Nominal Price Rigidities in a Multisector Model*

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Abstract: This paper uses a multisector sticky price model with cash-in-advance constraint to examine the implications of sectoral nominal price rigidities for the cyclical behavior of sectoral and aggregate movements in prices and output. The data suggest that correlations between sectoral output and price changes are substantially lower than would be implied by a flexible price model with sectoral technology shocks. Some degree of price stickiness (but not too much) can help reconcile the price-output relationship implied by a multisector general equilibrium model to that seen in the data. Also, the sticky-price model produces aggregate inflation persistence comparable to that observed in the data.

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1. Introduction

That nominal rigidities are the most apt characterization of the short run behavior of the economy is a commonly accepted view among economists[1]. The idea to incorporate nominal rigidities into formal economy-wide models has largely been motivated by a desire to explain the short run non-neutrality of money, and the observation that in the short run price and wage levels do not change as much as the money supply does. While short run non-neutrality of money through price and wage rigidities was an important part of the Keynesian economics it was also present in models incorporating rational expectations, developed in the mid and late-1970s (for example, Barro (1977), Fischer (1977), Gray (1976)). The 1990s witnessed the introduction of nominal rigidities into general equilibrium business cycle models. All along, this literature has had two main objectives: to explain the interaction between real and nominal variables, and to evaluate the consequences of alternative monetary policy rules. While this literature has been successful in explaining some of the empirical facts there are puzzles that are yet to be resolved (see Taylor (1998) for an extensive survey).

In a previous study (Balke and Nath (2002)), we observed that sectoral price changes and output growth are negatively correlated (an average correlation of –0.27 across 35 sectors of the U.S. economy over a period from 1947 to 1989[2]). That sectoral Solow residual growth is positively correlated with sectoral output growth (0.45), and is negatively correlated with sectoral price changes (-0.51) indicate that sectoral technology

[1] In fact, many macroeconomic textbooks define short-run vs. long run in terms of these rigidities: the short-run being one in which prices are sticky while in the long-run they are flexible. For example, Mankiw (2001)

[2] We use a data set (known as KLEM data set) originally compiled by Jorgenson et al (987) and later extended by several authors. This data set consists of annual data on output, prices, and various inputs: labor, capital, material inputs and energy for 35 sectors of the U.S. economy. This classification roughly matches the 2-digit SIC classification.

shocks play an important role in the movements of prices and output. However, the less than perfect correlations may also indicate the presence of other factors in addition to technology shocks that affect sectoral price and output movements. A flexible price model with monetary shocks and sectoral technology shocks can, to some extent, reconcile the observed correlations of sectoral price changes with output growth or with sectoral Solow residual growth, but it produces little movement in output and implies too high a correlation between sectoral productivity growth and output growth. We found that 'demand shocks' such as sectoral autonomous expenditures shocks in addition to sectoral technology shocks were required to generate correlations between price changes, output growth and productivity growth similar to those observed in U.S. data.

In this paper, we introduce price rigidities into a sectoral general equilibrium model in order to determine what effects these might have on sectoral price-output relationships. In the presence of price rigidities monetary shocks are not neutral in the short-run. This could affect the relative movements of prices and output and will have implications for sectoral price-output correlations. In addition, sectoral price rigidities as they work their way through the input-output relationships in the economy have been suggested (Gordon (1990) and Blanchard (1987)) to imply greater aggregate price rigidity than implied by individual sectoral price rigidity (although Chari, Kehoe, and McGratten (2000) find little scope for price stickiness to produce a persistent output response to monetary shocks). In our model, each sector is assumed to consist of firms that sell differentiated products. The price setting behavior of the firms follows a Calvo rule: only a fraction of the firms in a particular sector changes their price in a given period. Through the input-output structure, price rigidity in one sector will have implications for marginal costs in other sectors.

The rest of the paper is organized as follows. In section 2, we discuss empirical evidence on price rigidities as documented in earlier studies. We also briefly review the general equilibrium models that incorporate price rigidities. Section 3 presents a multisector general equilibrium model with sectoral price rigidities. We first describe the economic environment of the model economy. The first-order conditions of the optimizing problems are then stated. We define a stationary equilibrium and discuss the near steady-state dynamics. Section 4 discusses how the parameters of the model are calibrated. In section 5, we present the simulation results for sectoral correlations. Section 6 discusses the implications of sectoral price rigidities for aggregate inflation. Section 7 includes a few concluding remarks.

2. Sticky price literature: in reality and in general equilibrium models

In this section, we shall briefly discuss some direct evidence on price rigidities as documented in earlier studies. Studies on empirical evidence on price rigidities go back as early as 1920s when Mill (1927) observed that the frequency of price change is U-shaped: goods with low frequency and high frequency price changes are more common than goods with medium frequency price changes. In recent years, there has been a substantial literature that has examined the frequency and other aspects of price changes based on empirical data. This literature finds evidence of some degree of price rigidities. Most of these studies, though important, are far from being exhaustive in the sense that they cover only a part of the economy. Thus, we know little about the price adjustment behavior in some important sectors of the economy. One difficulty of these empirical studies is the lack of appropriate price data. Nevertheless, we shall discuss some of the important studies.

Carlton (1986, 1989) uses actual transactions price data for a wide variety of products in the United States to show that there are differences in the length of time between adjustments of transactions prices. For example, the time interval between price changes is about 1-1/2 years for steel, cement, and chemicals while it is about six months for plywood and nonferrous metals. Kashyap (1995) similarly finds that the time interval between price adjustments may range from six months to two years. Blinder (1994) and Blinder et al. (1998) report the results of surveys on the price setting behavior of the firms. They find that about 40 percent of the firms they surveyed tends to change their prices once per year, while 10 percent changes prices more than once in a year. Thus, for about 50 percent of the firms the average interval between price changes is more than a year. Blinder et al. also find that there are differences among industries in average lags in price adjustments after an industry experiences a shock. For example, the trade sector adjusts its prices quickly while the service industries take longer to change prices. There are studies which also document that the frequency of price changes also depends on the state of the economy: for example, price changes are more frequent during the period of high inflation. Cecchetti (1986), in his study of the U.S. magazine prices, observes that the price adjustments were more frequent in the high inflation years of 1970s than in the low inflation years of 1950s.

Sticky prices in general equilibrium models

Early precursors of staggered price and wage setting in general equilibrium framework, include the work of Deborah Lucas (1985, 1986) who developed an optimizing model with some prices set in spot markets and others in contract markets. King (1990) and Cho and Cooley (1995) examine the quantitative implications of nominal rigidities in extended versions of real business cycle model. Yun (1996) develops a general equilibrium model with staggered price setting. Yun uses a Calvo rule of price setting for monopolistically competitive firms. Calvo (1983) introduced price rigidity in a utility maximizing framework to examine the macroeconomic implications of non-synchronized, discrete changes in individual prices. Kimball (1995) also constructs a general equilibrium model with staggered price setting to examine various features of the aggregate economy. King and Wolman (1996), on the other hand, develop a utility maximization model with price and wage rigidities to analyze monetary policy. More recently, Ellison and Scott (2000) construct a model similar to Yun, to study the consequences of price rigidity for short run output volatility. Finally, Chari, Kehoe, and McGratten (2000) examine whether staggered price setting can help explain persistence in output movements. They find that for most reasonable parameterizations of their model, the so-called price multiplier is relatively small. That is, the persistence of the output response to a monetary shock is essentially determined by the exogenously specified length of the price contract; the degree of price stickiness has little endogenous effect on output persistence.

3. The model

In this section we present a multisector general equilibrium model with price rigidities and a cash-in-advance constraint. The first-order conditions for utility maximization by the consumer and for cost minimization by the firms are stated. We also present the optimal price setting decision rules of the firms. We then discuss a stationary equilibrium and near steady state dynamics.

3.1. Economic environment

There are J different sectors in the economy, each consisting of a continuum of monopolistically competitive firms. Output of each sector has three potential uses: consumption, intermediate uses and government purchases.

