WHY DOES THE CYCLICAL BEHAVIOR OF REAL WAGES CHANGE OVER TIME?

Kevin X.D. Huang
Zheng Liu
Louis Phaneuf

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Research Division
Federal Reserve Bank of Kansas City

kevin.huang@kc.frb.org
zliu5@emory.edu

Abstract

This paper seeks to understand the evolution of the cyclical behavior of U.S. real wage rates from the interwar period to the post World War II period using a dynamic general equilibrium model that emphasizes demand-driven business cycle fluctuations. In the model, changes in the cyclical behavior of real wages arise endogenously from the interactions between nominal wage and price rigidities and an evolving input-output structure.

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1 Introduction

This paper seeks to understand the evolution of the cyclical behavior of U.S. real wage rates from the interwar period to the post World War II period using a dynamic general equilibrium model that emphasizes demand-driven business cycle fluctuations. In the model, changes in the cyclical behavior of real wages arise endogenously from the interactions between nominal wage and price rigidities and an evolving input-output structure. While the primary objective of the paper is to explain changes in the cyclicality of real wages over time, it also sheds light on the endogenous propagation of aggregate demand shocks during the course of business cycles.

Empirical evidence based on consistent measures of wages, prices, and output reveals that U.S. real wages have changed from mildly countercyclical in the interwar period to mildly procyclical in the postwar period. This finding is robust to specific choices of data frequency, variable definitions, and detrending methods (see Section 2 below). A possible explanation for this change is that demand shocks have led to countercyclical real wages during the interwar period, as standard Keynesian models would predict, while supply shocks have given rise to procyclical real wages during the postwar period, in the spirit of real business cycle models. The oil price shocks that occurred in the 1970s are often identified as a factor that has led to procyclical real wages during the postwar period.

The present paper proposes for a deviation from this conventional view based on the following considerations. First, the evidence reported in Susanto Basu and Alan M. Taylor (1999b) indicates that U.S. real wages have switched from being countercyclical to being procyclical from the interwar period (1919-1939) to the Bretton Woods period (1945-1971), a period prior to the onset of the major oil price shocks in the 1970s. Indeed, there is evidence that, even when the period from December 1973 through June 1980 is excluded from the entire postwar sample, real wages remain mildly procyclical [e.g., Christopher Hanes (1996)]. Second, several recent studies cast serious doubts on business cycle theories that assign a prominent role to exogenous variations in technologies in explaining the movements of real GDP and labor-input in the postwar U.S. economy [e.g., Timothy Cogley and James M. Nason (1995), Julio J. Rotemberg and Michael Woodford (1996), Basu (1998), Basu, John G. Fernald and Miles S. Kimball (1998), Jordi Gali (1999), and Neville Francis and Valerie A. Ramey (2002)]. Third, as we survey in Section 2, ample evidence indicates that monetary contractions have in general led to a rise in real wages during the interwar period, especially in the Great Depression, but

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a fall in real wages along with output during the postwar era, a changing cyclical pattern of real wages driven solely by demand shocks that is difficult to be explained by a theory that relies on "different mixtures of shocks."

These considerations, especially the third, lead us to choose to ignore explanations that would rely on the dominance of demand shocks over supply shocks in one period and vice versa in the other for the evolving pattern of real wage cyclicality and to focus instead on demand-driven business cycle fluctuations. We develop a dynamic stochastic general equilibrium business cycle model in which demand shocks are the only source of business cycle fluctuations and where the cyclical behavior of real wages can vary over time as the input-output structure of the economy evolves.

The model developed in the current paper is a variant of Basu's (1995) model with imperfect competition and intermediate goods in production. It differs from Basu's in three important aspects. First, in our model, capital is a variable input in addition to labor and intermediate goods. Second, following Olivier J. Blanchard and Nobuhiro Kiyotaki (1987), our model postulates imperfect competition both between households in the labor market and between producers in the goods market, not just between firms. Third, while Basu assumes price stickiness that is state-dependent, we consider both nominal price and wage rigidities that are time-dependent. As we show in the paper, each of these features plays an important role in generating our main findings.

We model production as an input-output process in the spirit of Basu (1995), who forcefully argues that input-output studies provide ample evidence on a "roundabout" production structure.[1] The linchpin of our analysis, as suggested by historical evidence produced by Hanes (1996, 1999) and corroborated by Basu and Taylor (1999a, b), is that more-processed products have become increasingly important in U.S. aggregate output from the interwar period to the postwar period, indicating increasing roundabout production throughout the twentieth century. In our model, this ascending sophistication of the input-output structure takes the form

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[1] While the input-output table of the Bureau of Economic Analysis apparently features both horizontal "roundabout" and vertical "in-line" production, Basu (1995, pp. 514-515) observes that, "Input-output studies certainly do not support the chain-of-production view; even the most detailed input-output tables show surprisingly few zeros. Empirically, the biggest source of any industry's inputs is usually itself: that is, the diagonal entries of input-output matrices are almost always the largest elements of each column (see Bureau of Economic Analysis, 1984). This seems to lend credence to the view of 'roundabout' rather than 'in-line' production."

of a rising share of intermediate input in production from the interwar period to the postwar period.

In our baseline experiment, we vary the share of intermediate input to examine its implications on the cyclical behavior of the real wage following a monetary policy shock, while maintaining the durations of wage and price contracts at lengths suggested by the empirical evidence surveyed in John B. Taylor (1999). Our main finding is that, as the share of intermediate inputs grows from a range plausible for the interwar period into a range plausible for the postwar period, the real wage switches from being mildly countercyclical to being modestly procyclical. This switch of real wage cyclicality is robust to changes in the monetary policy shock processes prior to and subsequent to World War II, and is accompanied by changes in the business cycle properties of U.S. output across the two periods which also arise endogenously in our model. In particular, fluctuations in aggregate output have become slightly more persistent as the share of intermediate input rises, and less volatile if the changes in monetary policy shock processes are also taken into account.

Our main result builds on a preliminary finding that, in the case with no or a small share of intermediate input, the real wage is countercyclical even when both pricing and wage decisions are staggered with *similar* contract durations, since the price level is less sticky than the nominal wage index due to the flexible capital rental rate.[2] As the share of intermediate inputs grows larger, the rigid intermediate input price becomes a more significant part of marginal cost, so that the price level adjustment becomes more sluggish and the real wage becomes less countercyclical or more procyclical. Meanwhile, the rising share of intermediate input also generates endogenous stickiness in nominal wages through the effect of substitutions between labor and intermediate input, which prevents the real wage from becoming perfectly correlated with real GDP even when the share of intermediate input approaches one. Consequently, the real wage changes from mildly countercyclical to acyclical, and then to moderately procyclical, as the share of intermediate inputs grows from a range plausible for the interwar period into a range plausible for the postwar era.

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[2]This finding stands in contrast to the conventional view articulated by, for example, Olivier J. Blanchard (1986) and Robert J. Barro and Herschel I. Grossman (1971), who abstract from capital accumulation.

2 The Cyclical Behavior of Real Wages: Interwar versus Postwar Evidence

There exists a large body of empirical literature on the cyclical behavior of real wages. The bulk of evidence produced with different types of data, sample periods, real wage definitions, detrending methods, and estimation procedures helps establish the following consensus: (i) measures of unconditional correlations between real wages and output reveal that real wages have changed from being mildly countercyclical during the interwar period to being modestly procyclical during the postwar period; (ii) real wages have switched from being countercyclical to being procyclical *before* the onset of major oil price shocks in the 1970s; and (iii) while a host of studies suggest that monetary shocks have caused real wages to be countercyclical in the interwar period, especially during the Great Depression, several studies indicate that monetary contractions typically lead to a fall in real wages along with output during the postwar period.

A. *The Unconditional Cyclical Behavior of Real Wages*

We first consider the changing cyclical behavior of real wages over time from the perspective of unconditional correlations between real wages and output. An insightful account of the different cyclical behavior of real wages during the interwar and the postwar periods is provided by Bernanke and Powell's (1986), who study the cyclical behavior of industrial labor markets for the two sample periods. In particular, they examine the cyclical properties of real wages at both the frequency domain and the time domain for the periods 1923-1939 and 1954-1982, and find evidence that real wages have become more procyclical during the postwar period. These findings lead them to conclude that there is a marked difference between the prewar and postwar behavior of real wages. The Bernanke-Powell study is important for yet an additional reason. It might be argued that, from the interwar to the postwar period, the sectoral composition used by the Bureau of Economic Analysis to estimate output may have changed, so that the observed changes in the cyclical behavior of real wages may simply be an artifact of the change in sectoral composition. Studies that use aggregate data cannot directly confront this issue. Bernanke and Powell use industry level data, so that the sectoral composition bias is controlled for, and they still find evidence of significant difference in the cyclical behavior of real wages from the interwar to the postwar period.

