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INTERINDUSTRY LINKAGES AND THE TIMING OF PRICE ADJUSTMENT*

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The gradual adjustment of the aggregate price level has been attributed to the driving force of fluctuation of output in Keynesian macroeconomics. The staggering timing pattern in price adjustment contributes to the inertia in the aggregate price level. This paper incorporates input-output relation into price setting firms in order to demonstrate that the staggered price setting is a stable equilibrium. The timing pattern in price setting is explained by two elements: heterogeneous inputs and information asymmetry. The result suggests that an input-output system has a hierarchical structure when staggering pattern arises. On the other hand, staggering is not likely to take place when each industry is not linked to other industries.

JEL Classification: E3
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I. INTRODUCTION

The gradual adjustment of the aggregate price level has been attributed to the main driving force of persistent fluctuations of output and employment though the existence of menu cost suffices the nonneutrality of monetary shock. The staggering timing pattern in price adjustment contributes to the inertia in the aggregate price level. This paper incorporates input-output relation into price setting firms in order to demonstrate that the staggered price setting is a stable equilibrium.

New Keynesian economics as a microfoundation of nominal price rigidity introduces the coordination failure among firms in price setting. Ball and Romer (1989) set up a model in which firm-specific productivity disturbances occur at

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different times for different firms. Synchronization is a stable Nash equilibrium if aggregate shock dominates firm-specific shocks. Staggering is a stable equilibrium if firm-specific shocks are present. The intuition is that staggering makes firms adjust fully to their idiosyncratic shocks. Ball and Cecchetti (1988) utilize imperfect information as a reason for staggered price adjustment. Because of information lag, there is an incentive for each firm to delay the adjustment and acquire more information on the shocks.

New Keynesian models exogenously assume the staggering timing pattern, or it is a stable equilibrium only in special cases. Ball and Romer (1989) and Ball and Cecchetti (1988) are two models that yield staggering pattern as a stable equilibrium. Ball and Romer's result, however, relies on a special assumption and the relations among sectors are not considered in Ball and Cecchetti.

This study introduces input-output relations into price setting firms in order to yield staggering timing pattern as a stable equilibrium. An input-output model is contrasted with Lucas' (1973) island model. The island model assumes that each island is isolated from each other and each island faces only an aggregate shock and a local shock. In an input-output model, industries are intertwined with input-output relations. Therefore, each industry faces a full set of economy-wide and industry-specific shocks. In order to set the state-contingent price, each firm must estimate not only changes in its own productivity, but also all the impacts of changes in upstream industries' productivities on its price. Without a market for information, staggering may be a sensible means of information acquisition.

As a consequence, the coordination failure in price setting is explained by two elements: heterogeneous inputs and information asymmetry. It is shown that staggering timing pattern is a stable Nash equilibrium when an input-output model is incorporated. This is because an industry prefers to adjust its price after the upstream industry changed its price in order to acquire the updated information on the aggregate demand and the upstream industry-specific productivity shocks.

The result suggests that when an input-output system is triangular or block-triangular, that is, the system has a hierarchical structure when staggering pattern arises in a decentralized economy. On the other hand, staggering is not likely to take place when each industry is not linked to other industries because information incentive is small. This model gives a microfoundation of staggered price adjustment in the product markets at industry level.

The timing and frequency of labor contracts have been well documented and investigated by many researchers. It is well known that the labor contracts in the unionized sectors are negotiated with one, two, or three year cycle and the negotiation timings are staggered (Taylor (1983), and Fethke and Policano (1990)). Blandchard (1987) uses the "cumulation hypothesis" to explain the considerable stickiness of the aggregate price level caused by staggering. The hypothesis states that individual prices are adjusted with a relatively short lag at the individual level while the aggregate price level (final good price) changes gradually because the lags at the individual level are accumulated through the stages of processing or the transactions among industries due to staggered adjustment caused by the friction like menu cost and information imperfection. Also he finds a strong evidence that supports the hypothesis.