3.1.1. Consumers and preferences

We assume that the economy is populated by a large number of identical and infinitely-lived consumers. The representative consumer has time-separable preferences summarized by the following utility function:

$$U = \sum_{t=0}^{\infty} \beta^t \left(\sum_{i=1}^{J} \theta_i \log(c_{i,t}) + \theta_0 \log(1 - \sum_{i=1}^{J} h_{i,t}) \right) \tag{1}$$

where $0 < \beta < 1$ is the discount factor and $\theta_i \geq 0$ for i = 1,2,……J. $c_{i,t}$ denotes the consumption of goods of sector i in period t, while $h_{i,t}$ is the hours supplied to sector i in period t. We normalize the time endowment to unity. Note that $c_{i,t}$ is a composite consumption good, which is related to the component goods (c(z),z [0,1]) produced by firms in sector i according to

$$c_{i,t} = \left(\int_0^1 c_{i,t}(z)^{\frac{\varepsilon_i - 1}{\varepsilon_i}} dz \right)^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \tag{2}$$

where ε_i is the constant price elasticity of demand for goods in sector i. Cost minimization on the part of the consumers implies that consumption demand for the zth good is $c_{i,t}(z) = (P_{i,t}(z)/P_{i,t})^{-\varepsilon_i} c_{i,t}$ where $P_{i,t}$ is the price index for the composite good produced by firms in sector i in period t and is given by:

$$P_{i,t} = \left(\int_0^1 P_{i,t}(z)^{1-\varepsilon_i} dz \right)^{\frac{1}{1-\varepsilon_i}} \tag{3}$$

The consumer earns wage income by supplying labor to various production sectors, and interest income from lending in the previous period. She receives a nominal lump-sum transfer T_t from the government in each period t. In addition to spending on consumption, the consumer lends and pays lump-sum taxes. Thus the budget constraint for the representative consumer is given by

$$\sum_{i=1}^{J} W_{i,t} h_{i,t} + R_{t-1} b_{t-1} + T_t + m_{t-1} \geq \sum_{i=1}^{J} P_{i,t} c_{i,t} + b_t + \tau_t + m_t \tag{4}$$

where $W_{i,t}$ is the nominal wage in sector i in period t; R_t is the rate of interest paid on lending in period t; b_t is the amount lent in period t; m_t is the nominal money balance with the consumer at the end of the period t. τ_t is the lump-sum tax paid by the consumer. We assume that labor is perfectly mobile across sectors and there is no adjustment cost. This implies that in equilibrium $W_{i,t} = W_t$. Note that capital letters are used to distinguish per capita real variables that a competitive consumer takes as parametric, from individual-specific variables, denoted by small letters, that are chosen by the consumer. In equilibrium, they will be the same.

Money is introduced in this model by specifying a cash-in-advance constraint as given below:

$$m_{t-1} + T_t \geq \sum_{i=1}^{J} P_{i,t} c_{i,t} \tag{5}$$

The consumer needs to hold enough money in the form of cash at the end of each period to make consumption purchases possible in the next period.

3.1.2. Firms and production

The technology available to a representative firm z[3] in sector i is given by a constant returns to scale production function of the Cobb-Douglas form:

$$y_{i,t}(z) = A_{i,t}\left(\mu_{i,t} h_{i,t}(z)\right)^{\alpha_i} \prod_{j=1}^{J} n_{i,j,t}(z)^{a_{i,j}} \tag{6}$$

where $\alpha_i > 0$ and $\alpha_i + \sum_{j=1}^{J} a_{i,j} = 1$. $y_{i,t}(z)$ is the gross output of firm z in sector i in period t; $A_{i,t}$ denotes total factor productivity in sector i in period t; $\mu_{i,t}$ denotes labor augmenting technical change in sector i in period t; $h_{i,t}(z)$ is the labor input used by firm z in sector i in period t. $n_{i,j,t}(z)$ is a composite index of material inputs used by firm z in sector i, and produced by various firms in sector j in period t, and is given by

$$n_{i,j,t}(z) = \left(\int_0^1 \left\{ n_{i,j,t}(z,x) \right\}^{\frac{\varepsilon_i - 1}{\varepsilon_i}} dx \right)^{\frac{\varepsilon_i}{\varepsilon_i - 1}} \tag{7}$$

Note that $n_{i,j,t}(z,x) = \left(\frac{p_{j,t}(x)}{p_{j,t}} \right)^{-\varepsilon_i} n_{i,j,t}(z)$ is the material inputs demanded by firm z in sector i from firm x in sector j. The firm z minimizes its cost $W_t h_{i,t}(z) + \sum_{j=1}^{J} P_{j,t} n_{i,j,t}(z)$ where $P_{j,t}$ is given by (3), subject to the technology given by (6).

3.1.3. Firm z's price setting decision

Following Calvo (1983), we assume that every period a fraction of the total number of firms in sector i, ψ_i is allowed to change their prices to a new optimal level while the remaining firms keep their prices fixed at previously determined levels. The

[3] Firms in a sector are identical to the extent that they behave in similar ways. However, they produce and sell differentiated products.

average duration of a price the firm sets is given by $\psi_i /(1-\psi_i)$. A firm will set its optimal price by maximizing the present discounted value of expected future profits:

$$\max_{P_{i,t}(z)} E_t \left\{ \sum_{k=0}^{\infty} (1-\Psi)^k \left(\prod_{l=1}^{k} R_{t+l-1} \right)^{-1} \left(P_{i,t}(z) - \lambda^c_{i,t+k} \right) \left(\frac{P_{i,t}(z)}{P_{i,t+k}} \right)^{-\varepsilon_i} y_{i,t+k} \right\} \tag{8}$$

where $\lambda^c_{i,t+k}$ is the marginal cost of producing goods in sector i in period t+k.

3.1.4. Government

Government expenditures, $g_{i,t}$s, are assumed to be exogenous. However, government faces the following budget constraint:

$$T_t + \sum_{i=1}^{J} P_{i,t} g_{i,t} = \tau_t \tag{9}$$

We further assume that the lump sum transfer, T_t, is equal to M_t - M_{t-1} where M_t is the per capita money supply in period t. The money stock follows a law of motion, $M_t = \nu_t M_{t-1}$ where ν_t is the gross growth rate of the money supply in period t.

3.1.5. Sectoral resource constraints

Finally, for each sector i, i=1,2,….J, total uses of the commodity must not exceed output in each period. If we use $y_{i,t}$ to represent total demand for sector i output, then

$$y_{i,t} = c_{i,t} + g_{i,t} + \sum_{j=1}^{J} n_{j,i,t} \tag{10}$$

Also, the demand faced by firm z in sector i in period t is given by:

$$y_{i,t}(z) = \left(\frac{P_{i,t}(z)}{P_{i,t}} \right)^{-\varepsilon_i} y_{i,t} \tag{11}$$

It is desirable that we can express sectoral output as a function of the sectoral factor inputs. We, therefore, define the following aggregator:

$$y^*_{i,t} = \int_0^1 y_{i,t}(z)dz \tag{12}$$

so that

$$y^*_{i,t} = A_{i,t}\left(\mu_{i,t}h_{i,t}\right)^{\alpha_i}\prod_{j=1}^{J} n_{i,j,t}{}^{a_{i,j}} \tag{13}$$

where

$$h_{i,t} = \int_0^1 h_{i,t}(z)dz \text{ and } n_{i,j,t} = \int_0^1 n_{i,j,t}(z)dz \tag{14}$$

Then market clearing implies

$$y^*_{i,t} = \int_0^1 \left(\frac{P_{i,t}(z)}{P_{i,t}}\right)^{-\varepsilon_i} y_{i,t}dz = \left(\frac{P_{i,t}}{\bar{P}_{i,t}}\right)^{\varepsilon_i} y_{i,t} \tag{15}$$

where

$$\bar{P}_{i,t} = \left(\int_0^1 P_{i,t}(z)^{-\varepsilon_i} dz\right)^{-\frac{1}{\varepsilon_i}} \tag{16}$$

Thus $\bar{P}_{i,t}$ is an alternative price index that relates $y^*_{i,t}$ to $y_{i,t}$.