Compelling evidence on the evolving nature of real wage cyclicality from the interwar period to the postwar period can also be found in Basu and Taylor (1999a, b). Using pooled annual time-series data for thirteen countries, these authors show that the contemporaneous correlation between the log of real wages and the log of output has changed from -0.059 in the interwar period (1919-1939), to 0.162 during the Bretton Woods period (1945-1971), to 0.271 during the more recent period of floating exchange rates (1972-1992).[3] This pattern of real wages—from mildly countercylical during the interwar period to modestly procyclical in the Bretton Woods era and even more procyclical during the period of floating exchange rates— is somewhat more pronounced for the U.S. economy, where the corresponding correlations are -0.444, 0.381, and 0.503, respectively. Thus, the change from countercyclical to procyclical real wages from the interwar to the postwar period had already taken place before the onset of major oil price shocks, which are viewed by many observers as a major source of supply shocks that have led to procyclical real wages during the postwar period. Looking at the producer price index of crude petroleum from 1947 to 2000, one realizes that, prior to 1971, changes in oil prices were not only infrequent but quantitatively insignificant. While more frequent and sizeable variations in oil prices may have contributed to making real wages more procyclical in the second half of the postwar period, forces other than oil price shocks seem nonetheless to be at work during the first half of the postwar period that have triggered the observed switch of real wages from being countercylical to procyclical.[4]

Corroborating evidence on the changing cyclical behavior of U.S. real wages from the interwar to the postwar period is provided by Hanes (1996).[5] Hanes measures the cyclical behavior as the coefficient from a regression of deviations from trend of the log of real wages on deviations from trend of the log of output using series detrended by the Hodrick-Prescott filter, in a sample of monthly U.S. data for the years 1923-1941 (interwar) and 1947-1990 (postwar). Coefficients on output are allowed to shift from the interwar period to the postwar

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[3]The sample of countries includes Argentina, Australia, Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, United Kingdom and the United States. Basu and Taylor detrend their series using a bandpass filter designed to isolate the fluctuations at business-cycle frequencies, i.e. those lasting between two to eight years [see Marianne Baxter and Robert G. King (1995) and James H. Stock and Mark W. Watson (1998)].

[4]We do not exclude the possibility that other supply shocks may have contributed to the procyclicality of real wages during the Bretton Woods period, but we cannot think of a likely candidate for the sample 1947-1971.

[5]Hanes (1993, 2000) also studies the development of nominal wage rigidity in the late ninetheenth century and in three major downturns: those of 1893, 1929 and 1981.

period. Hanes finds that the coefficient on output is negative in the interwar period and positive in the postwar period. Furthermore, the shift from a negative to a positive coefficient from the interwar to the postwar period is statistically significant at the one percent level. This result holds up even if the period from December 1973 through June 1980 is excluded from the postwar sample (hence, even if the major oil price shocks of 1974 and 1979 are omitted).

Yet, Hanes's study is most relevant to our work for another important reason: He provides evidence suggesting historical changes in the nature of consumption goods. Specifically, in the early twentieth century, a typical household purchased goods that were less finished, similar to the goods currently included in the bundle for the producer price index of crude-materials composed by the Bureau of Labor Statistics. Consumption goods have become more finished over the course of the twentieth century. Hanes reports that the value of farm, mining and fishing output used to produce final domestic output has fallen from twenty-six percent to only six percent of the value of final output from the beginning of the twentieth century to the end of the 1960s. Household budget surveys also indicate that the share of consumption expenditure devoted to food (excluding restaurant meals) has fallen from 44.1 percent at the turn of the twentieth century to 11.3 percent in 1983, while the share of the budget category "Other" that includes many complex goods such as automobiles has increased steadily from 17 percent to 45.8 percent over the same period. This evidence suggests a significant historical decline in the importance of crude materials in final consumption and an increase in the sophistication of input-output structure in the U.S. economy from the prewar to the postwar period. Basu and Taylor (1999b) interpret Hanes's evidence as to indicate increasing roundabout production throughout the twentieth century, a feature emphasized in the model developed in the next section.

In addition to the above historical evidence, there is abundant evidence suggesting that U.S. real wages are procyclical in the postwar period. For example, Mark Bils (1985) finds strongly procyclical real wages using disaggregated panel data collected by the National Longitudinal Survey from 1966 to 1980; Gary Solon, Robert Barsky, and Jonathan A. Parker (1994) control for a built-in composition bias in the wage data and corroborate Bils's findings in a sample with a longer period (1967-1987), using data from the Panel Study of Income Dynamics (PSID); Finn E. Kydland and Edward C. Prescott (1990), Paul Gomme and Jeremy Greenwood (1995), and Kydland (1995) report contemporaneous correlations between real wages and output between 0.35 and 0.40 using U.S. postwar macroeconomic variables detrended by the Hodrick-Prescott

filter.[6] In a more recent study, Wouter J. den Haan and Steven W. Sumner (2002) use the correlation coefficients of VAR forecast errors at different forecasting horizons, a measure of comovement originally proposed by den Haan (2000), and find a positive correlation between real wages and aggregate output (even at high frequencies) for the G7 countries over the period from February 1965 to December 2001.[7]

B. *The Conditional Cyclical Behavior of Real Wages*

Available evidence also suggests that real wages have responded differently to monetary shocks during the interwar and the postwar periods. In their monumental study on the monetary history of the United States, Milton Friedman and Anna J. Schwartz (1963) point to monetary policy as the primary cause of the U.S. downturn between 1929 and 1933. They also identify other episodes of the interwar period where an analysis of historical records leads them to conclude that monetary policy actions have had a significant impact on real activity. Recent accounts by James D. Hamilton (1987, 1988), Peter Temin (1989), Bernanke and Harold James (1992), Barry J. Eichengreen (1992), and Bernanke (1995) also attribute the severity of the Great Depression to U.S. monetary policy mistakes.

Multi-country studies by Eichengreen and Jeffrey Sachs (1985, 1986) and Bernanke and Kevin Carey (1996), who use money supplies and aggregate demand shifters as instruments to identify aggregate supply relationships, demonstrate that real wages were countercyclical in the interwar period and that monetary shocks were a central driving force of this result. Bernanke and Carey, in particular, argue on the basis of their findings using data during the 1929-1936 time period for a dismissal of explanations of the output-real wage relationship that do not involve nominal shocks and nonneutrality of money. After all, adverse technology shocks should induce low, not high real wages. Bordo, Christopher J. Erceg and Charles L. Evans (2000) present evidence consistent with this finding through simulations of a general-equilibrium model that features sticky nominal wages and monetary shocks. According to their model, contractionary monetary shocks increased real wages in the downturn phase of

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[6]All these studies employ some measure of real compensation per hour paid in the business sector. The sample period is 1954:I-1984:II in Kydland and Prescott (1990), 1957:I-1991:II in Gomme and Greenwood (1995), and 1954:I-1991:II in Kydland (1995).

[7]One important advantage of the procedure proposed by den Haan (2000) is that it does not require the use of a particular detrending method to induce stationarity in the data so that it does not lose useful information about the dynamics of a system.

1929-1933 and accounted for between 50 and 70 percent of the decline in real GNP at the Depression's trough in the first quarter of 1933.

Empirical studies also suggest that the response of real wages to monetary shocks during the postwar period differs sharply from that of the interwar period. A critical issue in the class of studies that seek to estimate the effects of monetary policy on macroeconomic variables during the postwar period is the identification of exogenous monetary policy shocks. One leading method for identifying monetary shocks is the "narrative approach" proposed by Christina Romer and David Romer (1989), who rely on a careful reading of the minutes of the Federal Open Market Committee, and hence on a sound interpretation of the policy-makers' statements about their own intentions. Using this approach, Marvin J. Barth III and Ramey (2001) find evidence of procyclical real wages at the onset of a Romer-Romer contractionary episode.[8] Another leading method to identify monetary policy shocks combines vector autoregression (VAR) analysis with prior information about the Fed's operating procedures. This is the approach followed by Lawrence J. Christiano, Martin Eichenbaum and Evans (1997, 2001), who find that monetary contractions typically lead to a fall in real wages in the postwar era. Yet, another identifying strategy is that of Olivier J. Blanchard and Danny Quah (1989), who impose long-run restrictions in order to separate the effects of aggregate demand and supply shocks. Using this procedure, Edward N. Gamber and Frederick L. Joutz (1993) find that positive aggregate demand shocks tend to generate a rise in real wages and output during the postwar period.[9]

In sum, the evidence surveyed in this section suggests that real wages have been mildly countercyclical during the interwar period and modestly procyclical during the postwar period. Furthermore, contractionary monetary shocks were followed by a rise in real wages during the interwar period and by a decline in real wages during the postwar period. The shift in the cyclical behavior of real wages from the interwar period to the postwar period has occurred

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[8]In unreported work, we have estimated the impact of a Romer-Romer dummy on the real wages for the entire postwar period and for the Bretton Woods period using quarterly U.S. data. We have found evidence of procyclical real wages during both periods.

[9]One study that arrives at a somewhat different result is that of Charles A. Fleischman (1999), who also impose long-run restrictions. His point estimates suggest a countercyclical response of real wages to aggregate demand shocks. However, the estimated correlations between real wages and output in response to aggregate demand shocks are so imprecise that he concludes that "in response to aggregate demand shocks, real wages and output are essentially uncorrelated." (p.24)

at a time when oil price shocks were virtually absent and when there has been an increase in roundabout production in the U.S. economy.

3 The Model

The economy is populated by a large number of households, each endowed with a differentiated labor skill indexed by $i \in [0,1]$; and a large number of firms, each producing a differentiated good indexed by $j \in [0,1]$. There is a government conducting monetary policy. In each period t, a shock s_t is realized. The history of events up to date t is denoted by $s^t \equiv (s_0, \cdots, s_t)$, with probability $\pi(s^t)$. The initial realization s_0 is given.

