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Labor Market Imperfections and the Dynamics of Postwar Business Cycles

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Abstract: An estimated dynamic general equilibrium model which features imperfectly competitive households, sticky nominal wages and costly labor input adjustment is shown to be consistent with several stylized aspects of U.S. postwar business cycle dynamics including the positive serial correlation of output, consumption, investment and employment growth over short horizons and the persistent, hump-shaped response of output to innovations in the temporary component.

Keywords: Imperfectly competitive households, Sticky nominal wages, Labor adjustment costs, Business cycles, Endogenous propagation mechanisms

JEL Classification: E32, E62

1 Introduction

One very active area of research in the recent macroeconomic literature has been to identify endogenous propagation mechanisms that can account for the dynamics of U.S. postwar business cycles. King, Plosser and Rebelo (1988) were the first to demonstrate that the standard neoclassical growth model fails to reproduce the positive serial correlation of output, investment and employment growth over short horizons. Since then, several researchers, including Watson (1993), Cogley and Nason (1995) and Rotemberg and Woodford (1996), have offered additional evidence corroborating that real business cycle (*RBC*) models cannot explain the dynamics of postwar business cycles via their endogenous structure. Cogley and Nason (1995) in particular find that a large class of *RBC* models, including models with capital adjustment costs, gestation lags, indivisible labor, labor adjustment costs and labor hoarding, cannot simultaneously account for the positive serial correlation of U.S. output growth over short horizons and the significant hump-shaped impulse response function of output to innovations in the temporary component obtained from a Blanchard and Quah (1989) vector autoregression (*VAR*). Schmitt-Grohé (2000) reaches a similar conclusion using a two-sector endogenous business cycle model with indeterminacy arising from sector-specific external increasing returns to scale. She argues that any model featuring production technologies with increasing returns to scale or some industries with market power will also fail to explain the dynamics of output.

The present paper explores the relationship between labor market frictions and the dynamics of U.S. postwar business cycles. The idea that the main features of business cycles may be related to particular aspects of the behavior of the labor market is a recurrent theme in macroeconomics. For instance, in their studies of economic fluctuations during the interwar period, Eichengreen and Sachs (1985) and Bernanke and Carey (1996) provide compelling evidence showing that slowly-adjusting nominal wages have been central to the propagation of monetary shocks, especially during the Great Depression. In a related study, Bordo, Erceg and Evans (2000) find that sticky nominal wages and costly labor input adjustment have accounted for most of the effects of monetary shocks on output and employment from 1929:4 to 1936:4. The apparent success of models which rely on labor market frictions to account for episodes such as the interwar period naturally leads one to ask whether the dynamics of postwar business cycles could also have their origins in the labor market. The evidence presented in this paper provides an affirmative answer to this question.

Our model is similar in spirit to the one used by Bordo, Erceg and Evans (2000) in their study of the Great Depression. It features both sticky nominal wages and costly labor input adjustment. However, despite some similarities, our approach differs from theirs in several respects. First, whereas Bordo, Erceg and Evans (2000) assume a wage setting rule à la Taylor (1979) without explicitly laying out its microfoundations, we introduce endogenous wage setting through the assumption of monopolistic competition among suppliers of differentiated types of labor. The wage for each type of labor is set by the monopoly supplier of that type, who then stands ready to supply as many hours of work as are demanded by the firms at that wage. In our framework, nominal wages are changed at stochastic intervals, when a random signal allows households to reoptimize as in Calvo (1983). Second, while there are only monetary shocks in the model of Bordo, Erceg and Evans (2000), we assume an economy subject both to monetary and technology shocks. This allows us to compare, as in Cogley and Nason (1995) and Schmitt-Grohé (2000), the impulse reponse functions of output implied by our model and by a Blanchard and Quah (1989) *VAR*. Our model, unlike the various incarnations of the *RBC* model, is able to generate a persistent, hump-shaped impulse response function to a non-technology shock.[1] Third, and perhaps more significantly, we estimate rather than calibrate the structural parameters of our model using a generalized method of moments (*GMM*) procedure which exploits a rich set of statistics describing the dynamics of

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[1] Two-shock *RBC* models imply a quantitatively-insignificant impulse response function of output to innovations in the temporary component. See for example the models of Cogley and Nason (1995) and Burnside and Eichenbaum (1996) which feature technology and government consumption shocks, and the model of Schmitt-Grohé (2000) which incorporates technology and sunspot shocks.

postwar business cycles. This allows us to perform an econometric test of the overall fit of our model and to provide estimates of the structural parameters which are important in determining the strength of endogenous propagation implied by our model. Among other results, our paper presents the first meaningful estimate using macro data of the elasticity of substitution between differentiated labor skills; it implies that a one percent rise in the nominal wage of a specific labor skill relative to the wage index leads to a 6.35 percent fall in the employed hours of that labor skill relative to aggregate employment.

Our work is most closely related to recent papers by Ascari (2000) and Huang and Liu (2002). Ascari (2000) develops a dynamic general equilibrium model with optimizing agents and Taylor's (1980) two-period staggered wage contracts.[2] His model generates a wage setting rule which is similar to Taylor's contract equation, with the important difference that the parameters of his wage rule are a function of the underlying parameters in preferences and technologies of the economy. He calibrates the microfounded parameters and then studies whether staggered wage contracts can generate near-random walk behavior in real GNP in response to monetary shocks as, for example, in the models of West (1988) and Phaneuf (1990) which incorporate exogenous Taylor wage-setting rules. He finds that near-random walk behavior of output in response to monetary shocks is an unlikely outcome when the microfoundations are taken into account explicitly. Here, we perform a different test. Following King, Plosser and Rebelo (1988), we study whether our model with optimizing agents and labor market imperfections can account for the positive serial correlation in output, consumption, investment and employment growth present in the data. Also, following Cogley and Nason (1995) and Schmitt-Grohé (2000), we explore whether the impulse responses of output to technology and monetary shocks implied by our estimated model match the impulse response functions to permanent and transitory shocks in a Blanchard and Quah (1989) bivariate *VAR*. In our framework, technology shocks are assumed to have a permanent effect on output. Hence, monetary shocks are not required to produce near-random behavior in output as

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[2] Unlike Ascari's model, ours also takes into account capital accumulation.

in Ascari (2000), although positive monetary shocks should generate a persistent, hump-shaped increase in output to be consistent with the empirical evidence from the vector autoregression.

Huang and Liu (2002) assume monopolistic competition in both the goods and the labor markets in an economy where business cycle fluctuations are driven exclusively by monetary shocks. They also assume Taylor's (1980) staggered contracts. Their model distinguishes between the microfoundations implied by staggered price setting and those implied by staggered wage setting. For each model, they compute a "contract multiplier" defined as the ratio of the output response after a monetary shock at the end of the initial contract duration to that in the impact period. They find that this multiplier is negative under the staggered price mechanism while it is positive and relatively large under the staggered wage mechanism. Their sticky wage model, however, predicts that the increase in output is largest immediately after the shock and that the response of output declines monotonically following the initial increase. Thus, it is unlikely that their model would predict a positive serial correlation in output growth as emphasized by Cogley and Nason (1995) and Schmitt-Grohé (2000). Moreover, they not study the dynamics of consumption, investment and employment growth.

Our main findings can be briefly summarized as follows. First, based on a test of its overidentifying restrictions, our model is far from being rejected. Second, combining sticky nominal wages and labor adjustment costs yields a positive serial correlation of output, consumption, investment and employment growth over short horizons as found in the data. Third, our model also produces a persistent, hump-shaped impulse response of output following a monetary shock which is similar to the response of output to a temporary shock in a Blanchard and Quah (1989) *VAR*. In contrast, a model where households change nominal wages in each period shares the difficulties of standard *RBC* models. Fourth, we show that it is necessary to have both nominal wage rigidity and costly labor input adjustment to successfully account for the dynamics of U.S. postwar business cycles, just as the same combination of two ingredients helps providing a satisfactory account of the severe downturn in economic activity that took place during the Great Depression according to

Bordo, Erceg and Evans (2000). These findings have the important implication to suggest that a common framework can be used to understand the nature and causes of economic fluctuations (or business cycles) during the interwar and the postwar periods.

The rest of the paper is organized as follows. Section 2 lays out the stylized facts of U.S. postwar business cycle dynamics which will be the object of our attention throughout the paper. Section 3 presents our dynamic general equilibrium model with labor market imperfections. Section 4 discusses the econometric methodology used for the estimation of our model. Section 5 looks at the implications of our model for the dynamics of postwar business cycles and examines the respective contribution of nominal wage rigidities and labor adjustment costs to the propagation of shocks to the economy. Section 6 contains concluding remarks.

2 Postwar Business Cycle Dynamics

This section briefly documents some stylized facts about U.S. postwar business cycle dynamics. First, following King, Plosser and Rebelo (1988), we look at first differenced statistics using quarterly data from 1960:I to 1993:IV. These are the serial correlation in growth rates of per capita private output, per capita private consumption, per capita private investment and per capita total hours worked.[3] They are reported in Figure 1. Solid lines represent the autocorrelations from the first to sixth lag, while the dashed lines are 95% confidence interval bands. The autocorrelations are estimated by *GMM* and the confidence intervals are computed with an estimate of the variance-covariance matrix following the procedure proposed by Newey and West (1994). The four variables exhibit positive serial correlation over short horizons. The autocorrelations of output growth are respectively 0.4, 0.21, 0.18 and 0.08 from the first to the fourth lag and -0.16 and -0.03 for the fifth and sixth lag. The corresponding autocorrelations are 0.33, 0.23, 0.31, 0.12 -0.01 and 0.14 for consumption growth, 0.26, 0.10, 0.01, -0.03, -0.24 and -0.22 for investment growth,

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[3] Our emphasis on private output stems from the fact that our model will abstract from government spending and taxation. Our choice of a sample period is constrained by the fact that the total hours worked from the Household Survey are not available after 1993:IV.

and 0.17, -0.01, 0.05, 0.32, -0.08 and -0.16 for employment growth. King, Plosser and Rebelo (1988) have shown that the standard, stochastic, neoclassical growth model fails to reproduce the positive serial correlation in the growth rates of output, investment and hours worked. Specifically, they find that the neoclassical model implies an autocorrelation of 0.02 at a lag of 1, 2 and 3 quarters for output growth, and a negative serial correlation for the same lags both for investment and hours worked.

