Persistent Relative Price Movement and Monetary Policy Shocks *

Lin Liu†

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Abstract

This paper examines the impact of an unexpected monetary policy movement in an economy with both durables and non-durables. In response to a monetary policy shock, identified by a structural Vector Auto-Regression (SVAR) model with the short-run recursive assumption, there are statistically significant and persistent shifts in relative price and relative output, with both moving in the opposite direction. This persistence can not be easily reconciled by most sticky price models. We show the key to resolve this puzzle is that the identified monetary shocks are not truly exogenous, but instead contaminated by sector-specific technology shocks. To distinguish technology shocks from monetary policy shocks, we introduce the long-run identifications à la Fisher (2006). As a result, responses of relative price and relative output in the long-run are much more dampened, and monetary effects are more front-loaded. It implies much smaller nominal frictions in a Dynamic New-Keynesian model, which are more in line with the micro-empirical evidences.

JEL Classification: E52; E32; C32.
Key Words: Monetary Policy Shocks, Persistence, Relative Price, Long-run Identification, Sector-specific Technology Shocks, New-Keynesian Model, Durables.

1 Introduction

This paper examines the impact of an unexpected monetary policy movement in an economy with both durables and non-durables. This is important for the following two reasons. One is that compared with non-durable goods and services, durables including both consumption goods and investment are more sensitive to change in interest rate and monetary policy, and often exhibit greater cyclical fluctuations. The differential monetary effects on durables and

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†Department of Economics, Harkness Hall, University of Rochester, Rochester, NY 14627, USA, Email: linliu@rochester.edu

non-durables provide us criteria for evaluating economic models and help us gauge the importance of monetary shocks in explaining the business cycle. The other reason is that when setting monetary policy, central bank closely tracks the development in non-durable and durable goods sectors.[1] Change in monetary policy reflects change in economic conditions of both sectors, which should be included in central bank's information set when deriving monetary policy shocks.[2] Therefore, in this paper we include relative price and relative output of durables and non-durables into an otherwise standard Vector Auto-Regression (VAR) framework.[3] Throughout the paper, relative price is defined as price of durables divided by price of non-durables, and relative output is defined as durable output divided by non-durable output.

The central issue of understanding monetary effects is how to identify exogenous movements in monetary policy. The most common practice in monetary economics is short-run recursive assumption (See Sims 1992, Christiano, Eichenbaum and Evans 1999, etc.).[4] With this standard specification, empirical evidence shows that responses of output and price are largely in line with the consensus view, that is, monetary shocks have transitory impact on the economy lasting for about three years. However, anomalies arise when we look at movements of relative price and relative output. In response to a contractionary monetary shock, relative price declines gradually for a couple of years, and relative output drops initially and reverts back. Six years after the shock, they remain significantly deviated from steady-states with both moving in the opposite direction. This suggests monetary shocks have large and long-running effects on the real economy, which is difficult to rationalize in a standard model setting.

[1] Before each Federal Open Market Committee (FOMC) meeting, an in-depth analysis about current economic development, officially titled "Current Economic and Financial Conditions" (Greenbook) is distributed to FOMC meeting attendees. Part II domestic non-financial development contains detailed accounts about labor market development and production across major industries, consumption expenditure in various categories, particularly retail sales for motor vehicles and housing market development etc. For more details, refer to http://www.federalreserve.gov/monetarypolicy/.

[2] The alternative way is to use factor augmented VAR, for example Bernanke, Boivin and Elizsz (2005). The advantage is that it extracts information from a large amount of time series data and derives impulse responses for variables not yet included in VAR. However, latent factors from factor analysis are not transparent and hard to interpret. Since this paper is not only interested in deriving monetary policy shocks, but other structural innovations to the variables contained in VAR, introducing the variables directly into a VAR instead of latent factors provides a clean interpretation of their structural innovations.

[3] In general, there are two approaches for estimating effects of monetary policy shocks. One is SVAR with certain identification assumptions and the other is narrative approach (Friedman and Schwartz, 1963 and Romer and Romer, 2004). In this paper, we focus on the former.

[4] The short-run recursive assumption is the most widely used identification in deriving monetary policy shocks because it can be easily applied and generates plausible impulse responses. Other identifications include short-run non-recursive assumption (Sims and Zha, 2006), sign restriction (Uhlig, 2005) and long-run restrictions in the sense that money has no persistent effects on real variables (Bernanke and Mihov, 1998).

More recently, Erceg and Levin (2006) study a related problem.[5] They look at the impact of monetary shocks on price and output for durables and non-durables, respectively. The gaps between responses, for both price and output, still persist five years after the shock, with negative relative price and positive relative output deviations from steady-states.[6] But persistent responses are not their focus in the paper. Furthermore, few papers look at differential monetary effects from other angles and a similar persistence problem is documented, though without much explanation. Bils, Klenow and Kryvtsov (2003) examine relative price between flexible-price and sticky-price goods, and find that monetary shocks have persistent effects. Boivin, Giannoni and Mihov (2009) investigate monetary effects on disaggregated prices, and find that after four years price responses do not all converge to the same level. Interestingly, Bils, Klenow and Kryvtsov (2003) also find that monetary shocks have persistent effects on relative quantities, moving in the direction opposite to responses of relative price. Boivin, Giannoni and Mihov (2009) find that sectors in which prices fall the most tend to be sectors in which quantities fall the least, that is, relative price and relative quantity tend to move in the opposite direction.[7] Note that the same identification strategy for monetary policy shocks – exclusion restriction on contemporaneous relationship, is used across all these studies.

There are two possible explanations for the estimated persistent monetary effects. One is that there are strong internal propagation mechanisms in the economy, such that even a small and transitory monetary shock can generate large and persistent effects. However, the contract multiplier required to explain the persistence here is well beyond what most sticky price models can offer, including both time-dependent (Chari, Kehoe and McGrattan 2000, Christiano, Eichenbaum and Evans 2005, etc.) and state-dependent models (Golosov and Lucas 2007, Nakamura and Steinsson 2010, etc.). This leaves us with the other possibility that the identified shocks themselves are very persistent. But if the observed persistent shifts in relative price and relative output result from a very persistent shock, the shock

[5]Barsky, House and Kimball (2003) also study the similar problem, but use Romer Date as monetary shocks. We do not touch on the endogeneity problem of Romer Date monetary shocks in this paper. However, as discussed by Leeper (1997), the identification problems that plague time series models also afflict the narrative approach.

[6]Since Erceg and Levin (2006) examine the impact of monetary shocks on price and output, we do not know whether the gap between the responses of durables and non-durables in the long-run are statistically significant or not.

[7]Bils, Klenow and Kryvtsov (2003) estimate a standard structural VAR, and use the estimated innovations as measures for monetary policy shocks. They suggest misidentification of monetary policy shocks is likely to be the reason behind the persistent relative price and relative output shift puzzle. However, they did not explore further in this direction. Boivin, Giannoni and Mihov (2009) use factor augmented VAR. To identify monetary policy shocks, they assume that federal funds rate may respond to contemporaneous fluctuations in estimated factors, but that none of the latent common components of the economy can respond within current period to unanticipated changes in monetary policy, which is the factor-augmented VAR extension of the short-run recursive restriction we use in the paper. To reconcile their results with the persistent relative price and output shift puzzle, they estimate effects on monetary shocks with additional restrictions that all responses of prices and outputs in the long-run converge to the same level. And they show that this hypothesis can not be rejected.

is unlikely to be a monetary policy shock. In other words, monetary policy shocks are misidentified. The questions we want to ask in this paper are: which shocks contaminate monetary policy shocks and are responsible for the persistent shift in relative price and relative output? What are the implications for the estimated impulse responses functions (IRFs) and variance decomposition? How this changes our understanding about the nature of frictions in the economy, as the estimated IRFs are often used as criteria for evaluating economic models?

We think supply shocks, in particular technology shocks, are more likely to be the candidate for contaminating monetary policy shocks for the following two reasons. One is that monetary shocks are usually considered to generate short-run fluctuations, while technology shocks are persistent and have much more protracted impact on the economy; and the other is that in the long-run relative price and relative output move in the opposite direction. To distinguish technology shocks from monetary shocks, we introduce the long-run identifications à la Fisher (2006). To motivate the analysis, we provide a dynamic New-Keynesian model with non-durable and durable goods sectors, similar to Barsky, House and Kimball (2007). The model features staggered price and wage contracts, such that there is a short-run money non-neutrality. It also incorporates stochastic trends subject to two technology shocks – an aggregate technology shock applying to both sectors and a sector-specific technology shock applying to durable goods sector only. The model implies that only sector-specific shocks affect relative price in the long-run, and both aggregate and sector-specific technology shocks affect output in the long-run. These provide us with the long-run restrictions needed for further disciplining monetary shocks.

With the long-run identifications for both technology shocks, two econometric approaches are explored in the paper. One approach is a modified structural Vector Auto-regression (SVAR) model. We incorporate the long-run identifications for technology shocks while largely respect the short-run identifications for monetary shocks. We only relax the short-run restrictions on relative price, such that it can respond to monetary policy shocks contemporaneously. To see how the results vary as different long-run restrictions are imposed, we experiment with three specifications – long-run identifications for sector-specific technology shocks only, for aggregate technology shocks only and for both technology shocks. The other approach is a structural Vector Error-Correction model (SVECM), initially proposed by King, Plosser, Stock and Watson (1991). The advantage is that it explicitly separates innovations to short-run fluctuations (transitory shocks) from innovations to long-run trends (permanent shocks), and few identifying restrictions are required. As suggested by the theory and confirmed with co-integration test, there are three stochastic trends subject to three permanent shocks – aggregate technology shocks, sector-specific shocks and nominal permanent shocks. Following Gali (1992), where monetary policy shocks (innovations to federal funds rate) are shown to generate long-run movement of price level and monetary aggregate, we consider them as nominal permanent shocks. With long-run restrictions, three permanent shocks can be identified, and no short-run identifying assumptions are needed.

The impulse responses and variance decomposition for monetary shocks estimated with additional long-run restrictions are different from those with standard specification in the following ways. First, responses of relative price and relative output in the long-run are much more dampened, and monetary shocks do not have persistent effects on real variables. In particular, we find that sector-specific shocks are responsible for persistent relative price shift. With a monetary contraction, relative output drops and then reverts back to steady-state. And responses of relative price are small and insignificant. Second, monetary effects on output are more front-loaded, especially with SVECM estimation. Output reaches the trough after two quarters, compared with one-and-half years in the standard specification. Third, responses of price level depend on the assumption about whether monetary shocks are transitory or permanent. Fourth, monetary shocks account for small fluctuations of real variables, especially in the long-run. Either they are negligible throughout all the horizons, or they play a large role in the first couple of years with the importance declining over time. In contrast, with the standard specification monetary shocks play an increasingly larger role in explaining forecast error variance. Therefore, the empirically observed large and persistent monetary effects are a result of misidentification and monetary policy shocks are contaminated by technology shocks.

King, Plosser, Stock and Watson (1991) point out transient economic fluctuations can arise as responses to change in long-run factors, in particular technological improvements, rather than short-run factors, e.g. monetary policy shocks.[8] So short-run fluctuations and shifts in long-run trends are closely related. This paper demonstrates that with an identification for short-run factors relying solely on contemporaneous relationship, they can easily be corrupted by long-run factors. Instead of identifying short-run factors, it picks up a combination of both short-run and long-run factors.[9] As a result, the estimated impulse responses of short-run factors display large and persistent effects, which are in fact generated by long-run factors. Many studies also find that monetary policy change may induce drawn-out responses in output and other real variables, because monetary shocks are not truly exogenous for various other reasons. For example, Cochrane (1998) shows that output responses to money innovations in a VAR context is puzzlingly protracted, and suggests anticipated as well as unanticipated changes in money may affect output. Bernanke and Mihov (1998) find that the explanation for a protracted response of output is that the broad measures of money contain an endogenous non-policy component. This paper is also related to a large number of literature on the monetary SVAR analysis, with some of those suggesting SVAR

[8]For fluctuations of real economic variables, money policy shocks are considered to be short-run factors since they only have transient impact on the economy. This is what we mean here. In the SVECM estimation, monetary policy shocks are treated as nominal permanent shocks or long-run factors, because they may affect price level and monetary aggregate in the long-run, but not real variables. Thus, the fact that monetary policy shocks are treated as short-run factors here is not inconsistent with the SVECM estimation.