Denote by $L(s^t)$ a composite of differentiated labor skills $\{L(i, s^t)\}_{i \in [0,1]}$ such that $L(s^t) = \left[\int_0^1 L(i, s^t)^{(\sigma-1)/\sigma} di \right]^{\sigma/(\sigma-1)}$, and by $X(s^t)$ a composite of differentiated goods $\{X(j, s^t)\}_{j \in [0,1]}$ so that $X(s^t) = \left[\int_0^1 X(j, s^t)^{(\theta-1)/\theta} dj \right]^{\theta/(\theta-1)}$, where $\sigma \in (1, \infty)$ and $\theta \in (1, \infty)$ are the elasticity of substitution between the skills and between the goods, respectively. The composite skill and the composite good are both produced in an aggregation sector that is perfectly competitive. The demand functions for labor skill i and for good j resulting from the optimizing behavior in the aggregation sector are given by

$$L^d(i, s^t) = \left[\frac{W(i, s^t)}{\bar{W}(s^t)} \right]^{-\sigma} L(s^t), \quad X^d(j, s^t) = \left[\frac{P(j, s^t)}{\bar{P}(s^t)} \right]^{-\theta} X(s^t), \tag{1}$$

where the wage rate $\bar{W}(s^t)$ of the composite skill is related to the wage rates $\{W(i, s^t)\}_{i \in [0,1]}$ of the differentiated skills by $\bar{W}(s^t) = \left[\int_0^1 W(i, s^t)^{1-\sigma} di \right]^{1/(1-\sigma)}$, and the price $\bar{P}(s^t)$ of the composite good is related to the prices $\{P(j, s^t)\}_{j \in [0,1]}$ of the differentiated goods by $\bar{P}(s^t) = \left[\int_0^1 P(j, s^t)^{1-\theta} dj \right]^{1/(1-\theta)}$.

The defining feature of the model is that, while the composite skill serves only as an input for the production of each differentiated good, the composite good can serve either as a final consumption or investment good, or as an intermediate production input [e.g., Basu (1995)].

The production of a type j good requires capital, labor, and intermediate inputs, with the production function given by

$$X(j, s^t) = \Gamma(j, s^t)^\phi \left[K(j, s^t)^\alpha L(j, s^t)^{1-\alpha} \right]^{1-\phi} - F, \tag{2}$$

where $\Gamma(j, s^t)$ is the input of intermediate goods, $K(j, s^t)$ and $L(j, s^t)$ are the inputs of capital and the composite skill, and F is a fixed cost that is identical across firms. The parameters

$\phi \in (0, 1)$, $\alpha \in (0, 1)$, and $(1 - \alpha)$ are the elasticities of output with respect to intermediate input, capital input, and labor input, respectively.

Firms are price-takers in the input markets and imperfect competitors in the output markets, where they set prices for their goods, taking the demand schedule in (1) as given. At each date t, a fraction $1/N_p$ of the firms chooses new prices after the realization of the shock s_t. Once a price is set, it remains effective for N_p periods. All firms are divided into N_p cohorts based on the timing of their pricing decisions. A firm j in the cohort that can choose a new price at date t solves the problem:

$$\max_{P(j,s^t)} \sum_{\tau=t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau|s^t) \left[P(j, s^t) X^d(j, s^\tau) - V(X^d(j, s^\tau)) \right], \tag{3}$$

where $D(s^\tau|s^t)$ is the price of one dollar at s^τ in units of dollars at s^t, and $V(X^d(j, s^\tau))$ is the cost of producing $X^d(j, s^\tau)$, equal to $V(s^\tau)[X^d(j, s^\tau) + F]$, with $V(s^\tau)$ denoting the marginal cost of production at s^τ.

Solving the profit-maximization problem (3) yields the optimal pricing decision rule:

$$P(j, s^t) = \frac{\theta}{\theta - 1} \frac{\sum_{\tau=t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau|s^t) X^d(j, s^\tau) V(s^\tau)}{\sum_{\tau=t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau|s^t) X^d(j, s^\tau)}, \tag{4}$$

which says that the optimal price is a constant markup during a weighted average of the marginal costs for the periods in which the price will be effective. Solving the firm's cost-minimization problem yields the marginal cost function:

$$V(s^\tau) = \bar{\phi} \bar{P}(s^\tau)^\phi [R^k(s^\tau)^\alpha \bar{W}(s^\tau)^{1-\alpha}]^{1-\phi}, \tag{5}$$

where $\bar{\phi}$ is a constant determined by ϕ and α. The (conditional) demand functions for intermediate input and for primary factor inputs in producing $X^d(j, s^\tau)$ derived from cost-minimization are given by

$$\Gamma(j, s^\tau) = \phi \frac{V(s^\tau)[X^d(j, s^\tau) + F]}{\bar{P}(s^\tau)}, \tag{6}$$

$$K(j, s^\tau) = \alpha(1 - \phi) \frac{V(s^\tau)[X^d(j, s^\tau) + F]}{R^k(s^\tau)}, \tag{7}$$

and

$$L(j, s^\tau) = (1 - \alpha)(1 - \phi) \frac{V(s^\tau)[X^d(j, s^\tau) + F]}{\bar{W}(s^\tau)}. \tag{8}$$

Even if a firm cannot choose a new price at a given date, it would still need to choose the inputs of the intermediate good, the capital, and the composite labor in order to minimize the production cost.

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Each household i has a subjective discount factor $\beta \in (0,1)$ and a utility function

$$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t) \left\{ \ln C^*(i, s^t)) - \eta \frac{L(i, s^t)^{1+\xi}}{1+\xi} \right\}, \qquad (9)$$

where $C^*(i, s^t) \equiv [bC(i)^\nu + (1-b)(M(i)/\bar{P})^\nu]^{1/\nu}$ is a CES composite of consumption good and real money balances, and $L(i, s^t)$ is the household's hours worked.

The budget constraint facing the household in event history s^t is

$$\bar{P}(s^t)Y(i, s^t) + \sum_{s^{t+1}} D(s^{t+1}|s^t)B(i, s^{t+1}) + M(i, s^t) \leq$$
$$W(i, s^t)L^d(i, s^t) + R^k(s^t)K(i, s^{t-1}) + \Pi(i, s^t) + B(i, s^t) + M(i, s^{t-1}) + T(i, s^t), \quad (10)$$

where $B(i, s^{t+1})$ is a nominal bond that represents a claim to one dollar in event s^{t+1} and costs $D(s^{t+1}|s^t)$ dollars at s^t, $W(i, s^t)$ is a nominal wage for i's labor skill, $L^d(i, s^t)$ is a demand schedule for type i labor specified in (1), $R^k(s^t)$ is a nominal rental rate on capital, $K(i, s^{t-1})$ is i's beginning-of-period capital stock, $\Pi(i, s^t)$ is its share of profits, and $T(i, s^t)$ is a lump-sum transfer it receives from the government. The composite good $Y(i, s^t)$ can be either consumed or invested. Thus

$$Y(i, s^t) = C(i, s^t) + K(i, s^t) - (1-\delta)K(i, s^{t-1}) + \psi \frac{(K(i, s^t) - K(i, s^{t-1}))^2}{K(i, s^{t-1})}, \qquad (11)$$

where $\delta \in (0,1)$ is a capital depreciation rate and the quadratic term is a capital adjustment cost with a scale parameter $\psi > 0$.

Households are price-takers in the goods markets and imperfect competitors in the labor markets, where they set nominal wages for their skills, taking the demand schedule (1) as given. At each date t and upon the realization of the shock s_t, a fraction $1/N_w$ of the households chooses new wages. These wages, once set, remain effective for N_w periods. All households are divided into N_w cohorts based on the timing of their wage decisions. Each household maximizes (9) subject to (10), (11), and a borrowing constraint $B(i, s^{t+1}) \geq -\underline{B}$, for some large positive number $\underline{B}$. The initial conditions on bond, money, and capital are given. At date t, if a household i can set a new wage, then the optimal choice of its nominal wage is given by

$$W(i, s^t) = \frac{\sigma}{\sigma - 1} \frac{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t)L^d(i, s^\tau)MRS(i, s^\tau)}{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t)L^d(i, s^\tau)}, \qquad (12)$$

where $MRS(i, s^\tau)$ denotes the marginal rate of substitution between leisure and income. Thus the optimal wage is a markup over a weighted average of the MRS during the periods in

which the wage will remain effective. All households need to make decisions on consumption, investment, money balances, and bond holdings, and we have used the standard first order condition for bond holdings in deriving (12).

Our purpose is to establish a link between the increasing sophistication of input-output connections and the evolving nature of the cyclical behaviors of real wages over time in the U.S. economy. For reasons stated in the introduction, we focus on demand-driven business cycle fluctuations. In what follows, we examine the dynamic effects on real GDP and the real wage of a monetary policy shock, which is a particular type of aggregate demand shock.[10]

In the model economy, monetary policy is conducted via a lump-sum transfer so that $\int_0^1 T(i, s^t) = M^s(s^t) - M^s(s^{t-1})$. Money stock grows at a rate $\mu(s^t)$, which follows a stationary stochastic process given by

$$\ln \mu(s^t) = \rho \ln \mu(s^{t-1}) + \varepsilon_t, \tag{13}$$

where $0 < \rho < 1$ and ε_t is a white noise process with a zero mean and a finite variance σ_ε^2.

An equilibrium for this economy consists of allocations $C(i, s^t)$, $K(i, s^t)$, $B(i, s^{t+1})$, $M(i, s^t)$, and wage $W(i, s^t)$ for household i, for all $i \in [0, 1]$, allocations $\Gamma(j, s^t)$, $K(j, s^t)$, $L(j, s^t)$, and price $P(j, s^t)$ for firm j, for all $j \in [0, 1]$, together with prices $D(s^{t+1}|s^t)$, $\bar{P}(s^t)$, $R^k(s^t)$, and $\bar{W}(s^t)$, that satisfy the following conditions: (i) taking the wages and all prices but its own as given, each firm's allocations and price solve its profit maximization problem; (ii) taking the prices and all wages but its own as given, each household's allocations and wage solve its utility maximization problem; (iii) markets for money, bonds, capital, the composite labor, and the composite good clear; (iv) monetary policy is as specified.

We suppose that there are state-contingent financial contracts that make it possible to insure each household against the idiosyncratic income risk that may arise from the asynchronized wage adjustments. We assume that, with such financial arrangements, equilibrium consumption, investment, and holdings of real money balances are identical across households, although nominal wages and hours worked may differ.[11] It follows that $Y(i, s^t) = \int_0^1 Y(i, s^t) di = Y(s^t)$

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[10]In a unreported experiment, we find that the results are robust when we consider an alternative form of aggregate demand shocks, in particular, shocks to nominal GDP.