3.2. Decentralized Optimization

In our analysis below, we normalize real sectoral output and sectoral demand components by their respective sectoral growth component, $D_{i,t} = (\eta_{y_i})^t$.So that nominal expenditures are constant in the steady state, we normalize nominal sectoral expenditures by M_t. Thus, the nomalized price of sectoral output is $p_{i,t} = P_{i,t} D_{i,t}/M_t$; the normalized wage rate is $w_t = W_t / M_t$. Finally, both money holdings and lump sum taxes are normalized by M_t.

3.2.1. First-order Conditions for Consumer's Utility Maximization

We know that the representative agent's utility function is given by equation (1), her budget constraint is given by equation (4) and the cash-in-advance constraint is given by (5). Normalizing and taking first order conditions for the consumer's utility maximization yields:

$$\frac{\theta_j}{c_{j,t}} = p_{j,t}\,(\lambda^*_t + \gamma^*_t) \tag{17}$$

$$\frac{\theta_0}{1 - \sum_{j=1}^{J} h_{j,t}} = \lambda^*_t w_t \tag{18}$$

$$\beta R_t E_t\left(\frac{\lambda^*_{t+1}}{\nu_{t+1}}\right) = \lambda^*_t \tag{19}$$

$$\lambda^*_t = E_t\left[\frac{\beta}{\nu_{t+1}}(\lambda^*_{t+1} + \gamma^*_{t+1})\right] \tag{20}$$

$$E_t\left[\sum_{j=1}^{J} w_t h_{j,t} + \frac{1}{\nu_t} m_{t-1} + \frac{b_{t-1}R_{t-1}}{\nu_t} + \frac{\nu_t - 1}{\nu_t} - \sum_{i=1}^{I} p_{j,t}\, c_{j,t} - b_t - \tau_t - m_t\right] = 0 \tag{21}$$

$$\frac{m_{t-1}}{\nu_t} + \frac{(\nu_t - 1)}{\nu_t} - \sum_{i=1}^{I} p_{i,t}\, c_{i,t} = 0 \tag{22}$$

Note that λ_t and γ_t are the Lagrange multipliers for the budget constraint (4) and the cash-in-advance constraint (5) in the consumer's problem, respectively. For convenience, we make the following transformations:

$\lambda_t^* = \lambda_t / \beta^t$ and $\gamma_t^* = \gamma_t / \beta^t$.

(ii) First-order Conditions for Firm's Cost Minimization

Firm z in sector i minimizes costs given production technology (equation(6)) and output and input prices yielding[4]:

$$\alpha_i \lambda^c_{i,t} y_{i,t} = w_t h_{i,t} \tag{23}$$

$$a_{i,j} \lambda^c_{i,t} y_{i,t} = p_{j,t} n_{i,j,t} \tag{24}$$

Note that the Lagrange multiplier of the firm's cost minimization problem, $\lambda^c_{i,t}$ can be interpreted as the marginal cost of producing goods in sector i. Note that since we have normalized all real and nominal variables before deriving the first-order conditions, the marginal costs are, by definition, normalized. Substituting for $h_{i,t}$ and $n_{i,j,t}$ into the production function in detrended form, and using the constant returns to scale assumption we derive the following expression for marginal cost:

$$\lambda^c_{i,t} = A^{-1}_{i,t} \mu^{-\alpha_i}_{i,t} \alpha_i^{-\alpha_i} w_t^{\alpha_i} \prod_{j=1}^{J} p_{j,t}^{a_{i,j}} \prod_{j=1}^{J} a_{i,j}^{-a_{i,j}} \tag{25}$$

(iii) Firm's Optimal Pricing Rule

We derive the first-order optimizing condition for the representative firm's price setting decision with the variables in detrended, normalized form. We also make a substitution for R_t from the first order conditions for the consumer's utility maximization behavior. This leads to the following expression for $p_{i,t}$ (z) set by firm z:

[4] Note that the real variables are now normalized; for parsimony we are using the same notations.

$$p^*_{i,t}(z) = \frac{\varepsilon_i \sum_{k=0}^{\infty}(1-\Psi_i)^k \beta^k E_t\left(\left\{\prod_{l=1}^{k}\frac{E_t \nu^{-1}_{t+l}\nu^{-1}_{t+l+1}}{E_t \nu^{-1}_{t+l}}\nu^{\varepsilon_i+1}_{t+l}\eta^{-\varepsilon_i}_{i,t+l}\right\}p^{\varepsilon_i}_{i,t+k}\lambda^{c}_{i,t+k}y_{i,t+k}\right)}{(\varepsilon_i - 1)\sum_{k=0}^{\infty}(1-\Psi_i)^k \beta^k E_t\left(\left\{\prod_{l=1}^{k}\frac{E_t \nu^{-1}_{t+l}\nu^{-1}_{t+l+1}}{E_t \nu^{-1}_{t+l}}\nu^{\varepsilon_i}_{t+l}\eta^{1-\varepsilon_i}_{i,t+l}\right\}p^{\varepsilon_i}_{i,t+k}y_{i,t+k}\right)} \tag{26}$$

The sectoral price level is given by the following equation

$$p_{i,t} = \left(\Psi_i {p^*_{i,t}}^{1-\varepsilon_i} + (1-\Psi_i)p^{1-\varepsilon_i}_{i,t-1}\left\{\frac{\mu_{i,t}}{\nu_t}\right\}^{1-\varepsilon_i}\right)^{\frac{1}{1-\varepsilon_i}} \tag{27}$$

The alternative price index is given by:

$$\bar{p}_{i,t} = \left(\Psi_i {\bar{p}^*_{i,t}}^{-\varepsilon_i} + (1-\Psi_i)\bar{p}^{-\varepsilon_i}_{i,t-1}\left\{\frac{\mu_{i,t}}{\nu_t}\right\}^{-\varepsilon_i}\right)^{\frac{1}{-\varepsilon_i}} \tag{28}$$

(iv) Market Clearing Conditions

Market clearing in the sectoral goods market implies

$$y_{i,t} = c_{i,t} + x_{i,t} + g_{i,t} + \sum_{j=1}^{J} n_{j,i,t} \tag{29}$$

and for money it implies

$$m_t = 1 \qquad (30).$$

Furthermore, supply and demand of sectoral inputs of labor ($h_{i,t}$) will be equal in equilibrium.

3.3. Stationary Equilibrium

A *stationary equilibrium* for this economy is defined as the sequences of the price vector $\left\{\mathbf{p}_t\right\}_{t=0}^{\infty}$, wage $\{w_t\}_{t=0}^{\infty}$, vector of marginal cost $\{\boldsymbol{\lambda}^c_t\}_{t=0}^{\infty}$, quantity vectors

$\left\{\mathbf{c}_t, \mathbf{h}_t, \mathbf{y}_t\right\}_{t=0}^{\infty}$ and shadow price $\{\gamma_t\}_{t=0}^{\infty}$ such that for given sequences of vector $\{\mathbf{A}_t\}_{t=0}^{\infty}$ of technology shifts, money supply growth $\left\{\nu_t\right\}_{t=0}^{\infty}$, and of sectoral government (autonomous) expenditures denoted by vector $\{\mathbf{g}_t\}_{t=0}^{\infty}$,

(1) the consumer's problem is solved; that is, conditions (17) - (22) are satisfied;

(2) the necessary and sufficient conditions for the firm's cost minimization, (23) - (25) are satisfied;

(3) all markets clear.

