Market structure and business cycles: Do nominal rigidities influence the importance of real shocks?

Dave, Chetan and Dressler, Scott
Villanova School of Business, Villanova University

February 2007

Market Structure and Business Cycles: Do Nominal Rigidities Influence the Importance of Real Shocks?*

Chetan Dave†
University of Texas at Dallas

Scott J. Dressler‡
Villanova University

First version: May 2006
This version: February 2007

Abstract

This paper investigates the relative importance of shocks to total factor productivity (TFP) versus the marginal efficiency of investment (MEI) in explaining cyclical variations. The literature offers contrasting results: TFP shocks are important in neoclassical environments, while relatively unimportant in neo-Keynesian environments. A model with endogenous capital utilization captures both results depending upon the degree of nominal rigidity. In the model, MEI shocks create a wedge between the *nominal* returns on bonds and capital. Nominal rigidities activate this wedge and place the relative importance on MEI shocks, while TFP shocks dominate when prices are perfectly flexible.

Keywords: Business Cycle Fluctuations, Nominal Rigidities, Exogenous Shocks
JEL: C51, E10, E32

*We thank David N. DeJong for his helpful comments, as well as comments from seminar participants at the University of Tennessee. All errors are those of the authors.

†Address: University of Texas at Dallas; School of Economic, Political and Policy Sciences; 2601 N. Floyd Rd.; Richardson, TX 75083. Phone: (972) 883-2306. Fax: (972) 883-6297. Email: cdave@utdallas.edu.

‡Address: Villanova University; 800 Lancaster Avenue; Villanova, PA 19085-1699. Phone: (610) 519-5934. Fax: (610) 519-6054. Email: scott.dressler@villanova.edu.

1. Introduction

A primary goal of real business cycle research is to explain observed variations in macroeconomic aggregates. Following Kydland and Prescott (1982) and Long and Plosser (1983), business cycle fluctuations are initiated by shocks to total factor productivity (TFP) which alter the productivity of all factors of production proportionately. While these shocks can be interpreted as reflecting broad changes in technology, prices of raw materials, or even rules of law, they stand in contrast to Keynes' (1936) view that shocks to the marginal efficiency of investment (MEI) are a primary source of business cycle fluctuations. Greenwood et al. (1988) analyze MEI shocks and variable capital utilization in a neoclassical framework and conclude they can match observed fluctuations in output as well as Prescott (1986) who only considers shocks to TFP.

Current economic environments developed to analyze a myriad of cyclical observations occasionally employ shocks to TFP, MEI, and many other exogenous variables. While adding exogenous processes may enrich model dynamics and facilitate estimation of key parameters, analyses conducted on the individual roles played by TFP and other shocks in multiple-shock settings offer contrasting results. DeJong et al. (2000) compare the relative importance of TFP and MEI shocks in explaining business cycle fluctuations in a neoclassical environment. They conclude that both shocks are important in understanding output fluctuations, but TFP shocks are of primary importance.[1] In contrast, Ireland (2004) compares the relative importance of TFP and several other shocks in a neo-Keynesian environment. Ireland concludes that preference shocks and cost-push shocks (i.e. shocks influencing the price elasticity of each monopolistically-produced intermediate good) dominate TFP in explaining output fluctuations.[2]

This paper attempts to reconcile the conflicting results regarding the relative importance of TFP shocks discussed above by considering an environment featuring *both* of Keynes' main assumptions: imperfectly competitive markets with nominal rigidity as in Ireland (2004),

[1]DeJong et al. (2000) conclude that TFP shocks generally conincide with the onset and recovery of recessions and have a greater initial impact on output and investment, while MEI shocks have a more persistent impact.

[2]Ireland (2004) does not include physical capital in his analysis and therefore does not consider (MEI) shocks to investment.

and MEI shocks combined with variable capital utilization as in DeJong et al. (2000). The environment follows Ireland (2003) and features variable capital utilization and shocks to TFP and MEI only.[3] Key model parameters are estimated via maximum likelihood, and the relative importance of each shock in explaining US output fluctuations is assessed through forecast error variance decompositions and the fitted probability of each shock in predicting NBER dated recessions.

It is shown below that the model captures both the conclusions of DeJong et al. (2000) and Ireland (2004) conditional upon the degree of nominal rigidity. In a version of the model with nominal rigidities, MEI shocks dominate TFP and account for over 75 percent of the short-run variation in output and investment. This result mirrors Ireland's (2004) conclusion that shocks other than TFP dominate in explaining business cycle fluctuations. However, in a version of the model where prices are assumed to be perfectly flexible, TFP shocks dominate and account for over 90 percent of the short-run variation in output, but only 45 percent of the variation in investment. This result mirrors the conclusion of DeJong et al. (2000) that although TFP shocks dominate, MEI shocks retain some importance. The reason for these results stems from the fact that in the model, MEI shocks create a wedge between the *nominal* returns on bonds and capital. Nominal rigidities activate this wedge and place the relative importance of explaining real variations on MEI shocks. In a model with perfectly flexible prices, the wedge is inactive and both shocks are given equal footing in explaining real and nominal variations.

Since neo-Keynesian models differ from their neoclassical counterparts and place heavy emphasis on nominal variables and endogenous monetary policy, one might not be surprised that different shocks can explain features of the data better under different economic assumptions. However, the results presented here stress that the relative importance of competing *real* shocks in explaining *real* aggregates depend upon the degree of *nominal* rigidity in the model. These results are stressed further in a probit analysis where the estimated shock processes are used to predict US recessions. As one may suspect, when either TFP or MEI

[3]Similar environments have been used extensively by Hairault and Portier (1993), Ireland (1997, 2000), and Kim (2000). Christiano et al. (2005) offer an alternative framework which features capital utilization rates without MEI shocks.

shocks dominate the other in explaining short-run variation of real aggregates, then that exogenous process also dominates in predicting recessions. However, it is shown that when using both shock processes together, versions of the model both with and without nominal rigidity do equally well in predicting post-war US recessions. This suggests that a number of competing models featuring a large variety of exogenous shocks have the ability to fit aspects of the data equally well. When analyzing a model with only a limited number of exogenous shock processes, however, the assumptions of the economic environment is of the utmost importance.

The paper is organized as follows. Section 2 presents a monopolistically competitive environment with potential nominal rigidities. Section 3 presents the empirical evaluation of the model, and discusses the relative importance of MEI and TFP shocks in explaining business-cycle variation, and a sensitivity analysis; section 4 concludes.

2. The Model

2.1. Environment

The economy consists of a representative household, a representative final goods-producing firm, a continuum of intermediate firms indexed by $i \in [0, 1]$, and a monetary authority. Each intermediate firm produces a distinct, perishable good which is sold as an intermediate good to the final goods firm. Intermediate firm i produces good i, but the model contains enough symmetry to focus on the behavior of a representative intermediate firm.

Households maximize expected discounted utility defined over consumption (c_t), real money balances (M_t/P_t), and hours worked (h_t)

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, \frac{M_t}{P_t}, h_t\right), \tag{1}$$

where E_0 is the expectations operator conditional on information available at time 0 and $\beta \in (0, 1)$ is the discount factor.

