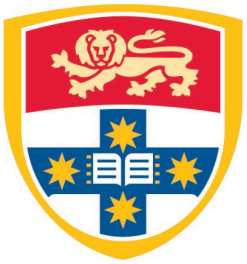

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Transmission of monetary policy shocks: do input-output interactions matter?

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Abstract

We examine whether input-output interactions among industries impact the transmission of monetary policy shocks through the economy. Using Vector Autoregressive (VAR) methods we find evidence of heterogeneity in the output response to a monetary policy shock in both finished goods industries and intermediate goods industries. While output responses in finished goods industries can be related to heterogeneity in industry characteristics, this relationship is not so obvious for intermediate goods industries. For the intermediate goods industries in our sample we find new evidence of demand-spillover effects that impact the transmission of monetary policy via input-output linkages.

Keywords: Monetary policy transmission; input-output; VAR; intermediate goods.
JEL codes: E52; E30; C67.

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1 Introduction

Do input-output linkages that feature prominently in the production chains of the modern economy also impact the transmission of monetary policy?[1] The idea that input-output connections play an important role in business cycle dynamics dates back to von Hayek (1931). According to him, an expansionary monetary policy affects the allocation of factors of production among different stages of production, with the ones further away from consumers (upstream industries in the production chain) experiencing the strongest growth. These distortions along the production chain are ultimately corrected (more strongly for upstream industries) when monetary expansion is reversed. More recently, in examining the transmission effect of demand and supply shocks via input-output linkages, Acemoglu, Akcigit and Kerr (2015) find that demand shocks propagate upstream while supply shocks propagate downstream. The objective of this paper is to isolate the contribution of input-output interactions in the transmission of monetary policy shocks through the economy using standard Vector Autoregressive (VAR) methods and disaggregated data.[2]

While there are many empirical studies that use disaggregated data to document the response of prices to a monetary policy shock, only a few of these studies examine the response of output. Ganley and Salmon (1997) analyze the response of output for 24 U.K. sectors to a monetary policy shock. They classify industries based on their exposure to construction, consumer expenditure or other industrial spending, firm size and concentration and find some evidence for a credit or balance sheet effect of the monetary shock. Dedola and Lippi (2005) conduct a comparable analysis across industries in five OECD countries: France, Germany, Italy, the UK and the US. They find that the cross-country difference in industry-level responses is small compared to the differences across industries. They too focus on industry characteristics such as product durability, firm size, leverage and working capital measures. They find evidence for both the traditional demand channel and the cost channel of monetary policy transmission.[3] Documenting the heterogeneous response

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[2]The two channels generally studied in this literature are the demand channel and the cost channel of monetary transmission. See Mishkin (1996) for an overview.

[3]In a related study, Shea (1993) examines the short-run responses of price and quantity to exogenous demand shocks for disaggregated U. S. manufacturing industries using information on input-output linkages. These linkages are used to identify industries whose fluctuations

of prices to a monetary policy shock and examining the role of input-output interlinkages, Clark (1999) finds that prices at the early stages of production (upstream industries, with less processed output) are more flexible than the prices for finished goods.[4]

In this paper, we examine the response of both prices and output, though we focus primarily on the response of output, to a monetary policy shock using VAR methods. We use price and output data from 35 US industries for the period 1985-2007.[5] These industries represented about 53.4 percent of US manufacturing output in 2007. Consistent with the existing literature, we find that for our sample of industries prices in finished good industries and industries producing more processed goods are more rigid than those in upstream industries, producing primarily intermediate goods. We also find that the examination of price responses alone is not sufficient to infer the response of output across our sample of industries.

Examining the differences in cross-industry output responses and relating them to industry characteristics that proxy for the channels of monetary transmission, we find that both the traditional demand channel (identified through goods' durability) and the cost channel (operating through financing requirements as proxied by working capital commitments) operate more clearly in the sub-sample of finished goods industries. Also, for these finished goods industries, more flexible prices are associated with a more muted response in output, consistent with the predictions of standard models of monetary policy with sticky prices, at least in terms of the sign of our estimated coefficient.

It is then natural to ask why intermediate goods industries appear to behave differently. Could it be that, while finished goods industries are directly exposed to final demand, intermediate goods industries are also exposed to demand spill-over effects based on input-output linkages? Using our sample, we construct three production chains and find new evidence of positive co-movement in the output responses of industries along their respective production chains; changes in output of processed finished goods following the

serve as exogenous demand shocks for other industries.

[4]More recently, DSGE models have incorporated input-output interactions to explain the persistence in aggregate output and inflation (e.g. Huang and Liu, 2001), co-movement in output responses between sticky-price and flexible-price sectors (e.g. Bouakez, Cardia and Ruge-Murcia, 2009), and the observed difference in the speed of sectoral price responses following a shock (e.g. Carvalho and Lee, 2011), among others.

[5]We start the sample in 1985 because the producer price data is not publicly available for most of the industries in our sample before 1985, and we end the sample in 2007 in order to focus our analysis on the effects of conventional monetary policy.

TABLE 1. DATA OVERVIEW

Variable name	Data source
Real GDP (GDP)	FRED
GDP chain-type price index (P)	FRED
GDP implicit price deflator (Def)	FRED
Capacity utilization (TCU)	FRED
Effective federal funds rate (FFR)	FRED
Non-borrowed reserves of depository institutions (NBR)	FRED
Total reserves of depository institutions (TR)	FRED
Industrial production for industry i (IP_i)	Board of Governors
Industry producer price index for industry i (PP_i)	BLS

shock are accompanied by similar movements in the output of their upstream industries. Using a simple correlation analysis we also confirm that the output response to a monetary policy shock in seemingly heterogeneous intermediate goods industries (based on firm characteristics and price response) is related to the output response of their downstream industries: an upstream effect.

The rest of the paper is organized as follows. Section 2 describes the data and methodology. In Section 3 we discuss the results, and Section 4 concludes.

2 Methodology

In this section we first determine the baseline specification of the macro economy which then serves as the macro block in our augmented industry-level VAR specification. We also report the estimated price responses to a monetary policy shock across our sample of industries, which is not the main focus of the paper, for easy comparison with related literature.

