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Abstract

The co-movement of output across the sector producing non-durables (that is, non-durable goods and services) and the sector producing durables is well-established in the monetary business-cycle literature. However, standard sticky-price models that incorporate sectoral heterogeneity in price stickiness (that is, sticky non-durables prices and flexible durables prices) cannot generate this feature. We argue that an input-output structure provides a solution to this problem. Here we develop a two-sector model with an input-output structure, which is calibrated to the U.S. economy. In the model, each sector's output affects those of the others by acting as an intermediate input This connection between the sectors provides a channel through which sectoral co-movement is induced.

Keywords: Monetary Policy; Input-Output Matrix; Durables; Non-durables
JEL classification: E5, E6

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1 Introduction

The co-movement of output across the sector producing non-durables (that is, non-durable goods and services) and the sector producing durables is a key feature of U.S. monetary business cycles. In the wake of a monetary-policy shock, the observed changes in the two outputs have the same sign. For example, using a vector autoregression (VAR) approach, Erceg and Levin (2002) document that both the non-durables output (that is, expenditure on non-durable goods and services) and the durables output (that is, consumer durables expenditure, business equipment expenditure, business structures, and residential investment) decline in response to a rise in the federal funds rate. Barsky et al. (2003, 2007) report on the co-movement across sectors after the Romer dates. Interestingly, in addition to this co-movement, these two studies also point out that the responses of durables outputs are larger than the responses of non-durables outputs.

Contrary to these observations, however, it is not easy to generate this co-movement using standard sticky-price models. Current theories of monetary business cycles attribute the real effects of monetary-policy innovations to the price stickiness of firms' products. The sign and magnitude of the impact of a monetary-policy shock across sectors are considered to be related to the frequencies of price adjustment by the firms in each sector (Bils et al., 2003)[1]. When sectors with heterogeneous frequencies of price adjustment coexist in an economy, as observed by Bils and Klenow (2004), the equilibrium responses of output to a monetary-policy shock vary across sectors (Ohanian et al., 1995; Carvalho, 2006). Ohanian et al (1995) present a general equilibrium multi-sector model, in which one product has a flexible price and the others have a sticky price, to show that a monetary-policy shock might induce a negative co-movement of output across these goods.

As for the frequencies of price adjustment across non-durables and durables, Bils and Klenow (2004) report a higher frequency of price adjustment for consumer durables than services. However, for long-lived durables other than consumer durables, such as houses and factories, empirical studies along the same lines are so far absent from the literature. Erceg and Levin (2002, 2006) assume that non-durables and durables are equally sticky. Barsky et al. (2003), and Carlstrom and Fuerst (2006), by contrast, develop a model in which durables prices are flexible and non-durables prices are sticky. They argue that houses are expensive on a per unit basis, and that prices are negotiated for each contract. Studies in the housing literature also assume that house prices are flexible (for example, Aoki et al, 2002; Iacoviello, 2005). We follow these studies and assume that the prices of durables are flexible.

However, when flexible durables prices are included, standard multi-sector sticky-price models cannot account for the co-movement of the value-added across sectors. The models imply that a monetary-policy shock induces a lack of co-movement across sectors, as shown in Barsky et al. (2003) and Carlstrom and Fuerst (2006). In response to a monetary expansion, as non-durables prices are sticky and durables prices are flexible, the relative price of the durables ascends in the short run. The value-added of durables decreases while the value-added of non-durables rises, because the households prefer cheaper non-durables to more expensive durables. This implication contradicts the empirical findings of Erceg and Levin (2002), and Barsky et al. (2003). Carlstrom and Fuerst (2006) call this inconsistency the "co-movement puzzle."

The negative co-movement between non-durables and durables has an important implication

[1] The empirical literature on price-setting behavior by firms reveals that the frequency of price adjustments differs across sectors, see for example Bils and Klenow (2004), and Nakamura and Steinsson (2007), for the U.S. economy, Alvarez (2006) for euro area countries, and Higo and Saita (2007) for Japanese economy.

for the aggregate economy. Barsky et al. (2003, 2007) stress that the presence of a flexible durables sector in an economy dampens the effect of monetary policy significantly. In the wake of a monetary expansion, the increase of value-added in the non-durables-producing sector is offset by the decrease of value-added in the durables-producing sector, leaving the sum of the two (that is, the gross domestic product or GDP) relatively unresponsive to a monetary-policy shock. That is, money is neutral for the aggregate economy, even in the short run.

This paper develops a two-sector dynamic general-equilibrium model, which can account for the co-movement of value-added in response to monetary-policy shocks. Most recent papers that focus on the quantitative performance of multi-sector sticky-price models assume that each sector uses only primary inputs (for example, Barsky et al., 2003, 2007; Carlstrom and Fuerst, 2006; Carvalho, 2006).

The U.S. input-output table shows us, by contrast, that the share of payments to intermediate inputs in the total production cost is large for all sectors. We thus add intermediate inputs in the input-output production structure to an otherwise standard sticky-price model. In our model, the product from each sector serves either as a final consumption product, or as an intermediate production input. The size of the intermediate input flow from one sector to the other depends on the input-output structure, which is expressed by the off-diagonal entities of the input-output matrices. In contrast to a multi-sector model in which goods are produced by independent sectors, the equilibrium response of our economy depends heavily on the matrix structure. We show that the U.S. input-output matrix delivers the co-movement of value-added between the non-durables-producing sector and the durables-producing sector.

Many studies on the input-output matrix focus on productivity shocks. Dupor (1999) and Horvath (1998) investigate the role of the input-output matrix in an economy in which a source of fluctuation is a sector-specific shock. They show that a certain class of matrices transmits a shock in one sector to the others, leading to a large aggregate fluctuation. In particular, Dupor (1999) emphasizes the role of the sectors that provide intermediate inputs to many others. Shocks that occur in these sectors have disproportionately large effects on an aggregate economy through the input-output relationship across sectors.

In the present paper, we study the response of an economy to a monetary-policy shock. The key feature of the input-output matrix that delivers our main result is the transmission mechanism of the matrix. Conventional sticky price models tell us that the output in a sector with a low frequency of price adjustment is more sensitive to the shock. In a model with input-output structure, output variations in the sticky price sector affect those of the sectors that use these products as intermediate inputs. This propagating effect is amplified when the sticky-price sector has a row with many large entities in the input-output matrix. We show that a two-sector input-output matrix for the U.S. economy indicates that the non-durables-producing sector is such a material provider. This characteristic of the U.S. input-output matrix implies that the behavior of the non-durables-producing sector is playing an important role in both sectors, and in the economy as a whole.[2]

[2] Bouakez et al (2005) demonstrate that the input-output matrix has one other implication for a monetary-policy effect. The output variations in the sticky-price sector propagate to the other sector through the demand channel. For example, when a sector with a low frequency of price adjustment uses the products from the flexible sectors, more products from the flexible sectors are needed as the production of the sticky sector rises.

