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AND THE DYNAMIC EFFECTS OF MONETARY SHOCKS 
ON OUTPUT, INFLATION, AND REAL WAGES 

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ABSTRACT

This paper investigates the contributions of staggered price contracts, staggered wage contracts, and an input-output production structure in generating the observed persistence of real output and inflation, and the weak but persistent response of real wages following monetary shocks. It examines the interactions of these three mechanisms in a dynamic general equilibrium (DGE) environment, with pricing decision and wage setting rules derived from individual optimization. Following a monetary shock, (i) a staggered wage model generates more persistence in both inflation and output than does a staggered price model when intermediate goods are used in production; (ii) adding intermediate goods causes a tradeoff between output persistence and inflation persistence: it magnifies the autocorrelations of output while reducing those of inflation in both the short and medium horizons; (iii) a combination of staggered prices and staggered wages is required to generate the observed weak but persistent response of real wages to a monetary shock, and incorporating intermediate goods in such a model is essential to make the real wage response weakly procyclical.

JEL classification: E31, F32, F52

Key words: staggered contracts; input-output structure; business cycle persistence; monetary policy
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1 Introduction
A central issue concerning economists and policymakers is the short-run dynamics of inflation and output following a monetary shock. Empirical studies reveal that a monetary shock leads to persistent responses of real output and inflation, and a weak but persistent response of real wages. Yet, it has been a challenge to explain these empirical regularities in a dynamic general equilibrium environment.¹

The objective of this paper is to compare the abilities of three important monetary transmission mechanisms to meet this challenge. The mechanisms considered here include a staggered price mechanism, a staggered wage mechanism, and an input-output production structure. We first construct a DGE model that is flexible enough to net six different models as special cases, including a staggered price model, a staggered wage model, and a model with both staggered prices and staggered wages, each with or without intermediate goods. We then evaluate the models’ abilities to reproduce the observed dynamic effects of money on real output, inflation, and real wages. We find that, with intermediate goods used in production, a model with staggered wage contracts generates more persistence in both inflation and output than does a model with staggered price contracts. Adding intermediate goods in production, however, causes a tradeoff between output persistence and inflation persistence: it magnifies the autocorrelations of output while reduces those of inflation in both the short and medium horizons. Moreover, to generate the observed weak but persistent response of real wages following a monetary shock, a combination of staggered prices and staggered wages is needed.

In the literature, staggered price (or wage) contracts in the spirit of Taylor (1980) have been considered a promising mechanism in generating the observed persistent real effects of money. In Taylor's original setup, there is a fraction \(1/N\) of firms that can set new wages in each period, and once set, a wage remains effective for \(N\) periods. Thus, when making wage decisions, firms (or workers) must look at the wages that will be paid to other workers during their own contract period, and are reluctant to change relative wages following a shock. In consequence, the responses of employment and output last well beyond the initial contract duration. More recent literature focus on examining the implications of a Taylor type of nominal contracts on real persistence, with wage or pricing rules derived from individual optimization. A leading example is Chari, et al. (CKM) (1998), who assume that pricing (rather than wage) decisions are staggered. They find that, in general, a monetary shock cannot generate persistent output responses. In their model, the key persistence parameter is a function of fundamental

parameters in preferences and technologies. With calibrated values of the fundamental parameters, the implied persistence parameter is inadequate to generate real persistence, a puzzle in light of Taylor's (1980) insights. Subsequently, Huang and Liu (1998) construct a model with staggered wage contracts and show that optimal wage decision rules can be derived by assuming monopolistic competition in the labor markets. They find that the ability of a model with staggered wage contracts to generate persistence is much greater than a model with staggered price contracts since the key persistence parameter under the two different types of nominal contracts is linked to preferences and technologies in different ways.²

In addition to staggered nominal contracts, the input-output production structure has also been recognized as important in generating real persistence. For example, Basu (1995) shows that, if price changes are costly, the use of intermediate goods causes price inflexibility and thus helps magnify the real effects of money. More recently, Bergin and Feenstra (2000) construct a staggered price model and show that the interactions between the input-output structure proposed by Basu and a non-CES aggregation technology are important in generating persistent real effects of money. Here in this paper, we assume a standard CES aggregation technology and find that adding intermediate goods results in larger autocorrelations of real output.³

A novel finding in our experiments is that there is a tradeoff between output persistence and inflation persistence, and the tradeoff is determined by the share of intermediate goods in production. A larger share of intermediate goods leads to more persistent real effects of money, but at a cost of weaker autocorrelations of the inflation rate. In the literature, explaining inflation persistence has been a challenging issue. For example, Nelson (1998) examines the ability of a class of sticky price models to reproduce the autocorrelations of inflation observed in the U.S. data. He finds that few models can pass the test. An exception in Nelson's experiment is the model proposed by Fuhrer and Moore (1995). Their model features staggered contracts formed in real terms so that it is the inflation rate rather than the price level that is persistent.⁴ The specific form of contracts in the Fuhrer-Moore model, however, is simply assumed rather than being derived from first principles, a task which accordingly to Taylor

⁴The Taylor type of nominal-contract models, in their original form, has been criticized for its inability to generate inflation persistence. For example, Ball (1994, 1995) shows that, in such a model, a permanent (and credible) reduction in
(2000) is likely to be difficult. In the models we consider here, pricing and wage decision rules are derived from individual optimization, and the models can produce substantial inflation persistence.

Our final criterion of evaluating the models is their abilities to generate the observed weak but persistent response of real wages following a monetary shock. To pass this test, a model with both staggered price contracts and staggered wage contracts is needed. The real wage response in a staggered price model is strongly procyclical and short-lived, while the response in a staggered wage model is countercyclical but persistent. Combining the two types of nominal contracts in a model serves to weaken the real wage response, and the use of intermediate goods in production helps further weaken the response while increasing its persistence. Without intermediate goods, real wage is weakly countercyclical in a model with both staggered price and staggered wage contracts. With empirically plausible values of the share of intermediate goods, real wage response becomes acyclical or even weakly procyclical.

