MONETARY POLICY AND SECTORAL SHOCKS:
DID THE FED REACT PROPERLY TO THE HIGH-TECH CRISIS?

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ABSTRACT

This paper presents an identification strategy that allows us to study both the sectoral effects of monetary policy and the role that monetary policy plays in the transmission of sectoral shocks. We apply our methodology to the case of the U.S. and find some significant differences in the sectorial responses to monetary policy. We also find that monetary policy is a significant source of sectoral transfers. In particular, a shock to Equipment and Software investment, which we naturally identify with the High-tech crises, induces a response by the monetary authority that generates a temporary boom in Residential Investment and Durable Consumption but has almost no effect on the high-tech sector. Finally, we perform an exercise evaluating what the model predicts regarding the automatic and a more aggressive monetary policy response to a shock similar to the one that hit the U.S. in early 2001. We find that the actual drop in interest rates we have observed is in line with the predictions of the model.

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1 Introduction

The long boom experienced by the U.S. during the 90's came to an end in 2001 with a large decline in information technology (IT) investment. After growing at 16% during 2000, IT spending fell by 6% in 2001, while the NASDAQ lost half its value between September 2000 and March 2001.

The Federal Reserve responded to the end of the high-tech bubble and the general collapse of U.S. stock markets by sharply reducing interest rates, cutting them by a total of 4.75 percentage points during 2001. This loosening of monetary policy was accompanied by markedly different performances across sectors. While sectors like housing and automobiles experienced a significant boom, IT spending remained largely unaffected during 2002.[1] These differences brought into the debate the ability of an interest rate based monetary policy to deal with sectoral shocks.

There are two aspects in this debate. The first aspect is about the sectoral effects of monetary policy. There are, of course, important reasons to care about these effects. For example, monetary policy will have a strong redistributive component if different sectors of the economy have different interest rate sensitivities. In this case, aggregate output stabilization via monetary policy would be achieved by inducing larger cyclical fluctuations in interest rate sensitive sectors. The decoupling of these sectors with respect to the rest of the economy may induce some important redistributive effects in the presence of sector specific factors of production. For instance, a monetary policy aimed to stabilize aggregate output may fail to stabilize employment in response to a shock to a low interest rate sensitivity sector when there are some sector specific aspects of human capital. A different reason to care about the heterogeneous effect of monetary policy is the implications it has about the effectiveness of monetary policy as a policy tool. The ability of an interest-rate-based monetary policy to jump-start the economy will depend on the relative importance of high interest rate sensitivity sectors as a fraction of GDP. We may expect then to find a link between output composition and the effectiveness of monetary policy, which may be especially important for policymakers.

The second aspect of the debate is about the role that monetary policy plays in the transmission of sectoral shocks. By changing the level of interest rate in response

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[1]IT spending remained flat during 2002, and business forecasts predict only a small recovery for 2003. On the other hand, construction of new homes hit a 16-year high in December 2002, and sales of new cars experienced its largest historical volume during 2001.

to a sectoral shock, monetary policy may either dampen or amplify the dynamic propagation of shocks across sectors. An appropriate understanding of the way in which monetary policy interacts with sectoral shocks is also very important for policy design, and has been largely unexplored in the literature.

This paper presents an empirical methodology based on the estimation of a structural VAR to analyze the sectoral effects of monetary policy. This methodology allows us to compare the effects of monetary policy across sectors in terms of their delay, persistence, and sacrifice ratio. In addition, our methodology also allows us to determine how a sectoral shock is transmitted to the rest of the economy, both directly (through the interactions among sectors) and indirectly (through monetary policy).

The methodology we propose is an extension of the standard VAR models of monetary policy (Bernanke and Blinder (1992), Bernanke and Mihov (1998), Christiano and Eichenbaum (1992), Christiano, Eichenbaum, and Evans (1999)) that decomposes aggregate GDP and includes all the components simultaneously in the VAR. The identification of this structural VAR is largely based on standard assumptions: (i) monetary policy responds contemporaneously only to the aggregate price index and GDP; (ii) all the components of GDP responds to monetary policy only with a lag. The only additional assumption we make is that the only source of contemporaneous comovement across sectors is the presence of correlated innovations.[2] This assumption allows us to solve the problem in the degrees of freedom that arises in the unrestricted estimation.

We apply our methodology to U.S. data. We decompose GDP into 7 components– durable consumption, non-durable consumption, consumption of services, residential investment, investment in structures, equipment-and-software investment, and a residual–and characterize the response of each of this components to a monetary policy shock. The results we obtain show that, even at this level of aggregation, there are considerable differences across components in the response to monetary policy. In particular, consumption of durables, consumption of non-durables, and residential investment have the largest response to monetary policy. A mild response is observed in equipment-and-software investment, and, as in other studies (Bernanke and Gertler (1995)), we find that investment in structures does not respond to monetary policy.

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[2]The assumption that there is no contemporaneous relation across sectors has however been implicitly present in papers that study the sectoral effects of monetary policy by looking at one sector at a time (Bernanke and Gertler (1995), Barth and Ramey (2001), Rigobon and Sacks (1998)). In contrast to our approach, these papers do not assume any correlation among sectoral perturbations.

We also find that a shock to investment in equipment-and-software generates a significant effect on aggregate GDP. However, its effect on the consumption of durables, consumption of non-durables, and residential investment is brief because of the countervailing effect of the automatic monetary policy response induced by the shock. Moreover, we find that a monetary policy shock aimed to smooth the shock to equipment-and-software will generate a significant boom in the rest of the economy, especially in residential investment and durable consumption.

Overall, the simulated pattern of responses shows remarkable similarity with the evolution of the U.S. economy after the high-tech crises, both qualitatively and quantitatively, which highlights the usefulness of our methodology for the analysis of monetary policy.

This paper is part of the vast empirical literature on the effects of monetary policy. Our methodology builds on the structural VAR approach used in this context by Bernanke and Blinder (1992), Bernanke and Mihov (1998), Christiano and Eichenbaum (1992), and Christiano, Eichenbaum, and Evans (1996b,a), among others. We extend this methodology to explore the sectoral effects of monetary policy and to consider the transmission of sectoral shocks. The sectoral effects of monetary policy have been previously studied by Bernanke and Gertler (1995) and Barth and Ramey (2001), among others. Our paper extends this literature in several dimensions. First, these papers rely on the standard recursiveness assumption for identification and typically add a subset of sectors to an aggregate VAR to avoid getting into a degrees of freedom problem.[3] The problem with this approach is that the whole VAR is re-estimated for each subset of sectors added to the specification.[4] Therefore, the structural parameters of the monetary policy rule are allowed to change across specifications.[5] Second, by analyzing all sectors simultaneously we can study how shocks

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[3] Under the recursiveness assumption, the number of structural parameters grows quadratically with the number of sectors in the VAR. So, adding one sector requires a significant increase in the number of observations.

[4] In this sense, the approach lacks internal consistency. Some of the papers in this literature (Barth and Ramey (2001), Dedola and Lippi (2000)) have an additional consistency problem: they add each sector at the bottom of the aggregate VAR. This boils down to assume that monetary policy affects aggregate GDP only with a lag, but affects contemporaneously each of its components.

[5] Rigobon and Sacks (1998) partially addressed the issue of the stability of the parameters by using a two step procedure that first estimates the structural innovations from an aggregate VAR and then feeds these innovations as exogenous variables in the dynamic specification of sectoral output. Even though this approach maintains the parameters of the monetary policy response stable across sectors, it is less efficient than our procedure, and it also does not permit to analyze the transmission of sectoral shocks.

to particular sectors impact other sectors and the rest of the economy. In contrast, most of the papers in the literature study one sector at a time using the recursiveness assumption. Therefore, they cannot be used to analyze the transmission of sectoral shocks.

The rest of the paper is structured as follows. Section 2 describes the empirical methodology and the identification assumptions. Section 3 documents the sectoral effects of monetary policy in the U.S.. In section 4, we use our model to analyze the effect of a shock to equipment-and-software on the rest of the U.S. economy and to determine the consequences of a monetary policy aimed to stabilize that shock. Section 5 concludes.

2   Empirical methodology

2.1   Standard VAR Analysis of Monetary Policy

We will use a Vector-Autoregression (VAR) model to estimate the sectoral effects of monetary policy. The use of VAR to identify exogenous shocks to monetary policy and their effect on different economic aggregates was pioneered by Sims (1980) and further developed by Bernanke and Blinder (1992) and Christiano and Eichenbaum (1992), among others. The standard model in the literature can be represented by the following structural VAR:

$$A_0 X_t = \sum_{i=1}^{q} A_i X_{t-i} + \varepsilon_t, \tag{1}$$

where $X_t = (Z_t, S_t)'$, S_t is the instrument of the Monetary Authority, Z_t are the variables in the Monetary Authority's information set, and q is a non-negative integer. This specification assumes that the Monetary Authority follows a policy rule that is linear on the variables in Z_t and their lags. In addition, it is assumed that the perturbations ε_t have the following properties:

$$E[\varepsilon_t] = 0; E[\varepsilon_t \varepsilon_\tau'] = \begin{cases} D & \tau = t \\ 0 & \text{otherwise} \end{cases}.$$

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The estimation of this model is usually performed in two steps. First, the parameters of the corresponding reduced form VAR are estimated:

$$X_t = \sum_{i=1}^{q} B_i X_{t-i} + u_t,$$

then the structural parameters (A_i and D) are recovered by making a series of identification assumptions. The most widely used identification assumption in the literature is the "recursiveness assumption". This approach corresponds to assume that the structural errors (ε_t) are orthogonal ($D = I$) and the matrix summarizing the contemporaneous relations between the variables in the VAR (A_0) is block diagonal. That is, it is assumed that the variables in X_t can be arranged as $X_t = (Z'_{1t}, S_t, Z'_{2t})'$ and

$$A_0 = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix}.$$

Intuitively, the recursiveness assumption corresponds to assume that the monetary policy rule responds to contemporaneous values of the variables in Z_{1t}, but these variables respond to the monetary policy instrument only with a lag. Analogously, variables in Z_{2t} are contemporaneously affected by the monetary policy instrument, but they affect the monetary policy rule only with a lag.

The recursiveness assumption is not enough to recover all the structural parameters of the model. The reason is that the equations in the upper and lower block of the matrix are indistinguishable from each other because of the block diagonal structure of A_0. Nevertheless, it can be demonstrated that the assumption is sufficient to identify the column of A_0 associated with the monetary policy instrument, which is enough to determine the response of all the variables to a monetary policy shock. However, identification through the recursiveness assumption does not permit to determine the response of the different variables to any other structural shock.

The set of variables included in the monetary policy rule (Z_t) varies considerably among the papers in the literature. The most simple model considers a measure of activity (usually GDP) and a measure of price level (usually the CPI or the GDP deflator).[6] There are also differences regarding the variable to include as the monetary

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[6]Most of the papers also include a measure of commodity prices to account for the "price puzzle"

policy instrument. While some papers argue in favor of using the Federal Funds Rate (Bernanke and Blinder (1992), Bernanke and Mihov (1998)), others have argued in favor of using the level of non-borrowed reserves (Christiano and Eichenbaum (1992)) or the ratio of non-borrowed to total reserves (Strongin (1995)). Regardless of the monetary policy instrument considered, the literature typically assumes that the monetary policy rule responds to contemporaneous values of the measures of activity and prices, but these respond to the monetary policy instrument only with a lag.[7]

This methodology has proved to be extremely useful in understanding the dynamics of a monetary economy, but it is not exempt of critique. Particularly, the zero-restrictions implicit in the block diagonal structure of A_0, which are crucial for the identification of the monetary policy innovations, are arbitrary and have been subject to debate.[8] We do not address these critiques in this paper, as we are mainly concerned with understanding the sectorial aspects of monetary policy.

In summary, the standard way of determining the effects of monetary policy in the literature is to estimate a reduced form VAR model including at least a measure of activity, price level, and a monetary policy instrument. The recursiveness assumption is then used to identify the relevant structural parameters. In the next section we will show how, with minor modifications, this simple framework can be extended to the analysis of the sectoral effects of monetary policy and the interactions among sectors.

