in the two periods, and find that the monetary authority has been much less aggressive against inflation in the earlier period. Since the estimated interest rate rule in the earlier period may lead to equilibrium indeterminacy, they argue that the monetary authority may have been responsible in part for the poor macroeconomic performance of the Seventies. On the other hand, Sims and Zha (2005) estimate a structural VAR, and find that the monetary policy rule has not been substantially different between the two periods, and they attribute the greater macroeconomic instability of the earlier period to the larger volatilities of the structural shocks.

With the aim at contributing to the research on the issue, we report the estimation results for the period 1960:I–1979:II in Table 4, and we compare them with the estimation results for the period 1982:IV–2003:IV. As in Clarida, Gali and Gertler (2000), we drop the period 1979:III–1982:III because it is commonly agreed that the newly appointed Fed

Chairman Volcker did not follow a Taylor interest rate rule during that period. To make the comparison transparent, we choose to adopt the same priors for the earlier period as for the later period, although, in doing so, we obviously need to disregard differences in our prior information.

Table 4: Posterior moments (Quarterly data 1960:I–1979:II)

Parameter	Segmented Markets			Full Participation		
	Mean	Std. dev.	95% IQR	Mean	Std. dev.	95% IQR
λ	0.125	0.0333	[0.067 0.195]	—	—	—
β	0.993	0.0036	[0.984 0.998]	0.992	0.0040	[0.983 0.998]
φ	0.019	0.0055	[0.010 0.031]	0.046	0.0170	[0.020 0.086]
γ	1.856	0.4106	[1.034 2.651]	1.909	0.4171	[1.086 2.730]
ρ_i	0.560	0.0367	[0.486 0.632]	0.540	0.0384	[0.463 0.615]
κ_π	2.866	0.3118	[2.333 3.549]	2.876	0.3200	[2.332 3.565]
κ_y	0.357	0.0473	[0.273 0.457]	0.341	0.0477	[0.258 0.443]
ρ_h	0.997	0.0026	[0.990 1.000]	0.998	0.0022	[0.992 1.000]
σ_i	1.318	0.1056	[1.131 1.541]	1.396	0.1144	[1.183 1.634]
σ_h	1.200	0.1116	[1.006 1.439]	1.109	0.0879	[0.952 1.294]
σ_μ	4.309	0.3482	[3.703 5.063]	4.312	0.3624	[3.671 5.111]
σ_π	1.615	0.1425	[1.363 1.924]	1.678	0.1436	[1.427 1.990]
log ML	-689.84			-692.75		
	(0.143)			(0.730)		

Consistent with data on market participation, the estimate of the proportion of traders λ is lower than for the later period. We notice that a lower value for λ implies a more delayed output response to monetary policy shock, which is qualitatively consistent with the findings of Boivin and Giannoni (2002), although quantitatively the amount of delay is small.

With regard to the interest rate rule, we estimate a larger first-order autocorrelation ρ_i for the earlier period than for the later period, a smaller response coefficient to inflation deviations κ_π , and a larger response coefficient to output deviations κ_y . Relative to Clarida, Gali and Gertler (2000), however, the difference between the estimated interest rate rule in the two periods is much less pronounced. Moreover, the estimated

coefficients are far from the region leading to equilibrium indeterminacy.

Finally, the estimates of the volatilities σ_i and σ_h of the two structural shocks are larger in the earlier period than in the later period. The estimated volatility of the technology shock σ_h is substantially larger (1.2 relative to 0.755), while the estimated volatility of the monetary policy shock σ_i is only slightly larger (1.318 relative to 1.162).

We interpret the above results as suggesting that the larger volatilities of the structural shocks have been an important cause of the greater macroeconomic instability in the earlier period. In particular, the volatility of the technology shock has played a more important role than the volatility of the monetary policy shock. With regard to the estimated interest rate rule, we find that the monetary authority has paid more attention to output deviations and less to inflation deviations in the earlier period than in the later period. For both periods, however, our estimates of the monetary policy rule are far from the region leading to equilibrium indeterminacy.

6 Conclusion

In this paper, we proposed a segmented markets model with endogenous production and evaluated it as a framework suitable for empirical monetary analysis. The model was estimated using Markov chain Monte Carlo methods and then was compared, both quantitatively and qualitatively, to a benchmark full participation monetary model.

