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Input-Output Structure and Nominal Staggering:
The Persistence Problem Revisited *

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Abstract:

This paper re-examines the conventional wisdom on the equivalence of staggered-wage setting and staggered-price setting in generating persistent real effects of aggregate demand shocks in a dynamic general equilibrium framework with an input-output production structure. Under staggered-wage setting, a relative wage consideration of households induces sluggish wage adjustments and thus sluggish price adjustments as well, just as in the case with no input-output connections. Under staggered-price setting, relative wages are constant, but the presence of the input-output structure creates a real wage effect which prevents nominal wages from deviating too much from the sticky intermediate input prices, resulting in an endogenous nominal wage rigidity; at the same time, the stickiness in the intermediate input prices translates directly into the sluggishness in marginal cost movements, reinforcing the real wage effect to increase the rigidity in firms' pricing decisions. Thus, while not helping the staggered-wage setting, the input-output structure improves the ability of the staggered-price setting in generating persistence. As a result, the conventional wisdom may continue to hold for some reasonable parameter values.

Keywords:

Input-output structure; Staggered nominal contracts; Business cycle persistence.

JEL classification: E24, E32, E52

1. Introduction

Recent years have witnessed a surged interest in developing dynamic general equilibrium models to explain the observed persistent real effects of aggregate demand shocks.¹ Following the lead of Taylor (1980) and Blanchard (1983, 1986), a growing body of literature focuses on models with staggered-wage setting or staggered-price setting.² The conventional wisdom holds that the two types of nominal staggering are two alternative yet equivalent mechanisms in generating persistence. Recently, this view is reiterated by Taylor (1999) and is made implicit in Chari, Kehoe, and McGrattan (2000).

This view is challenged, however, by Andersen (1998) and Huang and Liu (1998) who argue that, for plausible parameter values, staggered-wage setting is better able to generate persistence than is staggered-price setting in a dynamic general equilibrium framework. In this paper, we show that staggered-price setting may be as able as staggered-wage setting in generating persistence under reasonable parameter values, once an empirically relevant input-output production structure is taken into account.

Our model is a dynamic extension of Blanchard and Kiyotaki (1987) featuring monopolistic competition in goods markets and in labor markets, in which imperfectly competitive firms set nominal prices for differentiated goods and imperfectly competitive households set nominal wages for differentiated labor skills. The model has the additional features that a composite of the differentiated goods can serve either as a final consumption good or as an intermediate input for the production of the differentiated goods, and that prices or wages are set in a staggered fashion. To obtain analytical solutions in a system of log-linearized equilibrium conditions, we abstract from capital

¹See, for example, Blanchard and Quah (1989), Gali (1992), Sims (1992), Leeper, Sims, and Zha (1996), Christiano, Eichenbaum, and Evans (1997, 1999), Kiley (1999), and Basu and Taylor (1999) for related empirical evidence.

²Taylor (1999) provides an excellent survey of this literature. In addition to the issue of output and price level persistence, the issue of inflation persistence is also widely studied. See, for example, Ball (1994, 1995), Fuhrer and Moore (1995), Nelson (1998), Mankiw (2001), and Mankiw and Reis (2001).

accumulation. This simplification does not alter our basic conclusions.³ We find that the use of intermediate input in production interacts with staggered-wage setting and with staggered-price setting in different ways: while it does not affect the property of output dynamics under staggered-wage setting, it improves the ability of staggered-price setting to generate persistence.

To illustrate the intuition, consider a positive aggregate demand shock. With nominal staggering of either type, part of the shock transmits into a higher demand for labor and a higher real income and, therefore, the marginal disutility of working rises and the marginal utility of consumption falls, inducing a household to raise its nominal wage whenever this is possible. If it is wage-setting decisions that are staggered, then an increase in the household's nominal wage will result in an increase in its relative wage, creating an incentive for firms to substitute its labor service by the relatively cheaper labor services provided by other households. This substitution tends to reduce the household's hours worked and its marginal disutility of working, discouraging the household from raising its nominal wage too much. With synchronized pricing decisions, the price level and thus the price of the intermediate input coincide with each individual firm's price, which is a markup over the firm's marginal cost. Hence, the rigidity in the firm's pricing decision arises entirely from the rigidity in the nominal wage index, just as in the case with no intermediate input. If it is pricing decisions that are staggered, then an increase in a household's nominal wage, while not affecting its relative wage due to synchronized wage-setting decisions, will increase the real wage. The higher real wage creates an incentive for firms to substitute the relatively cheaper intermediate input for the composite labor service, discouraging the households from raising their nominal wages too much. This endogenous nominal wage rigidity reinforces the stickiness of the price of the intermediate input to deliver a sluggish marginal cost movement, discouraging firms from raising their prices too much.

