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# Inventory-Theoretic Model of Money Demand, Multiple Goods, and Price Dynamics

**Hirokazu Ishise* and Nao Sudo****

**Abstract**

Despite the theoretical prediction based on sticky-price models, it is empirically suggested that the tie between the frequencies of price adjustment across goods and the relative price responses of goods (price index of specific goods over non-durable aggregate price index) to a monetary policy change is limited.

We offer an alternative view of the price dynamics of goods. We develop a multi-sector extension of an inventory-theoretic model of money demand (segmented market model). In our model, the diversity in the characteristics of goods, that is, durability, luxuriousness and cash intensity (the portion of the payment that is paid by cash in the purchase of goods), yields the dispersion of relative prices responses to a monetary policy shock, across goods. The model implies that the relative prices of durables, luxuries and less cash-intensive goods tend to decline in a monetary contraction.

We test the empirical plausibility of our model, using two approaches: a measure of monetary policy shock developed by Romer and Romer (2004), and a factor-augmented VAR used in Bernanke et al. (2005). In both econometric methodologies, we find that the data are consistent with our model, in terms of durability and luxuriousness.

**Keywords:** Baumol-Tobin model; Durable; Luxury; Credit goods; Monetary policy

**JEL classification:** E5, E6

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# 1 Introductory remarks

In the macroeconomics literature, a monetary policy effect is considered to be tightly related to prices responses to a policy change. As monetary policy focuses on the aggregate demand of an economy, many studies, such as Rotemerg and Woodford (1997) and Goodfriend and King (1998), regard an aggregate price index of non-durables, as a relevant price series for policy analysis.

Recently, macroeconomists turned their attention to a more disaggregated level of prices (Bils et al., 2003; Erceg and Levin. 2002; Barsky et al., 2007; Boivin et al., 2007). In particular, Boivin et al. (2007) investigate the sectoral responses of prices to a monetary policy shock, using item level of personal consumption expenditure (PCE) data and producer price indices. They observe a large cross-sectional dispersion across items, in the way the prices of those items respond to a monetary policy shock. That is, relative prices across goods change drastically following a monetary policy shock. For example, they report clear heterogeneity in price responses betweem durables and non-durables. Other studies focus on more aggregated prices, and find a similar pattern of heterogeneity across sectors.

To examine this heterogeneity more closely, we estimate the impulse response functions (IRFs) of prices to a contractionary monetary policy shock, for 189 PCE items. IRFs are calculated using the approach of Romer and Romer (2004) (see Appendix B for details). For convenience of analysis, we normalize each of the price indices by an aggregate non-durables price index. Table 1 reports the number of prices that either rise or decline significantly, with respect to the aggregate non-durables price index, after a monetary policy shock[1]. Among 189 items, the relative prices rise for 15 items, while for 62 items, the relative prices decline significantly. Among durables, relative prices decline for more than half of the items.

(Table 1)
(the number of items whose relative prices either rises or declines)

| | | |
|---|---|---|
| All Items (189 items) | Rise | 15 items |
| | Decline | 62 items |
| Durables (30 items) | Rise | 0 items |
| | Decline | 17 items |
| Non-durables (159 items) | Rise | 15 items |
| | Decline | 45 items |

The mechanism that produces the cross-sectional differences in the relative prices is not well understood so far. In the sticky-price framework, a dispersion in the frequency of price adjustments across sectors operates as a strong mechanism that yields the cross-sectional differences in price responses to a shock. In the multi-sector extension of the sticky-price model (see, for example,

[1] To determine the significance, we calculate the 10% confidence interval. The prices of the items are considered to be significantly rising (or declining), if there is at least a month when the lower (upper) bound of the confidence interval crosses zero within a two-year horizon.

Ohanian et al., 1995; Carvalho, 2006), sectors that adjust prices frequently coexist with those that adjust them infrequently. Prices in the former respond faster to a monetary policy shock, than those in the latter, leading to a short-run change in the relative price of the two goods.

It is observed, however, that the actual price dynamics of goods are not closely linked to the frequency of price adjustments of goods (Bils et al., 2003; Bils and Klenow, 2004). Following Christiano et al. (1999), Bils et al. (2003) estimate the empirical responses of goods prices to a monetary policy shock, to observe the inconsistency between the data and the prediction of the sticky-price model. They find that the relative price of flexible-price goods, with respect to sticky-price goods, descends following a monetary expansion shock.

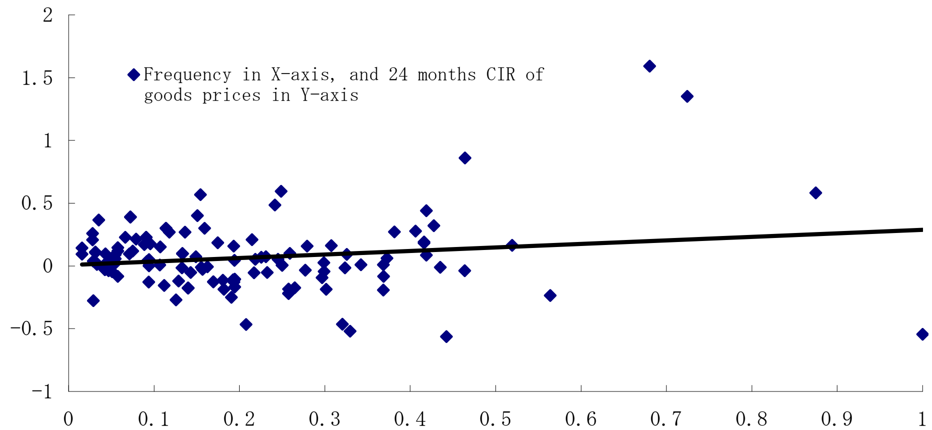
The weakness of the link can also be seen by a different approach. We first estimate the cumulative impulse response (CIRs) of the relative prices of PCE items to a monetary policy shock, using two recently developed econometric procedures. One is a regression using a measure of monetary policy shock provided in Romer and Romer (2004). The other is the factor-augmented VAR (FAVAR), developed in Bernanke et al. (2005), and applied to disaggregated price analysis in Boivin et al. (2007) (see Section 4 and Appendix B for details). We then regress each of the estimated CIRs of the PCE items on the frequencies of price adjustment of goods that are reported in Nakamura and Steinsson (2007)[2], to see the tie.

Figure 1 and Figure 2 plot the CIRs of the relative prices of the PCE items to a contractionary monetary policy shock, and the frequency of price adjustment of the PCE items. CIRs are estimated by Romer and Romer (2004) and FAVAR, respectively. In Boivin et al. (2007), it is argued that higher price flexibilities imply larger negativeness of the CIRs. Similarly, in the panels below, higher frequencies of price adjustment should imply larger negativeness of the CIRs of relative prices of the PCE items.

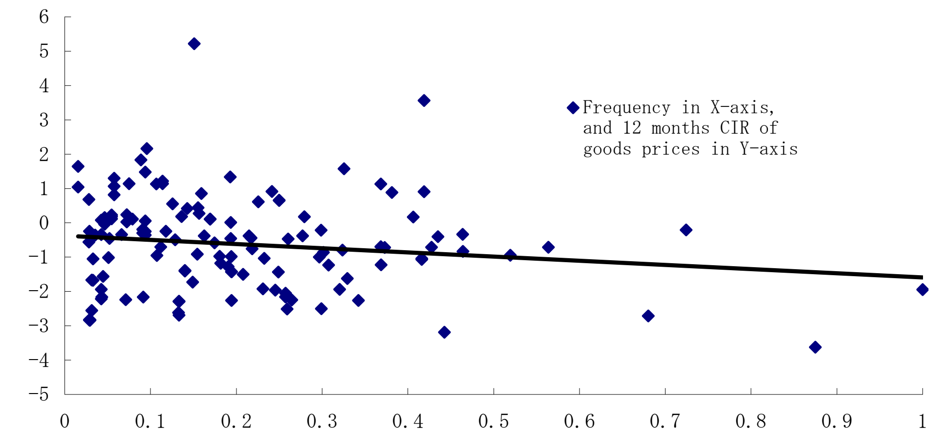
Our estimates, however, do not yield the clear link between the CIRs and the frequencies. It is observable that the coefficient of the frequency of price adjustment is positive in Figure 1. On the other hand, the sign is opposite in Figure 2. Thus only the latter result is consistent with the prediction of the sticky price model. Similar results are obtained if we instead include the frequency of price adjustment reported in Bils and Klenow (2004). Based on these observations, although we do not exclude the possibility that the frequency of price adjustments is one of the determinants of the price dynamics of goods after a monetary policy shock, we believe that their role is limited.

[2] Boivin et al. (2007) take a similar approach. They estimate CIRs of prices of the PCE items to a monetary policy shock, using FAVAR, then compare each CIRs with the market power of the industry.

(Figure 1) Regression of CIRs on the Frequency of Price adjustment (Romer and Romer)




(Figure 2) Regression of CIRs on the Frequency of Price adjustment (FAVAR)




To answer to the same question, but from a different perspective, we develop an inventory-theoretic model of money demand. The classic works on the inventory-theoretic model by Baumol (1952) and Tobin (1956) are extended, following the subsequent works by Grossman and Weiss (1983) and Alvarez et al. (2003), so that we are able to analyze the effect of a monetary policy shock on the price responses of various goods. In our economy, no friction associated with price settings is assumed. We instead assume a friction in accessing the financial market. We consider an economy where the financial market and the goods market are separated, and access to the financial market incurs costs on households[3]. Given this access cost, households withdraw money from banks infrequently, and they spend the money over several periods. Because only a portion of money present in the economy is used for transactions, a change in aggregate money supply is not fully reflected in a change in the prices of goods that are purchased during the period. Thus, in a

[3]In the literature, there are various ways of modeling the current type of financial frictions. Grossman and Weiss (1983) and Alvarez et al. (2003) assume a Taylor type of financial friction. In these models, households are allowed to access the financial market every $N$ periods, where $N$ exogenous. In Chiu (2005) and Khan and Thomas (2007), $N$ is endogenously determined by households. We follow the former approach.

wake of monetary policy shock, such as an exogenous fall in money supply, prices adjust sluggishly.

In order to discuss the relative price of goods in the inventory-theoretic framework, we incorporate the multiple-goods set up used in Bils and Klenow (1998). Using standard consumption theory, Bils and Klenow (1998) ask if the dispersions of the cyclicality of consumption goods can be attributed to the characteristics of goods. They find that "durability" and "luxuriousness" make the responses of goods to aggregate shocks more cyclical. Following their approach, we analyze the tie between the characteristics of goods and the price responses of goods to a monetary policy shock. In addition to "durability" and "luxuriousness", we study the implication of "cash goods vs credit goods" distinction, for the price response to a monetary policy shock. Existing monetary models, including Lucas and Stokey (1987) and Hodrick et al. (1991), classify goods by the way of settlement. In these studies, goods paid for by cash are called cash goods, and goods paid for by private credit are called credit goods. We follow their approach, and describe the goods that are paid for by cash as cash-intensive goods.