3.4. Steady State and Near Steady State Dynamics

In this section, we present some key steady state ratios that will be useful for calibrating the model. The share of real consumption expenditures of sector i's output is given by

$$\frac{c_i}{y_i} = \frac{\theta_i}{\Gamma_i} \tag{31}$$

where Γ_i is the ith element of the vector $\mathbf{\Gamma} = (\mathbf{I} - \mathbf{a}\boldsymbol{\rho})^{-1}\boldsymbol{\theta}$ **,** $\mathbf{I}$ is a J × J identity matrix**,** $\mathbf{a}$ is the input-output matrix and $\boldsymbol{\rho}$ is a vector of ρ_is where

$$\rho_i = \delta_i \times \frac{\left(1 - (1-\psi_i)\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i - 1}\right)}{\left(1 - (1-\psi_i)\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i}\right)} \tag{32}$$

where δ_i is the steady state value of the markup in sector i and ψ_i is the fraction of firms in sector i that adjust their prices in a year. ν and η_i are respectively the steady state growth rates of money stock and sector i's output. Note that θ is the vector of sectoral shares of aggregate nominal consumption expenditures and Γ is the vector of sectoral shares of total nominal expenditures. The fraction of sector i's output that is used as materials inputs in industry j is given by

$$\frac{n_{j,i}}{y_i} = a_{j,i} \times \rho_j \times \frac{\Gamma_j}{\Gamma_i} \tag{33}$$

where ρ_j is as given by equation (32) and the steady state markup for sector i is given by:

$$\delta_i = \frac{\varepsilon_i}{\varepsilon_i - 1} \times \frac{\left(1 - (1-\psi_i)\beta\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i - 1}\right)}{\left(1 - (1-\psi_i)\beta\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i}\right)} \tag{34}$$

In our analysis below, we analyze the local dynamics around the steady state when the economy faces various shocks, both sectoral and aggregate. The random variations in sectoral technology (represented by $A_{i,t}$s in the model), and sectoral government expenditures (denoted by $g_{i,t}$s) are taken to be sectoral shocks while random variations in money supply growth (denoted by ν_t) are taken to be aggregate shocks, and all of them are modeled as first-order autoregressive processes. In Appendix A, we present the linear system used to approximate the dynamics of the model.

4. Calibration

We calibrate this model to 35 sectors of the U.S. economy[5]. This sectoral classification scheme is taken from Jorgenson et al (1987) so that we can use the KLEM data set to calculate Solow residuals to calibrate sectoral technology shocks.

We set the discount factor, $\beta = 0.95$, which is comparable to those used in other studies. We also set $\nu = \exp(0.0486)$, which implies an approximate growth rate of 5 percent for money supply. This figure is obtained from the estimation of an AR(1) equation for money base in the U.S.

The Input-Output (I-O) Tables provide a well-defined structure at various levels of disaggregation that is representative of the way the sectors interact among themselves.
In 1987 benchmark I-O tables, 95 industries are covered at the two-digit level, while details are provided for 480 industries at the six-digit level. We consolidate the 1987 I-O table to thirty-five sectors to conform to the sectoral classification of the KLEM data set.
This provides us with the I-O matrix, $\mathbf{a}$, which describes the input-output relationships between sectors. The share of compensation of employees in (nominal) output is computed for each of the thirty-five sectors from the assumption of constant returns to scale, i.e. $\alpha_i = 1 - \sum_{j=1}^{J} a_{i,j}$. It also allows us to obtain g_i by calculating the fraction of each sector's output purchased by the government in that year.

To calculate the vector θ, we use the relationship $\theta = (\mathbf{I} - \mathbf{a}\rho)\Gamma$, implied by the steady state optimal decision rules for consumption (equation (31)). The share of sector i's

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[5] Table A.1 lists 35 sectors along with the fractions of each sector's output that goes for intermediate uses or for final uses such as consumption or government purchases in 1987. Note that in order to be consistent with the specification and calibration of the model, we have left out gross fixed investment from final uses of output and have combined net exports with government purchases.

output in aggregate output (Γ_i) is calculated from the 1987 I-O table. In order to obtain the vector ρ, we need the values for δ and ψ. We set $\delta_i = 1.2$ uniformly across sectors. This value is close to the estimates of average markup by Basu and Fernald (1994) and used by Yun (1996) earlier. We use several values between 0.5 and 1 for ψ_i. Note that $\psi_i = 1$ is the case where prices are fully flexible: all firms change their prices during a year. Considering that this fraction may vary across sectors, we also use different values based on the mean lags in price adjustment as reported by Blinder et al (1998) for 5 major industry groups. The ratio $\frac{\nu}{\eta_i}$ that represents the trend growth rate of price, is calibrated from a regression of price for each sector on a constant and time for the period from 1947 to 1989. The values are shown in the Table A.2. The values for ε_i, the price elasticity are calibrated using the expression for steady state markup as given by equation (34).

As mentioned earlier, sectoral Solow residuals, which represent sectoral technology shocks are calculated by using the KLEM data set. There are no time series data on sectoral government purchases. We obtain annual data on "sectoral government expenditures" as residuals after subtracting sectoral consumption and gross fixed investments from sectoral real GDP. Since there is no way that we can decompose these residuals into government expenditures and net exports in a meaningful way these data are subject to the volatility that is present in net exports. For this reason, we call them "sectoral autonomous expenditures" instead of "sectoral government expenditures". Our methodology to construct this variable is discussed in Appendix B. Annual data on money base for the period from 1947 to 1989 are obtained from the DRI-Pro database.

In order to calibrate shocks to sectoral technology and sectoral autonomous expenditures we first detrend these variables by subtracting the respective trend components obtained from linear regressions of these variables on a constant and time. We then estimated AR(1) models for the detrended variables and save the residuals from these regressions. For money growth rates, we simply estimate an AR(1) model for the growth rates of money stock and save the residuals. In most of the experiments below, shocks will be set to resampled residuals. By using the empirical distribution of shocks, we can maintain in our simulations the covariance structure of shocks seen in the data, without having to specify a particular joint distribution for these shocks. The AR coefficients are reported in Table A.2.

5. Simulation results: sectoral correlations

We conduct a series of experiments. For each of these experiments we specify and calibrate the model as described above and simulate it 1,000 times for 40 periods, with an initial startup of 50 periods to eliminate any potential effect of initial conditions. For each simulation, we calculate important average sectoral correlations along with 95 percent interval of the distribution of simulated correlations.

5.1. Sectoral technology shocks and aggregate monetary shocks

In this experiment, we examine the implications of nominal price rigidities for sectoral price-output correlations. We consider two cases: one with the I-O structure and the other without it. As we can see from Table 1, with flexible prices, these average correlations have the correct signs but are higher than those in the data (in absolute value). A comparison between panel A and panel B reveals that with flexible prices, the I-O structure reduces the correlations of sectoral Solow residual growth with sectoral price changes, and with sectoral output growth. That the correlation between sectoral price changes and output growth does not change indicates that the I-O structure generally act like additional supply shocks (changing marginal costs).[6]

Adding price stickiness generally lowers the correlation between sectoral price changes and sectoral output growth in absolute value. In fact, enough price stickiness can change the average correlation from negative to positive. Greater price stickiness also reduces the sectoral price change-sectoral Solow residual correlation in absolute value, but not to the level seen in the data.

5.2. Sectoral demand shocks

In this experiment we include sectoral autonomous expenditures shocks in addition to sectoral technology and aggregate monetary shocks. The results are reported in Table 2. Comparing Tables 1 and 2, we observe that adding sectoral demand shocks, not surprisingly, lowers sectoral price-output correlations. On the other hand, it has little effect on the correlation between sectoral price changes and sectoral Solow residual growth or on the correlation between sectoral output and Solow residual growth. With both price stickiness and demand shocks, the model is capable of generating sectoral price-output correlations similar to those found in the data. The correlation between sectoral price changes and Solow Residual growth does not change (Compare columns 2 through 5 of Panel B of Table 1 with the corresponding columns of Table 2).

[6] In Balke and Nath (2002) this is not always the case. However, in that model there were capital stocks and one important use of output was as investment good.

6. Sectoral price rigidities and aggregate inflation persistence

In this section we examine the implications of sectoral nominal price rigidities for the aggregate economy. In a multisector model like ours the input-output structure presumably provides a channel through which various sectoral shocks affect the economy. For comparison, we also report the results from the simulations of the model in which there is no input-output structure so that we can assess the importance of input-output structure in addition to that of nominal rigidities themselves.

The observed persistence of aggregate inflation has intrigued many economists and it has generated a substantial literature. A part of this literature has successfully used nominal rigidities to reproduce inflation persistence. Nelson (1998) provides a summary of this literature. In this subsection, we shall first document inflation persistence in the U.S. price data by plotting the impulse response of inflation to a one percent monetary innovation from a bivariate VAR (see Figure 1). We use sectoral price data from the KLEM data set and aggregate them using output shares as the respective weights for 35 sectors. We also use annual data on monetary base to calculate money growth in the U.S. As we can see from the figure, inflation responds to a monetary shock with a lag, then reaches a peak and slowly declines over a period of time.