This demand channel is also examined by Hornstein and Praschnik (1997), who investigate the co-movement of production and employment between the non-durables-producing sector and the durables-producing sector in response to technology shocks.

The input-output structure of an economy is not the only explanation for the "co-movement puzzle". Carlstrom and Fuerst (2006) suggest an alternative solution. They show that nominal wage rigidity along with a suitable size of adjustment cost in the durables-producing-sector generates the co-movement of value-added across sectors in response to a monetary-policy shock[3]. In contrast to an explanation based on sticky wages, the input-output scenario is based on an observed input-output table released by the Bureau of Economic Analysis, and it offers the co-movement of numerous variables across sectors that include labor productivity, gross output, and total working hours, as well as value-added.

This paper is organized into several sections. Section 1 has provided an introduction to the present study followed by its aim and specific objectives. Section 2 describes the model that we propose for the study. Our model is a two-sector sticky-price model in which the non-durables-producing sector and the durables-producing sector coexist. Production in the two sectors is assumed to be interrelated and can then be used in the input-output structure model. In section 3, we calibrate a two-sector input-output matrix from the U.S. input-output table. Using the matrix, we calculate the impulse-response functions of variables in response to monetary-policy shocks. Our models generate positive co-movement of value-added across sectors. Section 4 is devoted to the discussion of the role of the input-output matrix. Finally, section 5 draws a brief conclusion.

2 The economy

2.1 Household

We consider the household as an infinitely-lived representative agent with preference over the non-durables consumption, C_t, the services from the stock of durables, D_t, the real money balance, $\frac{M_t}{P_t}$, and work effort, L_t, as described in the expected utility function, (1)[4]

[3]DiCecio (2005) shows, with slightly different specifications, that a two-sector model with a sticky wage generates the co-movement of output in response to a neutral-technology shock and an embodied-technology shock as well as a monetary-policy shock.

[4]Our numerical exercise is conducted using a Cobb-Douglas utility function, the form of which implies that the elasticity of substitution of each product is unity. Carlstrom and Fuerst (2006) analyze the relationship between the functional form of the utility function and the co-movement across goods using a constant elasticity of substitution (CES) function:

$$U_t = \frac{\left[\left[\psi_c C_t^{\frac{\rho-1}{\rho}} + \psi_d D_t^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}\right]^{1-\sigma}}{1-\sigma}$$

where ρ is the elasticity of substitution. They report that the co-movement is only obtained when ρ is unrealistically small.

$$U_0 \equiv E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^{\psi_c} D_t^{\psi_d}\right)^{1-\sigma}}{1-\sigma} - \varphi \frac{L_t^{1+\omega}}{1+\omega} + V\left(\frac{M_t}{P_t}\right) \right] \tag{1}$$

where $\beta \in (0,1)$ is the discount factor, $\sigma > 0$ is the intertemporal elasticity of substitution, $\omega > 0$ is the inverse of the Frisch labor-supply elasticity, and φ is the weighting assigned to leisure. The utility associated with the real money balance, $\frac{M_t}{P_t}$ is separate, where V is a concave function of $\frac{M_t}{P_t}$. The parameters ψ_c, ψ_d represent relative weightings between non-durables and durables. We assume that $\psi_c + \psi_d = 1$.

The budget constraint for households is:

$$P_t^x X_t + P_t^c C_t + M_t \leq W_t L_t + \Pi_t + M_{t-1} + T_t \tag{2}$$

where P_t^x and P_t^c denote the nominal prices of the durables and non-durables, W_t is the nominal wage rate, and Π_t is the profit returned to consumers through dividends. T_t is the lump-sum nominal transfer from the monetary authority. M_t represents the nominal money balances held at time t.

The law of motion for the stock of durables is:

$$D_t = (1-\delta) D_{t-1} + X_t \tag{3}$$

where $\delta \in (0,1)$ is the depreciation rate of the durables stock.

2.2 Firm

The economy consists of two distinct sectors of production: the non-durables-producing sector and the durables-producing sector. Following the specification of the model described by Huang et al. (2004), we assume that both sectors contain a continuum of firms, each producing differentiated products, as indexed by $j \in [0,1]$, $k \in [0,1]$, respectively.

We use C_t^g to denote a gross output of composite of differentiated non-durables $\{C_t^g(j)\}_{j\in[0,1]}$, and X_t^g to denote a gross output of composite of differentiated durables $\{X_t^g(k)\}_{k\in[0,1]}$. The production functions of the two composites are:

$$C_t^g = \left[\int_0^1 C_t^g(j)^{(\theta-1)/\theta} dj\right]^{\theta/(\theta-1)} \text{ and } X_t^g = \left[\int_0^1 X_t^g(k)^{(\theta-1)/\theta} dk\right]^{\theta/(\theta-1)}$$

where $\theta \in (1,\infty)$ denotes the elasticity of substitution between products. The composite products are produced in an aggregation sector that faces perfect competition. The demand functions for the non-durables-producing firm j and for the durables-producing firm k are derived from the optimization behavior of the aggregation sector, represented by:

$$C_t^g(j) = \left[\frac{P_t^c(j)}{P_t^c}\right]^{-\theta} C_t^g \text{ and } X_t^g(k) = \left[\frac{P_t^x(k)}{P_t^x}\right]^{-\theta} X_t^g \tag{4}$$

where P_t^c and P_t^x are the prices of the composite of the non-durables and the durables. These prices are related to the prices of the non-durables $\{P_t^c(j)\}_{j\in[0,1]}$ and the durables $\{P_t^x(k)\}_{k\in[0,1]}$ by:

$$P_t^c = \left[\int_0^1 P_t^c(j)^{(1-\theta)}\, dj\right]^{1/(1-\theta)} \text{ and } P_t^x = \left[\int_0^1 P_t^x(k)^{(1-\theta)}\, dk\right]^{1/(1-\theta)}$$

In our economy, the composites serve either as final-consumption goods or as intermediate production inputs. The allocation of the gross output of the non-durables is:

$$C_t^g = C_t + C_t^m = C_t + \int_0^1 C_t^m(j)\, dj + \int_0^1 C_t^m(k)\, dk$$

where C_t^m is a composite of the non-durables that are used as intermediate inputs, $\{C_t^m(j)\}_{j\in[0,1]}$ are intermediate production inputs used by firm j in the non-durables-producing sector, and $\{C_t^m(k)\}_{k\in[0,1]}$ are intermediate production inputs used by firm k in the durables-producing sector.