³A model with capital accumulation and simulation results are available upon request from the authors.

Our results suggest that modeling an input-output structure may be useful for understanding some important issues. In this paper, we focus on showing how differently an input-output structure may interact with staggered-price setting and with staggered-wage setting, and on the implications of these interactions about persistence under each of the two types of nominal staggering. In general, there may be interesting interactions of an input-output structure and other types of mechanisms, and such interactions may be critical for understanding other issues. For example, Bergin and Feenstra (2000) emphasize the role in generating persistence of a non-linear interaction of an input-output relation and translog preferences under staggered-price setting. Huang, Liu, and Phanuef (2001) incorporate an input-output structure in a model with both types of nominal staggering, and they find that this input-output relation is an essential ingredient of the model for explaining simultaneously real wage behavior and output persistence. In open-economy setups, Bergin and Feenstra (2001) and Huang and Liu (2000, 2001b) demonstrate that international input-output connections may be an important mechanism for transmitting aggregate demand shocks across countries. The importance of input-output connections in explaining economic fluctuations has also been investigated by many others.⁴

In what follows, Section 2 sets up the model, Section 3 presents the results, and Section 4 concludes the paper.

2. The model

Time is discrete and is indexed by $t = 1, 2, \dots$. There is 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 $j \in [0, 1]$. At each date t , the economy experiences a realization of shocks s_t , and the history of events up to date t is $s^t = (s_1, \dots, s_t)$, with probability $\pi(s^t)$. The initial realization s_1 is given.

⁴See, for example, Means (1935), Blanchard (1983, 1987), Long and Plosser (1983, 1987), Gordon (1990), Basu (1995), Hornstein and Praschnik (1997), Horvath (1998, 2000), Dupor (1999), Clark (1999), Lindbeck and Snower (1999), and Huang and Liu (2001a).

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

$$L^d(i, s^t) = \left[\frac{W(i, s^t)}{\bar{W}(s^t)} \right]^{-\theta_l} L(s^t), \quad (1)$$

$$X^d(j, s^t) = \left[\frac{P(j, s^t)}{\bar{P}(s^t)} \right]^{-\theta_x} X(s^t). \quad (2)$$

The zero-profit condition implies that the wage rate $\bar{W}(s^t)$ for the composite skill is related to the wage rates $\{W(i, s^t)\}_{i \in [0,1]}$ for the differentiated skills by $\bar{W}(s^t) = \left[\int_0^1 W(i, s^t)^{1-\theta_l} di \right]^{1/(1-\theta_l)}$, 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 $\bar{P}(s^t) = \left[\int_0^1 P(j, s^t)^{1-\theta_x} dj \right]^{1/(1-\theta_x)}$.

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 good or as an intermediate production input (e.g., Basu (1995)).

The technology for producing a good j is a constant returns to scale production function:

$$X(j, s^t) = \Gamma(j, s^t)^\phi L(j, s^t)^{1-\phi}, \quad (3)$$

where $\Gamma(j, s^t)$ and $L(j, s^t)$ are the intermediate input and the composite labor, respectively, and $\phi \in (0, 1)$ is the share of the intermediate input in production.

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 (2) 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:

$$\max_{P(j, s^t)} \sum_{\tau=t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau | s^t) [P(j, s^t) - Q(s^\tau)] X^d(j, s^\tau) \quad (4)$$

where $D(s^\tau | s^t)$ is the price of one dollar at s^τ in units of dollars at s^t , and $Q(s^\tau)$ is the unit cost of production at s^τ (which is also the marginal cost due to the constant returns to scale technology) given by

$$Q(s^\tau) = \min_{\Gamma, L} \bar{P}(s^\tau)\Gamma + \bar{W}(s^\tau)L \quad \text{s.t.} \quad \Gamma^\phi L^{1-\phi} \geq 1. \quad (5)$$

The solution to the problem stated in (4) is

$$P(j, s^t) = \frac{\theta_x}{\theta_x - 1} \frac{\sum_{\tau=t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau | s^t) X^d(j, s^\tau) Q(s^\tau)}{\sum_{\tau=t}^{t+N_p-1} \sum_{s^\tau} D(s^\tau | s^t) X^d(j, s^\tau)}. \quad (6)$$