A representative household begins period t with amounts of money (M_{t-1}), bonds (B_{t-1}), and physical capital (k_t). It receives a lump-sum monetary transfer (T_t) from the central bank, and B_{t-1} units of additional money after the bonds mature. The household then uses some of this money to purchase B_t new bonds at cost $1/R_t$, where R_t denotes the gross nominal interest rate between periods t and $t+1$. Finally, the household supplies h_t units of labor and k_t units of capital to the intermediate firms in exchange for competitively determined nominal wage (W_t) and gross nominal rental (Q_t) rates, respectively.

The household uses its funds to purchase final output at nominal price P_t from the final goods firms and divides it into consumption (c_t) and investment (i_t). Investment increases the stock of capital in the following period according to

$$k_{t+1} = x_t i_t + \left[1 - \delta\left(\upsilon_t\right)\right] k_t. \tag{2}$$

Capital accumulation in (2) follows Greenwood et al. (1988) by featuring a shock to the marginal efficiency of investment (x_t) and a depreciation rate of the capital stock (δ) dependent upon the rate of capital utilization (υ_t). Variable depreciation illustrates Keynes' notion of 'user costs': the higher the utilization rate, the higher the capital depreciation rate ($\delta', \delta'' > 0$). The MEI shock evolves according to

$$\ln\left(x_t\right) = \rho_x \ln\left(x_{t-1}\right) + \varepsilon_{xt}, \tag{3}$$

where $\rho_x \in [0, 1)$, and $\varepsilon_{xt} \sim N\left(0, \sigma_x^2\right)$.

At the end of period t, the household receives a cash transfer from the monetary authority (T_t), dividend payments (D_t) from the intermediate firms, and carries M_t, B_t, and k_{t+1} into period $t+1$. This timing results in a series of household budget constraints.

$$\frac{M_{t-1} + T_t + B_{t-1} + W_t h_t + Q_t k_t + D_t}{P_t} \geq c_t + \frac{k_{t+1}}{x_t} + \frac{B_t/R_t + M_t}{P_t} \tag{4}$$

It should be noted that capital is priced at an effective rate Q_t which is to be determined by the intermediate firms who decide how intensively to use existing capital when providing the households with dividends.[4]

[4] This amounts to using (2) to substitute i_t out of an otherwise standard budget constraint, and replacing the net nominal return on capital, say Q_t^*, with its gross effective return $Q_t = Q_t^* + \left[1 - \delta\left(\upsilon_t\right)\right] P_t$. See

The representative final goods firm purchases y_{it} units of intermediate good i at price P_{it} to produce y_t units of the finished good according to the CRS technology

$$y_t = \left[\int_0^1 y_{it}^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}, \tag{5}$$

where $\theta > 1$. Standard profit maximization results in the firm's demand function for intermediate good i to be determined according to

$$y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\theta} y_t. \tag{6}$$

Zero profits amongst competing final goods firms determines P_t as

$$P_t = \left[\int_0^1 P_{it}^{1-\theta} di \right]^{\frac{1}{1-\theta}}. \tag{7}$$

The representative intermediate firm i hires h_{it} units of labor and k_{it} units of capital, and chooses a utilization rate of capital in order to produce y_{it} according to the CRS technology

$$y_{it} = z_t \left(\upsilon_{it} k_{it} \right)^{\alpha} h_{it}^{1-\alpha}, \tag{8}$$

where z_t is an exogenous level of total factor productivity (TFP) which evolves according to

$$\ln(z_t) = (1 - \rho_z) \ln(z) + \rho_z \ln(z_{t-1}) + \varepsilon_{zt} \tag{9}$$

with $\rho_z \in [0, 1)$, and $\varepsilon_{zt} \sim N(0, \sigma_z^2)$.

Imperfect substitution of intermediate goods in (5) allows the representative intermediate firm to sell its output in a monopolistically competitive market. The firm sets its nominal price (P_{it}), subject to satisfying the representative final goods firm's demand (6) taking P_t and y_t as given. When setting P_{it}, the intermediate firm faces a quadratic cost of adjusting its price between periods. As in Rotemberg (1982), the cost is measured in terms of the

Christiano et al. (2005) who model utilization as a houshold's decision by choosing effective capital units.

finished good and is given by

$$\frac{\phi_P}{2}\left[\frac{P_{it}}{\pi P_{it-1}}-1\right]^2 y_t, \tag{10}$$

where $\phi_P \geq 0$ governs the size of the price adjustment cost and π denotes the gross, long-run inflation rate.

The intermediate firm seeks to maximize its total market value,

$$E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t \frac{D_{it}}{P_t}, \tag{11}$$

where $\beta^t \lambda_t$ measures the representative household's marginal utility of consumption and (D_{it}/P_t) is the real value of the firm's dividend payment during period t.

$$\frac{D_{it}}{P_t} = \frac{P_{it}y_{it} - W_t h_{it} - Q_t k_{it}}{P_t} - \frac{\phi_P}{2}\left[\frac{P_{it}}{\pi P_{it-1}}-1\right]^2 y_t + \left[1-\delta\left(\upsilon_{it}\right)\right]\frac{k_{it}}{x_t} \tag{12}$$

The last term in (12) is a result of having the capital utilization rate being a choice of the firm. Clearly, if the firm can observe the marginal benefit of an increase in the utilization rate (increased output), it must be able to observe the marginal cost (lower dividends due to increased user costs). Since firm's are maximizing dividends on behalf of the households, modeling utilization rates this way is straightforward.

Finally, the monetary authority follows a policy rule of the form

$$\hat{R}_t = \omega_\pi \hat{\pi}_t + \omega_y \hat{y}_t, \tag{13}$$

where $\pi_t = P_t/P_{t-1}$, and a hat denotes the deviation of that variable from its long-run (steady state) value. Changes in the nominal interest rate are facilitated through lump-sum transfers of cash to households. The total stock of money in the economy evolves according to $M_t = \mu_t M_{t-1}$, and the monetary authority's budget constraint is given by $T_t = M_t - M_{t-1}$.

2.2. Equilibrium

Restricting attention to a symmetric equilibrium implies all intermediate firms make identical decisions (i.e. $P_{it} = P_t$, $y_{it} = y_t$, $h_{it} = h_t$, $k_{it} = k_t$, $\upsilon_{it} = \upsilon_t$, and $D_{it} = D_t \; \forall i$). The nominal variables of the model are rendered stationary by transforming them into their real counterparts (e.g. $m_t = M_t/P_t$). A symmetric equilibrium is defined as a list of prices $\{\pi_t,\ w_t,\ q_t,\ R_t\}_{t=0}^{\infty}$ and allocations $\{y_t,\ k_t,\ h_t,\ \upsilon_t,\ d_t,\ m_t,\ B_t,\ c_t,\ i_t,\ \mu_t\}_{t=0}^{\infty}$ such that: (i) Households maximize (1) subject to (4); (ii) Intermediate firms maximize (11) subject to (7) and (12); (iii) Final goods firms maximize profits; (iv) The monetary authority satisfies (13); and (v) Markets for goods $\left(y_t = c_t + i_t + (\phi_P/2)\left[\pi_t/\pi - 1\right]^2\right)$, money $(M_t = M_{t-1} + T_t)$, and bonds $(B_t = B_{t-1} = 0)$ clear.