2.1 Baseline model for the macroeconomy

Following Christiano, Eichenbaum and Evans (1996), transmission of monetary policy shocks in the aggregate economy is typically examined via a four variable system in real GDP, a measure of prices (e.g. the GDP price deflator, GDP chain-type price index), the effective federal funds rate and a measure of monetary aggregates which is the ratio of non-borrowed reserves to total reserves. However, it has been noted that since this basic VAR system often ignores key variables that influence a policymaker's reaction function such as expectations of future inflation and output gap, the misspecification can im-

pact the correct identification of the monetary policy shock.[6] Following Giordani (2004), we include a measure of capacity utilization (TCU), as a proxy for the output gap in our baseline specification where the variables are ordered as $[GDP\ TCU\ P\ FFR\ NBR/TR]'$. Table 1 provides details about the sources of the data used in the paper. We also use the input-output data from the US Bureau of Economic Analysis (BEA).[7].

We estimate the VARs in levels, data is quarterly and seasonally adjusted; all variables, excluding the effective federal funds rate and capacity utilization, are in logs. Figure 1 plots the response of the price level and output to a monetary policy shock estimated over two different sample periods, 1967-1992 and 1985-2007. Both prices and output fall in response to a monetary policy tightening shock. However, in the latter sample the overall magnitude of the price and output response is approximately 50 percent of that of the earlier period. This result is consistent with the findings of the Great Moderation literature (e.g. Kim and Nelson, 1999 and McConnell and Perez-Quiros, 1998).

2.2 VAR model for industry-level analysis

We now augment the baseline model for the aggregate economy with industry-level variables. The variables in the aggregate economy block are $[GDP\ TCU\ P\ FFR\ NBR/TR]'$, while the industry block variables are $[IP_i\ PP_i]'$.[8] For consistent identification of the monetary policy shock and to compare responses across industries, we assume that the industry variables do not impact the estimation of the macro block and impose coefficient restrictions such that the response of the macro block is unchanged even when we add the industry-level variables. In particular, following Davis and Haltiwanger (2001) and Barth and Ramey (2001), consider the following system of equations for industry i, suppressing the industry-specific subscript for simplicity:

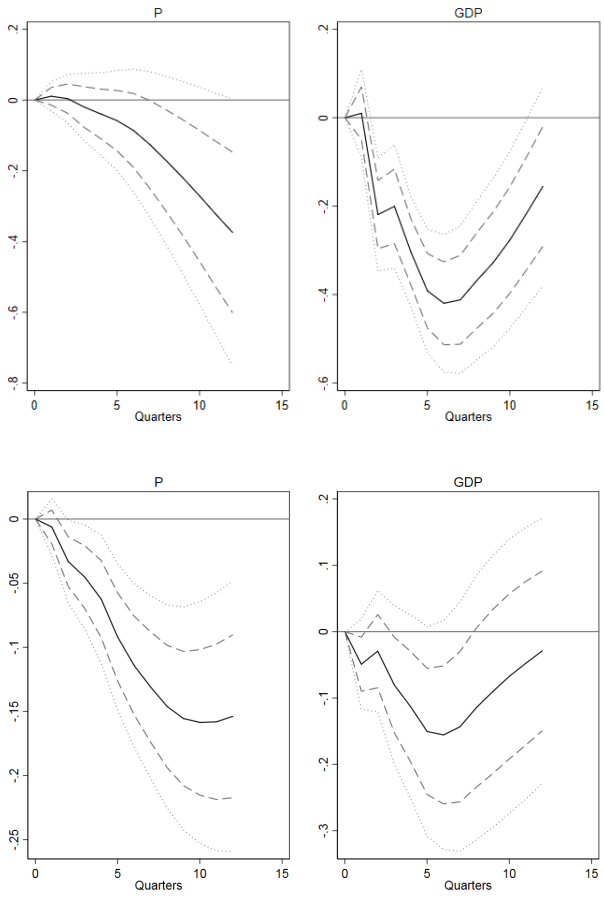
$$Y_t = C + \sum_{j=1}^{p} A_j{}' Y_{t-j} + \epsilon_t, \tag{1}$$

[6]This model mispecification has often been cited as the main reason for the "price puzzle", where the price level measure responds by increasing over a number of quarters following a contractionary monetary policy shock. There are other studies, however, that argue that such a price increase is consistent with the cost channel of monetary policy transmission.

[7]We use the 2007 Input-Output accounts data, in particular Use tables after redefinitions, valued at producers prices, released by the BEA on November 13, 2014.

[8]The monthly data on TCU, FFR, NBR, TR, PP_i was converted into a quarterly frequency and the non seasonally adjusted data such as the TR and PP_i was adjusted using the X11 procedure.

FIGURE 1. PRICE AND OUTPUT RESPONSE IN THE BASELINE SPECIFICATION



Notes: The figure plots the response of the price level and real GDP to a one standard deviation increase in the effective federal funds rate in the baseline specification. The vertical axis measures the percent change. The one standard deviation confidence interval is given by the dashed lines while the 90 percent confidence interval is given by the dotted line. The sample period for the top and bottom panel is 1967:Q1-1992:Q4 and 1985:Q1-2007:Q4 respectively. The VAR is ordered as $[GDP\ TCU\ Def\ FFR\ NBR/TR]'$.

where

$$Y_t^{'} = [GDP_t\ TCU_t\ P_t\ FFR_t\ NBR/TR_t\ IP_{i,t}\ PP_{i,t}]^{'}, \tag{2}$$

and

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}.$$

Here C is a vector of constants, A_{11} is a 5x5 matrix, A_{12} is 5x2 but all its elements are zero, A_{21} is 2x5 and A_{22} is 2x2. The A matrix restrictions ensure that the coefficients of the aggregate block are the same across all vector autoregressions while the industry specific coefficients differ. As is standard in the recursive VAR setting, we identify innovations to monetary policy using a Choleski decomposition, as disturbances to the federal funds rate. We select four lags based on the likelihood ratio test. The sample period is 1985:Q1-2007:Q4.

Table 2 lists the industries that are included in our analysis, their NAICS codes and their share of total US manufacturing output.[9] Overall these 35 industries constituted a 53.4 per cent share of total US manufacturing output. Throughout the paper we classify these industries along a continuum between finished goods producing industries and intermediate goods producing industries. Finished good industries are industries whose output is mostly either consumed (i.e. domestic consumption) or invested (i.e. residential and non-residential investment in equipment and structures). The intermediate goods industries are industries whose output is primarily employed as a production input by other industries. Table 3 reports the share of each industry's output among alternative uses as a percentage of total output, which is the sum of intermediate goods, finished goods, net exports and other uses. Column (ii) reports finished goods output as a share of intermediate and finished goods production and the industries in this table are ordered based on this column; we use this measure for the purposes of our analysis.