There are two reasons why a model with staggered price and wage contracts and with intermediate goods used in production can generate a weakly procyclical and yet persistent response of real wages. The first is the real rigidity associated with firms' pricing decisions, introduced via the use of intermediate goods in production. In the absence of intermediate inputs, firms' marginal cost is a weighted average of nominal wage index and nominal rental rate on capital. Since wage is sticky while the capital rental rate is not, marginal cost changes more quickly than does the wage index, so do the pricing decisions and the price level. In consequence, real wages tend to fall in response to an expansionary monetary shock. With intermediate inputs, however, the price level enters marginal cost as an additional component, which tends to reduce the variability of marginal cost and hence of pricing decisions. The larger is the share of intermediate goods in production, the more sluggish the price level adjustment is, and given sticky nominal wages, the more likely for real wage to rise following an expansionary monetary shock. The other factor contributing to the pattern of real wage responses is the real rigidity associated with households' wage-setting decisions, introduced through an intertemporal smoothing incentive in labor hours. Following a shock, those households who can renew their wage contracts do not have incentive to excessively adjust their relative wages as long as they would like to smooth labor hours across time. The easier to substitute between labor skills, the less the incentive for households to change wages. Thus, a larger elasticity of substitution between labor skills leads to greater nominal inflation does not cause an output loss, which is at odds with empirical evidence. Roberts (1997) finds that incorporating less-than-perfectly rational expectations helps explain the costly disinflation.
wage inertia and hence, given sticky prices, a more modest but more persistent increase in real wage. Since a larger share of intermediate goods in production and a greater elasticity of substitution between labor skills both serve to induce a more sluggish price level adjustment, they also serve to increase output persistence.

In what follows, we present the general model in Section 2, describe the calibration methods in Section 3, summarize the findings in Section 4, and conclude in Section 5. We describe the data in the Appendix.

2 The model

The economy is populated by a large number of households and firms. 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 $s^t \equiv (s_0, \ldots, s_t)$, with probability $\pi(s^t)$. The initial realization $s_0$ is given.

A household $i \in [0, 1]$ is endowed with a differentiated labor skill $L(i, s^t)$. It purchases a composite of differentiated goods $X(i, s^t)$ that can be either consumed or invested. It derives utility from consumption $C(i, s^t)$, real money balances $M(i, s^t)/\bar{P}(s^t)$, and leisure $1 - L(i, s^t)$, where the total time endowment is normalized to unity. The utility function is given by

$$U^i \equiv \sum_{t=0}^{\infty} \sum_{s^t} \beta^t \pi(s^t) \left[ \ln C^*(i, s^t) + \eta \ln(1 - L(i, s^t)) \right]$$

where $\beta \in (0, 1)$ is a discount factor and $C^*(i) \equiv [bC(i)^\nu + (1-b)(M(i)/\bar{P})^\nu]^{1/\nu}$ is a CES composite of consumption and real money balances. In each period $t$ and for each event $s^t$, the household faces a budget constraint given by

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

where $B(i, s^{t+1})$ is $i$'s holding of a nominal bond that costs $D(s^{t+1}|s^t)$ dollars at $s^t$ and pays one dollar in period $t + 1$ if $s^{t+1}$ is realized, $W(i, s^t)$ is a nominal wage of $i$'s labor skill, $L^d(i, s^t)$ is a demand schedule for type $i$ labor, $R^k(s^t)$ 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 $X(i, s^t)$ can be either consumed or invested. Thus

$$X(i, s^t) = C(i, s^t) + K(i, s^t) - (1 - \delta)K(i, s^{t-1}) + \psi \frac{(K(i, s^t) - K(i, s^{t-1}))^2}{K(i, s^{t-1})},$$
where \( \delta \in (0, 1) \) is a capital depreciation rate and the quadratic term is a capital adjustment cost with a scale parameter \( \psi > 0 \).

The consumption or investment good \( X(i, s^t) \) is a CES composite of a continuum of differentiated goods (e.g., Dixit and Stiglitz (1977)). In particular,

\[
X(i, s^t) = \left[ \int_0^1 X(i, j, s^t)^{\frac{\theta}{\theta - 1}} dj \right]^{\frac{\theta - 1}{\theta}},
\]

where \( \theta > 1 \) is an elasticity of substitution between differentiated goods. Minimizing expenditures on all goods subject to (4) results in the demand function of \( i \) for good \( j \). It is given by

\[
X^d(i, j, s^t) = \left( \frac{P(j, s^t)}{\bar{P}(s^t)} \right)^{-\theta} X(i, s^t),
\]

where \( \bar{P}(s^t) \equiv \left( \int_0^1 P(j, s^t)^{1-\theta} dj \right)^{\frac{1}{1-\theta}} \) is a price index. The total demand of all households for good \( j \) is the sum of all individual demand, that is,

\[
X^d(j, s^t) = \left( \frac{P(j, s^t)}{\bar{P}(s^t)} \right)^{-\theta} \int_0^1 X(i, s^t) di.
\]

Good \( j \in [0, 1] \) is produced using an intermediate good \( Z(j, s^t) \), a capital stock \( K(j, s^t) \), and a composite of labor skills \( L(j, s^t) \). The production function is given by

\[
Y(j, s^t) = Z(j, s^t)^{\phi} K(j, s^t)^{(1-\phi)\alpha} L(j, s^t)^{(1-\phi)(1-\alpha)},
\]

where \( \phi \in [0, 1] \) is the share of intermediate goods in production and \( \alpha \in (0, 1) \) is the share of capital in value added. The intermediate good is a composite of all types of goods. That is,

\[
Z(j, s^t) = \left[ \int_0^1 Z(j, k, s^t)^{\frac{\phi}{\phi - 1}} dk \right]^{\frac{\phi - 1}{\phi}}.
\]

The capital input is also a composite good supplied by the households. The labor input is a composite of all types of labor skills. Specifically,

\[
L(j, s^t) = \left[ \int_0^1 L(j, i, s^t)^{\frac{\phi}{\sigma - 1}} di \right]^{\frac{\phi - 1}{\sigma}},
\]

where \( \sigma > 1 \) is an elasticity of substitution between differentiated labor skills.