2.2   A sectoral model of monetary policy

The approach we follow to estimate the sectoral effects of monetary policy is a simple extension of the standard model in the literature. As discussed in the previous section, the simplest model of monetary policy in the literature considers a monetary policy rule based on aggregate activity and prices. The structural VAR representation of this model corresponds to equation (1), where $X_t = (Y_t, P_t, F_t)$, Y_t is the GDP level, P_t is the price level, and, following Bernanke and Blinder (1992), F_t, the Federal Funds rate, is the policy instrument. The model is usually estimated in reduced

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(see Christiano, Eichenbaum, and Evans (1999)).

[7]Bernanke and Blinder (1992) and Christiano, Eichenbaum, and Evans (1996b) consider also the possibility that the monetary policy instrument responds only with a lag to activity and prices, which respond contemporaneously to the monetary policy shock.

[8]See Faust (1998), Faust, Rogers, Swanson, and Rigth (2003), Rudebusch (1998), and Uhlig (1999).

form, and the structural parameters relevant for the transmission of monetary policy are recovered using the recursiveness assumption.

To understand the sectoral effects of monetary policy, we decompose the measure of activity into N different components, so $X_t = (Y_{1t}, \ldots, Y_{Nt}, P_t, F_t)$. If we were to identify this VAR through the recursiveness assumption we would have to assume that:

$$A_0 = \begin{bmatrix} A_{11} & A_{12} & 0 \\ A_{21} & a_{22} & 0 \\ A_{31} & a_{32} & a_{33} \end{bmatrix} \tag{2}$$

where A_{ij} are the natural expansions of the a_{ij} elements to N variables.[9]

This identification would allow us to recover the structural parameters from the reduced form parameters. However, the disaggregation of the measure of activity into its components would lead us very quickly into a degrees of freedom problem. Indeed, this model has $(N+2)^2(q+1) + 1$ parameters,[10] so we would need at least $(N+2)(q+1) + 1$ observations of each variable. Assuming that the frequency of the data is equal to the number of lags, this implies that we would need at least $T = (N+2) + (N+3)/q$ years of data in order to estimate the parameters. For example, if we were using 7 sectors and quarterly data, 12 years of data would leave us with zero degrees of freedom.

An additional problem with the use of the recursiveness assumption to estimate the sectoral model is that it can only identify the sectoral effects of monetary policy, but it cannot identify the effects of a sectoral shock on the rest of the economy. Identifying the effect of these shocks requires assumptions on the coefficients of A_0 beyond the block diagonal structure. In particular, it requires that enough conditions are imposed on the coefficients of A_{11} so that each equation can be individually identified.

For the previous reasons, we depart from the recursiveness assumption and use an identification scheme that combines some elements of the recursiveness assumption with additional assumptions from the simultaneous equations view of identification. In particular, we assume that (i) the price level index relevant for monetary policy depends only on aggregate activity, (ii) the monetary policy rule is a function only of the aggregate activity and price level index, (iii) the structural innovations to different

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[9]For example, a_{31} is a 1 x 1 element that corresponds to the response of the interest rate to output, then A_{31} is the 1 x N vector of how the N sectors impact the interest rate.

[10]Under the recursiveness assumption, A_0 has $(N+2)(N+1) + 1$ parameters, A_i $i = 1, \ldots, q$ has $(N+2)^2$, and D has $(N+2)$ variances.

sectors are correlated, (iv) each sector's activity affects other sectors only with a lag. These assumptions impose the following structure on A_0 and D:

$$A_0 = \begin{bmatrix} I_N & A_{12} & 0 \\ \alpha\,e_N' & 1 & 0 \\ \beta\,e_N' & \beta_p & 1 \end{bmatrix}, \tag{3}$$

$$D = \begin{bmatrix} \Sigma & 0 & 0 \\ 0 & \sigma_p^2 & 0 \\ 0 & 0 & \sigma_F^2 \end{bmatrix}, \tag{4}$$

where e_N is a vector of ones of dimension N and Σ is a NxN matrix Assumptions (i) and (ii) are captured by imposing a common coefficient for all sectors in the rows of A_0 associated with the price index and monetary policy rule (α and β respectively). These assumptions are implicit in the papers that estimate the effects of monetary policy using aggregate data (e.g. Bernanke and Blinder (1992), Christiano and Eichenbaum (1992)), and they help us to reduce the degrees of freedom problem. They boil down to assume that the Taylor rule followed by the Monetary Authority depends only on aggregate indicators. Assumptions (iii) and (iv) are non-standard and require further discussion. As previously mentioned, the standard recursiveness approach would have A_{11} unrestricted and Σ diagonal, so the sectoral shocks would be completely idiosyncratic and any contemporaneous comovement across sectors would be due to the simultaneous relations captured in A_{11}. Instead, our identification scheme assumes that all contemporaneous comovement among sectors is due to the correlation among their structural innovations. By doing so, we reduce the number of structural parameters to be estimated in $N(N-1)/2$. The obvious cost of this assumption is that we impose symmetry in the contemporaneous relations across sectors.

Before proceeding further, note that assumptions (i)-(iv) are not necessary to identify the sectoral effects of monetary policy. Besides the degrees of freedom issue, which is not minor, the sectoral effects of monetary policy could be determined from the estimation of the structural model of equation (2) under the recursiveness assumption. What we buy with assumptions (iii) and (iv) is the possibility of analyzing the effects of a sectoral shock. The cost is that the structural sectoral shocks are non-orthogonal. So, a possible critique to our approach is that we make assumptions

to identify the effect of sectoral shocks, but we obtain a model in which these shocks are not truly independent. In order to address this critique, we also estimate our model imposing some additional structure in the covariance matrix that introduce independent sectoral shocks. In particular, we also consider the case in which sectoral shocks are orthogonal and all the correlation among sectors is due to an aggregate shock. This corresponds to assume that:

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\begin{aligned}
\varepsilon_t &= \Gamma z_t + \mu_t, \\
E[z_t] &= 0, \; E[z_t^2] = \sigma_z^2, \\
E[\mu_t] &= 0, \; E[\mu_t \mu_t'] = \Omega \text{ diagonal,}
\end{aligned}
$$

where $\Gamma = (\gamma_1, \ldots, \gamma_N, 0, 0)'$.

Of course, this is not the first attempt to estimate the sectoral effects of monetary policy. The main contribution of this paper is our identification approach, which allows us to identify the sectoral effects of monetary policy and the transmission of sectoral shocks simultaneously, making very few additional assumptions with respect to the standard VAR models in the literature. The approach typically followed in the literature on the sectoral effects of monetary policy (e.g. Barth and Ramey (2001), Dedola and Lippi (2000)) is to estimate a structural VAR that includes aggregate variables (GDP, a price index, and a commodity price index), the monetary policy instrument (usually the federal funds rate), and an index of industrial activity (typically an industrial production index)–in that order–and that identifies the effects of monetary policy using the recursiveness assumption. That is, they assume $X_t = (Y_t, \, P_t, \, CP_t, \, F_t, \, Y_{it})'$. Under the standard recursiveness assumption the ordering of this VAR assumes that the monetary policy rule reacts contemporaneously to the values of Y_t, P_t, and CP_t, but those variables react to the monetary policy instrument only with a lag. It also assumes that monetary policy responds to the activity of sector i with a lag, but sector i is affected contemporaneously by the monetary policy instrument. It is clear that these two sets of assumptions are mutually inconsistent: we cannot assume simultaneously that monetary policy does not affect any component of aggregate activity contemporaneously, but it does affect contemporaneously the sum of them. More importantly, by estimating a different VAR for each sector these papers permit variation both on the parameters of the monetary policy rule and on the information set relevant for the monetary policy response. This affects

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the ability of the model to make meaningful comparisons about the effects of monetary policy across sectors. In contrast, we provide a methodological framework that estimates a common monetary policy rule across sectors, which allows us to perform meaningful comparisons, and it is based on a clear set of identification assumptions that can be subject to debate and robustness checks.

3 Sectoral effects of monetary policy in the U.S.

This section presents the results obtained by applying our methodology to the estimation of the sectoral effects of monetary policy in the U.S.. We decompose U.S. GDP into seven components: Consumption of Durables ($CDUR$), Consumption of Non-Durables ($CNDUR$), Consumption of Services ($CSER$), Residential Investment ($IRES$), Equipment-and-Software Investment ($IEQUIP$), Investment in Structures ($ISTRUC$), and a residual compressing government expenditure, inventory investment, and net exports. We use the Consumer Price Index (CPI) as a measure of the price level and the Federal Funds Rate (FFR) as the monetary policy instrument. So, our vector X_t corresponds to ($CDUR_t$, $CNDUR_t$, $CSER_t$, $IRES_t$, $IEQUIP_t$, $ISTRUC_t$, $IRES_t$, CPI_t, FFR_t)$'$, and we estimate the structural parameters of (3) and (4) by Maximum Likelihood[11] using quarterly data for the period 1955:1-2002:3[12]. We fist present the results obtained for aggregate activity (the sum of the sectoral effects) and compare them with previous results in the literature as a benchmark for our methodology. Next we turn into the sectoral results.

3.1 An aggregate benchmark

In an aggregate model of monetary policy with GDP, prices, and the Federal Funds Rate (FFR) in the VAR, the matrix A_0 has 3 relevant parameters: (i) the effect of output on prices, (ii) the automatic response of the FFR to output, and (iii)

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[11]The parameters can also be estimated by a two-step procedure in which the first step consists on the estimation of the reduced form parameters and the second step recovers the structural parameters using GMM. The results obtained with both procedures are remarkably similar. The main difference is that, consistent with the larger degrees of freedom of the ML estimation, the main structural coefficients (A_0 and Σ) are more precisely estimated. For a discussion of the results obtained with the two-step procedure see the appendix.

[12]The data on the GDP components was obtained from the Bureau of Economic Analysis. Data on CPI and the FFR was obtained from the website of the Federal Reserve Bank of St. Louis.

the automatic response of the FFR to prices. As our methodology assumes that the *contemporaneous* Taylor rule followed by the Monetary Authority responds only to aggregate quantities, we directly estimate each of this parameters (α, β, and β_p in equation (3) respectively). The coefficients estimated for these parameters are reported in Table 1. The results are consistent with a policy rule aimed to stabilize output and prices. The coefficients of β and β_p are negative, which implies that the Monetary Authority tends to raise the FFR as a response to an increase in output or prices. The three coefficients are statistically significant at conventional levels.

[Table 1 about here.]

The coefficient obtained for α is somewhat puzzling because it implies that prices fall contemporaneously as a response to an increase in output. There could be two possible explanations for this result: First, commodity prices induce negative correlation between prices and output and we are not controlling for them. In general, an increase in oil prices (for example) increases the aggregate price and tends to reduce output. Indeed, our impulse responses clearly show the well known "price puzzle" which requires the introduction of commodity prices to eliminate it. Second, it is possible that this output innovations could be productivity shocks. In those circumstance, a productivity increase is associated with a reduction in prices.

Figure 1 presents the impulse response function of aggregate GDP and prices to a one standard deviation shock to the FFR. The GDP is computed by aggregating the individual sectorial responses to the monetary policy innovation.

The monetary policy shock–corresponding to an 80 basis points rise in the FFR– induces an immediate response on aggregate GDP, which contracts for about 8 quarters before starting to return to its baseline level.[13] Prices experience an initial increase but start falling around the 5th quarter[14] The main message from this exercise is that our estimations of the size of the shock and the responses of the aggregate variables are qualitatively and quantitatively consistent with previous estimations

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[13]The magnitudes are expressed in percentage points. As the GDP series is normalized by the average real GDP in the last 5 years, the impulse responses correspond to percentage deviations from that baseline

[14]The initial rise in prices corresponds to the so-called "price puzzle". The usual explanation for the price puzzle is that it is due to the misspecification resulting from omitting some leading indicators of inflation that are part of the Central Bank's information set (Sims (1992)). The typical solution to the price puzzle is to include a commodity price index in the VAR. We do not include it in order to focus on the sectoral results.

from aggregate VAR (see Bernanke and Gertler (1995), Christiano, Eichenbaum, and Evans (1999)).

