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Are the effects of monetary policy larger in recessions? A reconciliation of the evidence[☆]

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ABSTRACT

This paper investigates whether there are significant differences in the response of U.S. output to monetary policy shocks in expansions vs. recessions. Much of the existing literature has found that monetary policy shocks have larger effects during recessions. However, recent influential work by Tenreyro and Thwaites (2016) finds the opposite result, and leaves the literature on this important question with a lack of consensus. Using the empirical framework of Tenreryo and Thwaites (2016) as a baseline, we provide a systematic exploration for the key drivers of differing results regarding the effects of monetary policy shocks over the business cycle. We find two key elements drive the results, the first being whether the local projection impulse response function estimator is conducted in levels vs. long differences of the data, and the second being the treatment of outliers observed in measures of monetary policy shocks during the Volcker disinflation. We conclude that the evidence is more supportive of monetary policy shocks having larger effects during recessions.

1. Introduction

There is substantial interest in whether the output effects of U.S. macroeconomic policy shocks vary with the business cycle. For example, in the aftermath of the Great Recession, a large literature emerged investigating the size of fiscal policy multipliers in expansions vs. recessions.[1] Meanwhile, a long-standing literature has focused on whether U.S. monetary policy shocks have asymmetric effects in economic downturns vs. expansions.[2] In this paper, we contribute to the literature studying business cycle state-dependence in the effect of monetary policy shocks. Specifically, we provide a systematic exploration of the primary features of the data and empirical framework that drive conflicting results in this literature.

Most early studies, such as Garcia and Schaller (2002), Kaufmann (2002), Lo and Piger (2005), Peersman and Smets (2002), and Thoma (1994), find that monetary policy has a larger impact on output during recessions than during expansions. However, more recent evidence from Tenreyro and Thwaites (2016) finds that the output effects of monetary policy shocks are much larger in expansions than recessions. This influential paper has left the literature with a lack of consensus, or even a changed consensus, regarding the potentially time-varying effects of monetary policy over the business cycle. This topic is of crucial importance given

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[1] See, among many others, Auerbach and Gorodnichenko (2012, 2013), Bachmann and Sims (2019), Caggiano et al. (2015), Fazzari et al. (2014), Goemans (2022), Owyang et al. (2013) and Ramey and Zubairy (2018).

[2] See Garcia and Schaller (2002), Kaufmann (2002), Lo and Piger (2005), Peersman and Smets (2002), Tenreyro and Thwaites (2016), and Thoma (1994).

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the reliance of modern economies on monetary policy as a stabilization tool. If traditional monetary policy is not very effective at impacting output during recessions, then fiscal policy and non-traditional monetary policy might have more of a place moving forward. The goal of this paper is to systemically address why the literature comes to different conclusions about the effects of monetary policy over the business cycle.

We find several reasons for the conflicting results in the literature. First, the choice of data transformation when estimating impulse response functions, specifically the choice of levels vs. long differences, has a significant impact on results. Most early papers in this literature assumed the presence of stochastic trends and estimated models in log first differences of the response variable. More recent papers, and especially those using the local projections framework for estimating impulse responses (see Ramey and Zubairy (2018) and Tenreyro and Thwaites (2016)), estimate impulse response functions using models specified in log levels. We find the evidence again flips in favor of monetary policy shocks having larger effects during recessions when impulse response functions are estimated in a long-differenced specification. While these two specifications should be asymptotically equivalent, recent evidence from Piger and Stockwell (2023) show that in small samples, local projection models estimated in long-differences display less bias and more accurate coverage rates than models estimated in log levels, even for data that is persistent, but stationary.

Second, we find that outliers in the monetary policy shock measure have a large impact on the estimated state-dependent impulse response functions. In this paper we follow Tenreyro and Thwaites (2016) in the use of an updated measure of the Romer and Romer (2004) monetary policy shocks. This series contains a number of very significant outliers during the 1979–1982 Federal Reserve experiment with non-borrowed reserves targeting, and Romer and Romer (2004) note that the validity of their proposed shock series is questionable over this period. Outliers over the non-borrowed reserves targeting period are also seen in other commonly used monetary policy shock measures, such as those obtained from vector autoregressions, and it is common in the literature measuring the effects of monetary policy shocks to conduct robustness checks to exclusion of this period.[3] Here we find that outliers observed in the 1979–1982 period are very influential when measuring state dependence in the effects of monetary policy related to the business cycle. When we simultaneously account for both outliers and use a long-differenced specification, the results are very strongly in favor of monetary policy having much larger and more persistent effects during recessions than during expansions.

In addition to the features discussed above, we additionally investigate whether changes to the measure and frequency of economic output can affect results regarding time-varying effects of monetary policy shocks over the business cycle. We find that moving away from quarterly real GDP toward monthly industrial production further pushes the conclusions toward monetary policy shocks having larger effects during recessions.

The remainder of the paper proceeds as follows. Section 2 lays out the empirical question, the models to be estimated and hypotheses to be tested, and the measurement of output, monetary policy shocks, and the business cycle. Section 3 lays out the results of the analysis, moving through a variety of potential explanations for differences in the empirical results in the existing literature. Section 4 concludes.