Now we examine whether our model is capable of producing persistence of aggregate inflation as observed in the data. Figure 2 plots the impulse responses of inflation to a one percent monetary innovation. We consider two cases: one with input-output structure (part (a) of Figure 2) and the other with no input-output structure (part (b) of Figure 2). As we can see from these figures, price rigidities produce inflation persistence. Surprisingly, the responses in both cases are not qualitatively different: the I-

O structure only accentuates the effects. However, the change in inflation reaches its peak instantaneously. Thus the model is not quite successful in reproducing the lag between monetary shock and inflation response. As Nelson (1998) discusses at great length, this is a common failure of this type specification of price rigidities.

7. Summary and conclusion

In this paper, we investigate the implications of sectoral nominal price rigidities for sectoral and aggregate behavior of the economy using a multisector general equilibrium model. The data suggest that correlations between sectoral output and price changes are substantially lower than would be implied by a flexible price model with sectoral technology shocks. Some degree of price stickiness (but not too much) can help reconcile the price-output relationship implied by a multisector general equilibrium model to that seen in the data. It also produces aggregate inflation persistence comparable to that observed in the data.

The model used in this paper has a simple structure. One extension of this research would require incorporation of capital so that we can study the important dynamics of the economy. It may also enhance the importance of the input-output linkages between sectors. One formidable obstacle is that we will have a huge system of equations with large number of state variables, which may be difficult to solve. Also, we have not introduced nominal wage rigidities in this model. It would be interesting to see how results change when we introduce wage rigidities in this multisector framework.

Appendix A: Linearized Solutions

Fluctuations of the variables around their steady state values are approximated by the solution to a log-linear approximation to the equilibrium conditions involving normalized, de-trended variables as derived in Section 3. We denote the percentage deviations of all transformed variables around the steady state by using circumflex. Thus the linearized version of the marginal cost equation is given by

$$\hat{\boldsymbol{\lambda}}_{\mathbf{t}}^{\mathbf{c}} = \mathbf{b}\hat{w}_{\mathbf{t}} + \mathbf{a}\hat{\mathbf{p}}_{\mathbf{t}} - \hat{\mathbf{A}}_{t} \tag{A.1}$$

Combining (17) and (23), we obtain an expression for λ and substitute it into equation (18), take the log-linear approximation and substitute for H from the linearized version of equation (24) to obtain

$$\hat{w}_{\mathbf{t}} = \mathbf{H}'\hat{\boldsymbol{\lambda}}_{\mathbf{t}} + \mathbf{H}'\hat{\mathbf{y}}_{\mathbf{t}}^{*} + (\mathbf{1} - \sum_{\mathbf{i=1}}^{\mathbf{I}} \mathbf{H}_{\mathbf{i}})\hat{\mathbf{v}}_{\mathbf{t+1}} \tag{A.2}$$

Log-linear approximation of the market clearing conditions: equations (15) and (29) implies

$$\hat{\mathbf{y}}_{\mathbf{t}}^{*} = \boldsymbol{\varepsilon}\left(\hat{\mathbf{p}}_{\mathbf{t}} - \hat{\bar{\mathbf{p}}}_{\mathbf{t}}\right) + \hat{\mathbf{y}}_{t} \tag{A.3}$$

$$\hat{\mathbf{p}} + \hat{\mathbf{y}}_{\mathbf{t}} = \boldsymbol{\varepsilon}\left(\hat{\mathbf{p}}_{\mathbf{t}} - \hat{\bar{\mathbf{p}}}_{\mathbf{t}}\right) + \mathbf{a}'\boldsymbol{\lambda}\mathbf{y}^{*}\left(\hat{\boldsymbol{\lambda}}_{\mathbf{t}}^{\mathbf{c}} + \hat{\mathbf{y}}_{\mathbf{t}}^{*}\right) + \mathbf{g}\left(\hat{\mathbf{p}}_{\mathbf{t}} + \hat{\bar{\mathbf{G}}}_{\mathbf{t}}\right) + \mathbf{G}\hat{\mathbf{G}}_{t} \tag{A.4}$$

The above equations can written in matrix form as given below:

$$\begin{pmatrix} \mathbf{I} & -\mathbf{F}_1 & -\mathbf{F}_1 & \mathbf{0} \\ -\mathbf{I} & \mathbf{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I} & -\mathbf{b} \\ \mathbf{0} & -\mathbf{H}' & -\mathbf{H}' & \mathbf{1} \end{pmatrix} \begin{pmatrix} \hat{\mathbf{y}}_{\mathbf{t}} \\ \hat{\mathbf{y}}_{\mathbf{t}}^{*} \\ \hat{\lambda}_{t} \\ \hat{w}_{\mathbf{t}} \end{pmatrix} = \begin{pmatrix} \boldsymbol{\varepsilon} - \mathbf{I} + \mathbf{F}_2 & -\boldsymbol{\varepsilon} \\ \boldsymbol{\varepsilon} & -\boldsymbol{\varepsilon} \\ \mathbf{a} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \hat{\mathbf{p}}_{\mathbf{t}} \\ \hat{\bar{\mathbf{p}}}_{\mathbf{t}} \end{pmatrix} + \begin{pmatrix} \mathbf{0} & \mathbf{G} & \mathbf{0} & \mathbf{F}_2 \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ -\mathbf{I} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \left(\mathbf{1} - \sum_{\mathbf{i=1}}^{\mathbf{I}} \mathbf{H}_{\mathbf{i}}\right)\boldsymbol{\rho}_{\mathbf{v}} & \mathbf{0} \end{pmatrix} \begin{pmatrix} \hat{\mathbf{A}}_{\mathbf{t}} \\ \hat{\mathbf{G}}_{\mathbf{t}} \\ \hat{\upsilon}_{\mathbf{t}} \end{pmatrix}$$

where $\mathbf{F_1} = \mathbf{a}\mathrm{diag}(\lambda^{c})\mathbf{y}^{*}$, H is a vector of steady state values of labor input, and $\mathbf{F_2}$ = diag ($\mathbf{g}$) where $\mathbf{g}$ is a vector of output shares of government purchases for different sectors. We now rewrite the above system as follows:

$$\prod_0 \mathbf{Y_t} = \prod_1 \mathbf{P_t} + \prod_2 \mathbf{X_t} \qquad \text{(A.5)}$$

where the matrices: **Π**s and vectors: **P** and **X** are as defined above. Then we can solve for **Y**, the vector of the control variables, as functions of the price vector **P** and the vector of exogenous variables **X**.

$$\mathbf{Y_t} = \prod_0^{-1} \prod_1 \mathbf{P_t} + \prod_0^{-1} \prod_2 \mathbf{X_t}$$

$$\mathbf{Y_t} = \mathbf{YP}\,\mathbf{P_t} + \mathbf{YX}\,\mathbf{X_t} \qquad \text{(A.6)}$$