[Figure 1 about here.]

3.2 How the residuals look like?

In the empirical literature of monetary policy under the structural VAR approach, the estimated structural residuals of the monetary policy equation are interpreted as monetary policy shocks. Similarly, in our approach the structural innovations to a sector's equation are interpreted as (non-orthogonal) shocks to that sector. In this section, we describe some characteristics of the structural residuals and compare them with previous estimations of the innovations to monetary policy and recent events in the U.S. economy. This comparisons allows us to observe whether our model is capturing some salient features of the data.

3.2.1 Comparing the policy shock measure

Figure 2 compares the policy shock measure obtained in our estimations with two previous measures of monetary policy shocks in the literature: the Romer's dates (Romer and Romer (1989)) and one of the measures obtained by Christiano, Eichenbaum, and Evans (1996b)[15]. We observe that there is a strong correlation between our measure and the one obtained using the Christiano et al. model. This is not really surprising if we remember that our identification assumptions regarding the monetary policy rule are very similar to theirs.[16] The main difference between our specification and theirs is that Christiano et al. assume that the Monetary Authority also responds to the level of total and non-borrowed reserves (though only with a lag). This seems not to be a first order issue given the high correlation between the two series of structural residuals.

The relation between our policy shock measures and the Romer episodes is also surprisingly good. With the exception of the third quarter of 1978–period in which

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[15]For comparability reasons, we use the specification with the Federal Funds Rate as policy instrument, no commodity prices, and benchmark identification (see Christiano, Eichenbaum, and Evans (1996b), pp. 43). As the authors emphasize, all their measures are qualitatively similar.

[16]As noted above, the restrictions imposed on the parameters force the monetary policy rule to respond only to aggregate GDP and price levels, not to their composition. This is exactly what Christiano et al. implicitly assume by using aggregate data.

the Romer report a tightening of monetary policy–the Romer episodes are clearly associated with the presence of positive monetary policy shocks.

In summary, the monetary policy shocks estimated from the structural residuals of our model seem to conform well with the results of previous studies.

[Figure 2 about here.]

3.2.2 The High-Tech crises and the 1990-1991 recession

The late 90's saw an immense expansion of the IT related businesses. The NASDAQ composite index, which was closely associated with the "new economy", reached a peak in February 2000 at almost 5000 points, three times larger than its 1997 level of about 1500. All these hype came to a sudden stop in late 2000 and early 2001. Between August 2000 and August 2001 the NASDAQ fell from 4200 to 1800 points, a 60% fall in only 1 year. At the same time, after growing at 16% during 2000, IT investment fell by 6% in 2001. The onset of crisis on the high-tech sector marked the end of the 90's expansion in the U.S. and started the beginning of the current recession. This episode is clearly captured by our methodology. Our estimated structural residuals show a 2.6 and 3.9 standard deviation shocks to equipment and software investment precisely in the first two quarters of 2001.[17] This situation is depicted in Figure 3, which shows the structural residuals of the equipment and software investment series.[18] We clearly observe a large negative shock in the late 2000 and early 2001. Note that this shock is larger than any other shock previously experienced by this sector. Additionally, notice that our residuals also show consecutive positive innovations during the 90's reflecting the large boom that the sector experienced during that time.

[Figure 3 about here.]

Our structural residuals also seem to be capturing the events of the 1990-1991 recession. Between the second quarter of 1990 and the second quarter of 1991 (the official peak and trough dates according to the NBER) we observe large negative shocks

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[17]Shocks of this magnitude are rare, with only 4 episodes of shocks larger than 2.5 standard deviations observed within sample (2% of observations). In other words, the distribution of the structural residuals has no particularly fat tails (though they are fatter than the normal case).

[18]By construction, the structural residuals are serially uncorrelated, so the series are very noisy. Following Christiano, Eichenbaum, and Evans (1996b), we report the centered three quarter moving average of the residuals.

to residential investment (2 std. dev.), consumption of services (2.5 std. dev.), and consumption of durables (1.8 std. dev). The situation is summarized in Figure 4, which shows that this was clearly an episode of constrained aggregate demand. Overall, these findings are consistent with the general view that the 1990-1991 recession was largely associated with a consumer confidence crises.

[Figure 4 about here.]

3.2.3 September 11 and the Accounting Scandals

The economy was also subject to two important shocks at the end of 2001 and the beginning of 2002: September 11 and the accounting scandals after the collapse of Enron. Because our data is quarterly it is impossible for us to disentangle these two shocks. However, we can evaluate their overall effect.

As can be seen in Figure 5, most sectors were recovering from the High-Tech crisis when they were hit by September 11 and the accounting scandals shock. Most sectors show positive innovations at the end of 2001 that are reverted considerably for the first quarter of 2002 and beyond.

[Figure 5 about here.]

3.3 Sectoral sacrifice ratios to monetary policy tightening.

Figure 6 shows the impulse responses functions of the different GDP components to a one standard deviation contractionary shock to the Federal Funds Rate. The figure also displays the 90% confidence bands associated to the impulse response functions.[19]

The monetary policy shock has a significant and lasting effect in four sectors: Consumption of Durables, Consumption of Non-Durables, Consumption of Services, and Residential Investment. A minor effect is observed in Equipment-and-Software Investment. As previously found in the literature (Bernanke and Gertler (1995)), Investment in Structures is largely unaffected.

[Figure 6 about here.]

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[19]The confidence bands were estimated by bootstrap. Our procedure to build the confidence intervals is more conservative than the standard approach followed in the literature, so our bands tend to be wider. The procedure is described in the appendix.

The delay of monetary policy is roughly similar across sectors, but some interesting differences are observed. The trough of the response of GDP to the shock is achieved in 8 quarters. So, the maximum effect of monetary policy is achieved two years after a shock. This magnitude is similar across those sectors in which monetary policy has a statistically significant effect: the maximum effect of the shock in Consumption of Durables, Services, and Residential Investment is also experienced at the 8th quarter. The only deviation is observed for Consumption of Non-durables, with a trough in the 12th quarter. Some differences in delay across these sectors are also observed when we compare the first period in which their response to the monetary policy shock is statistically different from zero. According to this measure, the delay of monetary policy is shorter in Residential Investment and Services than in the Consumption of Durables and Non-Durables: while Residential Investment and Services respond almost immediately to the monetary policy shock, the shock has no effect on the Consumption of Durables and Non-Durables until around the second quarter.

One of the sectors with the longest delay to monetary policy is Equipment-and-Software Investment with a trough at the 10th quarter. This finding provides some evidence that Equipment-and-Software has a particularly slow response to monetary policy. Indeed, it is only around the 8th quarter that the effect of monetary policy is statistically different from zero for reasonable (although non-standard) confidence levels.

The impulse response functions also show that the monetary policy shock is highly persistent. According to the point estimators, GDP has still not returned to its baseline level after 20 quarters. This high persistence is also observed across sectors, where, with the exception of Services, none has returned to its baseline level after 20 quarters. A conservative measure of the persistence of monetary policy is given by the number of periods during which the effect of monetary policy is significantly different from zero at conventional levels. Using this measure we obtain that the persistence is of about 9 quarters for Consumption of Durables, 12 quarters for Consumption of Non-durables, 4 quarters for Consumption of Services, and 14 quarters for Residential Investment. Under this measure the persistence in Equipment-and-Software Investment would be around 2 quarters.

A probably more interesting measure of the effect of monetary policy across different sectors is the sacrifice ratio. These ratios are reported for the different sectors in Table 2. The ratios were computed using the point estimates and represent a measure

of the output loss resulting from the monetary policy shock for each sector as a fraction of its baseline level. They correspond to the area under the normalized impulse response functions during the period of time elapsed until each series returns to its baseline level or twenty quarters. The normalized impulse responses for the different sectors are reported in Figure 7. We observe in Table 2 that the two sectors with the largest sacrifice ratio are Residential Investment and Consumption of Durables. This is not surprising considering that Residential Investment is only 4.5 percent of the economy but contributes with one quarter of the aggregate response. On the other hand, Consumption of Services has the smallest sacrifice ratio among those sectors with a significant response to monetary policy, which is not surprising given that the Consumption of Services represents one third of the economy.

[Figure 7 about here.]

[Table 2 about here.]

Overall, despite the usual amount of noise present in the estimation of impulse response functions, we observe some interesting differences in the effect of monetary policy across sectors. The evidence reported above suggest that monetary policy has its largest effect on Consumption of Durable and Residential Investment; Structures and Equipment-and-Software are much less sensitive. These findings are consistent with the observed behavior of the U.S. economy after the high tech crises. The low sensitivity of Equipment-and-Software Investment to monetary policy can explain why the IT sector has remained depressed despite the sharp interest rate cuts by the Federal Reserve, while the high sensitivity of the Consumption of Durables and Residential Investment is also consistent with the temporary booms experienced by the housing and automobile sectors. This results are not significantly affected by excluding the last two years from the sample. The only effect of this modification is that Equipment-and-Software becomes slightly more sensitive to monetary policy, which has a statistically significant effect between the 6th and 9th quarters. The relative sensitivity of Equipment-and Software is however unaffected. This evidence suggest that the latest episode is not driving the results considerably.

More generally, these differences across sectors imply that monetary policy has the potential to generate inter-sectoral transfers. These transfers can be particularly important if the monetary policy response is triggered by a sectoral shock because the

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change in interest rate can induce negative comovement between the sector affected by the shock and the interest rate sensitive sectors. The transmission of a sectoral shock, the role played by monetary policy on its transmission, and the pattern of sectoral decoupling will be analyzed in the next section which applies our methodology to the high tech crises.

4   The transmission of a sectoral shock: the high-tech crisis.

One of the main advantages of our methodology is that it allows us to identify the effect of sectoral shocks and the role that the monetary policy rule plays in their transmission. As previously explained, the crucial identification assumption is that all contemporaneous comovement across sectors is the result of the correlation of their structural innovations. This assumption, however, complicates the interpretation of the sectoral shocks and the impulse response functions. Typically, the impulse response functions plot the response of the VAR to a structural shock to one of the variables. Under the standard recursiveness approach, the structural shocks are *orthogonal* by assumption, so the source of the innovation is clearly determined. In our case, the structural innovations to different sectors are correlated,[20] so a sectoral shock will typically coincide with simultaneous shocks to the rest of the sectors. It is this correlation which generates the contemporaneous comovement observed in the impulse responses.

As described in section 2.2, there are basically two ways of understanding the correlation of the structural innovations. The first is to assume that it corresponds to the correlation among the sectoral shocks. Under this view, there are no idiosyncratic shocks. The second is to assume that the correlation is due to the presence of an aggregate shock. Under this view, the structural innovations correspond to the combination of an aggregate shock and an idiosyncratic sectoral shock. Certainly, there is no empirical way of telling between these two worlds. The true nature of the sectoral shocks, however, must lie somewhere in the middle. Looking at the effect of a sectoral shock under both extreme identification assumptions gives us some *bounds*

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[20]We still maintain the assumption that the structural shocks to monetary policy and prices are orthogonal to the rest of the shocks and among themselves.

within which the true impulse response function must lie. We believe that this is an important step forward with respect to the current state of the literature, which makes no attempt to identify the effect of this kind of perturbations.

We applied our methodology to explore the effect of a shock to equipment-and-software investment which we associate with the kind of shock that triggered the recent U.S. high-tech crises. In order to understand the role played by monetary policy in the transmission of the shock, we document both the impulse response functions of the economy predicted by the full VAR and the counterfactual impulse response functions obtained when the monetary policy channel of the VAR is suppressed. We also analyze what would be the dynamic response of the economy if, in response to the shock to Equipment-and-Software, the Monetary Authority reacted with a monetary policy shock targeted to stabilize output within an specific time horizon (considering the dynamics as given): we simulate the results for an horizon of 4, 8 and 12 quarters.

The results obtained under the two alternative identification assumptions are discussed next. Overall, the results we present show that the automatic reaction of the Monetary Authority has a significant role in the propagation of sectoral shocks. We also find that the predicted response of our VAR shows some remarkable similarities with the events observed in the U.S. in recent years. This similarity is more profound when we assume that, in addition to its automatic response, the Monetary Authority reacts to the fall in GDP with a monetary policy shock.