Thus the optimal price is a markup over a weighted average of the marginal costs for the periods in which the price will be effective. Embodied in this profit maximization problem is the cost minimization problem (5), the solution of which yields $Q(s^\tau) = \bar{\phi} \bar{P}(s^\tau)^\phi \bar{W}(s^\tau)^{1-\phi}$, where $\bar{\phi}$ is a constant determined by ϕ . Implicit in this cost minimization problem are the demand functions for the intermediate input and the composite labor in producing $X^d(j, s^\tau)$:

$$\Gamma(j, s^\tau) = \left[\frac{\phi}{1-\phi} \frac{\bar{W}(s^\tau)}{\bar{P}(s^\tau)} \right]^{1-\phi} X^d(j, s^\tau), \quad (7)$$

$$L(j, s^\tau) = \left[\frac{\phi}{1-\phi} \frac{\bar{W}(s^\tau)}{\bar{P}(s^\tau)} \right]^{-\phi} X^d(j, s^\tau). \quad (8)$$

Even if a firm can not choose a new price at a given date, it would still need to choose the inputs of the intermediate good and the composite labor in order to minimize the unit production cost. In other words, it has to solve the problem stated in (5) and, therefore, (7) and (8) hold for all firms.

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

$$\sum_{t=1}^{\infty} \sum_{s^t} \beta^{t-1} \pi(s^t) \left\{ U(C(i, s^t)) + V(L(i, s^t)) \right\}, \quad (9)$$

where $C(i, s^t)$ and $L(i, s^t)$ are consumption and labor hours, respectively, U is strictly increasing, V is strictly decreasing, and both are strictly concave and twice continuously differentiable. The budget constraint facing the household in event history s^t is

$$\bar{P}(s^t)C(i, s^t) + \sum_{s^{t+1}} D(s^{t+1}|s^t)B(i, s^{t+1}) \leq W(i, s^t)L^d(i, s^t) + \Pi(i, s^t) + B(i, s^t), \quad (10)$$

where $\Pi(i, s^t)$ represents its claims to firms' profits, net of a lump-sum tax. Each of the nominal bonds $B(i, s^{t+1})$ represents a claim to one dollar in event s^{t+1} and costs $D(s^{t+1}|s^t)$ dollars at s^t .

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) and a borrowing constraint $B(i, s^{t+1}) \geq -\underline{B}$, for some large positive number \underline{B} . The initial condition $B(i, s^1)$ is given. At date t , if a household i can set a new wage, then the optimal choice of its nominal wage is given by

$$W(i, s^t) = \frac{\theta_l}{\theta_l - 1} \frac{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t)L^d(i, s^\tau)[-V_l(i, s^\tau)/U_c(i, s^\tau)]\bar{P}(s^\tau)}{\sum_{\tau=t}^{t+N_w-1} \sum_{s^\tau} D(s^\tau|s^t)L^d(i, s^\tau)}, \quad (11)$$

where $-V_l(i, s^\tau)$ and $U_c(i, s^\tau)$ denote the marginal utility of leisure and of consumption, respectively. Thus the optimal wage is a markup over a weighted average of the dollarized marginal rates of substitution between leisure and consumption for the periods in which the wage will be effective. All households need to make decisions on consumption and bond holdings, and we have used the standard first order condition for bond holdings in deriving (11).

An equilibrium for this economy consists of allocations $C(i, s^t)$, $B(i, s^{t+1})$, and wage $W(i, s^t)$ for household i , for all $i \in [0, 1]$, allocations $\Gamma(j, s^t)$, $L(j, s^t)$, and price $P(j, s^t)$ for firm j , for all $j \in [0, 1]$, together with prices $D(s^{t+1}|s^t)$, $\bar{P}(s^t)$, and wage $\bar{W}(s^t)$, 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 bonds, the composite labor, and the composite good clear.