Second, we consider the impulse response functions of output from an estimated vector autoregression which imposes long-run restrictions to identify the shocks. Blanchard and Quah (1989) use information on output growth and the unemployment rate to identify permanent and transitory shocks to GNP. Assuming two kinds of orthogonal shocks, they postulate that one has a permanent effect on output while the other only has a temporary effect. Following Cogley and Nason (1995), we estimate instead a bivariate *VAR* in the growth rate of per capita output and the difference between the log of per capita output and the log of per capita consumption. The solid lines in Figure 2 are the dynamic responses and the dotted lines are 95% confidence interval bands which are computed by bootstrapping and by including a first-order bias correction following the method proposed by Killian (1998). After a permanent shock, output rises gradually, to reach a plateau after about 15 quarters. Note, however, that compared to the long-run response, the short-run response of output to a permanent shock is estimated very imprecisely. On the other hand, the response of output after a transitory shock is persistent and hump-shaped and displays a peak around the fourth quarter.[4]

3 The Model

To explain these stylized facts, we develop a model of an economy inhabited by a continuum of monopolistically competitive households indexed on the unit interval, a perfectly competitive firm,

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[4] Blanchard (1989), Gali (1992) and Gamber and Joutz (1993) obtain similar impulse responses of output to a supply (or permanent) shock and to an aggregate demand (or transitory) shock using vector autoregression systems that include more than two variables.

and a monetary authority. Money is introduced in the form of a cash-in-advance constraint faced by households. Households reoptimize nominal wages at stochastic intervals and supply the quantity of labor demanded by the firm at the given wage rate.[5] The representative firm rents capital and labor services from the households and maximizes the present value of profits. Varying the quantity of labor is costly to the firm.

3.1 Households and Wage Setting

Each household is endowed with a specific type of labor skill h. Aggregate labor supply, N_t, is a composite of all labor skills:

$$N_t = \left(\int_0^1 N_t(h)^{1/(1+\theta_w)} dh \right)^{(1+\theta_w)}, \tag{3.1}$$

where $N_t(h)$ denotes hours worked by household h. The demand function for labor skill of type h is

$$N_t(h) = \left(\frac{X_t(h)}{W_t} \right)^{-(1+\theta_w)/\theta_w} N_t, \tag{3.2}$$

where $(1+\theta_w)/\theta_w$ is the elasticity of substitution between differentiated labor skills, $X_t(h)$ is the nominal wage rate for labor skill of type h, and W_t is the wage index:

$$W_t \equiv \left(\int_0^1 X_t(h)^{-1/\theta_w} dh \right)^{-\theta_w}. \tag{3.3}$$

Equation (3.2) says that the demand for labor skill h relative to the labor index is a decreasing function of its relative wage.

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[5] Sticky wage models are sometimes criticized for implying that real wages are countercyclical (McCallum, 1986). Unconditional postwar correlations suggest that real wages are either acyclical or weakly procyclical. Bénassy (1995) shows that sticky wage models can account for this unconditional correlation if the economy is subject both to monetary and technology shocks. The evidence based on conditional correlations is mixed. Christiano, Eichenbaum, and Evans (CEE) (1997) presents some evidence that real wages decline following a contractionary monetary policy shock, while Fleischman (1999) finds that real wages rise. Hence, a critical issue is that of the identification of exogenous monetary policy shocks. CEE identifies the policy shock by imposing short-run restrictions, while Fleischman uses long-run restrictions which are more consistent with the standard long-run assumptions of our optimization-based model.

The household endowed with labor skill h has preferences defined over two types of consumption goods and leisure:

$$E_t \sum_{i=0}^{\infty} \beta^i \Big(\omega \ln \left(C_{1t+i}(h) \right) + (1-\omega) \ln \left(C_{2t+i}(h) \right) \\ + \phi \frac{1}{1-\chi} \left(1 - N_{t+i}(h) \right)^{1-\chi} \Big), \tag{3.4}$$

where $0 < \beta < 1$ and $0 < \omega < 1$; the endowment of time per period is normalized to one, and E_t is an expectations operator conditional on the information available in period t which includes the current and lagged values of all variables and shocks. Households enter the period with nominal money balances M_t carried over from the previous period. They receive a nominal lump sum transfer T_t at the beginning of the period, which is identical across households. We assume, as in Cooley and Hansen (1995), that $C_1(h)$ is a *cash good* and $C_2(h)$ is a *credit good*. Purchases of the cash good must satisfy the following cash-in-advance constraint given by:

$$P_t C_{1t}(h) \leq m_t(h) + T_t, \tag{3.5}$$

where P_t is the aggregate price level.[6] Household allocations must also satisfy a sequence of budget constraints given by:

$$C_{1t+i}(h) + C_{2t+i}(h) + I_{t+i}(h) + \frac{M_{t+i+1}(h)}{P_{t+i}} + B_{t+1}(h)\varphi_t = \\ \frac{X_{t+i}(h)}{P_{t+i}} N_{t+i}(h) + R_{t+i} K_{t+i}(h) + \frac{T_{t+i}}{P_{t+i}} + \frac{M_{t+i}(h)}{P_{t+i}} + B_t(h), \tag{3.6}$$

where $K_t(h)$ is the household's holdings of capital, R_t is the capital rental rate, $I_t(h)$ is its gross investment, $B_{t+1}(h)$ is a vector of state-contingent claims whose prices are given by the vector φ_t, and $B_t(h)$ is the value of household h's claims purchased in the previous period given the realization of the state of nature. Household expenditures on the left hand side of (3.6) include purchases of the two consumption goods, gross investment, and money carried into the next period.

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[6] The distinction between cash and credit goods is a convenient way of introducing interest-elastic money demand into the model: see Cooley and Hansen (1995).

Available funds include labor and capital incomes, currency carried over from the previous period, and cash transfers from the government. Agents maximize (3.4) subject to (3.5), (3.6), and non-negativity constraints. The law of motion of capital is given by,

$$K_{t+1}(h) = (1-\delta)\, K_t(h) + I_t(h), \tag{3.7}$$

where δ is the depreciation rate of capital. Consumption, investment and money holdings are identical across households since we assume complete contingent claims markets for assets. Hours worked vary across households. Hence, for the remainder of the paper, we drop the index h for all variables except for the hours worked. The nominal wage set in period t is denoted by X_t.

Each period, nominal wages have a constant probability, $(1-d)$, of being readjusted. Nominal wages are set so that households maximize utility subject to their sequence of budget constraints and the derived demand for their labor services. The first order condition for the choice of X_t is given by:

$$E_t \sum_{i=0}^{\infty} (\beta d)^i \left(\frac{1}{1+\theta_w} \frac{X_t}{P_{t+i}} \lambda_{t+i} + V_{N,t+i}(h) \right) N_{t+i}(h) = 0, \tag{3.8}$$

where λ_{t+i} is the marginal utility of consumption common across households and $V_{N,t+i}(h)$ is

$$V_{N,t+i}(h) \equiv -\left(1 - N_{t+i}(h)\right)^{-\chi}.$$

Once nominal wages are set, households supply labor according to the derived labor demand function in (3.2).

Perfect nominal wage flexibility implies setting $(1-d) = 1$, so (3.8) becomes[7]

$$\frac{W_t}{P_t} = \frac{V_{N,t}}{(1+\theta_w)\lambda_t}. \tag{3.9}$$

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[7] Erceg, Henderson and Levin (2000) assume that employment is subsidized in order to eliminate the distortion caused by monopolistic competition in the labor market. They do this in order to ensure that the equilibrium with flexible wages is Pareto optimal. We are concerned with the cyclical properties of the model, which are not affected by the existence of a constant markup ratio.

3.2 The Representative Firm

The representative firm maximizes profits. Since households own the firm, profits are discounted using households' subjective discount rate and future real profits are weighted by the expected marginal utility of consumption, which corresponds to the expected marginal utility of a unit of output to the households,

$$E_t \sum_{i=0}^{\infty} \beta^i \lambda_{t+i} \pi_{t+i}. \tag{3.10}$$

Real profits at time t, $\pi_{t,}$ are determined by

$$\pi_t = Y_t - \frac{W_t}{P_t} N_t - R_t K_t - \frac{q}{2} A_t \left(N_t - N_{t-1}\right)^2. \tag{3.11}$$

The last term in this equation represents the cost associated with varying hours worked. These costs are assumed to depend on the level of technology to ensure the existence of a balanced growth path in the economy.

To produce output, the representative firm uses labor-augmenting technological progress, A_t, aggregate per capita capital stock, K_t, and per capita hours worked, N_t, in the form of the following Cobb-Douglas production function:

$$Y_t = A_t N_t^{\alpha} K_t^{(1-\alpha)}.$$

The natural log of labor-augmenting technological progress A_t follows a random walk with drift,

$$\ln\left(A_{t+1}\right) = \ln\left(A\right) + \ln\left(A_t\right) + \varepsilon_{t+1}, \tag{3.12}$$

where ε_t is an i.i.d. shock. The technology shock therefore has a permanent effect on output.

3.3 Nominal Wage Rigidity

By using a linear approximation in the neighborhood of steady state equilibrium, equation (3.8) can be used to obtain the following law of motion for the contract wage (see the appendix for a complete derivation):

$$\tilde{X}_t = dE_t \tilde{X}_{t+1} + (1-d)\tilde{W}_t + (1-d)\gamma\left(\tilde{N}_t - \tilde{N}_t^o\right), \tag{3.13}$$

where $\tilde{N}_t^o$, referred to as notional labor supply, is the aggregate supply of labor if nominal wages are perfectly flexible, hence satisfying equation (3.9); the tildes denote proportional deviations of variables from their steady-state values. The coefficient γ is given by:

$$\gamma \equiv \frac{\frac{NV_{NN}}{V_N}}{1+\frac{NV_{NN}}{V_N}\frac{(1+\theta_w)}{\theta_w}},$$

where variables without subscripts are steady state levels and V_{NN} is given by

$$V_{NN} \equiv -\chi\left(1-N\right)^{-(\chi+1)}.$$

Equation (3.13) is similar to the wage contract equation in Taylor (1980), except that in the present context the parameters of the wage setting rule have a structural interpretation. The average duration of wage fixity is equal to the inverse of the probability that a wage contract is adjusted in a given period, $1/(1-d)$. As in Taylor's formulation, a key parameter is γ. Lower values of γ imply more persistence. The value of γ decreases with the elasticity of substitution between types of labor, $(1+\theta_w)/\theta_w$, and increases with the relative risk aversion with respect to labor hours, $\frac{NV_{NN}}{V_N}$.