4.1 Correlated sectoral shocks

The impulse response functions of the economy and its different sectors to a one standard deviation correlated innovation to Equipment-and-Software Investment are reported in figures 8 and 9.[21] Figure 8 shows that the shock has a significant impact on GDP, which falls in 54 basis points respect to its baseline level after two quarters.

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[21]The effect of the correlated sectoral shock is determined as follows. Let R represent the correlation matrix of the structural innovations. That is:

$$R = diag(\Sigma)^{-1/2} \, \Sigma \, diag(\Sigma)^{-1/2}.$$

Column j of R contains the correlations between sector j and the rest of the sectors:

$$R_{.j} = \begin{pmatrix} \rho_{1j} \\ \vdots \\ \rho_{Nj} \end{pmatrix}$$

According to its Taylor rule, the contemporaneous response of the Monetary Authority is a reduction of the interest rate of 5 basis points. As activity keeps contracting after the initial shock, the Monetary Authority keeps reducing the interest rate until achieving a fall of 40 basis points two quarters after the shock. There is a significant fall in prices which still persists after 20 quarters. Notice that the shock by itself is highly persistent and output remains below its natural level for several years.

As the correlations across sectors are typically positive, almost every sector experiences a contraction as a result to the shock to Equipment-and-Software. However, the speed of recovery is significantly different across sectors: Consumption of Services, Consumption of Durables, and Residential Investment return to their baseline level much faster than Consumption of Non-Durables, Equipment-and-Software Investment, and Structures Investment. Remember from the previous section, that the former are precisely those sectors with the highest sensitivity to monetary policy. So their fast recovery can be attributed to effect of the fall in interest rates resulting from the automatic response of the Monetary Authority. On the other hand, we previously found that Equipment-and-Software had a small response to monetary policy, so it is not surprising that the sector seems to be unaffected by the reaction of the Monetary Authority, and it remains in recession after a significant amount of time. This evidence suggest that the way in which monetary policy stabilizes output in response to a shock to a low interest rate sensitivity sector is by inducing significant transfers towards high interest rate sensitivity sectors.

[Figure 8 about here.]

[Figure 9 about here.]

Figures 10 and 11 show the counterfactual impulse response functions obtained when the monetary policy part of the VAR is suppressed. Figure 10 shows the impulse response functions only of Equipment-and-Software and aggregate GDP, and Figure

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Let σ_j be the standard deviation of the structural innovation to sector j. The impulse response function to a one standard deviation shock to sector j is then determined by setting:

$$\begin{pmatrix} Y_{10} \\ \vdots \\ Y_{N0} \end{pmatrix} = \sigma_j \begin{pmatrix} \rho_{1j} \\ \vdots \\ \rho_{Nj} \end{pmatrix}.$$

11 shows the impulse response functions of all the different sectors. These figures show that, as expected, output recovery is considerably slower in absence of the stimulus provided by the reduction of interest rates. More interestingly, the sectoral impulse response functions presented in Figure 11 provide an interesting benchmark: comparing the sectoral impulse response functions of Figure 9 with those of Figure 11 we can determine the part of the sectorial dynamics that are determined by monetary policy. The comparison shows that the quick recovery of Consumption of Durables, Services, and Residential Investment observed in Figure 9 is exclusively due to the effect of monetary policy: without an active monetary policy the effect of the shock to Equipment-and-Software Investment on these sectors is large and long-lasting. In addition, an active monetary policy make these sectors significantly less correlated with less interest sensitive sectors like Investment in Structures.

[Figure 10 about here.]

[Figure 11 about here.]

Figures 12 and 13 show the impulse response functions of the economy and the different sectors to a different counterfactual policy exercise: we analyze what happens to the economy if the response of the Monetary Authority to the sectoral shock goes beyond the automatic reaction dictated by its Taylor rule.[22] In particular, we ask what happens if the Monetary Authority responds with a monetary policy shock aimed to stabilize aggregate output in less than two year (eight quarters). Figure 12 shows that the necessary monetary policy shock is of 47 basis points, which added to the automatic response dictated by the policy rule (5 basis points) induces a contemporaneous decline in interest rates of 52 basis points. As this swift contemporaneous response induces a fast recovery in aggregate activity, the interest rate does not fall much further in future periods: it only declines by additional 24 basis points the next quarter before starting to return to its baseline level. However, Figure 13 shows that this swift policy reaction is unable to stabilize the Equipment-and-Software sector: the recession in this sector still continues after two years. On the other hand, there is a boom in Residential Investment and Consumption of Durables, which recover after 3 quarters and enter into an expansion thereafter. The effect on inflation is small.

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[22]This exercise would be affected by the Lucas' critique if the shock reveals any new information about the preferences of the Monetary Authority. We assume that this is not the case.

[Figure 12 about here.]

[Figure 13 about here.]

4.2 Idiosyncratic sectoral shocks

Figures 14 and 15 report the impulse response functions of the economy and its different sectors to an *orthogonal* innovation to Equipment-and-Software Investment. In this case, all correlations across sectors are assumed to be due to the aggregate shock.[23] So, the innovation to Equipment-and-Software has no contemporaneous effect on the other sectors, and its aggregate effect has to be smaller than in the correlated case. Therefore, this exercise gives us a lower bound on the true effect of a sectoral shock.[24]

Figure 14 shows that, even under this extreme assumption, the sectoral shock induces a significant decline in both aggregate GDP and interest rates. As expected, the response is quantitatively smaller than in the correlated case: GDP falls by about 28 basis points after three quarters, the interest rate responds contemporaneously with a decline of only 2 basis points after which keeps falling reaching a maximum decline of 21 basis points.

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[23]More precisely, we are assuming that

$$\varepsilon_t = \Gamma z_t + \mu_t,$$

so the variance of the structural innovation to sector j corresponds to

$$\sigma_j^2 = \gamma_j \sigma_z^2 + \sigma_{\mu_j}^2.$$

The impulse response function is obtained by setting

$$Y_{i0} = \begin{cases} 0 & i \neq j \\ \sigma_{\mu_j}^2 & i = j \end{cases}$$

[24]The structural VAR under the assumption that all sectoral correlations are generated by an aggregate shock is different from the structural VAR with unrestricted correlation of sectoral shocks. So, the parameters of this VAR were estimated anew. The results obtained for the structural parameters, presented in the appendix, are remarkably similar to those obtained in the unrestricted VAR. This similarity implies that the covariance matrix of sectoral shocks is amenable to this kind of structure. In addition, it makes us very confident in our estimation procedure. The only problem with the restricted estimation is that the hessian of the likelihood function (the information matrix) is less well behaved than in the unrestricted case. For this reason, the confidence intervals tend to be significantly larger (see discussion in the appendix).

The shock has a very small effect in Consumption of Durables, Services, and Residential Investment (Figure 15). The largest effects are observed in Consumption of Non-Durables, Investment in Structures, and Equipment-and-Software. So, the evidence shows that the small decline in interest rates is enough to stabilize the output of high interest rate sensitivity sectors, but it is not enough to stop the recession in the rest of the economy.

[Figure 14 about here.]

[Figure 15 about here.]

Figures 16 and 17 show the results obtained for the stabilization exercise. In order to stabilize the output within two years, the Monetary Authority would have to react with a monetary policy shock of 36 basis points, achieving a total contemporaneous decline in interest rates of 38 basis points. Similarly to the case of the correlated sectoral shock, the interest rate would keep falling by 16 additional basis points before starting to return to its baseline level, reaching a maximum decline of 54 basis points.

[Figure 16 about here.]

[Figure 17 about here.]

Table 3 provides an overall comparison of the contemporaneous response of interest rates for the cases of a correlated and independent sectoral shocks. The table presents the contemporaneous decline in interest rates under four different stances of monetary policy: automatic response implied by the Taylor's rule, and aggregate output stabilization within four, eight, and twelve quarters. The results previously discussed are those corresponding to the automatic response and to the eight-quarter stabilization. As expected, the shorter the targeted stabilization period, the larger the required contemporaneous drop in interest rates. As also expected, the required declines in interest rate are systematically smaller in the independent sectoral shock case. More interestingly, the decline required to stabilize output within eight quarters is of the same magnitude than the actual decline in interest rate induced by the FED during 2001. As documented in section 3.2.2, the structural residuals obtained with our methodology indicate two consecutive shocks to Equipment-and-Software investment during the first two quarters of 2001: a 2.5-standard-deviation shock and

a 4-standard-deviation shock. A back of the envelope calculation suggests that the size of the monetary policy shock required to stabilize aggregate output within two years should be around 1.7 percentage points with a total decline in interest rate of about 2.5 percentage points after two quarters. This amount corresponds to roughly half of the 4.75 percentage point decline in interest rates during 2001.

[Table 3 about here.]

Overall, both assumptions about the correlations among sectoral shocks produce similar results. They show that a shock to Equipment-and-Software Investment generates a significant decline in aggregate output and interest rates. The decline in interest rates resulting from the automatic response of the Monetary Authority–given by its Taylor rule–is enough to stabilize the output of high interest rate sensitivity sectors, such as Consumption of Durables and Residential Investment. If the Monetary Authority also reacted with a shock to the interest rate designed to stabilize output within a year, these sectors would experience a temporary boom. In none of these case, however, is monetary policy able to quickly stabilize the output of sectors that are less sensitive to monetary policy such as Equipment-and-Software or Structures.

5 Conclusion

In this paper we present a new methodology that allows us to investigate both the sectoral effects of monetary policy and its role in the transmission of sectoral shocks. We apply our methodology to the U.S. and demonstrate that there are interesting differences in the response to monetary policy among U.S. sectors. Moreover, we show that, due to these differences, a monetary policy rule aimed to stabilize aggregate output and prices will have an asymmetric effect across sectors: high interest rate sensitivity sectors will experience larger cyclical fluctuations than low sensitivity ones. Our results also suggest that the sectoral "transfers" involved are potentially significant. In other words, monetary policy will achieve stabilization only by inducing relatively large expansions and contractions on high interest rate sensitivity sectors.

Our estimates indicate that the High-Tech crisis in 2001 represented a shock of roughly 6.5 (2.6 + 3.9) standard deviations. According to our estimates the simultaneous automatic response of monetary policy would be between 6 and 17 basis points

with a trough 4 quarters into the recession where the rate has been reduced between 70 and 117 basis points. On the other hand, if the monetary policy had an objective to recover aggregate output within 8 quarters the reaction to the shock would have been much larger. Our estimate suggest that the FED should have dropped interest rates immediately in between 117 and 152 basis points. The path of interest rates would have implied that the interest rate should have been reduced in something in between 177 and 259 basis points. This estimates indicate that after the High-Tech crisis we should have expected that a relatively concerned FED should have reduced the interest rate in a maximum of 2.5 percentage points. This is remarkably close to what the FED indeed reduced. Furthermore, this estimate includes only the High-Tech shocks, clearly if we were able to disentangle the aggregate component implied by the September 11 and ENRON collapse the predicted interest rate reduction would have been much closer to the 4.5 percent it actually cut.

From the policy point of view our results indicate that monetary policy, unfortunately, is not well equipped to deal with sectoral shocks. It indeed produces large reallocations. Therefore, it cannot deal with a sectoral recession, specially if that sector is not interest sensitive, and if the recession is due to overcapacity. Monetary policy is, therefore, well equipped to deal with aggregate shocks. The sectoral shocks have to be dealt with fiscal policy. This is similar to the discussion that existed in Europe before the reunification (Dornbusch, Favero, and Giavazzi (1998)). Further research should apply the methodology developed here to evaluate the recent experiences in the Euro zone.

In this paper we have used demand components to make claims about sectors. This is indeed a short cut, but one that we feel provides very interesting insights about the dynamic response of the different components to monetary policy. However, future research should replicate this results using sectoral output - or employment.

Several other questions are left unanswered in this paper. Probably the most important is why different sectors have different sensitivities to monetary policy. We can speculate that differences in the importance of financial constraints, price stickiness, or durability are potential causes to be explored, and they should also form part of future research.