Section Ⅱ sets up a model of price adjustment in which input-output system has a hierarchical structure. Section Ⅲ analyzes two pricing regimes: synchronization and uniform staggering. The last section includes concluding remarks.

Ⅱ. A GENERAL MODEL OF PRICE ADJUSTMENT

The industries in an economy are known to be interdependent with one another. A few input-output analysts attempted to find a hierarchical structure in a complex input-output system (Chenery and Watanabe (1958), Simpson and Tsukui (1965), Korte and Oberhofer(1970), and Leontief(1986)). In particular, they triangularize an input coefficient matrix. A triangular input coefficient matrix implies that there are only one-way flows of transactions among industries. Under a triangular system, each industry uses only the inputs produced by the industries on the lower stages of processing while each industry sells its output only to the industries on the upper stages of processing. The input-output system of this economy is assumed to be block-triangular for simplicity[1].

The equilibrium relative price of the i-th industry in log is assumed to be

$$p_i - p = z_i + a_{i-1,i}(p_{i-1} - p) \tag{1}$$

where p_i is the i-th industry's nominal price, p is the aggregate price level, z_i is the i-th industry's adverse productivity shock, and $a_{i-1,i}$ is a direct input coefficient of the i-th industry on the $(i-1)$th industry. We need to note the assumption that an industry uses only its upstream industry's products. The labor market is disregarded for simplicity.

We may derive the price equation (1) in a general equilibrium framework like Ball and Cecchetti (1988). However it is important that firm's price depends on upstream industry's price. The price equation (1) expresses such relation reasonably. We also assume that there are many firms with some monopolistic power in an industry and it is not necessary to distinguish firms in the same industry because a firm is a representative firm.

Continuously substituting input prices into (1), we have the reduced form of the equilibrium relative price

$$p_i - p = \sum_{h=1}^{i-1}\left(\prod_{j=h}^{i-1} a_{j,j+1}\right) z_h + z_i$$

[1] An input-output system is said to be block-triangular if each block is dependent only on its upstream block and the industries in each block are arranged in triangular form.

$$= \sum_{h=1}^{i} \alpha_{hi}\, z_h, \qquad \alpha_{ii} = 1 \tag{2}$$

where a_{hi} is a direct input coefficient of the i-th industry on the h-th industry, and

$$\alpha_{hi} = \prod_{j=h}^{i-1} a_{j,j+1},$$

that is, α_{hi} is defined as the linkage coefficient of the h-th and i-th industry.

Therefore, we assume that each firm in the i-th industry maintains the equilibrium nominal price under no uncertainty and in the absence of price adjustment cost as follows:

$$p_{it}^{*} = \sum_{h=1}^{i} \alpha_{hi} z_{ht} + p_t\,. \tag{3}$$

The equilibrium relative price equation (3) shows how much information on all relevant industries a single individual firm must collect and process to set the state-contingent price when a firm can not observe the current values of the productivity shocks and interindustry linkages. Suppose that firms must incur some sort of adjustment cost in changing their prices. Because of the imperfect information and adjustment cost C, each firm must estimate the future equilibrium prices and fix price at a certain level for T periods of time.

Each firm is assumed to choose price p_{it} to minimize the average loss over the interval of price change T, ignoring discounting:[2]

$$L_{it} = \frac{1}{T} \int_0^T E_t (p_{i\ t+s}^{*} - p_{it})^2 ds + \frac{C}{T} \tag{4}$$

where $E_t X_t$ is the expectation conditional on the information available to each firm in the i-th industry at time t, that is, $E_t X_t = E(X_t \mid \Omega_{it})$. It may be more general that both timing and interval of price adjustment are endogenous. However, this study focuses on showing how the timing of price adjustment is determined. So the time interval of adjustment is fixed. A solution p_{it} to the minimization problem is

$$p_{it} = \frac{1}{T} \int_0^T E_t p_{i\ t+s}^{*}\, ds. \tag{5}$$

The nominal aggregate demand shock $\{m_t\}_{t=0}^{\infty}$ is assumed to be a Brownian