With complete asset markets, the households that reoptimize nominal wages in period t choose the same wage. The wage index W_t can be approximated by

$$\tilde{W}_t = \sum_{i=0}^{\infty}\left(1-d\right)d^i\tilde{X}_{t-i}. \tag{3.14}$$

Given (3.14), $\tilde{X}_t$ in (3.13) contains a backward-looking component via $\tilde{W}_t$. Therefore, shocks are passed on from one contract to another, a channel which in Taylor's terminology is referred to as the *contract multiplier*. Lagging equation (3.14) by one period, multiplying by d and subtracting gives the following law of motion for the wage index:

$$\tilde{W}_t = d\tilde{W}_{t-1} + \left(1-d\right)\tilde{X}_t. \tag{3.15}$$

The dynamics of the contract wage and the wage index are therefore captured by two first-order difference equations.

3.4 The Monetary Authority

The monetary authority transfers cash balances to the households. Its flow budget constraint is

$$M_{t+1} - M_t = T_t, \tag{3.16}$$

where M_t is the per capita money stock.

Following Ireland (1997) and Galí (1999), we assume that the growth rate of money supply is generated by an autoregressive process and that it can possibly be adjusted in response to technology shocks. Specifically, the money supply rule is

$$\ln\left(M_{t+1}/M_t\right) \equiv ln\left(g_t\right) = (1-\rho_m)\mu_m + \rho_m \ln\left(g_{t-1}\right) + \eta\varepsilon_t + \upsilon_t \tag{3.17}$$

where $0 < \rho_m < 1$ determines the persistence of money growth, μ_m is the unconditional average money growth rate, and υ_t is a white noise shock to the money supply growth process. The parameter η determines the extent to which the monetary authority accommodates technology shocks. If $\eta = 0$, (3.17) reduces to a purely autoregressive process. Given the change in the money stock, transfers are determined endogenously in order to satisfy the government's budget constraint.

3.5 General Equilibrium and Model Solution

The definition of equilibrium is standard. Both the representative firm and the monopolistically competitive households solve their optimization problems subject to the constraints they face. Their decision rules are compatible with the corresponding aggregate decision rules. With perfectly flexible nominal wages, employment satisfies both the labor demand and supply equations. With sticky nominal wages, employment is determined by the representative firm's labor demand. In the deterministic steady state, employment equals its flexible-wage equilibrium level.

Since the economy's production technology follows a random walk with drift and that the rate of growth of the money supply is stochastic, our model has two sources of nonstationarity. Real variables are detrended by dividing them by the level of technology. To detrend nominal variables, we divide by the nominal money stock. Hence, the first order conditions for the maximization problems of the representative firm and monopolistically competitive households can be expressed in terms of stationary variables.

To obtain the model's deterministic steady state, we set the stochastic shocks to zero, drop the time subscripts from the normalized variables, and then solve the resulting system of nonlinear equations numerically. We linearize the equations of the model around the steady-state values of its endogenous variables. As in the equations for the wage dynamics above, all variables are measured as proportional deviations from their steady state values. This leads to a state-space representation of the dynamics of the economy from which forward-looking variables can be eliminated using techniques described by King, Plosser and Rebelo (1987) and Blanchard and Kahn (1980). The log-linearized version of the model can be written in a state-space representation:

$$H_{t+1} = A(\theta)H_t + D(\theta)\bar{\epsilon}_{t+1}, \tag{3.18}$$

$$Z_t = C(\theta)H_t, \tag{3.19}$$

where H_t is a vector of state variables that includes the monetary shock and the technology shock with the other state variables. The vector Z_t contains the endogenous variables. The vector $\bar{\epsilon}_{t+1}$ contains innovations to the technology and money growth processes. The matrices $A(\theta)$, $D(\theta)$ and $C(\theta)$ are functions of the structural parameters of the model. Using this space-state representation and given the assumptions about the variance-covariance properties of the $\bar{\epsilon}_{t+1}$ innovations, equations (3.18) and (3.19) can be used to derive analytical expressions for the asymptotic covariance matrices of the state and endogenous variables. In this way, we can calculate the unconditional second moments of the model without actually simulating the exogenous processes.

4 Econometric Procedure

We estimate the structural parameters of the model with the generalized method of moments (*GMM*). The estimator of the parameter vector (θ) is the solution to the following problem:

$$\hat{\theta}_T = \arg\min_{\theta\in\Theta} \left(\frac{1}{T}\sum_{t=1}^{T} f(z_t,\theta)\right)' W_T \left(\frac{1}{T}\sum_{t=1}^{T} f(z_t,\theta)\right), \tag{4.20}$$

where W_T is a random non-negative symmetric matrix, z_t is the entire set or a subset of the model's variables, and $f(z_t,\theta)$ is a q-vector of unconditional moment restrictions. As we discuss below, most moment restrictions involve the difference between an unconditional moment predicted by the model and the corresponding moment in the data, where the predicted moments are calculated for given parameter values using the linearized version of the model summarized by equations (3.18) and (3.19), with no need to simulate the model. An optimal weighting matrix W_T is obtained as the inverse of the variance-covariance matrix of the moment conditions evaluated at a set of first-step estimates, in which W_T is set equal to the identity matrix. This matrix is consistently estimated using the estimator proposed by Newey and West (1994). Heuristically, it gives more weight to moments that are precisely estimated in the data.

This econometric method has several attractive features. First, it allows flexibility in selecting the moments that describe the business cycle. The set of moments may include unconditional means, variances, covariances and autocovariances. Hence, more information from the data can be used in the estimation than with some alternative methods. For example, calibration typically involves using unconditional first moments (long-run averages) to informally estimate the models' structural parameters, and then making informal comparisons of second moments to evaluate their performance. Second, our method has the advantage of relying on variables which are measured accurately. For instance, the capital stock, which is known to be poorly measured in the data, can be excluded from the set of moments. Other econometric methods that utilize *GMM* directly to estimate the optimality or orthogonality conditions of structural models are often forced to use data on such poorly measured variables. Third, our method allows simultaneous estimation of the model's structural parameters and of the parameters of the stochastic processes generating its forcing variables. This is done by augmenting the state transition equations (3.18) with equations that define these stochastic processes. Estimates of the forcing variable processes can be obtained even if they are not directly observable, and without having to simulate the model. This procedure is similar to the one proposed by Bansal, Gallant, Hussey and Tauchen (1995), but differs from many other simulated method of moments techniques in which the laws of motion of the forcing variables are fixed by preliminary estimates, such as in Jonsson and Klein (1996). Finally, when the dimension of the vector of moments (q) is greater than the dimension of the vector of structural parameters, the overidentifying restrictions implied by the model can be tested formally.

To estimate the structural parameters of the model, we use a rich set of moments which broadly describe the main features of U.S. postwar business cycles. As emphasized by Kydland and Prescott (1982), one subset of moments consists of the volatility of output growth measured by its standard deviation in percentage, and of the relative standard deviations of consumption growth, investment growth, and employment growth. Since our model incorporates monetary shocks, we also include the relative standard deviations of inflation and of nominal wage growth. A second subset of moments includes comovements between variables; these are the contemporaneous correlations between output growth on the one hand, and consumption growth, investment growth, employment growth, inflation, and nominal wage growth on the other hand. A third subset of moments which has been largely ignored in the estimation of dynamic general equilibrium models includes the autocorrelations of output growth, employment growth and nominal wage growth at a lag of one, two and three quarters. With this particular subset of moments, we want to put our model to the test of generating plausible U.S. postwar business cycle dynamics. So far we have a total of twenty unconditional moments.

We complete our estimation strategy by adding other moment restrictions which help to identify specific structural parameters of our model. Including the difference between the level of per capita hours in the data and the steady-state level of labor supply in the model allows estimating ϕ, the weight on leisure in the utility function. This gives:

$$E\left[\ln N_t - \ln N\right] = 0,$$

where N is the steady-state level of labor supply. Using the difference between the rate of growth of per capita output in the data and the steady-state rate of growth of per capita output in the model permits identification of $\ln(A)$. The moment restriction is:

$$E\left[\Delta \ln Y_t - \ln(A)\right] = 0.$$

We also use the difference between the rate of growth of $M2$ in the data and the steady-state rate of money growth in the model in order to estimate the value of μ_m. This gives the following condition:

$$E\left[\Delta \ln M_t - \mu_m\right] = 0.$$

To identify the AR(1) parameter in the money growth equation, we use the following moment:

$$E\left[\left(\ln(g_{t-1}) - \mu_m\right)\left(\left(\ln(g_t) - \mu_m\right) - \rho_m\left(\ln(g_{t-1}) - \mu_m\right)\right)\right] = 0. \tag{4.21}$$

We impose a zero covariance between the innovations to the aggregate technology and money supply processes. The variance of ν_t is pinned down using the following moment:

$$E\left[\left(\left(\ln(g_t) - \mu_m\right) - \rho_m\left(\ln(g_{t-1}) - \mu_m\right)\right)^2 - \left(\eta^2\sigma_\varepsilon^2 + \sigma_\nu^2\right)\right] = 0. \tag{4.22}$$

This moment restriction is a direct consequence of the law of motion for the money supply described in equation (3.17).

5 Estimation Results and Business Cycle Dynamics

5.1 Data

The model is estimated with quarterly data from 1960:1 to 1993:4. Private consumption, C_t, is measured by private-sector expenditures on nondurable goods plus services. Private investment,

I_t, is the sum of the purchases of consumer durables, gross private nonresidential (structures and equipment) and residential investment. Private output, Y_t, is private consumption plus private investment. The price level, P_t, is the deflator corresponding to the measure of private output. Hours worked, N_t, is the seasonally adjusted hours series from the Household Survey. The nominal wage, W_t, is the hourly compensation in the non-farm business sector. The nominal money stock, M_t, is M2.[8] Consumption, investment, output, hours worked, and the nominal money stock are converted to per capita terms using the civilian noninstitutional population aged 16 and over. All series have been obtained from Citibase (the complete list of mnemonics can be found in an appendix).