[9]In this paper, we do not delve into the reasons for misidentification. The possible reasons are misspecification, incorrect identifying assumption, finite sample, etc.

to be misspecified.[10]

One of the reasons that we are interested in investigating effects of monetary shocks is that the responses can be used as matching moments to estimate structural parameters and evaluate economic models. We examine how the estimated parameter values in a dynamic New-Keynesian model vary, when the IRFs generated from different identification strategies are used for the targets. We find that the more persistent the estimated monetary effects are, the larger the model implied nominal stickiness. For example, with the standard short-run specification the average duration of staggered price contract for non-durables is 20 quarters, while with SVECM estimation the average duration of staggered price and wage contracts are less than 3 quarters. Moreover, since both wage stickiness and price stickiness with adjustment cost can generate persistence in output, examining differential monetary effects between durables and non-durables is the key for us to discriminate between the competing models. With the IRFs derived with standard short-run specifications, the estimates suggest the frictions in the economy fall mostly on price stickiness and adjustment cost. In contrast, with the IRFs derived with additional long-run restrictions, the estimates imply that the frictions mainly come from wage stickiness. This is consistent with Christiano, Eichenbaum and Evans (2005), but for different reasons. They suggest staggered wage contract is important because it accounts for inflation inertia. We provide additional piece of evidence for the importance of wage stickiness, as it explains the relative movement between durables and non-durables. Our paper is also related to Barsky, House and Kimball (2003) and Carlstrom and Fuerst (2006), which explore wage stickiness to resolve the co-movement puzzle between durables and non-durables.[11]

The paper is organized as follows: Section 2 presents the empirical puzzle; Section 3 investigates a dynamic New-Keynesian model and provides long-run identifications; Section 4 presents econometric approaches with additional long-run restrictions; Section 5 discusses the results on the estimated IRFs and various decomposition, Section 6 evaluates how the structural parameter values in a New-Keynesian model change when the various IRFs are used as matching moments in an estimation, and Section 7 concludes.

2 Empirical Puzzle

This section investigates the effects of monetary policy shocks in an economy with both durables and non-durables. Relative price is defined as price of durables divided by non-

[10]Rudebusch (1998) provides a sharp critique by claiming that the estimated policy reaction function and the estimated structural shocks have little to do with the policy reaction function and the structural shocks perceived by financial market participants. Carlstrom, Fuerst and Paustian (2009) provide an analytic explanation for the misidentification.

[11]In Barsky, House and Kimball (2007), they find that in response to a monetary policy shock durable and non-durable goods production always move in the opposite direction. This is at odds with the data, and called "co-movement puzzle".

durables, and relative output is durable output divided by non-durable output. We incorporate them into an otherwise standard monetary VAR framework.[12] Other variables included are real GDP, GDP deflator, commodity price, federal funds rate (FFR) and monetary aggregate $M2$.[13] Innovations to federal funds rate are considered to be monetary policy shocks. For the identification of monetary shocks, the natural starting point is the short-run recursive assumption, examined in Sims (1992), Christiano, Eichenbaum and Evans (1999), etc. and widely used in monetary economics. It assumes that central bank observes current economic activities when setting interest rate, while these activities respond to monetary shocks with one-period lag. Note that this assumption only identifies monetary policy shocks.[14]

The data are from National Income and Product Accounts (NIPA). It includes each component of real GDP and its corresponding price deflator, from which we construct time series data for output and price of non-durables and durables, respectively. For the non-durables, we define it as the combination of both non-durable goods and services.[15] The total consists of a relative constant share of GDP with 54 percent in 1960 and 61 percent in 2007. For the durables, we use the data for the durable consumption goods, consisting 8.5 percent of GDP in 1960 and in 2007 remains 8.4 percent. The data are in a quarterly frequency. A constant and time trend are also included in the estimation. In the baseline, sample period is from 1960 to 2007, as federal funds rate reaches zero lower bound since 2008. We use 4 periods of lags in the estimation, and 95 percentage confidence bands are presented in all the graphs along with the point estimation.[16]

Figure 1 presents the IRFs of output, price, relative output and relative price to a one-standard deviation increase in monetary policy shocks. Price remains inertial for the first two periods and then declines gradually. Output displays hump-shaped responses reaching

[12]cite papers using monetary VAR

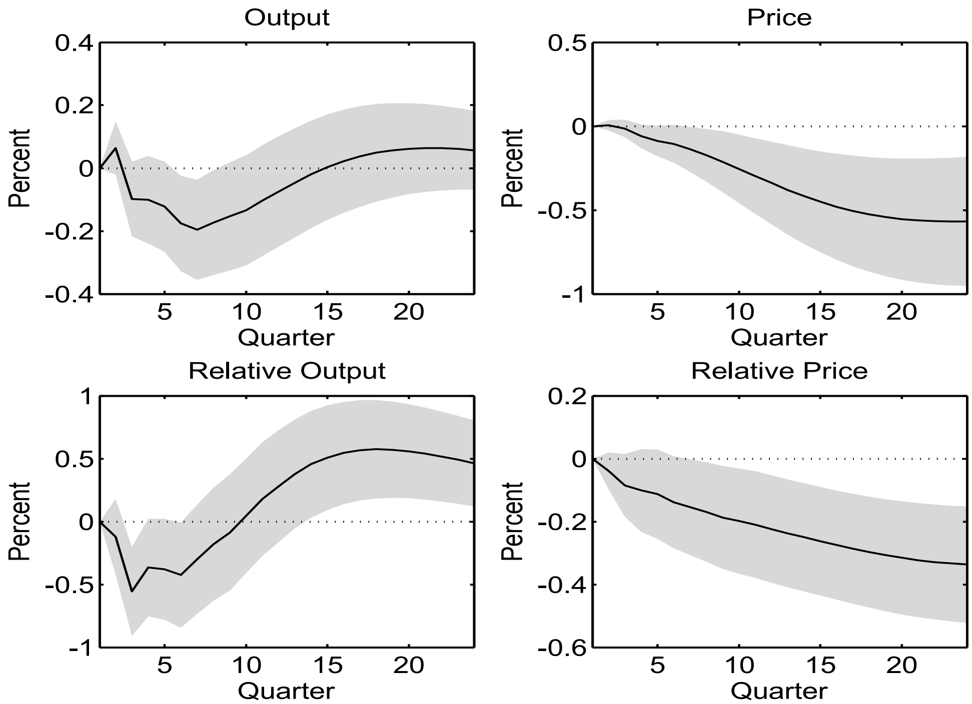
[13]All the variables are in log levelS except the FFR. Following the convention, commodity price is included for resolving the price puzzle – counter-intuitive price increase after a monetary contraction, pointed out by Sims (1992). The monetary aggregate $M2$ is included to control for open market operation, motivated by Bernanke and Mihov (1998). In the literature, other monetary aggregates are also included, for instance non-borrowed reserve, total reserve etc. When we incorporate all these monetary aggregates in the estimation, results largely remain the same. Thus, due to the dimensionality we do not include all of them in the estimation here.

[14]The ordering of the variables in the estimation is relative price, output, relative output, price deflator, commodity price, FFR, M2. With the recursive short-run assumption, the exact ordering of the variables before federal funds rate has no impact on the estimated impulse responses of monetary policy shocks. Please see Christiano, Eichenbaum and Evans (1999) for more details.

[15]In 1960, non-durable goods expenditure is 24.7 percent of GDP and services is 28.8 percent. Over the past few decades, we have seen a dramatic rise in the services industry. By 2007, personal consumption from services is three times of that from non-durable goods. Since non-durable goods consumption is the expenditure on tangible commodities with an average life of no more than 3 years and services is the expenditure on commodities that cannot be stored, in our empirical estimation, we combine both together as the non-durables. In 1996, the U.S. Department of Commerce began using chain-aggregated data in the NIPA. The lack of additivity invalidates the direct addition and subtraction. Following Whelan (2002), we use the Divisia index to combine quantity and price deflator for non-durable goods and services. For more details, please refer to the data appendix.

[16]The confidence intervals are computed using a bootstrap Monte Carlo procedure following Christiano, Eichenbaum and Evans (1999).

Figure 1. The Impulse Responses to a Monetary Policy Shock Identified by SVAR Short-Run Identification

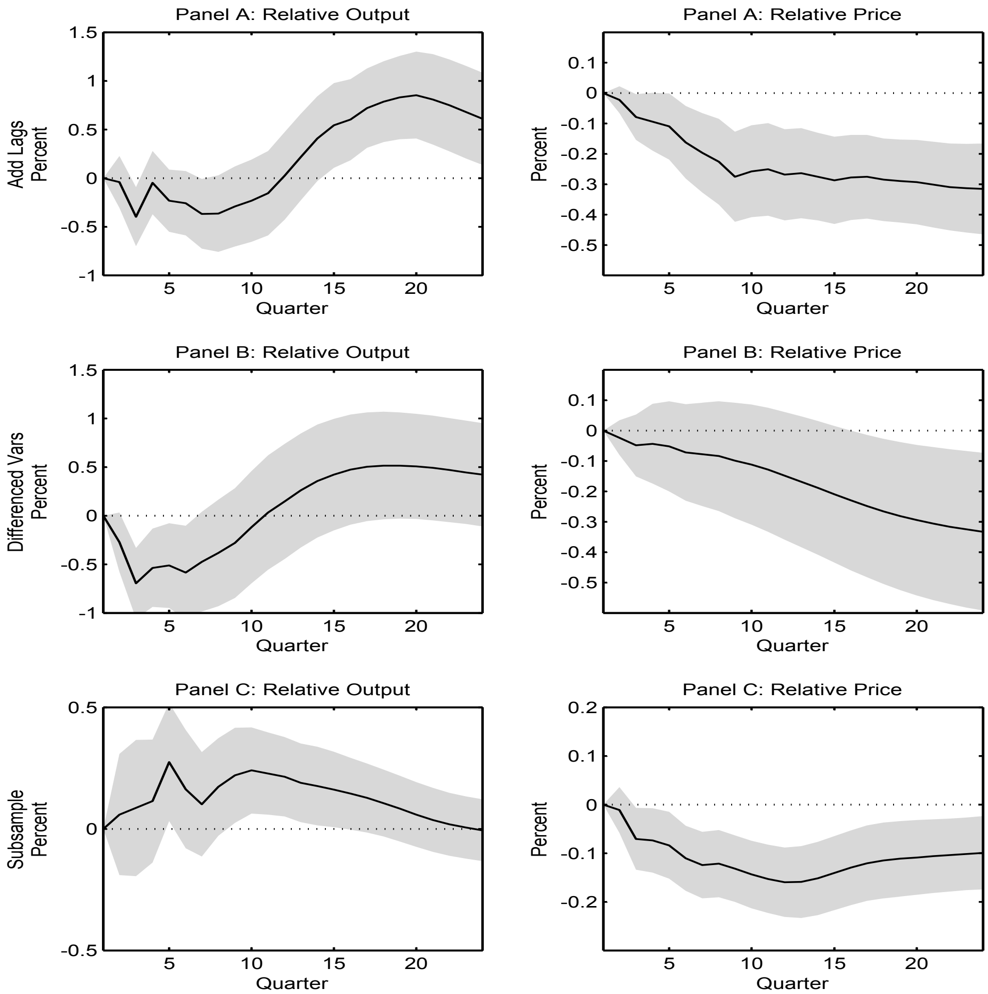


Notes: The figure depicts the impulse responses of output, price, relative output, relative price to a one-standard deviation increase in monetary policy shocks, along with 95 percentage confidence bands (shaded area). Monetary policy shocks are identified with the short-run recursive assumption.

trough seven quarters after the shock. Overall, the results are consistent with the existing literature – a sluggish decline in price level and humped shaped responses of output with maximal decline occurring a year and a half after the shock. Even though monetary effects are significant and protracted in the short-run, monetary policy shocks have no long-running effects on the economy. This is, however, severely challenged when we examine the IRFs of relative price and relative output, which imply that monetary effects last much longer. In response to a monetary contraction, relative price declines gradually and shows no sign of reverting back to the steady-state. But unlike price level – a nominal variable, relative price is a real variable. Relative output drops initially for two periods and converges back to the steady-state. Then it overshoots and is significantly above the steady-state six years after the shock. The persistent shifts of relative price and relative output, that is, a significant gap between responses of durables and non-durables in the long-run, seem to suggest that monetary shocks have long-lasting real effects on the economy.

To assess the robustness of this result, we experiment with various other specifications. For each specification, a similar seven variable VAR is estimated with short-run identification, and the results are shown in Figure 2. For the sake of conciseness, we only report the IRFs

Figure 2. The Impulse Responses of Relative Output and Relative Price to a Monetary Policy Shock for Various Specifications



Notes: The figure depicts the impulse responses of relative output and relative price to a monetary policy shock for various specifications, along with 95 percentage confidence bands. The identification and estimations are the same as the baseline. For each specification, only the responses of relative output (the left panel) and relative price (the right panel) are reported here. Panel A depict the impulse responses estimated with 8 periods or 2 years lags. Panel B depict the estimation results with first differenced variables for relative output and relative price. Panel C are the estimation results with sub-sample period - from 1984Q1 to 2007Q4. Panel D are the estimation with residential investment as durables.

of relative output (the left panels) and relative price (the right panels). First, to see it is not sensitive to the number of lagged variables included in the estimation, in Panel A we estimate a SVAR with two years or eight periods of lags. The results are close to those in Figure 1. Second, instead of using the variables in log levels, we use first difference of log relative output and log relative price. The results shown in Panel B are the same but with wider confidence intervals. Third, we estimate with the subsample period - from 1984 to

2007, usually thought to be a period with relatively stable monetary policy and economic development. Relative output rises immediately when the shock occurs, and there is sluggish and significant decline in relative price, though quantitatively smaller than those in the full sample period as expected. Finally, we use durables other than durable consumption goods. Panel D depicts the responses when residential investment is used as durables. Relative price declines and tends to go back after fours years. But by six years it is still 0.3 percentage significantly below steady-state. The same pattern of relative price movement holds true for non-residential investment and fixed investment (not shown in the figure). Thus, the differential monetary effects between durables and non-durables, in particular relative price, suggest monetary effects can potentially be very long-lasting.