The same equation holds for a composite of durables X_t^m and intermediate production inputs $\{X_t^m(j)\}_{j\in[0,1]}$, $\{X_t^m(k)\}_{k\in[0,1]}$. Therefore, the allocation of the gross output of the durables is:

$$X_t^g = X_t + X_t^m = X_t + \int_0^1 X_t^m(j)\, dj + \int_0^1 X_t^m(k)\, dk$$

The inputs used by firms in each sector are labor and intermediate inputs[5]. The production function of firm j in the non-durables-producing sector is given by:

$$C_t^g(j) = [C_t^m(j)]^{\gamma_{11}} [X_t^m(j)]^{\gamma_{21}} [L_t(j)]^{1-\gamma_{11}-\gamma_{21}} - F_c \tag{5}$$

Similarly, the production function of firm k in the durables-producing sector is given by:

$$X_t^g(k) = [C_t^m(k)]^{\gamma_{12}} [X_t^m(k)]^{\gamma_{22}} [L_t(k)]^{1-\gamma_{12}-\gamma_{22}} - F_x \tag{6}$$

where parameters γ_{il} for $i, l = 1, 2$ denote the cost share of total expenditure on inputs in sector l due to the purchase of intermediate inputs from sector i. We assume that the values of γ_{il} are identical across firms in the same sector. $L_t(j)$ and $L_t(k)$ are the labor inputs used in production by firm j and firm k, respectively. F_c and F_x are fixed costs that are identical for all firms [6]. Using γ_{il}, the input-output matrix of an economy Γ is given by:

$$\Gamma = \begin{bmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{bmatrix}$$

[5] To compare our model with those of Barsky et al. (2003, 2007), and Carlstrom and Fuerst (2006), we restrict our analysis to a model with no capital accumulation. Our result for co-movement is robust to the modifications in which capital accumulation is explicitly modeled.

We develop a two-sector model where both consumer durables and productive capital K_t that are held by the households, are present. We assume the two goods are produced from the durables-producing sector. This modification adds a law of motion for capital to household's problem, and it changes the cost structures of firms so that they are dependent on the rental price of K_t. With sizable adjustment cost in capital accumulation, we found that the co-movement across the two sectors obtained in the main text are obtained in this specification.

[6] F_c and F_x are set so that there is no incentive for a firm in one sector to enter into the market of other products. This condition implies that the profits from operating in either of the two sectors are zero at the steady state (Huang et al., 2004).

Firms j, k are price-takers in the input markets. In this set-up, the cost-minimization problem of firm j in the non-durables-producing sector and firm k in the durables-producing sector yield the following marginal cost function:

$$MC_t(j) = \bar{\phi}_c [P_t^c]^{\gamma_{11}} [P_t^x]^{\gamma_{21}} [W_t]^{1-\gamma_{11}-\gamma_{21}} \text{ and } MC_t(k) = \bar{\phi}_x [P_t^c]^{\gamma_{12}} [P_t^x]^{\gamma_{22}} [W_t]^{1-\gamma_{12}-\gamma_{22}} \tag{7}$$

where $\bar{\phi}_c$ and $\bar{\phi}_x$ are constant.

Firms j, k are monopolistic competitors in the products market, where they set prices for their products in reference to the demand given by (4)

As for the pricing of products, we assume sticky prices with a Calvo mechanism. In each period, fraction d of the firms in each sector cannot reset prices. These firms must maintain the price of the previous period. The fraction d is constant over time. We assume that d differs by sector, following Carlstrom and Fuerst (2006), and Barsky et al. (2003, 2007). That is, $d = d_c$ for the non-durables-producing sector and $d = d_x$ for the durables-producing sector.

Firm j in the non-durables-producing sector that can reset the price therefore solves the following problem:

$$\max_{\{C_t^m(j),\, X_t^m(j),\, L_t(j), P_t^c(j)\}} E_t \sum_{s=0}^{\infty} (\beta d_c)^s \frac{\Lambda_{t+s}}{\Lambda_t} \frac{D_{t+s}(j)}{P_{t+s}^c} \tag{8}$$

$$s.t.\ D_{t+s}(j) = P_t^c(j)\, C_t^g(j) - P_t^c(j)\, C_t^m(j) - P_t^x(j)\, X_t^m(j) - W_t L_t(j) \tag{9}$$

where Λ_t is the Lagrange multiplier associated with budget constraint (2) The optimal reset prices $P_t^*(j)$ are:

$$P_t^*(j) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{s=0}^{\infty} (\beta d_c)^s \left(\frac{\Lambda_{t+s}}{\Lambda_t}\right) C_{t+s}^g(j)\, MC_{t+s}(j) / P_{t+s}^c}{E_t \sum_{s=0}^{\infty} (\beta d_c)^s \left(\frac{\Lambda_{t+s}}{\Lambda_t}\right) C_{t+s}^g(j) / P_{t+s}^c} \tag{10}$$

The same equations hold for price-resetting firm k in the durables-producing sector.

The prices of the non-durables and the durables evolve:

$$P_t^c = \left[d_c \left(P_{t-1}^c\right)^{1-\theta} + (1-d_c)\left(P_t^*(j)\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \text{ and } P_t^x = \left[d_x \left(P_{t-1}^x\right)^{1-\theta} + (1-d_x)\left(P_t^*(k)\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{11}$$

As an aggregate variable, real GDP Y_t is defined so that it is consistent with Barsky et al. (2003, 2007).

$$Y_t \equiv \bar{P}^c C_t + \bar{P}^x X_t \tag{12}$$

where $\bar{P}^c$ and $\bar{P}^x$ are the steady-state values of the non-durables and durables composite prices.

2.3 Government

Monetary policy is conducted via lump-sum transfer so that:

$$T_t = M_t - M_{t-1}. \tag{13}$$

2.4 Closing the model

At the symmetric equilibrium, the market-clear conditions for the products are:

$$C_t^g = \left[\int_0^1 C_t^g (j)^{(\theta-1)/\theta} \, dj \right]^{\theta/(\theta-1)} = C_t + \int_0^1 C_t^m (j) \, dj + \int_0^1 C_t^m (k) \, dk \tag{14}$$

$$X_t^g = \left[\int_0^1 X_t^g (k)^{(\theta-1)/\theta} \, dk \right]^{\theta/(\theta-1)} = X_t + \int_0^1 X_t^m (j) \, dj + \int_0^1 X_t^m (k) \, dk \tag{15}$$

The labor market is[7]:

$$L_t = \int_0^1 L_t (j) \, dj + \int_0^1 L_t (k) \, dk \tag{16}$$

2.5 Equilibrium

An equilibrium consists in a set of allocations, $\{ C_t, C_t^g, C_t^g (j), C_t^m (j), C_t^m (k), X_t, X_t^g, X_t^g (k), X_t^m (j), X_t^m (k), P_t^c (j), P_t^x (k), P_t^c, P_t^x, W_t, M_t \}_{t=0}^{\infty}$, for all $j, k \in [0, 1]$, which satisfy the following conditions: (*i*) the household's allocation solves its utility-maximization problem; (*ii*) each producer's allocations and price solve its profit-maximization problem taking the wage and all prices of intermediate goods; and (*iii*) all markets clear.