Based on the current model, the price responses of goods to a monetary policy shock are linked to the characteristics of the goods. Similarly to the model of Alvarez et al. (2003), we assume that all the goods are endowed exogenously, and the prices of goods are determined by the households' consumption decisions. In the economy, as households differ from each other in their timing of access to the financial market, the impact of a policy shock is not uniform among them. Some types of households become richer, and others become poorer, as a consequence of a monetary policy shock. The equilibrium relative prices of each goods to the shocks are thus determined by the consumption decisions by each type of households, and the relative importance of the specific types.

From the simulation exercises that investigate a tie between goods' characteristics and relative price responses of goods to a monetary policy shock, we find that the relative prices of durables, luxuries and credit goods tend to descend (ascend), following a contractionary (expansionary) monetary policy shock. This observation is invariant to the various specifications of the parameters associated with the size of the financial frictions, or law of motion of the money supply shock.

We then investigate the plausibility of our theoretical results using the U.S. data. For each of the PCE items, we estimate the responses of the relative prices of goods, with respect to the aggregate price index of non-durables, to a monetary policy shock, using a measure of monetary policy developed by Romer and Romer (2004), and the factor-augmented VAR. We test whether the size and the sign of the estimated responses are related to the depreciation rate, luxuriousness and cash intensity of the items, in the manner that our theory suggests. We find from the data analysis that the depreciation rate and luxuriousness are the important determinants of the price responses of goods after a monetary policy shock.

The rest of the paper is organized into four sections. Section 2 describes our model— inventory-theoretic model with multiple consumption goods. Section 3 demonstrates how the characteristics of goods—durability, luxuriousness and cash intensity of the goods—affect price responses of the goods to a monetary policy shock. Section 4 presents an empirical observation on the price responses of goods to a monetary policy shock. Section 5 concludes.

# 2 The Model

## 2.1 Environment

We consider an economy where $j = 1, ..., J$ consumption goods, and $s = 0, \ldots, N-1$ equally divided types of agents are present. We assume that the $J$ items may be different from each other, in terms of durability, cash intensity of payment, and luxuriousness. We say that an item $j^A$ is more durable than an item $j^B$ when the depreciation rate of the item $\delta_{j^A} \in [0,1]$ is smaller than $\delta_{j^B} \in [0,1]$. Similarly, we define the cash intensity of payment for an item $j$, by a size of the portion of the payment that households pays by cash for the purchase of the item $\theta_j \in [0,1]$. We define luxuriousness by the income elasticity, following the terminology used by Bils and Klenow (1998). We will see that the income elasticity is governed by the parameter $\sigma_j > 0$ in the utility function. For simplicity of analysis, we treat an item $j = 1$ as numeraire, and we assume that the depreciation rate, cash intensity and $\sigma_j$ are all unity for the numeraire.

A coalition is characterized by the initial period type and each fraction consists of $1/N$ measure of people. In each period, agent moves forwardly: type 0 becomes type 1, type 1 to type 2, ..., and type $N-1$ to type 0. The economy is composed of the two separate markets, and each agent has an account for each market. One market is the financial market where agents trade interest-bearing assets. Following Alvarez et al. (2003), we call the accounts used for the market as "brokerage accounts." The other market the a goods market where agents trade goods, and the accounts associated with this market are named "bank accounts." The two types of accounts are segmented from each other, in the sense that only type $s = 0$ agent can rebalance assets between the two accounts. When type $s = 0$ agents access their brokerage account, they transfer a nominal money, $x_t$, from the brokerage account to the bank account. The money in the bank account serves to the purchase of goods in the goods market. Once they have rebalanced their assets, the agents $s = 0$ need another $N-1$ months before the next rebalancing.

The supply side of our model is comparatively simple. In each period, every agent, type $s = 0, \ldots, N-1$ receives an equal amount of endowments for goods $j$, for $j = 1, ..., J$. Each household is divided into shopper-saler pair, so that they cannot consume their own endowments. Agents purchase goods either by cash or by credit or both. The payments for the purchases of goods are deducted from the bank account if they are paid by cash, and from the brokerage account if they are paid by credit. Earnings from selling their endowments are transferred to the accounts. Following Alvarez et al. (2003), we assume that of the payments for goods that are settled by cash, a portion $\gamma \in [0, 1]$ of the payment is sent to the bank account, and the rest of the payment is sent to the brokerage account. All the payments via credit are transferred to the brokerage account.

## 2.2 Households problem

Each type of agent maximizes utility over the stock of goods, $k_j$ for $j = 1, ..., J$. Utility function satisfies standard increasing and diminishing marginal utility condition, $u_{k_j} \to \infty$ if $k_j \to 0$ for $j = 1, ..., J$:

$$\sum_{t=0}^{\infty} \sum_{h^t} \beta^t \Pr(h^t) u(k_{1,t}(s, h^t), ...k_{J,t}(s, h^t)), \tag{1}$$

where $h^t$ is the history to date $t$, $\Pr(h^t)$ is the probability of realizing a particular history of the economy and $\Pr(h^t|h^{t-1})$ is the conditional probability of reaching $h^t$ given $h^{t-1}$.

Following Bils and Klenow (1998), we assume that the temporal utility function has the following addilog form:

$$u(k_{1,t}(s, h^t), ..k_{J,t}(s, h^t)) = \sum_{j=1}^{J} \alpha_j \frac{k_{j,t}(s, h^t)^{1-\sigma_j} - 1}{1 - \sigma_j}, \tag{2}$$

where $\sum_{j=1}^{J} \alpha_j = 1$, and $\alpha_j$ stands for the steady state expenditure share of the goods $j$ over the consumption basket. A goods-specific income elasticity for goods $j$ is captured by the intertemporal elasticity parameter $\sigma_j$, as in Bils and Klenow (1998). The law of motion for the durable stock of goods $j$, $k_{j,t}(s, h^t)$ held by type $s$ agent at period $t$ is:

$$k_{j,t}(s, h^t) \leq [1 - \delta_j] k_{j,t-1}(s - 1, h^{t-1}) + c_{j,t}(s, h^t). \tag{3}$$

where $\delta_j \in [0, 1]$ denotes the goods-specific depreciation rate, and $c_{j,t}(s, h^t)$ is the amounts of goods $j$ that are purchased by agent $s$ at the period $t$. For any goods $j$, all agents receive an equal amount of endowment $y_{j,t}(h^t)$ in each period. $c_{j,t}(s, h^t)$ does not need to be equalized to $y_{j,t}(h^t)$, because $c_{j,t}(s, h^t)$ is an endogenous variable while $y_{j,t}(h^t)$ is an exogenous variable.

Households face a cash-in-advance constraint (or "bank account" constraint) and cash holding transition:

$$\sum_{j=1}^{J} \theta_j P_{j,t}(h^t) c_{j,t}(s, h^t) + Z_t(s, h^t) = M_t(s, h^t), \tag{4}$$

$$M_t(s, h^t) = Z_{t-1}(s - 1, h^{t-1}) + \sum_{j=1}^{J} \theta_j \gamma_j P_{j,t-1}(h^{t-1}) y_{j,t-1}(h^{t-1}) + \mathbf{1} \cdot P_t(h^t) x_t(h^t) \tag{5}$$

where $\theta_j \in [0, 1]$ denotes the goods-specific cash intensity, and $M_t(s, h^t)$ are the cash holdings in the bank account that belong to type $s$ at period $t$. (4) denotes the way cash holdings by households of type $s$ at period $t$, $M_t(s, h^t)$, are spent. In each period $t$, households of type $s$ spend a portion of their cash holdings for the purchasing of goods (the first term on the left-hand-side (LHS) of (4)), and carry the rest of their money, $Z_t(s,h^t)$, in the bank accounts to period $t+1$. (5) indicates the various components that constitute a cash holding at period $t$, $M_t(s,h^t)$. Namely, $M_t(s,h^t)$ is the sum of $(i)$ money that is carried by type $s-1$ at period $t-1$, from the previous period, which is $Z_{t-1}(s-1,h^{t-1})$, $(ii)$ a portion of their earnings from selling their endowments that are deposited in their bank accounts (the second term on the right-hand-side (RHS) of (5)), and $(iii)$ a transfer of cash from their brokerage account, $P_t(h^t)x_t(h^t)$. Note that $\mathbf{1}$ is an index function taking 1 if $s=0$ and 0 otherwise.

A brokerage account constraint is described as follows:

$$\sum_{h_{t+1}} q_{t+1}^t(h^{t+1})B_t(s,h^{t+1}) + A_t(s,h^t) + \mathbf{1}\cdot P_t(h^t)x_t(h^t) + \sum_{j=1}^{J}[1-\theta_j]P_{j,t}(h^t)c_{j,t}(s,h^t)$$
$$= B_{t-1}(s-1,h^t) + A_{t-1}(s-1,h^{t-1}) + \sum_{j=1}^{J}\theta_j\left[1-\gamma_j\right]P_{j,t-1}(h^{t-1})y_{j,t-1}(h^{t-1})$$
$$+\sum_{j=1}^{J}\left[1-\theta_j\right]P_{j,t}(h^t)y_{j,t}(h^t) - P_t(h^t)\tau_t(h^t), \tag{6}$$

where $B_t(s,h^{t+1})$ is the amount of bond holdings of the households of type $s$ at $t$, $q_{t+1}^t(h^{t+1})$ is the price of a one-period-ahead bond returning one dollar, and $A_t(s,h^t)$ is the cash holding at the brokerage account. This equation shows how the assets belonging to the households of type $s$ at period $t$ are accumulated. Note that a fraction of the payments for purchasing goods $j$ that are paid for by credit, $[1-\theta_j]P_{j,t}(h^t)c_{j,t}(s,h^t)$, is deducted directly from the brokerage account, while the rest of the payments are deducted from the bank account. The earnings from selling their endowments of goods $j$, $\theta_j\left[1-\gamma_j\right]P_{j,t-1}(h^{t-1})y_{j,t-1}(h^{t-1})$ and $\left[1-\theta_j\right]P_{j,t}(h^t)y_{j,t}(h^t)$, flow into the brokerage account at each period. $\tau_t(h^t)$ is the lump-sum transfer by the government.