For correctly deriving monetary policy shocks and examining differential monetary effects between sectors, it is important for us to incorporate relative price and relative output of durables and non-durables in a VAR framework. However, the persistent shifts of relative price and relative output in response to a monetary policy shock are very puzzling. There are two possible explanations for the persistence. One is that there are strong internal propagation mechanisms in the economy, such that even a small and transitory monetary shock can generate long-running effects. But contract multipliers required to explain the persistence here are well beyond what most sticky price models can offer. [17] So the persistence can not be easily reconciled by a large class of monetary models. Since the sluggish and persistent relative price shift can not be rationalized easily in a standard model setting, this leaves us with the other possibility that the shocks themselves are very persistent. If the empirically observed persistent shifts in relative price and relative output result from a very persistent shock, the shock is unlikely to be a monetary policy shock. This leads us to question validity of the identifying assumption and authenticity of the derived monetary policy shocks. That is, the source of the estimated persistent monetary effects is that the identified monetary shocks are not truly exogenous, but instead contaminated by other fundamental economic innovations, which are indeed responsible for the persistent shift. Then, which shocks contaminate monetary policy shocks and are responsible for the long-running effects? Supply shocks, in particular technology shocks, are more likely to be the candidate for contaminating monetary policy shocks for the following two reasons. One is that monetary shocks are usually considered to generate short-run fluctuations, while technology shocks are persistent and have a long protracted impact on the economy; and the other is that in the long-run

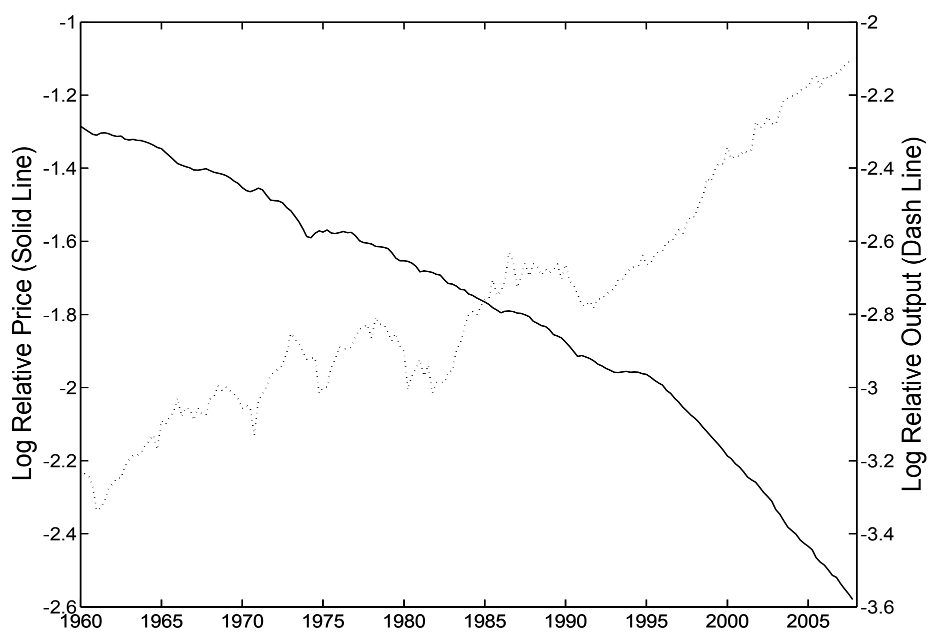
[17] Golosov and Lucas (2007) show that in a menu cost model monetary effects can only be small and transient. Nakamura and Steinsson (2010) augment the model with intermediate inputs and multisectors, which enhance strategic complementarity and generate monetary effects lasting for about one and half years. State dependent models fail to explain the persistence, so do time dependent models. Christiano, Eichenbaum and Evans (2005) provide a model with many propagation mechanisms and effects of monetary shocks last for about three years. Chari, Kehoe and McGrattan (2000) also show that for a wide rage of parameter values, the amount of endogenous stickiness in a sticky price model is small. All the models mentioned here do not explicitly model durables and non-durables. But it is not hard to see that if we augmented these models with durables and non-durables, they can not generate very persistent monetary effects on relative price and relative output.

relative price and relative output move in the opposite direction. If this is true, how do the estimated IRFs and variance decomposition change, when we distinguish technology shocks from monetary policy shocks? And how this changes our understanding about nature of the frictions in the economy, as the estimated IRFs are often used as criteria for evaluating economic models?

3 Econometric Approach

In this section, we incorporate the long-run identifications for technology shocks. Two approaches are implemented – SVAR and SVECM. We consider innovations to output as aggregate technology shocks and innovations to relative price as sector-specific technology shocks.[18]

Figure 3. Time Series Data for Relative Price and Relative Output



Notes: The figure depicts time series data of log relative price and log relative output for durable consumption goods from 1960 to 2007. The solid line is relative price with value on the left y-axis, and the dotted line is relative output with value on the right y-axis.

For the identification strategies, a unit root in relative price and output is the key to identify the shocks. Figure 3 presents time series data of relative price and relative output for durable consumption goods. There is a steady decline in relative price for the past five decades, while relative output increases over time. Table 1 provides a unit root test with

[18]In fact, Blanchard and Quah (1988) and etc. consider innovations to labor productivity as aggregate technology shocks, and Fisher (2006) and etc. consider the residual from the relative price regression equation as investment-specific technology shocks.

Table 1. Unit Root Test

	Augmented Dickey-Fuller Test Statistics	Schmidt-Phillips Test Statistics
Relative Output (RQ_t)	-1.82	-8.04
Relative Price (RP_t)	1.21	-1.73
Output (Y_t)	-4.27^{**}	-11.97
Price (P_t)	-1.67	-0.87
PCOM (PC_t)	-2.45	-7.90
FFR (R_t)	-1.67	-11.49
M2 (M_t)	-0.89	-1.42

Notes: The null hypothesis for both tests is unit root. The critical values for ADF test are -3.96 (1%) and -3.41 (5%). The critical values for Schmidt-Phillips test are -25.2 (1%) and -18.1 (5%). ** denotes the null is rejected at 1% significance level.

both Augmented Dickey-Fuller test and Schmidt-Phillips test. For both relative output and relative price, we fail to reject null hypothesis that the series contain a unit root. For other variables except output, we can not reject the null hypothesis either. It has always been a controversy whether output is trend stationary or follows a unit root process. With ADF test and linear trend for output, the null is rejected at 5% significance level. However, we fail to reject the null when the linear trend is removed. Moreover, the test statistics of Schmidt-Phillips test also fail to reject unit root hypothesis for output. So we think output can be reasonably treated as a unit root process.

3.1 Identification with SVAR

In this subsection, we derive the IRFs of monetary policy shocks with a modified SVAR. The identification strategy is similar to Blanchard and Quah (1989), Gali (1992), Barth and Ramey (2002), etc., where long-run restrictions are imposed to identify technological shocks and short-run assumptions are imposed to identify monetary shocks. The intention of these papers for introducing long-run restrictions are that they are interested in the effects of technology shocks. We are not really interested in technology shocks per se. But we find that the estimated responses of monetary shocks differ substantially whether or not we control for technology shocks.

To be more specific, consider the following moving-average representation for the dynamics of variable Z_t:

$$Z_t = [I - B(L)]^{-1} Fe_t,$$

where I is seven dimensional identity matrix. Here Z_t is a seven dimensional vector with

$$Z_t = [\,\Delta RP_t,\, \Delta Y_t,\, \Delta RQ_t,\, \Delta P_t,\, \Delta PC_t,\, R_t,\, \Delta M_t\,]',$$

where Δ denotes the first difference. That is, we assume all variables except federal funds rate contain a unit root. This is because as suggested by the model, if the economy contains stochastic trends, most of economic variables follow a unit root process. The matrix $[I - B(1)]^{-1} F$ is the sum of all moving-average coefficient matrices representing long-run effects of structural shocks, and the matrix F describes the contemporaneous effects of structural shocks.

To see how the estimated IRFs vary as long-run restrictions are imposed, we experiment with three different specifications. In the first scenario, to assure monetary shocks are not contaminated by sector-specific technology shocks, we assume only sector-specific shocks have permanent effects on relative price. In the second scenario, to assure monetary shocks are not contaminated by aggregate technology shocks, we assume aggregate technology shocks have no permanent effects on output.[19] In the third scenario, we assume only sector-specific shocks affect relative price in the long-run and both technology shocks affect output in the long-run. Moreover, since we work with just identified model, that is, the number of restrictions is exactly enough to create a one to one mapping between the structural and the reduced form parameters,[20] the introduction of long-run restrictions allow us to relax some of the short-run identifications. For all three cases, we relax the restriction on relative price, such that it can respond to monetary policy shocks contemporaneously. The overall price level may not respond to change in monetary policy in the current period, but it is much harder to imagine durables like motor vehicles, housing etc. are slow in reacting to monetary shocks.

3.2 Identification with SVECM

The theory points out that economic variables share common stochastic trends, which offers another approach for imposing identifying restrictions. The method is initially proposed by King, Plosser, Stock and Watson (1991). The advantage of implementing SVECM is that it takes into account explicitly the division between permanent and transitory shocks. As a result, few restrictions are required for the identification.

[19] Since sector-specific shocks can affect output in the long-run, when we identify aggregate technology shocks by assuming they do not affect output in the long-run, the identified shocks contain aggregate technology shocks and part of sector-specific shocks.

[20] Most applications involving some kind of long-run restrictions work with just identified models, for example Blanchard and Quah (1989), Gali (1992), Barth and Ramey (2002) and etc. Otherwise, the model has more restrictions and the whole estimation process becomes a nonlinear optimization, jointly over all the coefficients. We use OLS for the reduced form estimation and then solve a set of nonlinear equations for the structural parameters. The confidence intervals are calculated by Monte-Carlo simulations.

The method requires all variables are at most $I(1)$.[21] When economic variables share common stochastic trends, they are necessarily co-integrated. Table 2 summarize Johansen's trace cointegration tests. The rank for which null hypothesis cannot be rejected for the first time is then chosen as the number of cointegrating vectors. So the number of cointegrating vectors is four, implying that there can be four transitory shocks and three permanent shocks. As suggested by the theory, the three permanent shocks are: aggregate technology shocks, sector-specific technology shocks and nominal permanent shocks. Nominal shocks can have permanent effects because the variables include price level and monetary aggregates. We rearrange the order of the variable in Z_t such that the corresponding vector for structural shocks contains permanent shocks first and then transitory shocks. As usual, innovations to relative price are taken as sector-specific technology shocks, and innovations to output are taken as aggregate technology shocks. There are two candidates for nominal permanent shocks – innovations to federal funds rate and innovations to monetary aggregate. Following Gali (1992), where innovations to federal funds rate are shown to generate long-run movement of price level and monetary aggregate, we consider monetary policy shocks here are one of the permanent shocks, that is,

$$Z_t = [\, RP_t,\, Y_t,\, R_t,\, RQ_t,\, P_t,\, PC_t,\, M_t \,]' \,.$$

Since monetary shocks are one of permanent shocks, they can potentially have much bigger and long-running impacts on the economy.[22]

Consider the following VECM for the dynamics of Z_t:

$$\Delta Z_t = \alpha_1 \alpha_2' Z_{t-1} + \Gamma(L)\Delta Z_t + F e_t,$$

where Δ denotes the first difference and $\Gamma(L)$ is the lag polynomial. α_1 and α_2 are 7×4 matrices, and the term $\alpha_1 \alpha_2' Z_{t-1}$ is referred to as error correction term. According to Granger's representation theorem, the dynamics of Z_t can be written as:

$$Z_t \;=\; \Psi F \sum_{i=1}^{t} e_i + \sum_{j=0}^{\infty} \Psi_j F e_{t-j} + Z_0,$$

where Z_0 is the initial value. Ψ_j are absolutely summable, which implies that these matrices converges to zero for $j \to \infty$. So the term $\sum_{j=0}^{\infty} \Psi_j F e_{t-j}$ is the transitory part of the shocks.

[21] For all the first differenced variables, null hypothesis of both ADF test and Schmidt-Phillips is rejected. Thus, all the variables are at most $I(1)$.

[22] Alternatively, we derive monetary effects when innovations to monetary aggregate are assumed to be nominal permanent shocks, while innovations to FFR are assumed to be one of transitory shocks, that is, $Z_t = [\, RP_t,\, Y_t,\, M_t,\, RQ_t,\, P_t,\, PC_t,\, R_t \,]'$. To identify transitory shocks, we resort to restrictions on contemporaneous relationships by assuming output, relative output and price respond to monetary policy shocks with one-period lag. This is similar to the short-run assumptions used in SVAR. We find that effects of monetary shocks are much smaller. The qualitative responses of output, price and FFR are similar to the baseline case, but with smaller magnitude. There are no long-run shift of relative output and relative price.