3 Simulation

In this section we select parameter values and simulate the model described above.

Parameter calibration

[7] We assume completely mobile labor across sectors, following Barsky et al. (2003, 2007), and Carlstrom and Fuerst (2006). Erceg and Levin (2002, 2006), and Bouakez et al (2005), by contrast, assume friction in sectoral labor mobility. In Barsky et al. (2003, 2007), and Carlstrom and Fuerst (2006), a lack of co-movement of value-added is accompanied by a lack of co-movement of sectoral labor inputs. One could argue that the presence of friction may block the lack of co-movement. We compute the equilibrium response to a monetary-policy shock of an economy in which the production functions of each sector are linear with respect to attached sectoral labor, following the specification of Erceg and Levin (2002, 2006). This model generates the negative co-movement of value-added, although the acyclic response of the durables is smaller than that of the linear model with a mobile labor supply.
The friction in the labor mobility weakens the lack of co-movement across sectors, but its effect is not large enough to generate the co-movement.

Here we choose preference parameters so that they are consistent with precedents. These parameters include the subjective discount factor β, the Frisch labor-supply elasticity ω, the weight on leisure φ, the weight on the products ψ_c and ψ_d, the depreciation rate of durable goods δ, and the intertemporal elasticity of substitution σ.

As for the firms' parameters, we set the elasticity of substitution between differentiated products θ, the Calvo lottery parameter of the non-durables-producing sector d_c, and that of the durables-producing sector d_x, in a similar manner.

The Cobb-Douglas coefficients γ_{il} for $i, l = 1, 2$, in an input-output matrix are set to the two-sector input-use matrix of the U.S. economy. We first assign each industry in the input-use table to either the non-durables-producing sector or the durables-producing sector, following the categorization method used in Baxter (1996). The non-durables-producing sector includes the following: farming, forestry, fishing, and related activities; utilities; wholesale trade; retail trade; transportation; credit intermediation and related activities; services; and manufacturing of non-durables. The durables-producing sector includes the remaining industries, except those in the government sector. γ_{il} values are calculated as the nominal cost share of intermediate inputs over the value of the gross output of each sector.

The calculation based on the procedure noted above gives us:

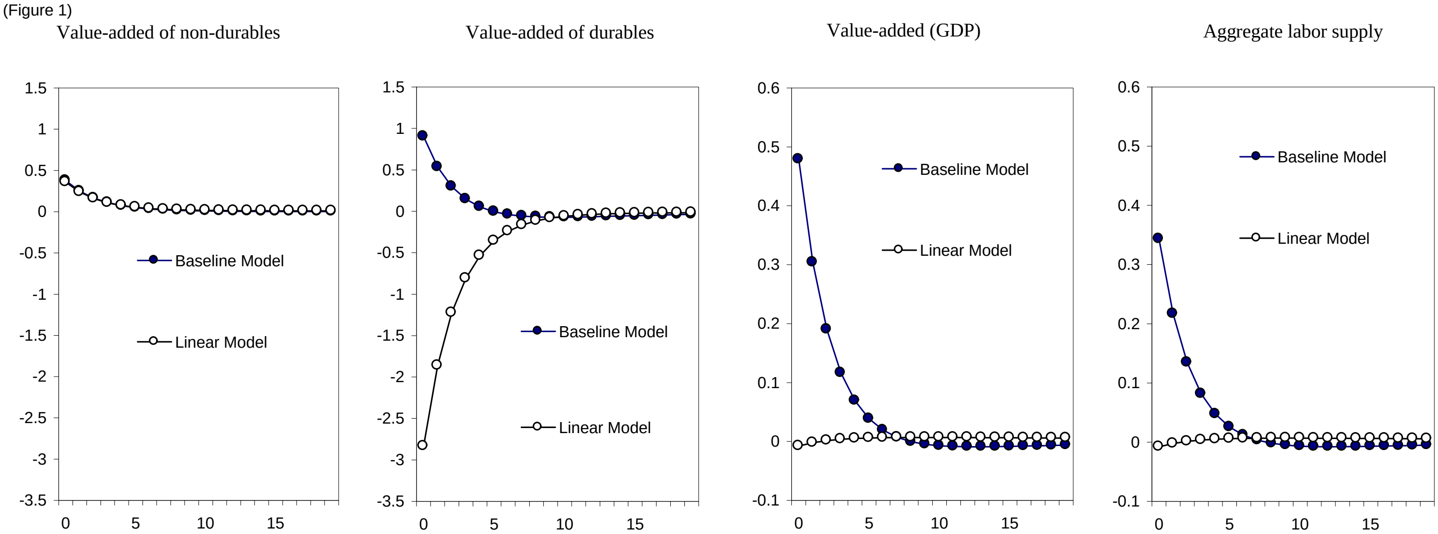
$$\Gamma_{2005} = \begin{pmatrix} .374 & .281 \\ .057 & .282 \end{pmatrix} \tag{17}$$

where Γ_{2005} is a two-sector matrix calculated from the input-use table for the year 2005.

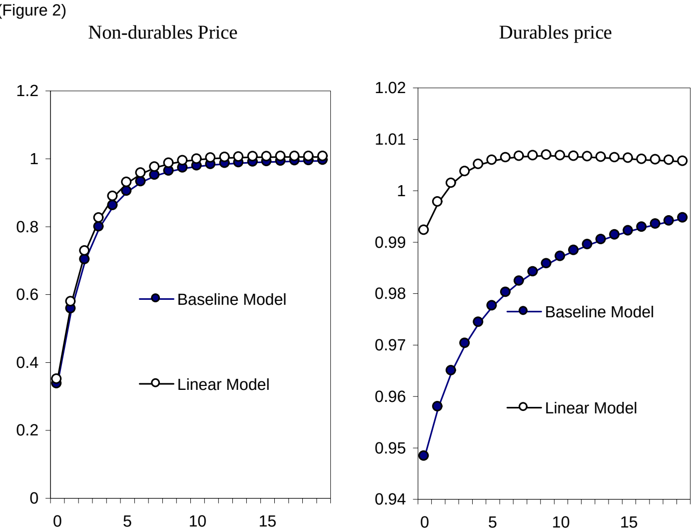
Simulation results

Figure 1 and Figure 2 show the behavior of an economy in the wake of a monetary expansion. To compare the implications of our model with those of preceding works, we focus on the responses of an economy to an unanticipated permanent increase of the money supply by 1.00 percent (Barsky et al., 2003, 2007). The lines in the figures are the impulse-response functions (IRFs) of the variables after the shock that occurs at $t = 0$. They are computed using a linear approximation around the non-stochastic steady states.