In addition to the accounts, households face nonnegativity constraints of $Z_t(s,h^t)$, $M_t(s,h^t)$, $A_t(s,h^t)$. As for the purchase of goods $c_{j,t}(s,h^t)$ for $j=1,...J$, we assume the nonnegativity constraint:

$$c_{j,t}\left(s,h^t\right)\geq 0 \tag{7}$$

The government faces the following government budget constraint:

$$B_{t-1}(h^t) = M_t(h^t) - M_{t-1}(h^{t-1}) + P_t(h^t)\tau_t(h^t) + \sum_{h_{t+1}} q_{t+1}^t(h^{t+1})B_t(h^{t+1}), \tag{8}$$

where $M_t(h^t)$ and $B_t(h^t)$ are the average values of money and bonds in the economy, respectively. We also define the growth rate of money by $\mu_t = M_t/M_{t-1}$. We assume $\mu_t$ follows a stationary AR(1) process, where $\rho_M \in (0,1]$ :

$$\mu_t = \rho_M \mu_{t-1} + \varepsilon_t. \tag{9}$$

Asset prices are related to nominal interest rate as follows.

$$\frac{1}{1+i_t(h^t)} = \sum_{h_{t+1}} q_{t+1}^t(h^{t+1}). \tag{10}$$

The velocity of money circulation, $v_t(h^t)$, is

$$v_t(h^t) = \frac{\frac{1}{N}\sum_{j=1}^J P_{j,t}(h^t)\sum_{s=0}^{N-1} c_{j,t}(s,h^t)}{M_t(h^t)}. \tag{11}$$

**Definition**: A *Competitive Equilibrium* of the Economy is
a sequence of prices $\{\{P_{j,t}(h^t)\}_{j=1}^J, q_{t+1}^t(h^{t+1})\}_{t=0}^\infty$ and
the allocations $\{\{\{c_{j,t}(s,h^t), k_{j,t}(s,h^t)\}_{j=1}^J, x_t(h^t), B_t(s,h^{t+1}), A_t(s,h^t), M_t(s,h^t), Z_t(s,h^t)\}_{s=0}^{N-1}\}_{t=0}^\infty$
for a given government policy $\{\tau_t(h^t), M_t(h^t), B_t(h^t)\}_{t=0}^\infty$, endowment process $\{\{y_{j,t}(s,h^t)\}_{j=1}^J\}_{t=0}^\infty$
and initial conditions $\{\{k_{j,-1}(s-1)\}_{j=1}^J, B_{-1}(s-1,.), A_{-1}(s-1,.), Z_{-1}(s-1,.)\}_{s=0}^{N-1}$ such that for all $t, h^t$ :

$(i)$household maximizes utility given the prices;
$(ii)$the government budget constraint holds;
$(iii)$markets clear:

$$\frac{1}{N}\sum_s c_{j,t}(s,h^t) = y_{j,t}(h^t) \text{ for } j = 1,..J \tag{12}$$

$$\frac{1}{N}\sum_s B_t(s,h^{t+1}) = B_t(h^{t+1}) \tag{13}$$

$$\frac{1}{N}\sum_s [M_t(s,h^t) + A_t(s,h^t)] = M_t(h^t). \tag{14}$$

Following Alvarez et al. (2003), we focus on an economy with a positive interest rate, so that $A_t(s,h^t) = Z_t(N-1,h^t) = 0$. The endowment process is assumed to have no trend growth. We use a log-linearized rational expectations model to analyze the dynamics of the model. The behavior of the economy is described as the deviation from the following non-stochastic steady state where all the real variables stay constant:

**Definition**: *Non-Stochastic Steady State* of the Economy is an Equilibrium with $A_t(s) = 0$, $Z_t(N-1) = 0$, such that $\{\{c_{j,t}(s), k_{j,t}(s)\}_{j=1}^{J}, x_t, B_t(s), m_t(s), z_t(s), m_t, \{p_{j,t}\}_{j=1}^{J}\}_{s=0}^{N-1}$ $= \{\{\overline{c}_j(s), \overline{k}_j(s)\}_{j=1}^{J}, \overline{x}, \overline{B}(s), \overline{m}(s), \overline{z}(s), \overline{m}, \{\overline{p}_j\}_{j=1}^{J}\}_{s=0}^{N-1}, \overline{\mu} = M_t/M_{t-1} = \overline{\pi} = P_t/P_{t-1}$ and $q_{t+1}^{t}/P_t$ is constant.

## 2.3 How the model works

In this section, we briefly discuss the equilibrium responses of the variables to a monetary policy shock.

The first order conditions with respect to the numeraire consumption and money holdings give the following Euler equations for agent $s$, for $s = 0, ..., N-1$:

$$u_1\left(s, h^t\right) = \beta E_t\left[\frac{u_1\left(s+1, h^{t+1}\right)}{\pi_{t+1}\left(h^{t+1}\right)}\right] + P_t(h^t)\lambda_t^z(s, h^t), \tag{15}$$

where $u_1\left(s, h^t\right)$ denotes the marginal utility for households of type $s$ from consuming numeraire $c_1\left(s, h^t\right)$, and $\lambda_t^z(s, h^t)$ is the Lagrange multiplier associated with nonnegativity of $Z_t(s, h^t)$[4]. $E_t$ denotes expectation conditional on time $t$ information.

Similarly to the model of Alvarez et al. (2003), the cash-in-advance constraint is binding for transactions in the goods market, and the consumption growth rate is a function of the price growth rate $\pi_{t+1}$. The equilibrium levels of money holdings by households are determined, so as to be consistent with the growth rate of their numeraire consumption. At each period, a portion of the households' money holdings $Z_t(s, h^t)$ for $s = 1, ..., N-1$ is not used for goods purchasing and is carried over to the next period. As rebalancing between the accounts happens only once every $N$ periods, money holdings for each household decline over successive periods, until they access to their brokerage accounts again.

In this environment, a monetary policy shock, such as an unexpected exogenous change in aggregate money supply, does not incur an immediate one-for-one rise in goods' price levels. A change in the aggregate money supply leads to a gradual change in money that is used as a means of exchange. Provided that supplies of goods are constant, prices adjust sluggishly.

Using (15) and (10), it is shown that the asset price in the financial market is determined by the marginal utility of a dollar for households of type $s = 0$. Equivalently, the nominal interest rate $i_t$ is expressed as[5]:

[4] Alvarez et al. (2003) point out that in an economy with positive inflation, households of type $s = N-1$ does not carry money to the next period. As the households are able to rebalance their assets between the brokerage account and bank account in the subsequent period, there is no incentive for them to keep their money unspent, or equivalently, leaving $Z\left(N-1, h^t\right)$ positive.

[5] In order to derive the equation below, we need to impose some class of initial distribution for the bonds endowment. See Alvarez et al. (2003) for details.

$$\frac{1}{1+i_t} = \beta E_t \left\{ \frac{u_1(0, h^{t+1})}{u_1(0, h^t)\, \pi_{t+1}(h^{t+1})} \right\}. \tag{16}$$

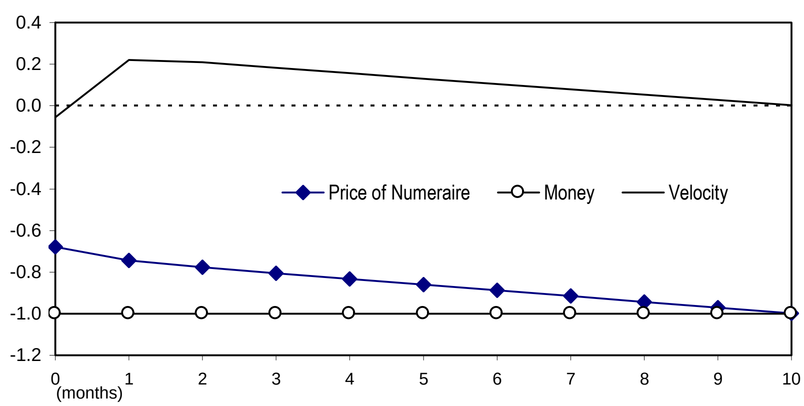
As only a subset of the households participate in the financial market, a monetary policy shock primarily affects the money holdings of the households who rebalance their assets during the period of innovation. Suppose a monetary contraction shock occurs at period $t$. Households that are type $s = 0$ during this period receive less money than those who were type $s = 0$ at period $t-1$. As a consequence, the numeraire consumptions by the active households decline at period $t$, because the share of aggregate real money balances held by those households shrinks in the short run, leading to a rise in the interest rate.

As for the substitution between goods $j$ and the numeraire, combining the first order conditions for the numeraire and for the goods $j$ yields the user cost equation:

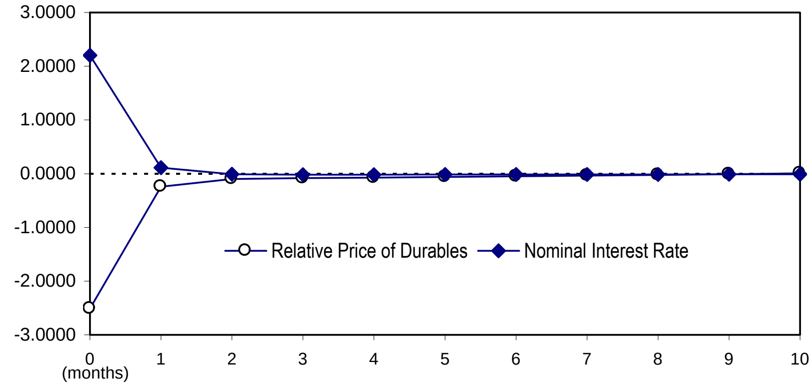
$$\begin{aligned} c_j(s, h^t)^{-\sigma_j} u_1(s, h^t) &= p_{j,t}(h^t) \frac{\left[\theta_j u_1(s, h^t) + [1-\theta_j] u_1(0, h^t) + \lambda_t^j(s, h^t)\right]}{u_1(s, h^t)} \\ -\beta[1-\delta_j] E_t p_{j,t+1}(h^{t+1}) &\left\{ \frac{\theta_j u_1(s+1, h^{t+1})}{u_1(s, h^t)} + \frac{[1-\theta_j]}{r_t(h^t)} \frac{u_1(0, h^t)}{\beta u_1(s, h^t)} + \frac{\lambda_{t+1}^j(s+1, h^{t+1})}{u_1(s, h^t)} \right\}, \end{aligned} \tag{17}$$

where $u_j(s, h^t)$ denotes marginal utility for agent $s$ from consuming the goods $j$, $r_t(h^t)$ is the real interest rate measured by the numeraire, and $\lambda_t^j(s, h^t)$ is the Lagrange multiplier associated with the nonnegativity constraint. Clearly, the consumption decisions of households of type $s$ on goods $j$ depend on the goods-specific parameters $\delta_j$, $\theta_j$ and $\sigma_j$. We will see in the next section that the impact of a monetary policy shock is not uniform across the households, depending on what their types are at the period of the monetary policy shock. Thus the aggregate demand of goods $j$ is determined by both the goods-specific parameters and the households' type. Note that provided that goods supply is unaffected by a monetary policy shock in the current model, the relative price $p_{j,t}(h^t)$ changes so that (17) holds for every type $s$.

(Figure 3)



(Figure 4)




To see the quantitative implications of our model, we calculate the IRFs of certain variables to a monetary policy shock. Alvarez et al. (2003) concentrate on how the price sluggishness is generated through inventory-theoretic model of money demand. Keeping the features highlighted in Alvarez et al. (2003) in the model, we study more disaggregated level of prices.

Following Erceg and Levin (2006) and Barsky et al. (2007), we disaggregate an economy into two sectors, so that $J = 2$, where one sector is non-durables (nondurable goods and services) sector and the other sector is durable. The details of the parameterization are described in Appendix A.

Figure 3 shows the IRFs of selected variables to a monetary policy shock. The line with black diamonds depicts the equilibrium response of the price level of the numeraire, the line without symbols displays that of the aggregate velocity of the economy, and the line with white circles displays that of the aggregate money supply. We consider a one time, negative monetary policy shock, by one unit, that happens at period 0. The figure indicates a sluggish dynamics of the numeraire price, relative to a money supply in a wake of monetary policy shock. The price level of numeraire does not fall one-for-one with the drop of aggregate money supply. As a consequence, an aggregate velocity, which is defined by (11) rises, in the short run.