Table 2. Johansen Trace Cointegration Test

Number of Cointegrating Vectors	Likelihood Ratio	P-Value	99% Critical Value	95% Critical Value
0	231.66**	0.00**	161.11	150.35
1	151.35**	0.00**	127.04	117.45
2	101.83**	0.00**	96.97	88.55
3	63.37*	0.05*	70.91	63.66
4	36.41	0.19	48.87	42.77
5	19.05	0.28	30.67	25.73
6	5.21	0.57	16.22	12.45

Notes: ** denotes the null hypothesis rejection with a 1% significance level and * denotes the null hypothesis rejection with a 5% significance level. The rank for which the null hypothesis cannot be rejected for the first time is then chosen as the number of co-integrating vectors.

Since $\sum_{i=1}^{t} e_i$ is a random walk, long-run effects of shocks are represented by the term $\Psi F \sum_{i=1}^{t} e_i$, capturing the common stochastic trends.[23] Thus, permanent and transitory shocks can be identified by imposing restrictions on the matrices ΨF – representing long-run effects and F – representing contemporaneous effects. [24]

To identify permanent shocks, we assume only sector-specific shocks affect relative price in the long-run, both aggregate and sector-specific technology have permanent effects on output, and monetary policy shocks do not affect relative price and output in the long-run. With long-run restrictions, three permanent shocks can be identified, and no short-run identifying assumptions are needed.

4 Findings

This section presents and discusses the dynamic effects of monetary policy shocks on the economy, and the contributions to the variance of $q-$quarters ahead forecast errors.

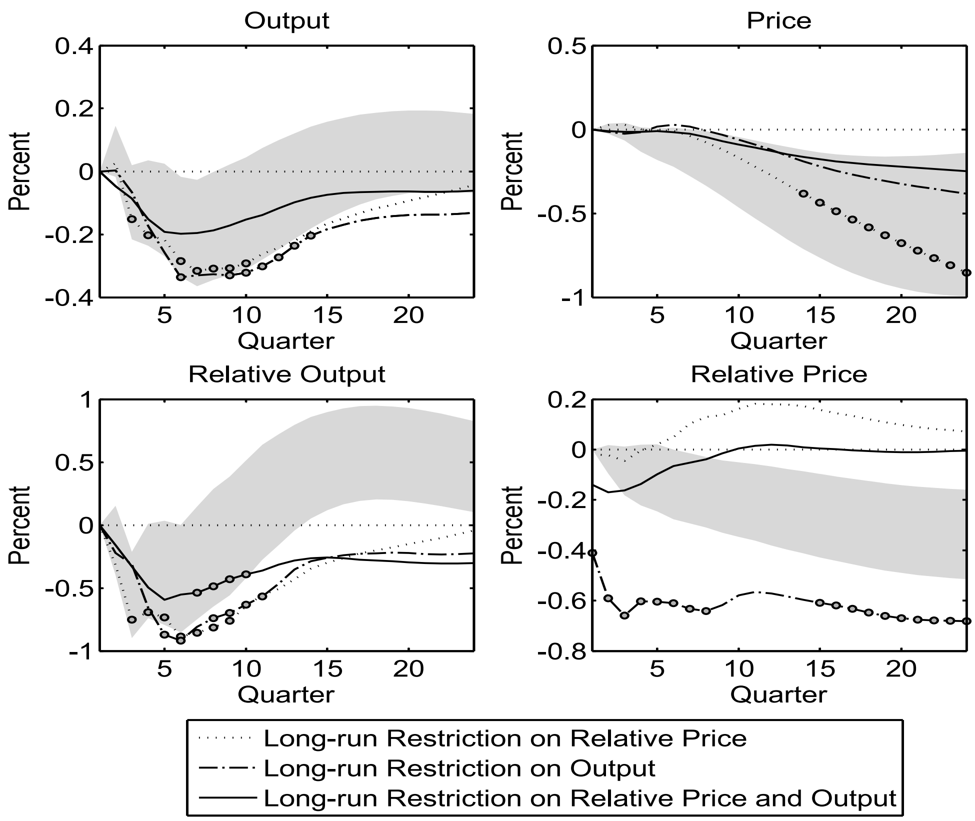
[23] The matrix $\Psi = \alpha_{2\perp}\left[\alpha'_{1\perp}(I_k - \sum_{i=1}^{p-1}\Gamma_i)\alpha_{2\perp}\right]^{-1}\alpha'_{1\perp}$, where $\perp$ denotes the orthogonal complement of that matrix.

[24] Let k denotes number of variables included in the estimation with $k = 7$, and r denotes number of cointegrating vectors with $r = 4$. Similarly to SVAR, for just identification we need a total of $k(k-1)/2 = 21$ independent restrictions. Since a co-integrating rank $r = 4$ is diagnosed and four transitory shocks are justified, the last four columns of the matrix ΨF can be restricted to zero. Because the matrix ΨF has reduced rank $k - r$, each column of zeros stands for $k - r$ independent restrictions. Thus, the r transitory shocks represent $r(k - r) = 12$ independent restrictions, and we still need 9 restrictions. Therefore, for the just identification, we need $((k - r) * ((k - r) - 1)/2 = 3$ restrictions for identifying permanent shocks and $r * (r - 1)/2 = 6$ restrictions for transitory shocks. For a detailed discussion of the econometric methodology on SVECM, see Lutkepohl (2006).

4.1 Impulse Responses

Figure 4 displays the estimated responses of output, price level, relative output and relative price to a monetary policy shock, identified by SVAR with both long-run and short-run restrictions. The dotted lines denote the IRFs estimated with only long-run restrictions on relative price; the dash lines denote the IRFs estimated with only long-run restrictions on output; and the solid lines denote the IRFs estimated with long-run restrictions on both relative price and output. The impulse responses which are significant at 95% significance level are marked with filled circle. To facilitate the comparison, the impulse responses and confidence bands of the baseline case in Figure 1 are depicted as the shaded area.

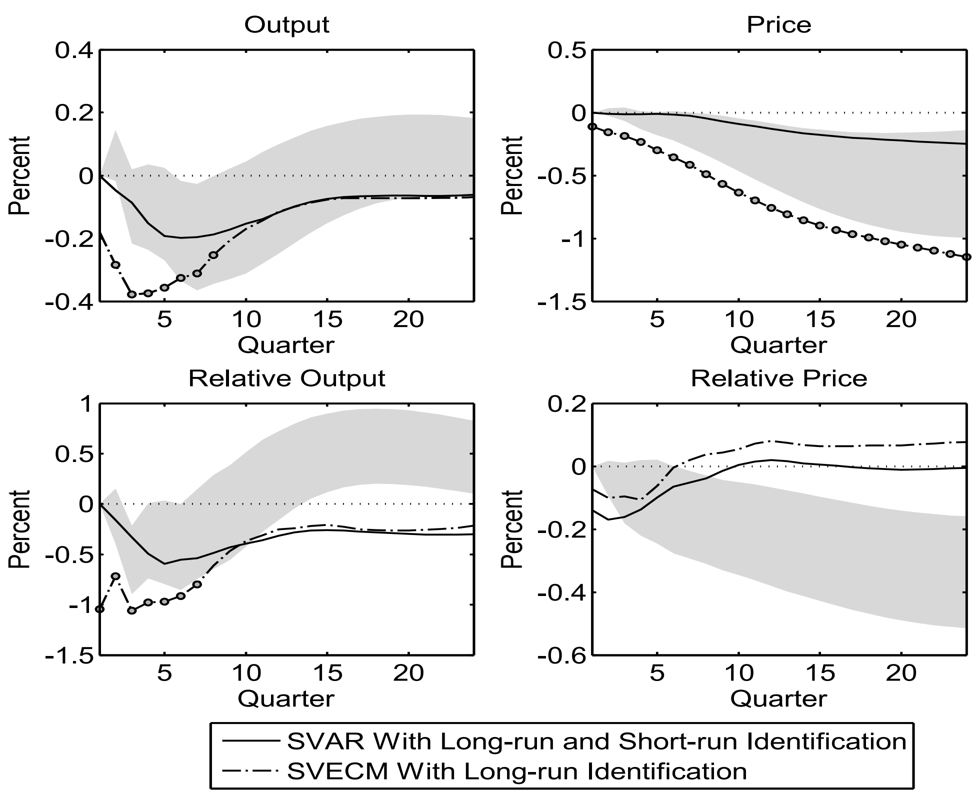
Figure 4. The Impulse Responses to a Monetary Policy Shock Identified by SVAR with Both Long-run and Short-run Identifications



Notes: The figure depicts the impulse responses of output, price, relative output, relative price to a one-standard deviation increase in monetary policy shocks. The dotted lines denote the IRFs estimated by SVAR with additional long-run restrictions on relative price; The dash lines denote the IRFs estimated by SVAR with additional long-run restrictions on output; and the solid lines denote the IRFs estimated by SVAR with additional long-run restrictions on both relative price and output. The impulse responses which are significant at 95% significance level are marked with filled circle. The shaded area are the impulse responses and 95% confidence bands for the baseline case in Figure 1.

Considering the responses of relative price, the persistent movement vanishes once we impose long-run restrictions to control for sector-specific shocks, seen from both the dotted and solid lines. In contrast, if we only impose long-run restrictions on output, we control for aggregate technology shocks, but leave the possibility that monetary shocks can be contaminated by sector-specific shocks. The dash lines clearly shows what appears to be a large and persistent monetary effect on relative price is in fact caused by sector-specific technology shocks. Thus, sector-specific shocks are responsible for the sluggish and persistent shift in relative price. For relative output, both technology shocks are apparently important for generating the overshooting and persistent deviations. This is consistent with the model implication that both aggregate and sector-specific technology shocks have large and protracted impact on relative output, though only sector-specific shocks affect the growth trend of relative output. Across all three scenarios, output remains hump-shaped responses. With long-run restrictions for both relative price and output (the solid lines), it reaches the trough slightly early than both the other two scenarios and baseline case. But the estimated responses are insignificant.

Figure 5. The Impulse Responses to a Monetary Policy Shock Identified with Additional Long-run Identifications



Notes: The figure depicts the impulse responses of output, price, relative output, relative price to a one-standard deviation increase in monetary policy shocks. The solid lines denote the IRFs estimated by SVAR with both long-run and short-run identifications, and the dash lines denote the IRFs estimated by SVECM with long-run identifications. The impulse responses which are significant at 95% significance level are marked with filled circle. The shaded area are the impulse responses and 95% confidence bands for the baseline case in Figure 1.

In Figure 5, we provide the impulse responses estimated with SVECM. For comparison, we include the estimation results with SVAR controlling for both technology shocks, as well as the baseline shown as the shaded area. The impact of monetary shocks on relative price and relative output is qualitatively similar for both identification strategies. Responses of relative price and relative output in the long-run are much more dampened, in contrast with 0.5% significant decline in the baseline. In response to a contractionary monetary policy shock, relative price drops immediately and starts converging back to steady-state. The responses are small and insignificant. With a monetary contraction, relative output drops and then converges back to steady-state. For SVAR estimation, the initial response is restricted to be zero, while there is an immediate and large drop with SVECM estimation. Moreover, with SVECM estimations, relative output reaches trough after two quarters, while it is five quarters for SVAR estimation.

The SVECM with permanent monetary shocks provides us with an upper bound on the significance and persistence of monetary policy shocks. This is clearly demonstrated by the impulse responses of price level. The movement of price level is dampened when estimated with SVAR, and when we assume monetary shocks have permanent effects, price drops immediately and declines gradually. The timing and size of the responses of price level critically depend on the estimation assumption that whether monetary shocks are transitory or permanent. Moreover, when we assume monetary shocks are permanent, they do not have long-run effects on any of the real variables – output, relative output and relative price. Thus, we can conclude that if monetary shocks have long-run impacts, it only applies to nominal variables. In addition, monetary shocks identified with the permanent assumption here resemble money supply shocks examined in Gali (1992), which are considered to be one of the the sources responsible for unit root in nominal variables. [25]

If monetary policy shocks are misidentified for relative price, surely it affects our understanding about output. For both identification strategies, output display a hump-shaped response. With SVAR estimation, the maximal decline occurs five quarters after the shock, and with SVECM estimation, it occurs only after two quarters. Similar to relative output, for SVAR stimation the initial response is restricted to be zero, while there is an immediate and large drop with SVECM estimation where no exclusion restriction on contemporaneous relationship is imposed.[26] This contradicts to the consensus reached in the literature about the delayed and protracted response of output to a monetary policy shock. Our results suggest that when controlling for both persistent technology shocks, the estimated monetary

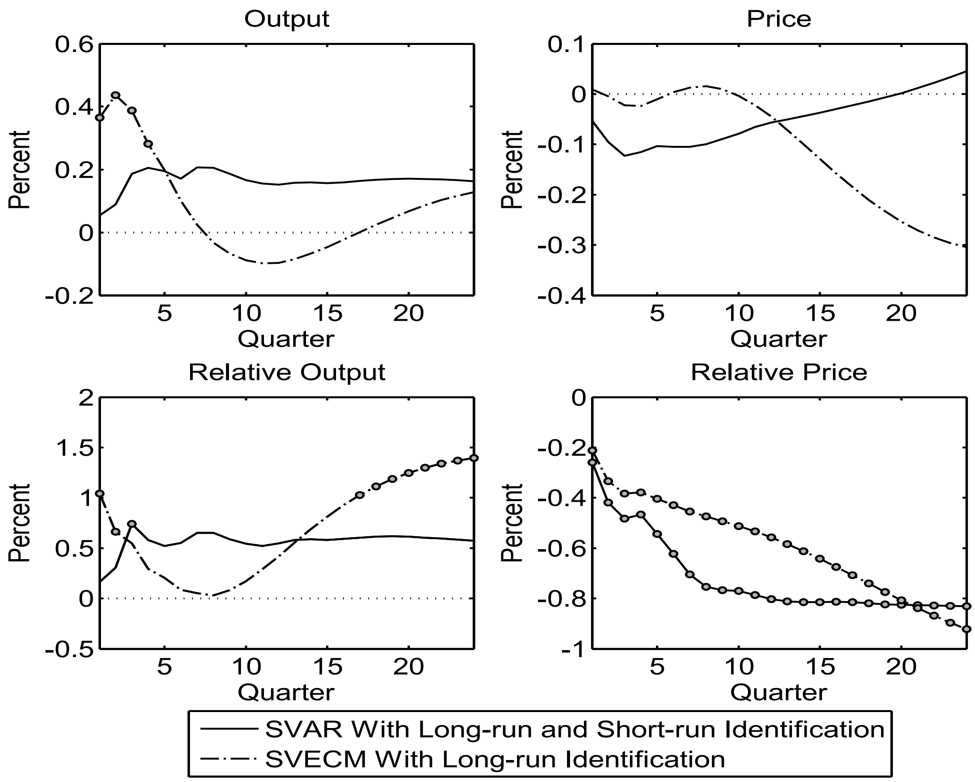
[25]For both of those monetary shocks, nominal interest rate increases initially and declines to the new steady-state; output drops and reaches the trough four quarters after the shock for about 0.6%; price declines steadily and monetary aggregates declines and reaches the new lower steady-state. For conciseness, the estimation results for monetary aggregates are not shown here. Even though the identification strategy we employ is different from the identification assumption used in Gali (1992), the similarity between the two responses gives us confidence that the permanent monetary shocks are correctly identified.