The equilibrium conditions of the model can be used to illustrate the impact of MEI innovations in an environment with potential nominal rigidities. Combining the household's first order conditions with respect to k_{t+1} and B_t results in

$$x_t = E_t\left[\frac{R_t}{q_{t+1}\pi_{t+1}}\right]. \tag{14}$$

With the MEI shock fixed at its' steady-state value of one, equation (14) follows standard Fisherian fundamentals and equates the expected nominal returns to capital loans and bonds. However, a MEI innovation will create a *nominal* wedge between the two returns. To see how nominal rigidities may potentially influence the impact of real innovations, combining the firm's first order conditions with respect to υ_{it} and P_{it} and linearizing around the model's steady state results in

$$\hat{x}_t + \hat{z}_t = (1-\alpha)\left(\hat{k}_t - \hat{h}_t\right) + (\gamma - \alpha)\,\hat{\upsilon}_t + \left(\frac{\phi_P}{1-\theta}\right)\left(\hat{\pi}_t - \beta E_t\hat{\pi}_{t+1}\right), \tag{15}$$

where $\gamma = \delta'\upsilon/\delta$. Equation (15) states that the exogenous shocks are completely absorbed by changes in either real factors of production or nominal prices. In a neutral environment $(\phi_P = 0)$, the final term of (15) drops out and real innovations are entirely absorbed by changes in output factors *ceteris paribus*. However, nominal rigidities $(\phi_P > 0)$ will absorb a portion of the real innovations and in turn influence changes in output factors. The extent to which this wedge influences the importance of the two competing innovations on real factors versus nominal prices is quantitatively assessed in the following section.

3. Quantitative Analysis

The model's dynamic properties are ultimately dependent upon the parameter values. These parameters are partitioned into two groups and determined via a combination of estimation and calibration. In order to isolate the quantitative impact of real innovations and their relationship with nominal rigidities and endogenous monetary policy, all parameters with the exception of $\{\rho_x, \rho_z, \sigma_x, \sigma_z, \omega_y, \omega_\pi, \phi_P\}$ are calibrated so the resulting steady-state of the model matches particular long-run properties of the US economy. The remaining parameters are estimated via maximum likelihood. This section discusses the functional form assumptions, calibration and estimation of each parameter group in detail, and concludes with the quantitative properties of the model and sensitivity analyses.

3.1. Calibration and Functional Forms

The functional forms and calibrated parameters values are determined according to the business cycle literature (e.g. Cooley and Hansen, 1989) so the resulting steady-state of the model matches particular long-run properties of the US economy. The discount parameter β is set to 0.99, α is set to 0.34, and the steady-state average money growth rate (μ) is set to 3 percent annually. All parameters detailed below are summarized in Table 1.

The utility function is chosen to be

$$u\left(c_t, m_t, h_t\right) = \frac{\left[\left(\varsigma c_t^{\frac{\eta-1}{\eta}} + \left(1-\varsigma\right) m_t^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}} \left(1-h_t\right)^{\psi}\right]^{1-\sigma}}{1-\sigma}, \tag{16}$$

where ς is the share parameter, η is interest elasticity, ψ is the weight on leisure, and σ reflects risk aversion. This functional form is considered by Chari et al. (2000) and is shown to be consistent with balanced growth. Chari et al. (2000) estimate $\varsigma = 0.94$ and $\eta = 0.39$ based upon an optimal expression common to models with preferences concerning real balances.

Table 1: Parameter Calibration

Parameter	Symbol	Value
Discount factor	β	0.99
Money Growth	μ	$(1.03)^{.25}$
Effective Capital Share	α	0.34
Relative Risk Aversion	σ	1.0
Utility Share	ς	0.94
Interest Elasticity	η	0.39
Leisure Weight	ψ	1.3388
Depreciation Rate	δ	0.024
User Cost Parameter	γ	1.409
User Cost Scale	ν	0.047
Price Mark-up	θ	6.0

The parameter ψ is calibrated so the representative household's average allocation of time devoted to market activity (net of sleep and personal care) is one-third as estimated by Ghez and Becker (1975). Setting $\sigma = 1$ results in log preferences.

The functional form for the user cost of capital utilization follows Greenwood et al (1988): $\delta(\upsilon_t) = \frac{\nu}{\gamma}\upsilon_t^{\gamma}$ with $\nu > 0$ and $\gamma > 1$. The average utilization rate of capital is assumed to be 80 percent, and together with a 10 percent annual depreciation rate implies $\nu = 0.047$ and $\gamma = 1.409$. The parameter θ is calibrated so the average mark-up of an intermediate good is 20 percent (see Ireland, 2003).

3.2. Estimation Results: TFP versus MEI

The remaining parameters $\{\rho_x, \rho_z, \sigma_x, \sigma_z, \omega_y, \omega_\pi, \phi_P\}$ are unidentified in the model's steady state but can be estimated via maximum likelihood (see DeJong, 2006). Two versions of the model are considered: a sticky-price (SP) model where $\phi_P > 0$, and a flexible-price (FP) model where $\phi_P = 0$.[5] Each version of the model can be represented in state space form,

[5]For the FP model, an additional assumption of perfect competition was employed resulting in intermediate firms not having price markups. The results presented below are robust to the presence or absence of

yielding a likelihood via the Kalman Filter with the observer equation containing detrended investment and inflation. Since it is well documented in the literature that an observed shift in correlations between nominal and real variables occurred around the appointment of Paul Volker as Federal Reserve chairman in August 1979 (see Gavin and Kydland, 1999 and Clarida et al., 2000), the parameters are estimated for three distinct time periods: 1959:QI-2006:Q3, 1959:QI-1979:Q4 and 1980:QI-2006:Q3.[6]

3.2.1. The SP Model

The estimated parameters for the SP model are presented in Table 2.[7] The first two columns report estimates for the full data sample and their standard errors. All estimates are statistically significant, including the degree of price stickiness ($\phi_P = 155$). When breaking the data into pre and post-1979 subsamples, two similarities emerge. First, the persistence in the TFP shock is larger than the MEI shock ($\rho_z > \rho_x$). Second, the response of monetary policy to the output gap (ω_y) is close to zero while the response to deviations of inflation (ω_π) is slightly active.[8]

Table 3 decomposes forecast error variances in per-capita output, investment, inflation, and nominal interest rates into components attributable to the orthogonal disturbances ε_{xt} and ε_{zt}. The columns report the percentage of the variance attributable to MEI shocks (the remainder is attributable to TFP). The table indicates that shocks to MEI account for a majority of the unconditional variance in output and investment in the full data sample, especially in the short-run. At forecast horizons shorter than 10 years, MEI shocks account for over 50 percent of the output variance and over 96 percent of the investment variance. In the subsample results, MEI shocks account for over 65 percent of the variance in real output and almost all of the variance in real investment at all forecast horizons. When looking at

---

markups.

[6]While the date of the break has been imposed on the data, it is approximately equal to an optimal break date found by Garcia and Perron (1996) and references therein. An appendix contains data definitions and construction.

[7]A two step maximum likelihood technique was employed to estimate the parameters of the SP model. In particular, the first step of the estimation procedure fixed ϕ_P and estimated the remaining parameters while the second step estimates ϕ_P. This method is consistent and was estimated for several initial values to ensure robustness.

[8]It should be noted that the estimates for ω_π in every version of the model are not boundary solutions and are within the parameter space for a unique, stable equilibrium.