In equilibrium, the contingent bonds provide complete insurance against idiosyncratic risks facing households and, therefore, a single consumption profile characterizes the optimal consumption plans for all households. Assuming an equally distributed initial wealth, we have $C(i, s^t) = \int_0^1 C(i, s^t) di = Y(s^t)$ for all i and for every s^t , where $Y(s^t)$ denotes real GDP.⁵ Given this relation, along with (7) and (8), the market clearing condition $\int_0^1 C(i, s^t) di + \int_0^1 \Gamma(j, s^t) dj = X(s^t)$ for the composite good implies that

$$Y(s^t) = \left\{ 1 - \left[\frac{\phi}{1 - \phi} \frac{\bar{W}(s^t)}{\bar{P}(s^t)} \right]^{1-\phi} G(s^t) \right\} X(s^t), \quad (12)$$

and the market clearing condition $\int_0^1 L(j, s^t) dj = L(s^t)$ for the composite labor implies that

$$L(s^t) = \left[\frac{\phi}{1 - \phi} \frac{\bar{W}(s^t)}{\bar{P}(s^t)} \right]^{-\phi} G(s^t) X(s^t), \quad (13)$$

where $G(s^t) \equiv \int_0^1 [P(j, s^t)/\bar{P}(s^t)]^{-\theta_x} dj$. Equations (12) and (13), together with the price-setting equation (6) and the wage-setting equation (11), characterize an equilibrium.

3. The results

We consider two alternative cases, one with wage staggering in which $N_w = N$ and $N_p = 1$, and the other with price staggering in which $N_w = 1$ and $N_p = N$, where N is an integer larger than 1 and N periods of the model time correspond to a year. Our objective is to examine whether and how modeling the use of the intermediate input in production can affect the persistence implications of the two types of nominal staggering. To help exposition, we derive analytical solutions to a log-linearized system

⁵In this closed economy with no investment or government spending, real GDP is equal to aggregate consumption.

of the equilibrium conditions, and we use lowercase letters to denote the log-deviations of the corresponding level variables from their steady state values.⁶

The persistence implications of wage staggering and price staggering are embodied in the wage-setting equation and the price-setting equation, both of which take a common log-linear form given by

$$z_t = \sum_{j=1}^{N-1} b_j z_{t-j} + \sum_{j=1}^{N-1} b_j E_t z_{t+j} + \frac{\gamma_z}{N-1} \sum_{j=0}^{N-1} E_t y_{t+j}, \quad (14)$$

where $b_j = (N-j)/[N(N-1)]$, E_t is a conditional expectation operator, and we have set $\beta = 1$ to help exposition. Equation (14) corresponds to the wage-setting rule if $z = w$ and to the pricing-decision rule if $z = p$. The two parameters γ_w and γ_p are given by

$$\gamma_w = \frac{\xi_c + \xi_l}{1 + \theta_l \xi_l}, \quad (15)$$

$$\gamma_p = \frac{(\xi_c + \xi_l)(1 - \phi)}{1 + f(\phi, \theta_x) \xi_l}, \quad (16)$$

where $f(\phi, \theta_x) \equiv \phi/[\phi + \theta_x(1 - \phi)]$, and $\xi_c = -CU_{cc}/U_c$ and $\xi_l = LV_{ll}/V_l$ denote the steady state relative risk aversion in consumption and in labor hours, respectively.

The first two terms on the right hand side of (14) imply that households or firms would like to keep their wages or prices in lines with those set in the past and those expected to be set in the future by their peers that will be effective within their own contract duration. Taylor (1980) suggests that this backward- and forward-looking effect is a promising avenue to generate price level inertia and output persistence. Clearly, the magnitude of this effect is the same, as each b_j is, regardless of whether it is wage-setting decisions or pricing decisions that are staggered; and, arbitrary persistence would obtain were wages or prices exogenously sticky for arbitrarily long periods of time. Yet, as most empirical studies suggest, the length of nominal contracts on average is about one year (e.g., Taylor (1999)), which is much shorter than the duration of a typical business cycle. The difficult problem is to generate long periods of endogenous nominal stickiness

⁶Since in equilibrium, a household or a firm is identified by the time it can set a new wage or a new price, we can drop the indexes i and j for individual households and firms, replace the event argument s^t by the time subscript t , and denote by W_t and P_t the wage and the price set at time t , respectively.

and real persistence from short periods of exogenous nominal stickiness. Endogenous nominal stickiness requires that households (firms) choose not to change their wages (prices) much when they can do so, while endogenous real persistence is captured by output dynamics beyond the point in time when all households (firms) have had the chance to change their wages (prices), that is, beyond the initial N periods following a shock.