[26]Uhlig(2005) also relax the zero restriction on the initial output response. He imposes sign restrictions on the impulse responses of prices, non-borrowed reserves and federal funds rate, and no restrictions are imposed on the response of real GDP. He finds that monetary shocks have an ambiguous effect on real GDP.

effects are more front-loaded, especially with SVECM estimation.

Our estimation strategy for monetary policy shocks is to control for both technology shocks, which are identified and estimated as a by-product. Figure 6 presents the impulse responses to a one-standard deviation increase in sector-specific technology shocks, and Figure 7 presents the impulse responses to a one-standard deviation increase in aggregate technology shocks. Clearly, sector-specific shocks are the main driving force for the sluggish decline of relative price, and both technology shocks are responsible for the persistent deviation of relative output.

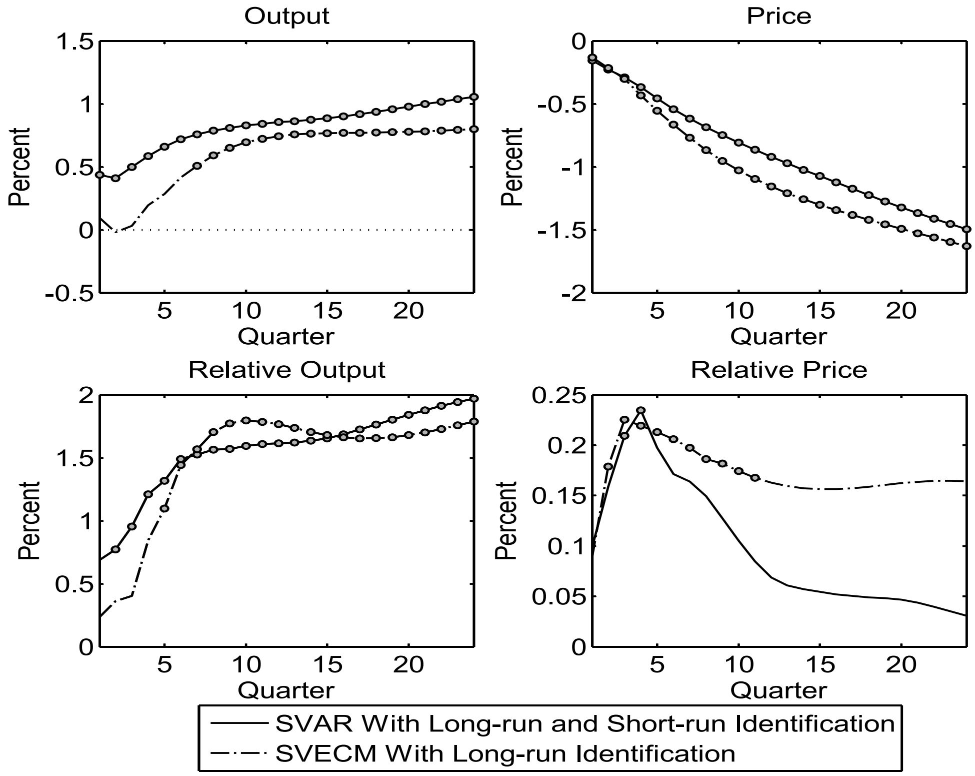
Figure 6. The Impulse Responses to Sector-Specific Technology Shocks



Notes: The figure depicts the impulse responses of output, price, relative output and relative price to one-standard deviation increase in sector-specific technology shocks. The solid lines denote the responses estimated by SVAR with long-run and short-run identifications, and the dash lines denote the responses estimated by SVECM with long-run identifications. The impulse responses which are significant at 95% significance level are marked with full dark circle.

Therefore, after controlling for technology shocks, responses of relative price and relative output to a monetary policy shock in the long-run are much more damped, and monetary effects on real variables are more front-loaded, especially with SVECM estimation. It shows with improper identification, how a shock to a stochastic trend may contaminate the estimated dynamic effects of a transitory shock, which only has a very short-lived impact on the economy. It is the shock to a stochastic trend giving rise to the sluggish and persistent

Figure 7. The Impulse Responses to Aggregate Technology Shocks



Notes: The figure depicts the impulse responses of output, price, relative output and relative price to one-standard deviation increase in aggregate technology shocks. The solid lines denote the responses estimated by SVAR with long-run and short-run identifications, and the dash lines denote the responses estimated by SVECM with long-run identifications. The impulse responses which are significant at 95% significance level are marked with full dark circle.

movement, and responsible for the observed spurious relationship between monetary shocks and economic variables.

4.2 Variance Decomposition

The difference in the dynamic effects of monetary shocks between the baseline and the estimations with long-run restrictions has important implications for both the significance and time pattern of forecast error variance decomposition.

Table 3 Panel C and D show the contributions of monetary policy shocks to the variance of $q-$quarters ahead forecast errors for relative output and relative price. In the baseline 12 percent of relative output's and 21 percent of relative price's forecast errors over six years are accounted for by monetary policy shocks. These contributions become smaller when we explore long-run restrictions. This is true for both identification strategies implemented. Moreover, in the baseline, contribution of monetary shocks builds up over time. For example, In the first four quarters, monetary shocks account for a small fraction of relative price's forecast error. Then the contribution rise steadily, mirroring more and more larger responses of relative price to a monetary policy shock in the baseline. In contrast, for the estimation with long-run restrictions, either the contributions exhibit a declining trend especially after three yeas, or remain relatively small. This is consistent with the much more dampened and less sluggish dynamic effects of monetary shocks. Thus, monetary shocks are less important for the fluctuations of relative price, especially in the long-run. We find that sector-specific shocks are largely responsible for the fluctuations in relative price, and the importance grows over time. For example, sector-specific shocks account for 20 percent of forecast error in the first quarter to 75 percent after six years. Nevertheless, sector-specific shocks do not account for much variation in relative output. Instead, it is largely explained by the innovations to both output and relative output.

Table 3 Panel A shows the contribution of monetary shocks to forecast errors of output. There is a debate in the literature on how important monetary shocks to the volatility of aggregate output. It could be as high as 44% or as low as only 5%.[27] To facilitate the comparison, we also present the variance decomposition for the estimation used commonly in the literature, the baseline case without relative price and relative output. As we can see, monetary shocks explain up to 16% variance of output in long horizon. The impact mostly concentrates on the medium to the long-run, and little variation of output in the short-run about $0 - 5\%$ is explained by monetary shocks. When we include relative price and relative output in the estimation, only a negligible amount of output variance is explained by monetary shocks. Comparing the estimation with and without long-run restrictions, if sizable portion of output variance is accounted for by monetary shocks, they tend to be more important in the first couple of years, rather than in the long horizon when estimated with long-run restrictions. For instance, when estimated with SVECM, monetary shocks account for 25 percent of forecast error in the first year and quickly drops to 9 percent after six years. Therefore, what do we learn from the output variance decomposition? One is that it is very sensitive to the estimation methods, which explains the disagreement existing in the literature. The other is that if monetary shocks do matter for the fluctuations of output, the impact should concentrate on the first few years and decline over time. Aggregate technology shocks, rather than monetary shocks, play a major role in explaining the output fluctuations in the long horizon. For example, in the SVECM estimation, 70% variance of output is accounted for by aggregate technology shocks after six years.

The contribution of monetary shocks to the fluctuations of price level is shown in Table 3 Panel B. For all the estimation methods, monetary shocks become more and more important for the fluctuations of price level over time. For the estimation without long-run restrictions, monetary shocks account for $14 - 21\%$ forecast errors after six years. This is consistent with

[27]In Christiano, Eichenbaum and Evans (1999), monetary shocks when measured by federal funds rate account for 21%, 44% and 38% of the variance of the 4, 8 and 12 quarter ahead forecast error variance in output, respectively. In Uhlig (2005), monetary policy shocks account for $5 - 10\%$ of the variations in real GDP at all horizons.

Table 3. Variance Decomposition

Horizon (Quarters)	1	4	8	12	16	20	24
	Panel A: Output						
Baseline (w/o RP & RQ)	0.00	0.05	0.15	0.17	0.17	0.16	0.16
Baseline	0.00	0.02	0.05	0.05	0.04	0.04	0.04
SVAR	0.00	0.01	0.01	0.02	0.02	0.02	0.02
SVECM	0.09	0.25	0.25	0.17	0.13	0.10	0.09
	Panel B: Price						
Baseline (w/o RP & RQ)	0.00	0.00	0.02	0.07	0.13	0.18	0.21
Baseline	0.00	0.01	0.03	0.06	0.10	0.12	0.14
SVAR	0.00	0.00	0.02	0.04	0.06	0.06	0.05
SVECM	0.26	0.28	0.29	0.34	0.38	0.41	0.42
	Panel C: Relative Output						
Baseline	0.00	0.04	0.04	0.03	0.06	0.09	0.12
SVAR	0.00	0.01	0.01	0.02	0.02	0.02	0.02
SVECM	0.24	0.36	0.25	0.17	0.14	0.11	0.09
	Panel D: Relative Price						
Baseline	0.00	0.02	0.05	0.08	0.13	0.17	0.21
SVAR	0.10	0.09	0.09	0.09	0.08	0.08	0.08
SVECM	0.02	0.01	0.01	0.01	0.01	0.01	0.01

Notes: The table provides point estimates at a given horizon of the percentage contribution of a monetary policy shock to the forecast error of output (Panel A), price (Panel B), relative output (Panel C) and relative price (Panel D). It shows the results for four identification strategies: baseline without relative price and relative output, baseline with relative price and relative output, a modified SVAR with additional long-run restriction and SVECM.

most of the empirical literature. However, when imposing long-run restrictions, there is a sharp divide in the variance decomposition depending on the estimation assumption about monetary shocks. When monetary shocks are assumed to be transitory, they explain only a negligible part of price fluctuation for all horizon. In contrast, when monetary shocks are assumed to be permanent, 42% forecast error in six years are accounted for by monetary shocks. This is in line with the estimated dynamic effects of monetary shocks on price level.

Therefore, with the standard short-run identification, monetary policy shocks become more and more important in accounting for fluctuations over time. In contrast, with additional long-run restrictions for technology shocks, monetary shocks become less and less important in explaining the variance. The only exception is for the variance of price level.

5 Implications

5.1 Model

From an economic model, this section provides long-run identifications for technology shocks. This is also the model to be estimated later. Since some kind of nominal rigidity is required for money to be non-neutral, we examine a dynamic New-Keynesian model.

The basic model setup is similar to Barsky, House and Kimball (2007). There are three distinct features. First, in addition to monetary policy shocks, we introduce two types of technology shocks – aggregate and sector-specific technology shocks, giving rise to stochastic trends in the model. It is very close in spirit to Fisher (2006), where he looks at a neoclassical growth model with both neutral and investment-specific technology shocks. The model implies that only sector-specific technology shocks can generate long-run movement of relative price, and both technology shocks can affect output in the long-run. These provide additional long-run identifications. Second, as pointed out by Christiano, Eichenbaum and Evans (2005), etc., staggered wage contract is the critical nominal friction for the model to account for inertial inflation and protracted output responses to a monetary policy shock. We incorporate both staggered price and wage contracts to demonstrate that the model fails to generate the persistent shifts in relative price and relative output, even though it successfully explains the movement of other aggregate variables. This supports our conjecture that monetary shocks are misidentified. Third, the model adopts information structure consistent with the short-run identifying assumption used in the previous section. We assume both firms and households make decisions after realization of current period technology shocks, but before realization of current period monetary shocks.