In Figure 4, the line with black diamonds displays the equilibrium response of the nominal interest rate to the monetary policy shock, and the line with white circles displays that of the relative price of durables. Upon the shock, as the quantity of money supply drops in the financial market, the nominal interest rate rises (liquidity effect. see, for example, Edmond and Weill (2005)). As for the relative price of durables, the time path shows that it declines for a while and returns to the steady state.

As discussed in Alvarez et al. (2003) and Edmond and Weill (2005), the inventoy-theoretic model delivers the price sluggishness in an environment where the price is flexible. Price level deviates from the quantity of money in the short run. In the next section, we argue that the model also implies that the price responses of goods to a monetary policy shock are not uniform. Figure 4 indicates that the price response of durable is different from that of non-durable. We examine the underlying mechanism that renders this heterogeneity of price responses in the section below.

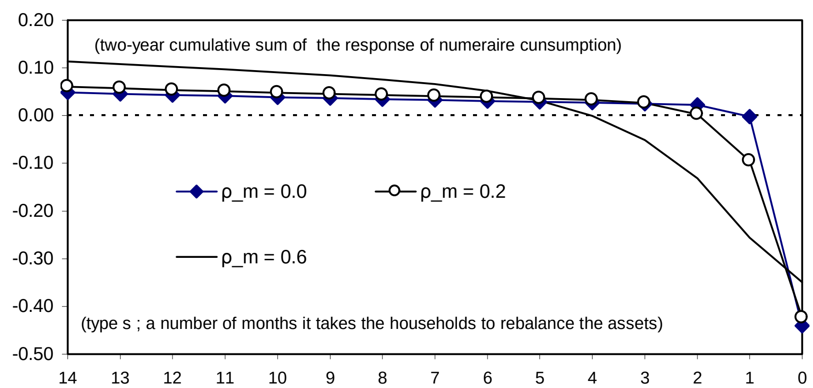
# 3 Relative price responses and goods characteristics

In this section, we investigate the link between the characteristics of goods, and the price responses of goods to a monetary policy shock. We claim that the characteristics of goods are the important determinants of the observed price response dispersions across goods in a monetary policy shock.

A consumption theory, such as Bils and Klenow (1998), provides theoretical grounds for the model implications. Because explicit production sectors are missing in our model, households' consumption decisions are the only source of the dispersion of the price responses across goods to a monetary policy. For a given income level, households' decisions about their expenditure on goods are affected by the characteristics of the goods. That is, durability, cash-intensity and luxuriousness of the goods are playing a part in households' demand decisions. Bils and Klenow (1998), using the representative agent model, show that following an increase in income, the households' demands for durables and luxuries tend to be higher compared with the demand for the "numeraire".

Our model is not a representative agent model, and households are heterogeneous in terms of the timing of the rebalancing of their assets. A monetary policy shock, in this environment, does not bring a uniform increase of wealth to all the households. The size and the sign of the impact of the monetary policy shock for households is type specific.

(Figure 5)




To see this quantitatively, we show how household type matters to the households' responses to a monetary policy shock. Figure 5 plots the CIRs of the numeraire consumption for each household after a monetary contraction shock, in terms of the deviation from the steady state. Along the $x$-axis, each household is grouped according to its type at the period when the policy shock occurs. For each household type of $s = 0, ...14$, a positive (negative) value of CIR along the $y$-axis indicates the household increases (decreases) the numeraire consumption after the monetary policy shock, implying the household becomes richer (poorer) upon the shock. The line with black diamonds denotes the CIRs when the policy shock is one time, and one unit decline of money growth rate. This corresponds to the case where $\rho_M = 0.0$ (see, (9)). The line with white circles, and the line without circles depict the CIRs of the numeraire consumption for the case where $\rho_M = 0.2$ and for the case where $\rho_M = 0.6$, respectively.

Figure 5 shows, for all three specifications of $\rho_M$, that the CIRs of the numeraire consumptions take negative values for households with smaller $s$ at the period of innovation, and positive values for households with larger $s$ at the same period. While the persistency of the money growth shock to some extent changes the pattern of the distribution, it is clear that the impact of the monetary policy shock is different across the households, depending on the household type at the period of innovation. For example, for households that are type $s = 0$ at the occurrence of the policy shock, the monetary policy shock always works as a negative income shock that leads to the reduction of the consumption. A fall in the money supply in the financial market results in the decline of money holdings by the households who transfer money to their bank account at that time. The portion of the real money balances held by these households shrink, and the households reduce their goods purchases. For those that have rebalanced their assets before the policy shock, the shock works as a positive income shock that results in an increases in their consumption. Their money holdings are invariant to the shock, but the price level of goods become lower after the shock as the aggregate money stock shrinks, and they become richer in the short run.

In this section, we see that the response of each household to an income shock is an important determinant of household's expenditure decision. It is notable, however, that the equilibrium relative price response of goods $j$ is determined by the relative size of the aggregate demand for the goods $j$, compared with the aggregate demand for the numeraire, which reflects the consumption decisions of those heterogenous households discussed above.

## 3.1 Durables vs Non-durables

First, we examine the role of durability of goods in determining their price responses to a monetary policy shock. To see this, we consider goods $j$ with $\delta_j$, which is strictly smaller than unity. We assume that goods $j$ is different from the numeraire only in terms of its durability. That is, $\sigma_j$ and $\theta_j$ are both unity.

If we ignore the terms associated with the nonnegativity constraint for simplicity, combining the first order conditions for the households of type $s$, with respect to goods $j$ and the numeraire yields the user cost equation:

$$\frac{u_j(s,h^t)}{u_1(s,h^t)} = p_{j,t}\left(h^t\right) - \beta\left[1-\delta_j\right] E_t p_{j,t+1}\left(h^{t+1}\right) \frac{u_1\left(s+1,h^{t+1}\right)}{u_1(s,h^t)}, \tag{18}$$

where $p_{j,t}\left(h^t\right)$ is the relative price of the goods $j$ with respect to the numeraire, and $u_j\left(s,h^t\right)$ denotes the marginal utility of the service flow from an additional unit of the durables $j$, for households of type $s$.

According to Bils and Klenow (1998), consumption theory implies that the durables expenditure $c_j\left(s,h^t\right)$ is more responsive to an income change, than the non-durables expenditure $c_1\left(s,h^t\right)$.

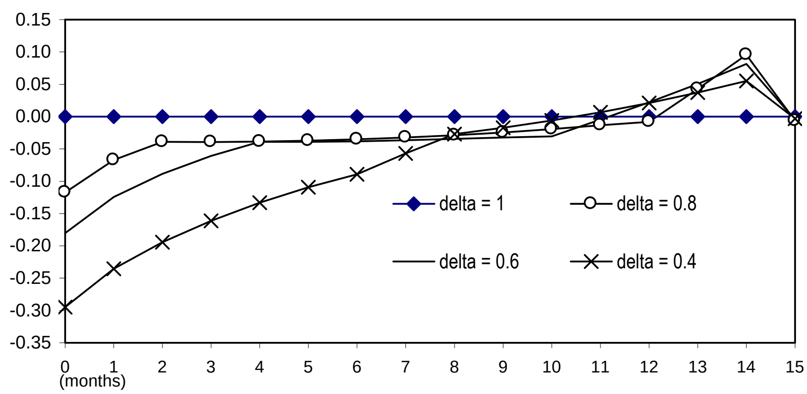
Suppose that there is an unexpected increase in households' income at $t-1$, and that the relative price $p_{j,t}(h^t)$ is constant, then the first order conditions derived from the utility function (2) gives us the following relations:

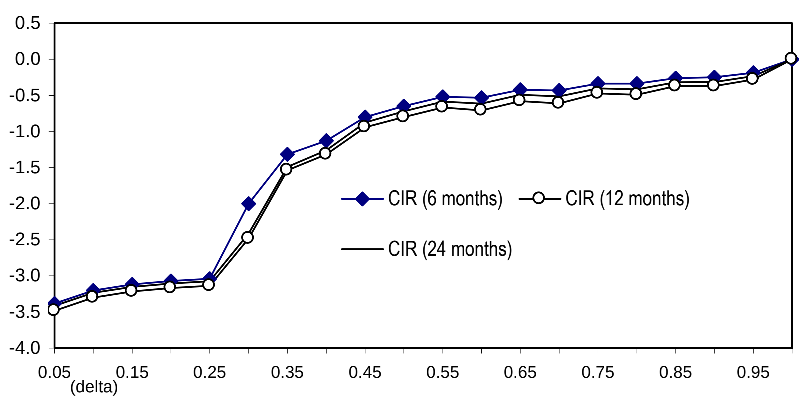
$$\tilde{c}_j\left(s,h^t\right)=\frac{\tilde{k}_j\left(s,h^t\right)}{\delta_j}>\tilde{k}_j\left(s,h^t\right)=\tilde{c}_1\left(s,h^t\right), \tag{19}$$

where $\tilde{x}_j(s,h^t)$ is the percentage deviation of the variable $x_j(s,h^t)$, around the non-stochastic steady state. This equation says that in a wake of positive income shock, goods $j$ is more needed by the households than the numeraire, at period $t$. A lower depreciation rate implies that goods $j$ is more preferred by the households. If a shock of an equal size but opposite sign happens, conversely, goods with lower depreciation rate is less wanted. In an economy where goods supply is unchanged, the relative price $p_{j,t}(h^t)$ varies, so as to clear the market.

As we have seen in Figure 5 above, a monetary policy shock, in our model, invokes a distributional shock across household types. While aggregate quantities of goods are unaltered by the monetary policy shock, some types of households reduce their consumption, while others increase their consumption. In our economy, households hit by a positive income shock and those hit by a negative income shock coexist.

(Figure 6)




The upper panel in Figure 6 displays IRFs of the relative price of durables $j$ over the numeraire, to a monetary policy innovation. We consider one time negative shock to money growth, by one unit, as before (monetary contraction). The IRFs are drawn for the various annual depreciation rates of goods $j$, $\delta_j$. See Appendix A for details of other parameterizations.

The figures show that the durables price drops in a monetary contraction, compared with the numeraire's price. When $\delta_j$ is unity, the relative price is unaffected by the monetary policy shock. As goods become more durable, prices decline more severely. This observation implies that the fall in demand for goods $j$ by the poor households outweighs the rise in demand for goods $j$ by rich households. The lower panel of Figure 6 reports the CIRs of the relative price of goods $j$, as a function of the depreciation rate $\delta_j$. For each $\delta_j$, the CIRs are calculated for a 6-month period, a 12-month period and a 24-month period. For all the CIRs with different time horizons, the size of the relative price decline measured by the CIRs, is larger for the goods with a smaller depreciation rate $\delta_j$.

The same pattern is observed even when we change the parameterization of the model. Table C1 in Appendix C represents the CIRs of the relative price of goods $j$ to a contractionary monetary policy innovation, for several different rates of annual depreciation. We report the CIRs for several parameterizations of money growth persistency parameter $\rho_M$, and the frequency with which the households access to their brokerage accounts, $N^{-1}$. We consider $\rho_M = 0.0$, 0.2, 0.4, 0.6, and 0.8. For $N$, we consider $N = 6$, 15 and 24. For each combination of $\rho_M$ and $N$, a reduction in depreciation rate $\delta_j$ leads to larger negativeness of the CIRs. Moreover, given the size of depreciation rate, either higher $\rho_M$ or higher $N$ implies larger negative CIRs for the relative price of goods $j$.