[2] Quadratic loss functions have been used in a great deal of macroeconomic literature as an approximation to true objective function (Gray (1978) and Fethke and Policano (1984)).

motion process. Its variance is $\sigma_m^2 t$. Its increment is defined as

$$\delta_{t-s} = m_t - m_s, \qquad t > s$$

An industry-specific productivity shock $\{z_{it},\ i=1,2,\cdots,n\}_{t=o}^{\infty}$ is assumed to follow a Brownian motion process. Its variance is $\sigma_i^2 t$. Its increment is defined as

$$\xi_{i\,t-s} = z_{it} - z_{is}, \qquad t > s.$$

Industry-specific shocks are assumed to be independent. To capture the idea of the uncertainty on interindustry linkages, the impact of indirectly linked industry-specific productivity shocks on the i-th industry price is defined as

$$x_{it} = \sum_{h=1}^{i-2} \alpha_{hi} z_{ht}. \tag{6}$$

The movement of the impacts $\{x_{it},\ i=1,2,\cdots,n\}_{t=o}^{\infty}$ follows a Brownian motion process with variance $\theta_i^2 t$. Its increment is defined as

$$\chi_{i\,t-s} = x_{it} - x_{is}, \qquad t > s. \tag{7}$$

III. THE EQUILIBRIUM TIMING OF PRICE ADJUSTMENT

The following assumptions are made with regard to information on the variables.

1) The current observations on prices are not known.
2) The observations on aggregate demand and industry-specific shocks are known with a T-period lag.
3) Only the linkage coefficients of the $(i-1)$th and i-th industry, $\alpha_{i-1,i}$, are known. Firms do not know the linkage coefficients of indirectly linked industries, $\alpha_{hi}(h=1,2,\cdots,i-2)$.
4) The total impacts of indirectly linked industries on the i-th industry price, $x_{it} = \sum_{h=1}^{i-2} \alpha_{hi} z_{ht}$, are known with a T-period lag.
5) In addition, firms can infer the new values of aggregate demand, and industry-specific shocks after the industries set their prices.
6) Firms do not use the current information on the indirectly linked industry-specific shocks because they do not know the relevant linkage coefficients[3]

[3] Assumptions 3 and 6 are reasonable because it is very difficult for a single firm to compute how much the relevant industries affect its price even though it is aware of what is happening in those industries.

7) It takes T/n periods of time to process information.

Assumption 5 needs to be explained more. The aggregate and industry-specific shocks are fully known with T-period lag. Firms can observe the prices and get the information on the noisy observation on shocks. Therefore, they can infer new information on aggregate and industry-specific shocks.(Ball and Cecchetti, 1988) For example, a firm can observe the noisy observations on aggregate and industry-specific shocks of other firms by seeing their prices. The industry-specific shocks average to zero over the many price setters. So it can know the updated information on aggregate shocks. We may specify the lags about those shocks more rigorously. However it is reasonable that firms can get new information on the aggregate and industry-specific shocks with observed prices. I study only particular timing patterns of price adjustment, synchronization and uniform staggering.

1. Synchronization

In this subsection, I will show that synchronization is not a Nash equilibrium. Synchronization is a Nash equilibrium if no firm can gain by breaking from synchronization, taking the behavior of others as given, that is, if

$$L_{it}^{syn} \leq L_{sw\ t}. \tag{8a}$$

It is a stable equilibrium if[4]

$$L_{it}^{syn} < L_{sw\ t} \tag{8b}$$

where $L_{sw\ t}$ is switcher's loss when it sets price at a point of time after all other firms change prices. We compare the loss of a firm under synchronization with its loss if it switches to see when synchronization is an equilibrium.

(1) Firm's Information

Suppose that all firms change prices at t simultaneously and fix them for T periods of time (see Figure 1). Because no firm adjusts price for the time periods $(t-T, t)$, only the T-period lagged information are available. So the information available to each firm in the i-th industry at time t is[5]

[4] There may be many reasonable definitions of stability. We could make only one firm in an industry switch its timing of adjustment while leaving the other industries unchanged and compare the losses of a firm in the perturbed industry before and after it moves. We could also perturb a considerable proportion of an industry while leaving the other industries unchanged and compare the losses of the two groups in the perturbed industry. This model is analyzed with a weak definition of stability.