The model is briefly described as follows.

Firms. There are two sectors: non-durable and durable goods sectors. In each sector, there are many final goods production firms. They take final goods price P_t^j ($j = C$ for non-durables and $j = D$ for durables) and intermediate goods prices $\{q_t^j(i)\}$ as given, where i denotes each intermediate firm. They maximize profits subject to the production function:

$$Y_t^j = \left(\int_0^1 y_t^j(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}},$$

where $y_t^j(i)$ is the intermediate good i and ϵ is the elasticity of substitution between various differentiated intermediate goods. This gives demand function for each intermediate good

$$y_t^j(i) = \left(\frac{q_t^j(i)}{P_t^j} \right)^{-\epsilon} Y_t^j, \quad \text{and price index} \quad P_t^j = \left(\int_0^1 q_t^j(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}.$$

In each sector, there are continuum intermediate goods firms from 0 to 1, each of which produces a differentiated intermediate good with labor as the only input. The only difference between the two sectors is the production technologies, which are given as

$$y_t^C(i) = A_t L_t^C(i)$$

for non-durable goods sector and

$$y_t^D(i) = V_t A_t L_t^D(i)$$

for durable goods sector. A_t is the level of labor augmenting technology or aggregate technology, and V_t is the level of durable goods sector-specific technology. We assume

$$\frac{A_t}{A_{t-1}} = \exp(a + \xi_t^a), \qquad \text{and} \qquad \frac{V_t}{V_{t-1}} = \exp(v + \xi_t^v).$$

That is, they follow unit root processes with drifts a and v. ξ_t^a and ξ_t^v denote time t innovations to aggregate and sector-specific technology shocks, respectively.

Labor is assumed to be mobile across all the firms and sectors, and thus wage is equalized. Nominal marginal costs for producing non-durable and durable goods are $MC_t^C = W_t/A_t$, and $MC_t^D = W_t/(V_t A_t)$. We use Calvo price setting mechanism (Calvo 1983). At time t all the intermediate firms, regardless of any history, choose the optimal price with probability $1 - \theta^j$ $(0 \leq \theta^j \leq 1)$ and with probability θ^j price remains the same as the last period. The intermediate goods firm i which gets to choose price at time t solves the following maximization problem:

$$\max_{q_t^j(i)} \quad E_{\Omega_t^j} \sum_{k=0}^{\infty} (\theta^j)^k \Lambda_{t,t+k} (q_t^j(i) - MC_{t+k}^j)(\frac{q_t^j(i)}{P_{t+k}^j})^{-\epsilon} Y_{t+k}^j,$$

where $\Lambda_{t,t+k}$ is the stochastic discount factor with $\Lambda_{t,t+k} = \beta^k \frac{U_c(C_{t+k}, D_{t+k})/P_{t+k}^c}{U_c(C_t, D_t)/P_t^c}$. Ω_t^j denote the set of information available for the firms at time t. We allow firms at different sector to have different information sets. In the baseline, $\Omega_t^j = \{Z_{t-1-k}, \xi_{t-k}^a, \xi_{t-k}^v, \xi_{t-1-k}^R\}$ with $k \geq 0$. Z_t denotes all the endogenously determined variables and ξ_t^R is the monetary policy shock. It says that at time t when firms make price decisions, they observe all the past endogenous variables, all the past exogenous shocks, and current period aggregate and sector-specific technology shocks. The evolution of price index is:

$$(P_t^j)^{1-\epsilon} = \theta^j (P_{t-1}^j)^{1-\epsilon} + (1 - \theta^j)(q_t^{j\,*})^{1-\epsilon}.$$

Households. There is a representative household, who derives utility from consuming both non-durable goods C_t and service flow from durable goods stock D_t, and disutility from working N_t. Durables are accumulated according to:

$$D_t = I_t + (1-\delta)D_{t-1},$$

where I_t is durable investment and δ is the depreciation rate. Moreover, there is quadratic-form adjustment cost for durables $\frac{1}{2}\phi(\frac{I_t}{D_{t-1}} - \delta)^2 D_{t-1}$. Each household faces the following budget constraint:

$$P_t^C C_t + P_t^D (I_t + \frac{1}{2}\phi(\frac{I_t}{D_{t-1}} - \delta)^2 D_{t-1}) + \frac{1}{R_t} B_t \leq W_t N_t + B_{t-1} + \Pi_t,$$

where B_t is one-period risk free bond, R_t is interest rate and Π_t is profit from the owned firms. Households supply labor N_t with wage setting following Erceg, Henderson and Levin (2000), which is directly analogous to Calvo pricing. With probability θ^W $(0 \leq \theta^W \leq 1)$ the wage remains unchanged and with probability $1-\theta^W$ the household can set optimal wage.

For the balanced growth path to be feasible, we choose a simple parametric utility functional form and each household solves the following maximization problem:

$$\max_{\{C_t, N_t, I_t B_t\}} E_{\Omega_t^H} \sum_{t=0}^{\infty} \beta^t [\psi^C \log(C_t) + (1-\psi^C)\log(D_t) - \psi^N \frac{\eta}{\eta+1} N_t^{\frac{\eta+1}{\eta}}],$$

subject to all the constraints mentioned above. β is the discount factor, η is the Frisch labor supply elasticity, and ψ^C, ψ^N are the relative weights. Ω_t^H denotes the set of information available for households at time t and $\Omega_t^H = \{Z_{t-1-k}, \xi_{t-k}^a, \xi_{t-k}^v, \xi_{t-1-k}^R\}$ with $k \geq 0$. It says that at time t when households make consumption and wage decisions, they observe all the past endogenous variables, all the past exogenous shocks, and current period aggregate and sector-specific technology shocks, but not current period monetary policy shocks.

Monetary policy rule. Central bank adopts Taylor rule and adjusts nominal interest rate in response to deviations of inflation rate π_t and output Y_t from their targeted levels. The total real output $Y_t = Y_t^C + \frac{P_t^D}{P_t^C} Y_t^D$. The aggregate price index is given as $P_t = (P_t^C)^{\varphi}(P_t^D)^{1-\varphi}$, where φ is the share of non-durable goods production along the balanced growth path with $\varphi = Y^C / \left[Y^C + \frac{P^D}{P^C} Y^D \right]$. The variables without time subscript are the values along the balanced growth path. Then, gross inflation rate is $\pi_t = \frac{P_t}{P_{t-1}}$. The interest rate rule is given as:

$$\log(R_t/R) = b_R \log(R_{t-1}/R) + (1-b_R)(b_\pi \log(\pi_t/\pi) + b_Y \log(Y_t/Y)) + \xi_t^R,$$

where b_R is the interest rate inertial coefficient. b_π and b_Y are the responding coefficients for inflation rate and output, respectively. ξ_t^R is the monetary policy shock. Note that central bank adjusts interest rate after observing all the past and current endogenous variables and exogenous shocks.

Market Clear. In equilibrium, all markets clear and we have:

$$
\begin{aligned}
Y_t^C &= C_t \\
Y_t^D &= I_t + \frac{1}{2}\phi(\frac{I_t}{D_{t-1}} - \delta)^2 D_{t-1} \\
N_t &= L_t^C + L_t^D.
\end{aligned}
$$

We assume all shocks are orthogonal to each other and follow AR(1) processes:

$$\xi_t^i = \rho^i \xi_{t-1}^i + e_t^i \quad (i = a, v, R),$$

where ρ^i are the auto-correlation coefficients. The innovations e_t^i are i.i.d and follow normal distribution with zero mean and standard deviation σ^i.

To solve the model, we detrend all the variables by their stochastic trends and convert nominal variables into their real counterparts. Then, we linearize the model around the stationary steady-state. Since the model contains different information sets, it is solved by Christiano (2002). This method can easily accommodate models in which different time t endogenous variables are based on different information sets.

Define stochastic trends $Q_t^C = A_t$ and $Q_t^D = V_t A_t$. It is straightforward to see that along a balanced growth path $\frac{Y_t^C}{Q_t^C}, \frac{W_t}{Q_t^C}, \frac{Y_t^D}{Q_t^D}$ and L_t^C, L_t^D are stationary. So relative output Y_t^D/Y_t^C grows at the same rate as $Q_t^D/Q_t^C = V_t$. When prices are assumed to be fully flexible, relative price $\frac{P_t^D}{P_t^C} = \frac{\frac{\epsilon}{\epsilon-1}MC_t^D}{\frac{\epsilon}{\epsilon-1}MC_t^C} = \frac{W_t/(Y_t^D/L_t^D)}{W_t/(Y_t^C/L_t^C)}$, which grows at the same rate as $Q_t^C/Q_t^D = 1/V_t$. This remains to be true when prices are sticky. Total output Y_t grows at the same rate as A_t. How robust is this result as in the baseline model production functions are extremely simple with labor as the only input? We find that when we relax the assumption on the production functions by adding capital or intermediate inputs, the results remain unchanged, except that both aggregate and sector-specific technology shocks affect growth trend of total output.[28] Therefore, the model implies that only sector-specific technology shocks have permanent effects on relative price, and both technology shocks have long-run effects on total output. This provides us the long-run identifications for technology shocks.[29]

Next we examine the short-run responses of endogenous variables, and provides a clear picture on how they behave in response to each of the shocks. For parameters values, we follow the literature. To be consistent with empirical data, the model is set in quarterly frequency. Discount rate β is chosen so annual interest rate is 3.5%. We choose ψ^C so that in the balanced growth path non-durable goods production consists of 75% of GDP. Frisch labor supply elasticity η equals to one, and ψ^N is chosen to target labor supply $N = \frac{1}{3}$. Depreciation rate δ for durable goods is chosen so the annual depreciation rate is 10%, and adjustment cost parameter $\phi = 0.455/\delta$. Elasticity of substitution for intermediate goods and labor supply are set so the markup is 10%. For the monetary policy rule, the interest rate inertial coefficient b_R equals to 0.95, and the responding coefficients for inflation rate and output are 1.5 and 0.5, respectively. As shown by empirical literature (Bils and Klenow 2004) that consumer durables have much greater frequency of price adjustment than non-durables, we choose $\theta^C = 0.75$ and $\theta^D = 0.25$.[30] Wage stickiness is given by $\theta^W = 0.25$. We assume all shocks are transitory, and standard deviations are $\sigma^a = 0.6\%, \sigma^v = 0.2\%$ and $\sigma^R = 0.2\%$.

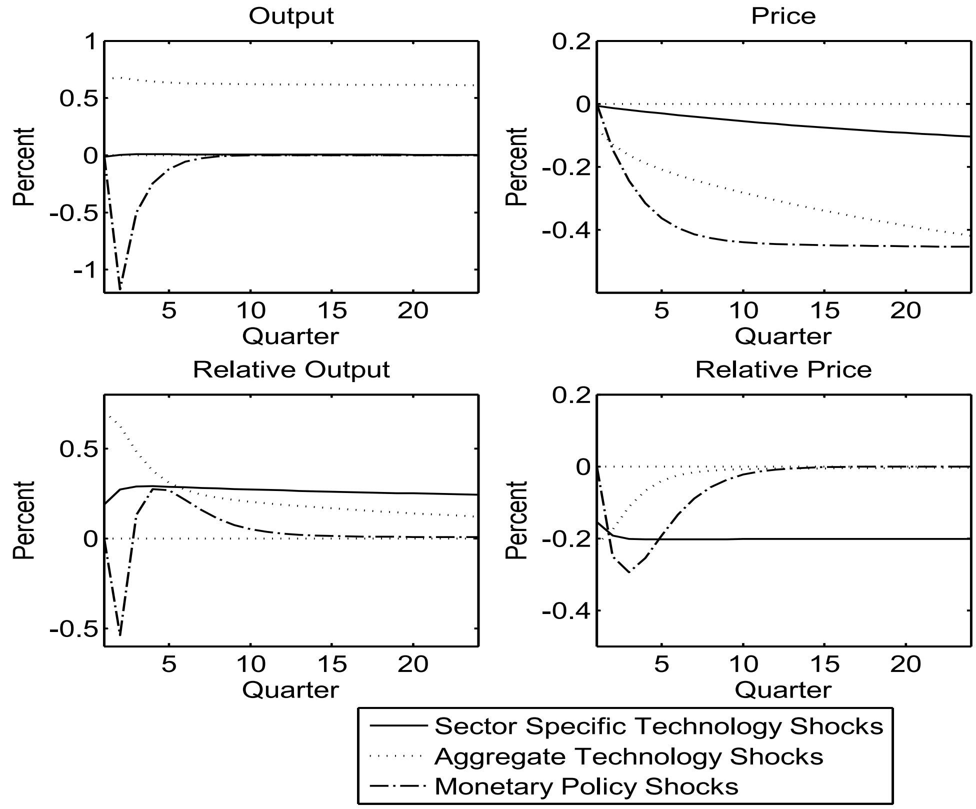
Figure 8 depicts the movements of total output, price level, relative output and relative