The amount of endogenous stickiness is negatively related to the magnitude of γ_z , the reaction of wage-setting decisions or pricing decisions to the average expected changes in aggregate demand conditions within a contract duration, as revealed by the third term on the right hand side of (14). A small γ_z can interact with exogenous nominal stickiness to help generate endogenous nominal stickiness and real persistence. This role of γ_z in generating persistence has been emphasized by Huang and Liu (1998) and Chari et al. (2000). If γ_z is less than 1, then there is endogenous real persistence; the amount of the persistence is larger, the smaller is γ_z . Thus, the ability of staggered-wage mechanism and staggered-price mechanism in generating persistence lies with the magnitude of γ_w and γ_p , respectively.

We now provide some intuition for why γ_w and γ_p are linked to the fundamental parameters in different ways via the functional forms in (15) and (16). Consider a one percent aggregate demand shock. With the nominal staggering of either type, part of the shock transmits into a higher demand for labor and a higher real income. Thus the marginal disutility of working rises and the marginal utility of consumption falls, inducing a household to raise its wage whenever it can do so. This is why ξ_l , which determines how rapidly the marginal disutility of working rises as hours worked increase, and ξ_c , which determines how fast the marginal utility of consumption falls as consumption rises, enter the numerators of the expressions for both γ_w and γ_p .

If it is wage-setting decisions that are staggered, then an increase in the household's nominal wage will lead to an increase in its relative wage, creating an incentive for firms to substitute its labor service by the relatively cheaper labor services provided by other households. This substitution tends to reduce the household's hours worked and

its marginal disutility of working, discouraging the household from raising its nominal wage too much. As a result, the optimal increase in the household's nominal wage is less than $\xi_c + \xi_l$. This is why both θ_l , which determines how rapidly the amount the household works falls as its nominal wage rises, and ξ_l enter the denominator of the expression for γ_w . With synchronized pricing decisions, the price level and so the price of the intermediate input coincide with each individual firm's price. Hence, the rigidity in each firm's pricing decision arises entirely from the rigidity in the nominal wage index and the optimal adjustment of each firm's price is given by γ_w as well, just as in the case with no intermediate input.

In the case that pricing decisions are staggered while wage-setting decisions are synchronized, an increase in a household's nominal wage will not affect its relative wage; yet, as all households raise their wages in the face of the sticky nominal prices, the real wage will go up. Since the cost of the intermediate input is equal to the price level, a rise in the real wage creates an incentive for firms to substitute the relatively cheaper intermediate input for the composite labor. This substitution tends to reduce households' hours worked and their marginal disutility of working, discouraging them from raising nominal wages too much. Consequently, the optimal increase in the households' nominal wages, which in the present case coincide with the nominal wage index, is less than $\xi_c + \xi_l$. This endogenous nominal wage rigidity explains why $f(\phi, \theta_x)$ and ξ_l enter the denominator of the expression for γ_p . Here $f(\phi, \theta_x)$ determines how rapidly the households' hours worked fall as the nominal wage index rises. The larger the share ϕ of the intermediate input in production, the larger is the substitution effect between labor and intermediate input, and the smaller is the adjustment in the nominal wages by the households. This is why $f(\phi, \theta_x)$ is increasing in ϕ . On the other hand, the larger the demand elasticity parameter θ_x is, the smaller is the markup of firms' prices over their marginal costs, and the closer are the nominal wage index and the price level prior to the shock. Consequently, the substitution effect is smaller, and the adjustment in the nominal wages by the households is larger. This is why $f(\phi, \theta_x)$ is decreasing in θ_x . To understand why the term $(1 - \phi)$ appears in the numerator of the expression for γ_p , observe that, with ϕ share

of the intermediate input in production, marginal cost is composed of ϕ fraction of the price level and of $(1 - \phi)$ fraction of the nominal wage index. Thus, exogenous nominal stickiness in the form of staggered-price setting translates directly into the sluggishness in the movements of this former part of the marginal cost. Since a firm's optimal price is a markup over a weighted average of the marginal costs within its contract duration, we can scale down ϕ fraction of the rise in the nominal wage index to get the optimal price response for the firm.