We now take log-linear approximations of equations (24), (25) and (26) and substitute for the control variables from (A.6) and obtain

$$\begin{aligned}\hat{p}_t = &\sum_{k=0}^{\infty}\left[\mathbf{\Phi}(\mathbf{I}-\mathbf{\Psi_N})\mathbf{\Psi_N^k}(\boldsymbol{\varepsilon}+\mathbf{Y_p}+\mathbf{\Lambda_p})-\mathbf{\Phi}(\mathbf{I}-\mathbf{\Psi_D})\mathbf{\Psi_D^k}(\boldsymbol{\varepsilon}+\mathbf{Y_p})\right]\mathbf{\hat{p}_{t+k}}\\ &+\sum_{k=0}^{\infty}\left[\mathbf{\Phi}(\mathbf{I}-\mathbf{\Psi_N})\mathbf{\Psi_N^k}(\boldsymbol{\varepsilon}+\mathbf{Y_{\bar{p}}}+\mathbf{\Lambda_{\bar{p}}})-\mathbf{\Phi}(\mathbf{I}-\mathbf{\Psi_D})\mathbf{\Psi_D^k}(\mathbf{Y_{\bar{p}}})\right]\mathbf{\hat{\bar{p}}_{t+k}}\\ &+\mathbf{p_A}\mathbf{\hat{A}_t}+\mathbf{P_G}\mathbf{\hat{\bar{G}}_t}+\mathbf{P_G}\mathbf{\hat{G}_t}+\mathbf{P_v}\mathbf{\hat{v}_t}+\mathbf{P_\eta}\boldsymbol{\hat{\eta}}_t+(\mathbf{I}-\mathbf{\Phi})\mathbf{\hat{p}_{t-1}}\end{aligned} \qquad \text{(A.7)}$$

$$\begin{aligned}\mathbf{\hat{\bar{p}}_t} = &\sum_{k=0}^{\infty}\left[\mathbf{\bar{\Phi}}(\mathbf{I}-\mathbf{\Psi_N})\mathbf{\Psi_N^k}(\boldsymbol{\varepsilon}+\mathbf{Y_p}+\mathbf{\Lambda_p})-\mathbf{\bar{\Phi}}(\mathbf{I}-\mathbf{\Psi_D})\mathbf{\Psi_D^k}(\boldsymbol{\varepsilon}+\mathbf{Y_p})\right]\mathbf{\hat{p}_{t+k}}\\ &+\sum_{k=0}^{\infty}\left[\mathbf{\bar{\Phi}}(\mathbf{I}-\mathbf{\Psi_N})\mathbf{\Psi_N^k}(\boldsymbol{\varepsilon}+\mathbf{Y_{\bar{p}}}+\mathbf{\Lambda_{\bar{p}}})-\mathbf{\bar{\Phi}}(\mathbf{I}-\mathbf{\Psi_D})\mathbf{\Psi_D^k}(\mathbf{Y_{\bar{p}}})\right]\mathbf{\hat{\bar{p}}_{t+k}}\\ &+\mathbf{\bar{p}_A}\mathbf{\hat{A}_t}+\mathbf{\bar{P}_G}\mathbf{\hat{\bar{G}}_t}+\mathbf{\bar{P}_G}\mathbf{\hat{G}_t}+\mathbf{\bar{P}_v}\mathbf{\hat{v}_t}+\mathbf{\bar{P}_\eta}\boldsymbol{\hat{\eta}}_t+(\mathbf{I}-\mathbf{\bar{\Phi}})\mathbf{\hat{p}_{t-1}}\end{aligned} \qquad \text{(A.8)}$$

where Φ and $\bar{\Phi}$ are diagonal matrices with diagonal elements $\phi_i = 1-(1-\psi_i)\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i-1}$ and $\bar{\phi}_i = 1-(1-\psi_i)\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i}$. Similarly, Ψ_N and Ψ_D are diagonal matrices with diagonal elements $\psi_{N_i} = (1-\psi_i)\beta\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i}$ and $\psi_{D_i} = (1-\psi_i)\beta\left(\frac{\nu}{\eta_i}\right)^{\varepsilon_i-1}$ respectively. Y_P, $Y_{\bar{P}}$, Λ_P and $\Lambda_{\bar{P}}$ are partitioned matrices obtained from YP such that

$$\mathbf{YP} = \begin{pmatrix} \mathbf{Y_P} & \mathbf{Y_{\bar{P}}} \\ \mathbf{Y_P^*} & \mathbf{Y_{\bar{P}}^*} \\ \mathbf{\Lambda_P} & \mathbf{\Lambda_{\bar{P}}} \\ \mathbf{W_P} & \mathbf{W_{\bar{P}}} \end{pmatrix}$$

$\mathbf{P_A}$, $\mathbf{P_{\bar{G}}}$, $\mathbf{P_G}$, $\mathbf{P_v}$, $\mathbf{\bar{P}_A}$, $\mathbf{\bar{P}_{\bar{G}}}$, $\mathbf{\bar{P}_G}$, and $\mathbf{\bar{P}_v}$ are complicated matrices of the parameters of the model. After algebraic simplifications, the system two equations (A.7) and (A.8) can be written as:

$$\mathbf{A_2}\, E_t\, \mathbf{P_{t+2}} + \mathbf{A_1}\, E_t\, \mathbf{P_{t+1}} + \mathbf{A_0}\, \mathbf{P}_t + \mathbf{A_{-1}}\, \mathbf{P_{t-1}} = \mathbf{A_X}\, \mathbf{X_t} \tag{A.9}$$

where

$$\mathbf{P_t} = \begin{pmatrix} \hat{p}_{\mathbf{t}} \\ \hat{\bar{p}}_{\mathbf{t}} \end{pmatrix},$$

$$\mathbf{X_t} = \begin{pmatrix} \hat{\mathbf{A}}_{\mathbf{t}} \\ \hat{\mathbf{G}}_{\mathbf{t}} \\ \hat{\eta}_t \\ \end{pmatrix}$$

and A s are complicated matrices of the parameters of the model. Define $\mathbf{D_t} = \mathbf{P_{t-1}}$, a vector of predetermined variables such that $\mathbf{D_{t+1}} = \mathbf{P_t}$. Let $\mathbf{F_t} = E_{\mathbf{t}}\, \mathbf{P_{t+1}}$ such that $E_t\, \mathbf{F_{t+1}} = E_t\, [\, E_{t+1}\, \mathbf{P_{t+2}}\,] = E_t\, \mathbf{P_{t+2}}$. Then

$$\mathbf{A}\begin{pmatrix} \mathbf{D_{t+1}} \\ E_t \mathbf{P_{t+1}} \\ E_t \mathbf{F_{t+1}} \end{pmatrix} = \mathbf{B}\begin{pmatrix} \mathbf{D_t} \\ \mathbf{P_t} \\ \mathbf{F_t} \end{pmatrix} + \mathbf{CX}_t \tag{A.10}$$

where

$$\mathbf{A} = \begin{pmatrix} \mathbf{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{A}_2 \end{pmatrix}, \quad \mathbf{B} = \begin{pmatrix} \mathbf{0} & \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I} \\ -\mathbf{A}_{-1} & -\mathbf{A}_0 & -\mathbf{A}_1 \end{pmatrix} \quad \text{and} \quad \mathbf{C} = \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{A}_X \end{pmatrix}$$

We can rewrite the above system as

$$\begin{pmatrix} \mathbf{D}_{t+1} \\ \mathrm{E}_t \mathbf{P}_{t+1} \\ \mathrm{E}_t \mathbf{F}_{t+1} \end{pmatrix} = \mathbf{W} \begin{pmatrix} \mathbf{D}_t \\ \mathbf{P}_t \\ \mathbf{F}_t \end{pmatrix} + \mathbf{Q}\mathbf{X}_t \qquad \text{(A.11)}$$

where $\mathbf{W} = \mathbf{A}^{-1}\,\mathbf{B}$ and $Q = \mathbf{A}^{-1}\,\mathbf{C}$. We then follow Blanchard and Kahn (1980) to solve this system.

Appendix B: Construction of data on sectoral autonomous expenditures

For the simulation of the model, we need to calibrate shocks to the sectoral government expenditures, which are assumed to be exogenous. Data on government expenditures by sectors are, however, not readily available. Therefore, we decompose sectoral real GDP into three final expenditure components, namely, consumption, investment and government expenditures. This decomposition scheme exactly matches the market clearing conditions of our model. The method we use for decomposition involves the following steps:

1) We obtain data on 'personal consumption expenditures' and 'gross fixed investments' by major type of products from unpublished tables of the National Income and Product Accounts (NIPA) for a period from 1947 to 1997. Note that consumption data are available for 83 product categories and investment data are available for 26 product categories.
2) These consumption and investments by products are then mapped into consumption and investments by two-digit input-output (I-O) industries using a mapping scheme outlined in Survey of Current Business (April, 1994) for 1987 Benchmark Input-Output Tables. Note that there are ninety-five two-digit I-O industries.
3) These consumption and investments data are then consolidated to match thirty-five sectors of the KLEM data set.
4) We obtain data on GDP by 2-digit SIC industries from the National Income and Product Accounts (NIPA) "Income, Employment and Product by Industry" unpublished detail tables and consolidate, wherever necessary, for thirty-five sectors.