[5] The information on the shocks are obtained by assumption 2.

[Figure 1] Timing of Price Adjustment under Synchronization

	t-T	t	t+T	time
industry adjusting price	all industries	all industries	all industries	

$$\Omega_{it}^{syn}=\{m_s(s\le t-T),\ x_{is}(s\le t-T), z_{hs}(h=i-1,\ i,\ s\le t-T)\}. \tag{9}$$

(2) The Price Level and Firm's Loss

Assume that the price level responds to changes in the monetary shock with a T-period lag.[6]

$$p_{t+s}=m_{t-T}, \qquad 0\le s<T. \tag{10}$$

Taking the conditional expectation to (3) and using (9) and (10), the expectation of industry price is

$$\begin{aligned} E_t p_{i\ t+s}^{*} &= E_t\left(\sum_{h=1}^{i}\alpha_{hi}z_{h\ t+s}\right)+E_t\,p_{t+s}, \quad 0\le s<T, \\ &= x_{i\ t-T}+\alpha_{i-1,i}z_{i-1\ t-T}+z_{i\ t-T}+m_{t-T}. \end{aligned} \tag{11}$$

It holds that

$$p_{it}=E_t p_{i\ t+s}^{*}. \tag{12}$$

Substituting (3) and (11) in (4) yields a firm's loss under synchronization

$$L_{it}^{syn}=\frac{3}{2}[\theta_i^2+\alpha_{i-1,i}^2\sigma_{i-1}^2+\sigma_i^2]T+\frac{C}{T}. \tag{13}$$

(3) Equilibrium and Stability

Suppose that a switcher firm can choose the timing of adjustment. Then the switcher firm in industry i will delay time periods of T/n when the other firms change prices at time $t-T/n$ (see Figure 2). A switcher can observe other firms' prices including the $(i-1)$ and i-th industry prices set at time $t-T/n$. So the new information on aggregate demand $m_{t-T/n}$ and its own and upstream

[6] The assumption on the aggregate price level (10) is similar to a solution of the average of individual prices because the industry-specific shocks average to zero over many price setters.

[Figure 2] Switcher Firm under Synchronization

	t-T/n-T	t-T	t-T/n	t	t-T/n+T	t+T	time
industry adjusting price	all industries	switcher	all industries	switcher	all industries	switcher	

industry-specific productivity shocks, $z_{i\,t-T/n}$ and $z_{i-1\,t-T/n}$, are available. Therefore, the switcher firm's information set is

$$\Omega_{sw\,t}=\left\{m_s\left(s\le t-\frac{T}{n}\right),\ x_{is}(s\le t-T),\ z_{i-1\,s}\left(s\le t-\frac{T}{n}\right),\ z_{is}\left(s\le t-\frac{T}{n}\right)\right\}. \quad (14)$$

Because a switcher is small compared with the economy, we assume that it does not affect the aggregate price level when it switches. Therefore, the price level is given by (10).

Using (3), (10), and (14), the price set by a switcher firm becomes

$$p_{it}=E_t p^*_{i\,t+s}=m_{t-T}+x_{i\,t-T}+\alpha_{i-1,i}z_{i-1\,t-T/n}+z_{i\,t-T/n}. \quad (15)$$

A switcher's loss is

$$L_{sw\,t}=\left(\frac{1}{2}+\frac{1}{n}\right)(\alpha^2_{i-1,i}\,\sigma^2_{i-1}+\sigma^2_i)T+\frac{3}{2}\,\theta^2_i\,T+\frac{C}{T}. \quad (16)$$

Comparing (13) with (16), we find

$$L^{syn}_{it}>L_{sw\,t}, \qquad n\ge 2.$$

The switcher firm does not move back to the synchronized timing pattern. Therefore, synchronization is not a Nash equilibrium.[7]