(Figure 1)



(Figure 2)



We report two simulation results for two distinct economies that differ only by input-output matrix Γ. All other conditions are the same. In the first economy, Γ is constructed from the actual input-use table of the U.S. economy in 2005. That is, $\Gamma = \Gamma_{2005}$ (17) . We call this economy baseline model. In the second economy, we assume that the production technologies of both the non-durables-producing sector and the durables-producing sector are linear with respect to labor inputs. That is, the four elements of Γ are all zero. This linear specification is used as reference model in Barsky et al. (2003) and Carlstrom and Fuerst (2006), and we have so far followed their approach. In both models, a common setting is maintained in which non-durables prices are sticky and durables prices are flexible.

The lines with black circles depict the IRFs of the variables in the baseline economy in which the input-output matrix Γ is consistent with the U.S. data. The lines with white circles show the IRFs in the economy where the production functions are linear.

The equilibrium responses of real value-added in each sector are shown in Figure 1. In the baseline model, expenditure in both the non-durables and the durables sectors increase in the first quarter after the shock, and return to the steady state gradually. The response of the durables appears to be more sensitive to the shock: at the time of impact, the response of the durables is more than twice that of the non-durables. Erceg and Levin (2002, 2006), and Barsky et al. (2003), also report the co-movement across sectors and the larger response of the durables expenditure than that of the non-durables. In this respect, the model is consistent with the empirical studies.

In the linear model, the value-added of the durables decreases, while that of the non-durables increases. Thus, the result of co-movement is not obtained. The response of the durables is also sensitive to the shock, but in the opposite direction. It is clear that the baseline model generates a more-plausible time path of the value-added of sectors after the shock than does the linear model.

The last two estimates in Figure 1 exhibit the aggregate response of the economy. In the baseline model, the real GDP and aggregate labor supply react sharply to the shock. In the linear model, by contrast, such responses are barely observed. As pointed out by Barsky et al. (2003, 2007), the monetary-policy effect is dampened significantly (that is, money-neutrality), as the counter-cyclical response of the durables expenditure offsets the response of the non-durables expenditure.

Figure 2 displays the equilibrium response of prices to a monetary-policy shock. The 1 percent increase of money supply implies a 1 percent increase of the price level in the long run. In both models, the price level of the non-durables ascends gradually to the new price level. This is because the non-durables prices are adjusted infrequently. As for the durables prices, they ascend more slowly in the baseline model than in the linear model. We show in the next section that these price dynamics are important to the equilibrium dynamics of the value-added in each sector.

4 The role of the input-output matrix

In the previous section, we discussed the fact that the structure of the input-output matrix is important for both the sectoral response and the aggregate response of an economy to a monetary-policy shock. This section is devoted to explaining the role of the input-output matrix Γ in generating the co-movement of value-added across sectors, and money-non-neutrality in an economy.

Prices with input-output matrix

We first describe how the nominal prices of non-durables, durables, and labor inputs are related to each other through the input-output matrix structure. Earlier studies demonstrate that the responses of the sectoral outputs to a monetary-policy shock are determined by the relative price changes across products (see for example, Ohanian et al., 1995; Barsky et al., 2003, 2007; Carlstrom and Fuerst 2006).

In Figure 2 in the previous section, we saw that under the assumption of sticky non-durables prices and flexible durables prices, a monetary expansion leads to a rise of the durables price relative to the non-durables price in the short run. The non-durables prices are adjusted slowly, while the durables prices are adjusted immediately to the new steady-state level. The speeds of the price adjustments are affected by the input-output matrix.

In Calvo price setting, the active firm j resets the price $P_t^*(j)$, according to the pricing-decision rule (10). Combining (10) with (7) gives the price dynamics equations for the non-durables and durables prices:

$$\tilde{p}_t^c = d_c \tilde{p}_{t-1}^c + (1-d_c)\,\tilde{p}_t^*(j) \text{ and } \tilde{p}_t^x = d_x \tilde{p}_{t-1}^x + (1-d_x)\,\tilde{p}_t^*(k) \tag{18}$$

where

$$\tilde{p}_t^*(j) = (1-d_c\beta)\,E_t\left\{\sum_{s=0}^{\infty}(d_c\beta)^s\, m\tilde{c}_{t+s}(j)\right\} \text{ and } \tilde{p}_t^*(k) = (1-d_x\beta)\,E_t\left\{\sum_{s=0}^{\infty}(d_x\beta)^s\, m\tilde{c}_{t+s}(k)\right\} \tag{19}$$

$$m\tilde{c}_{t+s}(j) = \gamma_{11}\tilde{p}_{t+s}^c + \gamma_{21}\tilde{p}_{t+s}^x + (1-\gamma_{11}-\gamma_{21})\,\tilde{w}_{t+s} \tag{20}$$

$$m\tilde{c}_{t+s}(k) = \gamma_{12}\tilde{p}_{t+s}^c + \gamma_{22}\tilde{p}_{t+s}^x + (1-\gamma_{12}-\gamma_{22})\,\tilde{w}_{t+s} \tag{21}$$

We use $\tilde{z}_t$ to denote a percent deviation of the variable Z_t around the non-stochastic steady state. E_t denotes expectations, which are conditional on the information set available at time t.

Equations (18), (19), (20) and (21) suggest that the price dynamics of non-durables and durables are determined by the input-output structure. The expressions (20) and (21) show that the deviation of the nominal marginal costs from their steady-state levels are given by the linear combination of the deviations of the nominal prices of the non-durables composite, the durables composite, and the labor inputs, weighted by the Cobb-Douglas coefficient γ_{il} for $i, l = 1, 2$. The active firms set the prices referring to present and future nominal marginal costs (19). The price levels of the composites are determined by the newly reset price and the price one period before (18). Hence, the input-output matrix is playing an important role in the change in price dynamics across products.

In the linear model, the four entities in Γ are all zero, indicating that nominal marginal costs are common to all of the firms in an economy, $\tilde{w}_t$. The key parameter delivering the diversity in the equilibrium price dynamics between the non-durables and the durable goods is Calvo parameter d. A lower d implies that a sector's price response to an innovation in the nominal marginal cost is fast. For a product with $d = 0$, the price dynamics are essentially equal to those of the nominal wage. The size of the relative price change across products is entirely attributed to the difference in the value of the parameter d across sectors.