2.3 Price response and related literature

Although the focus of this paper is to understand differences in output responses to a policy shock, reported in Section 3, we also report the response of industry producer prices for two main reasons. First, this enables us to

[9]Output for industry 32711 is proxied using industry code 3271, and output for industry 321991 using "all other wood product manufacturing", because of a lack of disaggregated data for these two industries in the Use Tables.

TABLE 2. INDUSTRY OVERVIEW

Industry	NAICS Code	Share of US manufacturing
Chemicals	325	13.8
Plastics	326	3.9
Primary metal	331	5.0
Fab. metal	332	6.4
Sugar	3113	0.5
Fruit and veg.	3114	1.1
Dairy	3115	1.6
Beverage	3121	1.8
Fibers	3131	0.1
Basic chemicals	3251	4.7
Resins	3252	2.1
Agric. chemicals	3253	0.6
Pharmaceuticals	3254	3.4
Cleaning products	3256	1.6
Ind. machinery	3332	0.7
Power equipment	3336	0.8
Comm. Equipment	3342	1.1
Semiconductors	3344	2.3
Appliances	3352	0.4
Aerospace	3364	3.2
Rolling stock	3365	0.2
Ships	3366	0.5
Furniture	3371	0.9
Carpets	31411	0.3
Pulp	32211	0.1
Paper	32212	0.9
Paperboard	32213	0.5
Pap. containers	32221	0.9
Paint	32551	0.4
Tires	32621	0.3
Ceramics	32711	0.2
Cement	32731	0.2
Constr. machinery	33312	0.6
Automobile	33611	4.7
Mobile homes	321991	0.5

Notes: The table reports (in percent) the share of each industry's output in total US manufacturing output (NAICS codes 31-33).

TABLE 3. INDUSTRY OUTPUT BY USE (PERCENT OF TOTAL)

Industry	Intermediate Goods	Finished Goods		Government	Net Exports	Other
		(i)	(ii)			
Automobile	0	145	100	0	−44	0
Appliances	25	142	85	3	−72	3
Carpets	17	94	85	0	−11	0
Beverage	19	95	83	0	−16	1
Constr. machinery	17	74	82	8	4	−2
Ind. machinery	21	74	78	1	3	1
Ships	15	46	75	29	7	3
Fruit and veg.	30	77	72	0	−6	0
Rolling stock	28	68	71	8	−4	0
Cleaning products	30	67	69	0	2	0
Furniture	46	98	68	0	−47	0
Pharmaceuticals	45	93	67	0	−40	1
Sugar	39	73	65	0	−11	−1
Comm. equipment	61	95	61	29	−83	−2
Dairy	51	48	49	0	1	1
Tires	82	58	42	0	−41	1
Mobile homes	71	42	37	0	−12	0
Chemicals	74	32	30	0	−7	0
Aerospace	38	16	30	12	29	5
Paper	77	27	26	0	−4	0
Power equipment	83	22	21	2	−7	1
Ceramics	134	27	17	0	−62	0
Plastics	94	13	12	0	−7	0
Agric. chemicals	103	11	10	0	−14	1
Fab. metal	100	7	7	1	−8	0
Fibers	93	2	2	0	5	−1
Basic chemicals	96	2	2	0	1	0
Paint	95	1	2	0	4	0
Pap. containers	98	1	1	0	1	0
Semiconductors	84	0	1	0	14	1
Resins	86	0	0	0	14	0
Pulp	97	0	0	0	3	1
Paperboard	111	0	0	0	−12	0
Cement	115	0	0	0	−16	1
Primary metal	121	0	0	0	−22	0

Notes: The table reports industry output by use as a percent of the total output: intermediate goods output (column 2), finished goods output (column 3), government, net exports and other (columns 5-7). Note that in constructing the finished goods output (column 3) we exclude the last 3 columns. Column (ii) reports finished goods as a percent of the sum of intermediate and finished goods output (column i) and industries are ordered based on this column.

FIGURE 2. PRICE RESPONSE TO A MONETARY POLICY SHOCK

The figure plots the price response of the industries in our sample to a one standard deviation increase in the effective federal funds rate. The vertical axis measures percent changes. The one-standard error bands are given by the dashed lines while the 90 percent confidence bands are given by the dotted lines.

establish that using our VAR specification and methodology, we obtain cross-industry price responses that are consistent with the existing literature. Second, in the following section we examine whether there is any relationship between the price response of an industry to a monetary policy shock (as a proxy for price rigidity) and its output response to the same shock.

Figure 2 plots the impulse response functions of each industry's producer price index to a monetary policy shock. The figure clearly illustrates that there is heterogeneity in the price response of the industries in our sample.[10] More-

[10]Bouakez, Cardia and Ruge-Murcia (2014) also find cross-sector heterogeneity with respect to the response of inflation and output to a monetary policy shock; for inflation this is primarily because of differences in sectoral price rigidity but, for output response it is also due to

over, consistent with the previous literature, in all industries except communication equipment, prices fall in response to a contractionary monetary policy shock.[11] Also, twelve quarters after the shock, prices remain lower in approximately 90 percent of our sample. This is similar to the response observed for the aggregate price level in Figure 1.[12] Comparing industries, we see that industries displaying smaller maximum price responses include a number of consumer goods producing industries (e.g. beverages, sugar, cleaning products and household goods) as well as industries with complex production processes (e.g. ships, communication equipment, machinery, aerospace products and motor vehicles). Less processed industrial goods and materials (for example pulp, paper, resins, rolling stock and cement), on the other hand, display a relatively stronger price response to the monetary policy shock.

In Figure 3 we plot each industry's average price response between quarters 5 and 8 (one to two years) following the policy shock along the vertical axis against the share of finished goods output in each industry's total output. Therefore, industries close to a value of zero on the horizontal axis primarily produce intermediate goods (e.g. primary metals, resins and pulp), while industries whose final output is almost exclusively a finished good will be close to 1 (e.g. appliances and automobiles). We see that the magnitude of the price response to a monetary policy shock falls as the share of finished goods increases in total industry output, which is a rough proxy for a higher level of processing. Therefore, we find that the stages of processing matter for the magnitude of price responses; whether the final output is primarily a finished or an intermediate good is a key contributor to observed differences in the response of prices across industries to a monetary policy shock.[13] Using a recursive VAR,

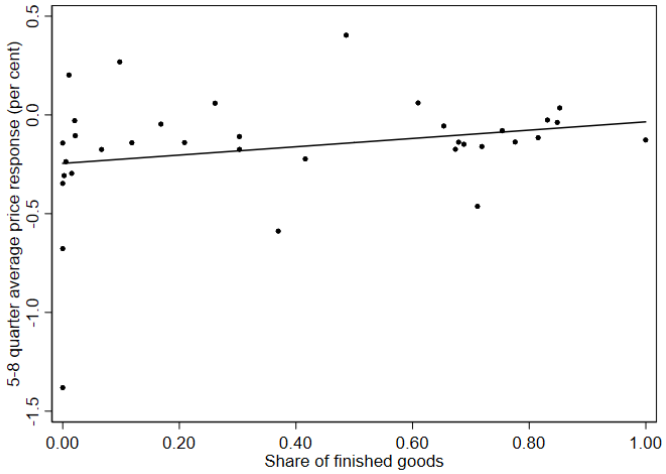
differences in whether the sector produces capital goods. Our results in Section 3 are complementary to Bouakez, Cardia and Ruge-Murcia (2014) to the extent that we also isolate other channels that impact the response of output to a monetary policy shock.