5.2 Parameter Estimates

Table 1 presents the parameter estimates obtained with the *GMM* procedure. Unfortunately, we cannot simultaneously identify $(1-d)$ and γ in the estimation. However, according to Taylor's (1999) survey, there is a consensus in the literature that the average duration of nominal wage rigidity in the U.S. economy during the postwar period has been close to one year. In terms of our model, this means that nominal wages have a probability, $(1-d)$, equal to 25 percent of being readjusted in each period. By fixing $(1-d)$, we were able to estimate γ and the elasticity of substitution between labor skills, $(1+\theta_w)/\theta_w$. Moreover, the estimates were not sensitive to increasing $(1-d)$ by up to 40 percent.

The structural parameters of the model are estimated quite precisely. The overidentifying restrictions implied by the model easily pass a standard Hansen J-test. Thus, we are unable to reject the null hypothesis that the sets of unconditional moments in the model and in the data are the same. Our estimated value for γ is 0.098 with a standard error of 0.0016, which is quite low. The elasticity of substitution between types of labor skills, which is estimated at 6.35, is statistically significant. The labor adjustment cost parameter, q, is estimated at 7.91, and based on a one-side

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[8] We also used M1 in the estimation. The results were basically identical to those presented here. As in Ireland (1997), we report only those with M2.

test the null hypothesis $q = 0$ is rejected at the 5% level. Our estimate of ω, the relative weight on the cash good in total consumption, is 0.817 and is consistent with Lucas' (1988) calculations and with surveys of consumer transactions. The estimate of the discount rate β is 0.996, while in many representative consumer studies it is above unity. The estimated values of α and δ are respectively 0.593 and 0.027, and hence are similar to values typically assumed in many *RBC* studies even if we did not have to rely on data on labor's share in national income to estimate α, or on gross investment and capital stock data to estimate δ. Our estimated value of η, which is 0.36, suggests that the Federal Reserve has somewhat accommodated technology shocks during the postwar period. The variation in money growth not explained by the Fed's endogenous response to shocks is $\sigma_v = 0.0082$, and the estimate $\rho_m = 0.654$ indicates that shocks to the rate of money growth tend to persist. These estimates are consistent with those of Ireland (1997). Finally, the size of the estimated standard deviation of the aggregate technology shocks, σ_ε = 0.009, is roughly of the same magnitude as in the standard *RBC* literature.

5.3 Labor Market Frictions and Business Cycle Dynamics

We simulate the model using the estimated parameter values. For the autocorrelation functions of the model's endogenous variables, we calculate the analytical solution to the asymptotic variance-covariance matrix using equations (3.18) and (3.19). For calculating impulse response functions, we equate the model's technology shock to the permanent shock in the data and the shock to money supply growth as the transitory shock. Figure 3 compares the autocorrelations of output, consumption, investment and employment growth in two models: one, labeled *SW*, features sticky nominal wages and costly labor input adjustment, while the other, labeled *FW*, features perfectly flexible nominal wages (i.e. $d = 0$) and labor adjustment costs. The *FW* model generates a weak, positive serial correlation of output and consumption growth and a weak, negative serial correlation of investment and employment growth. Hence, the *FW* model suffers from the same kind of problems as standard *RBC* models: it embodies weak endogenous propagation mechanisms and does not generate interesting dynamics via its internal structure. These findings are not surprising since in the *FW* model monetary shocks have real effects only through the inflation tax effect such as in the model of Cooley and Hansen (1989). It is well known that the nonneutralities produced by the inflation tax are small. Hence, the *FW* model behaves very much like an *RBC* model. In contrast, the *SW* model delivers autocorrelations which are quite similar to those found in the data. In particular, the autocorrelations of output growth at lags of 1, 2, 4, 5 and 6 quarters lie inside the confidence interval bands; the autocorrelation is about 0.3 for the first lag and 0.1 for the second lag. The autocorrelations of consumption and investment growth all fall inside the confidence interval bands. The *SW* model does particularly well in accounting for the positive serial correlation of investment growth, with the autocorrelations at lags of 1 and 2 quarters being 0.22 and 0.05 in the model compared to 0.26 and 0.1 in the data. It is interesting to note that Carlstrom and Fuerst (1998) also obtain plausible investment dynamics through the assumption of endogenous agency costs while in our model the positive serial correlation of investment growth is an outcome of sticky nominal wages. The model also generates interesting dynamics in the growth rate of hours worked, although the aucorrelation at a lag of one quarter is somewhat higher than the actual one. Thus, the combination of nominal wage stickiness and costly labor input adjustment produces rich and plausible business cycle dynamics, comparable to those in postwar U.S. data.

Figure 4 compares the dynamic response of output, consumption, investment and hours worked to a technology shock in the *FW* and *SW* models. These are the responses to a positive, one-standard deviation shock to technology. Compared to the *FW* model, the *SW* model yields a hump-shaped response of output, investment and hours worked following a positive technology shock. The short-run response of output to a technology shock produced by the *SW* model differs from that of the vector autoregression, but for the most part, the output response generated by the model is well within the 95% confidence interval bands. The hump-shaped response of investment implied by our model is very similar to that of the agency-cost model of Carlstrom and Fuerst (1998). The rise in hours worked following a positive technology is consistent with the *VAR* evidence reported by Christiano, Eichenbaum and Vigfusson (2002) but not with the evidence presented by Galí (1999) who finds a decline in hours worked. Christiano, Eichenbaum and Vigfusson (2002) obtain an increase in hours worked by assuming that per capita hours worked is stationary in the *VAR*, in contrast to Galí (1999) who assumes that hours are difference stationary, and argue in favour of their specification on the basis of formal statistical tests.[9]

Figure 5 presents the impulse responses to a monetary shock which is measured by a positive, one-standard deviation to the growth rate of money supply. Monetary shocks virtually have no effect on output, hours worked and investment in the *FW* model. In contrast, if nominal wages are sticky, monetary shocks have a persistent, hump-shaped impact on output, hours worked and investment. In particular, the model does remarkably well in explaining the hump-shaped response of output to a monetary shock, with the model's response falling inside the 95% confidence interval around the *VAR* response along its entire path.

5.4 Sensitivity Analysis

We now want to examine the separate roles of staggered contracts and labor adjustment costs in propagating shocks to the economy. We do this by looking at the sensitivity of our results to changes in q, d, and γ. In each case, other parameters are kept at their estimated values. Figure 6 displays the response of output to technology and monetary shocks, and the autocorrelations of output growth if nominal wages are perfectly flexible ($d = 0$). The labor adjustment cost parameter is successively set equal to 0, 10 and 20. According to the first column, increasing the labor adjustment cost parameter attenuates somewhat the impact effect of a technology shock on output but has no effect on the response of output to a monetary shock. As a result of the smaller impact effect of a technology shock on output, the growth rate of output exhibits weak positive serial correlation over short horizons as q increases. This can be seen in the third column. With

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[9] In Galí's (1999) model, the decline in hours worked results from sticky nominal prices and a weak accommodation of technology shocks by the monetary authority.

$q = 0$, the autocovariance generating function of output growth is close to a white noise process, while setting q as high as 20 yields autocorrelations at lags of one and two quarters of about 0.09 and 0.06 compared to 0.40 and 0.21 in the data. Thus, labor adjustment costs alone are not a plausible source of business cycle dynamics.

Figure 7 studies the sensitivity of our results to changes in the average duration of nominal wage fixity, while assuming that it is costless for the representative firm to adjust its labor input ($q = 0$). We assume that d, the probability that nominal wages are not readjusted in each period, is successively equal to 0.5, 0.75 and 0.875 which implies that, on average, nominal wages are sticky during two, four and eigth quarters, respectively. The first column reveals that increasing d magnifies the impact effect of a technology shock on output. Moreover, as d increases from 0.5 to 0.875, the response of output displays a hump-shaped pattern. With $d = 0.875$, however, the response of output lies outside the 95% confidence interval bands over the first twenty quarters. According to the second column, increasing d also magnifies the effect of a monetary shock on output and gradually introduces a hump-shaped pattern in the response of output to a monetary shock. With $d = 0.5$, the response of output is too small and does not persist compared to the impulse response estimated with the *VAR*. In contrast, with $d = 0.875$, the output response is too strong, lying outside the 95% confidence interval bands during the first four quarters. With $d = 0.75$, the impact effect of output after a monetary shock also exceeds the upper 95% confidence interval. The third column shows that with $d = 0.5$, the autocorrelations of output growth are weakly negative, while with $d = 0.75$, the first two autocorrelations become positive (0.10 and 0.03), even though they are far from matching the actual ones. Assuming $d = 0.875$ makes the serial correlation in output growth predicted by the model closer to the actual autocorrelation function, although the autocorrelation at a lag of one quarter is still two standard deviations lower than the value observed in the data. Therefore, increasing nominal wage rigidity brings the serial correlation of output growth closer to the facts, but only if one assumes an implausibly high average duration of nominal wage fixity.

¿From equation (3.13) we know that γ is a key parameter. Figure 8 reports results with γ successively set equal to 0.098 as in the estimated model, 0.5 and 1.0. With a lower γ, technology shocks have a somewhat smaller impact effect on output. The response of output to a monetary shock is more sensitive to varying γ. Increasing γ reduces both the magnitude and persistence of the output response and lowers the serial correlation in output growth. With $\gamma = 0.5$ or $\gamma = 1.0$, the autocorrelations of output growth at lags of one, two and three quarters are all significantly different from the actual ones.

6 Conclusions

Labor market imperfections have long been considered a main cause of economic fluctuations, including in major episodes such as the Great Depression. The results presented in this paper suggest that the postwar period is no exception: labor market imperfections in the form of imperfectly competitive households, nominal wage rigidities and costly labor input adjustment are capable of producing the positive serial correlation of output, consumption, investment and employment growth over short horizons observed in the data, and the significant hump-shaped impulse response function of output to innovations in the temporary component obtained from a Blanchard and Quah (1989) vector autoregression.