## 3.2 Credit goods vs Cash goods

Second, we examine the importance of cash goods vs credit goods distinction, for the price responses of the items to a monetary policy shock. Earlier works in monetary economics, such as Lucas and Stokey (1987), Ogaki (1988), Hodrick et al. (1991) and Kakkar and Ogaki (2002), consider an economy where certain types of goods are purchased only with cash, and other goods are purchased only with privately offered credit contracts.

For instance, Kakkar and Ogaki (2002) regard that non-durable consumption and food consumptions as cash goods, and Ogaki (1988) regards automobiles as credit goods.

In Aizcorbe et al. (2003), the amount of debt of U.S. families is distributed by the purpose of the debt, based on the Survey of Consumer Finances. They report that throughout the surveys in 1992, 1995, 1998 and 2001, "Home purchase" and "Vehicles" constituted about 80% of the total amount of debt of all families, while the shares of "Goods and service" and "Education" are small. Klee (2008), using grocery store scanner data, shows that households' payment substitution between cash, debit card, credit card and check is correlated with average value per item they purchase. These empirical studies are consistent with the view that certain types of goods are always credit goods, and others are always cash goods.

There are, however, other empirical studies that shed lights on the different aspect of the payment system. Empirical studies by Borzekowski et al. (2006) find the cohort effect in the consumers' choice of payment instrument. That is, the payment instrument depends on the consumers' ages. Klee (2008) also reports that choice of the payment is strongly related to demographics. This suggests that payment instruments are rather agent specific, and distinctions such as cash goods vs credit goods may be misleading. In this paper, however, we follow the presumption that cash intensiveness and credit intensiveness is goods specific characteristics.

Consider a credit goods $j$ whose $\theta_j$ is zero. $\theta_j = 0$ indicates that the goods $j$ is cash-goods. By assumption, transaction of goods $j$ are free from inflationary tax. Assuming goods $j$ only differs from the numeraire by $\theta_j$, the first order conditions associated with the numeraire and goods $j$ are reduced to:

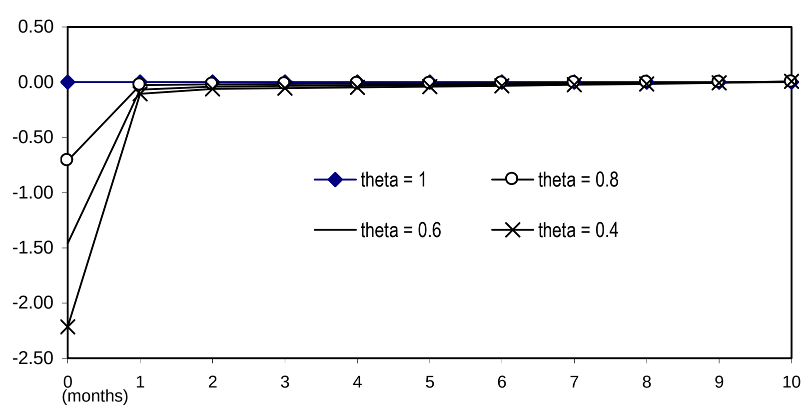
$$u_j\left(s, h^t\right) = p_{j,t}\left(h^t\right) u_1\left(0, h^t\right), \tag{20}$$

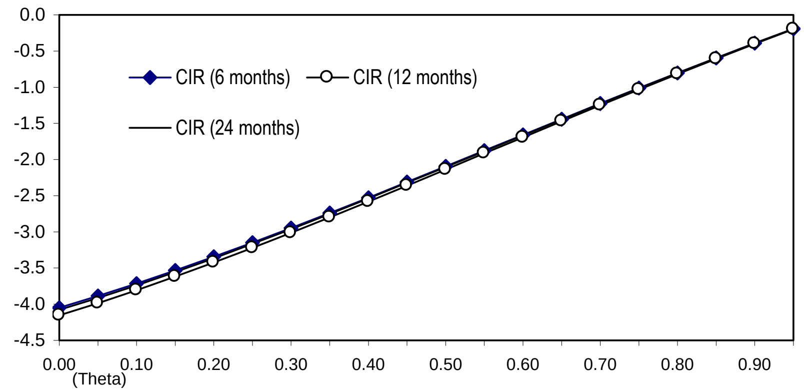
where $p_{j,t}\left(h^t\right)$ is the relative price of goods $j$ over that of the numeraire. Using the resource constraints (12), the deviation of the relative price of goods $j$ is described by the following equation:

$$\tilde{p}_{j,t}\left(h^t\right) = \phi \tilde{u}_1\left(0, h^t\right)^{-1} = \phi \tilde{c}_1\left(0, h^t\right), \tag{21}$$

where $\phi$ is a positive constant. This equation says that the relative price of goods $j$, $\tilde{p}_{j,t}\left(h^t\right)$, increases one-for-one with the increase of $\tilde{u}_1\left(0, h^t\right)^{-1}$, or equivalently with $\tilde{c}_1\left(0, h^t\right)$. Note that as $\tilde{p}_{j,t}\left(h^t\right)$ reflects the households' costs of paying a dollar from their brokerage accounts, instead of from their bank accounts, the variations of the prices are associated with the variations of utility of the households of type $s = 0$. When a monetary contraction induces a shortage of money supply in the financial market, a cost of paying a dollar from the brokerage account measured by $u_1\left(0, h^t\right)$ increases. A dollar in the brokerage account becomes more precious than a dollar in the bank account, and households avoid purchasing goods that are linked to the reduction of a dollar from the brokerage account. A monetary contraction leads to a decline in demand for credit goods $j$, for all the types of households. The relative price $\tilde{p}_{j,t}\left(h^t\right)$ then drops to clear the market.

(Figure 7)






The upper panel in Figure 7 displays IRFs of the relative price of credit goods $j$ over the numeraire goods, to a contractionary monetary policy shock for the various $\theta_j$. We consider the same monetary policy shock as in the previous section. Compared with the numeraire's price, the credit goods' price declines in a monetary contraction. As goods become less cash intensive, the price declines are more severe.

The lower panel of Figure 7 reports the CIRs, as a function of the size of $\theta_j$. For each $\theta_j$, the CIRs for 6-month period, 12-month period and 24-month period are plotted. For all CIRs with different time horizons, the size of the relative price decline measured by the CIRs, is larger for the goods with smaller $\theta_j$.

The role of $\theta_j$ in determining the relative price responses to a monetary policy innovation is unchanged in an economy where the environments are altered. Table C2 in Appendix C shows the CIRs of the relative price of goods $j$ to a contractionary monetary policy shocks, for several different degrees of cash intensity. As before, we report the CIRs for several parameterizations of $\rho_M$, and $N$. For each combination of $\rho_M$ and $N$, a reduction in cash intensity $\theta_j$ leads to larger negativeness of the CIRs. Moreover, given the level of cash intensity, either a higher $\rho_M$ or a higher $N$ implies more negative CIRs of the relative price of goods $j$.

## 3.3 Luxuries vs Necessities

The third characteristic we consider is the distinction between luxuries and necessities. Following Bils and Klenow (1998), the luxuriousness in our model is captured by the parameter $\sigma_j$ in addilog utility functions (2), where a higher $\sigma_j$ corresponds to necessities. Consider a goods $j$ with $\sigma_j$, that only differs from the numeraire by the income elasticity. That is, both $\delta_j$ and $\theta_j$ are unity. In this specification, the user cost equation for the goods $j$ and the numeraire is expressed as:

$$u_j\left(s, h^t\right) = p_{j,t}\left(h^t\right) u_1\left(s, h^t\right), \tag{22}$$

where $p_{j,t}\left(h^t\right)$ is the relative price of the goods $j$ with respect to the numeraire. Bils and Klenow (1998) argue that assuming that the relative price change $p_{j,t}$ is unchanged, luxury is preferred to the numeraire when the households receive an unexpected positive income shock. (22) with our utility function (1) yields:

$$\tilde{c}_{j,t}\left(s,h^{t}\right)=\frac{1}{\sigma_{j}}\tilde{c}_{1,t}\left(s,h^{t}\right). \tag{23}$$

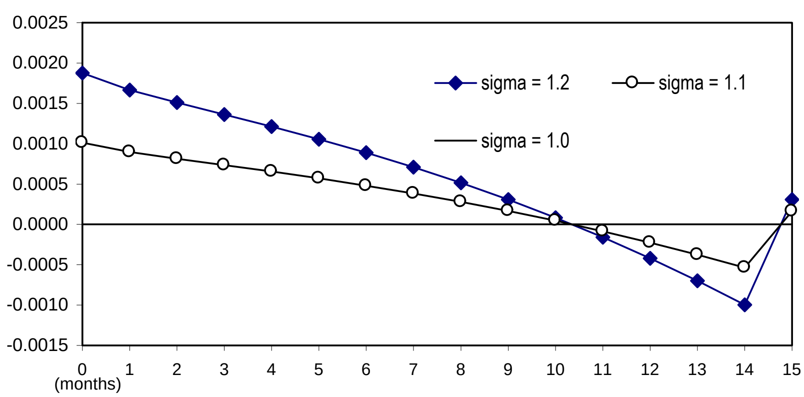
That is, given a change in consumption of the numeraire denoted by $\tilde{c}_{1,t}$, the demand for goods $j$ increases by $\tilde{c}_{1,t}\sigma_j^{-1}$. Note that $\sigma_j > 0$ indicates that goods $j$ consumption $\tilde{c}_{j,t}\left(s,h^{t}\right)$ and $\tilde{c}_{1,t}\left(s,h^{t}\right)$ co-move upon an income shock, and that $\sigma_j$ affects the relative size of $\tilde{c}_{j,t}\left(s,h^{t}\right)$, with respect to $\tilde{c}_{1,t}\left(s,h^{t}\right)$. Higher (lower) $\sigma_j$ implies that goods $j$ is less (more) demanded by the household of type $s$, compared with the numeraire, in a wake of positive income shock. As we have discussed above, in our specification, $p_{j,t}\left(h^{t}\right)$ clears the markets for both goods $j$ and the numeraire at the equilibrium.