Solving firm \( j \)'s cost-minimization problem results in factor demand functions and a demand function for the intermediate goods. They are given by

\[
K^d(j, s^t) = \frac{(1-\phi)\alpha V(s^t)}{R(k)(s^t)} Y(j, s^t),
\]
6

(11) \[ L^d(j, i, s^t)) = \left( \frac{W(i, s^t)}{W(s^t)} \right)^{-\sigma} \frac{(1 - \phi)(1 - \alpha)V(s^t)}{W(s^t)} Y(j, s^t), \quad i \in [0, 1], \]

(12) \[ Z^d(j, k, s^t)) = \left( \frac{P(k, s^t)}{P(s^t)} \right)^{-\theta} \frac{\phi V(s^t)}{P(s^t)} Y(j, s^t), \quad k \in [0, 1], \]

where \( V(s^t) = \hat{\phi} \bar{P}(s^t) \phi R^k(s^t)(1-\phi)\alpha \bar{W}(s^t)(1-\phi)(1-\alpha) \) is a unit cost function that is firm-independent, and \( \bar{W}(s^t) \equiv \left( \int_0^1 W(i, s^t)1-\sigma di \right)^{1-\sigma} \) is a wage index.

The total demand for type \( i \) labor skill is equal to the sum of all individual firms’ demand, that is,

(13) \[ L^d(i, s^t)) = \left( \frac{W(i, s^t)}{W(s^t)} \right)^{-\sigma} L(s^t), \]

where \( L(s^t) \equiv \int_0^1 \int_0^1 W(i, s^t)L(i, j, s^t)di dj = \frac{(1-\phi)(1-\alpha)V(s^t)}{W(s^t)} \int_0^1 Y(j, s^t) dj, \) with the second equality obtained from cost minimization.

Given the households’ demand for consumption or investment goods and the firms’ demand for intermediate inputs, we obtain the demand function for good \( j \). In light of (6) and (12), it is given by

(14) \[ Y^d(j, s^t) = \left( \frac{P(j, s^t)}{P(s^t)} \right)^{-\theta} Y(s^t), \]

where \( Y(s^t) \equiv \int_0^1 X(i, s^t)di + \phi \frac{V(s^t)}{P(s^t)} \int_0^1 Y^d(j, s^t) dj. \) It follows that

(15) \[ Y(s^t) = \frac{X(s^t)}{1 - \phi V(s^t)G(s^t)/\bar{P}(s^t)}, \]

where \( X(s^t) \equiv \int_0^1 X(i, s^t) \) and \( G(s^t) \equiv \bar{P}(s^t) \theta \int_0^1 P(j, s^t)^{-\theta} dj. \) Note that \( X(s^t) \) corresponds to the real GDP, which consists of aggregate consumption, aggregate investment, and capital adjustment cost.

We are interested in the effects of monetary policy on the dynamics of inflation and output. In this economy, monetary policy is conducted via a lump-sum transfer. Money stock grows at a rate \( \mu(\delta) \). In particular, we have

(16) \[ \int_0^1 T(i, s^t) = M^\delta(s^t) - M^\delta(s^t-1), \quad M^\delta(s^t) = \mu(s^t)M^\delta(s^t-1), \]

and the money growth rate follows a stationary stochastic process given by

(17) \[ \ln \mu(s^t) = \rho \ln(s^t-1) + \varepsilon_t, \]

where \( 0 < \rho < 1 \) and \( \varepsilon_t \) is a white noise process with a zero mean and a finite variance \( \sigma^2_\varepsilon \).
To generate real effects of monetary shocks, we assume that firms’ pricing decisions and households’ wage setting decisions are staggered (e.g., Taylor (1980) and Blanchard (1983, 1986)). Specifically, upon the realization of $s_t^e$ in each period $t$, a fraction $1/N_p$ of firms sets new prices and a fraction $1/N_w$ of households sets new wages. Once set, a price (or a wage) remains effective for $N_p$ (or $N_w$) periods.

Under staggered price contracts, if firm $j \in [0, 1]$ can set a new price in period $t$, it solves

$$
\text{Max}_{P(j, s^t)} \sum_{\tau = t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau | s^t) [P(j, s^t) - V(s^\tau)] Y_d(j, s^\tau),
$$

where $V(s^\tau)$ is the unit cost function and $Y_d(j, s^\tau)$ is the demand function for good $j$ given by (14). Note that, given the constant-returns-to-scale technology, the unit cost is also the marginal cost. The solution to (18) yields an optimal pricing rule

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

This equation says that firm $j$'s optimal price is a constant markup over a weighted average of its marginal costs within the contract duration, with the weights given by normalized quantities demanded. If there is no staggering, that is, if $N_p = 1$, the optimal price is a markup over the current period marginal cost.