[28]Here, we relax the assumption on the production functions and show the result holds true when we add capital or introduce intermediate inputs. First, we introduce capital K_t in the production functions with $Y_t^C(i) = K_t(i)^\alpha (A_t L_t(i))^{1-\alpha}$ for non-durable goods sector and $Y_t^D(i) = V_t K_t(i)^\alpha (A_t L_t(i))^{1-\alpha}$ for durable goods sector. α is the capital share. We assume durable goods are used as investment for accumulating capital goods. Define stochastic trends $Q_t^C = A_t V_t^{\frac{\alpha}{1-\alpha}}$ and $Q_t^D = A_t V_t^{\frac{1}{1-\alpha}}$. Along a balanced growth path, the following variables are stationary: $\frac{Y_t^C}{Q_t^C}, \frac{W_t}{Q_t^C}, \frac{Y_t^D}{Q_t^D} \frac{K_t}{Q_t^D}$ and L_t^C, L_t^D. Then, relative output grows along the path $Q_t^D/Q_t^C = V_t$, relative price grows along the path $Q_t^C/Q_t^D = 1/V_t$ and total output grows along the path $A_t V_t^{\frac{\alpha}{1-\alpha}}$. Second, we introduce intermediate inputs, that is, part of output of each sector servers as intermediate inputs in both sectors with $Y_t^C(i) = [(M_t^{CC}(i))^{\gamma_1} (M_t^{DC}(i))^{1-\gamma_1}]^\alpha (A_t L_t(i))^{1-\alpha}$ for non-durable goods sector and $Y_t^D(i) = V_t[(M_t^{CD}(i))^{1-\gamma_2} (M_t^{DD}(i))^{\gamma_2}]^\alpha (A_t L_t(i))^{1-\alpha}$ for durable goods sector. $M_t^{jk}(i)$ is the intermediate inputs produced in sector j and used as inputs in firm i of sector k. γ_1 and γ_2 are the share of intermediate inputs produced in the sector and used in the same sector, and let $\gamma = (1-\alpha\gamma_1)(1-\alpha\gamma_2) - \alpha^2(1-\gamma_1)(1-\gamma_2)$. Define stochastic trends $Q_t^C = A_t V_t^{\frac{\alpha(1-\gamma_1)}{\gamma}}$ and $Q_t^D = A_t V_t^{\frac{1-\alpha\gamma_1}{\gamma}}$. Along a balanced growth path, the following variables are stationary: $\frac{Y_t^C}{Q_t^C}, \frac{W_t}{Q_t^C}, \frac{Y_t^D}{Q_t^D} \frac{M_t^{CC}}{Q_t^C}, \frac{M_t^{CD}}{Q_t^C}, \frac{M_t^{DC}}{Q_t^D}, \frac{M_t^{DD}}{Q_t^D}$ and L_t^C, L_t^D. Then relative output grows at the same rate as $Q_t^D/Q_t^C = V_t^{\frac{1-\alpha}{\gamma}}$, relative price grows at the same rate as $Q_t^C/Q_t^D = 1/V_t^{\frac{1-\alpha}{\gamma}}$ and total output grows at the same rate as $A_t V_t^{\frac{\alpha(1-\gamma_1)}{\gamma}}$.

[29]Note that throughout we assume that durable goods sector is subject to sector-specific technology shocks. This is because existing evidence suggests that the biases of technological change is in favor of producing durable goods (See Basu, Fernald, Fisher and Kimball, 2009). However, it is equivalent if we assume non-durable goods sector is subject to sector-specific technology shocks.

[30]With various assumptions on relative degree of price stickiness in the two sectors, the short-run effects of all shocks are qualitatively similar. The only exception is the response of relative price to monetary shocks and aggregate technology shocks. It drops when durables are more price-flexible and the opposite is true when non-durables are more price flexible.

Figure 8. The Short-Run Effects of All the Shocks in the Model



Notes: The figure describes the theoretical short-run effects of one-standard deviation increase of each fundamental economic innovation in the model. The dash-dotted lines denote responses to monetary policy shocks, the solid lines denote responses to sector-specific technology shocks and the dotted lines denote responses to aggregate technology shocks. Here, we assume durables are more price-flexible than non-durables.

price in response to one-standard deviation of each shock. The impulse responses of endogenous variables confirm the long-run effects discussed early. Relative price and relative output shift to the new steady-states after a sector-specific shock, and so does output in response to an aggregate technology shock. With more complex production functions, sector-specific shocks can also have persistent effects on output. Moreover, the effects of monetary shocks and aggregate technology shocks on relative price are extremely short lived. A positive sector-specific shock generates a sluggish and persistent relative price movement. Note here we assume the shock is only transitory. With a positive auto-correlation in the shock process, we could have much more sluggish decline on relative price. In addition, in response to a monetary shock, relative output initially drops, while it increases when either technology shocks occur. We also find that even though aggregate technology shocks do not affect the growth trend of relative output, they do have a substantial and protracted impact on relative output. Therefore, the empirically estimated sluggish and persistent relative price movements is likely to be the result of a sector-specific shock. That is, it is sector-specific technology shocks that contaminate the identified monetary shocks.

5.2 Estimating Structural Parameters

In the previous sections, we see how the impulse responses of monetary policy shocks vary when we apply different identification strategies. One of the reasons that we are interested in investigating effects of monetary shocks is that the responses can be used as targeted moments to estimate structural parameters and evaluate economic models. In this section, we examine how the estimated parameter values in a dynamic New-Keynesian model vary, when the IRFs generated from different identification strategies are used for the targeted moments in an estimation.

The model we are going to estimate is the one presented in Section 3 – a dynamic New-Keynesian model with both durables and non-durables. Before going to the model estimation, we need to clarify what information structure is assumed in the model. As we know, to derive monetary shocks, we impose different exclusive restrictions on contemporaneous relationships, or timing assumptions regarding the arrival of monetary shocks. So in a model estimation when the impulse responses generated from each of the identification methods are used for targets, we tailor the model in the way such that it is consistent with that identification. For example, in the baseline case with only short-run identifications, we assume all firms and households make decisions before observing monetary shocks at current period, in both the identification and the model. When we introduce long-run identifications for technology shocks, there are two cases. When the IRFs derived by SVAR used as targets, in the model we assume that only firms in durable goods sectors make decisions after realizations of monetary shocks, and firms in non-durable goods sectors and households respond to monetary shocks with one-period lag. This implies that relative price may respond to monetary shocks in the current period, but not other economic variables.[31] When the IRFs derived by SVECM used as targets, we assume all firms and households respond to monetary policy shocks at current period. This is the information structure used in the standard New-Keynesian model.

As the IRFs derived from various identifications differ in their persistence, and particularly how relative output and relative price respond, we focus on estimating four structural parameters: price stickiness for non-durables (θ^C) and durables (θ^D), wage stickiness (θ^W) and adjustment cost (ϕ). Let $\Theta_1 = \{\theta^C, \theta^D, \theta^W, \phi\}$. The rest of parameters are the same as those used in Section 3, denoted as Θ_2. Θ_1 is then estimated by solving the following

[31] In response to a monetary policy shock, durable prices respond immediately, but not non-durable prices. This is justified by the empirical evidence that consumer durables have much greater frequency of price adjustment compared with non-durables (See Bils and Klenow 2004). Thus relative price responds to monetary shocks immediately. Strictly speaking, price level should also respond to monetary shocks at current period. But since durable consumption goods only account for a relatively small fraction of total output, the initial change in price level is largely affected by change in non-durable prices. This is confirmed by the model simulation.

Table 4. Estimated Structural Parameter Values

IRFs Targeted	Baseline (w/o RP & RQ)	Baseline	SVAR	SVECM
Adjustment Cost (ϕ)	70.3	23.2	18.5	19.8
	[57.8 82.2]	[20.0 26.4]	[15.9 21.1]	[18.6 21.0]
Price Stickiness:				
Non-durables (θ^C)	0.92	0.95	0.50	0.42
	[0.88 0.96]	–	[0.26 0.74]	[0.27 0.57]
Durable (θ^D)	0.29	0.11	0.62	0.17
	[0.04 0.54]	[0.00 0.25]	[0.47 0.77]	[0.11 0.23]
Wage (θ^W)	0.36	0.62	0.90	0.65
	[0.26 0.46]	[0.32 0.40]	[0.88 0.92]	[0.62 0.68]
Implied Duration (Quarters):				
Non-durables	11.87	20.00	2.01	1.72
Durables	1.42	1.15	2.62	1.21
Wage	1.56	2.62	9.85	2.81

Notes: The table presents the estimates for adjustment cost, price stickiness for non-durables and durables, wage stickiness and implied average time duration for price and wage stickiness in quarters. The first column uses the IRFs estimated in the baseline without relative price and relative output as matching targets. The second column uses the IRFs estimated in the baseline with relative price and relative output as matching targets. The third column uses the IRFs estimated by a modified SVAR with additional long-run restrictions as matching moments. The last column uses the IRFs estimated with SVECM as matching moments. Standard errors are calculated by delta method and 95 percentage confidence intervals are in parentheses. In the baseline case, price stickiness for non-durables is missing because the estimate falls on the boundary.

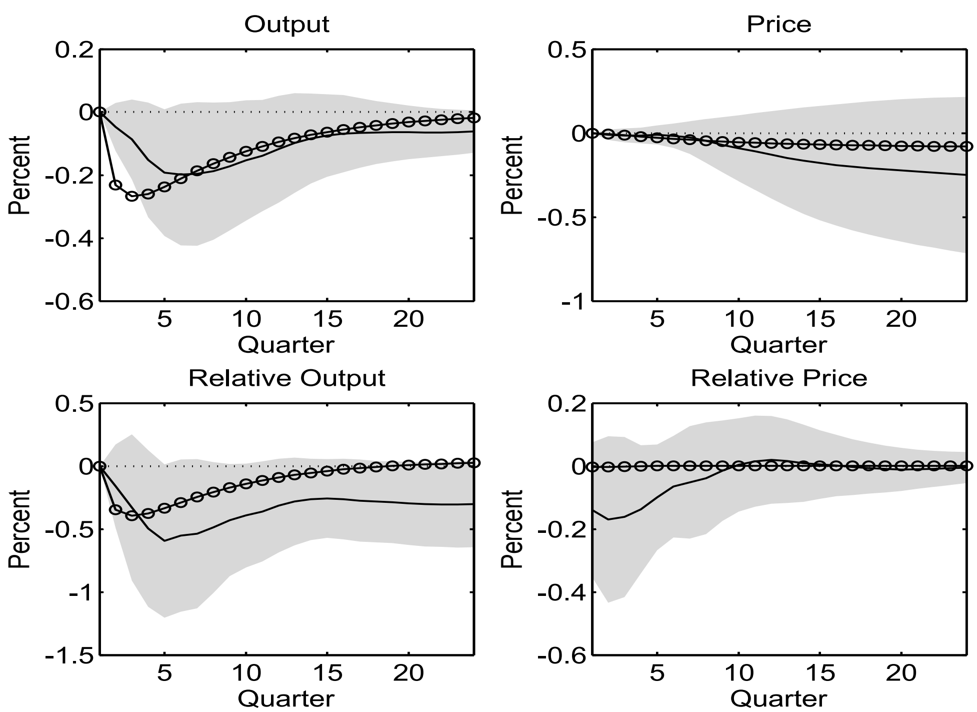
minimization problem:

$$\hat{\Theta}_1 \quad = \quad \arg\min_{\Theta_1} (\hat{\Lambda} - \Lambda(\Theta_1|\Theta_2))'\Sigma^{-1}(\hat{\Lambda} - \Lambda(\Theta_1|\Theta_2)).$$

$\hat{\Lambda}$ is the empirically estimated impulse responses. $\Lambda(\Theta_1|\Theta_2)$ is the theoretical impulse responses generated from the model. Σ is the efficient weighting matrix. The diagonal terms are given by the variances of the coefficients of the IRFs $\hat{\Lambda}$, and the off-diagonal terms are all zero. Then parameters $\hat{\Theta}_1$ is estimated by minimizing the weighted distance between $\hat{\Lambda}$ and $\Lambda(\Theta_1|\Theta_2)$. Standard errors are calculated by the delta method. The moments we choose to match are the IRFs of output, price, relative output and relative price to a monetary policy shock.

Table 4 reports the estimates for adjustment cost, price and wage stickiness and implied average duration between reoptimization. The first and second column are the estimates for matching the IRFs derived in the baseline with short-run identification only, while the third and fourth column are the estimates for matching the IRFs derived from SVAR and SVECM with additional long-run identification. We can see that in the first two columns, adjustment cost and non-durable price stickiness are much higher, compared with those in the last two columns. In particular, in order to match the sluggish and persistent relative price shift, the duration of price stickiness for non-durables is driven to be 20 quarters. Even so, if we look at Figure **??** and Figure **??**, we find that the model implied impulse responses still fail to fall into the 95 percentage confidence interval of the targeted responses. It is especially true for the delayed output responses and long-run movement of relative price. In contrast, when we use the responses estimated with long-run restrictions as matching moments, seen in Figure 9 and Figure 10, the model implied responses by and large stay inside the confidence bands. This is not surprising given the fact that monetary effects are less persistent and more front-loaded. Especially, the small and insignificant responses of relative price suggest the implied duration for reoptimizing price between durables and non-durables are not that substantially different.