In light of (15) and (16), the intermediate input share ϕ enters into the key persistence parameters γ_w and γ_p in different ways, implying that the use of the intermediate input in production interacts with staggered-wage setting and with staggered-price setting differently: while it does not help staggered-wage setting to generate extra endogenous persistence beyond what is already implied by the wage staggering (for γ_w is independent of ϕ), it improves the ability of staggered-price setting to generate persistence (for γ_p is decreasing in ϕ). This observation suggests that the relative capacity of the two types of nominal staggering in generating persistence depends critically on whether the input-output structure is taken into account. In the extreme case that ϕ is set to zero, γ_p is larger than γ_w and it is less likely to generate persistence under staggered-price setting than is under staggered-wage setting (e.g., Andersen (1998) and Huang and Liu (1998)). With a positive value of ϕ , γ_p can be equal to or less than γ_w , and thus persistence can be the same or even more under staggered-price setting than under staggered-wage setting. In the other extreme case that ϕ is set arbitrarily close to one, γ_p is arbitrarily close to zero, and arbitrary persistence obtains under staggered-price setting, while the implication on persistence of staggered-wage setting remains the same as in the case where ϕ is set to zero.

For concreteness, we provide now numerical examples in which γ_p can be equal to γ_w under some reasonable parameter values so that the two types of nominal staggering can be equally able to generate persistence. By virtue of (15) and (16), γ_p and γ_w are equal if and only if

$$(1 + \theta_l \xi_l)(\theta_x - 1)\phi^2 + (\theta_l \xi_l - \theta_x - \xi_l - 2\theta_x \theta_l \xi_l)\phi + \theta_x \theta_l \xi_l = 0. \quad (17)$$

An empirically plausible range for θ_l , the elasticity of substitution of differentiated labor skills, is from 2 to 4, according to Griffin (1992, 1996). A reasonable range for θ_x , the elasticity of substitution of differentiated goods, is from 4 to 10, in light of the empirical studies of Domowitz, Hubbard, and Petersen (1986), Shapiro (1987), Basu (1996), Basu and Kimball (1997), Basu and Fernald (1994, 1995, 1997), and Linnemann (1999). To pinpoint a range for the relative risk aversion parameter ξ_l , one usually appeals to the estimates of the intertemporal hours elasticity of substitution based on the intensive margin. Early studies along this avenue mostly suggest that such elasticity is smaller than 1, as surveyed by Pencavel (1986). Recent work demonstrates that these estimates can be subject to large downward biases (e.g., Rupert, Rogerson, and Wright (2000)). In particular, Mulligan (1998) finds that the elasticity is instead in the 1-2 range. Recent empirical studies also show that the employment elasticity based on the extensive margin can be much greater than 1 (e.g., Kimmel and Kniesner (1998)). We consider the value of ξ_l from 0.5 to 2, corresponding to the intertemporal labor elasticity of substitution between 2 and 0.5.

Table 1 displays the intermediate input share ϕ (between 0 and 1) that solves (17) under the above values of θ_l , θ_x , and ξ_l . Some of these values of ϕ are consistent with the empirical evidence. For example, the estimates of Jorgenson, Gollop, and Fraumeni (1987) show that ϕ is at least 0.5 for U.S. manufacturing industries over the period 1947-1979. The recent empirical study by Hanes (1999) suggests that the input-output relations in the actual economy have become more sophisticated in the recent years than in the further past, suggesting an increasing intermediate input share over time. Basu (1995) argues that ϕ can lie between 0.8 and 0.9 if fixed costs are taken into account (see, also, Bergin and Feenstra (2000)); yet, the implied markup drawn from Domowitz et al. (1988) is often viewed as somewhat large. We consider 0.5-0.7 as a reasonable range for ϕ , and we note that many values in Table 1 lie in this range or in its close vicinity. Thus, for some empirically plausible values of the fundamental parameters,

staggered-price setting and staggered-wage setting can be two equivalent mechanisms in generating persistence.⁷

To help get a further quantitative feel, we plot in Figure 1 the impulse responses of real GDP following an aggregate demand shock under each of the two types of nominal staggering for a spectrum of values of the share ϕ of intermediate input in production. To be specific, we denote by $m_t = \bar{p}_t + y_t$ the nominal GDP (in a log-deviation form) and assume that m_t is exogenous, with its growth rate $\mu_t = m_t - m_{t-1}$ following an AR(1) process given by $\mu_t = \rho\mu_{t-1} + \varepsilon_t$, where ε_t is a white-noise process. We interpret changes in ε_t as shocks to aggregate demand. To generate the plots, we set $N = 4$ so that one period in the model corresponds to a quarter of a year, and we set $\beta = 0.99$, $\xi_c = 1$, $\xi_l = 1$, $\theta_l = 2$, and $\theta_x = 10$, which are all standard values used in the literature. In addition, we set $\rho = 0.57$ in light of a simple money growth regression using quarterly M1 data (e.g., Chari, et al. (2000)).⁸