Under staggered wage contracts, if household $i$ can set a new wage, it chooses $W(i, s^t)$, along with $C(i, s^t), K(i, s^t), B(i, s^{t+1}), M(i, s^t)$, to maximize utility (1) subject to the budget constraints (2)-(3), a borrowing constraint $B(i, s^t) \geq -B$ for some large positive number $B$, and the labor demand schedule (13). It takes prices set by firms and wages set by other households as given. The initial conditions $B(i, s^0), M(i, s^{-1}),$ and $K(s^{-1})$ are also taken as given. The first order conditions are

$$
\frac{U_m(i, s^t)}{\hat{P}(s^t)} = \frac{U_c(i, s^t)}{\hat{P}(s^t)} - \beta \sum_{s^{t+1}} \pi(s^{t+1} | s^t) \frac{U_c(i, s^{t+1})}{\hat{P}(s^{t+1})},
$$

$$
D(s^{t+1} | s^t) = \beta \pi(s^{t+1} | s^t) \frac{U_c(i, s^{t+1})}{U_c(i, s^t)} \frac{\hat{P}(s^t)}{\hat{P}(s^{t+1})},
$$

$$
U_c(i, s^t) \left[ 1 + 2\psi \left( \frac{K(i, s^t)}{K(i, s^{t-1})} - 1 \right) \right] = \\
\beta \sum_{s^{t+1}} \pi(s^{t+1} | s^t) U_c(i, s^{t+1}) \left\{ \frac{\hat{P}(s^{t+1})}{\hat{P}(s^{t+1})} + 1 - \delta + \psi \left( \frac{K(i, s^{t+1})}{K(i, s^t)} \right)^2 - 1 \right\},
$$
where $U_c(i, s^t)$, $U_m(i, s^t)$, and $U_L(i, s^t)$ denote the marginal utility of consumption, real money balances, and leisure, respectively, and $\pi(s^\tau|s^t) = \pi(s^\tau)/\pi(s^t)$ is the conditional probability of $s^\tau$ given $s^t$, for $\tau \geq t$.

Equations (20)-(23) are standard first order conditions with respect to money balances, bond holdings, and capital investment, respectively. Equation (23) corresponds to the wage-setting rule. The left-hand side of (23) is the expected present value of marginal utility gains resulting from an increase in wage and thus more leisure time within the contract duration, while the right-hand side is the expected present value of marginal utility losses because of unemployed hours and thus a lower wage income. The wage is set to balance the gains and the losses at the margin. Given the labor demand function (13), the wage setting rule (23) can be rewritten as

\begin{equation}
W(i, s^t) = \frac{\sigma}{\sigma - 1} \frac{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} \beta^{\tau-t} \pi(s^\tau|s^t)U_L(i, s^\tau)L^d(i, s^\tau)}{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} \beta^{\tau-t} \pi(s^\tau|s^t)(U_c(i, s^\tau)/\tilde{P}(s^\tau))L^d(i, s^\tau)},
\end{equation}

which says that the optimal wage is a constant "markup" over the ratio of average marginal utilities of leisure within the contract duration to average marginal utilities of income during the same periods, both weighted by normalized labor demand. In the case with $N_w = 1$, the optimal wage is simply a "markup" over the marginal rate of substitution between leisure and consumption.

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

To compute an equilibrium, we first reduce the equilibrium conditions to four equations, including a pricing decision equation, a wage-setting equation, a capital Euler equation, and a money demand equation. The decision variables are current prices, current wages, aggregate consumption, and aggregate capital stock. These variables are functions of the state variables that consist of lagged prices, lagged wages, the capital stock, and the money growth rate. We then log-linearize the equilibrium
conditions around a deterministic steady state, and compute the linear decision rules using standard methods.5

3 The calibration

The parameters to be calibrated include the subjective discount factor $\beta$, the preference parameters $b$, $\nu$, and $\eta$, the share $\phi$ of intermediate goods in production, the share $\alpha$ of capital income in value-added, the elasticity of substitution $\sigma$ between labor skills and $\theta$ between goods, the capital depreciation rate $\delta$, the adjustment cost parameter $\psi$, the duration $N_p$ and $N_w$ of price and wage contracts, and the monetary policy parameters $\rho$ and $\sigma_c$. The calibrated values are summarized in Table 1.

Following the standard business cycle literature, we choose $\beta = 0.99$, $\alpha = 1/3$, and $\delta = 0.021$. Following Chari, et al. (1998), we set $\theta = 10$, corresponding to a steady state markup of 11%.

To assign values for $b$ and $\nu$, we use the implied money demand equation

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

where $R(s^t) = (\sum_{t+1} D(s^t+1|s^t))^{-1}$ is the gross nominal interest rate. A regression of consumption velocity on nominal interest rates implies that $b = 0.998$ and $\nu = -1.75$. The implied interest elasticity is 0.36, with a standard error of 0.04, similar to those obtained by CKM (1998) and Lucas (1988).

To calibrate $\sigma$, the elasticity of substitution between labor skills, we resort to the micro-studies by Griffin (1992, 1996). Griffin uses disaggregated firm-level data and obtains estimates of $\sigma$ values in the range between 2 and 6. We thus choose $\sigma = 4$ as a benchmark.

In what follows, we compare the implications of six alternative models on the dynamic responses of real output, inflation, and real wages. These models include (1) a model with staggered prices, staggered wages, and intermediate goods (SPWI); (2) a model with staggered prices and intermediate goods (SPI); (3) a model with staggered wages and intermediate goods (SWI); (4) a model with staggered prices and staggered wages, but with no intermediate goods (SPW); (5) a model with staggered prices only (SP); (6) a model with staggered wages only (SW). The first model (SPWI) is described in Section 2, and the other five models are all special cases of SPWI, with different values of $N_p$, $N_w$, and $\phi$. We describe in Table 2 the implied restrictions on the values of these parameters in each model.