[11]The financial arrangements that we imagine here serve only to insure households' consumption and real balances, but not leisure. The reason that we assume the existence of such implicit financial arrangements is to help simplify expositions [e.g., Rotemberg and Woodford (1997) and Christiano, et al. (2001)]. In the Appendix, we present an alternative model structure where no such financial arrangements are necessary for aggregation purposes and where equilibrium dynamics are identical as those in the baseline model.

for all i and for every s^t, where $Y(s^t)$ denotes real GDP. Given this relation, along with (6), the market clearing condition $\int_0^1 Y(i, s^t)di + \int_0^1 \Gamma(j, s^t)dj = X(s^t)$ for the composite good implies that equilibrium real GDP is related to gross output by

$$Y(s^t) = X(s^t) - \phi \frac{V(s^t)}{\bar{P}(s^t)} \left[G(s^t)X(s^t) + F \right], \tag{14}$$

where $G(s^t) \equiv \int_0^1 [P(j, s^t)/\bar{P}(s^t)]^{-\theta}dj$ captures the price-dispersion effect of staggered price contracts. Meanwhile, the market clearing conditions $\int_0^1 K^d(j, s^t)dj = \int_0^1 K(i, s^{t-1})di \equiv K(s^{t-1})$ for capital and $\int_0^1 L(j, s^t)dj = L(s^t)$ for the composite skill, along with (7)-(8), imply that equilibrium aggregate capital stock and composite skill are related to gross output by

$$K(s^{t-1}) = \alpha(1 - \phi) \frac{V(s^t)}{R^k(s^t)} \left[G(s^t)X(s^t) + F \right], \tag{15}$$

$$L(s^t) = (1 - \alpha)(1 - \phi) \frac{V(s^t)}{\bar{W}(s^t)} \left[G(s^t)X(s^t) + F \right]. \tag{16}$$

Equations (14), (15), (16), the money market clearing condition, together with the price-setting equation (4) and the wage-setting equation (12), characterize an equilibrium.

4 Parameter Calibration

The parameters to be calibrated include the subjective discount factor β, the preference parameters b, ν, and ξ, the technology parameters ϕ and α, the elasticity of substitution between differentiated goods θ and between differentiated labor skills σ, the capital depreciation rate δ, the adjustment cost parameter ψ, the duration of nominal contracts N_p and N_w, and the monetary policy parameters ρ and σ_ε.[12] We also need to calibrate the steady state ratio of the fixed cost to gross output F/X. The calibrated values are summarized in Table 1.

A period in our model corresponds to a quarter of a year. Following the standard business cycle literature, we set $\beta = 0.99$, $\xi = 2$, and $\delta = 0.021$, so that, in a steady state, the annualized real interest rate is 4 percent, the intertemporal elasticity of labor hours is 0.5, and the annual capital depreciation rate is 8.4 percent. To assign values for b and ν, we use the equilibrium money demand equation

$$\log \left(\frac{M(s^t)}{P(s^t)} \right) = -\frac{1}{1-\nu}\log \left(\frac{b}{1-b} \right) + \log(C(s^t)) - \frac{1}{1-\nu}\log \left(\frac{R(s^t)-1}{R(s^t)} \right),$$

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[12]The parameter η in the utility function does not affect equilibrium dynamics (in the log-linearized equilibrium system) and thus we do not need to assign a particular value to it.

where $R(s^t) = \left(\sum_{s^{t+1}} D(s^{t+1}|s^t) \right)^{-1}$ is the gross nominal interest rate. A regression of consumption velocity on nominal interest rates, using U.S. M1 data from quarter one of 1959 to quarter four of 1999, results in $b = 0.998$ and $\nu = -1.76$. The implied interest elasticity is 0.36, with a standard error of 0.04, similar to those obtained by V.V. Chari, et al. (2000) and Robert E. Lucas, Jr. (1988).[13] We calibrate the capital adjustment cost parameter ψ so that the model generates a standard deviation of investment 2.3 times as large as that of real GDP, in accordance with the evidence produced by Eric Leeper, et al. (1996).[14]

The parameter θ determines the steady-state markup of prices over marginal cost, with the markup given by $\mu_p = \theta/(\theta - 1)$. Recent studies by Basu and Fernald (1997a, 2000) suggest that the value-added markup, controlling for factor capacity utilization rates, is about 1.05. Thus, we set $\theta = 21$, so that $\mu_p = 1.05$.[15] The parameter σ measures the elasticity of substitution between differentiated labor skills. We set $\sigma = 3$ based on the micro-evidence produced by Peter Griffin (1992, 1996), implying that a one-percent rise in a household's nominal wage relative to the wage index leads to a three-percent fall in its employed hours relative to aggregate employment.

Given the calibrated value of θ (or μ_p), we set the steady state ratio of the fixed cost to gross output F/X equal to $\mu_p - 1 = 0.05$, so that the steady state profits for firms are zero (and there will be no incentive to enter or exit the industry in the long-run). With zero economic

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[13]The theoretically correct measure of money should be non-interest-bearing instruments, that is, the monetary base. Since our model nests a few popular models in the literature as special cases (e.g., Chari, et al. (2000) and Huang and Liu (2002a)), and these authors use M1 to calibrate their money demand parameters, we also use M1 in our baseline calibration to have our model better connected to this strand of literature. The main results are not sensitive to the use of M0 in place of M1 (not reported).

[14]The reason that we include capital adjustment costs is to get the volatilities of investment and output right [e.g., Chari, et al. (2000)]. The patterns of real wage cyclicality is not sensitive to the inclusion of adjustment costs.

[15]Basu and Fernald (2000) report that, without any utilization correction, the value-added markup is about 1.12, similar to the values used by some other studies [e.g., Rotemberg and Woodford (1997)]. Basu and Fernald (2000) also note that, in the presence of intermediate input, if the intermediate input price differs from gross output price, then the gross-output markup (corresponding to $\theta/(\theta - 1)$ in our model) is no larger than the value-added markup. Since the symmetry in our model implies that the price index serves as the deflator for both value added and gross output, the value-added markup in the model equals the gross-output markup. We have also experimented with other values of μ_p and find that the main results do not change for any given value of ϕ (not reported). Yet, as we will make clear below, the markup parameter does affect our calibration of ϕ.

profit, the parameter α corresponds to the share of payments to capital in total value added in the National Income and Product Account (NIPA). The implied value of α is 1/3.[16]

The parameter ϕ measures the share of payments to intermediate input in total production cost (i.e., the cost share). With markup pricing, it equals the product of the share of intermediate input in gross output (i.e., the revenue share) and the steady state markup. We rely on two sources of data to calibrate the value of ϕ for the postwar U.S. economy. The first source is the study by Dale Jorgenson, et al. (1987), who find that the revenue share of intermediate input in total manufacturing output is 50 percent or more for the period 1947-1979. Based on this study, Basu (1995) views 0.5 as a lower bound for ϕ. The second source is our direct calculation using data in the 1998 Annual Input-Output Table of the Bureau of Economic Analysis (BEA 1998). In the Input-Output Table, the ratio of "total intermediate" to "total industry output" for the manufacturing sector is 0.6. Thus, given that the calibrated markup is $\mu_p = 1.05$, the cost share of intermediate input ϕ should lie in the range between 0.53 and 0.63. We take $\phi = 0.6$ as a benchmark for the postwar U.S. economy, while we also consider ϕ in the range between 0.6 and 0.7 as plausible for this sample period.[17]

Unlike the postwar period, there seems to be little direct evidence on the share of intermediate input in manufacturing output during the interwar period. Historical evidence suggests that the input-output structure in the U.S. economy has become more sophisticated from the interwar period to the postwar period (e.g., Hanes (1996)). In the early years, a household's consumption basket was primarily made up of relatively unfinished goods. Since then, there has been more roundabout production before a typical good enters the final consumption basket. This general tendency suggests that the value of ϕ has increased over time. For instance, John W. Kendrick (1961) reports gross output and value added for several key sectors in the prewar period, but all numbers are indexes with 1929 being 100, except for farm output in Table B-1 (p. 347), where he reports the constant 1929 dollar values. Using this information,

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[16]A variety of evidence suggests that profit rates are close to zero [e.g., Rotemberg and Woodford (1995) and Basu and Fernald (1997b)]. We are grateful to an anonymous referee who suggests the inclusion of the fixed cost so that the economic profit is zero in the long-run and α can be calibrated using consistent data in the NIPA.

[17]As we have noted in footnote 1, BEA's (1998) input-output table suggests that industries in the U.S. economy are inter-connected through both roundabout and vertical "in-line" production, while our model has roundabout production only. In this sense, the parameter ϕ summarizes the importance of both roundabout and in-line production.

we can directly calculate the share of intermediate input in gross farm output for the interwar period: it lies in the range between 0.18 and 0.22 in the period 1919-1937. In the postwar period, according to BEA (1998), the corresponding share has risen to around 0.6. Although this information does not help us pin down a specific range of the share parameter in the manufacturing sector during the interwar period, it does confirm the general tendency that the input-output structure has become more sophisticated over time. In light of the limited evidence, it seems reasonable to consider a value of ϕ between 0.3 and 0.5 during the interwar period, when the input-output structure was relatively simple.

In our quantitative experiments, we do not restrict ϕ to a particular value. Instead, we examine the cross-correlations between real wages and output for a range of ϕ values between 0 and 0.9 to illustrate the evolving pattern of the cyclical behavior of real wages as the input-output structure becomes more sophisticated.