Table 2: Estimation Results: SP Model

Parameter	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
	Full Sample		*Pre-1979 Sample*		*Post-1979 Sample*	
ρ_x	0.9171	0.0257	0.8275	0.0385	0.9057	0.0237
ρ_z	0.9826	0.0122	0.9128	0.0447	0.9677	0.0000
σ_x	0.0034	0.0007	0.0040	0.0009	0.0027	0.0005
σ_z	0.0031	0.0012	0.0063	0.0020	0.0030	0.0002
ω_y	0.0315	0.0176	0.0090	0.0362	0.0300	0.0006
ω_π	1.0239	0.0292	1.0244	0.0362	1.00764	0.0000
ϕ_P	154.9400	14.0518	157.164	16.7297	155.102	15.7418
$\log L$	1162.760		490.671		683.551	

inflation and nominal interest rates, however, the table indicates that TFP shocks account for a large percentage of the unconditional variance at all data samples and all forecast horizons.

3.2.2. The FP Model

In order to assess the extent to which nominal rigidities are driving the SP model results, a flexible-price (FP) version of the model was estimated for the same three data samples. The estimated parameters for the FP model are reported in Table 4. The parameter estimates share similar features with the SP model: TFP shocks have more persistence than MEI shocks, the monetary authority's response to the output gap is near zero, and the response to inflation is more active than in the SP case but still quite small. The log-likelihood values with respect to the subsamples are also quite similar. Only in the full data sample can a likelihood-ratio test of the null hypothesis that $\phi_P = 0$ be rejected. Nonetheless, if nominal rigidities were the driving force behind equation (14) becoming active and delivering the increased relative impact of MEI shocks on real aggregates, then there should be a reversed result in the forecast error variances attributable to each shock. This result is reported in Table 5. Shocks to MEI never explain more than 16 percent of the variance in real output in any data sample and at any forecast horizon. Shocks to MEI still explain a slight majority of the variance in investment at short horizons (one year or less using the full data sample),

Table 3: Forecast Error Variance Decompositions: SP Model

Quarters Ahead	**Output**	**Investment**	**Inflation**	**Nominal IR**
		Full Sample		
1	77.15	98.57	0.73	2.66
4	74.00	98.26	0.47	0.95
8	69.98	97.84	2.35	1.86
12	66.32	97.45	4.87	4.06
20	60.25	96.91	8.96	8.19
40	51.35	96.66	12.38	12.01
∞	44.02	96.74	11.07	10.84
		Pre-1979 Sample		
1	83.90	99.98	0.49	1.71
4	80.72	99.94	2.69	0.92
8	77.62	99.81	6.33	4.38
12	75.77	99.63	9.60	6.91
20	74.23	99.26	14.15	12.25
40	73.71	98.77	18.33	17.28
∞	73.69	98.61	19.35	18.48
		Post-1979 Sample		
1	84.41	99.67	0.24	1.60
4	81.94	99.62	0.97	0.80
8	78.84	99.57	4.47	3.39
12	76.12	99.54	8.38	7.14
20	71.99	99.53	14.26	13.30
40	67.37	99.52	19.40	18.97
∞	65.72	99.38	19.93	19.67

Note: Numbers indicate percentage of forecast error variance in each variable attributable to MEI shocks.

Table 4: Estimation Results: FP Model

Parameter	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
	Full Sample		*Pre-1979 Sample*		*Post-1979 Sample*	
ρ_x	0.9205	0.0265	0.7571	0.0700	0.8875	0.0426
ρ_z	0.9514	0.0231	0.8397	0.0572	0.9083	0.0352
σ_x	0.0068	0.0013	0.0050	0.0011	0.0048	0.0014
σ_z	0.0071	0.0013	0.0068	0.0010	0.0056	0.0010
ω_y	0.0353	0.0195	0.0600	0.0334	0.0370	0.0254
ω_π	1.1228	0.0522	1.1783	0.0858	1.1236	0.0720
$\log L$	1013.42		494.375		686.383	

but this result diminishes at longer horizons as well as in subsamples of the data. Another stark difference between tables 3 and 5 is that MEI shocks now account for a much larger percentage of the variance in inflation and nominal interest rates.

3.2.3. Predicting US Recessions

An additional criterion for assessing the relative importance of these real shocks is their ability to predict US business cycle recessions. The smoothed Kalman Filter iterations allow the construction of implied series for the two shock processes. These series can be employed as explanatory variates in a probit regression for predicting NBER dated economic downturns. Figure 1 illustrates the fitted probabilities from the SP model obtained by a probit analysis of regressing the NBER business cycle dates against the contemporaneous and four lagged values of the TFP shocks (top panel) and MEI shocks (bottom panel). As the top panel suggests TFP innovations do a poor job in predicting NBER recessions in the presence of nominal rigidities. There are zero successful predictions of a US recession using either the full or post-79 data sample, and just one successful prediction using the pre-79 data sample. Unsurprisingly, the fitted probabilities generated with MEI innovations have more success. They successfully predict all but two US recessions in the full data sample, all but one in the pre-79 data sample, and all recessions post-79.

The probit results under the FP model are presented in Figure 2 and paint a more balanced picture. In the FP model, TFP and MEI innovations are equally successful and

Table 5: Forecast Error Variance Decompositions: FP Model

Quarters Ahead	**Output**	**Investment**	**Inflation**	**Nominal IR**
		Full Sample		
1	9.09	53.20	48.00	59.46
4	9.55	50.81	40.22	51.84
8	10.12	48.17	31.62	42.72
12	10.66	46.11	25.44	35.54
20	11.60	43.55	19.27	27.27
40	13.28	41.98	18.52	23.98
∞	15.18	42.23	22.15	26.30
		Pre-1979 Sample		
1	7.58	44.36	56.52	74.80
4	7.12	39.40	45.99	65.83
8	7.07	36.67	38.47	58.08
12	7.26	35.95	35.56	54.31
20	7.74	35.86	34.13	51.46
40	8.61	35.91	33.95	49.45
∞	9.43	35.90	34.01	48.10
		Post-1979 Sample		
1	7.99	46.50	58.95	71.22
4	8.63	44.93	51.54	64.61
8	9.48	43.42	43.24	56.53
12	10.27	42.48	37.46	50.29
20	11.65	41.71	32.30	43.62
40	13.88	41.67	32.33	41.28
∞	15.97	41.80	34.89	42.24

Note: Numbers indicate percentage of forecast error variance in each variable attributable to MEI shocks.

both predict all but two US recession in the full data sample. A shared similarity emerges in the pre-79 data sample (both innovations can predict all but the 1970 recession), but the post-79 data sample suggests that MEI innovations successfully predict US recessions better than TFP innovations. This coincides with the slightly larger forecast error variance of investment attributable to MEI shocks in the post-79 sample. Taken together, these results mirror the conclusion by DeJong et al. (2000) and suggest that both TFP and MEI innovations are important for predicting US recessions in a model with nominal neutrality.

While the two previous figures were able to attribute predictability of NBER dated recessions to either shock dependent upon the degree of nominal rigidity in the environment, how do the SP and FP models compare when using all available information? Figure 3 compares the fitted probabilities obtained using each model for the full data sample estimates where the probit regressions contain the contemporaneous and four lagged values of both shocks. As the figure illustrates, the predictability from each model is almost indistinguishable. While the source of the fluctuations may change depending on the degree of nominal rigidity, both the SP and FP models successfully predict all but the 1970 recession without false predictions. Comparisons using each data subsample delivered similar results.