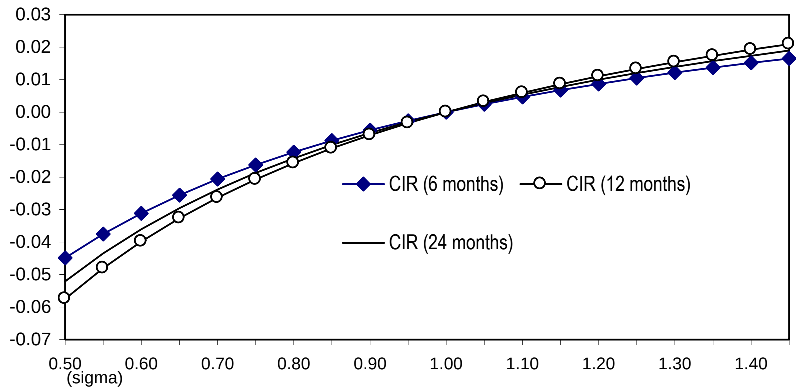
Using the resource constraints (12), the deviation of the relative price of goods $j$ is described by the following equation:

$$\tilde{p}_{j,t}=\left(\sum_{s=0}^{N-1}\bar{c}_{1}(s)^{\frac{1}{\sigma_{j}}}\right)^{-1}\sum_{s=0}^{N-1}\bar{c}_{1}(s)^{\frac{1}{\sigma_{j}}}\tilde{c}_{1,t}(s). \tag{24}$$

This equation indicates that the relative price of goods $j$, $\tilde{p}_{j,t}\left(h^{t}\right)$, is determined by the linear combination of $\tilde{c}_{1,t}(s,h^{t})$ for $s=0,...,N-1$. If all agents in an economy reduce their expenditures in a monetary contraction, (23) indicates that the demands toward luxury lessen more, compared with those toward the numeraire. Then the price of goods with lower $\sigma_j$ should decline quicker than the numeraire to clear the market. As we have seen in the previous sections, however, the signs of the income shocks to each households are not the same. The size and the sign of the relative price changes, $\tilde{p}_{j,t}(h^{t})$, after a monetary policy shock, are dependent on both how each types of the households respond to the shock, and the relative significance of the household, $\left(\sum_{s=0}^{N-1}\bar{c}_{1}(s)^{\frac{1}{\sigma_{j}}}\right)^{-1}\bar{c}_{1}(s)^{\frac{1}{\sigma_{j}}}$.

(Figure 8)






The upper panel in Figure 8 displays the IRFs of the relative price of goods $j$ over the numeraire, to a contractionary monetary policy shock for the various $\sigma_j \geq 1$. We consider the same monetary policy shock as in the previous sections. Compared with the numeraire's price, the price of necessities rises in a monetary contraction. As goods becomes more luxurious, that is as $\sigma_j$ approaches unity, the rise in the relative price gets smaller.

The lower panel of Figure 8 reports the CIRs of the relative price of goods $j$, as a function of the income elasticity parameter $\sigma_j$. For each $\sigma_j$, the CIRs for 6-month period, 12-month period and 24-month period are plotted. For all CIRs with different time horizons, the size of the relative price decline, measured by the CIRs, is larger for the goods with smaller $\sigma_j$. If $\sigma_j$ is smaller than unity, the goods are luxurious, and the relative prices decline upon the shock. For goods with $\sigma_j$ greater than unity (necessity), the relative price rises, upon the same shock.

Similarly to the experiments conducted in the previous sections, we test the robustness of this pattern, using various other parameterizations. Table C3 in Appendix C shows the CIRs of the relative price of goods $j$, to contractionary monetary policy shocks, for several different values of income elasticity parameter. As we did before, we report the CIRs for several parameterizations for $\rho_M$ and $N$. For each combination of $\rho_M$ and $N$, a reduction in income elasticity parameter $\sigma_j$ leads to larger negativeness in CIRs. Moreover, for a given size of $\sigma_j$, either a higher $\rho_M$ or a higher $N$ implies more negative CIRs for the relative price of goods $j$.

# 4 Empirical evaluation

In this section, we empirically investigate the link between the responses of relative prices to a monetary policy shock and the goods' characteristics. We test our model using two econometric procedures: a measure of the monetary policy innovation developed in Romer and Romer (2004), and the factor-augmented VAR proposed in Bernanke et al. (2005). See Appendix B for details.

Mapping from the relative price responses of specific goods to a monetary policy shock to the goods' characteristics requires rich knowledge about the goods' characteristics, such as the size of $\delta_j$, $\sigma_j$ and $\theta_j$ of the goods. In the empirical analysis below, most of these goods-specific parameters are taken from the previous studies, especially from Bils and Klenow (1998). They report two series of goods-specific parameters, that are directly related to $\delta_j$ and $\sigma_j$. One series is "Expected life of service time" reported for 43 consumption goods. These figures are based on an interoffice memo of a major property-casualty insurance company and Fixed Reproducible Tangible Wealth published by the Bureau of Economic Analysis. We calculate the depreciation rate $\delta_j$ of goods $j$ from the reported expected lives of goods $j$. For the items that belong to service in PCE, Bils and Klenow (1998) do not provide the associated depreciation rates. We assume that all items in Service have a unit depreciation rate. The other series that Bils and Klenow (1998) report is related to the goods' specific income elasticity $\sigma_j$. Using the panel data released from the Bureau of Labor Statistics, they estimate the goods-specific "Engel curves" for many consumption goods. Their definition of the "Engel curve" is the elasticity of expenditure on goods $j$ with respect to households' total nondurable consumption. From (23) ,this elasticity of expenditure corresponds to $\sigma_j^{-1}$ in our model. As Bils and Klenow (1998) concentrate their analysis on goods, we have limited sample data for $\sigma_j$ in which the items that belong to services are not included.

Lastly, we set the parameters for cash intensity of goods $j$, $\theta_j$, based on the premise made in Kakkar and Ogaki (2002). Following them, foods are regarded as cash goods whose $\theta_j s$ are unity in our empirical analysis. As we do not know the cash intensity for the other goods, we use dummy variable for the PCE items that belong to food, and check whether those dummies are significant in the estimation.

To see the role of goods' characteristics in determining the price responses of goods $j$, we follow Davis and Haltiwanger (2001) and Boivin et al. (2007). We first calculate impulse response functions (IRFs) for a monetary policy shock, either using the regression developed in Romer and Romer (2004) or using FAVAR, for each PCE item. We then regress the CIRs calculated for each item, on the each item's characteristic parameters, $\delta_j$, $\sigma_j$ and $\theta_j$.

We run five regressions where the dependent variable is always the CIRs of the relative prices for each goods, and the explanatory variables are each one of the goods characteristic paramters discussed earlier: depreciation rate ($LS_1$), income elasticity ($LS_2$), food dummy ($LS_3$), and frequency of price adjustment ($LS_4$). We also run a regression where all the depreciation rates, income elasticities and food dummies are included as the explanatory variables ($LS_5$). As the parameters reported in Bils and Klenow (1998) are limited to goods, the samples used in $LS_2$ and $LS_5$ include only durables and nondurable goods, while the samples used in $LS_1$, $LS_3$ and $LS_4$ include durables, nondurable goods and services (see Appendix B for details).

(Table 2)

(regression of CIRs of relative prices on goods' characteristics, CIRs estimated by Romer and Romer (2004))

| | LS (1) | LS (2) | LS (3) | LS (4) | LS (5) |
|---|---|---|---|---|---|
| (explanatory variable) | | | | | |
| **constant** | -0.11* | -0.27* | -0.07* | 0.01 | -0.29* |
| | (0.04) | (0.13) | (0.03) | (0.04) | (0.13) |
| **δ** | 0.21* | | | | 0.39 |
| | (0.05) | | | | (0.21) |
| **σ** | | 0.37* | | | 0.20* |
| | | (0.17) | | | (0.17) |
| **food dummy** | | | 0.08** | | -0.16 |
| | | | (0.06) | | (0.19) |
| **freqnency** | | | | 0.28 | |
| | | | | (0.31) | |

Figures in brankets are standard deviation, that are calculated by bootstrap.
* denotes 5% significance, and ** denotes 10% significance.

(Table 3)

(regression of CIRs of relative prices on goods' characteristics, CIRs estimated by FAVAR)

| | LS (1) | LS (2) | LS (3) | LS (4) | LS (5) |
|---|---|---|---|---|---|
| (explanatory variable) | | | | | |
| **constant** | -0.28* | -0.51* | -0.03 | 0.13 | -0.67* |
| | (0.09) | (0.25) | (0.05) | (0.06) | (0.20) |
| **δ** | 0.35* | | | | 0.50 |
| | (0.11) | | | | (0.31) |
| **σ** | | 0.57* | | | 0.30* |
| | | (0.33) | | | (0.21) |
| **food dummy** | | | -0.31 | | 0.48* |
| | | | (0.11) | | (0.26) |
| **freqnency** | | | | -0.78* | |
| | | | | (0.22) | |

Figures in brankets are standard deviation, that are calculated by bootstrap.
* denotes 5% significance, and ** denotes 10% significance.

Table 2 reports the results where a measure of Romer and Romer (2004) is used for the estimation. Table 3 reports the cases where the dependent variables (CIRs) are estimated by FAVAR. For both cases, we consider a positive innovation in Federal Fund Rate as a contractionary monetary policy shock.

As for the durability of goods $\delta$, it is noticeable from both Table 2 and Table 3, that the relative price of items that have higher durability (or equivalently, lower $\delta$) tend to descend in monetary contraction shock. Regressions in which goods and services are included in the samples ($LS_1$ and $LS_2$) yield the positive and significant coefficients for depreciation rate of items. In the regressions where items in services are excluded from the sample ($LS_5$), the coefficients become less significant (11% significance), but the estimated sign for $\delta$ is consistent with the model.

As for the income elasticity of goods $\sigma$, it is also evident that the relative price of items that have higher income elasticity (or equivalently, smaller $\sigma$) tend to descend in a monetary contraction. The sign and the significance of $\sigma$ are maintained in both specifications of the estimations ($LS_2$ and $LS_5$).

The role of the food dummy is, on the other hand, not clear from the data. The coefficient estimated by the Romer and Romer measure has the correct sign and is significant, but the coefficient estimated using FAVAR has the opposite sign. Weakness in the regressions relating the CIRs of the prices and the cash intensities lies on the fact that we do not have explicit goods specific figures for cash intensity. In addition, as we discussed above, the assumption that some goods are always purchased with cash and the others are purchased with credit may be a strong assumption.

The quantitative role of the frequency of price adjustments in determining the relative price responses of goods is also ambiguous. Along the line of the standard Keynesian model, including Carvalho (2006), higher frequency of price adjustment suggests more negativeness in the relative price responses of goods to a contractionary monetary shock. This theoretical prediction is consistent with the FAVAR estimates, but it is not so with the results by Romer and Romer (2004).

In summary, our empirical result suggests that there is a model implied relationship between the estimated relative price responses of PCE items, and the goods' characteristics parameters reported in Bils and Klenow (1998) and Kakkar and Ogaki (2002). That is, the relative prices of more durable goods and more luxurious goods tend to descend in a wake of monetary contraction. The role of cash intensity in determining the price responses of goods to a monetary policy shock is less apparent from our experiments.

# 5 Conclusion

In this paper, we provided a theoretical basis for understanding the price responses of goods to a monetary policy shock. Using an inventory-theoretic model of money demand framework, we show that the characteristics of the consumption goods are important determinants of the price dynamics of goods after a monetary policy shock. Our model implies that prices of more durable goods, more luxurious goods and less cash intensive goods descend more to a monetary contraction shock, compared with the price of the numeraire. This implication is robust to the various parameterizations of the model, such as the persistency of the money growth rate, and the frequency of asset rebalancing for households.