In the figure, the upper panel displays the responses of real GDP to a one percent shock in ε_0 , and the lower panel displays these responses normalized by the initial responses. These panels confirm our analytical result that a larger share ϕ of intermediate input in production helps generate more persistence under staggered-price setting, but not under staggered-wage setting. In the extreme case that ϕ is set to zero, there is more persistence under staggered-wage setting than is under staggered-price setting. As ϕ goes up from zero, the magnitude of persistence under staggered-price setting increases while that under staggered-wage setting stays the same. As ϕ rises from 0.5 to

⁷With a separable utility (9) in consumption and leisure, the balanced growth path property requires that $\xi_c = 1$. Then, for all the values of θ_l , θ_x , ξ_l , and ϕ displayed in Table 1, the corresponding γ_w and γ_p are not only equal, but less than 1, and there is an equal amount of endogenous persistence under staggered-price setting and under staggered-wage setting.

⁸The shock in the nominal GDP process can loosely be reinterpreted as a money supply shock if there were a static money demand equation, or a constant velocity of money. In an unreported experiment, which is available upon request from the authors, we have examined the case with an iid μ_t process and found the qualitative features of our results unchanged.

0.7, the former catches up with and eventually exceeds the latter. Thus, once the empirically relevant input-output structure is taken into account, staggered-price setting may be as capable as staggered-wage setting in generating persistence for some reasonable parameter values.

4. Concluding remarks

We have shown that the presence of an input-output production structure helps generate more persistent response of real output to an aggregate demand shock under staggered-price setting, but not under staggered-wage setting. Under staggered-price setting, the input-output structure creates a real wage effect that prevents nominal wages from deviating too much from the sticky price of the intermediate input. This endogenous nominal wage rigidity reinforces the stickiness of the intermediate input price to increase the rigidity in firms' pricing decisions. As a result, the conventional wisdom on the equivalence of staggered-price setting and staggered-wage setting in generating persistence may continue to hold with optimizing individuals and some plausible values of fundamental parameters, once this empirically relevant input-output structure is taken into account.

The results presented in this paper suggest that the input-output connections in the actual economies may be an important mechanism that can help economists better understand some of the standing issues. Recent empirical studies suggest that the sophistication of the relations has increased over the years, both within the United States (e.g., Hanes (1999)) and in the global economy (e.g., Feenstra (1998), Hummels, Rapoport, and Yi (1998), and Hummels, Ishii, and Yi (2001)). Future research that captures this real-world feature should be both important and promising. The present paper only represents a small step toward this direction.

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Table 1

Value of the intermediate input share ϕ under which $\gamma_p = \gamma_w$

$\xi_l = 0.5$							
	$\theta_x = 4$	$\theta_x = 5$	$\theta_x = 6$	$\theta_x = 7$	$\theta_x = 8$	$\theta_x = 9$	$\theta_x = 10$
$\theta_l = 2$	0.4566	0.4632	0.4680	0.4717	0.4746	0.4770	0.4790
$\theta_l = 3$	0.5528	0.5595	0.5645	0.5683	0.5714	0.5740	0.5761
$\theta_l = 4$	0.6186	0.6250	0.6298	0.6336	0.6367	0.6392	0.6414
$\xi_l = 1$							
	$\theta_x = 4$	$\theta_x = 5$	$\theta_x = 6$	$\theta_x = 7$	$\theta_x = 8$	$\theta_x = 9$	$\theta_x = 10$
$\theta_l = 2$	0.5809	0.5918	0.6000	0.6065	0.6118	0.6162	0.6199
$\theta_l = 3$	0.6667	0.6763	0.6838	0.6897	0.6946	0.6988	0.7023
$\theta_l = 4$	0.7214	0.7298	0.7365	0.7418	0.7462	0.7500	0.7532
$\xi_l = 1.5$							
	$\theta_x = 4$	$\theta_x = 5$	$\theta_x = 6$	$\theta_x = 7$	$\theta_x = 8$	$\theta_x = 9$	$\theta_x = 10$
$\theta_l = 2$	0.6360	0.6488	0.6587	0.6667	0.6732	0.6787	0.6834
$\theta_l = 3$	0.7135	0.7243	0.7327	0.7395	0.7452	0.7500	0.7542
$\theta_l = 4$	0.7619	0.7709	0.7781	0.7840	0.7889	0.7931	0.7968
$\xi_l = 2$							
	$\theta_x = 4$	$\theta_x = 5$	$\theta_x = 6$	$\theta_x = 7$	$\theta_x = 8$	$\theta_x = 9$	$\theta_x = 10$
$\theta_l = 2$	0.6667	0.6805	0.6913	0.7000	0.7072	0.7134	0.7186
$\theta_l = 3$	0.7388	0.7500	0.7588	0.7661	0.7721	0.7773	0.7818
$\theta_l = 4$	0.7834	0.7926	0.8000	0.8061	0.8112	0.8156	0.8195