2. Uniform Staggering

In this subsection, I will show that uniform staggering is a stable Nash equilibrium under a certain condition. Uniform staggering is a Nash equilibrium if no firm can gain by switching to the other groups, taking the behavior of

[7] This result may not be robust. When the "price level effect" is considered, synchronization may be an equilibrium. Suppose that a proportion of switchers break synchronized pattern. As a result, the aggregate price level changes more gradually and the switchers' loss may increase because of higher output fluctuation. Therefore, they tend to move back to synchronized pattern.

others as given, that is, if

$$L_{it}^{stag} \leq L_{it}^{k}. \tag{17a}$$

It is a stable equilibrium if[8]

$$L_{it}^{stag} < L_{it}^{k}. \tag{17b}$$

where L_{it}^{k} is a switcher's loss when it joins the k-th industry in prices with the time interval of T/n for a pricing cycle T (see Figure 3).

(1) Firm's Information

For example, the first industry changes price at time t, the second industry changes it at time $t+T/n$, the third industry changes it at time $t+2T/n$, and so on. Since all firms of the (i-1)th industry adjust prices in advance, their prices reveal the information on the estimates of aggregate demand and the (i−1)th industry-specific productivity shocks. So the updated information on aggregate demand and the (i-1)th industry-specific productivity shocks, $m_{t-T/n}$ and $z_{i-1\,t-T/n}$, are available to the firms of the I-th industry by observing the prices set by the (i-1)th industry at time t. This is additional information under staggering. So the information available to each firm of the i-th industry is[9]

$$\Omega_{it}^{stag} = \{m_s(s \leq t-T/n),\ x_{is}(s \leq t-T),\ z_{i-1\,s}(s \leq t-T/n),\ z_{is}(s \leq t-T)\}. \tag{18}$$

(2) The Price Level and Firm's Loss

The price level is assumed to respond gradually to changes in the monetary shock.

$$p_{t+s} = m_{t-T/n}, \qquad 0 \leq s < T/n,$$

[Figure 3] Timing of Price Adjustment under Uniform Staggering

	t-T/n-T	t-T	t+T/n-T	t-T/n	t	t+T/n	t+(n-1)T/n	t+T	t+(n+1)T/n	time
industry adjusting price	···i-1	i	i+1······n12······	i-1	i	i+1······n12······	i-1	i	i+1	

[8] Also see note 4.

[9] Firms can get updated values of the shocks using noisy observations on the shocks by assumption 5.

$$\begin{aligned} &p_{t+T/n+s} = m_t, && 0 \leq s < T/n, \\ &p_{t+2T/n+s} = m_{t+T/n}, && 0 \leq s < T/n, \\ &\cdots\cdots \\ &p_{t+(n-1)T/n+s} = m_{t+(n-2)T/n}, && 0 \leq s < T/n, \end{aligned} \tag{19}$$

The average price level for the interval $(t,\ t+T)$ is defined as

$$p_{t+s} = \frac{1}{n} \sum_{j=1}^{n} p_{t+(j-1)T/n}, \qquad 0 \leq s < T. \tag{20}$$

Therefore, the average price level is[10]

$$p_{t+s} = \frac{1}{n}(m_{t-T/n} + m_t + m_{t+T/n} + \cdots\cdots + m_{t+(n-2)T/n}), \quad 0 \leq s < T. \tag{21}$$

Using (3), (18), and (21), we compute the price set by the firms of the i-th industry:

$$\begin{aligned} p_{it} &= E_t p_{i\ t+s}^{*} \\ &= x_{i\ t-T} + \alpha_{i-1,i} z_{i-1\ t-T/n} + z_{i\ t-T} + m_{t-T/n}. \end{aligned} \tag{22}$$

Therefore, each firm's loss in the i-th industry under uniform staggering is

$$L_{it}^{stag} = \left[\left(\frac{1}{3} - \frac{1}{2n} + \frac{1}{6n^2}\right)\sigma_m^2 + \frac{3}{2}\,\theta_i^2 + \left(\frac{1}{2} + \frac{1}{n}\right)\alpha_{i-1,i}^2\,\sigma_{i-1}^2 + \frac{3}{2}\,\sigma_i^2\right]T + \frac{C}{T}. \tag{23}$$