Finally, from a methodological point of view, we see our methodology as a useful tool to explore some unanswered questions about the effects of monetary policy and to test different hypothesis about the behavior of the Monetary Authority. For

example, within academic and policy circles is frequently speculated that the Monetary Authority pays more attention to some specific sectors (for example Residential Investment) to decide the stance of monetary policy. This hypothesis can be easily tested in our framework by relaxing the assumption that the Taylor rule followed by the Monetary Authority depends only on aggregate output and prices. We plan to tackle the question of distributional aspects in the Taylor rule in future research.

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A Data

Data for the estimation was obtained from the Bureau of Economic Analysis and the Federal Reserve Bank of St. Louis. The GDP data is at quarterly frequency. Quarterly values for the Federal Funds Rate and the CPI correspond to the quarterly averages of monthly data. The GDP data is expressed in levels, deflated by the CPI,[25] and expressed as a fraction of the last 6 quarters average real GDP, which is therefore defined as the baseline level. Therefore, the impulse responses corresponds to percentage deviations of this baseline.[26] The CPI and the FFR are expressed in percentage points. The data was de-trended and demeaned previous to estimation (using a linear trend). Results are similar if the trend and constants are estimated in the VAR.

B Estimation of bands

The confidence bands for the impulse response functions reported in the paper were built b bootstrapping. The detailed procedure is as follows. Let θ be the vector of parameters of the structural model. The estimators of these parameters $(\hat{\theta})$ were obtained by Maximum Likelihood; therefore:

$$\hat{\theta} = \arg\max_{\theta} L(y \mid \theta)$$

This estimators are asymptotically normally distributed. Their asymptotic covariance matrix corresponds to the information matrix:

$$\text{AsyVar}(\hat{\theta}) = -\left\{ \frac{\partial^2 L(y \mid \hat{\theta})}{\partial \hat{\theta} \, \partial \hat{\theta}'} \right\}^{-1},$$

therefore:

$$\hat{\theta} \overset{dist}{\rightsquigarrow} \mathcal{N}(\theta, \text{AsyVar}(\hat{\theta})).$$

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[25]Results are similar if the GDP deflator is used instead.

[26]Results are qualitatively similar if the VAR is estimated in logs. We checked this results only using the two step procedure, as the estimation is computationally burdensome. It requires to use the share data at each point in time to recover the aggregate log GDP from the sectoral log outputs. This aggregation is necessary because both prices and the monetary policy rule are assumed to depend only on aggregates. In the estimation, shares were considered as given.

For the bootstrap, we draw 500 independent draws of the parameters according to the normal distribution above. For each set of parameters we estimated the implied impulse response function. To construct the bootstrap bands we filter the 90% of the impulse responses with the smallest overall distance to the impulse response obtained with the point estimators: let Ψ represent the impulse response function associated with the point estimators. Ψ is a $(N+2)xL$ matrix containing the impulse response function of each VAR series to an specific shock–where L is the number of periods considered for the impulse response functions. Analogously, let Ψ^k represent the impulse response matrix associated with the kth draw from the normal distribution. Define the distance between these two impulse response matrices as:

$$D_k = ||\Psi^k - \Psi||^2 = \sum_{i=1}^{N+2} \sum_{j=1}^{L} \left(\Psi_{ij}^k - \Psi\right)^2.$$

Next, rank the bootstrap impulse responses according to this distance. The upper band reported in the paper corresponds to the impulse response at the 95th percentile level of this ranking, and the lower band corresponds to the impulse response at the 5th percentile level of this ranking. Therefore the bands represent a 90% confidence interval around the point estimates.[27]

A different procedure to estimate the confidence bands of the impulse response functions that does not relies in the asymptotic normality of the parameters is performing a non-parametric bootstrap on the residuals. Under this procedure, the residuals are sampled with replacement, after which a fictitious data is generated using the sample residuals and the estimated parameters. Given that the asymptotic variances of some of the coefficients of the lags matrices are large, this procedure will tend to create smaller confidence intervals than those reported in the paper. However, this procedure requires to re-estimate the structural parameters for each bootstrap iteration, which, given the size of the problem, renders it computationally unfeasible. However, we can get a flavor of the differences in the confidence intervals generated with both procedures by comparing them for the aggregate VAR case (in which GDP is not decomposed into sectors). Figure 18 reports this exercise.It shows the impulse response of aggregate GDP to a two standard deviation shock to FFR and the confi-

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[27]We select the bands in this manner because the impulse response functions of the different series in the VAR are not independent.

dence intervals under both procedures: bootstrap on the coefficients and bootstrap on the residuals. It can be seen that although the upper bands obtained with both procedures are similar, the lower band obtained bootstrapping the residuals is considerably smaller than the analogous band obtained bootstrapping the coefficients.

The difference between the two bootstrapping procedures should increase with the imprecision of the ML estimators. Indeed, as mentioned in the paper, when we estimate the model in which we restrict the correlation between sectoral shocks to be driven by a common factor, the bands are extremely imprecise and tend to be explosive. The reason is that when the parameters of the lag matrices are very imprecise, some of the draws may imply a dynamic structure with a unit root.[28,29]

C   Results for the two-step procedure

We also estimated the parameters of the model and the impulse response functions using a two-step procedure in which the first step consisted on estimating the parameters of the reduced form VAR by OLS, and the second step consisted on the recovering of the structural parameters via GMM. The advantage of this procedure is that it is much less computationally burdensome. The disadvantage is that the degrees of freedom in the first step (unrestricted) estimation are small so the structural parameters tend to be estimated very imprecisely. Despite the imprecision in the estimated parameters, the bands generated using this procedure are relatively small because its computational simplicity allows us to perform a non-parametric bootstrap in the residuals. The results obtained using this procedure for all the exercises presented in the paper is reported in Raddatz and Rigobon (2003). As a brief comparison, we next report the estimated coefficients of the matrix A_0, the variances of the different

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[28]The intuition is clear when we think of a univariate process. For instance, consider the process $x_t = \alpha x_{t-1} + \varepsilon_t$; assuming $\alpha = 0.8$ this process is stationary. Now assume that we obtain an estimator $\hat{\alpha} = 0.8$ with standard deviation of 0.1. Standard tests would correctly reject the hypothesis of a unit root. However, when drawing a sample from a normal with mean 0.7 and standard deviation 0.1 it is likely to obtain some explosive realizations. We conjecture that this is the reason of the explosive bands obtained for the restricted case. We are currently working on obtaining the confidence bands bootstraping over the residuals. Results using this procedure will be reported in future versions of the paper.

[29]We are confident however that the problem in the restricted estimation lies on the properties of the Hessian and not on the point estimates. We checked for the presence of a unit root in a coefficient by estimating the VAR in first differences. The point estimates and impulse response functions obtained were similar to those in levels and did not exhibit explosive confidence bands.

structural shocks, and the impulse responses to a monetary policy shock obtained with the two-step procedure, compared with the ML estimators. It can be seen that both procedures generate qualitatively similar results.

[Table 4 about here.]

[Figure 18 about here.]

[Figure 19 about here.]

Table 1: Coefficients of contemporaneous effects

Parameters		
$\widehat{\alpha}$	$\widehat{\beta}$	$\widehat{\beta}_p$
0.145	-0.238	-0.689
(0.049)	(0.140)	(0.205)

Table 2: Sacrifices ratios by sector

Sector	Sacrifice ratio (point est.)	Sacrifice ratio (upper band)
Consumption of Durables ($CDUR$)	-21.44	-3.83
Consumption of Non-Durables ($CNDUR$)	-8.96	-1.47
Consumption of Services ($CSER$)	-2.54	-0.07
Residential Investment ($IRES$)	-54.41	-15.17
Investment in Structures ($ISTRUC$)	1.89	-
Equipment-and-Software Investment ($IEQUIP$)	-16.29	-

Note: The sacrifice ratio using the point estimates corresponds to the area between the x-axis and the normalized impulse response function during the period elapsed between the monetary policy shock and the minimum of the quarter in which the series returns to its baseline level or 20 quarters. The normalized impulse correspond to the standard impulse responses divided by the average share of each sector in real GDP during the last 6 quarters of the data. The sacrifice ratio using the upper band (column 3) is the area between the x-axis and the upper confidence band of the normalized impulse response function computed during the quarters for which the impulse response function is statistically different from zero.

Table 3: Decline in FFR in response to a shock to E&S Investment (in basis points)

Mon. Policy Stance	Correlated shock to E&S Inv	Independent shock to E&S Inv
Automatic Response	5	2
Stabilization in a year	164	93
Stabilization in two years	52	38
Stabilization in three years	47	

Table 4: Comparison of two-step and ML procedures

	Coefficients	Two-step	MLE
A_0	α	0.094	0.145
	β	-0.266	-0.238
	β_p	-0.778	-0.689
Σ	σ_{CDUR}	0.123	0.120
	σ_{CNDUR}	0.083	0.073
	σ_{CSER}	0.070	0.089
	σ_{ISTRUC}	0.061	0.050
	σ_{IEQUIP}	0.093	0.086
	σ_{IRES}	0.078	0.070
	σ_{REST}	0.247	0.259
	σ_{CPI}	0.218	0.294
	σ_{FFR}	0.655	0.825

Figure 1: Effect of a shock to FFR on GDP, CPI, and FFR
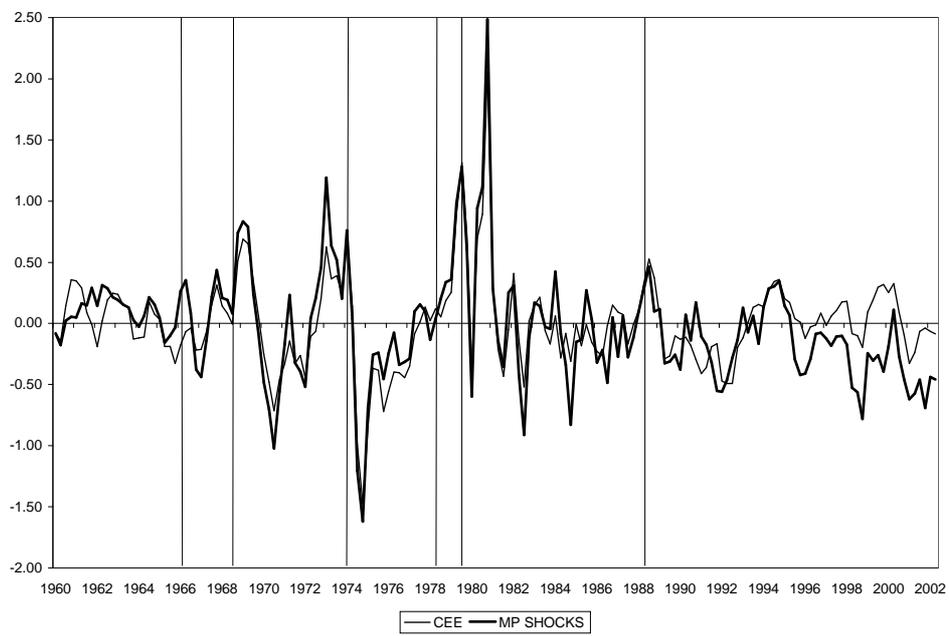
Figure 2: Measures of monetary policy shocks
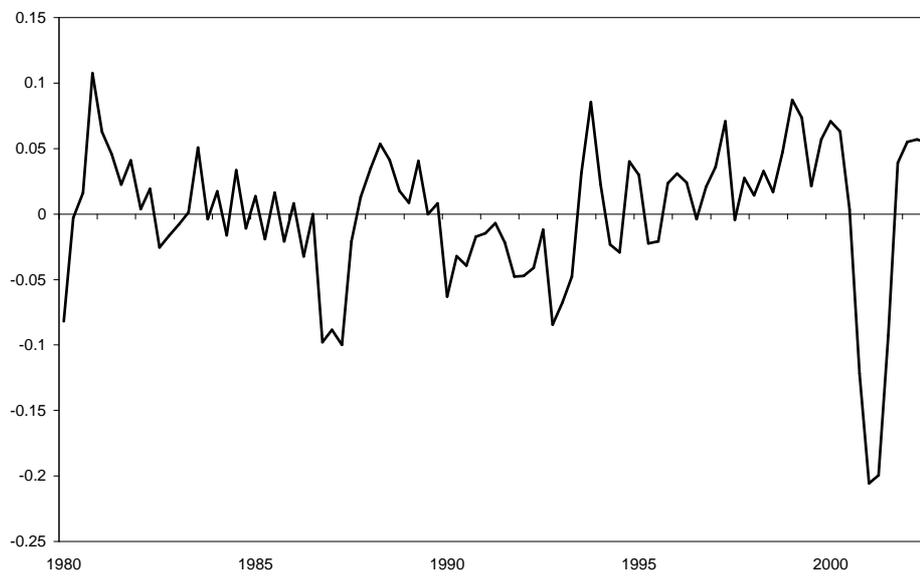
Figure 3: Shocks to Equipment-and-Software