3.2.4. Assessing the Model Dynamics

The easiest way to shed light on the above results is to consider the impulse responses of the two models. Figures 4 and 5 illustrate the model responses to a one-standard deviation of each shock in the SP and FP versions, respectively.[9]

The bottom two panels of the figures compare the impulse responses of the nominal bond rate and the effective nominal rate on physical capital. After a TFP shock, the nominal rates decrease and move perfectly together in both the FP and SP models. After a MEI shock, the wedge indicated in equation (14) results in an increase in the nominal bond rate while the effective nominal rate on capital declines in both models. In the SP model, nominal rigidities dampen the initial responses to a MEI shock by about 25 percent and increase their persistence relative to the FP model responses. Interestingly, the SP model also amplifies

[9] The impulse responses are shown for the full sample estimates. All impulse responses of the model estimated using data subsamples are qualitatively similar.

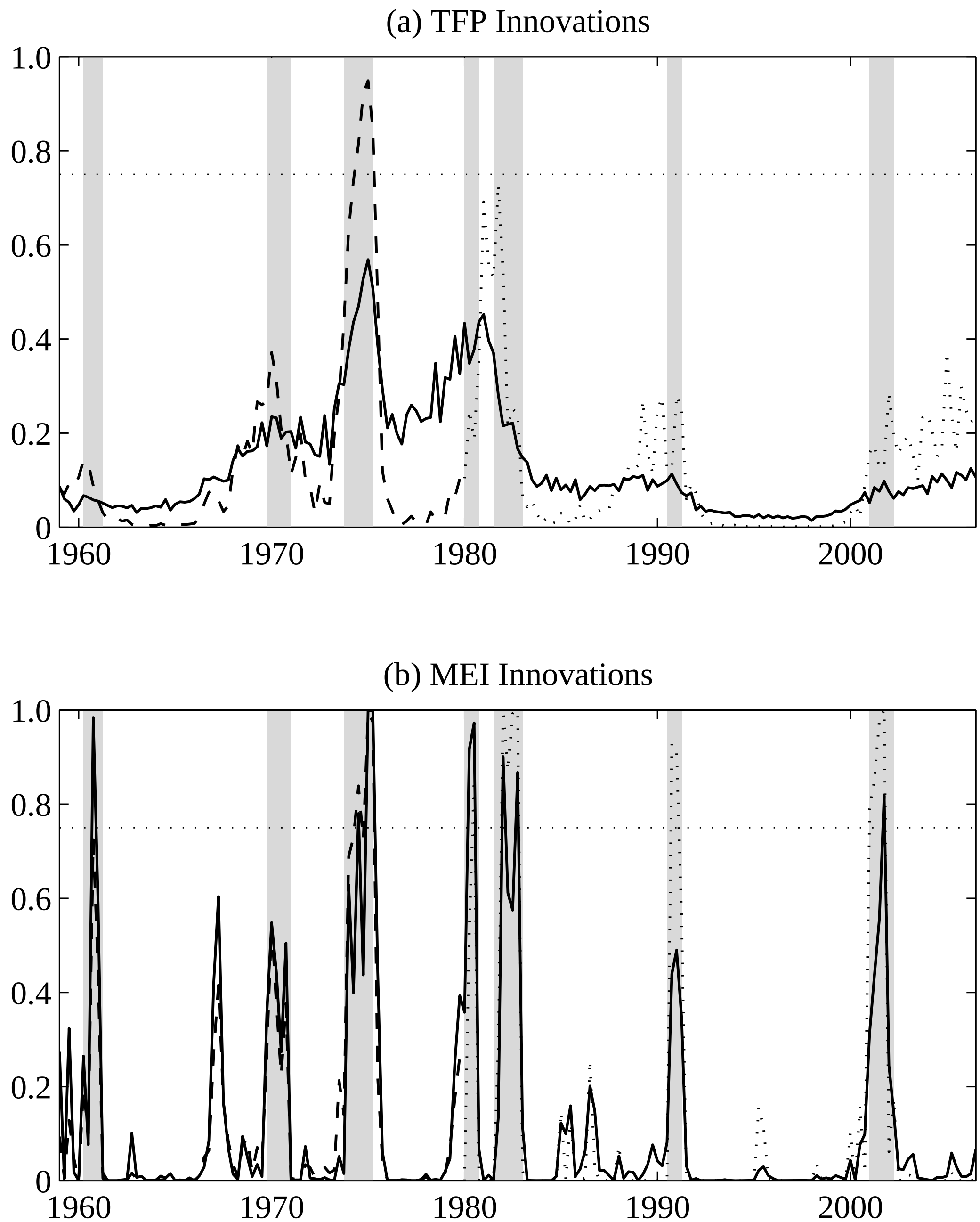

Figure 1: Fitted probabilities of NBER dated recessions, Sticky-Price (SP) Model. Probabilities generated by probit model employing current and four lagged realizations of TFP (top panel) and MEI shocks (bottom panel). Shaded bars denote recessions (NBER dating scheme), while solid and dashed (dotted) lines indicate fitted probabilities under the full sample and the pre-1979 (post-1979) subsample, respectively.