5Details of computation methods are available upon request.
In light of Taylor’s (2000) survey evidence, nominal contracts typically last for one year. Thus, in SPWI, we set \( N_p = 4 \) and \( N_{tu} = 4 \) so that, in each quarter, a fraction 1/4 of households and firms can adjust wages and prices, and once adjusted, a wage (or a price) remains fixed for four quarters. The estimated value of \( \phi \) by Jorgenson, et al. (1987) is 0.5 or above. More recently, Basu (1995) finds that an empirically plausible range of \( \phi \) values is between 0.8 and 0.9. Therefore, in SPWI, SPI, and SWI, we set \( \phi = 0.7 \).

In each model, we adjust the preference parameter \( \eta \) so that the average time allocated to market activity is 1/3, and we vary the capital adjustment cost parameter \( \psi \) so that, following a monetary shock, the model generates an impulse response of investment 2.3 times as large as that of real GDP, in accordance with the VAR evidence presented by Leeper, et al. (1996).

Finally, we set the serial correlation parameter \( \rho \) of money growth rate to 0.72 and the standard deviation of the innovation term in the money growth process \( \sigma_e \) to 0.006, based on M2 data.\(^6\)

4 Findings

In Table 3, we report the autocorrelations of real output and inflation, both in the U.S. data and in our models. The data are described in the Appendix. In computing the correlations, we apply the HP-filter to the log-level of real output to induce stationarity, but not to the inflation rate.\(^7\)

The table shows that, in the U.S. data, the fluctuations in both real output and inflation are highly persistent. The autocorrelation coefficients of real output are significantly above zero up to a lag of four quarters, and the autocorrelations of inflation do not die out even at a lag of six quarters.

The top panel of Table 3 shows that the models we consider have quite different implications on output persistence. A staggered price model (SP) predicts much lower autocorrelations of real output than does a staggered wage model (SW). Adding intermediate goods improves the predictions of SP, but the discrepancy of such a model (SPI) from the data is still large. In contrast, the predicted autocorrelations of output from models with staggered wage contracts (i.e., SPWI, SWI, SPW, and SW) are close to those observed in the data, at least over the short horizons (a lag of three quarters or less). It is interesting to note that a model with both staggered prices and staggered wages (SPW) does

\(^6\)We have also experimented with M1 data in our calibration and simulation, and obtained similar results (not reported).

\(^7\)The correlation statistics from the models are computed based on 300 random draws, each with a sample length of 100. The numbers shown in the table are averages across the 300 draws, with the first 20 observations in each draw discarded to avoid dependence on initial conditions.
no better than SW. In this sense, adding staggered price contracts on top of staggered wage contracts does not help generate persistence (in fact, it reduces persistence). This result seems to be robust to the inclusion of intermediate goods (SWI versus SPWI).

The lower panel of Table 3 displays the implications of the models on inflation persistence. Here, all the six models generate significant autocorrelations of inflation over the short and medium horizons (for a lag of at least six quarters). In models with either staggered prices or staggered wages, adding intermediate goods unambiguously reduces inflation persistence. In the model with both staggered price and wage contracts, introducing intermediate goods slightly increases the first order autocorrelation coefficient of inflation (from 0.74 to 0.77), but significantly reduces the autocorrelations at longer lags. Thus, in light of the results on output persistence, there is a tradeoff between inflation persistence and output persistence when intermediate goods are introduced.

To understand these results, we report impulse response functions in Figures 1 to 4. To compute the impulse responses, we choose the date-zero value of the innovation term $\pi$ in the money growth process (17) so that the money stock rises by 1% one year after the shock, and we set $\pi = 0$ for all $t \geq 1$.

Figure 1 displays the output responses in the six different models and Figure 2 contains the same information except that the output responses are normalized by the impact effect (so that the initial response in all cases is equal to 1%). The lower panel of Figure 2 shows that, in the absence of intermediate goods, output response is more persistent in a staggered wage model than in a staggered price model, and the magnitude of real persistence in a model with both staggered prices and staggered wages lies somewhere in between. The top panel of Figure 2 shows that adding intermediate goods magnifies the real persistence, but the magnification is less pronounced in the staggered wage model than in the other two models.

From Figures 1 and 2, we see that a staggered wage model (SW and SWI) generates more real persistence than a staggered price model (SP and SPI). The SP model produces a response of real output that does not last beyond the initial contract duration. This results is consistent with the findings in CKM (1998), despite the different labor market structures. In the SP model, the labor market is

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8Nelson (1998) has assessed the ability of a broad class of sticky price models to reproduce the autocorrelations of inflation observed in the U.S. data. He finds that only the Fuhrer-Moore (1995) type of model with real wage contracts and the Calvo (1983) model of price adjustment have the potential to produce serial correlations close to those in the data. Here, we show that several models with a Taylor (1980) type of staggered nominal contracts and with intermediate goods can produce inflation persistence broadly consistent with those in the data.
monopolistically competitive. Since wages are flexible in this model, the optimal wage rule implies that the real wage is a constant "markup" of the marginal rate of substitution (MRS) between leisure and consumption. In CKM’s model, labor market is perfectly competitive, and the real wage is equal to the MRS. Following a monetary shock, since pricing decisions are staggered in the SP model, real aggregate demand rises. Those firms that cannot adjust prices face a higher demand for their products and thus have to increase their demand for labor. Since households take the labor demand schedule as given, if they do not change their wages, then they will have to supply more labor, increasing their marginal utility of leisure. Meanwhile, since households have higher real income and hence more consumption, the marginal utility of consumption falls. In consequence, the MRS between leisure and consumption rises sharply, so does the real wage. Facing a higher real wage and a higher capital rental rate, firms’ marginal cost rises sharply and they will respond by setting a higher price whenever they have the chance to renew contracts. Therefore, the price level rises quickly and the response of real output is short lived. Adding intermediate goods will partially reduce the variability of marginal cost and hence make the output response more persistent. But for plausible values of the share of intermediate goods, the resulting persistence is not quantitatively important (see the SPI model in the top panel of Figure 2). In the SW model, however, the output response is much more persistent. This is so because households prefer smoothed labor hours across time (i.e., they are risk-averse with respect to leisure time), and under staggered wage contracts, they can avoid excessive fluctuations of the demand for their labor skills only if they can keep their wages in line with others. The easier to substitute one skill for another, the more reluctant the households are to change their relative wages, and thus the smaller the response of the nominal wage index following the shock.