We estimate the relative price responses of goods to a monetary policy shock, using the monetary policy shock measure provided in Romer and Romer (2004), and FAVAR developed in Bernanke et al (2005). We examine whether the estimates of those relative prices are statistically related to the goods specific parameters of durability, luxuriousness and the cash intensity of goods that are reported in Bils and Klenow (1998) and Ogaki and Kakkar (2002). In terms of durability and luxuriousness, both Romer and Romer (2004) and FAVAR yield the pattern of relative price responses that are consistent with our model. We, however, do not find an empirical evidence that relative prices of credit goods fall following a monetary policy shock. One interpretation of this observation may be that the payment instruments are rather agent specific, and not goods specific.

## Appendix A: Parameters for calibration

In Section 2.3, we simulate our model using a two-sector specification. A two-sector model where an economy is composed of a non-durables sector and a durables sector is analyzed in the previous literature, such as Erceg and Levin (2006) and Barsky et al. (2007). The non-durable sector is numbered as one, and the durables sector is numbered as two. The simulation is conducted monthly. The parameters used for the simulations are;

Parameters

| Parameter | Value | Description |
|---|---|---|
| $N$ | 15 | Period of the cycle |
| $\beta$ | 0.962 | Discount factor |
| $\sigma_1$ | 1.00 | Intertemporal elasticity of substitution of numeraire |
| $\sigma_2$ | 1.00 | Intertemporal elasticity of substitution of durables |
| $\alpha$ | 0.2 | Durable share parameter |
| $\delta$ | .22 | Depreciation of durables |
| $\gamma_1$ | 0.6 | Ratio endowed to banking account |
| $\gamma_2$ | 0.6 | Ratio endowed to banking account |
| $\overline{\mu}$ | 1.05 | Mean of money growth |
| $\rho_\mu$ | 0.00 | Persistence of money growth shock |
| $\sigma_\mu$ | 1 | s.d. of money growth innovation |

The parameters, $N, \sigma_1, \sigma_2, \gamma_1, \gamma_2, \bar{\mu}, \rho_\mu, \sigma_\mu$ are taken from Alvarez et al. (2003). $\alpha$ corresponds to the steady state share of the durables goods, and is set to be the long-run average nominal expenditure share of durable (relative to total consumption), which is around 0.2 in the US. For the annual depreciation rate, we follow the specification of Baxter (1996).

## Appendix B: Description of the data

### Price series

The disaggregated price data used in the current paper are the monthly series of personal consumption expenditures (price indexes and nominal expenditure). Data are seasonally adjusted. All item series are normalized by the price index of the aggregate non-durables, which we constructed from the nondurable goods series and the services series of PCE, using a Tornqvist approximation (see Welan (2000)).

In each regression above, we drop some of the items for the following reasons.

In estimating the regressions where the frequencies of price adjustments of goods are involved, we disregard some of the samples because of the difficulties of relating the price indices of the PCE items to their frequencies, reported in Nakamura and Steinsson (2007). Among the PCE items in 2003, although most of the items are deflated by the consumer price indices (CPI), some items are deflated by the producer price indices (PPI) (e.g., proprietary hospitals) or other price measure (e.g., clubs & fraternal organizations). In addition, there are items that are deflated by the CPI but by broader categories of the CPI than the item stratum (e.g., casino gambling). We exclude the items of the PCE that are not deflated by the CPI, and the items that are deflated by broader categories than Major Group, CPI. These procedures reduce the number of sample items that are for our regressions to 134.

Table 2 and Table 3 report regression of the CIRs on the depreciation rates. Our depreciation series is based on Bils and Klenow (1998). Because of the lack of correspondence, we drop 12 items from the 134 items. For the same reason, the number of the sample in $LS_2$ and $LS_5$ is limited to 39.

**Frequency of price adjustment**

Figures for the frequency of price adjustment are taken from Nakamura and Steinsson (2007). All the estimates reported in our paper refer to the frequency of price change by category for 1998-2005 in Nakamura and Steinsson (2007). These series include sales. Their frequency data are constructed for Entry Level Item (ELI) category, while each item's stratum in PCE covers one or more ELIs. We average the reported frequencies for each ELI with its weight reported in Nakamura and Steinsson (2007), to yield frequencies of the CPI item stratum. The matching between ELI and CPI item stratum is done, using the BLS Handbook of Methods, released by the Bureau of Labor Statistics.

**Sample period**

The data sample period for the all estimations in the current paper is from January 1976 to December 1996. The initial period of the samples used in Boivin et al (2007) is January 1976, and the measure of Romer and Romer (2004) is available from January 1969 to December 1996. The length of our sample period is thus chosen so that the samples of the disaggregated price series are the same for both estimations, FAVAR and the estimation using the measure of Romer and Romer (2004).

**Calculating IRFs of disaggregated relative prices using Romer and Romer (2004)**

The IRFs of relative prices are estimated using the two measures of monetary policy innovations mentioned above. In estimating the IRFs using the measure of monetary policy shocks developed by Romer and Romer (2004), we use the following regression for each of the relative prices, based on Romer and Romer (2004):

$$\Delta p_{j,t}(j) = c_0 + \sum_{i=1}^{24} \beta_i \Delta p_{j,t-i}(j) + \sum_{i=1}^{48} c_i \Delta S_{t-i} + e_t, \tag{25}$$

where $\Delta p_{j,t}(j)$ is the log-difference of each of the disaggregated relative price index of goods $j$, and $c_0, \beta_i$ and $c_i$ are the estimated parameters of the explanatory variables. $S_t$ is the monetary policy shock provided in Romer and Romer (2004).

**Calculating IRFs of disaggregated relative prices using FAVAR**

In estimating the IRFs using the FAVAR methodology, we need to specify a panel of economic indicators, to estimate common factors. In Bernanke et al. (2005), the panel contains 120 macroeconomic variables. In addition to the variables employed in Bernanke et al. (2005), we add 194 real personal consumption expenditure series, 154 producer price indices and 194 relative price series of personal consumption expenditure series. They are transformed to the stationary series by taking the first difference of their logarithms.

## 5.1 Appendix C: Robustness tests

(Table C1) Cumulative Response Functions after a Monetary Policy Shock and Depreciation Rate

| persistency of money | depreciation rate | N = 6 | | N = 15 | | N = 24 | |
|---|---|---|---|---|---|---|---|
| | | 12 months | 24 months | 12 months | 24 months | 12 months | 24 months |
| 0.0 | 0.1 | -1.54 | -1.55 | -3.30 | -3.24 | -4.73 | -4.57 |
| | 0.2 | -1.51 | -1.51 | -3.17 | -3.10 | -4.50 | -4.35 |
| | 0.3 | -1.49 | -1.50 | -2.48 | -2.41 | -2.09 | -2.06 |
| | 0.4 | -1.49 | -1.49 | -1.32 | -1.26 | -1.12 | -1.07 |
| | 0.5 | -0.69 | -0.70 | -0.80 | -0.72 | -0.94 | -0.89 |
| | 0.6 | -0.41 | -0.41 | -0.71 | -0.61 | -0.77 | -0.73 |
| | 0.7 | -0.19 | -0.19 | -0.61 | -0.51 | -0.63 | -0.58 |
| | 0.8 | -0.20 | -0.21 | -0.49 | -0.42 | -0.55 | -0.52 |
| | 0.9 | -0.03 | -0.03 | -0.37 | -0.32 | -0.44 | -0.42 |
| | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.2 | 0.1 | -2.01 | -2.02 | -4.23 | -4.14 | -5.98 | -5.83 |
| | 0.2 | -1.97 | -1.97 | -4.06 | -3.97 | -5.69 | -5.55 |
| | 0.3 | -1.95 | -1.96 | -3.17 | -3.08 | -2.67 | -2.67 |
| | 0.4 | -1.94 | -1.95 | -1.72 | -1.65 | -1.46 | -1.43 |
| | 0.5 | -0.92 | -0.92 | -1.07 | -0.97 | -1.24 | -1.22 |
| | 0.6 | -0.56 | -0.57 | -0.96 | -0.84 | -1.03 | -1.03 |
| | 0.7 | -0.28 | -0.28 | -0.84 | -0.72 | -0.86 | -0.84 |
| | 0.8 | -0.30 | -0.30 | -0.68 | -0.59 | -0.75 | -0.75 |
| | 0.9 | -0.05 | -0.06 | -0.52 | -0.45 | -0.60 | -0.62 |
| | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.4 | 0.1 | -2.84 | -2.85 | -5.85 | -5.72 | -8.14 | -8.01 |
| | 0.2 | -2.79 | -2.80 | -5.62 | -5.50 | -7.75 | -7.64 |
| | 0.3 | -2.77 | -2.77 | -4.38 | -4.26 | -3.69 | -3.76 |
| | 0.4 | -2.76 | -2.76 | -2.45 | -2.34 | -2.09 | -2.12 |
| | 0.5 | -1.33 | -1.33 | -1.57 | -1.44 | -1.79 | -1.86 |
| | 0.6 | -0.84 | -0.84 | -1.42 | -1.27 | -1.52 | -1.59 |
| | 0.7 | -0.43 | -0.43 | -1.24 | -1.10 | -1.27 | -1.33 |
| | 0.8 | -0.47 | -0.47 | -1.03 | -0.91 | -1.11 | -1.18 |
| | 0.9 | -0.11 | -0.11 | -0.78 | -0.69 | -0.87 | -0.96 |
| | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.6 | 0.1 | -4.62 | -4.64 | -9.30 | -9.15 | -12.62 | -12.71 |
| | 0.2 | -4.55 | -4.57 | -8.97 | -8.82 | -12.04 | -12.13 |
| | 0.3 | -4.52 | -4.54 | -6.96 | -6.82 | -5.87 | -6.22 |
| | 0.4 | -4.51 | -4.52 | -4.08 | -3.92 | -3.49 | -3.75 |
| | 0.5 | -2.20 | -2.20 | -2.69 | -2.50 | -3.04 | -3.38 |
| | 0.6 | -1.41 | -1.41 | -2.44 | -2.24 | -2.60 | -2.94 |
| | 0.7 | -0.75 | -0.74 | -2.13 | -1.95 | -2.16 | -2.45 |
| | 0.8 | -0.83 | -0.83 | -1.75 | -1.62 | -1.86 | -2.17 |
| | 0.9 | -0.26 | -0.26 | -1.33 | -1.22 | -1.46 | -1.75 |
| | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.8 | 0.1 | -9.71 | -10.38 | -19.69 | -21.00 | -25.80 | -28.71 |
| | 0.2 | -9.61 | -10.28 | -19.09 | -20.36 | -24.70 | -27.52 |
| | 0.3 | -9.57 | -10.24 | -15.15 | -15.78 | -13.11 | -15.18 |
| | 0.4 | -9.55 | -10.22 | -9.39 | -9.61 | -8.29 | -9.92 |
| | 0.5 | -4.97 | -5.12 | -6.31 | -6.41 | -7.27 | -9.06 |
| | 0.6 | -3.34 | -3.45 | -5.71 | -5.85 | -6.19 | -7.93 |
| | 0.7 | -2.00 | -2.08 | -4.97 | -5.15 | -5.09 | -6.62 |
| | 0.8 | -2.15 | -2.26 | -4.11 | -4.31 | -4.34 | -5.80 |
| | 0.9 | -1.03 | -1.10 | -3.12 | -3.30 | -3.36 | -4.65 |
| | 1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