References

Ascari, Guido (2000), "Optimising Agents, Staggered Wages and the Persistence in the Real Effects of Money Shocks", *Economic Journal* 110, 664-686

Bansal, Ravi, A. Ronald Gallant, Robert Hussey and George Tauchen (1995), "Nonparametric Estimation of Structural Models for High-Frequency Currency Market Data", *Journal of Econometrics* 66, 251-287

Bénassy, Jean-Pascal (1995), “Money and Wage Contracts in an Optimizing Model of the Business Cycle”, *Journal of Monetary Economics* 35, 303-315

Bernanke, Ben and Kevin Carey (1996), “Nominal Wage Stickiness and Aggregate Supply in the Great Depression”, *Quarterly Journal of Economics* 111, 853-883

Blanchard Olivier J. (1989), “A Traditional Interpretation of Macroeconomic Fluctuations”, *American Economic Review*, 79, 1146-1164

Blanchard, Olivier J. and Charles M. Kahn (1980), “The Solution of Linear Difference Models under Rational Expectations”, *Econometrica* 48, 1305-1313

Blanchard, Olivier J. and Danny Quah (1989), “The Dynamic Effects of Aggregate Supply and Demand Disturbances”, *American Economic Review* 79, 655-673

Bordo, Michael, Chris Erceg and Charles Evans (2000), “Money, Sticky Wages, and the Great Depression”, *American Economic Review* 90, 1447-1463

Burnside, Craig and Martin Eichenbaum (1996), “Factor-Hoarding and the Propagation of Business-Cycle Shocks”, *American Economic Review* 86, 1154-1174

Calvo, Guillermo (1983), “Staggered Contracts and Exchange Rate Policy” in J.A. Frenkel, ed., *Exchange Rates and International Economics*. (Chicago, University of Chicago Press)

Carlstrom, Charles and Timothy Fuerst (1998), “Agency Costs, Net Worth and Business Fluctuations: A Computable General Equilibrium Analysis”, *American Economic Review*, 87, 893-910

Christiano, Lawrence, Martin Eichenbaum and Charles L. Evans (1997), “Sticky Price and Limited Participation Models: A Comparison”, *European Economic Review* 41, 1173-1200

Christiano Lawrence, Martin Eichenbaum and Robert Vigfusson (2002), “What Happens after a Technology Shock?”, draft, Northwestern University

Cogley, Timothy and James M. Nason (1995), “Output Dynamics in Real-Business-Cycle Models”, *American Economic Review* 85, 492-511

Cooley, Thomas F. and Gary D. Hansen (1989), “The Inflation Tax in a Real Business Cycle Model”, *American Economic Review* 79, 733-748

Cooley, Thomas F. and Gary D. Hansen (1995), “Money and the Business Cycle”, in T. Cooley, ed., *Frontiers of Business Cycle Research*. (Princeton, Princeton University Press)

Eichengreen, Barry and Jeffrey Sachs (1985), “Exchange Rates and Economic Recovery in the 1930s”, *Journal of Economic History* 45, 925-946.

Erceg, Christopher, Dale Henderson and Andrew Levin (2000), “Optimal Monetary Policy with Staggered Wage and Price Contracts”, *Journal of Monetary Economics* 46, 281-313

Fleischman, Charles A. (1999), “The Causes of Business Cycles and the Cyclicality of Real Wages”, Working Paper, Federal Reserve Board of Governors

Galí, Jordi (1992), “How Well Does the IS-LM Model Fit Postwar U.S. Data?”, *Quarterly Journal of Economics* 107, 709-738

Galí, Jordi (1999), “Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?”, *American Economic Review* 89, 249-271

Gamber, Edward and Frederick Joutz (1993), “The Dynamic Effects of Aggregate Demand and Supply Disturbances: Comment”, *American Economic Review* 83, 1387-1393

Huang, Kevin and Zheng Liu (2002), “Staggered Contracts and Business Cycle Persistence”, *Journal of Monetary Economics* 49, 405-433

Ireland, Peter N. (1997), “A Small Structural Quarterly Model for Monetary Policy Evaluation”, *Carnegie-Rochester Conference on Public Policy* 47, 83-108

Jonsson, Gunnar and Paul Klein (1996), “Stochastic Fiscal Policy and the Swedish Business Cycle”, *Journal of Monetary Economics* 38, 245-268

Killian, L. (1998), “Small-Sample Confidence Intervals for Impulse Response Functions”, *Review of Economics and Statistics* 80, 218-230

King, Robert G., Charles I. Plosser and Sergio T. Rebelo (1987), “Production, Growth, and Business Cycles: Technical Appendix”, mimeo, University of Rochester

King, Robert G., Charles I. Plosser and Sergio T. Rebelo (1988), “Production, Growth and the Business Cycle: I. The Basic Neoclassical Model”, *Journal of Monetary Economics* 21, 195-

232

Lucas, Robert E. Jr. (1988), “Money Demand, A Quantitative Review”, in Karl Brunner and Bennett McCallum, eds., *Money, Cycles and Exchange Rates; Essays in Honor of Alan Meltzer*. Carnegie-Rochester Conference Series on Public Policy 29

McCallum, Bennett T. (1986), “On ‘Real’ and ‘Sticky-Price’ Theories of the Business Cycle”, *Journal of Money, Credit and Banking* 18, 397-414

Newey, Whitney and Kenneth West (1994), “Automatic Lag Selection in Covariance Matrix Estimation”, *Review of Economic Studies* 61, 631-653

Phaneuf, Louis (1990), “Wage Contracts and the Unit Root Hypothesis”, *Canadian Journal of Economics* 23, 580-592

Rotemberg, Julio and Michael Woodford (1996), “Real Business Cycle Models and the Forecastable Movements in Output, Hours and Consumption”, *American Economic Review* 86, 71-89

Schmitt-Grohé, Stephanie (2000), “Endogenous Business Cycles and the Dynamics of Output, Hours, and Consumption”, *American Economic Review* 90, 1136-1159.

Taylor, John B. (1979), “Staggered Price Setting in a Macro Model”, *American Economic Review Papers and Proceedings* 69, 108-113

Taylor, John B. (1980), “Aggregate Dynamics and Staggered contracts”, *Journal of Political Economy* 88, 1-23

Taylor, John B. (1999), “Staggered Price and Wage Setting in Macroeconomics”, in J.B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics, v.1.* Amsterdam, North Holland

Watson, Mark (1993), “Measures of Fit for Calibrated Models”, *Journal of Political Economy* 101, 1011-1041

West, Kenneth (1988), “On the Interpretation of Near Random Walk Behavior in GNP”, *American Economic Review* 78, 202-209.

Appendix A: Contract Wage Dynamics

The terms for period $t+i$ of the household's first order conditon (3.8) can be approximated as

$$(\beta d)^i \, NV_N \left\{ \tilde{N}_{t+i}(h) - \tilde{N}_{t+i}(h) - \tilde{\lambda}_{t+i} - \tilde{X}_t + \tilde{P}_{t+i} + \frac{NV_{NN}}{V_N} \tilde{N}_{t+i}(h) \right\}$$

The derived labor demand equation (3.2) can be approximated as

$$\tilde{N}_{t+i}(h) \approx -\frac{1+\theta_w}{\theta_w} \left(\tilde{X}_t - \tilde{W}_{t+i} \right) . + \tilde{N}_{t+i}$$

Equation (3.9) is used to give notional labor supply. Linearizing this equation leads to

$$\tilde{P}_{t+i} - \tilde{\lambda}_{t+i} \approx \tilde{W}_{t+i} - \frac{NV_{NN}}{V_N} \tilde{N}^o_{t+i}.$$

Under flexible wages, all households can adjust their wage in each period. They will all choose the same wage, so indexing the variable $\tilde{N}^o_{t+i}$ is not necessary. Substituting the last two approximate equalities into the preceding expression gives

$$(\beta d)^i \, NV_N \left\{ - \left(1 + \frac{NV_{NN}}{V_N} \frac{1+\theta_w}{\theta_w} \right) \left(\tilde{X}_t - \tilde{W}_{t+i} \right) - \frac{NV_{NN}}{V_N} \left(\tilde{N}^o_{t+i} - \tilde{N}_{t+i} \right) \right\}$$

The first order condition for the choice of X_t can therefore be approximated by

$$\sum_{i=0}^{\infty} (\beta d)^i \, \tilde{X}_t \approx E_t \sum_{i=0}^{\infty} (\beta d)^i \left\{ \tilde{W}_{t+i} + \gamma \left(\tilde{N}_{t+i} - \tilde{N}^o_{t+i} \right) \right\}$$

$$\Rightarrow (1-\beta d)^{-1} \, \tilde{X}_t \approx E_t \sum_{i=0}^{\infty} (\beta d)^i \left\{ \tilde{W}_{t+i} + \gamma \left(\tilde{N}_{t+i} - \tilde{N}^o_{t+i} \right) \right\}$$

where

$$\gamma \equiv \frac{NV_{NN}/V_N}{1 + (NV_{NN}/V_N) \, \frac{1+\theta_w}{\theta_w}}$$

Forwarding this equation by one period, taking conditional expectations, subtracting the forwarded equation from the original one and simplifying leads to equation (3.13), with the additional simplifying assumption that $\beta \approx 1$.

Appendix B: Data Sources

The series are from Citibase and the (quarterly) sample is 1960:1 to 1993:4, with definitions as follows.

- C_t: private consumption, composed of consumption of non-durables ($gcnq$) and services ($gcsq$).

- I_t: private investment, defined as gross private domestic investment ($gpiq$) and consumption of durable goods ($gcdq$).
- Y_t: output, measured as private consumption plus private investment.
- P_t: the price level, which is just the deflator for our measure of output, measured as (($gcn + gcs + gcd + gpi$)/($gcnq + gcsq + gcdq + gpiq$)), where the series in the numerator are nominal values and the series in the denominator are measured in constant dollars.
- N_t: total hours worked ($lhours$).
- W_t: compensation per hour, nonfarm business sector ($lbpur$).
- M_t: M2 ($fm2$).

Consumption, investment, output, hours worked, and the money supply are deflated by total civilian population aged 16 and over ($p16$).