Ample empirical evidence reveals that the lengths of nominal contracts are roughly the same for both prices and nominal wages: they both last for about one year [see, for example, the comprehensive survey by Taylor (1999)]. Thus, we set $N_p = 4$ and $N_w = 4$ as the benchmark values, so that, in each quarter, a fraction 1/4 of firms and households can adjust prices and wages; and once adjusted, they remain effective for four quarters.[18]

Finally, we set the serial correlation parameter ρ of money growth rate to 0.68 and the standard deviation of the innovation term in the money growth process σ_ε to 0.008, based on M1 data in the postwar U.S. economy.[19]

5   Explaining the Cyclical Behavior of Real Wages

Empirical evidence reveals that real wages in the U.S. economy have switched from being mildly countercyclical during the interwar period to being mildly procyclical in the postwar era. At the same time, the input-output structure in the economy has become increasingly sophisticated. In this section, we explore the apparent connections between the historical

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[18]In an unreported experiment, we vary the lengths of nominal contracts and find that, as long as there is no significant difference in the durations of price and wage contracts, the real wage will change from modestly countercyclical for ϕ in a range plausible for the prewar era to weakly procyclical as ϕ grows into a range plausible for the postwar period.

[19]As we show in the next section, the main results are not sensitive if we calibrate the money shock process using prewar M1 data (see Figure 5).

evolution of the cyclical properties of real wages and the evolving input-output structure. We do so by considering three stylized models, each a special case nested by the baseline model, all with intermediate goods but with different sources of nominal rigidities. We investigate what mixture of nominal and real rigidities can account for the observed evolving nature of real wage cyclicality, while at the same time generate plausible output dynamics.

A. Staggered Price-Setting

The first model we consider features staggered price-setting and an input-output structure, with flexible nominal wage decisions. In the absence of intermediate goods, it is well known that a sticky price model tends to generate strongly procyclical real wages in response to aggregate demand shocks [e.g., Chari, et al. (2000)]. With sticky prices, an expansionary aggregate demand shock leads to higher real output and consumption. Meanwhile, the higher demand for goods pushes up the demand for labor input. Since nominal wages are flexible, the optimal wage-setting equation (12) implies that the real wage is a constant "markup" over the marginal rate of substitution (MRS) between leisure and consumption. With higher labor demand, the marginal disutility of working rises; with higher consumption, the marginal utility of consumption falls. In consequence, the MRS rises, so does the real wage. Adding intermediate goods in production does not dampen the increase in the real wage. As the share of intermediate goods rises, price adjustments become more sluggish and thus the responses of consumption and labor input become stronger. It follows that the MRS and therefor the real wage remain strongly procyclical.

Figure 1 plots the impulse responses of real GDP and the real wage following a one-percent shock to the money growth rate. The responses of the two variables apparently display very similar patterns, suggesting high cross-correlations between the two variables. Figure 4, which plots the contemporaneous cross-correlations between the real wage and output, confirms that this is indeed the case: With the calibrated money growth process and staggered price-setting, the correlation is strongly positive and is insensitive to changes in the share of intermediate input. Thus, staggered price-setting alone is incapable of generating the observed switch of real wage cyclicality, with or without intermediate input.

The strong procyclicality of real wage is accompanied by a lack of output persistence. Since the real wage is part of the real marginal cost, a strongly procyclical real wage forces firms to pass the increase in their labor cost to an increase in prices whenever they can set new prices.

With no intermediate goods, the price level will rise completely as soon as all firms finish adjusting prices and thus there is no output persistence. The incorporation of intermediate input in production reduces the share of labor cost and thus increases the price level rigidity and output persistence. Figure 1 confirms this intuition: with no intermediate goods, the response of real GDP does not last beyond the initial duration of the price contracts; as ϕ rises, the response of real GDP becomes more persistent, but the quantitative difference is small. The first-order autocorrelation coefficients displayed in Table 2 (the first row) conveys the same message: as ϕ rises, the autocorrelation of output also increases, but the magnitude remains small.

B. *Staggered Wage-Setting*

The second model we consider features staggered wage-setting and an input-output structure, with flexible price adjustments. Figure 2 displays the responses of real GDP and the real wage for various values of ϕ. The model produces a significant amount of output persistence. But it predicts strongly countercyclical movements of the real wage. This is because prices are a constant markup over the marginal cost, and the marginal cost, being composed of the rigid nominal wage index and the flexible nominal rental rate on capital, changes more quickly than does the wage index. Incorporating intermediate goods does not alter the real wage behavior, nor does it help magnify output persistence. Since pricing decisions are not staggered here, all firms set the same price in a symmetric equilibrium. Thus, the optimal pricing equation is the same with or without intermediate goods. This intuition becomes more transparent when we look at the optimal pricing decision rule, which is a special case of equation (4) and is given by

$$P(j, s^t) = \frac{\theta}{\theta - 1} \tilde{\phi} \bar{P}(s^t)^\phi R^k(s^t)^{(1-\phi)\alpha} \bar{W}(s^t)^{(1-\phi)(1-\alpha)}, \tag{17}$$

where we have plugged in the unit cost function from (5). With synchronized pricing decisions, $P(j) = \bar{P}$ for all j, and thus the pricing equation (17) reduces to

$$P(s^t) = \frac{\theta}{\theta - 1} \tilde{\phi} R^k(s^t)^\alpha \bar{W}(s^t)^{1-\alpha}, \tag{18}$$

which is formally identical (up to a constant) to the pricing equation in the model with staggered wage contracts but without intermediate goods [e.g., Huang and Liu (2002a)].[20] Thus a

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[20]With staggered wage-setting alone, the share of intermediate input only affects the steady state values, but not deviations from the steady state.

staggered wage model, with or without intermediate goods, generates substantial output persistence and strongly countercyclical responses of the real wage following a monetary shock.

We also compute the contemporaneous cross-correlations between the real wage and real GDP in the model with staggered wage-setting under calibrated money growth shocks. As is evident from Figure 4, the real wage is strongly negatively correlated with real GDP, and the correlations are not sensitive to the values of ϕ, conforming the near mirror-image responses of the two variables displayed in Figure 2. Meanwhile, Table 2 (the second row) shows that, under calibrated money shocks, the model with staggered wages generates substantially larger output persistence (measured by the autocorrelation coefficients) than does the model with staggered prices.

C. *Staggered Price-Setting and Staggered Wage-Setting*

Since real wages are procyclical under sticky prices and countercyclical under sticky wages, a common view is that having both pricing and wage decisions staggered should imply acyclical real wages [e.g., Blanchard (1986) and Barro and Grossman (1971)]. We find here that this is generally not the case in a dynamic general equilibrium model with capital accumulation. As shown in Figure 3 and Figure 4, in the absence of intermediate input, the real wage is countercyclical even when both pricing and wage-setting decisions are staggered with similar contract durations. The reason is that, with both labor and capital used in production, the marginal production cost records both the rigid wage index and the flexible capital rental rate, so that it varies more than the wage index, implying a more variable price level as well.[21]

With intermediate input in production, the real wage becomes less countercyclical or more procyclical. In particular, Figure 4 shows that the correlation between the two variables turns from negative when ϕ is small to positive when ϕ exceeds 0.55. As ϕ grows from between 0.3 and 0.5, a range plausible for the interwar period, to between 0.6 and 0.7, a range plausible for the postwar era, the correlation changes from between -0.26 and -0.07 to between 0.09 and 0.30. In this sense, the model with both staggered price-setting and staggered wage-setting, along with the roundabout input-output structure, is able to explain the observed patterns of real wage cyclicality: it switched from mildly countercyclical during the interwar period when

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[21]In a model like this (with capital accumulation but without intermediate input), one could still obtain the Blanchard-Barro-Grossman result by varying the durations of price and wage contracts. But there seems to be no evidence that these contract durations systematically differ.

the input-output structure was relatively simple to moderately procyclical during the postwar era when the input-output structure becomes more sophisticated. As ϕ rises, Figure 3 and Table 2 (the third row) shows that the fluctuations in real GDP also become more persistent.

The key to understanding why the model with all three rigidities is capable of generating the desired patterns of real wage movements while at the same time producing significant output persistence is to observe the response of marginal production cost to the shock. In this case, the marginal cost records not only the nominal wage index and the capital rental rate, but also the intermediate input price. The rigidity in the price of intermediate input due to staggered nominal contracts transmits into the sluggishness in the movements of this third part of the marginal cost and, as the share of intermediate input rises, the marginal cost becomes less procyclical even when the real wage becomes more so. A less variable marginal cost increases the rigidity in firms' pricing decisions and opens the way for the model to generate output persistence and to turn the response of the real wage from being countercyclical or acyclical into being weakly procyclical.

A natural question is that, as the input-output structure becomes more sophisticated, as is quite plausible in the future, would the real wage tend to become perfectly correlated with real GDP? The answer is negative. For the sake of argument, we extend the value of ϕ from its postwar upper bound of 0.7 to 0.9 to capture a possibly more sophisticated input-output structure in the future. We find that the correlation would not exceed 0.70. There are two factors in the model that prevent the real wage from becoming perfectly correlated with real GDP even as ϕ grows arbitrarily close to one. First, nominal wages are sticky. Second, deviations of the nominal wage index from the intermediate input price tend to induce firms to substitute away from labor and toward materials. The greater is the share of intermediate input, the larger the factor substitution effect is. Thus, even if the input-output structure is to become more sophisticated in the future, our model predicts that real wages may remain moderately procyclical.

D. *Did Changes in Monetary Policy Shock Process Drive the Results?*

The monetary policy shock process in the baseline model are calibrated to the postwar U.S. data. Since the policy may have changed from the interwar to the postwar period, one could reasonably argue that changes in the monetary policy shock processes, rather than the increasing complexity of input-output structure, might be responsible for the observed

evolution in the cyclical behavior of real wages in the U.S. economy. In other words, did changes in monetary policy shock process drive our results?