In the baseline model, elements of Γ are positive. Hence the size of the relative price change in response to a monetary policy shock is determined by both the input-out matrix Γ and the Calvo-parameter d. It is notable that γ_{12} is as large as γ_{22} in the U.S. input-output matrix Γ_{2005} (17) . This property of the matrix indicates that the price of non-durable is a principal determinant of the durables prices. Even though $d_x = 0$, it suggests that the durables price in the baseline model moves more slowly than in the linear model.

Households with the input-output matrix

The household's expenditure decision and labor supply decision $\{C_t, X_t, L_t\}_{t=0}^{\infty}$ are affected indirectly by the input-output matrix Γ. As we have seen above, the matrix is responsible for the equilibrium price dynamics in an economy. The households' decisions are made in reference to the price responses after a monetary shock.

The first order conditions of household's utility maximization problem yield equations shown below. The expressions are exactly the same as those of Barsky et al. (2003, 2007).

$$\frac{\psi_c C_t^{\psi_c(1-\sigma)-1} D_t^{\psi_d(1-\sigma)}}{\eta_t} = \frac{P_t^c}{P_t^x} \tag{22}$$

where $\psi_c C_t^{\psi_c(1-\sigma)-1} D_t^{\psi_d(1-\sigma)}$ denotes the marginal utility obtained from consuming C_t, and η_t denotes the present value of marginal utilities obtained from the service flow of the durables stock:

$$\eta_t = E_t \left[\sum_{s=0}^{\infty} \beta^s (1-\delta)^s \psi_d C_{t+s}^{\psi_c(1-\sigma)} D_{t+s}^{\psi_d(1-\sigma)-1} \right] \tag{23}$$

(22) indicates that the equilibrium responses of the expenditure on the non-durables and the durables are tied to the relative price.

Supposing that $\delta = 1$, (22) , in log-deviation form, is reduced to:

$$\tilde{x}_t - \tilde{c}_t = \tilde{p}_t^c - \tilde{p}_t^x \tag{24}$$

(24) says that household purchases goods that are relatively cheaper at period t. Given the equilibrium paths of $\tilde{c}_t$, it is easy to see that the occurrence of the co-movement of value-added is determined by the relative price change $\tilde{p}_t^c - \tilde{p}_t^x$. When δ is less than unity, the relationship between the household's consumption choice decision and the relative price becomes less clear. $\delta < 1$ implies that household considers the intertemporal substitution. The following two opposing views on the role of δ for household's choices are present in the literature.

Barsky et al. (2003, 2007) claim that goods with low δ might move acyclically to an aggregate shock. According to their argument, η_t in (23) is nearly constant when short-lived shocks such as monetary shocks, are considered. With a sufficiently small δ, η_t largely depends on the marginal utility from the service flow of the durable goods stock in the future periods far after t, suggesting $\eta_t \approx \eta$ (Barsky et al. (2003, 2007)). When this is the case, the household consumption choice at t becomes sensitive to the relative price of the durables at t. Even in a period of expansion, if durable goods are notably more expensive than other products, the expenditure on durables decreases.

Bils and Klenow (1998) propose an alternative view. They claim that goods with low δ should move more cyclically than the non-durables. When the household increases the service flow from the durable stock and the consumption of the non-durables by the same percentages, the expenditure on the durable goods becomes greater as the value of δ becomes smaller. For a given change in the durables stock, a smaller δ requires a larger percentage change in the durables expenditures. As far as a monetary policy effect is concerned, the observation is consistent with this view (see for example, Erceg and Levin (2002)).

From Figure 1, we see that our baseline model generates co-movement and larger response of the durables expenditure than that of the non-durables (corresponding to the second view). By contrast, the prediction made using the linear model is a lack of co-movement across sectors (corresponding to the first view). We show below that whether the first view or the second view holds depends on the structure of the matrix.

Finally, the durability δ also affects to the household's labor decision. According to Barsky et al. (2003, 2007), the property that the shadow value of the durables consumption is almost constant, $\eta_t \approx \eta$, has a striking implication for the aggregate behavior of an economy in response to a monetary policy shock. The labor decision rule of household in the current model is expressed in the same form as Barsky et al. (2003):

$$\varphi L_t^{\omega} = \frac{W_t}{P_t^x}\eta_t \tag{25}$$

where the left-hand side (LHS) of the equation is marginal disutility from an additional unit of labor input. The right-hand side (RHS) expresses the gain in terms of marginal utility. In the linear model, under the assumption that the durables have flexible prices, (21) implies that $\frac{W_t}{P_t^x}$ is equal to the markup which is constant. Provided that η_t is invariant in response to the short-lived shocks, (25) implies that L_t should also be unresponsive to the shock. When labor input is the only input in an economy, L_t being unchanged implies that monetary innovation has no effect on an aggregate economy. This is the outcome highlighted in Barsky et al. (2003, 2007), as "monetary neutrality."

In contrast to this specification, (21) and the fact that γ_{12} is positive suggest that our input-output model generates the short-run variations in $\frac{W_t}{P_t^x}$. As Basu (1995) has shown in a more general form, (21) shows that the price of durables, relative to the nominal wages, falls in a monetary expansion as the latter is adjusted quicker than the former. Hence, even when η_t is nearly constant, the RHS of (25) fluctuates upon the shock, as does L_t, bringing back "monetary non-neutrality" to the economy.

Firms with input-output matrix

The firms' decisions in the inputs market, $\{C_t^m(j), X_t^m(j), L_t(j)\}_{t=0}^{\infty}$ for firm j in the non-durables-producing sector, and $\{C_t^m(k), X_t^m(k), L_t(k)\}_{t=0}^{\infty}$ for firm k in the durables-producing sector, are affected by the input-output matrix Γ.

The cost minimization problem for firm j yields the following expression about non-durables inputs $C_t^m(j)$, durables inputs $X_t^m(j)$ and labor inputs that tie them to the gross output $C_t^g(j)$:

$$\frac{C_t^m(j)\,P_t^c}{\gamma_{11}} = \frac{X_t^m(j)\,P_t^x}{\gamma_{21}} = \frac{L_t(j)\,W_t}{1-\gamma_{11}-\gamma_{21}} = MC_t(j)\left[C_t^g(j)+F_c\right] \tag{26}$$

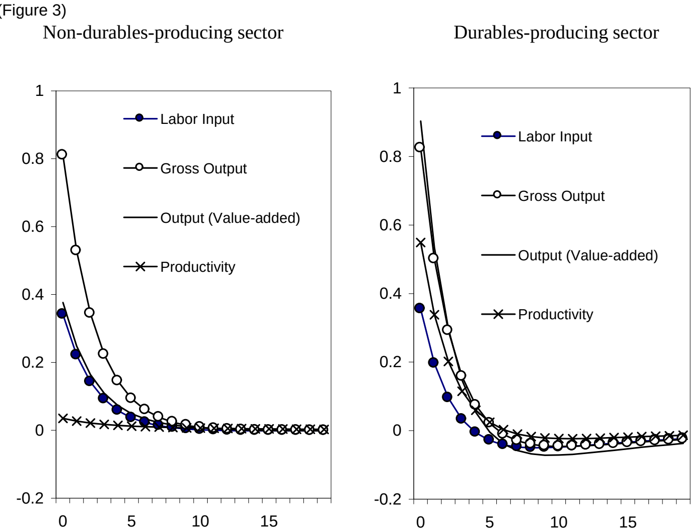
Similar expressions holds for any firm k in the durables-producing sector.