Figure 2 also reveals that, in the absence of intermediate goods, adding staggered price contracts on top of staggered wage contracts does not magnify but actually reduces real persistence. Without intermediate goods, firms’ marginal cost is composed of labor cost (i.e., the wage index) and capital rental rate. In the SW model, since wages are sticky but prices are not, real wage is countercyclical. Thus, following an expansionary monetary shock, even though the capital rental rate rises quickly, the fall in real wage provides a counter-balance that tends to reduce the variability in marginal cost. With a slow change in marginal cost, price adjustments will be sluggish and output response will thus be persistent. But if both pricing and wage decisions are staggered (SPW), real wage will be less countercyclical and the rise in the capital rental rate will cause a corresponding increase in marginal cost.

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9See Huang and Liu (1998) for a detailed exposition on this point.
forcing firms to change prices accordingly whenever they can renew price contracts. As a consequence, output response is shorter-lived than in the case with staggered wages only.

When intermediate goods are used in production, however, the model with both staggered prices and staggered wages (SPWI) can generate as much persistence as the one without staggered price contracts (SWI). The reason, again, has to do with the fluctuations in marginal cost. With intermediate goods, the price level enters the marginal cost as an additional component, introducing an additional rigidity in the adjustment of marginal cost. Although both prices and wages are sticky and thus real wage tends to be acyclical, the effect of the quick rise in the capital rental rate on marginal cost is partially muted since the share of the rental rate in the cost is now smaller. Therefore, with a larger share of intermediate goods, the adjustments in marginal cost and the price level will be more sluggish and the output response will be more persistent. When $\phi = 0.7$, Figure 2 shows that the models SPWI and SWI produce similar output responses, in contrast to the case when $\phi = 0$ (SPW versus SW in the lower panel of Figure 2).

Figure 3 displays the response of the inflation rate. We have seen in Table 3 that there is a tradeoff between output persistence and inflation persistence. In particular, adding intermediate goods will magnify output persistence at a cost of weaker inflation persistence. The main reason has to do with the effect of adding intermediate goods on the variability of marginal cost. When intermediate goods are used, the marginal cost adjustment becomes more rigid, and thus changes in the price level become more sluggish and the response of inflation is shorter-lived.

Finally, in Figure 4, we plot the real wage responses in all models. The model with staggered price contracts generates a strongly procyclical and temporary response of the real wage, while the model with staggered wage contracts produces a countercyclical but persistent response. Neither seems to be empirically plausible. Combining the two types of contracts (SPW) does improve the predictions: the real wage response becomes weakly countercyclical and persistent. If we further add intermediate goods in the model (SPWI), the response becomes weakly procyclical and even more persistent.

In the model with both staggered price and staggered wage contracts, the cyclical behavior of real wage depends largely on the input-output structure. In the absence of intermediate goods (SPW), firms' marginal cost is a weighted average of the wage index and the capital rental rate. Following an expansionary monetary shock, the rise in marginal cost is faster than the wage index since nominal wages are sticky while the nominal rental rate is not. Facing a quick rise in marginal cost, firms will raise their prices whenever they can renew contracts. Thus, the increase in the price level is faster than
that in the nominal wage index, and real wage tends to fall. With intermediate goods used in production (SPWI), however, price adjustments will be more sluggish since the price level enters firms' marginal cost as an additional component, which tends to reduce the variability of marginal cost. The larger the share of intermediate goods, the more sluggish the change in the price level relative to that in the nominal wage index, and the more likely to have a rise in real wage.

5 Conclusions

In this paper, we have examined the contributions of and interactions between staggered price contracts, staggered wage contracts, and an input-output structure in generating the observed persistent responses of output and inflation and the weak but persistent response of real wages following monetary shocks. We have shown that, with intermediate goods used in production, a model with staggered wage contracts generates more persistence in both inflation and output than does a model with staggered price contracts. Adding intermediate goods in production, however, causes a tradeoff between output persistence and inflation persistence: it magnifies the autocorrelations of output while reduces those of inflation in both the short and medium horizons. Finally, to generate the observed weak but persistent response of real wages following a monetary shock, a combination of staggered prices and staggered wages is needed. In such a model, incorporating intermediate goods is essential to make the real wage response weakly procyclical.