[11]The response of communication equipment manufacturing prices has potentially been impacted by 'digital-revolution' trends over the sample period, and these trends are not accounted for in our analysis.

[12]Note, however, that for some industries the price puzzle still persists even though the aggregate price level falls in response to a negative monetary policy shock in the macro block as seen in Figure 1. To address this issue, one could potentially include a measure of capacity utilization at the industry level but the disadvantage of such an approach would be that the estimate of the monetary policy shock would differ across industries making cross-industry comparisons difficult.

[13]In the literature there are broadly two ways of thinking of production chains: Basu's (1995) "roundabout" production model versus Blanchard's (1983) "inline" or "chain" production model. Using our sample of industries, we also examine whether industries with a higher ratio of intermediate inputs to total industry output present more muted price responses (as

FIGURE 3. PRICE RESPONSE AND THE STAGE OF PRODUCTION



Notes: The figure plots the 5-8 quarter average price response to the monetary policy shock for each industry in the sample (vertical axis, in percent) against the share of industry output classified as finished goods (horizontal axis), column (ii) in Table 3. The Spearman rank correlation between the two variables is 0.35, and it is significantly different from zero at the 5 percent confidence level.

Clark (1999) also finds that prices at the higher stages of production (crude or intermediate goods industries producing less processed output) respond more strongly than finished goods prices.

3 Results

In this section we first report cross-industry heterogeneity in output response to a monetary policy shock. We then examine whether there is any relationship between an industry's output response to a monetary policy shock, its price response to the same shock, industry characteristics and inter-industry linkages.

3.1 Response of output

While the literature has carefully documented the response of prices across various industries to a monetary policy shock, the response of output has been

measured by the average price response over 5-8 quarters), as implied by Basu's roundabout production model. The Spearman Rank correlation coefficient between the two variables is 0.02, and is not significantly different from zero. This result suggests that, even though the data has both inline and roundabout features, our sample of industries appears to be more consistent with the inline production process of Blanchard (1983) than the roundabout production process of Basu (1995), as also noted in Clark (1999).

FIGURE 4. OUTPUT RESPONSE TO A MONETARY POLICY SHOCK

The figure plots the response of industrial output in our sample of industries to a one standard deviation increase in the effective federal funds rate. The vertical axis measures percent change. The one-standard error bands are given by the dashed lines while the 90 percent confidence bands are given by the dotted lines.

TABLE 4. MAXIMUM RESPONSE BY INDUSTRY (IN PERCENT)

	Price	Output
Mobile homes	−0.69***	−3.89***
Rolling stock	−0.64*	−2.23**
Comm. equipment	0.01	−2.11*
Ind. machinery	−0.16***	−1.12
Fibers	−0.12	−1.10**
Aerospace	−0.21**	−0.94
Agric. chemicals	−0.06	−0.85***
Resins	−0.78	−0.84***
Ceramics	−0.22**	−0.82
Constr. machinery	−0.18*	−0.79
Primary metal	−0.41	−0.78*
Carpets	−0.18	−0.77**
Pulp	−1.76*	−0.77*
Appliances	−0.18*	−0.74***
Sugar	−0.13	−0.73**
Automobile	−0.24	−0.69
Basic chemicals	−0.12	−0.67**
Paper	−0.82*	−0.47**
Paint	−0.44*	−0.46*
Plastics	−0.32*	−0.45**
Furniture	−0.18***	−0.44*
Ships	−0.12	−0.38
Chemicals	−0.19	−0.35***
Tires	−0.37**	−0.35
Cement	−0.55	−0.28
Pap. containers	−0.51	−0.27*
Power equipment	−0.28***	−0.26
Pharmaceuticals	−0.20	−0.24
Dairy	−0.62**	−0.23
Fruit and veg.	−0.27***	−0.20**
Cleaning products	−0.15*	−0.14
Beverage	−0.14**	−0.04
Paperboard	−1.12**	−0.04
Fab. metal	−0.27	0.00
Semiconductors	−0.43	0.15
Aggregate	−0.16***	−0.16

Notes: The table reports the response in industry prices and output following a one-standard deviation shock to the effective federal funds rate. As the policy shock is a negative shock, 'maximum' responses displayed are intended to be the lowest points in Figures 2 and 4. The industries in the table are ordered based on the strength of their maximum output response to the monetary policy shock. Superscripts *, ** and *** indicate rejection of the null hypothesis of zero at the 10, 5 and 1 percent level respectively.

examined less often.[14] We report the estimated response of industrial output $[IPi]$ for our sample in Figure 4 and Table 4.

Like industry-level prices, output also falls after monetary policy is tightened and there is again heterogeneity in cross-industry responses (see Figure 4). However, twelve quarters after the shock, output in about two-thirds of industries has recovered. Comparing with the overall response of prices this suggests that the divergence of long-run effects of a monetary policy shock on real and nominal variables documented for aggregate data (see for example Christiano, Eichenbaum and Evans, 1996) is also seen at a more disaggregated level, consistent with other studies using industry level data such as Dedola and Lippi (2005), and Barth and Ramey (2001). From Figure 4 and Table 4, we can see that many of the industries displaying a strong output response can be classified within the heavy manufacturing industries group (for example rolling stock, machinery production, aerospace and chemicals); conversely, food-related goods and household consumables are among those industries that show very little response to the shock (fabricated metals represent somewhat of an exception to this pattern). To understand this heterogeneity in output responses, we relate the output response of industries in our sample to their price response and a range of industry characteristics in the following subsection.[15]

3.2 Price rigidity, industry characteristics and output response

Can we infer the response of output in our sample of industries based on cross-industry differences in price response to a monetary policy shock and industry characteristics? We examine this here.