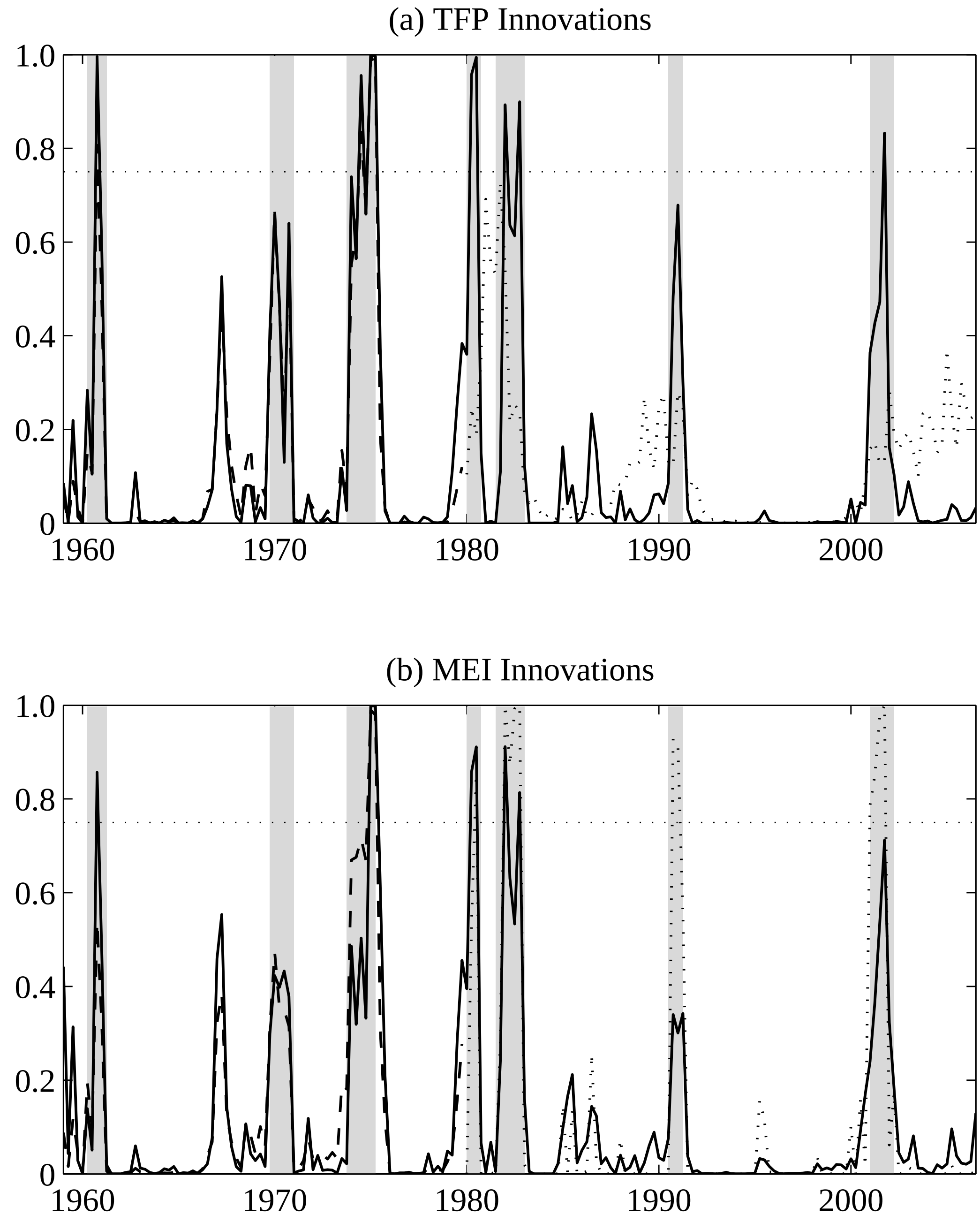

Figure 2: Fitted probabilities of NBER dated recessions, Flexible-Price (FP) Model. Probabilities generated by probit model employing current and four lagged realizations of TFP (top panel) and MEI shocks (bottom panel). Shaded bars denote recessions (NBER dating scheme), while solid and dashed (dotted) lines indicate fitted probabilities under the full sample and the pre-1979 (post-1979) subsample, respectively.

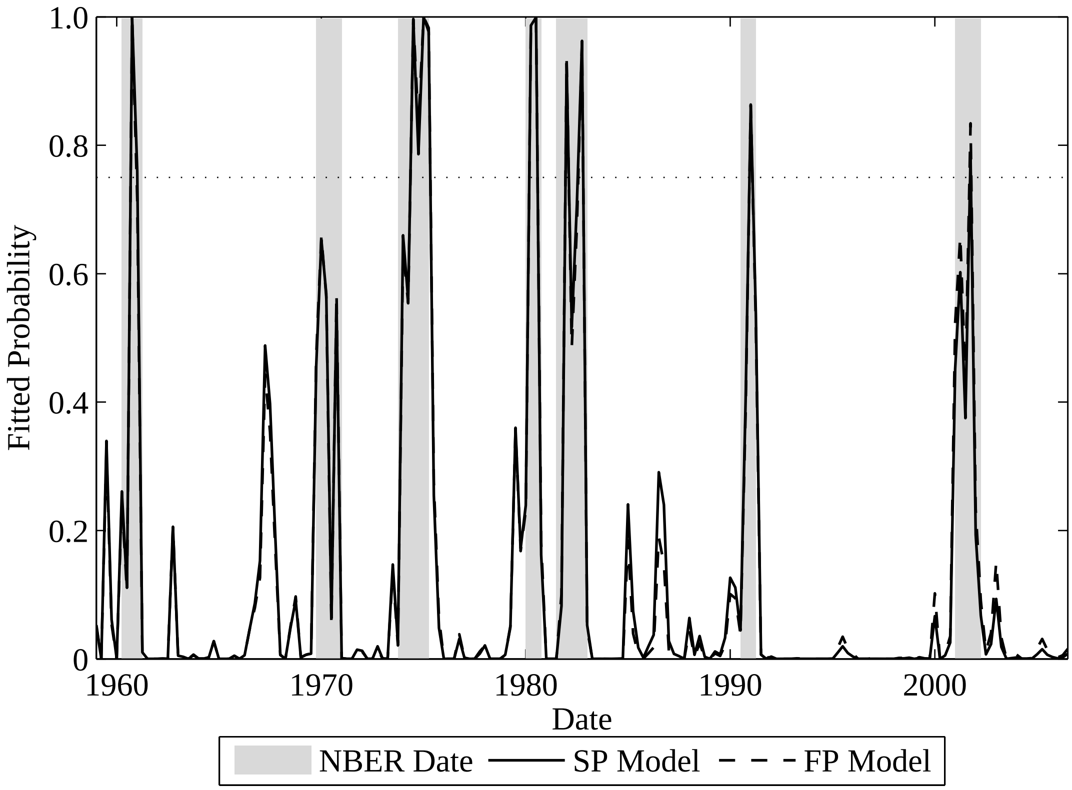

Figure 3: Fitted probabilities of NBER dated recessions. Probabilities generated by probit model employing current and four lagged realizations of TFP and MEI shocks. Shaded bars denote recessions (NBER dating scheme), while solid and dashed lines indicate fitted probabilities estimated under the Sticky-Price (SP) and Flexible-Price (FP) models, respectively.

the response of the nominal rates to a TFP shock by about 40 percent relative to the FP model.

The extent to which the movement in nominal rates combines with the exogenous shocks and influences real output, investment, labor, and utilization can be examined in the remaining panels. Both versions of the model predict positive responses to these four variables. However, the responses in the SP model from a MEI shock clearly dominate the responses from a TFP shock. This dominance delivers the large forecast error variance decompositions of both output and investment attributable to MEI shocks (see Table 3). This dominance is reversed in the FP model for output, but the model predicts roughly similar responses to both shocks for the other variables. These responses explain the dominance of TFP shocks in explaining the variance in real output, while MEI shocks still retain some importance because the variance for real investment is evenly distributed across TFP and MEI (see Table 5).

3.3. Sensitivity and Additional Analyses

The model results are robust to several model extensions and different parameter values. First, versions of the model including nominal interest rate smoothing in (13) as in Ireland (2004) and physical capital adjustment costs as in Ireland (2003) were examined. The degree of nominal interest rate smoothing was not estimated significantly in any version of the model over any data sample. Capital adjustment costs, while found to be important in estimating the degree of price rigidity in other analyses, were insignificant as a result of endogenous capital utilization.[10] Second, the SP and FP models were estimated with different values of risk aversion ($\sigma > 1$), preference parameters (ς and η), degree of price mark-up (θ), as well as the steady-state level of capital utilization (υ). While these changes led to slightly different empirical estimates, the qualitative results presented above were unaffected. In addition, changes in calibrated parameters prior to estimation result in different estimates, but the

[10] Another version of the model considered a more flexible policy rule taken from Ireland (2003).

$$\omega_R \hat{R}_t - \omega_\mu \hat{\mu}_t = \omega_y \hat{y}_t + \omega_\pi \hat{\pi}_t$$

Given that the estimation methodology employed here only used data on investment and inflation, it was unable to jointly identify ω_μ and ω_π.