Our conclusion that staggered price and wage contracts are important in explaining the observed real persistence is similar to Erceg, et al. (1999) but for different reasons. In their model, aggregate capital stock is exogenously fixed so that firms’ marginal cost is not affected by the capital rental rate. Thus, sticky wage directly translates into sluggish changes in marginal cost and hence in price level. In this sense, their model is a special case of our SPWI in which the share of intermediate goods is zero and the capital adjustment cost is infinity. Our finding that the use of intermediate goods in production helps generate real persistence is similar to Bergin and Feenstra (1998), but the models are different. We use a standard CES aggregation technology proposed by Dixit and Stiglitz (1977) while they use a translog aggregation technology. In addition, they do not consider staggered wage contracts. A comparison between our results and theirs suggests that, to generate the observed persistence in real output in a model with stationary market power (i.e., with a constant elasticity of substitution between goods and between labor services), nominal wage rigidity plays an important role.
Several issues merit further investigation. In a dynamic general equilibrium model with nominal rigidities such as ours, shocks to technologies, fiscal policy, and money demand, for example, are likely to play an important role in generating the observed aggregate dynamics and thus may have important implications on the conduct of monetary policy. Incorporating these shocks into the models will enable us to analyze the short-run tradeoff between inflation and real output and to assess the quantitative welfare effects of alternative monetary policy rules (e.g., Ireland (1996), Goodfriend and King (1997), and Clarida, et al. (1999)). We can also extend the model to an open economy and study issues such as international comovements. With nominal rigidities and intermediate goods, shocks (either real or monetary) can be transmitted across countries through the international input-output connections. Such an open-economy model will also be useful to assess the quantitative implications of alternative monetary policy rules such as interest rate targeting, inflation targeting, or exchange rate targeting.

Appendix

The data we have used in our calibration and simulation are taken from Citibase, with a quarterly frequency and a sample range from quarter one in 1959 to quarter four in 1999. Since we have a closed-economy model with no government spending, the aggregate output (i.e., total production net of intermediate goods) in our model corresponds to the real private sector GDP. We construct the real private GDP by summing up consumption of durable goods (Citibase gcdq), consumption of non-durable goods (gcnq), consumption of services (gcsq), and gross domestic private investment (gpiq), all in 1996 dollars. Similarly, we obtain the nominal private GDP series by summing up nominal consumption (Citibase gcd, gcn, and gcs) and nominal investment (gpi). We then use the implied deflator to compute the inflation rate. The money growth rate is obtained based on M2 data.

\footnote{The difficulties to account for the international comovements are summarized by, for example, Baxter (1995) and Backus, et al. (1995). More recently, Huang and Liu (2000) try to explain the comovements in a model with sticky prices and with vertical international trade.}
References


Table 1.

Calibrated Parameter Values

<table>
<thead>
<tr>
<th>Preferences:</th>
<th>( b = 0.998, \quad \nu = -1.75 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U(C, M, \bar{P}, L) = \log [bC^\nu + (1 - b)(M/\bar{P})^\nu]^{1/\nu} + \eta \log(1 - L) )</td>
<td>( \eta ) adjusted</td>
</tr>
<tr>
<td>Technologies: ( Y = Z^\phi K^{(1-\phi)\alpha} L^{(1-\phi)(1-\alpha)} )</td>
<td>( \phi \in {0.7, 0}, \quad \alpha = 1/3 )</td>
</tr>
<tr>
<td>Labor composite: ( L = \left[ \int L(i) \frac{e^{-i}}{\pi} d\pi \right] \frac{e^{-\pi}}{\pi} \right] )</td>
<td>( \sigma = 4 )</td>
</tr>
<tr>
<td>Goods composite: ( Y = \left[ \int Y(j) \frac{e^{-j}}{\pi} d\pi \right] \frac{e^{-\pi}}{\pi} \right] )</td>
<td>( \theta = 10 )</td>
</tr>
<tr>
<td>Capital accumulation: ( K_t = I_t + (1 - \delta) K_{t-1} )</td>
<td>( \delta = 0.021 )</td>
</tr>
<tr>
<td>Adjustment cost: ( \psi (K_t - K_{t-1})^2 / K_{t-1} )</td>
<td>( \psi ) adjusted</td>
</tr>
<tr>
<td>Money growth: ( \log \mu(s^t) = \rho \log(\mu(s^{t-1})) + \varepsilon_t )</td>
<td>( \rho = 0.72, \quad \sigma_{\varepsilon} = 0.006 )</td>
</tr>
<tr>
<td>Subjective discount factor</td>
<td>( \beta = 0.99 )</td>
</tr>
<tr>
<td>Contract duration (quarters)</td>
<td>( N_p \in {4, 1}, \quad N_w \in {4, 1} )</td>
</tr>
</tbody>
</table>

Table 2.

Parameter restrictions in alternative models

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SPW1</th>
<th>SPI</th>
<th>SWI</th>
<th>SPW</th>
<th>SP</th>
<th>SW</th>
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</thead>
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<tr>
<td>( N_p )</td>
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<td>4</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>( N_w )</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>( \phi )</td>
<td>0.7</td>
<td>0.7</td>
<td>0.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: The symbol “SPWI” stands for a model with staggered price and wage contracts and with intermediate goods, “SPI” for a staggered price model with intermediate goods, “SWI” for a staggered wage model with intermediate goods, “SPW” for a model with both staggered prices and staggered wages, “SP” for a staggered price model, and “SW” for a staggered wage model.
Table 3.
Correlations in alternative models

<table>
<thead>
<tr>
<th>Value of $j$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.88</td>
<td>0.68</td>
<td>0.47</td>
<td>0.26</td>
<td>0.04</td>
<td>-0.12</td>
</tr>
<tr>
<td>SPWI</td>
<td>0.88</td>
<td>0.62</td>
<td>0.31</td>
<td>0.06</td>
<td>-0.13</td>
<td>-0.25</td>
</tr>
<tr>
<td>SPI</td>
<td>0.78</td>
<td>0.39</td>
<td>0.01</td>
<td>-0.18</td>
<td>-0.25</td>
<td>-0.26</td>
</tr>
<tr>
<td>SWI</td>
<td>0.89</td>
<td>0.64</td>
<td>0.35</td>
<td>0.08</td>
<td>-0.13</td>
<td>-0.27</td>
</tr>
<tr>
<td>SPW</td>
<td>0.85</td>
<td>0.56</td>
<td>0.24</td>
<td>0.01</td>
<td>-0.16</td>
<td>-0.27</td>
</tr>
<tr>
<td>SP</td>
<td>0.51</td>
<td>-0.04</td>
<td>-0.34</td>
<td>-0.14</td>
<td>-0.02</td>
<td>-0.02</td>
</tr>
<tr>
<td>SW</td>
<td>0.89</td>
<td>0.64</td>
<td>0.34</td>
<td>0.07</td>
<td>-0.14</td>
<td>-0.28</td>
</tr>
</tbody>
</table>