Table 1

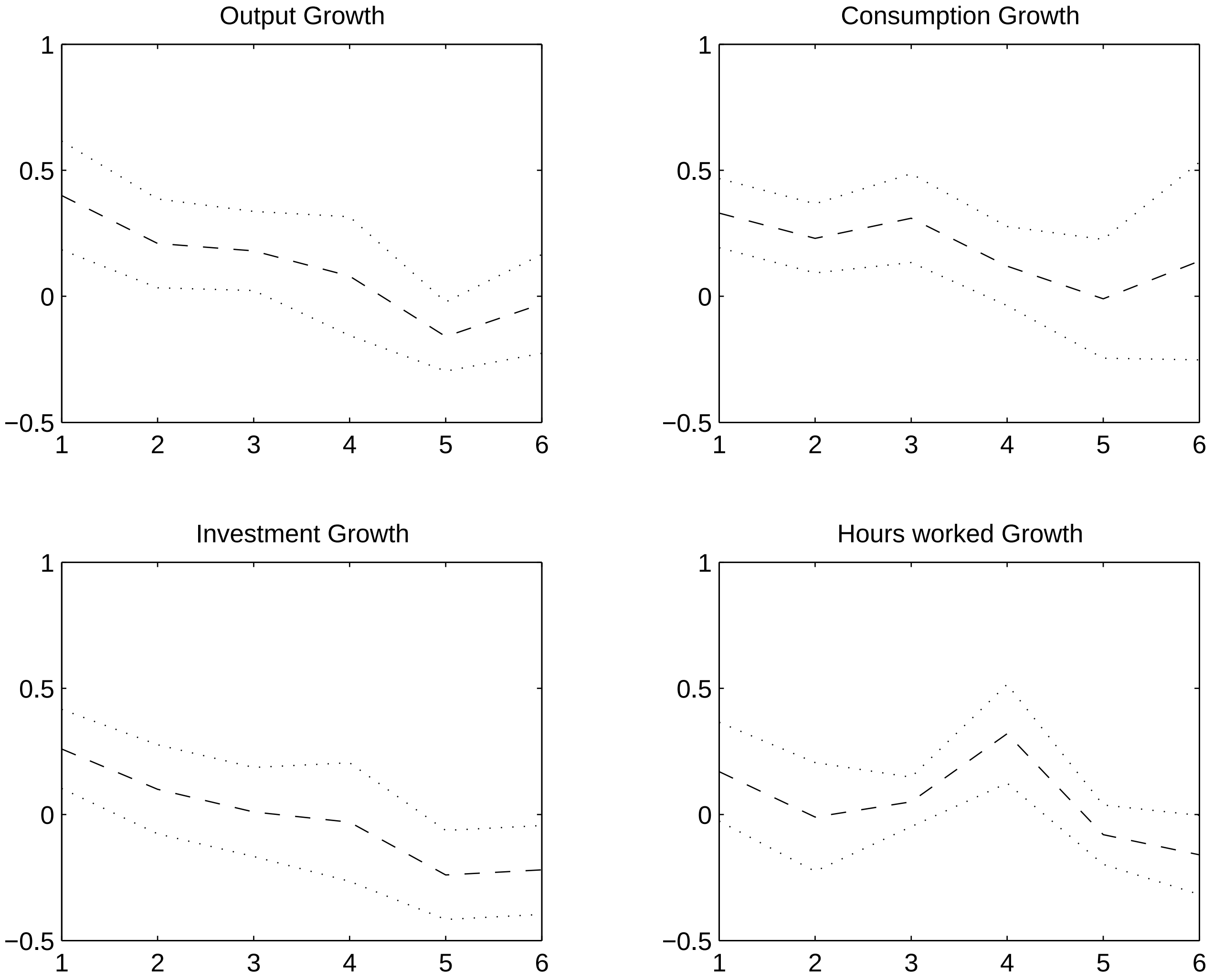
Model Parameter Estimates

(U.S. Economy 1960:I to 1993:IV)

Parameter	Value	s.e.
$\ln(A)$	.0055	.0010
μ_m	.0146	.0007
β	.9959	.0054
α	.5935	.0654
δ	.0274	.0090
ϕ	3.5171	.4210
ω	.8178	.0401
q	7.9188	4.008
ρ_m	.6537	.0277
η	.3640	.1550
σ_ε	.0099	.0019
σ_v	.0083	.0005
γ	.0979	.0159
$(1+\theta_\omega)/\theta_\omega$	6.3509	2.7571
J-test	15.49	p-value=.21

Figure 1

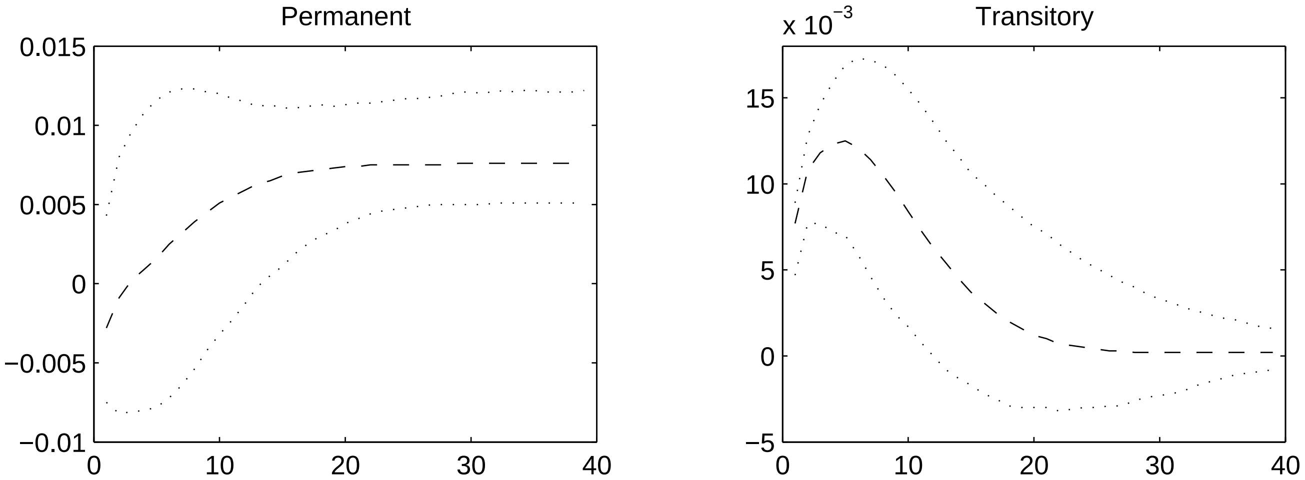
Actual Serial Correlation of Output, Consumption, Investment and Employment Growth



The long-dashed lines indicate the estimated autocorrelations and the dotted lines indicate 95% confidence bands.

Figure 2

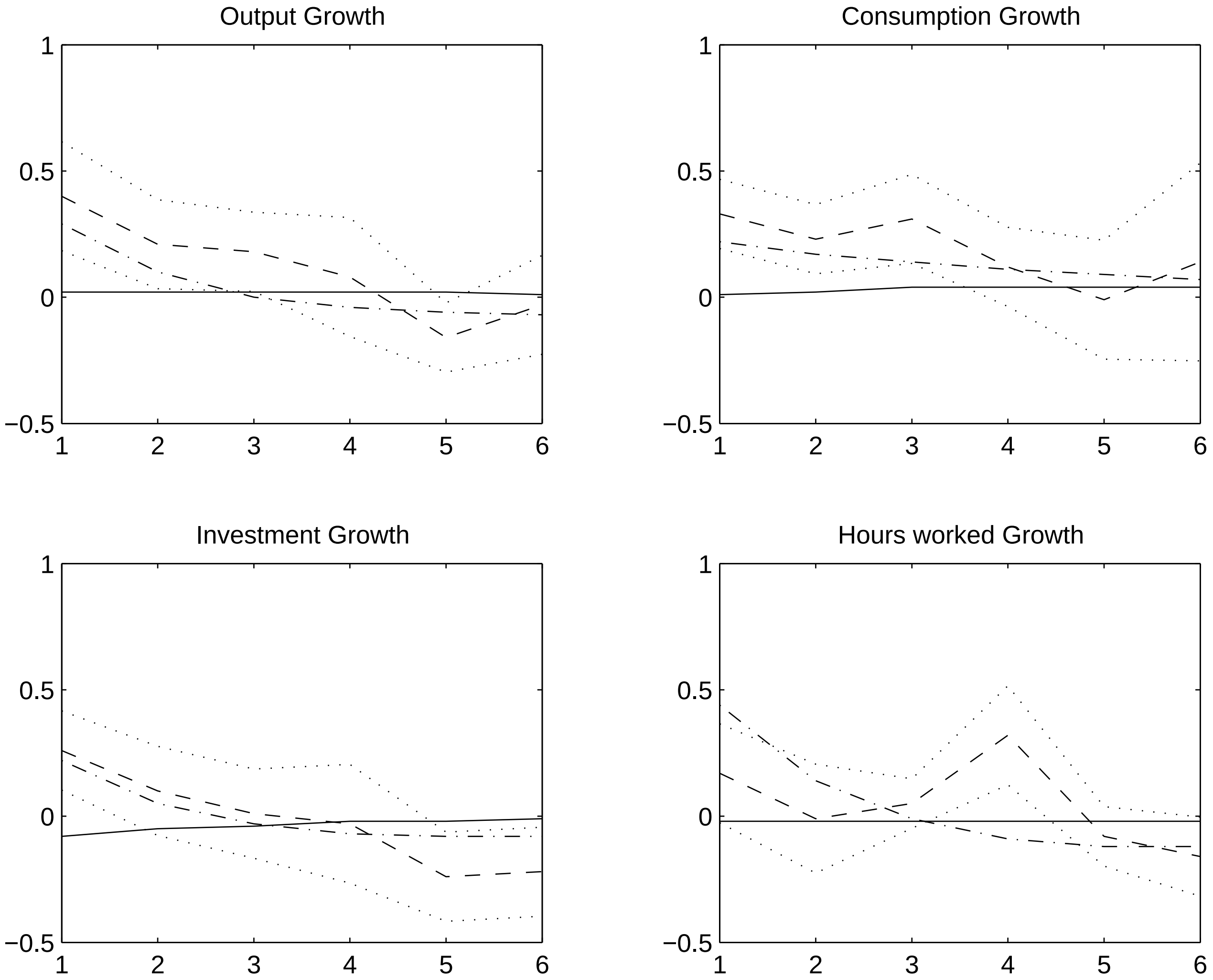
Permanent and Transitory Impulse Response of Output



The long-dashed lines indicate the estimated impulse response functions of output. The dotted lines indicate 95% confidence bands.