Using maximum output response to a monetary policy shock in each industry, we first examine whether industries with more flexible prices also exhibit a weaker output response to a monetary policy shock. Focusing on the full sample of industries, the first row in Table 5 reports the Spearman rank correlation, which is small and negative, between the maximum output response

[14] A few exceptions are Dedola and Lippi (2005), Barth and Ramey (2001), Ganley and Salmon (1997).

[15] We also examine whether there is a significant relationship between output response and the share of finished goods in an industry's output given our findings in Figure 3. However, the correlation between maximum output response and the share of finished goods is small, at -0.09, and with a p-value of 0.59. This suggests that the significant degree of heterogeneity in output responses across industries is not correlated with an industry's share of finished goods output in its total output.

for each industry and the average price response over 5-8 quarters after the initial shock. The negative correlation suggests that following a contractionary monetary policy shock, sectors that experience a large drop in prices exhibit a smaller output response. But since this correlation is small and not significant, we cannot infer output responses to a monetary policy shock in our sample of 35 industries based on price responses alone.[16]

We also examine how industry characteristics such as average firm size, short-term financing needs, and the nature of output produced – durable versus non-durable – influence the cross-industry output response. Following Ganley and Salmon (1997), we construct a measure of firm size based on average value added by dividing the total value added for each industry by the number of companies in the industry using data from the 2007 US Census. It is generally believed that industries with larger firms, on average, will display a smaller output response to the monetary policy shock.[17] For our full sample of industries we only find a weak positive relationship, see the second row in Table 5.

An industry's financing needs and its exposure to short-term debt have also been considered in the literature (for example, Barth and Ramey, 2001, and Dedola and Lippi, 2005) as a possible cost-channel factor that impacts how different industries respond to a policy shock. We proxy for an industry's short-term financing needs with a measure of inventory levels where the total value of end-of-year inventories is divided by the total value added for each industry using 2007 US Census data. The Spearman rank correlation between the maximum output response for each industry and our measure of financing needs is -0.31. Therefore, output in industries that hold a larger stock of inventories responds more strongly to a monetary policy shock. This is consistent with previous empirical findings, which typically identify this effect through broader measures of working capital.[18]

Finally, on the demand side, according to Mishkin (1996) a lower nominal

[16]The results in Tables 5 and 6 are qualitatively similar if we compute this correlation using 4-quarter or 6-quarter price response measures.

[17]Firm size can be used as a proxy for an industry's ability to withstand credit shocks where larger firms are likely to be less impacted by credit market imperfections. See Gertler and Gilchrist (1994) for more details.

[18]Barth and Ramey (2001) use both gross (inventories plus trade receivables) and net (minus trade payables) working capital measures to study the short-term transmission of monetary policy shocks via the cost channel. Dedola and Lippi (2005) construct a measure of working capital as the difference between current liabilities and current assets, divided by total liabilities: they find stronger output responses in industries with higher short-term finance requirements as proxied by this measure.

TABLE 5. RESPONSE OF OUTPUT

	Full sample	Finished goods	Intermediate goods
Price rigidity	−0.07	−0.16	0.04
	(0.71)	(0.58)	(0.85)
Firm size	0.04	0.04	−0.01
	(0.81)	(0.89)	(0.98)
Inventory size	−0.31	−0.45	−0.20
	(0.07)	(0.11)	(0.39)
Non-durable goods	−0.47%	−0.35%	−0.53%
	(0.00)	(0.04)	(0.00)
Durable goods	−0.96%	−1.06%	−0.85%
	(0.00)	(0.00)	(0.10)

Notes: The top panel reports the Spearman rank correlation of the maximum output responses with price rigidity, firm size and inventory size measures for the full sample, finished and intermediate goods industry. The bottom panel reports the average of the maximum response (in percent) for non-durable and durable goods industries. The p-values are reported in parenthesis.

interest rate reduces borrowing costs, thus stimulating both business investment and the purchase of consumer durables. Purchases of non-durable goods are expected to be less interest-sensitive.[19] The bottom panel in Table 5 reports the average maximum output responses for industries producing non-durable and durable goods. The NAICS classification of manufactured goods' durability is used to allocate industries between the two groups. As expected, on average, the output response in industries producing durable goods is larger relative to industries producing non-durable goods.

Overall, for our full sample of industries we find that the cross-industry output responses to a policy shock can be related to both: the cost channel operating through financing requirements as proxied by working capital commitments; and a traditional demand channel, identified through goods' durability.

Our main objective, however, is to understand whether input-output linkages between industries influence the transmission channels discussed above. For this purpose we split our sample of 35 industries in two groups: finished and intermediate goods producers (see last two columns of Table 5). 21 indus-

[19] According to Erceg and Levin (2006), durable goods are typically more responsive to an interest rate shock because demand for durables is a demand for stock and changes in stock demand imply much larger fluctuations in the flow of newly produced durable goods, and therefore industry output. Our findings in Table 5 are consistent with the responses these authors obtain from their two-sector VAR.

TABLE 6. ALTERNATIVE MEASURES OF OUTPUT RESPONSE

	Full sample	Finished goods	Intermediate goods
	8-quarter response		
Price rigidity	−0.26	−0.09	−0.28
	(0.14)	(0.76)	(0.21)
Firm size	0.05	0.17	−0.10
	(0.77)	(0.55)	(0.65)
Inventory size	−0.20	−0.57	0.03
	(0.25)	(0.04)	(0.90)
Non-durable goods	−0.09%	−0.19%	−0.04%
	(0.12)	(0.15)	(0.49)
Durable goods	−0.34%	−0.57%	−0.11%
	(0.13)	(0.05)	(0.75)
	5-8-quarter average response		
Price rigidity	−0.09	0.17	−0.13
	(0.62)	(0.57)	(0.58)
Firm size	0.06	0.16	−0.06
	(0.72)	(0.60)	(0.81)
Inventory size	−0.25	−0.42	−0.22
	(0.14)	(0.13)	(0.33)
Non-durable goods	−0.23%	−0.22%	−0.24%
	(0.00)	(0.15)	(0.00)
Durable goods	−0.48%	−0.60%	−0.37%
	(0.04)	(0.03)	(0.34)

Notes: The top panel reports the Spearman rank correlation of the 8-quarter output response with price rigidity, firm size and inventory size measures for the finished and intermediate goods industry. It also reports the average of the 8-quarter response (in percent) for non-durable and durable goods industries. The bottom panel reports the same statistics using the 5-8 quarter average output response. The p-values are reported in parenthesis.

tries whose 'finished goods share', as reported in the fourth column of Table 3, is lower than 50 percent are classified as intermediate goods producers and the remaining 14 as finished goods industries.