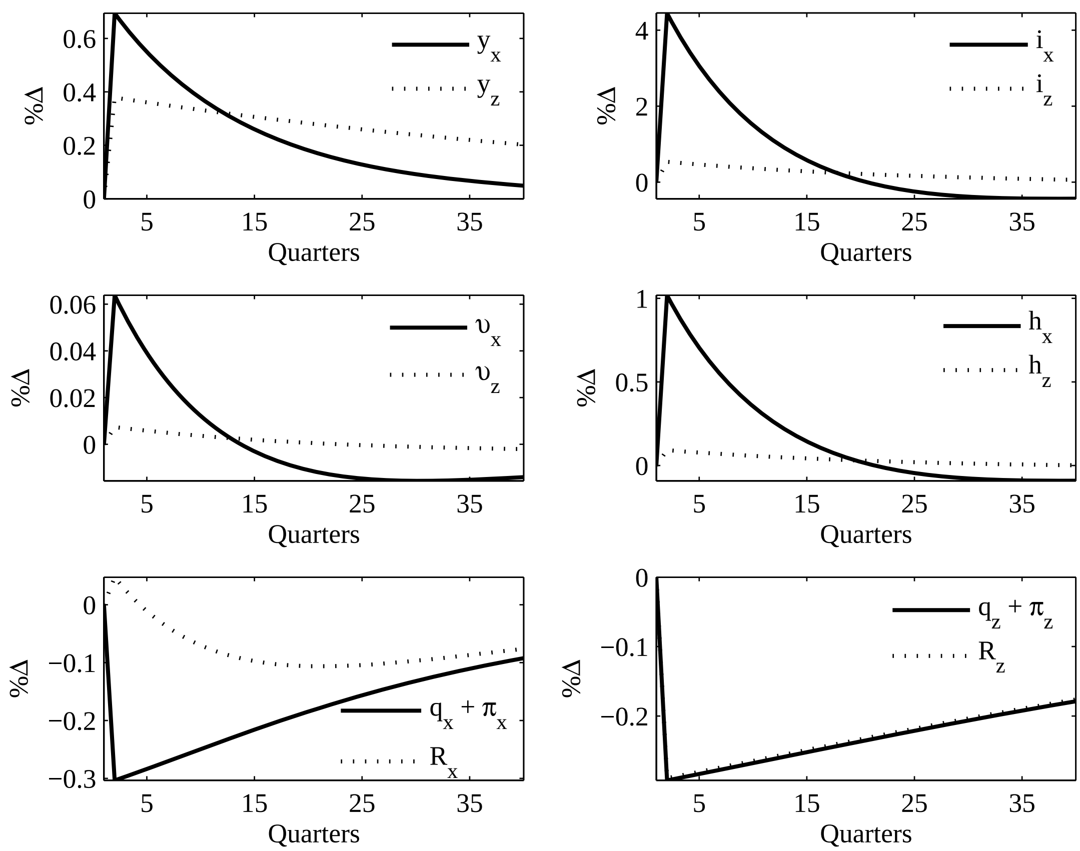

Figure 4: Response to a one-standard deviation of MEI (x) and TFP (z); Sticky-Price (SP) Model, full sample estimates. Subscript denotes dynamic response of variable to respective innovation.

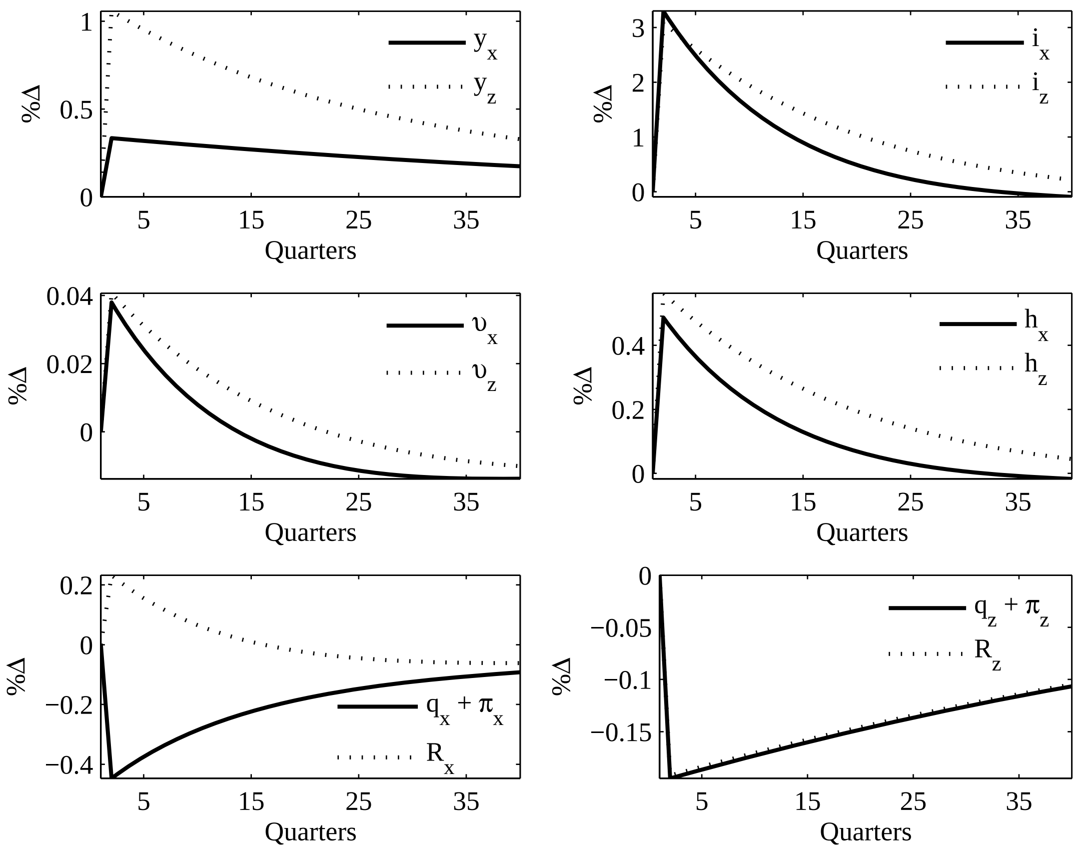

Figure 5: Response to a one-standard deviation of MEI (x) and TFP (z) ; Flexible-Price (FP) Model, full sample estimates. Subscript denotes dynamic response of variable to respective innovation.

qualitative results hold.

The results reported in the preceding section were a combination of the exercises conducted by DeJong et al. (2000) (probit analysis) and Ireland (2004) (variance decompositions and impulse responses). An additional exercise contained in DeJong et al. (2000) was to examine the correlations between the smoothed shocks and other business-cycle aggregates at various leads and lags. These correlations were computed and only reaffirmed the results gathered from the variance decompositions and the impulse responses that shocks which have a larger percentage of forecast error variance of a variable also are strongly correlated with that variable.[11]

4. Conclusion

This paper investigates the relative importance of shocks to TFP and MEI in explaining business cycle variations in an environment with potential nominal rigidities. The model has the ability to capture two contrasting conclusions from the literature regarding the relative importance of TFP, and shows that these conclusions are conditional upon the degree of nominal rigidity in the environment. MEI shocks create a wedge in the model between the nominal returns on bonds and capital which becomes active when nominal prices are rigid. In the presence of nominal rigidity, the model results accord with previous neo-Keynesian analyses and conclude that shocks other than TFP explain a majority of the cyclical variation in US data. In the absence of nominal rigidities, the model results accord with previous neoclassical analyses and conclude that TFP shocks dominate.