To answer this question, we begin by calibrating the interwar monetary policy shock process using quarterly U.S. M1 data from 1919:I to 1939:IV [taken from Robert J. Gordon (1986, Appendix B, pp. 803-805)], assuming that the money growth rate follows the same process as in (13), but with potentially different parameters. Simple autoregression of the money growth rate yields $\rho = 0.75$ and $\sigma_\varepsilon = 0.0167$ for the interwar period. We then compare the model's predicted cross-correlations between real wages and output under the interwar shocks versus the postwar shocks. Figure 5 shows that the results are not sensitive to changes in the shock processes. In particular, for any fixed value of ϕ in the plausible range for the two sample periods, the correlation coefficient does not switch sign as the monetary shock process switches from the interwar one to the postwar one. For example, if ϕ is fixed at 0.4, the real wage stays countercyclical regardless of which shock process is used; similarly, if ϕ is fixed at 0.6, the real wage remains procyclical regardless of the shock process. When ϕ increases from the prewar benchmark value of 0.4 (or even 0.5) to the postwar benchmark value of 0.6, the real wage switches from weakly countercyclical in the early years to weakly procyclical in the more recent periods, regardless of the money shock process. This finding does not provide for a support to the notion that changes in monetary policy process have caused the change in the cyclical patterns of real wages over time.

By calibrating monetary shock processes for the two periods separately, we can also address a related issue: Can the model generate the observed changes in the business cycle properties of real GDP? In particular, does the model predict more persistence and less volatility in real GDP as the U.S. economy moved from the interwar period to the postwar era, an observation documented in the literature (e.g., J. Bradford Delong and Lawrence H. Summers (1986))? To answer this question, we compare the autocorrelations and standard deviations of output in the two sample periods under the two separate money shock processes. If we take $\phi = 0.4$ and 0.6 as the respective benchmark value of the intermediate input share in the prewar and the postwar periods, then, under the prewar shock process, the autocorrelation coefficient in output is 0.725 and the standard deviation is 0.134; under the postwar shock process, the autocorrelation increases to 0.729 while the standard deviation falls to 0.05. Given that the standard deviation of the innovation to M1 growth rate was larger in the interwar period than that in the postwar period (0.0167 versus 0.008), the falling volatility in real GDP is perhaps not

surprising. The more interesting result is that output persistence has increased (although quite modestly) across the two sample periods, despite that the money growth process has become less persistent (the autocorrelation coefficient in the M1 growth process has fallen from 0.75 to 0.68). Our model suggests that a main driving force of the higher output persistence is the input-output connections. In general, output tends to be less volatile and more persistent across the two sample periods also under other plausible values of ϕ for these periods. The model's ability to generate the observed changes in the business cycle properties of real GDP over time lends further credence to the view that the complexity of input-output structure is an important business cycle propagation mechanism.

6 Conclusion

We have developed a dynamic stochastic general equilibrium theory that links two prominent empirical regularities in the U.S. economy. The model with staggered price- and wage-setting and a roundabout input-output structure provides a unified framework that offers a potential explanation for the mildly countercyclical or acyclical behaviors of real wages seen at early times when production involved simple input-output relations, and the mildly procyclical real wages observed in more recent years when the input-output connections have become more sophisticated.

To help illustrate this point, we have kept our model as simple as possible. Yet, our results suggest some potential extensions of the model. For example, existing evidence suggests that, in the postwar U.S. economy, real wages are more procyclical in the manufacturing sector than at the economy-wide level, and within the manufacturing sector, they are more procyclical in the durable goods industries than in the non-durable goods industries [e.g., Christiano, et al. (1997)]. Casual observations suggest that the share of intermediate inputs is larger in the manufacturing sector than in other sectors (such as the raw material sector and the service sector), and within the manufacturing sector, it is larger in the durable goods industries (such as the electronic equipment industries) than in the non-durable goods industries (such as the petroleum and coal industries). The results presented in this paper lead us to conjecture that the differing shares of intermediate inputs across sectors or industries are likely to be important in accounting for the observed differences in the behaviors of sectoral or industrial real wages. A formal analysis of this sort calls for an extension of our model to a multi-sector setup with

the shares of intermediate inputs in different sectors calibrated to those in the actual economy, and with some kind of impediments to the mobility of labor across sectors.

The model has potentially other testable implications. For example, our results suggest that real wages can be more procyclical in developed countries than in developing countries, since the input-output structures tend to be more sophisticated in the former than in the latter. Needless to say, a more careful analysis should take international connections and the transmissions of shocks across countries into account. This calls for an extension of our model to a global economy setup with countries at different stages of development and with real and nominal linkages across countries incorporated. Existing theoretical studies suggest that the cross-country input-output linkages in the actual economies can be an important international monetary transmission mechanism (e.g., Bergin and Feenstra(2001) and Huang and Liu (2002b)). There is also much empirical evidence regarding the impacts of different exchange rate regimes on the transmissions of monetary shocks and the behaviors of real and nominal economic variables (e.g., Basu and Taylor (1999)). The results presented here and the existing theoretical and empirical findings alluded to indicate that future research along this avenue should be both necessary and fruitful.

Appendix

In this appendix, we present an alternative model structure that does not require the implicit financial arrangements assumed in the baseline model for aggregation purposes. We show that this alternative model generates identical equilibrium dynamics as in the baseline model.

The good market structure remains the same as in the baseline model, but the labor market structure differs. Here, instead of assuming a continuum of households with differentiated labor skills, we assume that there is a representative household with a large number of family members, each endowed with a "raw labor skill." The representative household derives utility from consumption of a composite good and holdings of real money balances, and it also cares about each member's disutility of working. The lifetime discounted utility of the household is given by

$$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t) \left\{ \ln C^*(s^t) - \eta \int_0^1 \frac{\tilde{L}(i, s^t)^{1+\xi}}{1+\xi} di \right\}, \tag{19}$$

where $C^*(s^t)$ is a CES composite of the household's consumption and real money balances (as in the text), and $\tilde{L}(i, s^t)$ is the quantity of type i raw skills supplied by member i of the household at s^t.[22]

The budget constraint facing the household in event history s^t is given by

$$\bar{P}(s^t)Y(s^t) + \sum_{s^{t+1}} D(s^{t+1}|s^t)B(s^{t+1}) + M(s^t) \leq$$

$$\int_0^1 \Omega(i, s^t)\tilde{L}(i, s^t)di + R^k(s^t)K(s^{t-1}) + \Pi(s^t) + B(s^t) + M(s^{t-1}) + T(s^t), \quad (20)$$

where $\Omega(i, s^t)$ is the price of raw skills of type i, and other notations are the same as in the baseline model (without the individual index). The composite good $Y(s^t)$ can be either consumed or invested. Thus

$$Y(s^t) = C(s^t) + K(s^t) - (1-\delta)K(s^{t-1}) + \psi\frac{(K(s^t) - K(s^{t-1}))^2}{K(s^{t-1})}. \quad (21)$$

The optimal consumption-leisure choice implies that the marginal rate of substitution between member i's leisure and income equals the nominal price of i's raw skill, that is, $MRS(i, s^t) = \Omega(i, s^t)$ for all i and all s^t.

The household members cannot directly supply their raw skills to firms. Instead, they are each paired with an employment agency, who has a linear technology that transforms one unit of type i raw skill into one unit of type i "trained skill" that can then be used in producing goods. In other words, agency i's production function is given by $L(i, s^t) = \tilde{L}(i, s^t)$.

On the one hand, as does the household, an employment agency paired with a household member takes the price of each member's raw labor skill as determined in a competitive fashion.[23] On the other hand, the employment agencies are imperfect competitors with each others in the markets for the trained skills, where they set nominal wages for the trained skills that they produce, taking the demand schedule (1) as given. At each date t and upon the realization of the shock s_t, a fraction $1/N_w$ of the employment agencies choose new wages.

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[22]Because of the structural similarity, the model descriptions here overlap substantially with those in Section 3. In what follows, we will use the same notations where possible with the understanding that they denote the same variables as in the text, while we do not need to carry the individual index since we have here a representative household.

[23]To motivate this assumption, one can think of each member unit in the household as consisting of a large number of identical workers that supply a same type of 'raw' labor, and each employment agency paired with a given member unit of the household as consisting of a large number of identical subcontractors that use a same type of 'raw' labor to produce a same type of 'trained' labor.

These wages, once set, remain effective for N_w periods. All employment agencies are divided into N_w cohorts based on the timing of their wage decisions. At date t, if an employment agency i can set a new wage, then it choose a wage to solve the problem:

$$\max_{W(i,s^t)} \sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t) \left[W(i,s^t)L^d(i,s^\tau) - \Omega(i,s^\tau)\tilde{L}(i,s^\tau) \right], \tag{22}$$

subject to the production function $L(i,s^t) = \tilde{L}(i,s^t)$ and the demand function for the trained skill (1). Solving (22) yields the optimal wage-setting equation:

$$W(i,s^t) = \frac{\sigma}{\sigma-1} \frac{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t)L^d(i,s^\tau)MRS(i,s^\tau)}{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t)L^d(i,s^\tau)}, \tag{23}$$

where we have substituted the marginal rate of substitution between household member i's leisure and income for the price of i's raw skill. Thus the optimal wage for a trained skill of type i is a markup over a weighted average of the MRS's for household member i during the periods in which the currently chosen wage will remain effective. The wage setting rule (23) in this alternative model is apparently identical to that in the baseline model (equation (12) in the text). The rest of the equilibrium conditions are also identical to those in the baseline model.

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Table 1.