Autocorrelations of inflation: $corr(\pi_t, \pi_{t-j})$

<table>
<thead>
<tr>
<th>Value of $j$</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.69</td>
<td>0.64</td>
<td>0.61</td>
<td>0.56</td>
<td>0.57</td>
<td>0.58</td>
</tr>
<tr>
<td>SPWI</td>
<td>0.77</td>
<td>0.56</td>
<td>0.36</td>
<td>0.16</td>
<td>0.19</td>
<td>0.23</td>
</tr>
<tr>
<td>SPI</td>
<td>0.77</td>
<td>0.63</td>
<td>0.52</td>
<td>0.36</td>
<td>0.44</td>
<td>0.48</td>
</tr>
<tr>
<td>SWI</td>
<td>0.79</td>
<td>0.74</td>
<td>0.67</td>
<td>0.56</td>
<td>0.48</td>
<td>0.47</td>
</tr>
<tr>
<td>SPW</td>
<td>0.74</td>
<td>0.62</td>
<td>0.53</td>
<td>0.36</td>
<td>0.44</td>
<td>0.47</td>
</tr>
<tr>
<td>SP</td>
<td>0.79</td>
<td>0.76</td>
<td>0.76</td>
<td>0.60</td>
<td>0.64</td>
<td>0.60</td>
</tr>
<tr>
<td>SW</td>
<td>0.80</td>
<td>0.75</td>
<td>0.70</td>
<td>0.60</td>
<td>0.52</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Note: Output $y_t$ corresponds to private sector real GDP in the U.S. data, in 1996 dollars.
The inflation rate is given by $\pi(t) = \Delta \log(P_t)$, where $P_t$ is the price level, corresponding to the private GDP deflator.
Figure 1:—Response of real GDP in alternative models
Figure 2:—Response of real GDP relative to initial responses in alternative models
With intermediate goods

Without intermediate goods

Figure 3:—Response of inflation in alternative models
With intermediate goods

Without intermediate goods

Figure 4:—Response of real wage in alternative models
Staggered Contracts, Intermediate Goods, and the Dynamic Effects of Monetary Shocks on Output, Inflation, and Real Wages*

Kevin X. D. Huang, Zheng Liu, and Louis Phaneuf

April 2000

Abstract

This paper investigates the contributions of staggered price contracts, staggered wage contracts, and an input-output production structure in generating the observed persistence of real output and inflation, and the weak but persistent response of real wages following monetary shocks. It examines the interactions of these three mechanisms in a dynamic general equilibrium (DGE) environment, with pricing decision and wage setting rules derived from individual optimization. Following a monetary shock, (i) a staggered wage model generates more persistence in both inflation and output than does a staggered price model when intermediate goods are used in production; (ii) adding intermediate goods causes a tradeoff between output persistence and inflation persistence: it magnifies the autocorrelations of output while reduces those of inflation in both the short and medium horizons; (iii) a combination of staggered prices and staggered wages is required to generate the observed weak but persistent response of real wages to a monetary shock, and incorporating intermediate goods in such a model is essential to make the real wage response weakly procyclical.

Key Words: Staggered Contracts; Input-Output Structure; Business Cycle Persistence; Monetary Policy.

JEL classification: E31, E32, E52

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1 Introduction

A central issue concerning economists and policy makers is the short-run dynamics of inflation and output following a monetary shock. Empirical studies reveal that a monetary shock leads to persistent responses of real output and inflation, and a weak but persistent response of real wages. Yet, it has been a challenge to explain these empirical regularities in a dynamic general equilibrium environment.¹

The objective of this paper is to compare the abilities of three important monetary transmission mechanisms to meet this challenge. The mechanisms considered here include a staggered price mechanism, a staggered wage mechanism, and an input-output production structure. We first construct a DGE model that is flexible enough to nest six different models as special cases, including a staggered price model, a staggered wage model, and a model with both staggered prices and staggered wages, each with or without intermediate goods. We then evaluate the models' abilities to reproduce the observed dynamic effects of money on real output, inflation, and real wages. We find that, with intermediate goods used in production, a model with staggered wage contracts generates more persistence in both inflation and output than does a model with staggered price contracts. Adding intermediate goods in production, however, causes a tradeoff between output persistence and inflation persistence: it magnifies the autocorrelations of output while reduces those of inflation in both the short and medium horizons. Moreover, to generate the observed weak but persistent response of real wages following a monetary shock, a combination of staggered prices and staggered wages is needed.

In the literature, staggered price (or wage) contracts in the spirit of Taylor (1980) have been considered a promising mechanism in generating the observed persistent real effects of money. In Taylor's original setup, there is a fraction $1/N$ of firms that can set new wages in each period, and once set, a wage remains effective for $N$ periods. Thus, when making wage decisions, firms (or workers) must look at the wages that will be paid to other workers during their own contract period, and are reluctant to change relative wages following a shock. In consequence, the responses of employment and output last well beyond the initial contract duration. More recent literature focus on examining the implications of a Taylor type of nominal contracts on real persistence, with wage or pricing rules derived from individual optimization. A leading example is Chari, et al. (CKM) (1998), who assume that pricing (rather than wage) decisions are staggered. They find that, in general, a monetary shock cannot generate persistent output responses. In their model, the key persistence parameter is a function of fundamental