The goal of this analysis was to determine if nominal rigidities can influence the relative importance of real shocks, and the results suggest they do. Given the parsimony of our model, these results should not be interpreted as saying anything about the exact degree of nominal rigidity in the US economy. However, the results do imply that assumptions on market structure in analyzing questions of interest may be of utmost importance regardless of whether or not a particular question is monetary in nature. The extent to which this

[11] A final exercise performed considered the endogenous estimation of the probabilities of breaks in the estimated parameters (see DeJong et al., 2004). The procedure delivered no significant probabilities of a break in the data from 1975 to 1985, so the 1979:Q4 break date taken from the literature was imposed.

outcome influences the predictions of neo-Keynesian and neoclassical environments alike remains to be seen.

Appendices

Data Construction

All real variables used in this analysis are available from the Bureau of Economic Analysis at the U.S. Department of Commerce (BEA) and expressed in chained 1996 dollars. The full data sample is from 1958:Q1 to 2006:Q3. All real variables were transformed into per capita terms by dividing by the Working-age, Civilian Noninstitutional Population (CNP16OV). Real investment was taken to be Real Gross Private Domestic Investment (GPDIC1). Real output data was constructed by adding real investment with (per capita) Real Personal Consumption Expenditures (PCECC96).

Data for nominal interest rates were taken to be the 3-month Treasury Bill Rate (TB3M) and is available from the Federal Reserve Board of Governors. Inflation data was constructed as it is defined in the model using the Gross Domestic Product Implicit Price Deflator (GDPDEF) which is available from the BEA.

First Order Conditions

The household's problem is to choose $\{k_{t+1},\ M_t,\ B_t,\ c_t,\ h_t\}$ in order to maximize (1) subject to (4). Letting λ_t denote the multiplier associated with (4), the stationary first order conditions to the household's problem are given by the following.

$$\lambda_t x_t^{-1} = \beta E_t \lambda_{t+1} q_{t+1} \tag{17}$$

$$u_{2t} = \lambda_t - \beta E_t \lambda_{t+1} \pi_{t+1}^{-1} \tag{18}$$

$$\lambda_t R_t^{-1} = \beta E_t \lambda_{t+1} \pi_{t+1}^{-1} \tag{19}$$

$$u_{it} = \lambda_t \tag{20}$$

$$-u_{3t} = \lambda_t w_t \tag{21}$$

The problem of intermediate-firm i is to choose $\{k_{it},\ h_{it},\ \upsilon_{it},\ P_{it}\}$ in order to maximize (11) where D_{it}/P_t is given by (12) subject to (6). Letting φ_t denote the multiplier associated with (6), the stationary first order conditions are given by the following.

$$\lambda_t k_t \left[q_t - (1 - \delta(\upsilon_t))\, x_t^{-1}\right] = \varphi_t \alpha y_t \tag{22}$$

$$\lambda_t w_t h_t = \varphi_t (1 - \alpha)\, y_t \tag{23}$$

$$\lambda_t \nu \upsilon_t^{\gamma} k_t = \varphi_t \alpha y_t x_t \tag{24}$$

$$\lambda_t \phi_P \left[\frac{\pi_t}{\pi} - 1\right] \frac{\pi_t}{\pi} = \lambda_t (1 - \theta) + \varphi_t \theta + \beta \phi_P E_t \lambda_{t+1} \left[\frac{\pi_{t+1}}{\pi} - 1\right] \frac{\pi_{t+1}}{\pi} \frac{y_{t+1}}{y_t} \tag{25}$$

These conditions together with market clearing for goods, money, and bonds comprise the system of equations to the benchmark environment.

References

[1] Bryan, M. F., and Gavin, W. T., 1994. "A Different Kind of Money Illusion: the Case of Long and Variable Lags," Journal of Policy Modelling, 16, 529-540.

[2] Chari, V. V., Kehoe, P. J., and McGratten, E. R., 2000. "Sticky Price Models of the Business Cycle: Can the Contract Multiplier Solve the Persistence Problem?" Econometrica, 68(5), 1151-79.

[3] Christiano, L.J., Eichenbaum, M., and Evans, C., 2005. "Nominal Rigidities and the Dynamic Effects of a Monetary Policy Shock," Journal of Political Economy 113(1), 1-45.

[4] Clarida, R., Gali, J., and Gertler, M., 2000, "Monetary Policy Rules and Macroeconomic Stability: Evidence and some Theory," Quarterly Journal of Economics, 115, 147-180.

[5] Cooley, T. F., and Hansen, G. D., 1989, "The Inflation Tax in a Real Business Cycle Model," American Economic Review, 79(4), 733-748.

[6] DeJong, D. N. (with C. Dave), 2006, Structural Macroeconometrics, Princeton University Press, forthcoming.

[7] DeJong, D. N., Ingram, B. F. and C. H. Whiteman, 2000, "Keynesian Impulses versus Solow Residuals: Identifying Sources of Business Cycle Fluctuations," Journal of Applied Econometrics, 15, 311-329.

[8] DeJong, D. N., Liesenfeld, R., and Richard, J.F., 2004, "Timing Structural Change: A Conditional Probabilistic Approach," Journal of Applied Econometrics, forthcoming.

[9] Garcia, R. and Perron, P., 1996, "An Analysis of the Real Interest Rate under Regime Shifts," The Review of Economics and Statistics, 78(1), 111-125;

[10] Gavin, W. T. and Kydland, F. E., 1999, "Endogenous Money Supply and the Business Cycle," Review of Economic Dynamics, 2, 347-369.

[11] Ghez, G.R. and Becker, G.S., The Allocation of Time and Goods over the Life Cycle. New York: Columbia University Press, 1975.

[12] Greenwood, J., Hercowitz, Z. and G. W. Huffman, 1988, "Investment, Capacity Utilization and the Real Business Cycle," American Economic Review, 78, 402-417.

[13] Hairault, J. O., and Portier, F., 1993. "Money, New-Keynesian Macroeconomics and the Business Cycle," European Economic Review, 37, 1533-1568.

[14] Ireland, P. N., 1997, "A Small, Structural, Quarterly Model for Monetary Policy Evaluation," Carnegie-Rochester Conference Series on Public Policy, 47, 83-108.

[15] Ireland, P. N., 2000, "Interest Rates, Inflation, and Federal Reserve Policy since 1980," Journal of Money, Credit and Banking, 32, 417-434.

[16] Ireland, P. N., 2003, "Endogenous Money or Sticky Prices?" Journal of Monetary Economics, 50, 1623-1648.

[17] Ireland, P. N., 2004, "Technology Shocks in the New Keynesian Model," Review of Economics and Statistics, 86(4), 923-936.

[18] Kim, J., 2000, "Constructing and Estimating a Realistic Model of Monetary Policy," Journal of Monetary Economics, 45, 329-359.

[19] Kydland, F. and Prescott, E., 1982, "Time to Build and Aggregate Fluctuations," Econometrica, 50, 1345-1370.

[20] Long, J. and Plosser, C., 1983, "Real Business Cycles," Journal of Political Economy, 91, 39-69.

[21] Prescott, E., 1986. "Theory Ahead of Business Cycle Measurement," Federal Reserve Bank of Minneapolis Quarterly Review, 10, 9-22.

[22] Rotemberg, J. J., 1982, "Sticky Prices in the United States," Journal of Pollitical Economy, 90, 1187-1211.

[23] Rotemberg, J. J., 1996, "Prices, Output, and Hours: an Empirical Analysis Based on a Sticky Price Model," Journal of Monetary Economics, 37, 505-533.

[24] Taylor, J. B., 1993, "Discretion versus Policy Rules in Practice," Carnegie-Rochester Conference Series on Public Policy, 39, 195-214.