Calibrated parameter values

Preferences:	$b = 0.998, \quad \nu = -1.76$
$U(C, M/\bar{P}, L) = \log \left[bC^{\nu} + (1-b)(M/\bar{P})^{\nu} \right]^{1/\nu} - \eta L^{1+\xi}/(1+\xi)$	$\xi = 2$
Technologies: $X = \Gamma^{\phi}[K^{\alpha}L^{(1-\alpha)}]^{1-\phi} - F$	$\phi \in [0, 0.9], \quad \alpha = 1/3$
Labor composite: $L = \left[\int L(i)^{\frac{\sigma-1}{\sigma}} di \right]^{\frac{\sigma}{\sigma-1}}$	$\sigma = 3$
Goods composite: $X = \left[\int X(j)^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}$	$\theta = 21$
Capital accumulation: $K_t = I_t + (1-\delta)K_{t-1},$	$\delta = 0.021$
Adjustment cost: $\psi(K_t - K_{t-1})^2/K_{t-1}$	ψ adjusted
Money growth: $\log \mu(s^t) = \rho \log(\mu(s^{t-1})) + \varepsilon_t$	$\rho = 0.68, \quad \sigma_{\varepsilon} = 0.008$
Subjective discount factor	$\beta = 0.99$
Contract duration (quarters)	$N_p \in \{4, 1\}, \quad N_w \in \{4, 1\}$

Table 2.

The first-order autocorrelation coefficients in output

	$\phi = 0$	$\phi = 0.3$	$\phi = 0.4$	$\phi = 0.5$	$\phi = 0.6$	$\phi = 0.7$
SP	0.337	0.382	0.402	0.425	0.452	0.487
SW	0.809	0.809	0.809	0.809	0.809	0.809
SPW	0.707	0.714	0.718	0.722	0.729	0.737

Note: "SP" stands for the model with staggered prices; "SW" refers to the model with staggered wages; and "SPW" is the baseline model with both staggered prices and wages.
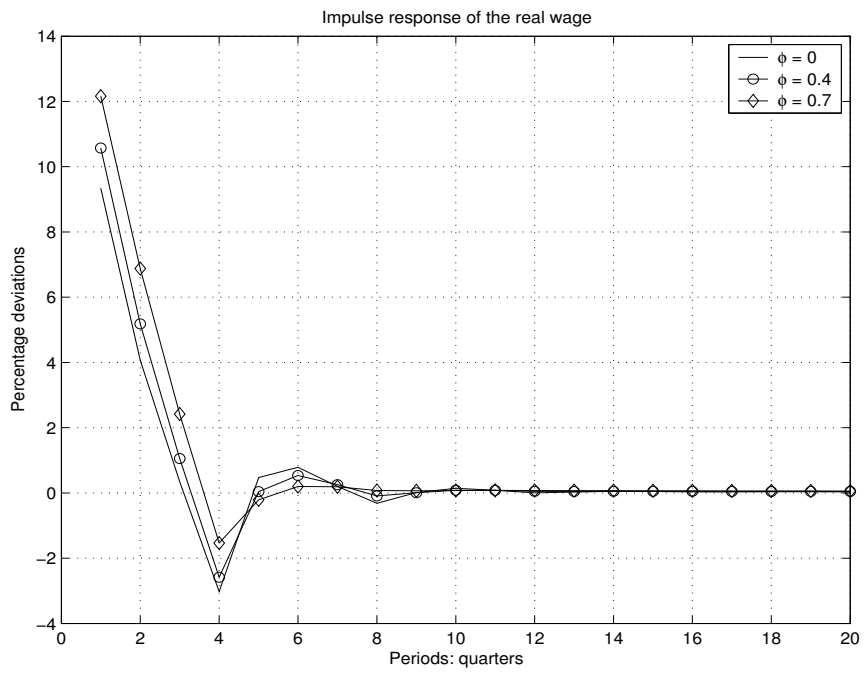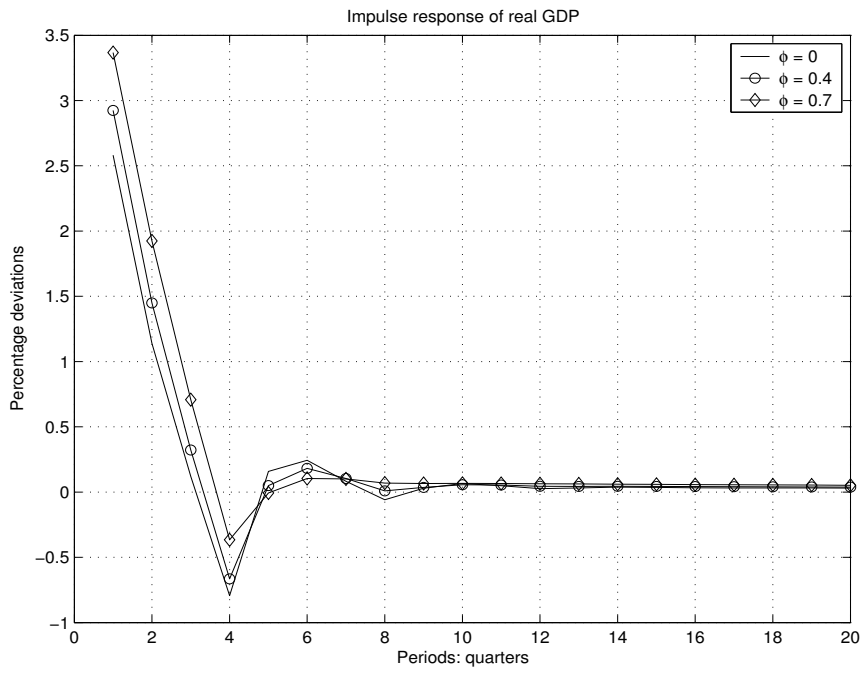
Figure 1:—The impulse responses of real GDP and the real wage
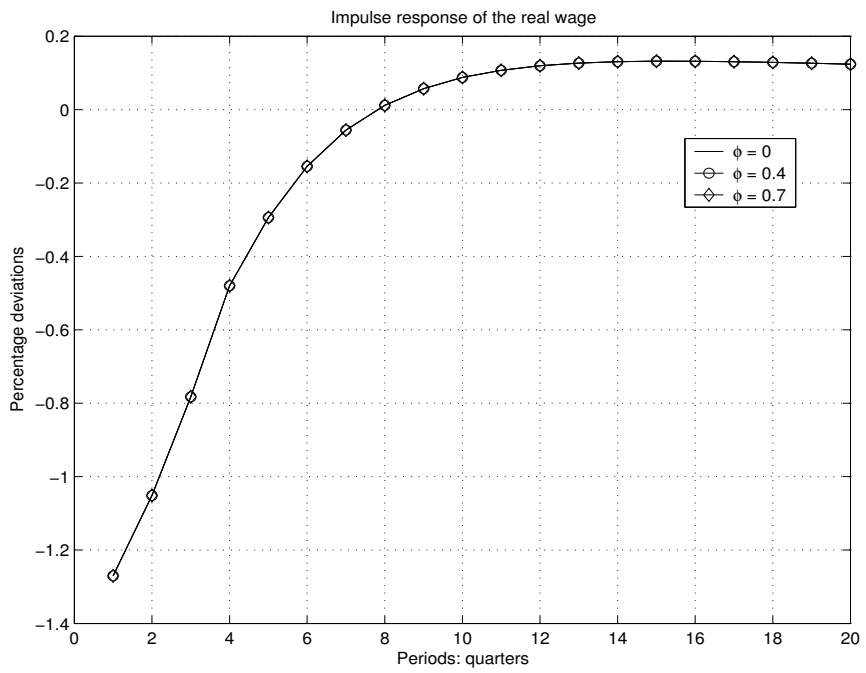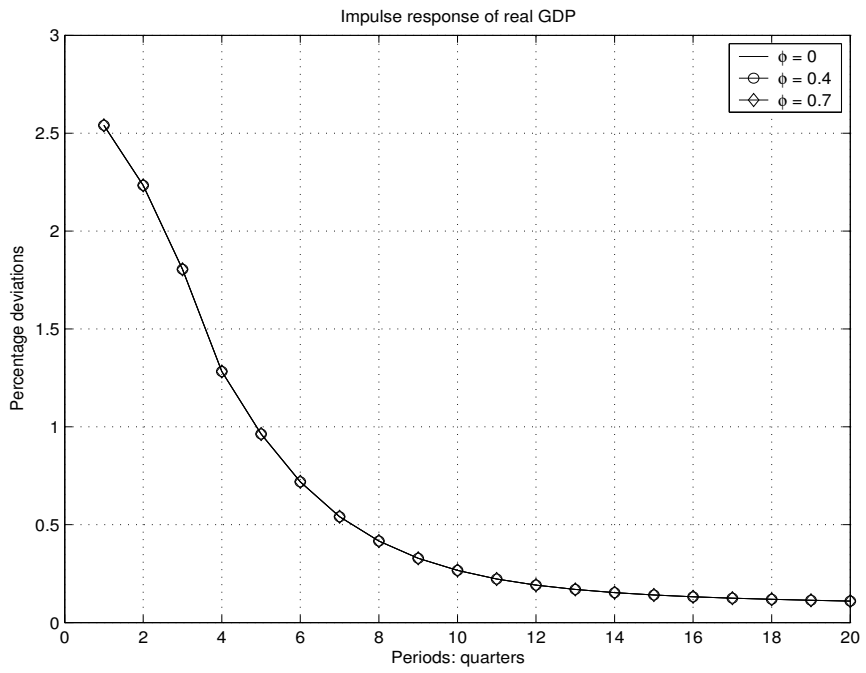in the model with staggered price-setting.