Interestingly, when considering finished goods industries alone, the correlation between the maximum output response in these industries and price rigidity and industry characteristics generally becomes stronger or remains unchanged, even though like in the full sample the p-values with respect to price rigidity are still very high. In particular, the average output response for durable goods within this group is -1.06 per cent, significantly larger than for non-durable goods at -0.35 per cent.[20]

On the other hand, the relationship between output response, price rigidity and industry characteristics becomes less clear for the intermediate goods industries group. In particular, the sign is incorrect with respect to price rigidity and firm size when considering intermediate goods industries and the relationship with respect to inventory size becomes weaker. In addition, for intermediate goods industries, the output response of durable goods industries is not statistically different from the response estimated for non-durable goods. The interest rate sensitivity of durable goods demand appears weakened when only considering intermediate goods, while it remains clear for finished goods. In the following subsection we explore more closely the output response of intermediate goods industries in light of their input-output connections with the finished goods sector, as a possible explanation for their seemingly weaker relationship with traditional monetary transmission channels.

So far in Table 5, we have only used maximum responses of output to a monetary policy shock for our sample of industries when considering the relationship between output response and price rigidity and industry characteristics. This measure has the advantage of isolating each industry's peak (most negative) response to the shock and, as shown in Table 4, a majority of the observations used is either significant or otherwise very close to zero. In Table 6 we examine whether our results are robust to the use of alternative measures of output response to the monetary policy shock. Following Dedola and Lippi (2005), we use two alternative measures: the output response 8 quarters following the policy shock; and an average of output responses between 5 and 8 quarters. Qualitatively, our main findings remain unchanged under most scenarios. The relationship between price rigidity and finished goods indus-

[20]The null hypothesis that these two averages are the same is rejected at the 95 per cent confidence level.

try output, however, has a positive sign when we use the average 5-8 quarters output response.

3.3 Input-output linkages and output response

In this subsection we first provide qualitative evidence on industry interlinkages by constructing three production chains. We then use our full sample of industries to examine whether the demand spill-overs from downstream industries impact their suppliers, the upstream effect, motivated by the analysis in Acemoglu, Akcigit and Kerr (2015). They find that demand shocks propagate upstream, with suppliers of industries that are directly affected by the shock impacted more than their downstream customers.

3.3.1 Examples of input-output chains

Splitting our sample of industries based on the primary use of their final output, as in Table 3, only provides us with a broad initial classification. To get a better understanding of how industries are inter-connected, we now construct three production chains and observe how industry output responds along these three chains: paper, construction material and chemicals. In each chain we have either grouped industries with material input-output linkages (e.g. paper chain), or industries with common downstream markets (e.g. construction material and chemical chains). The industries included in the three chains account for approximately one-third of US manufacturing production in 2007. Each entry in Table 7 reports the percentage of the intermediate output of the corresponding row industry purchased by the corresponding column industry. For example, in the chemical chain, an entry of 19 in the first row means that 19 percent of the intermediate output of the basic chemicals industry is purchased by the resin industry.[21]

The impulse response of output along the paper production chain provides initial evidence of co-movement (Figure 5, a) based on input-output linkages.[22] In response to the contractionary monetary policy shock, the output of the paperboard containers industry (facing a less volatile demand for its final output

[21]The rows in Table 7 do not sum to 100 because the table does not include all uses of the intermediate output of each industry; it only includes those that are in our sample.

[22]Note that in these impulse response functions, industrial output responds to the policy shock at date zero, as the FFR precedes the industry variables in the ordering of the VAR specification; while this is required for the identification of the shock, the contemporaneous responses don't necessarily have a practical interpretation.

TABLE 7. PRODUCTION CHAINS

PAPER CHAIN

	Pulp	Paper	Paperboard	Pap. containers	Chemicals	Plastics	Food/Bev	Constr.	Gov.
Pulp	6	57	3	7	5	–	–	–	–
Paper	–	–	–	26	1	3	–	1	11
Paperboard	–	–	–	41	1	1	1	2	–
Pap. containers	–	2	1	1	10	6	12	2	1

CONSTRUCTION MATERIAL CHAIN

	Cement and concrete	Primary metal	Fab. Metal	Constr. machinery	Carpets	Mobile homes	Motor vehic.	Other Transp.	Constr.	Gov.
Ceramics	2	11	1	–	–	–	1	–	55	1
Cement	73	–	–	–	–	–	–	–	14	–
Primary metal	–	25	25	1	–	–	12	3	1	–
Fab. Metal	1	2	12	1	–	–	10	3	23	2
Constr. machinery	–	–	–	7	–	–	–	1	44	–
Appliances	–	–	–	–	–	3	8	–	62	–
Furniture	–	–	–	–	–	5	2	–	50	–
Fibers	–	–	–	–	35	–	3	–	–	1
Carpets	–	–	–	–	6	2	51	16	23	–
Mobile homes	–	2	1	–	–	3	2	–	28	13

CHEMICAL CHAIN

	Basic chemicals	Resins	Paint	Plastics	Tires	Fab. metal	Motor vehic.	Constr.	Gov.
Basic chemicals	39	19	2	4	1	–	–	–	4
Resins	–	7	3	53	2	1	3	–	–
Paint	–	–	1	–	–	16	12	18	4
Plastics	1	1	–	8	1	1	10	14	5
Tires	–	–	–	4	4	–	30	11	9

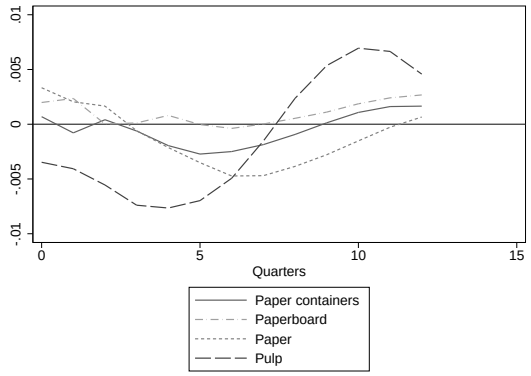
Notes: The table reports the percentage share of row industry intermediate output purchased by each column industry. Calculations are based on the 2007 US input-output table (Source: BEA).

from a varied group of industries, including food) presents a relatively muted response. In turn, the output of the paperboard industry, of which 41 percent is used as an intermediate good by the paperboard container industry, mimics the output response of the latter. The paper industry which supplies only 26 percent of its output to the paperboard containers industry, and is therefore less reliant on this industry's demand for its output, reacts more strongly to the monetary shock. Finally, further upstream, the pulp industry, which supplies 57 percent of its output to the paper industry, experiences an even greater fall in output, highlighting the role of demand-driven co-movements.