5) Data on government expenditures by sectors are then obtained as residuals by subtracting consumption and investments from sectoral GDP. Note that all these values are in current dollars. In order to convert them into 1987 constant dollar we deflate the government expenditures by the price indices obtained from the KLEM data set.

Note that sectoral GDP also includes a 'net exports' component and it is impossible to separate out this component from the residuals we obtain in the final step. Therefore, we prefer the nomenclature 'sectoral autonomous expenditures' to 'sectoral government expenditures'. Sectors that have relatively higher shares of net exports in their respective total GDPs will be subject to volatility that arises from changes in international market conditions.

Table 1

Simulation Results: Sectoral Technology Shocks and Aggregate Monetary Shocks

PANEL A: NO INPUT-OUTPUT STRUCTURE						
	Data	$\psi_i = 0.5$	$\psi_i = 0.6$	$\psi_i = 0.8$	Different ψ_i values across sectors	Flexible price
	(1)	(2)	(3)	(4)	(5)	(6)
Corr(Δp_i ,Δy_i)	-0.27	0.19 (0.09, 0.38)	-0.52 (-0.59, -0.29)	-0.97 (-0.98, -0.95)	-0.50 (-0.56, -0.31)	-0.999 (-1.00, -0.99)
Corr(Δp_i ,ΔA_i)	-0.51	-0.72 (-0.76, -0.63)	-0.81 (-0.83, -0.73)	-0.93 (-0.95, -0.86)	-0.81 (-0.83, -0.74)	-0.992 (-1.00, -0.95)
Corr(Δy_i ,ΔA_i)	0.45	-0.43 (-0.49, -0.29)	0.18 (0.15, 0.22)	0.87 (0.86, 0.87)	0.19 (0.16, 0.23)	0.996 (0.98, 1.00)
PANEL B: INPUT-OUTPUT STRUCTURE						
Corr(Δp_i ,Δy_i)	-0.27	0.22 (0.09, 0.47)	-0.50 (-0.59, -0.24)	-0.97 (-0.98, -0.94)	-0.48 (-0.55, -0.24)	-0.998 (-1.00, -0.99)
Corr(Δp_i ,ΔA_i)	-0.51	-0.71 (-0.76, -0.60)	-0.80 (-0.84, -0.70)	-0.90 (-0.93, -0.81)	-0.80 (-0.84, -0.70)	-0.918 (-0.94, -0.83)
Corr(Δy_i ,ΔA_i)	0.45	-0.40 (-0.48, -0.25)	0.20 (0.17, 0.24)	0.85 (0.83, 0.87)	0.22 (0.18, 0.26)	0.925 (0.88, 0.94)

Note: The five and ninety-five percentiles for the simulations are in parentheses.

Source: Authors' calculations.

Table 2

Simulation Results: Sectoral Technology and Demand Shocks and Aggregate Monetary and Government Expenditures Shocks

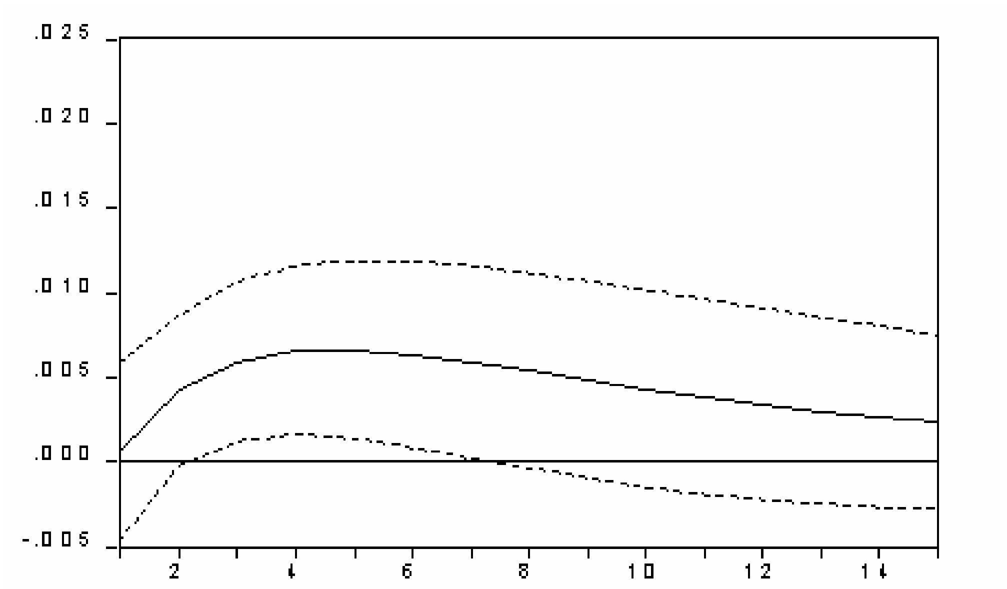
PANEL A: NO INPUT-OUTPUT STRUCTURE						
	Data	$\psi_i = 0.5$	$\psi_i = 0.6$	$\psi_i = 0.8$	Different ψ_i values across sectors	Flexible price
	(1)	(2)	(3)	(4)	(5)	(6)
Corr(Δp_i ,Δy_i)	-0.27	-0.04 (-0.11, 0.11)	-0.41 (-0.48, -0.31)	-0.74 (-0.80, -0.68)	-0.41 (-0.49, -0.31)	-0.90 (-0.93, -0.86)
Corr(Δp_i ,ΔA_i)	-0.51	-0.71 (-0.75, -0.62)	-0.81 (-0.83, -0.73)	0.93 (-0.94, -0.87)	-0.81 (-0.83, -0.73)	-0.91 (-0.94, -0.82)
Corr(Δy_i ,ΔA_i)	0.45	-0.09 (-0.14, -0.02)	0.23 (0.17, 0.29)	0.67 (0.60, 0.72)	0.26 (0.20, 0.32)	0.80 (0.76, 0.84)
PANEL A: INPUT-OUTPUT STRUCTURE						
Corr(Δp_i ,Δy_i)	-0.27	-0.01 (-0.10, 0.18)	-0.37 (-0.45, -0.26)	-0.69 (-0.76, -0.62)	-0.38 (-0.46, -0.26)	-0.80 (-0.85, -0.75)
Corr(Δp_i ,ΔA_i)	-0.51	-0.70 (-0.75, -0.59)	-0.80 (-0.83, -0.70)	-0.90 (-0.92, -0.80)	-0.79 (-0.83, -0.70)	-0.91 (-0.93, -0.80)
Corr(Δy_i ,ΔA_i)	0.45	-0.06 (-0.12, 0.00)	0.24 (0.17, 0.30)	0.63 (0.56, 0.69)	0.27 (0.21, 0.33)	0.76 (0.70, 0.81)

Note: The five and ninety-five percentiles for the simulations are in parentheses.

Source: Authors' calculations.