(Table C2) Cumulative Response Functions after a Monetary Policy Shock and Cash Intensity

| persistency of money | cash intensity | N = 6 | | N = 15 | | N = 24 | |
|---|---|---|---|---|---|---|---|
| | | 12 months | 24 months | 12 months | 24 months | 12 months | 24 months |
| 0.0 | 0.0 | -1.77 | -1.77 | -4.15 | -4.08 | -6.24 | -6.02 |
| | 0.1 | -1.62 | -1.63 | -3.81 | -3.74 | -5.70 | -5.51 |
| | 0.2 | -1.47 | -1.47 | -3.42 | -3.36 | -5.11 | -4.94 |
| | 0.3 | -1.30 | -1.30 | -3.01 | -2.96 | -4.48 | -4.33 |
| | 0.4 | -1.12 | -1.12 | -2.58 | -2.54 | -3.83 | -3.70 |
| | 0.5 | -0.93 | -0.93 | -2.14 | -2.10 | -3.16 | -3.05 |
| | 0.6 | -0.74 | -0.74 | -1.69 | -1.67 | -2.49 | -2.41 |
| | 0.7 | -0.55 | -0.55 | -1.25 | -1.23 | -1.83 | -1.77 |
| | 0.8 | -0.36 | -0.36 | -0.82 | -0.80 | -1.19 | -1.15 |
| | 0.9 | -0.18 | -0.18 | -0.40 | -0.39 | -0.58 | -0.56 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.2 | 0.0 | -2.28 | -2.29 | -5.29 | -5.19 | -7.87 | -7.65 |
| | 0.1 | -2.10 | -2.10 | -4.85 | -4.76 | -7.20 | -6.99 |
| | 0.2 | -1.89 | -1.90 | -4.36 | -4.28 | -6.45 | -6.27 |
| | 0.3 | -1.67 | -1.67 | -3.84 | -3.77 | -5.66 | -5.49 |
| | 0.4 | -1.44 | -1.44 | -3.29 | -3.23 | -4.83 | -4.69 |
| | 0.5 | -1.20 | -1.20 | -2.72 | -2.68 | -3.99 | -3.87 |
| | 0.6 | -0.95 | -0.95 | -2.16 | -2.12 | -3.14 | -3.05 |
| | 0.7 | -0.71 | -0.71 | -1.59 | -1.57 | -2.31 | -2.25 |
| | 0.8 | -0.46 | -0.46 | -1.04 | -1.02 | -1.51 | -1.47 |
| | 0.9 | -0.23 | -0.23 | -0.51 | -0.50 | -0.73 | -0.71 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.4 | 0.0 | -3.18 | -3.18 | -7.27 | -7.12 | -10.66 | -10.46 |
| | 0.1 | -2.91 | -2.92 | -6.66 | -6.52 | -9.74 | -9.56 |
| | 0.2 | -2.63 | -2.63 | -5.98 | -5.87 | -8.73 | -8.56 |
| | 0.3 | -2.32 | -2.32 | -5.26 | -5.16 | -7.65 | -7.50 |
| | 0.4 | -1.99 | -2.00 | -4.51 | -4.42 | -6.53 | -6.41 |
| | 0.5 | -1.66 | -1.66 | -3.73 | -3.66 | -5.39 | -5.29 |
| | 0.6 | -1.32 | -1.32 | -2.95 | -2.90 | -4.25 | -4.17 |
| | 0.7 | -0.98 | -0.98 | -2.18 | -2.14 | -3.13 | -3.07 |
| | 0.8 | -0.64 | -0.65 | -1.43 | -1.40 | -2.04 | -2.00 |
| | 0.9 | -0.32 | -0.32 | -0.70 | -0.69 | -0.99 | -0.98 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.6 | 0.0 | -5.06 | -5.07 | -11.42 | -11.23 | -16.40 | -16.43 |
| | 0.1 | -4.62 | -4.64 | -10.44 | -10.27 | -14.97 | -14.98 |
| | 0.2 | -4.15 | -4.17 | -9.37 | -9.23 | -13.41 | -13.42 |
| | 0.3 | -3.66 | -3.67 | -8.24 | -8.11 | -11.76 | -11.75 |
| | 0.4 | -3.14 | -3.15 | -7.05 | -6.95 | -10.04 | -10.03 |
| | 0.5 | -2.62 | -2.62 | -5.84 | -5.76 | -8.29 | -8.28 |
| | 0.6 | -2.08 | -2.09 | -4.63 | -4.56 | -6.54 | -6.53 |
| | 0.7 | -1.55 | -1.55 | -3.42 | -3.37 | -4.81 | -4.81 |
| | 0.8 | -1.02 | -1.02 | -2.24 | -2.21 | -3.14 | -3.13 |
| | 0.9 | -0.50 | -0.50 | -1.10 | -1.08 | -1.53 | -1.53 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.8 | 0.0 | -10.28 | -10.98 | -23.41 | -24.88 | -32.77 | -36.15 |
| | 0.1 | -9.34 | -9.98 | -21.33 | -22.67 | -29.87 | -32.90 |
| | 0.2 | -8.36 | -8.92 | -19.11 | -20.30 | -26.73 | -29.39 |
| | 0.3 | -7.34 | -7.83 | -16.77 | -17.81 | -23.41 | -25.71 |
| | 0.4 | -6.30 | -6.72 | -14.35 | -15.24 | -19.98 | -21.93 |
| | 0.5 | -5.24 | -5.59 | -11.89 | -12.63 | -16.50 | -18.09 |
| | 0.6 | -4.17 | -4.45 | -9.42 | -10.01 | -13.03 | -14.27 |
| | 0.7 | -3.11 | -3.32 | -6.98 | -7.41 | -9.61 | -10.52 |
| | 0.8 | -2.05 | -2.19 | -4.58 | -4.86 | -6.28 | -6.87 |
| | 0.9 | -1.02 | -1.09 | -2.25 | -2.39 | -3.07 | -3.35 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

(Table C3) Cumulative Response Functions after a Monetary Policy Shock and Income Elasticity

| persistency of money | Income Elasticity | N = 6 | | N = 15 | | N = 24 | |
|---|---|---|---|---|---|---|---|
| | | 12 months | 24 months | 12 months | 24 months | 12 months | 24 months |
| 0.0 | 0.5 | -0.02 | -0.04 | -0.06 | -0.05 | -0.12 | -0.11 |
| | 0.6 | -0.01 | -0.03 | -0.04 | -0.04 | -0.08 | -0.08 |
| | 0.7 | -0.01 | -0.02 | -0.03 | -0.02 | -0.06 | -0.05 |
| | 0.8 | -0.01 | -0.01 | -0.02 | -0.01 | -0.03 | -0.03 |
| | 0.9 | 0.00 | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.1 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 |
| | 1.2 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| | 1.3 | 0.00 | 0.01 | 0.02 | 0.01 | 0.03 | 0.03 |
| | 1.4 | 0.01 | 0.02 | 0.02 | 0.02 | 0.04 | 0.04 |
| | 1.5 | 0.01 | 0.02 | 0.02 | 0.02 | 0.05 | 0.04 |
| 0.2 | 0.5 | -0.02 | -0.06 | -0.07 | -0.07 | -0.15 | -0.14 |
| | 0.6 | -0.01 | -0.04 | -0.05 | -0.05 | -0.10 | -0.10 |
| | 0.7 | -0.01 | -0.03 | -0.03 | -0.03 | -0.07 | -0.07 |
| | 0.8 | -0.01 | -0.02 | -0.02 | -0.02 | -0.04 | -0.04 |
| | 0.9 | 0.00 | -0.01 | -0.01 | -0.01 | -0.02 | -0.02 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.1 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 |
| | 1.2 | 0.00 | 0.01 | 0.01 | 0.01 | 0.03 | 0.03 |
| | 1.3 | 0.01 | 0.01 | 0.02 | 0.02 | 0.04 | 0.04 |
| | 1.4 | 0.01 | 0.02 | 0.02 | 0.02 | 0.05 | 0.05 |
| | 1.5 | 0.01 | 0.02 | 0.03 | 0.03 | 0.06 | 0.06 |
| 0.4 | 0.5 | -0.02 | -0.07 | -0.10 | -0.09 | -0.20 | -0.20 |
| | 0.6 | -0.02 | -0.05 | -0.07 | -0.06 | -0.14 | -0.14 |
| | 0.7 | -0.01 | -0.03 | -0.05 | -0.04 | -0.09 | -0.09 |
| | 0.8 | -0.01 | -0.02 | -0.03 | -0.02 | -0.06 | -0.05 |
| | 0.9 | 0.00 | -0.01 | -0.01 | -0.01 | -0.02 | -0.02 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.1 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| | 1.2 | 0.00 | 0.01 | 0.02 | 0.02 | 0.04 | 0.04 |
| | 1.3 | 0.01 | 0.02 | 0.03 | 0.02 | 0.05 | 0.05 |
| | 1.4 | 0.01 | 0.02 | 0.03 | 0.03 | 0.07 | 0.07 |
| | 1.5 | 0.01 | 0.03 | 0.04 | 0.04 | 0.08 | 0.08 |
| 0.6 | 0.5 | -0.03 | -0.10 | -0.16 | -0.15 | -0.30 | -0.33 |
| | 0.6 | -0.02 | -0.07 | -0.11 | -0.10 | -0.21 | -0.23 |
| | 0.7 | -0.01 | -0.05 | -0.07 | -0.07 | -0.14 | -0.15 |
| | 0.8 | -0.01 | -0.03 | -0.04 | -0.04 | -0.08 | -0.09 |
| | 0.9 | 0.00 | -0.01 | -0.02 | -0.02 | -0.04 | -0.04 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.1 | 0.00 | 0.01 | 0.02 | 0.01 | 0.03 | 0.03 |
| | 1.2 | 0.01 | 0.02 | 0.03 | 0.03 | 0.06 | 0.06 |
| | 1.3 | 0.01 | 0.03 | 0.04 | 0.04 | 0.08 | 0.09 |
| | 1.4 | 0.01 | 0.03 | 0.05 | 0.05 | 0.10 | 0.11 |
| | 1.5 | 0.01 | 0.04 | 0.06 | 0.06 | 0.12 | 0.13 |
| 0.8 | 0.5 | -0.04 | -0.16 | -0.30 | -0.32 | -0.54 | -0.74 |
| | 0.6 | -0.03 | -0.11 | -0.21 | -0.22 | -0.37 | -0.51 |
| | 0.7 | -0.02 | -0.07 | -0.13 | -0.14 | -0.25 | -0.33 |
| | 0.8 | -0.01 | -0.04 | -0.08 | -0.09 | -0.15 | -0.20 |
| | 0.9 | 0.00 | -0.02 | -0.04 | -0.04 | -0.07 | -0.09 |
| | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1.1 | 0.00 | 0.02 | 0.03 | 0.03 | 0.06 | 0.07 |
| | 1.2 | 0.01 | 0.03 | 0.06 | 0.06 | 0.10 | 0.14 |
| | 1.3 | 0.01 | 0.04 | 0.08 | 0.08 | 0.14 | 0.19 |
| | 1.4 | 0.01 | 0.05 | 0.10 | 0.10 | 0.18 | 0.24 |
| | 1.5 | 0.01 | 0.06 | 0.11 | 0.12 | 0.21 | 0.28 |

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