(3) Equilibrium and Stability

Suppose that a switcher firm of the i-th industry can choose the timing of adjustment and change price together with the k-th industry ($k = 1, 2, \cdots, i-1, i+1, \cdots, n$) (see Figure 4). Then a switcher's information set depends on the timing relative to the $i-1$ and i-th industries. Therefore, a switcher's information set is

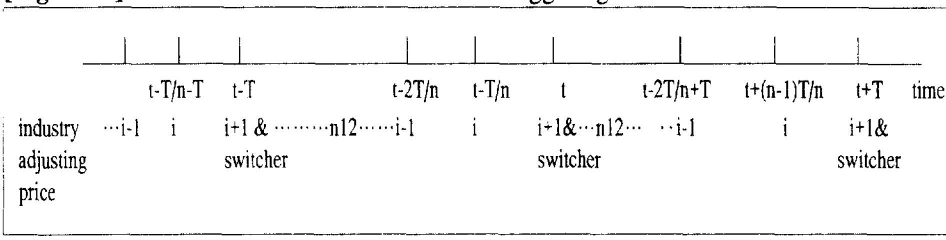
$$\Omega_{it}^{k} = \left\{m_s\left(s \leq t - \frac{T}{n}\right),\ x_{is}(s \leq t - T), z_{hs}\left(h = i-1,\ i,\ s \leq t - \frac{\lambda_{hk}}{n}\,T\right)\right\} \tag{24}$$

where λ_{hk} is the lag coefficient and defined as

$$\begin{aligned} &\lambda_{hk} = n - h + k, && \text{as } h = i-1,\ i, \text{ and } h \geq k, \\ &\lambda_{hk} = -h + k, && \text{as } h = i-1,\ i, \text{ and } h < k. \end{aligned} \tag{25}$$

[10] The assumption on the aggregate price level (19) is an approximation of the average of individual prices. The true price level has an inertia term, that is, a lagged price level.

[Figure 4] Switcher Firm under Uniform Staggering



For example, if a switcher joins the first industry ($k=1$), he can observe $(n-i+2)T/n$ period-lagged information on the $(i-1)$th industry-specific shock ($\lambda_{hk}=n-i+2$). The lag coefficient increases with an increase in k. On the other hand, if he joins the $(i+1)$th industry ($k=i+1$), he can observe T/n period-lagged information on the upstream industry shock ($\lambda_{hk}=1$). Again, the lag coefficient increases with an increase in k. Because a switcher is small compared with the economy, we assume that it does not affect the aggregate price level when it switches. Therefore, the price level is given by (21).

Using (3), (21), and (24), the price set by a switcher firm is

$$\begin{aligned} p_{it} &= E_t p^*_{i\ t+s} \\ &= x_{i\ t-T} + \alpha_{i-1,i} z_{i-1\ t-\lambda T/n} + z_{i\ t-\lambda T/n} + m_{t-T/n}, \quad \lambda=\lambda_{hk}. \end{aligned} \tag{26}$$

A switcher's loss is

$$L^k_{it} = \left[\left(\frac{1}{3} - \frac{1}{2n} + \frac{1}{6n^2} \right) \sigma^2_m + \frac{3}{2}\,\theta^2_i + \left(\frac{1}{2} + \frac{\lambda_{i-1\,k}}{n} \right) (\alpha^2_{i-1,i}\sigma^2_{i-1} + \sigma^2_i) \right] T + \frac{C}{T}. \tag{27}$$

We can easily see

$$L^{i+1}_{it} = \min(L^k_{it}), \quad k=1,2,\cdots,n, \text{ and } k \neq i.$$

That is, a switcher's loss is at minimum when it joins the $(i+1)$th industry. As $k=i+1$, (27) becomes

$$L^{i+1}_{it} = \left[\left(\frac{1}{3} - \frac{1}{2n} + \frac{1}{6n^2} \right) \sigma^2_m + \frac{3}{2}\,\theta^2_i + \left(\frac{1}{2} + \frac{1}{n} \right) (\alpha^2_{i-1,i}\sigma^2_{i-1} + \sigma^2_i) \right] T + \frac{C}{T}. \tag{28}$$