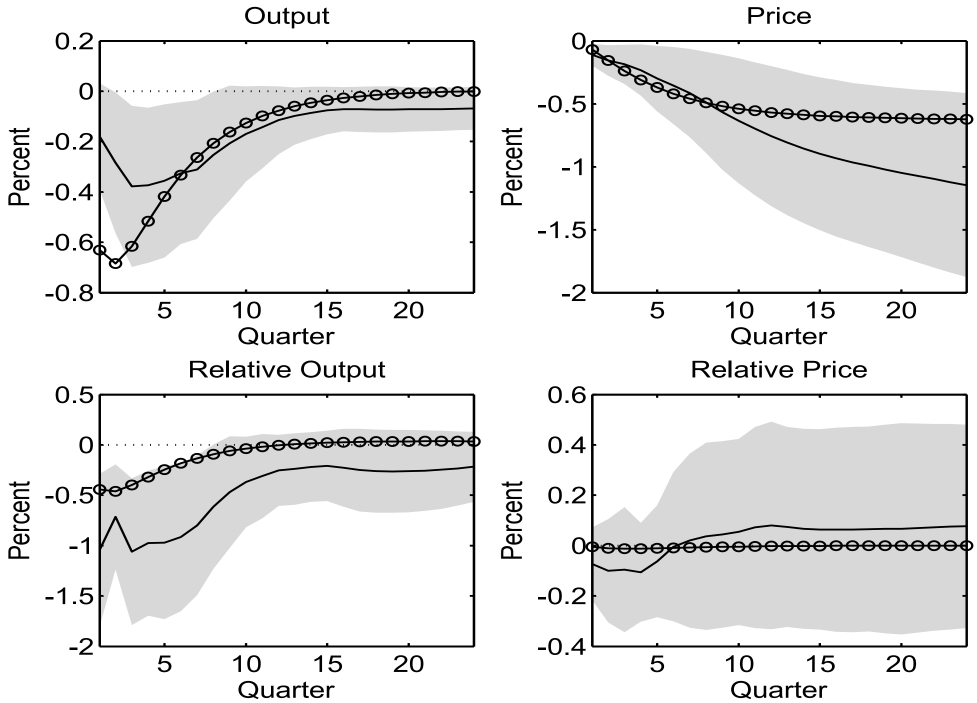
Figure 9. The IRFs to a Monetary Policy Shock (Estimation Target - SVAR)



Notes: The figure depicts the model implied and empirically estimated impulse responses. The solid lines are the IRFs estimated by SVAR with both long-run and short-run identifications. The lines with circles are the model implied IRFs when the empirical counterparts are used as targeting moments.

Furthermore, the first two columns suggest most of the model frictions come from price stickiness and adjustment cost, while the last two columns suggest most of the model frictions come from wage stickiness. Why this is so? If we examine the empirically estimated IRFs across the four identification strategies, they all share that output and price drop after

Figure 10. The IRFs to a Monetary Policy Shock (Estimation Target - SVECM)

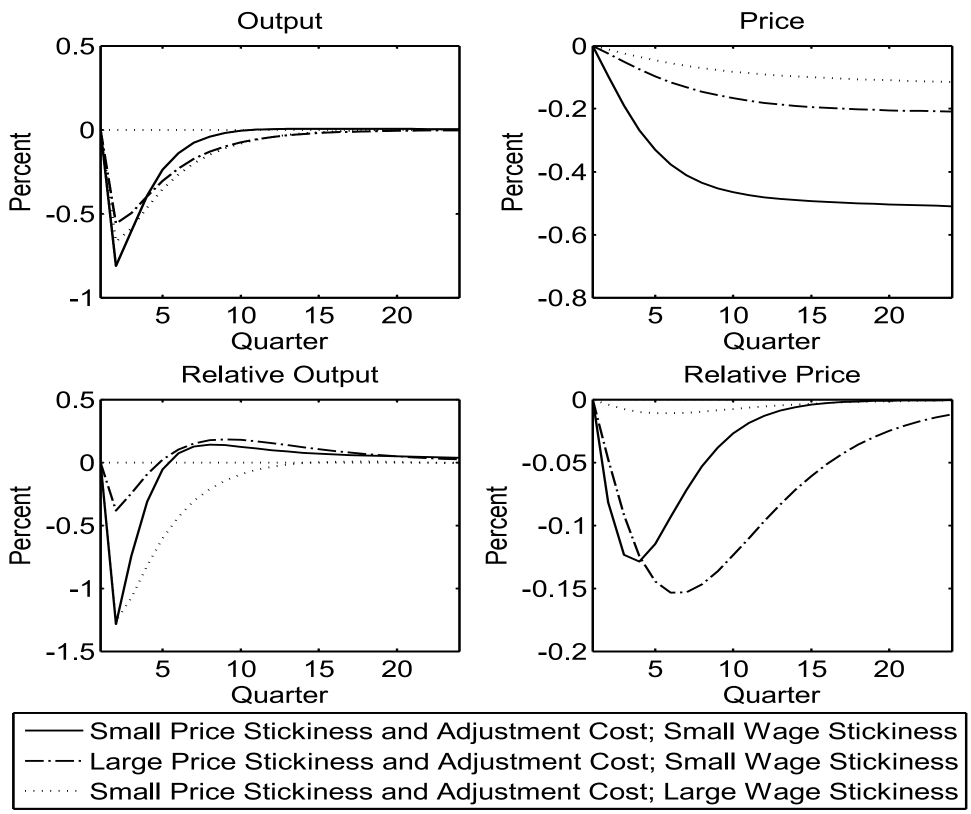


Notes: The figure depicts the model implied and empirically estimated impulse responses. The solid lines are the IRFs estimated by SVECM with long-run identifications. The lines with circles are the model implied IRFs when the empirical counterparts are used as targeting moments.

a monetary contraction, even though they differ in the initial response, persistence and magnitude. However, they have drastic different implications for the movement of relative output and relative price. In Figure 9 and Figure 10, in response to a monetary shock, relative output drops and then reverts back, and response of relative price is small and insignificant. In contrast, in Figure **??** relative output drops and converges back, and more importantly it tends to overshoot steady-state. And response of relative price is large and statistically significant. It is the difference between movement of relative output and relative price that drives the model towards either more wage stickiness or more price stickiness and larger adjustment cost.

This is clearly seen from Figure 11, depicting the model implied responses with various parameter values for price and wage stickiness and adjustment cost. We assume that durables are more price flexible than non-durables. The solid lines are the case with all the parameter values to be small. Now we conduct two experiments. In one case, we increase price stickiness and adjustment cost, shown as the dash lines, and in the other case we increase wage stickiness, shown as the dotted lines. For both experiments, output becomes more persistent and price declines for a smaller amount. So they have similar effects on output and price, that is, from response of output and price only we can not tell which model is

Figure 11. The Model Implied IRFs to a Monetary Policy Shock With Varying Structural Parameter Values



Notes: The figure depicts the model implied IRFs to a monetary policy shock with varying structural parameter values. The solid lines are the IRFs with small price stickiness and adjustment cost, and small wage stickiness. The dash lines are the IRFs with large price stickiness and adjustment cost, but small wage stickiness. The dotted lines are the IRFs with large wage stickiness, but small price stickiness and adjustment cost.

the correct one – the one with large wage stickiness or the one with large price stickiness and adjustment cost. However, if we look at relative output and relative price, results from the two experiments are very different. The one with large price stickiness and adjustment cost cause relative price to decline more and relative output to overshoot after converging back to steady-state. This corresponds to the empirically estimated IRFs in the baseline. The reason is that when we increase price stickiness, particular relative degree of price stickiness between durables and non-durables, relative price drops much more, and hence relative output increase much more.[32] With an additional larger adjustment cost, response of durable output is dampened, which leads to a smaller response of relative output. Thus, we see an upward

[32] This is consistent with the prediction in Barsky, House and Kimball (2007). In response to a contractionary monetary shock, as durables are more price flexible than non-durables, price of durables drops more than non-durables, and hence relative price drops. However, durable output increases and non-durable output decreases. Thus relative output increases after a monetary contraction. This is also called "co-movement" puzzle.

shift in the movement of relative output, but with smaller initial responses. In contrast, the experiment with large wage stickiness cause relative price to decline much less and relative output ceases to overshoot. This corresponds to the empirically estimated responses with additional long-run restrictions. The reason is that in a monopolistic setting, price is chosen to be a constant mark-ups over marginal cost, that is wage here. Wage stickiness effectively enhances price stickiness for both durables and non-durables, but reduces the relative degree of price stickiness as labor is mobile across sectors and wage is equalized. Thus we see much smaller responses in relative price, and relative output declines and then reverts back to steady-state.

Therefore, examining differential monetary effects between durables and non-durables provides us with additional insights about nature of the frictions in the economy. Correctly identifying monetary policy shocks are very important, as different impulse responses have different implications for which frictions are more important than others.

6 Conclusions

In this paper, we examine the impact of an unexpected monetary policy movement in an economy with both non-durable and durable goods sectors. Empirical evidence shows that in response to a monetary policy shock, identified by a structural VAR with short-run recursive assumption, there is a persistent shift in relative price of durables and non-durables. We suggest the key to solve the puzzle is that monetary policy shocks are misidentified and contaminated by technology shocks, which are indeed responsible for the persistent relative price shift. We also find that compared with monetary shocks identified with only short-run assumption, monetary shocks, identified with additional long-run restrictions on technology shocks, are less important for economic fluctuations, and their effects are more front-loaded. Furthermore, examining differential monetary effects between durables and non-durables provides us criteria to evaluate economic models, in addition to responses of output and price. Correctly identifying monetary policy shocks are very important, as different impulse responses have different implications for nature of the frictions in the economy.

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Appendix: Data

Quantity and price indexes for GDP and its components:

Quantity index and price deflator for real GDP and its components are from Bureau of Economic Analysis National Income and Product Accounts (NIPA) Table 1.1.3 (Real gross domestic product, quantity indexes [2005 = 100]), Table 1.1.4 (Price indexes for gross domestic output [2005 = 100]) and Table 1.1.5 (Gross domestic product [Billions of dollars]).

Following Whelan (2002), we calculate the combined index for both non-durable goods and services. In 1996 the U.S. Department of Commerce began using chain-aggregated data in the NIPA, pioneered by Fisher. However, the lack of additivity invalidates the direct addition and subtraction. Here, we use the Divisia index - a simple and very close approximation to the Fisher index. Suppose that we know the real and nominal series for a Fisher chain-aggregate, Y, and one of its components, X, and we want to construct a time series for real Y excluding X (call this series Z). Using the Divisia formula, we know that the following is approximately true:

$$\frac{\Delta Y_t}{Y_{t-1}} = \theta_t \frac{\Delta X_t}{X_{t-1}} + (1-\theta_t)\frac{\Delta Z_t}{Z_{t-1}},$$

where θ_t is the average of the ratio of nominal X to nominal Y in periods t and t-1. This equation can be re-arranged to arrive at an estimate of the growth rate of Z. The level of Z can then be constructed by setting it equal to the nominal series for Y minus the nominal series for X in the base year and chaining forward and back from the base year using the calculated growth rate. In the case of calculating the indexes for non-durable goods and services, we choose Y as personal consumption expenditure and X as durable goods, and then derive time series for Z, which is the aggregate of non-durable goods and services.

Federal funds rate, monetary aggregates and interest rates:

All interest rates and monetary aggregates are from Board of Governors of the Federal Reserve System.

Estimate and forecast $\pi_{t+1}^{D,e}$:

Since the expected price change for durables or expected capital gain ($\pi_{t+1}^{D,e}$) is formed in period t for period $t+1$, we formulate a statistical model of expectation to estimate and forecast the expected series quarter by quarter. For this, we combine the adaptive and extrapolative expectations mechanism as:

$$\pi_{t+1}^{D,e} - \pi_t^{D,e} = (1-\lambda_1)(\pi_t^D - \pi^{D,e}) + \lambda_2(\pi^D - \pi_{t-1}^D),$$

where π_t^D is the actual inflation rate, and λ_1 and λ_2 are the parameters of adaptive and extrapolative expectations, respectively. We have $0 \leq \lambda_1 < 1$ and $\lambda_2 > 0$. We assume $\pi_{t+1}^{D,e}$ is an unbiased estimator for π_{t+1}^D, that is $E(v_{t+1}) = 0$ where $v_{t+1} = \pi_{t+1}^D - \pi_{t+1}^{D,e}$ and v_{t+1} is a random error, distributed normally with white noise. We substitute this into the above equation and provide the estimating equation in the ARMA(1,1,1) process:

$$\Delta\pi_{t+1}^{D} = \lambda_2 \Delta\pi_t^{D} + \upsilon_{t+1} - \lambda_1 \upsilon_t.$$

Price deflator for durable consumption goods starting from year 1948 is used for the estimation and forecast. The resulting series of the expected inflation rate closely tracts the the realized inflation rate, but is much smoother.

We combine the adaptive and extrapolative expectation mechanism:

$$\pi_{t+1}^{e} - \pi_t^{e} = (1-\lambda)(\pi_t - \pi_t^{e}) + \beta(\pi_t - \pi_{t-1})$$

Assume $E_t\epsilon_{t+1} = 0$ where $\epsilon_{t+1} = \pi_{t+1} - \pi_{t+1}^{e}$, we have $ARMA(1,1)$ process:

$$\Delta\pi_{t+1} = \beta\Delta\pi_t + \epsilon_{t+1} - \lambda\epsilon_t$$

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