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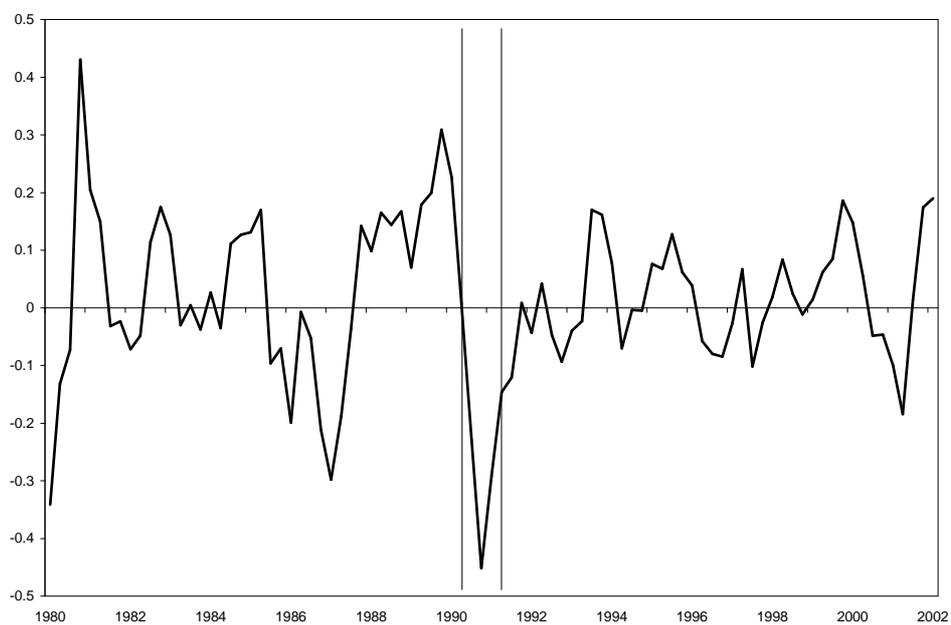
Figure 4: Sum of shocks to Durables, Non-durables, Services, and Residential Investment
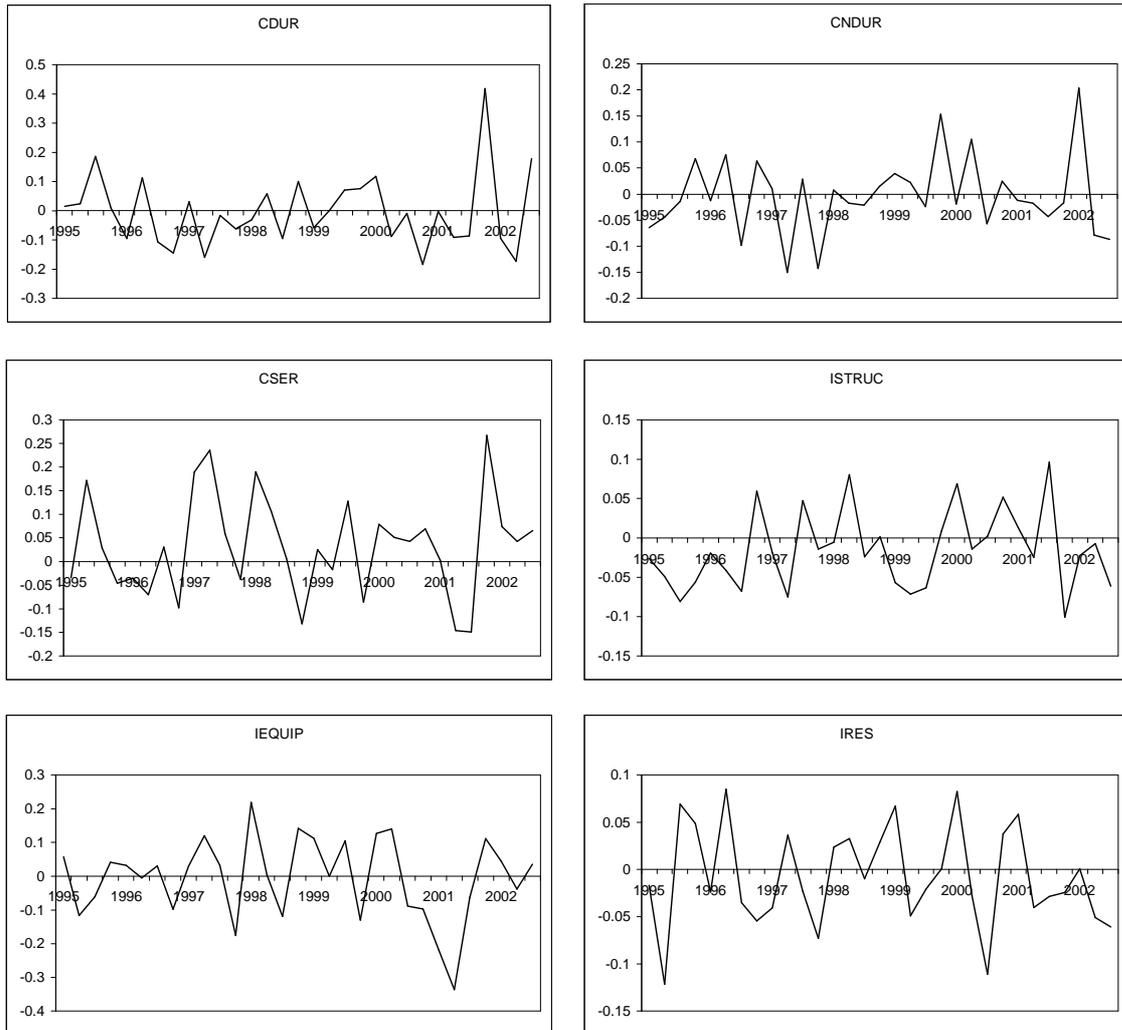
Figure 5: Sectoral Residuals
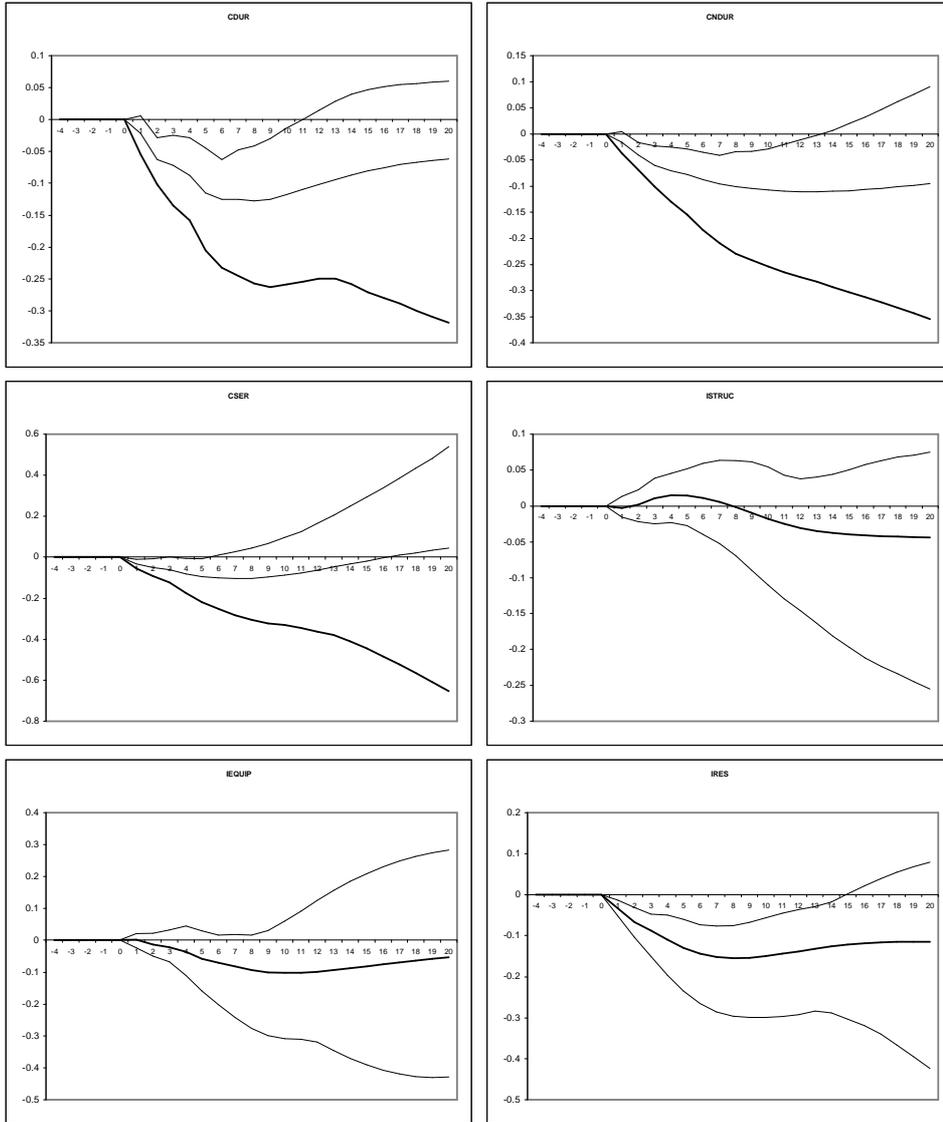
Figure 6: Sectoral effects of a monetary policy shock
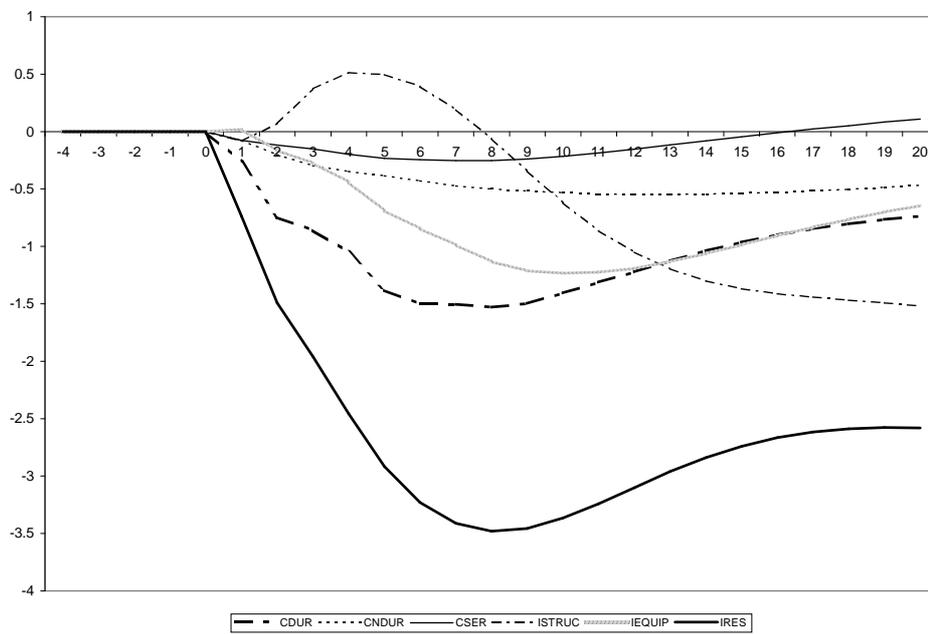
Figure 7: Sacrifice ratios (shock to FFR)
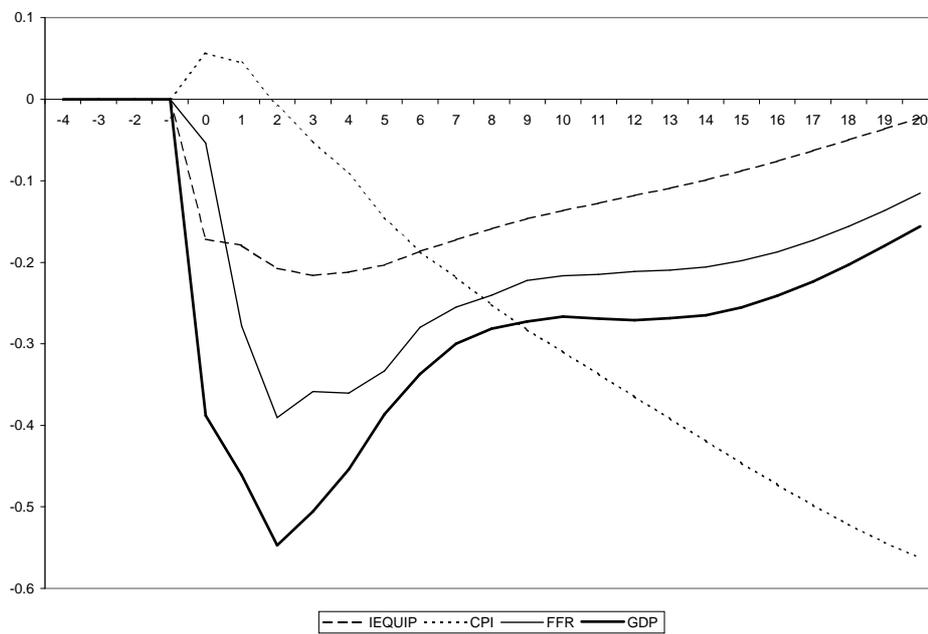
Figure 8: Aggregate effects of a correlated sectoral shock
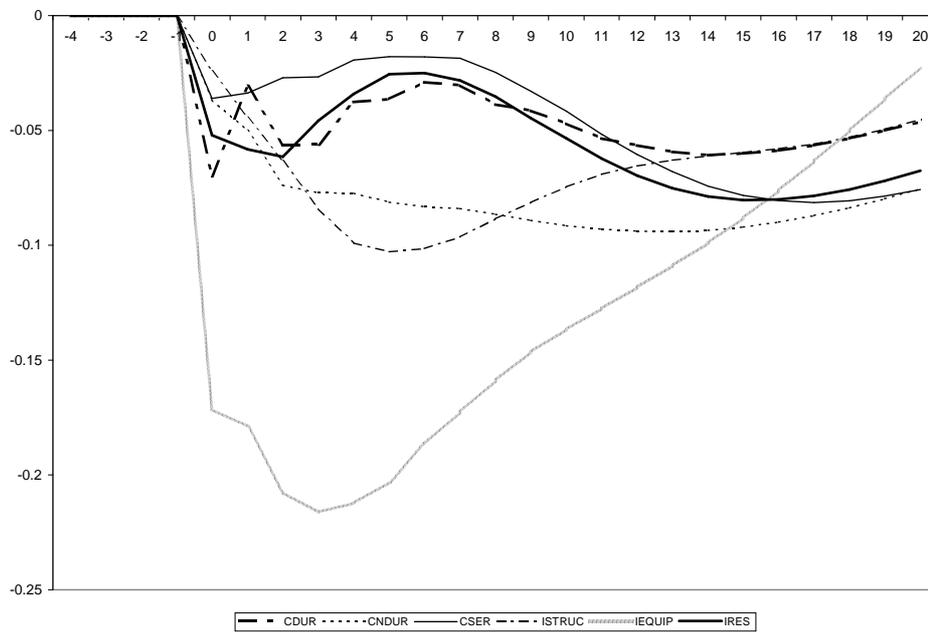
Figure 9: Sectoral effects of a correlated sectoral shock