The quantitative comparison was performed using Bayesian model comparison methods. We concentrated our analysis on the period after the Volcker disinflation and found that the Bayes factor was very much in favor of the segmented markets model that we propose over the benchmark full participation model. As the Bayes factor represents the relative out-of-sample prediction performance of the two models, this implies that the segmented markets model is a more appropriate model, in an out-of-sample prediction sense, for explaining the observed data than the benchmark model. We then estimated

and compared the segmented markets model to the full participation model using data from the 1960's and 1970's up until the start of the Volcker disinflation period. The results were similar to the results from the 1980's and 1990's in that the segmented markets model had a superior statistical fit than the full participation model.

While it is important for a model to have superior statistical properties, it is equally important that the model makes economic sense. Christiano, Eichenbaum and Evans (1999) argue that comparing a model's response to monetary policy shocks with the empirical response is an important criterion for selecting a framework for monetary analysis. Following their suggestion, we estimated the model's impulse responses of the endogenous variables to monetary policy shocks, and compared them to those reported in the empirical literature. We found that the impulse responses generated by the segmented markets model were qualitatively superior to those from the benchmark full participation model. In the segmented markets model all variables responded to a monetary policy shock with delay. The response of output, in particular, was 'hump-shaped'. The money growth rate and the interest rate moved in opposite directions for two periods, similarly to data. On the contrary, there was no delay in the impulse response function of the full participation model. Having regard to the sign, the magnitude and the persistence, the impulse response functions generated by the segmented markets model were consistent with data.

As part of the comparison and evaluation, we estimated several structural parameters that are of interest. We estimated the fraction of households actively trading in financial markets to be small, around 15 percent. We found that this fraction has increased over time, implying that the economy has responded to monetary policy with slightly less delay in the later period than in the earlier period. The labor supply elasticity was estimated to be large, around 40, which concords with estimates from the macroeconomic literature, and we found that the technology process contained a unit root.

We also estimated a Taylor interest rate rule for both the pre-1979 and post-1982 periods, and found that the estimates were stable across the periods. The estimate for the coefficient on inflation was higher for the later period suggesting that the monetary authority had a tougher stance on inflation after 1982. Our estimates of the Taylor rule were consistent with equilibrium determinacy in both periods. However, we did find that the volatilities of the structural shocks, especially the technology shock, were higher in the pre-1979 period, suggesting that the higher volatility in the observed data before 1979 could be due to the economy being hit with larger structural shocks rather than the monetary authority following looser monetary policy. This result is indicative of how the segmented markets approach can contribute with a complementary perspective to the monetary policy debate.

In conclusion, we found that the segmented markets friction vastly improves the statistical out-of-sample prediction performance of the model, and generates delayed and realistic impulse response functions to monetary policy shocks. This suggests that a segmented markets model, like the one proposed in this paper, could be adopted as an additional tool for positive and normative monetary analysis.

References

- [1] Alvarez, F., Atkeson, A., and Edmond, C. (2003). “On the Sluggish Response of Prices to Money in an Inventory-Theoretic Model of Money Demand,” *NBER Working Paper* No. 10016.
- [2] Alvarez, F., Atkeson, A., and Kehoe, P. J. (2002). “Money, Interest Rates and Exchange Rates with Endogenously Segmented Markets,” *Journal of Political Economy* **110(1)**, 73–112.
- [3] Alvarez, F., Lucas, R. E. Jr., and Weber, W. (2001). “Interest Rate and Inflation,” *American Economic Review, (Papers and Proceedings)* **91(2)**, 219–225.

- [4] Andrews, D.W.K. (1993) “Tests for Parameter Instability and Structural Change with Unknown Change Point,” *Econometrica* **61(4)**, 821–856.
- [5] Bernanke, B. S., and Mihov I. (1998). “Measuring Monetary Policy,” *Quarterly Journal of Economics* **113(3)**, 869–902.
- [6] Bilbiie, F. O. (2004). “The Great Inflation, Limited Assets Markets Participation and Aggregate Demand,” Manuscript.
- [7] Boivin, J, and Giannoni M. (2002). “Assessing Changes in the Monetary Transmission Mechanism: A VAR Approach” *Federal Reserve Bank of New York Economic Policy Review* **8(1)**, 97–111.
- [8] Christiano, L. J., and Eichenbaum. M. (1992a). “Liquidity Effects and the Monetary Transmission Mechanism,” *American Economic Review (Papers and Proceedings)* **82(2)**, 346–353.
- [9] Christiano, L. J., and Eichenbaum. M. (1992b). “Current Real-Business-Cycle Theories and Aggregate Labor Market Fluctuations,” *American Economic Review* **82(3)**, 430–450.
- [10] Christiano, L. J., Eichenbaum, M., and Evans, C. L. (1999). “Monetary Policy Shocks: What Have we Learned and to What End?” in Taylor, J. B., and Woodford, M., Editors (1999). *Handbook of Macroeconomics* **1A**, 65-148, North-Holland.
- [11] Clarida, R., Gali, J., and Gertler, M. (2000). “Monetary Policy Rules And Macroeconomic Stability: Evidence And Some Theory,” *The Quarterly Journal of Economics* **115 (1)**, 147–180.
- [12] Cooley, T. F., and Hansen, G. D. (1989). “The Inflation Tax in a Real Business Cycle Model,” *American Economic Review* **79(4)**, 733–748.