Subtracting (23) from (28) yields ($\alpha_{i-1,i} = a_{i-1,i}$)

$$L^{i+1}_{it} - L^{stag}_{it} = \left[\frac{1}{n}\, a^2_{i-1,i}\,\sigma^2_{i-1} - \frac{n-1}{n}\,\sigma^2_i \right] T. \tag{29}$$

Uniform staggering is a stable Nash equilibrium if $L_{it}^{i+1} > L_{it}^{stag}$. The condition holds if

$$n-1 < \frac{a_{i-1,i}^2 \sigma_{i-1}^2}{\sigma_i^2} \tag{30}$$

3. Results

Define (29) as the incentive to move back to uniform staggering. The incentive to uniformly stagger the adjustment increases when the linkage is larger. That is, if the linkage to its upstream industry $a_{i-1,i}$ increases, the incentive and stability of the staggering pattern increase. When $a_{i-1,i}$ decreases, the staggering pattern becomes less stable. The incentive decreases if the number of sectors increases. The number of sectors is also a determinant of the condition (30). When the number of sectors increases in (30), the aggregate price level changes more gradually, other things being equal. So each firm's loss may increase because of higher output fluctuation. Therefore, firms may move out of uniform staggering if the loss is greater than the information gain from staggering. (30) also indicates the maximum number of sectors that can be supported by a stable Nash equilibrium. The maximum number of sectors increases if the linkage to upstream industry is higher.

To see the information advantage from staggering, we compare the average mean squared error of the price estimator with new information to that only with T-period lagged information. Subtracting (23) from (13) yields

$$L_{it}^{syn} - L_{it}^{stag} = \left[\left(-\frac{1}{3} + \frac{1}{2n} - \frac{1}{6n^2} \right) \sigma_m^2 + \left(1 - \frac{1}{n} \right) a_{i-1,i}^2 \sigma_{i-1}^2 \right] T. \tag{31}$$

(31) measures the information gain from staggering, The larger the linkage coefficient $a_{i-1,i}$, the greater the information gain is. Each industry would prefer to delay price adjustment until its upstream industry adjusts its price and acquires more information on aggregate demand and upstream industry-specific shock. The model suggests that an input-output system is block-triangular, that is, the system has a hierarchical structure when the staggering pattern occurs in a decentralized economy. This result gives rise to microeconomic underpinning for an assumption of staggering imposed by many New Keynesian models.

If there is no linkages to upstream industries, the uniform staggering is not a Nash equilibrium as shown in (30). A block-triangular system with no linkage to upstream industry is a diagonal system. It is also identical to Lucas' island model or Ball and Cecchetti's model in shock structure. So each sector faces only aggregate and sector-specific shocks. Therefore, the uniform staggering is not a Nash equilibrium in a diagonal system. This result suggests that the uniform staggering is not likely to arise when each industry is not linked to other industries because information incentive is small.

The literature on the endogenous timing of wage and price adjustment shows that the timing pattern is determined by the nature of shocks (Fethke and Policano (1984) and Ball and Romer (1989)). On the other hand, the input-output approach shows that the technological characteristics embodied in an input-output table play an important role in the determination of timing of price adjustment.

Ⅳ. CONCLUDING REMARKS

This study incorporates a hierarchical input-output system into price setting firms to demonstrate that staggering is a stable equilibrium. As a result, this model shows that the staggering timing pattern can arise in a decentralized economy. Also this model shows that the technological factor of industries plays an important role in the determination of the timing pattern of price adjustment. This result suggests that an input-output system has a hierarchical structure when the staggering pattern occurs in a decentralized economy. On the other hand, staggering is not likely to take place when industries are not linked to other industries because the information gain from staggering is small. The existence of the staggering timing pattern is supported by Blanchard's (1987) empirical study.

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