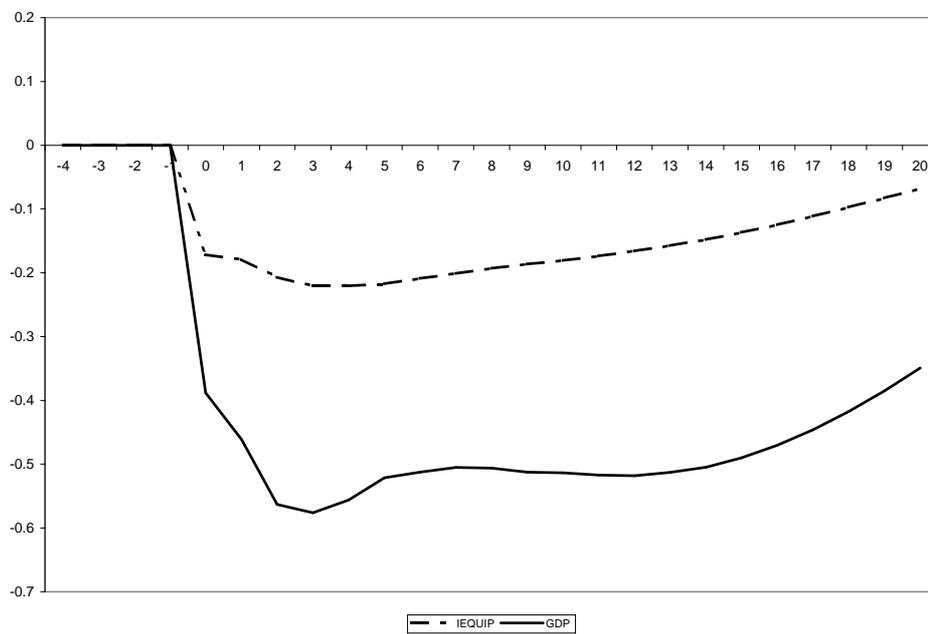
Figure 10: Aggregate effect of a correlated sectoral shock. No monetary policy case
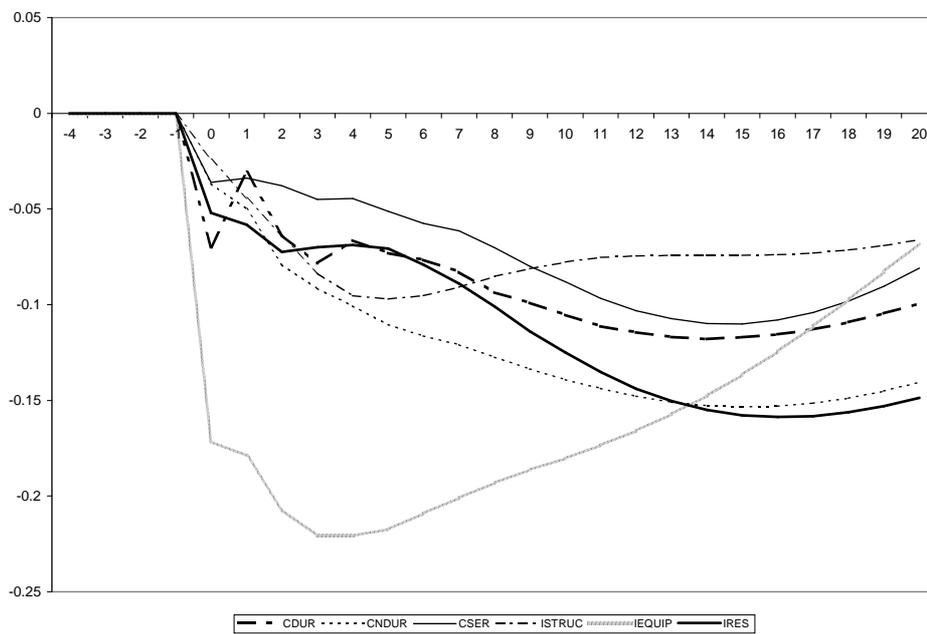
Figure 11: Sectoral effects of a correlated sectoral shock. No monetary policy case
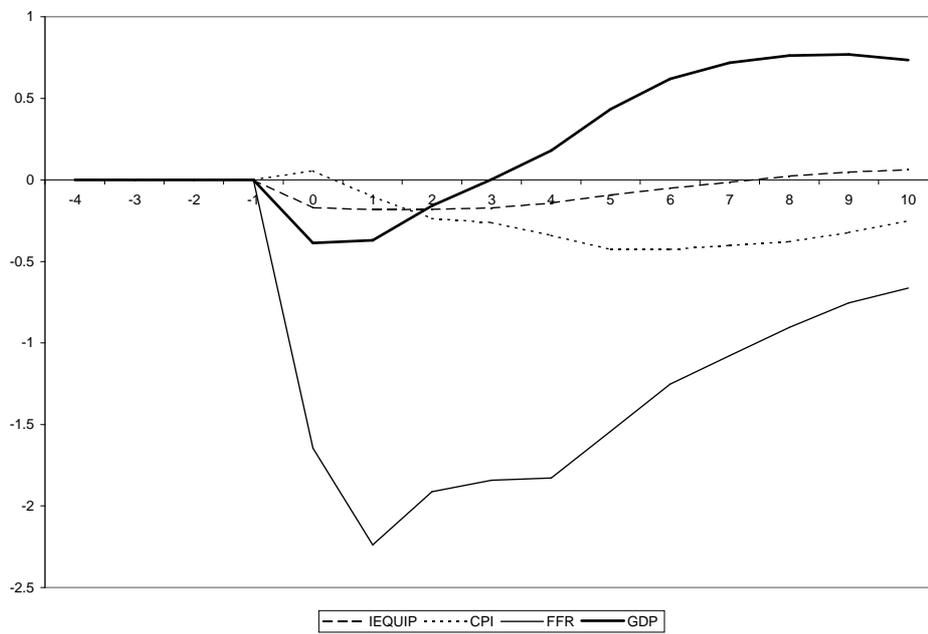
Figure 12: Aggregate effect of output stabilization policy (correlated sectoral shock)
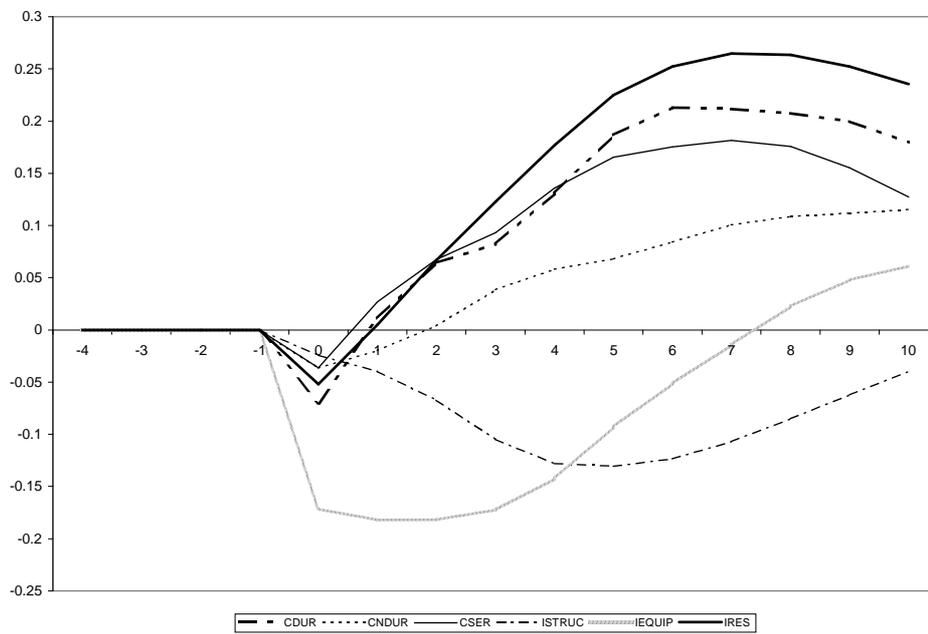
Figure 13: Sectoral effect of output stabilization policy (correlated sectoral shock)
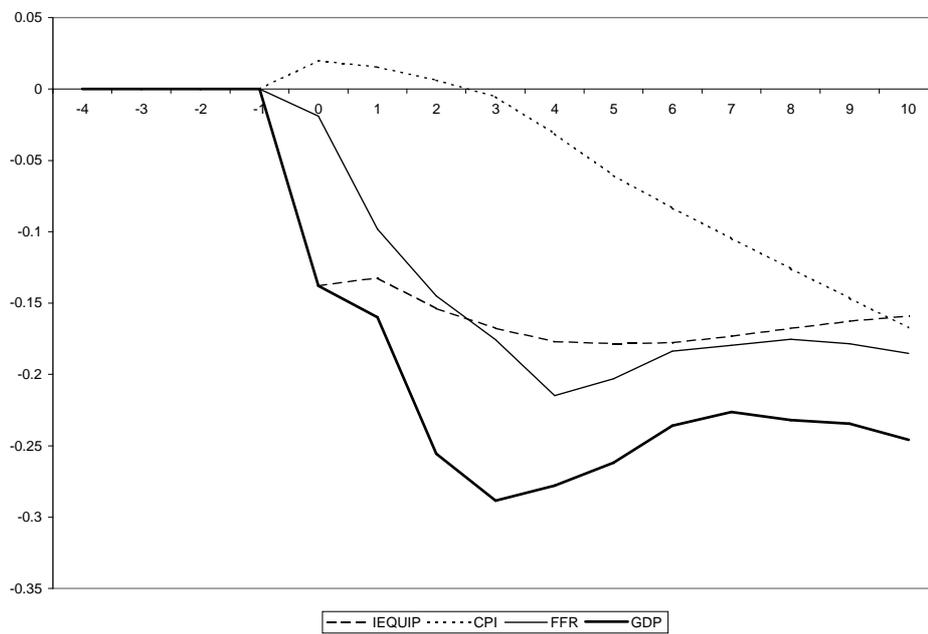
Figure 14: Aggregate effects of independent sectoral shock