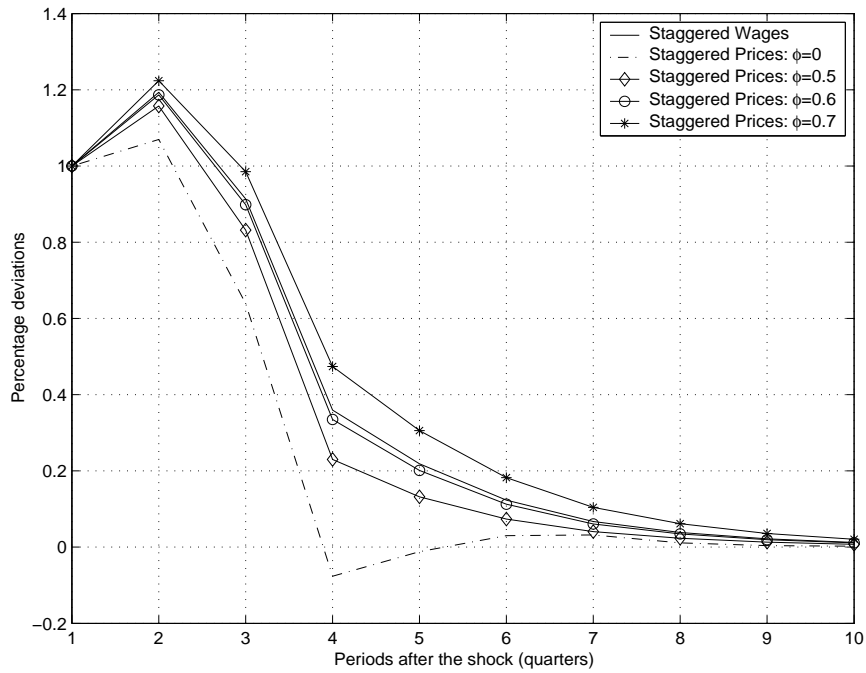
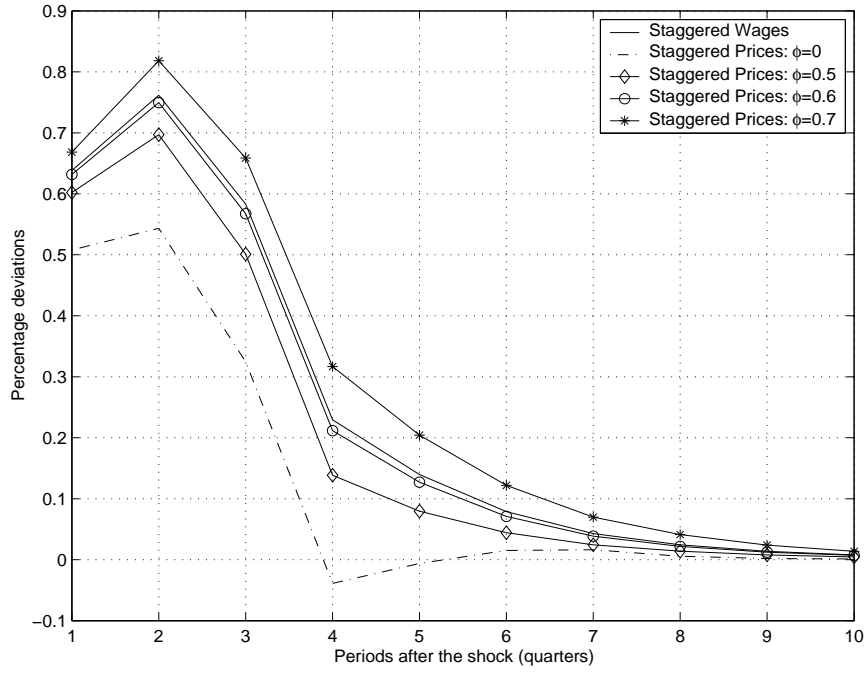


Figure 1:—The impulse responses of real GDP following an aggregate demand shock