Figure 3

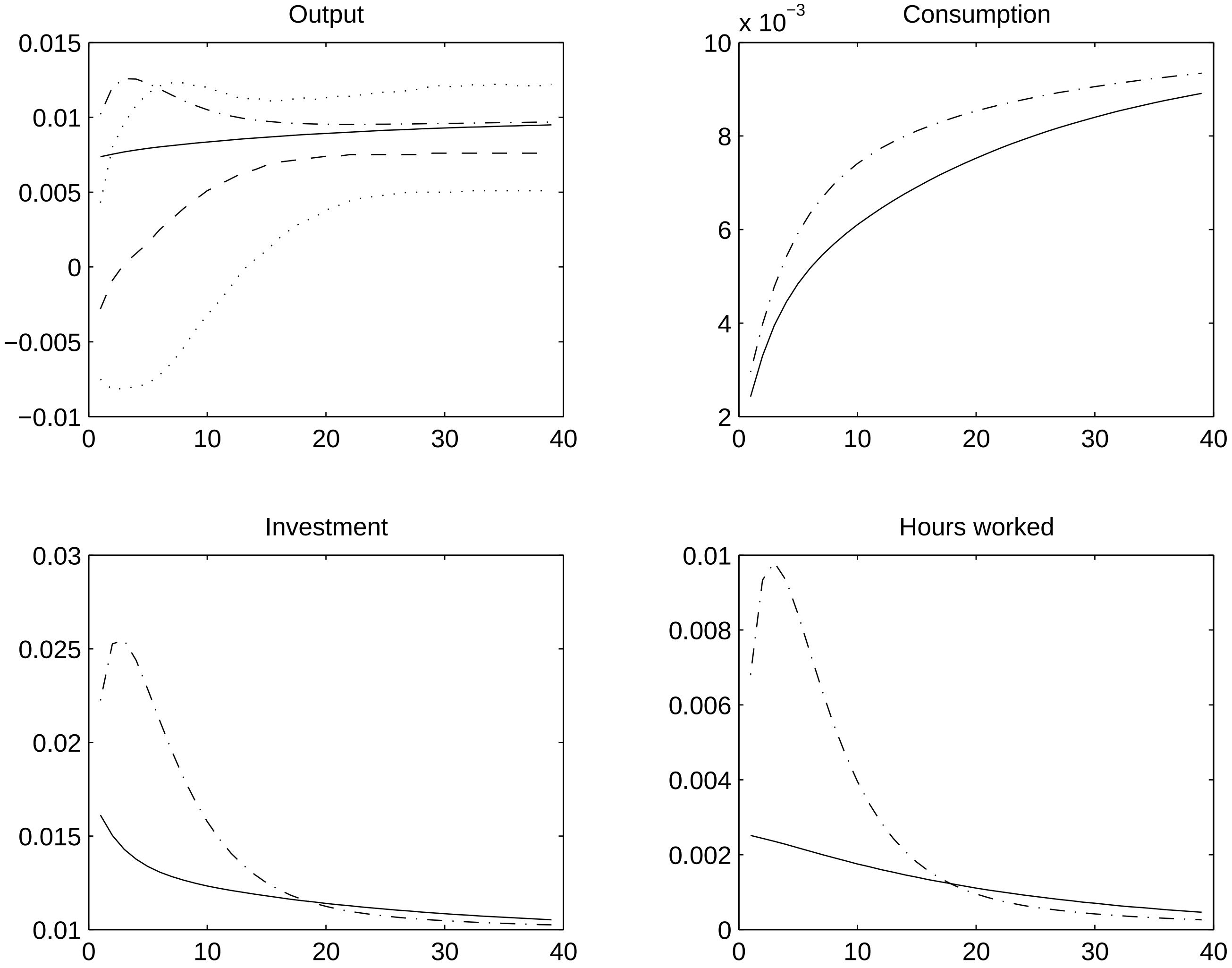
Serial Correlation of Output, Consumption, Investment and Employment Growth in the Flexible Wage (FW) and Sticky Wage (SW) Models



The long-dashed lines are the actual autocorrelations. The dashed-dotted lines and the solid lines are the autocorrelations predicted by the SW and FW models, respectively. The dotted lines are 95% confidence bands.

Figure 4

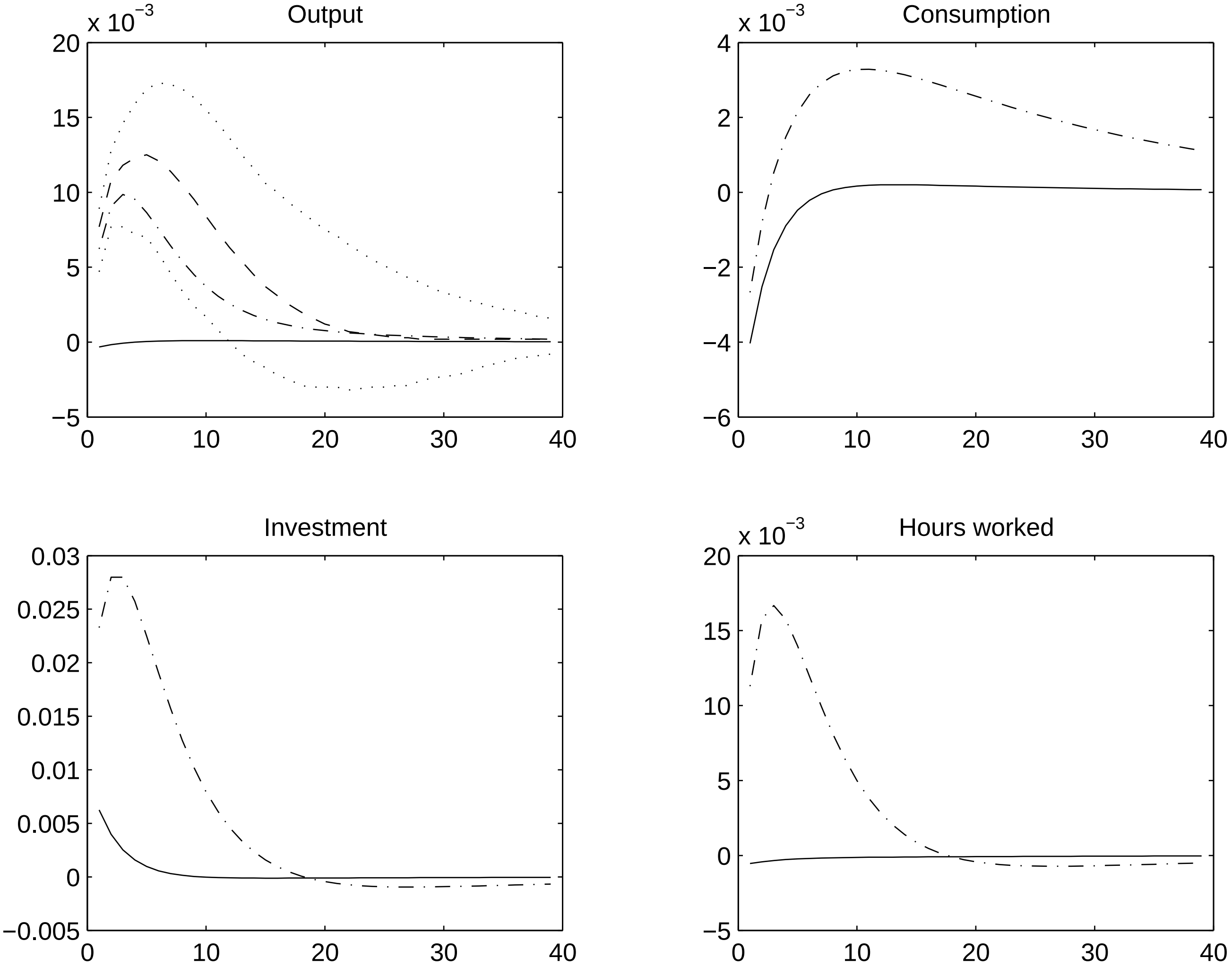
Impulse Response of Output, Consumption, Investment and Employment to a Technology Shock in the FW and SW Models



The long-dashed lines are the estimated impulse response functions. The dashed-dotted lines and the solid lines are the impulse response functions predicted by the SW and FW models, respectively. The dotted lines are 95% confidence bands.

Figure 5

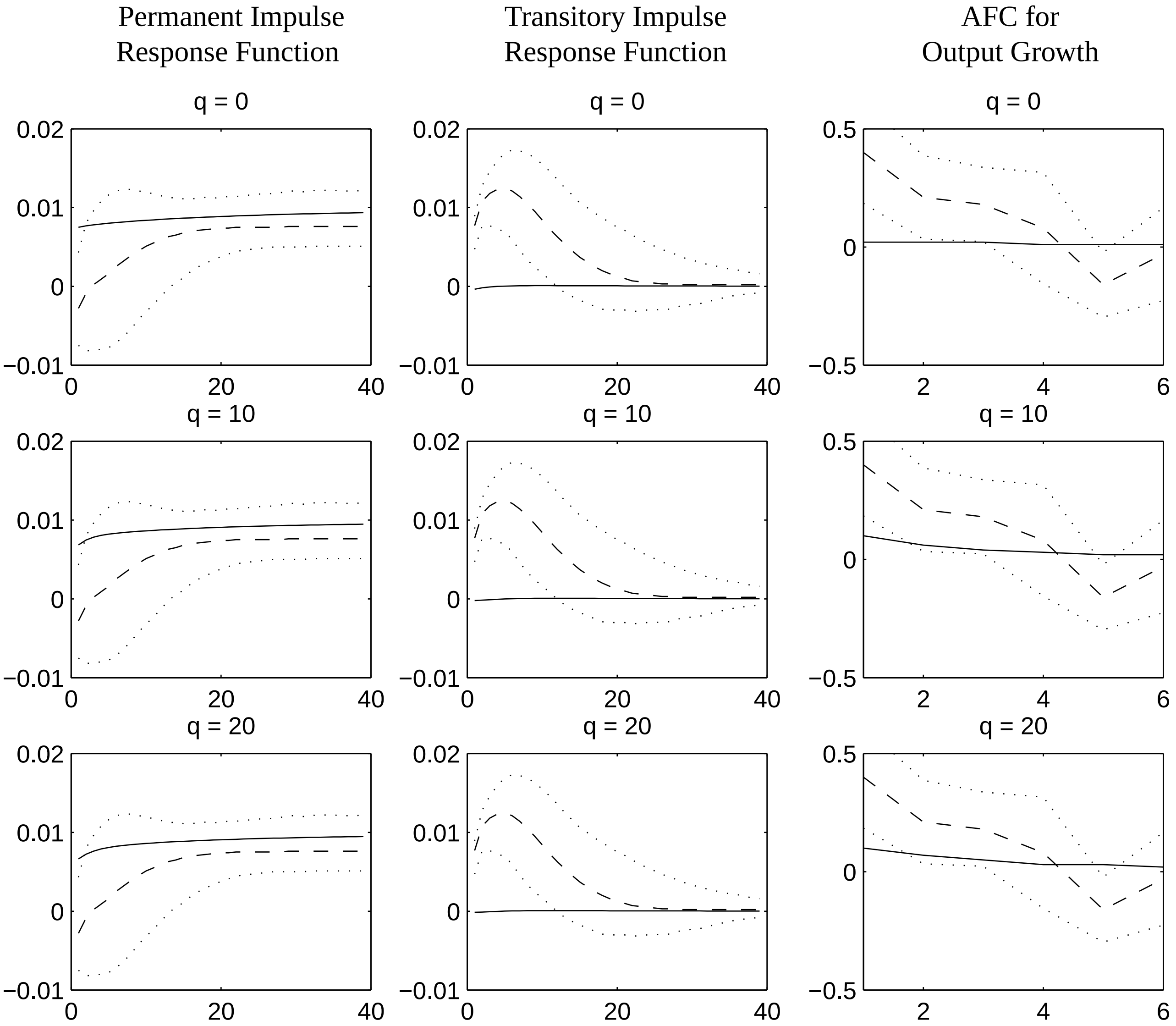
Impulse Response of Output, Consumption, Investment and Employment to a Monetary Shock in the FW and SW Models