Figure 2:—The impulse responses of real GDP and the real wage
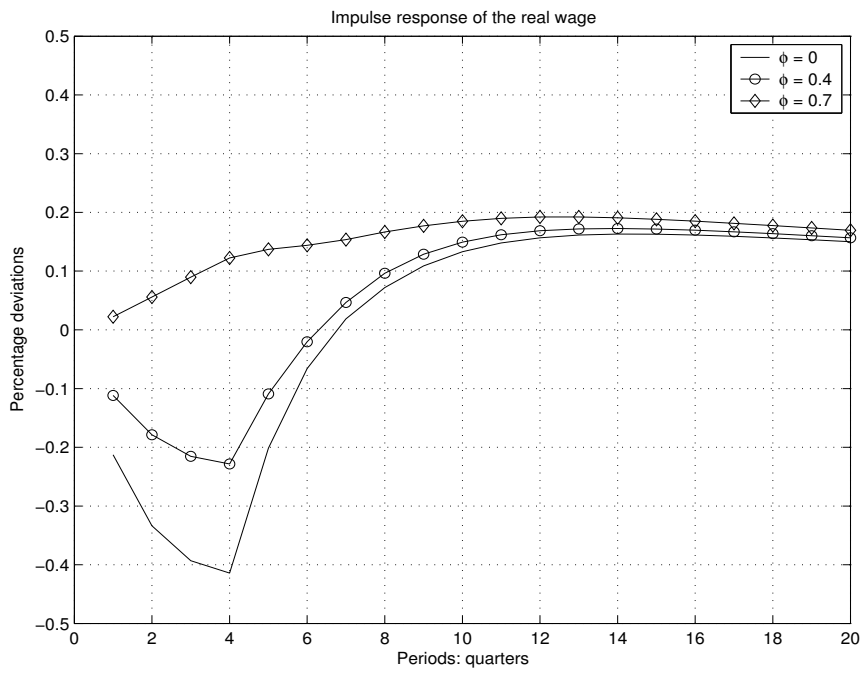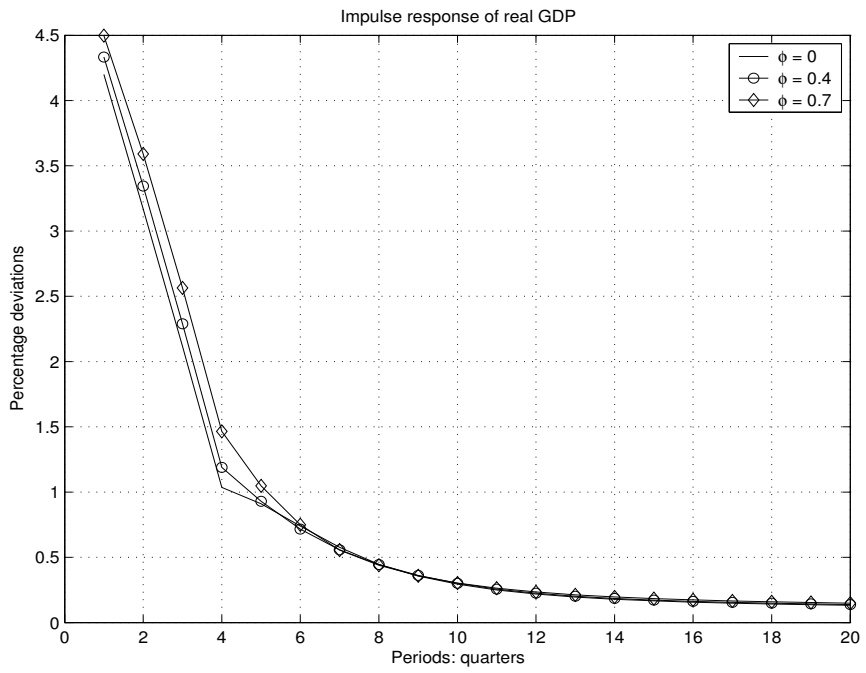in the model with staggered wage-setting.

Figure 3:—The impulse responses of real GDP and the real wage

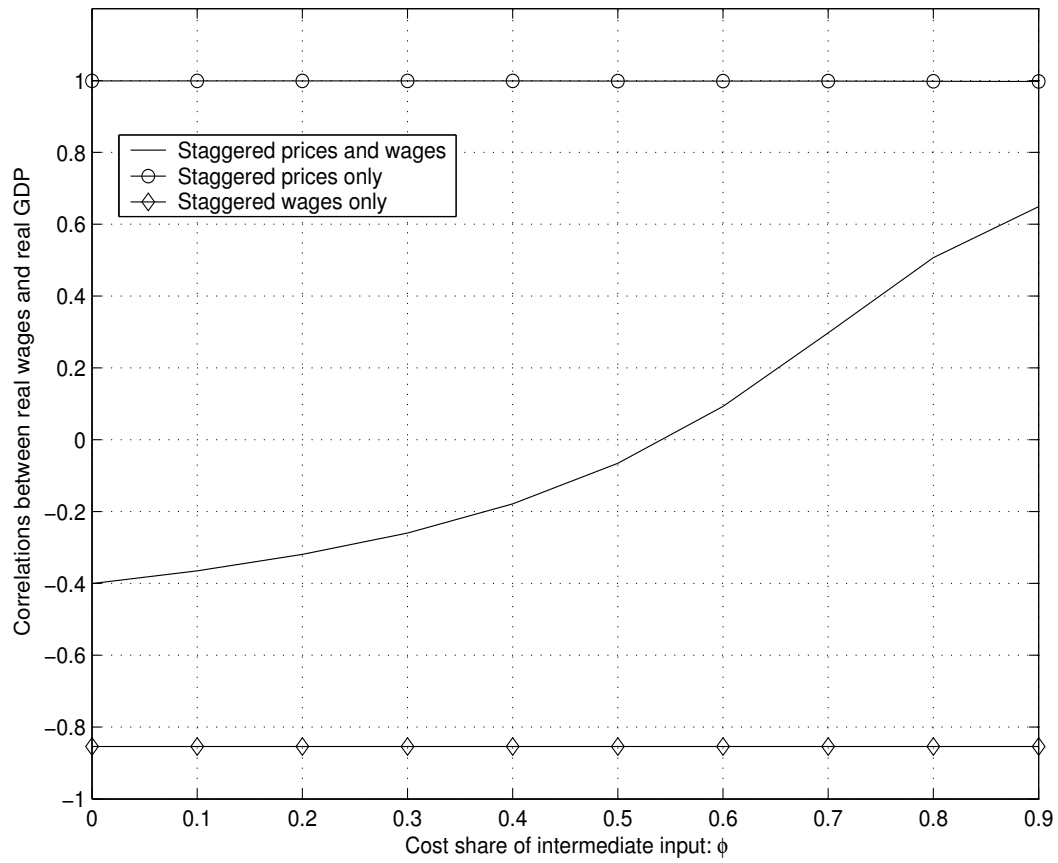in the model with staggered price-setting and staggered wage-setting.

Figure 4:—The contemporaneous cross-correlations between real wages and real GDP in the three models.
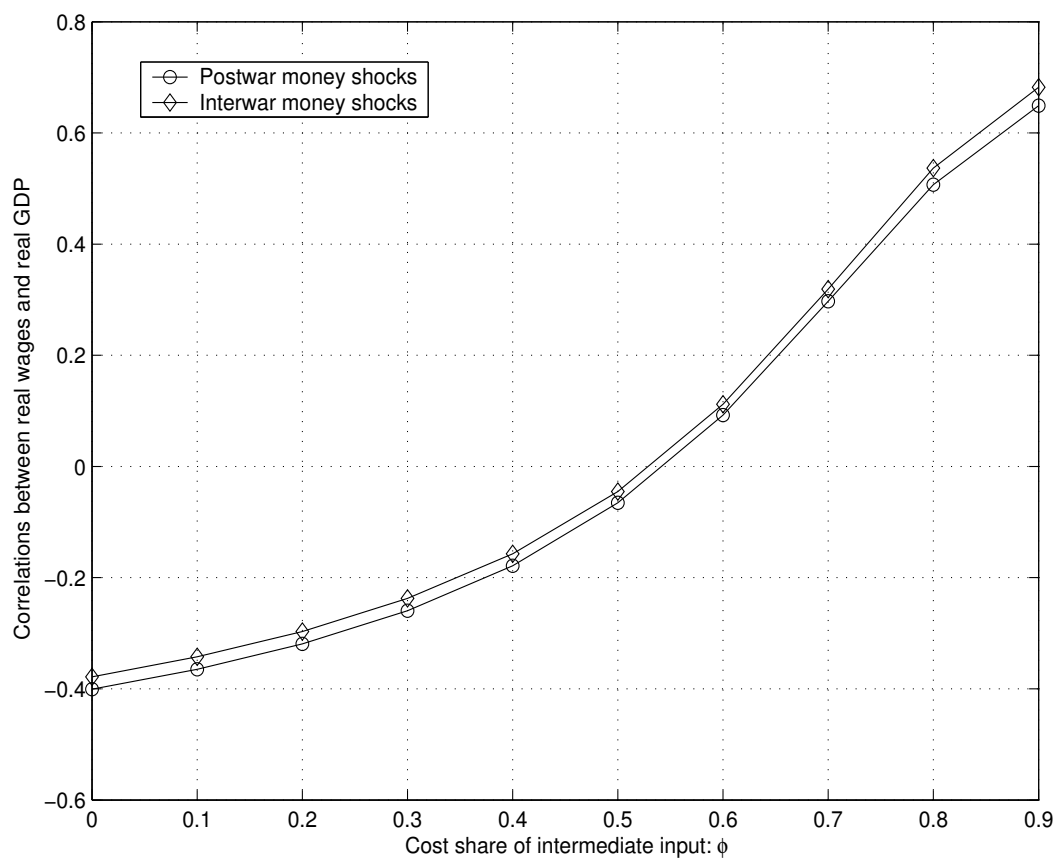
Figure 5:—The contemporaneous cross-correlations between real wages and real GDP in the baseline model: Postwar shocks versus interwar shocks.