$$\frac{C_t^m(k)\,P_t^c}{\gamma_{12}} = \frac{X_t^m(k)\,P_t^x}{\gamma_{22}} = \frac{L_t(k)\,W_t}{1-\gamma_{12}-\gamma_{22}} = MC_t(k)\left[X_t^g(k)+F_x\right] \tag{27}$$

The equation (26) and (27) indicate that in the economy represented by the matrix, firms substitute from more expensive inputs to cheaper inputs. In a monetary expansion, as non-durables become the cheapest inputs, they are preferred to the other inputs. The increased non-durables intermediate inputs raises the labor productivity of the user sectors[8]. Higher labor productivity induce higher labor inputs for the both sectors. In the non-durables sector, the gross output rises reflecting the increased demand from the user sectors. In the durables-producing sector, increase in gross output reflects the change in labor input and labor productivity. Thus, our model implies the co-movement of gross output, labor input, and labor productivity as well as value-added.

Figure 3 illustrates the equilibrium responses of the two sectors to the same monetary policy shock analyzed above, for labor input, gross output and output. All three variables in the two sectors co-move. Moreover, it can be seen from the figure that the labor productivity - a difference between the value-added and the labor input for each sector - also co-move, reflecting the increase of the non-durables intermediate inputs. This implication of the model is consistent with the empirical findings that says not only the value-added but also the production of the sectors co-move (Christiano and Fitzgerald, 1993; Rebelo, 2005) in business cycles.

(Figure 3)



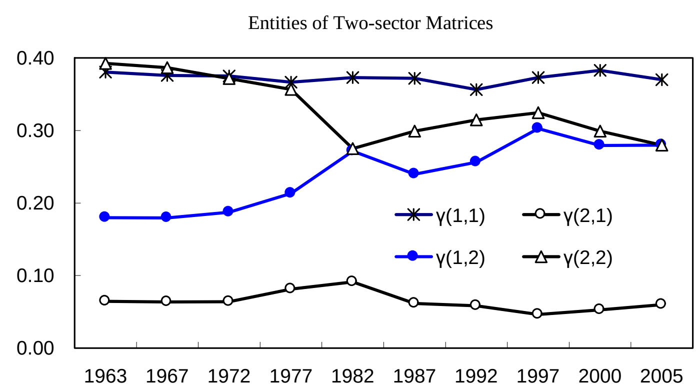
Input-output matrix of the U.S. economy

[8]As explained in Basu (1995), the presence of monopolistic competition, mark-up and price rigidity means that the amounts of the intermediate inputs produced in the non-durables-producing sectors at the steady state are too small. An expansionary monetary policy shock changes the mark-up of the non-durables-producing sector, leading to production increase in the non-durables-producing sector, and the productivity increases in the sectors that use the non-durables as intermediate inputs.

In this subsection, we characterize the actual input-output matrix of the U.S. economy and discuss why it delivers the co-movement of value-added to the economy, referring to the discussions above.

The actual matrix Γ_{2005} indicates the diagonal entities of input-out matrix are the largest elements of each column. It implies that the largest intermediate inputs provider for each sector is own sector. As discussed by Huang and Liu (2001a, 2001b), this property of the matrix makes the response of the non-durables prices more persistent and the responses of the non-durables output larger. A more important feature of the matrix, in relation to yielding the co-movement, however, is the asymmetry of off-diagonal entities in the matrix. (17) shows that the Cobb-Douglas coefficients γ_{12} is as large as γ_{22} while γ_{21} is negligibly small. This indicates that a large portion of the intermediate inputs in the durables-producing sector is delivered from the non-durables-producing sector. The durables-producing sector, by contrast, provides almost no intermediate inputs to the non-durables-producing sector. In other words, the non-durables-producing sector is a disproportionately large intermediate-inputs supplier in the U.S. economy. This asymmetry makes both the sectoral response and the aggregate response to a monetary policy shock more sensitive to the response of the non-durables-producing sector.

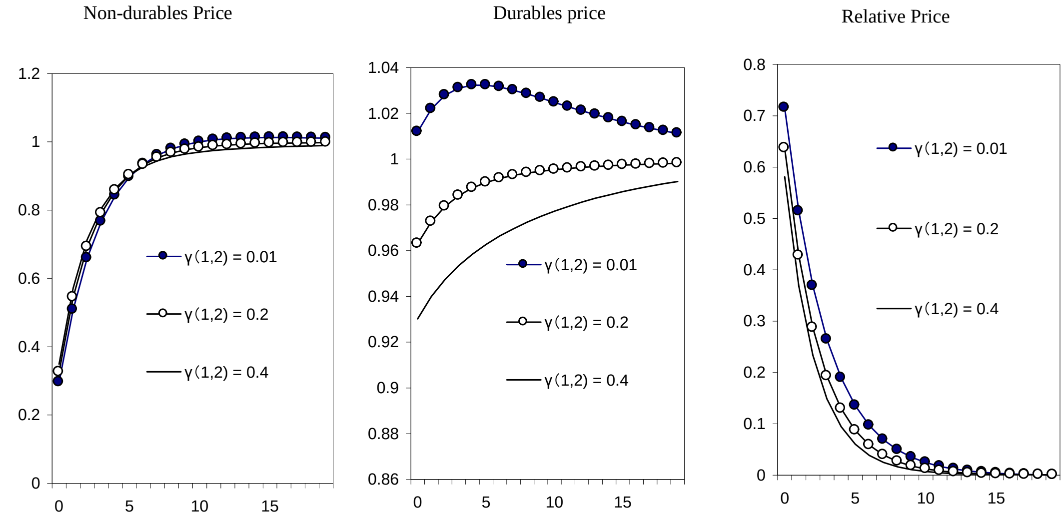
The year 2005 is not unusual for the post-war period. We have computed a two-sector input-output matrix Γ for the years 1963, 1967, 1972, 1977, 1982, 1992, 1997 and 2000, using the same classification and the procedure for Γ_{2005}. The graph below shows the changes of each entity γ_{il} in Γ over the period. $\gamma(i,l)$ in the graph corresponds γ_{il}.