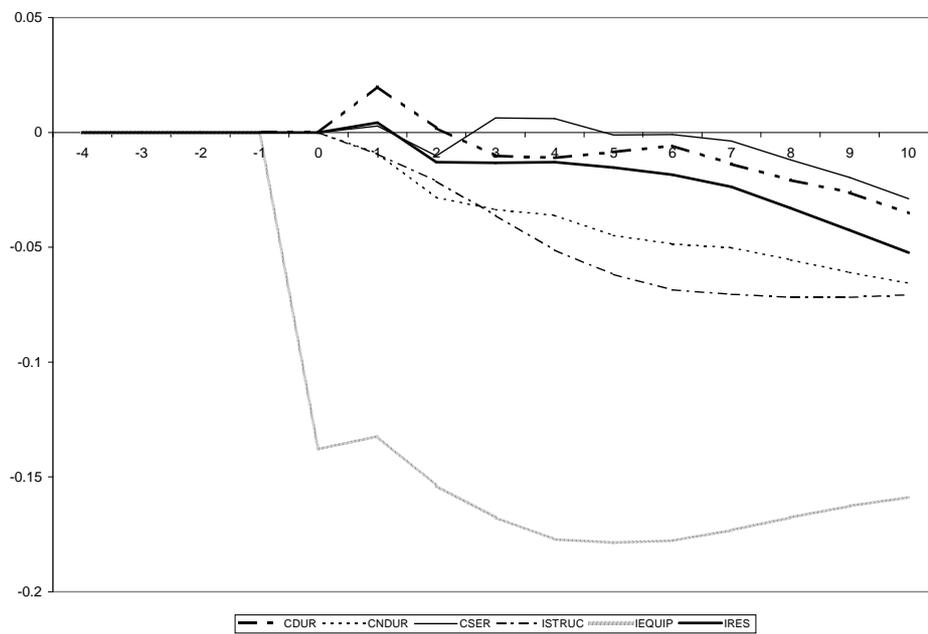
Figure 15: Sectoral effects of independent sectoral shock
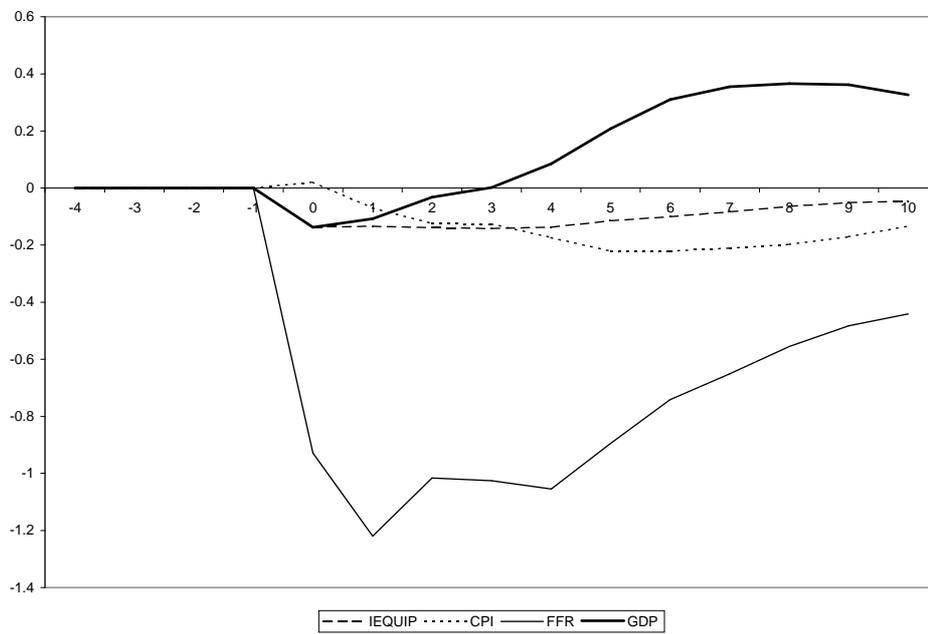
Figure 16: Aggregate effect of output stabilization policy (independent sectoral shock)
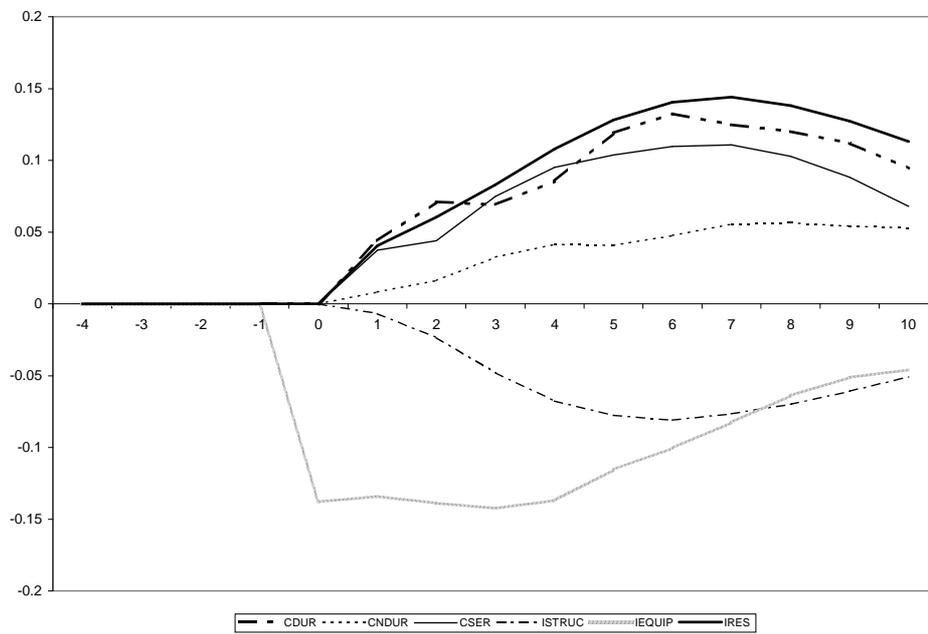
Figure 17: Sectoral effects of output stabilization policy (independent sectoral shock)
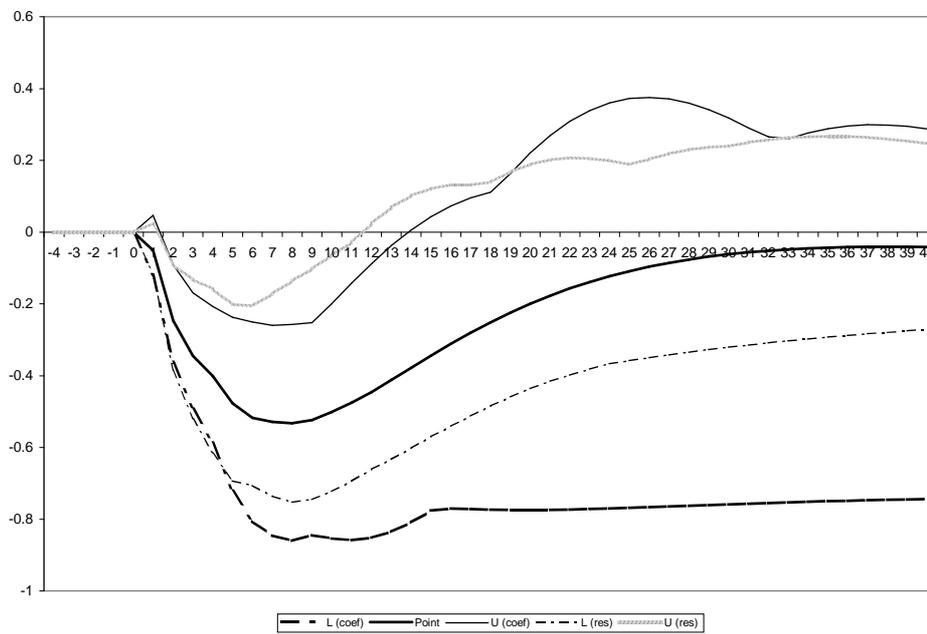
Figure 18: Sectoral effects of output stabilization policy (independent sectoral shock)
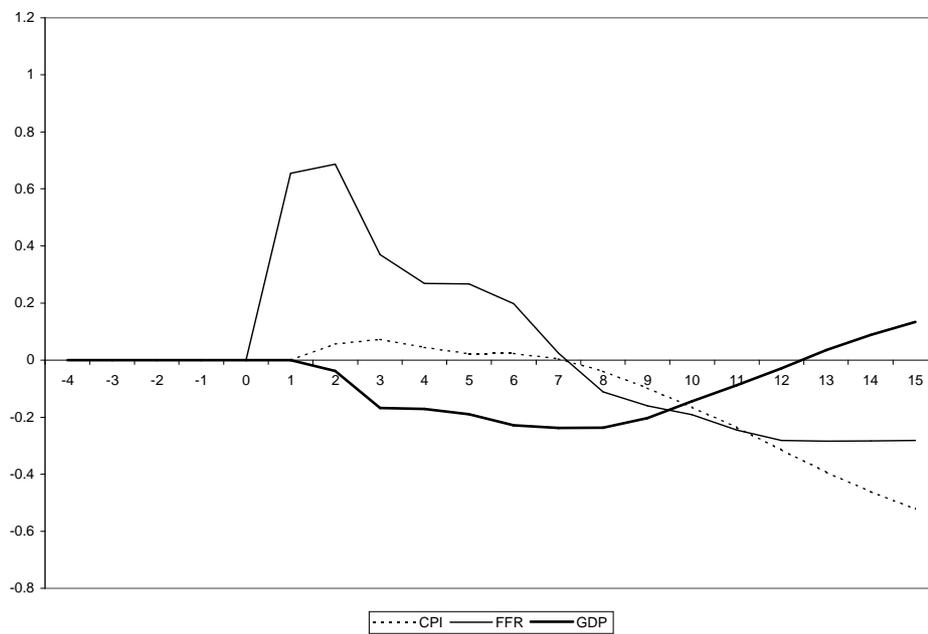
Figure 19: Effect of a shock to FFR on GDP, CPI, and FFR