The long-dashed lines are the estimated impulse response functions. The dashed-dotted lines and the solid lines are the impulse response functions predicted by the SW and FW models, respectively. The dotted lines are 95% confidence bands.

Figure 6

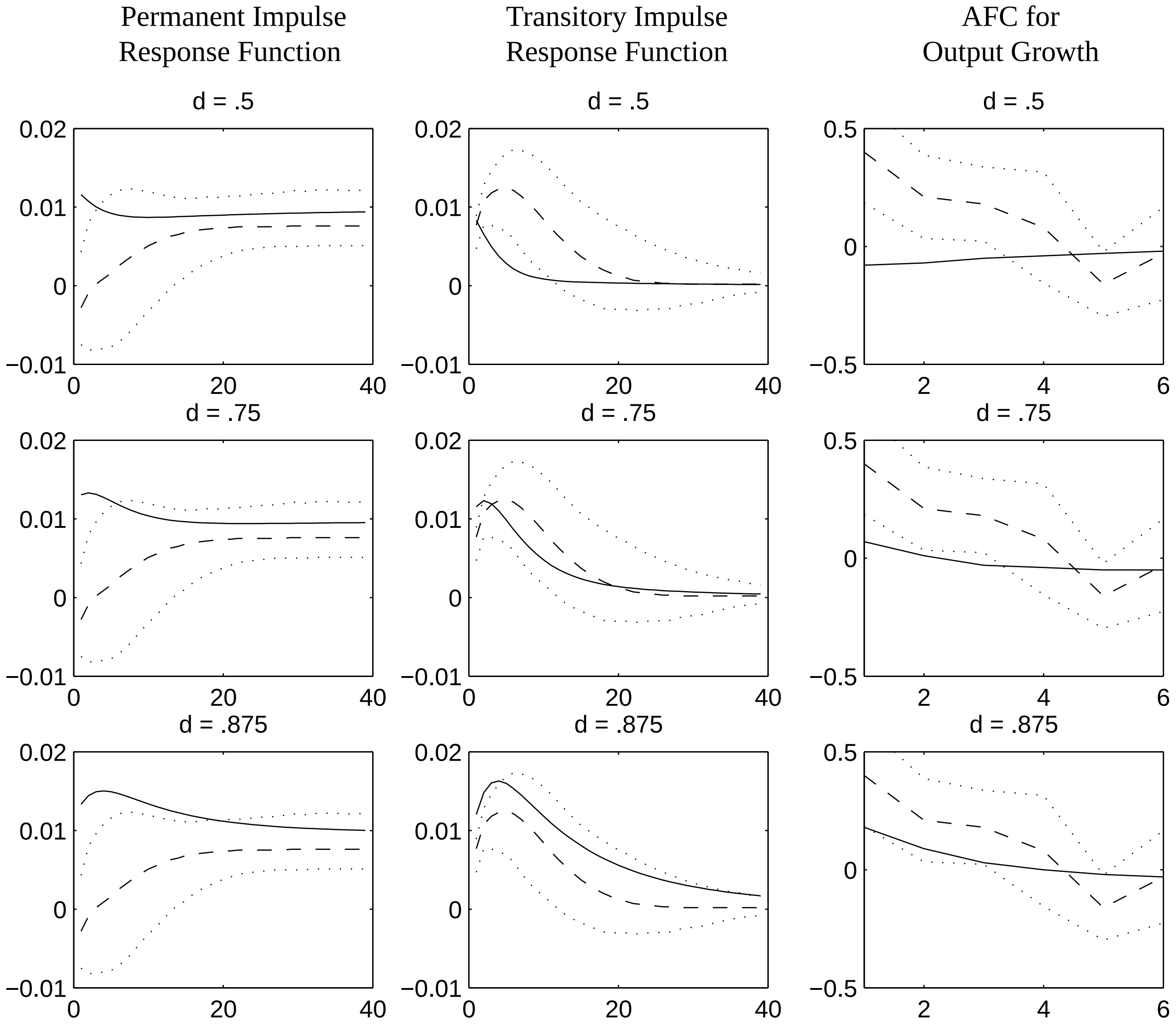
Business Cycle Dynamics with Costly Labor Adjustment Only



The long-dashed lines are the estimated impulse response functions and autocorrelations. The solid lines are the impulse response functions and autocorrelations predicted by the model. The dotted lines are 95% confidence bands.

Figure 7

Business Cycle Dynamics with Sticky Nominal Wages Only



Permanent Impulse Response Function

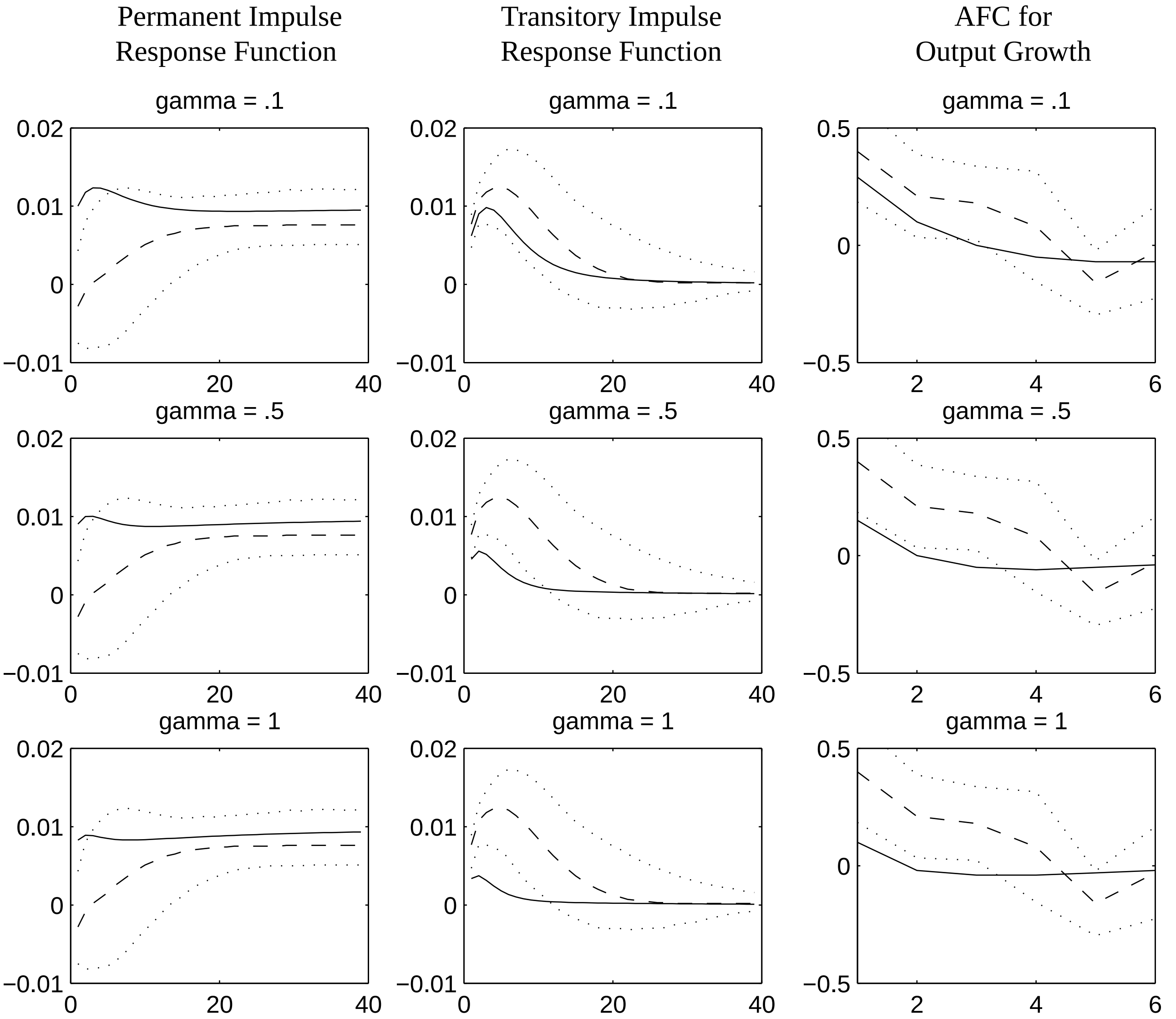
Transitory Impulse Response Function

AFC for Output Growth

The long-dashed lines are the estimated impulse response functions and autocorrelations. The solid lines are the impulse response functions and autocorrelations predicted by the model. The dotted lines are 95% confidence bands.

Figure 8

Sensitivity to Gamma Parameter



The long-dashed lines indicate the estimated impulse response functions and autocorrelations. The solid lines are the impulse response functions and autocorrelations predicted by the model. The dotted lines are 95% confidence bands.