Although the entities of each Γs vary to some extent, the asymmetric property of the matrix highlighted above is maintained in all of the nine matrices. The co-movement we obtain from our baseline model using $\Gamma = \Gamma_{2005}$ is also robust for those matrices. We have computed the equilibrium response of the variables to a permanent increase of money supply by 1%. All of the nine matrices yield the co-movement of value-added between the non-durables-producing sector and the durables-producing sector.

To determine the role of γ_{12} in an economy more explicitly, we compute the equilibrium responses of the variables to a monetary-policy shock, using three different hypothetical matrices Γ. A monetary shock is generated by the same manner as in the previous simulations. For each of the matrices used in the simulations, we vary the share of the intermediate inputs of non-durables in the durables-producing sector, γ_{12}, while keeping the share of the intermediate inputs in the sector and the other parameters in the economy constant.

(Figure 4)



(Figure 5)

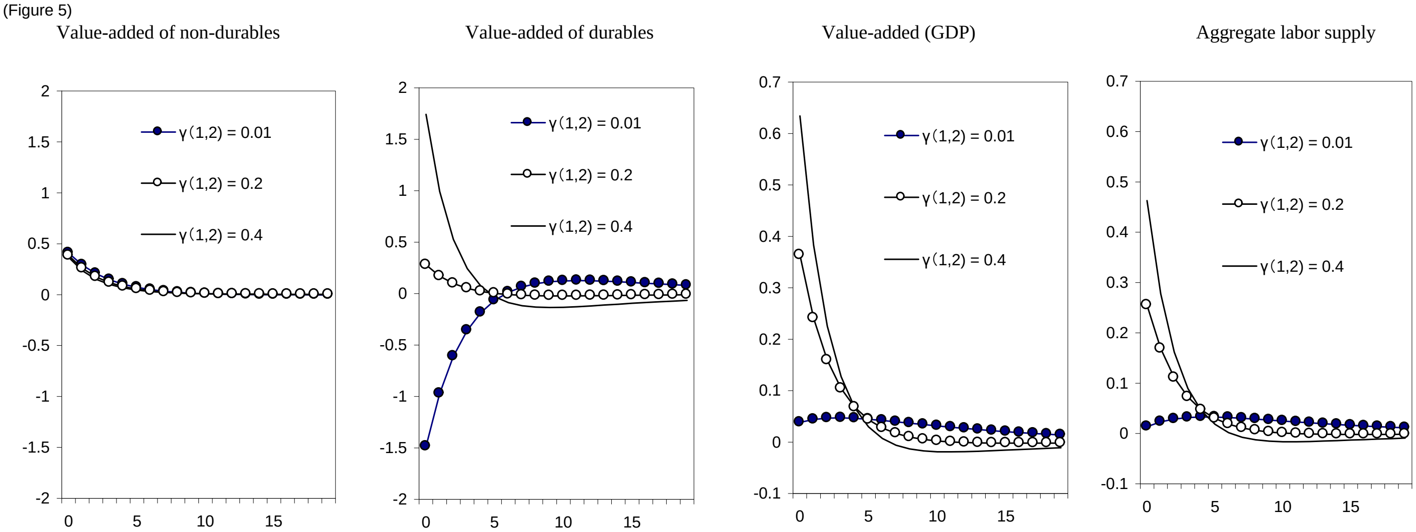


Figure 4 and Figure 5 above represent the simulation results of our model with three different values of γ_{12}. Figure 4 displays the IRFs of the prices, and Figure 5 displays those of the quantities. The lines with black circles depict the IRFs of the variables when $\gamma_{12} = .01$, the lines with white circles depict those when $\gamma_{12} = .2$ and the lines without circles depict those when $\gamma_{12} = .4$. When $\gamma_{12} = .01$, the matrix is nearly diagonal matrix, and as γ_{12} becomes larger, the role of the non-durables producing sector plays more important role in durables production.

As for the price dynamics, as the equation (21) indicates, a large γ_{12} implies that larger proportions of the durables price variations are explained by the variations in non-durables prices. Thus, the durables price tends to ascend slower with larger γ_{12} (seen in the upper right panel), reflecting more of the persistent dynamics of the non-durables prices shown in the upper left panel.

As for the value-added, the IRFs of the non-durables are essentially unaffected by differences in γ_{12}. The IRFs of the durables are, by contrast, sensitive to the choice of γ_{12}. As we know from the discussion above, a higher γ_{12} implies that the relative price increase of the durables in the transition path becomes softened, and that more intermediate inputs produced in the non-durables-producing sector are used in the durables-producing sector. As the durables become cheaper, household spends more on them. For the firms' side, as more of the intermediate inputs are used in the durables-producing sector, labor productivity here rises. From the second panel in Figure 5, it is clear that the Barsky et al. (2003, 2007) channel is dominant when the γ_{12} is low, and the Bils and Klenow (1998) channel becomes dominant as the γ_{12} gets higher.

The last two panels in Figure 5 illustrate the aggregate behavior of an economy as a function of γ_{12}. A greater monetary-policy effect is obtained with a higher γ_{12}. This observation is consistent with the equations (21) and (25).

5 Conclusion

In this paper, we propose one solution to the co-movement puzzle, as discussed previously by Carlstrom and Fuerst (2006), and Barsky et al. (2003, 2007). According to Barsky et al. (2003, 2007), when non-durables prices are sticky and durables prices are flexible, the standard sticky-price model implies a lack of co-movement across sectors and money-neutrality. This prediction is, however, not consistent with the data reported in the literature, for example by Erceg and Levin (2002), and Barsky et al.(2003).

We have constructed a two-sector model that incorporates the input-output matrix of the U.S. economy. Given the interdependence of the non-durables-producing sector and the durables-producing sector, the model generates co-movement across sectors and money-non-neutrality in response to an monetary-policy shock.

We have successfully demonstrated that the equilibrium responses of both sectors and the aggregate economy to a monetary-policy shock are dependent on the structure of the input-output matrix of the economy. The matrix of the U.S. economy indicates that the non-durables-producing sector serves as a large intermediate supplier to the durables-producing sector. This feature of the matrix makes the equilibrium response of the durables more affected by the response of non-durables, leading to the co-movement of value-added across sectors and a larger monetary policy effect.

6 Parameters

Parameters have been chosen following Carlstrom and Fuerst (2006).

Baseline parameters

Parameter	Value	Description
β	$(1.04)^{-1}$	Yearly subjective discount rate
σ	2	Intertemporal elasticity of substitution
ρ	1	Elasticity of substitution
ω^{-1}	1	Frisch labor-supply elasticity
θ	11	Elasticity of substitution across goods
δ	10%	Annual depreciation rate of durables
d_c	.67	Quarterly frequency of price non-adjustment
d_x	0	Quarterly frequency of price non-adjustment

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