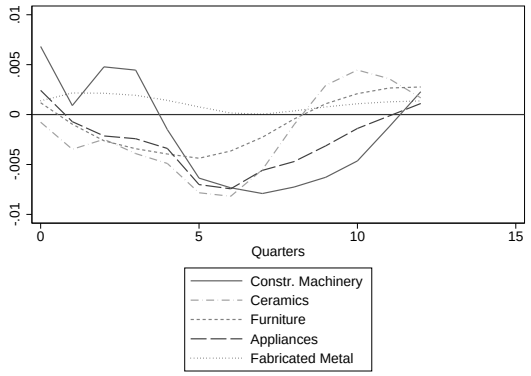
We also see evidence of industry-interlinkages in Figures 5 (b) and (c) where industries face common downstream markets and therefore have similar demand exposures. Figure 5 (b) plots the output response of industries that are exposed to the construction industry. We find that industries selling around a quarter or more of their intermediate goods output into construction co-move; output is slightly lower and broadly unchanged for the first three-four quarters following the shock, and then declines more strongly prior to recovering gradually after the sixth quarter.[23] Similarly, in the chemical chain in Figure 5

[23]This response is visible for both intermediate and finished goods industries exposed to construction. The finished good industries (e.g. appliances and construction machinery) are included in the figure to approximate the behavior of the construction sector, which is not directly included in our VARs due to lack of data. Lagged demand from the pipeline of con-

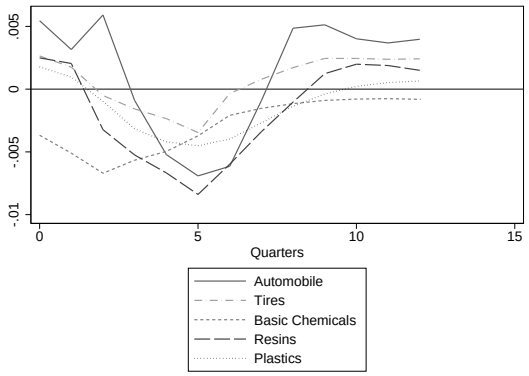
FIGURE 5. OUTPUT RESPONSE IN PRODUCTION CHAINS



(a) Paper chain



(b) Construction material chain



(c) Chemical chain

Notes: The figure plots the response of industrial output to a one-standard deviation increase in the effective federal funds rate in the three production chains. The vertical axis measures changes in log values.

(c), the output response of most industries closely follows the dynamics of automobile manufacturing: an initially muted response followed by a significant drop until the fifth quarter and finally a v-shaped recovery after the fifth quarter. This is possibly because approximately 10-30 percent of the final output in paint, plastics and tires is supplied to the motor vehicle manufacturing industry. Table 7 also outlines further direct links among chemical manufacturers contributing to observed co-movement.[24]

struction activity in the periods immediately following the shock could potentially be delaying the initial response.

[24]The smoother decline and recovery of plastics manufacturing output could be due to its exposure also to the construction industry, to which it sells 14 percent of intermediate output. Output of the tires industry, which displays a more moderate maximum response, is also exposed to more stable demand from government and final consumers (Table 3). Basic chemical manufacturing, with a broader client base, displays a stronger initial drop in production levels,

Overall, these three production chains provide visual evidence of co-movement in the output responses of industries with clear input-output linkages.

3.3.2 Full sample analysis

Here we examine whether the demand spill-overs from input-output linkages seen in the three production chains are also present in our full sample of industries. To isolate the impact of output responses to a monetary policy shock in downstream industries on their upstream suppliers we compute, for each industry i in the sample, the Spearman rank correlation between $\Delta IP_{i,t}$ and $\Delta Down_{i,t-1}$; where $\Delta IP_{i,t}$ is the estimated output impulse response in industry i to a time 0 monetary policy shock, expressed as deviation from the steady state and $Down_{i,t-1}$ is defined as follows:

$$Down_{i,t} = \sum_{j=1}^{34} \alpha_{ij} \Delta IP_{j,t}, \qquad i \neq j. \tag{3}$$

Note that α_{ij} is the share of industry i's intermediate output sold to industry j based on the 2007 input-output table. Therefore, the output response of each downstream industry is weighted by its relevance to the intermediate demand faced by industry i.[25]

In Figure 6 we plot along the vertical axis the Spearman rank correlation between each industry's own output response and that of its downstream industries, against the share of finished goods in each industry's total output. As before, industries close to a value of zero on the horizontal axis primarily produce intermediate goods, while industries whose final output is almost exclusively a finished good will be close to 1.

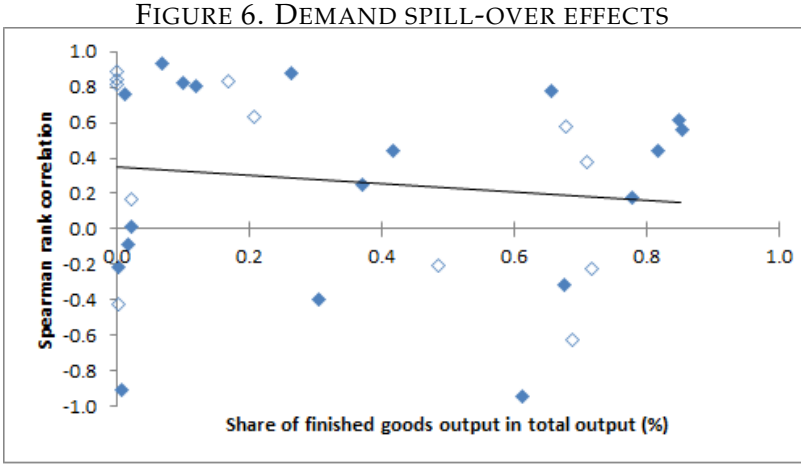
Our conjecture is that this spill-over demand channel should be more important for intermediate goods industries than for finished goods; we therefore expect the Spearman rank correlation for the former to be positive and larger relative to the latter. As expected, the slope of the fitted line in Figure 6 is negative at -0.24, although with a p-value of 0.47.[26] Note, also, that the aver-

followed by a slower recovery pattern.