Figure 1

Impulse Response of Inflation to 1% Monetary Innovation
Bivariate VAR



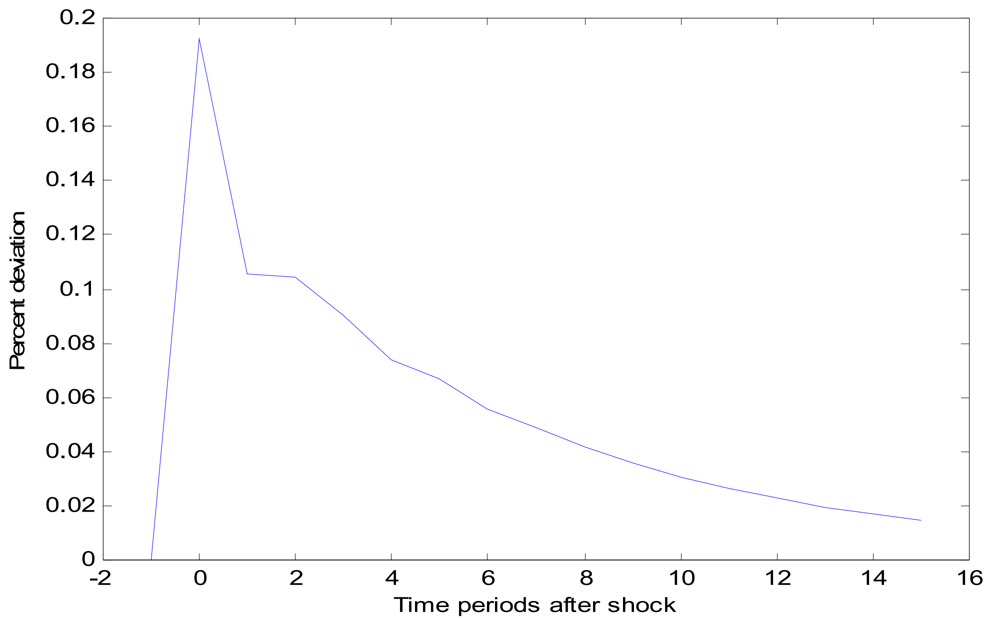
Periods after shock

Note: The dotted lines show 95% confidence interval

Figure 2

Impulse Response of Inflation to 1% Monetary Innovation
Sticky Price: $\psi_i = 0.6$

(a) With I-O structure



(b) With no I-O structure

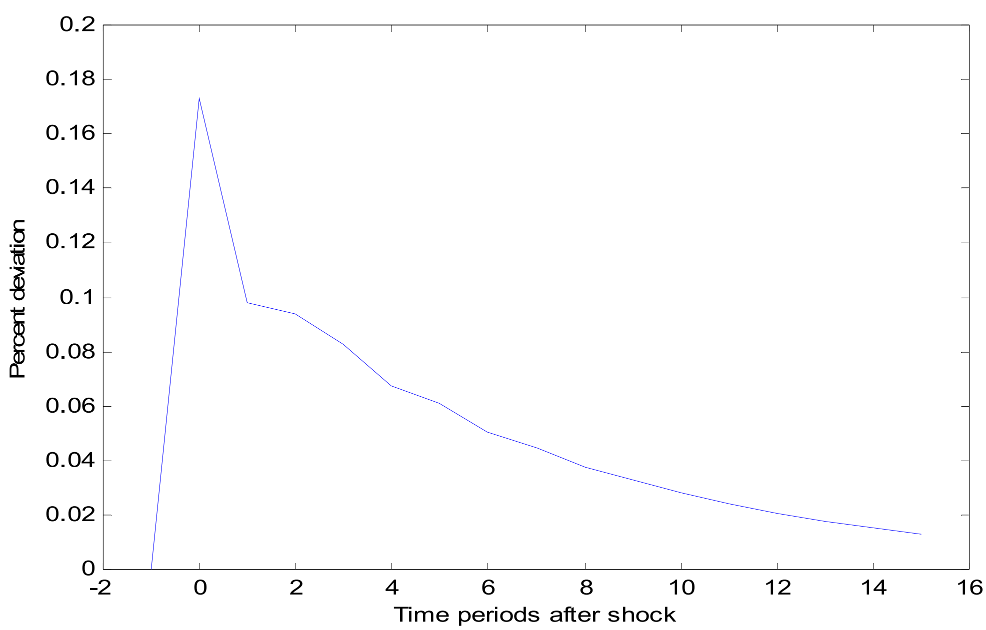


Table A.1

Shares of output uses

Sectors	Intermediate Use	Consumption	Govt. purchases	Output share
Agriculture	0.88	0.12	0.01	0.03
Metallic ores mining	1.02	0.00	-0.02	0.00
Coal mining	0.99	0.01	0.01	0.00
Crude petroleum and natural gas	1.00	0.00	0.00	0.01
Nonmetallic minerals mining	1.00	0.00	0.00	0.00
Construction	0.51	0.00	0.49	0.03
Food and kindred products	0.37	0.60	0.02	0.05
Tobacco products	0.15	0.85	0.00	0.00
Textile	0.87	0.12	0.01	0.01
Apparel	0.22	0.76	0.02	0.02
Lumber and wood products	0.97	0.03	0.00	0.01
Furniture and fixtures	0.15	0.77	0.08	0.00
Paper	0.86	0.11	0.03	0.02
Printing	0.64	0.28	0.08	0.01
Chemicals	0.67	0.28	0.05	0.03
Petroleum refining and related products	0.50	0.42	0.08	0.02
Rubber	0.90	0.09	0.02	0.02
Footwear, leather, and leather products	0.21	0.78	0.01	0.00
Stone	0.92	0.07	0.01	0.01
Primary metal	0.99	0.00	0.01	0.02
Fabricated metal	0.94	0.04	0.02	0.02
Machinery	0.80	0.05	0.14	0.02
Electrical machinery	0.65	0.25	0.10	0.02
Motor vehicle	0.36	0.59	0.05	0.03
Transportation equipment	0.26	0.12	0.62	0.01
Instruments	0.38	0.14	0.48	0.01
Miscellaneous manufacturing	0.24	0.72	0.04	0.01
Transport	0.66	0.28	0.06	0.04
Communications	0.53	0.41	0.06	0.02
Electric services (utilities)	0.51	0.40	0.09	0.02
Gas production and distribution	0.67	0.30	0.03	0.01
Wholesale and retail trade	0.30	0.68	0.01	0.14
Fire	0.39	0.59	0.02	0.16
Service water	0.44	0.55	0.01	0.20
Govt enterprise	0.56	0.39	0.05	0.01

Note: These shares are calculated from 1987 Benchmark I-O Use Table

Table A.2

Parameter Values

Sectors	μ_i	ρ_A	ρ_G	$\frac{v}{n_i}$	ψ_i
Agriculture	0.012	0.548	0.853	0.024	0.6
Metallic ores mining	-0.004	0.764	0.880	0.046	0.7
Coal mining	-0.002	0.948	0.836	0.041	0.7
Crude petroleum and natural gas	-0.019	0.909	0.911	0.057	0.7
Nonmetallic minerals mining	0.006	0.756	0.694	0.037	0.7
Construction	0.000	0.901	0.615	0.045	0.7
Food and kindred products	0.006	0.350	0.616	0.028	0.6
Tobacco products	0.004	0.733	0.522	0.043	0.6
Textile	0.013	0.655	0.856	0.020	0.6
Apparel	0.012	0.960	0.845	0.018	0.6
Lumber and wood products	0.005	0.718	0.702	0.038	0.6
Furniture and fixtures	0.007	0.630	0.923	0.036	0.6
Paper	0.004	0.524	0.505	0.039	0.6
Printing	0.000	0.943	0.603	0.045	0.6
Chemicals	0.010	0.799	0.458	0.032	0.6
Petroleum refining and related products	0.009	0.492	0.712	0.042	0.6
Rubber	0.010	0.753	0.870	0.032	0.6
Footwear, leather, and leather products	0.004	0.578	0.832	0.034	0.6
Stone	0.003	0.616	0.884	0.041	0.6
Primary metal	-0.002	0.513	0.960	0.049	0.6
Fabricated metal	0.004	0.545	0.767	0.042	0.6
Machinery	0.008	0.954	0.995	0.033	0.6
Electrical machinery	0.015	0.813	0.776	0.026	0.6
Motor vehicle	0.004	0.614	0.856	0.037	0.6
Transportation equipment	0.005	0.616	0.848	0.042	0.6
Instruments	0.012	0.817	0.913	0.031	0.6
Miscellaneous manufacturing	0.011	0.599	0.978	0.030	0.6
Transport	0.011	0.782	0.892	0.039	0.5
Communications	0.024	0.797	0.956	0.027	0.5
Electric services (utilities)	0.012	0.944	0.700	0.036	0.5
Gas production and distribution	-0.003	0.816	0.919	0.054	0.5
Wholesale and retail trade	0.009	0.744	0.924	0.036	0.8
Fire	0.004	0.921	0.930	0.045	0.5
Service water	0.004	0.894	1.026	0.049	0.5
Govt enterprise	-0.004	0.804	0.770	0.055	0.6

Note: The ψ values are assigned according to the average time lags for price adjustment in 5 major industry groups a documented in Blinder et al (1998)

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