- [13] DeJong, D., Ingram, B., and Whiteman, C. (1996). “A Bayesian Approach to Calibration,” *Journal of Business and Economic Statistics* **14(1)**, 1–9.
- [14] DeJong, D., Ingram, B., and Whiteman, C. (2000). “A Bayesian Approach to Dynamic Macroeconomics.” *Journal of Econometrics* **98(2)**, 203–223.
- [15] Fernandez-Villaverde, J., and Rubio-Ramirez, J. F. (2004). “Comparing Dynamic Equilibrium Models to Data: A Bayesian Approach,” *Journal of Econometrics* (**123**), 153–187.
- [16] Fuerst, T. (1992). “Liquidity, Loanable Funds and Real Activity,” *Journal of Monetary Economics* **29(1)**, 3–24.
- [17] Gali, J., Lopez-Salido, J. D., and Valles, J. (2004). “Rule-of-thumb Consumers and the Design of Interest Rate Rules,” *Journal of Money, Credit and Banking* **36(4)**, 739–764.
- [18] Geweke, J. F. (1999). “Computational Experiments and Reality,” Unpublished University of Iowa manuscript.
- [19] Grossman, S., and Weiss, L. (1983). “A Transactions-Based Model of the Monetary Transmission Mechanism,” *American Economic Review* **73(5)**, 871–880.
- [20] Hansen, G.D. (1985). “Indivisible labor and the business cycle,” *Journal of Monetary Economics* **16(3)**, 309–327.
- [21] Harvey, A. C. (1989). *Forecasting, Structural Time Series Models and the Kalman Filter*, Cambridge University Press, Cambridge, United Kingdom.
- [22] Kennickell, A. B., and Starr - McCluer, M. (1994). “Changes in Family Finances from 1989 to 1992: Evidence from the Survey of Consumer Finances,” *Federal Reserve Bulletin* **80**, 861–82.

- [23] Lahiri, A., Singh, R., and Vegh, C. (2003). “Segmented Asset Markets and Optimal Exchange Rate Regimes,” Manuscript.
- [24] Landon-Lane, J. S. (1998) “Bayesian Comparison and Evaluation of Dynamic Macroeconomic Models,” *University of Minnesota Ph.D. Dissertation*.
- [25] Leeper, E. M., Sims, C. A., and Zha, T. (1996). “What Does Monetary Policy Do?” *Brookings Papers on Economic Activity* **2**, 1–78.
- [26] Lucas, R. E. Jr. (1990). “Liquidity and Interest Rates,” *Journal of Economic Theory* **50(2)**, 237–264.
- [27] Occhino, F. (2004). “Modeling the Response of Money and Interest Rates to Monetary Policy Shocks: A Segmented Markets Approach,” *Review of Economic Dynamics* **7(1)**, 181–197.
- [28] Quandt, R. (1960). “Tests of the Hypothesis that a Linear Regression System Obeys Two Separate Regimes,” *Journal of the American Statistical Association* **55(290)**, 324–330.
- [29] Rogerson, R. (1988). “Indivisible labor, lotteries, and equilibrium,” *Journal of Monetary Economics*, **21(1)**, 3–16.
- [30] Rotemberg, J. J. (1984) “A Monetary Equilibrium Model with Transactions Costs,” *The Journal of Political Economy* **92(1)**, 40–58.
- [31] Schorfheide, F. (2000). “Loss function-based evaluation of DSGE models,” *Journal of Applied Econometrics* **15(6)**, 645–670.
- [32] Sims, C. A. and Zha T. (2005). “Were There Regime Switches in U.S. Monetary Policy?” Unpublished manuscript.

- [33] Smets, F., and Wouters, R. (2003). “An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area,” *Journal of the European Economic Association* **1(5)**, 1123–1175.
- [34] Taylor, J. B. (1993). “Discretion versus Policy Rules in Practice,” *Carnegie-Rochester Conference Series on Public Policy* **39**, 195–214.
- [35] Tierney, L. (1994). “Markov Chains for Exploring Posterior Distributions,” *Annals of Statistics* **22(4)**, 1701–1762.