[25]This analysis excludes the chemicals industry (NAICS 325) in order to avoid duplications with the sub-industries included, e.g. basic chemicals, resins, etc. It also excludes all instances of within-industry output usage, i.e. where $i = j$ in equation 3. In addition, in our dataset there are 3 industries (NAICS 33611, 3366, and 3121) that do not have any downstream industries that use their output as an intermediate good. For these industries, the Spearman rank correlation could not be computed.

[26]Also note that if we add a durable goods dummy, the slope of the fitted line in Figure 6 is still -0.22 with a p-value of 0.52.

FIGURE 6. DEMAND SPILL-OVER EFFECTS



Notes: For each industry i the figure plots Spearman rank correlation between ΔIP_t and $\Delta Down_{t-1}$ along the vertical axis and the share of finished goods in total output along the horizontal axis. The total number of industries is 31.

age of the Spearman rank correlation coefficients for the intermediate goods industries in our sample is 0.37 (p-value of 0.01), while for finished goods the average correlation is smaller at 0.12 and not statistically significant (p-value of 0.52). Further, most of the intermediate goods industries for which the correlation coefficient is statistically significant display large and positive spill-overs from their downstream industries (see top left corner of Figure 6).[27] For finished goods the significant coefficients are more dispersed.

Both the visual intuition from the example production chains and our correlation analysis suggest that relationships in the input-output table also matter for the transmission of monetary policy shocks. In particular we find that for our sample of intermediate goods industries, the transmission of monetary policy shocks is affected by demand-spillover effects via input-output linkages which are not captured by traditional analysis based on industry characteristics (Table 5).

4 Conclusion

We examine cross-industry differences in output responses to a monetary policy shock using standard econometric techniques from the empirical literature. We find evidence of strong heterogeneity in the response of finished goods industries and intermediate goods industries to a monetary policy shock. As

[27] Primary metal and semiconductors are an exception where the correlation is large and negative, even though these are primarily intermediate goods industries.

expected from theory, for industries producing finished goods, industry characteristics are closely related to the industry's output response. However, for intermediate goods industries the price response and industry characteristics play a relatively less important role. In our analysis of 35 industries, we find that it is input-output linkages that play an important role in these intermediate goods industries. In particular, output responses in downstream industries seem to impact the production levels of their suppliers. Therefore, our analysis suggests that underlying output responses in seemingly heterogeneous intermediate goods industries to a monetary policy shock there is a complementary demand channel, observed through output co-movement along our three sample production chains and in Figure 6.

In recent years, these input-output connections have been introduced in multi-sector DSGE models to evaluate the design of monetary policy rules.[28] Motivated by the empirical results in Clark (1999), Huang and Liu (2005) build a two sector DSGE model with a vertical input-output structure, with the intermediate goods sector selling its output as an input for the production of finished goods; they find that a policy rule in which both final goods and intermediate goods' inflation are targeted performs better that the traditional rule, where only final goods inflation is targeted. This is because, in these models, the relative price distortion between sectors generated by the input-output connections has a direct impact on sectors' real marginal costs. Using a similar model, Strum (2009) also finds that dual price level targeting (targeting both finished and intermediate goods' pricing) yields the best welfare outcomes. Our empirical analysis shows that a key distinction between the output response of finished goods and intermediate goods industries is that the latter face demand-spillover effects. What still remains to be examined in a DSGE setting is whether these spillover effects are quantitatively significant and should the policy also respond to the output gap in the intermediate goods sector in its policy rule.

[28] Another strand of the DSGE literature introduces these input-output interactions with the objective of resolving the co-movement puzzle between the durable and non-durable sector. See for example Bouakez, Cardia, and Ruge-Murcia (2011).

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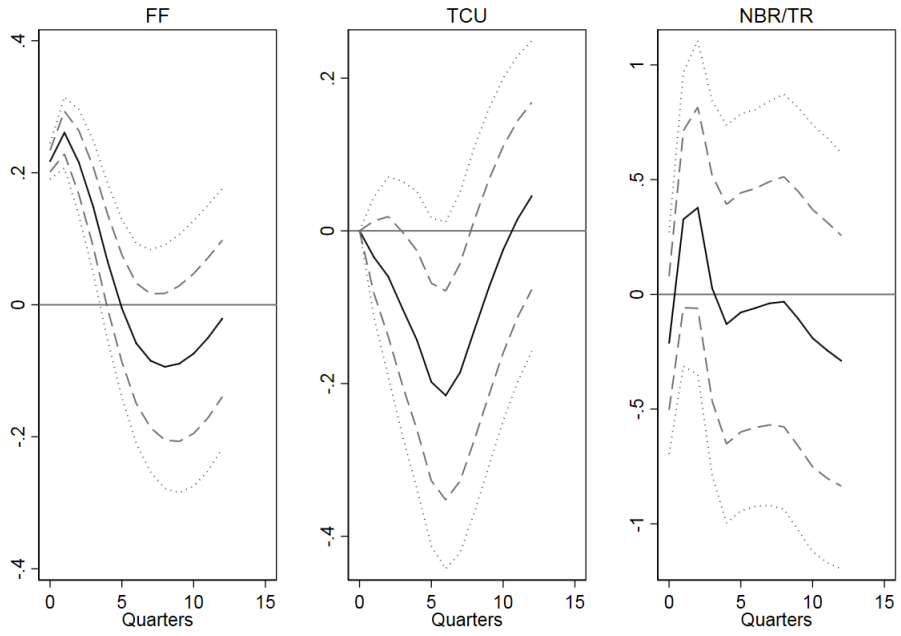
A Online Appendix

Figure A1 plots the response of the other variables in the macro block. The left panel plots the response of the federal funds rate (the monetary policy shock driving the responses of the other variables included in our main analysis), the middle panel plots the response of total capacity utilization and the right panel plots the response of NBR/TR following a contractionary monetary policy shock. The pattern of the shock is similar to that observed by Christiano, Eichenbaum and Evans (1996), although the later sample period used in our analysis leads to the identification of a shock of smaller magnitude. Note also that the response of the total capacity utilization variable is very similar to the response of the sensitive commodity price index, a variable used in their analysis to address the price puzzle.

FIGURE A1. RESPONSE OF OTHER VARIABLES IN THE MACRO BLOCK



Notes: The figure plots the response of the federal funds rate, total capacity utilization rate and the non-borrowed reserves to total reserves to a one standard deviation increase in the effective federal funds rate in the baseline specification. The vertical axis measures the percent change in NBR/TR. The one-standard error bands are given by the dashed lines while the 90 percent confidence bands by the dotted lines. The sample period is 1985:Q1-2007:Q4. The VAR is ordered as $[GDP\ TCU\ P\ FFR\ NBR/TR]'$.