2. Estimating the effects of monetary policy shocks over the business cycle

In this section, we lay out the empirical methods used in this paper to investigate potential differences in the effects of monetary policy shocks over the business cycle. We work with a baseline methodology similar to Tenreyro and Thwaites (2016) in which state-dependent impulse response functions are measured via the local projection methodology of Jordá (2005) augmented with an interaction variable measuring the business cycle, and monetary policy shocks are measured as in Romer and Romer (2004). We begin with a discussion of the local projection methodology for computing impulse responses and how state dependence can be tested in this framework. We then discuss the Romer and Romer (2004) monetary policy shock measure in more detail, as well as provide a description of our measure of the business cycle. Finally, we conclude with a description of the data used to measure all variables in our empirical models.

2.1. Local projections and testing for asymmetry

As in much of the recent literature studying the effects of monetary policy shocks, we use the local projection framework developed in Jordá (2005) to estimate impulse response functions. As discussed in Jordá (2005), the local projection approach has several advantages when estimating impulse responses over a VAR model. For our purposes, a primary advantage is that local projections, which are single equation models estimated via least squares, can easily accommodate the state-dependent specifications needed to study asymmetry in the effects of monetary policy shocks on response variables.[4] Specifically, our baseline model, which follows Tenreyro and Thwaites (2016), is as follows:[5]

$$y_{t+h} = F_t \left(\beta_r^h \varepsilon_t + (\gamma_r^h)' x_t\right) + (1 - F_t) \left(\beta_e^h \varepsilon_t + (\gamma_e^h)' x_t\right) + v_{t+h}. \tag{1}$$

[3] For example, Christiano et al. (1999), Coibion (2012), Ravn and Sola (2004), and Romer and Romer (2004).

[4] In recent work, Goncalves et al. (2023) show that the presumed advantages of local projections for state-dependent impulse response estimation have likely been overstated. Specifically, they show that when the state of interest is endogenously determined by the macroeconomic shock of interest, impulse response estimates can be severely biased. As our goal is to reconcile discrepancies in the existing literature, we continue to use the local projections framework as a baseline representation of existing results. Also, the findings in this paper, for example with respect to outliers, are relevant beyond the local projection framework.

[5] Auerbach and Gorodnichenko (2012) and Ramey and Zubairy (2018) use a similar specification to study asymmetries in the effects of fiscal policy over the business cycle.

In Eq. (1), y_{t+h} is a measure of U.S. output measured in log levels at time horizon h, ε_t is the monetary policy shock, and x_t is a vector of controls. F_t is the variable indicating the state of the U.S. business cycle in period t, where $F_t = 1$ indicates a recession and $F_t = 0$ indicates expansion. The coefficients of interest are then β_r^h and β_e^h, which indicate the response of the log level of output at horizon h to a monetary policy shock taken during a recession and expansion respectively.

As described in Stock and Watson (2018), we can alternatively estimate β_r^h and β_e^h using a cumulated differences, or "long-differenced", specification:

$$y_{t+h} - y_{t-1} = F_t\left(\beta_r^h \varepsilon_t + (\theta_r^h)' z_t\right) + (1 - F_t)\left(\beta_e^h \varepsilon_t + (\theta_e^h)' z_t\right) + u_{t+h}, \tag{2}$$

where β_r^h and β_e^h are again the responses of the log level of output to a monetary policy shock that occurs in a recession and expansion respectively. Following Tenreyro and Thwaites (2016), for the levels specification in Eq. (1) the control vector x_t will contain an intercept, linear time trend, and one lag each of the log level of output and the Federal Funds rate. For the long-differenced specification in Eq. (2) the control vector z_t will contain an intercept and one lag each of the log first difference of output and the Federal Funds rate.[6]

Despite the equivalence of the interpretation of β_r^h and β_e^h in Eqs. (1) and (2), estimates of these quantities from the alternative specifications can, and often do, vary significantly in practice. There is a growing literature demonstrating that local projections estimated in levels produce biased estimates of impulse response functions and incorrect confidence intervals in finite samples.[7] This bias becomes worse in smaller sample sizes, and thus is likely to be amplified in applications of local projections with state-dependent responses, which effectively divides the sample size across states. In contrast, recent work by Piger and Stockwell (2023) shows that local projections estimated in long-differenced specifications produce impulse response estimates with substantially less bias and have improved confidence interval coverage. This is true even in the case where the response variable of interest is stationary.

We employ the Newey–West methodology to estimate asymptotic standard errors. As Jordá (2005) shows, the disturbance term in the local projection equation is serially correlated and follows a moving average process. We use these standard errors to calculate 90% confidence intervals around the estimated impulse responses from both Eqs. (1) and (2). The maximum autocorrelation lag in the Newey–West estimator is set to $H + 1$ following Jordá (2005), where H is the maximum horizon considered in estimating the impulse response function. In our empirical results, we calculate impulse responses out to twenty quarters for quarterly measures of output, and 60 months for monthly measures.

To test for state dependence, Eq. (1) is rewritten as follows:

$$y_{t+h} = \beta_r^h \varepsilon_t + (\gamma_r^h)' x_t + (1 - F_t)\left(\alpha^h \varepsilon_t + (\lambda^h)' x_t\right) + v_{t+h}. \tag{3}$$

In this specification, the coefficient α^h has the interpretation of being the difference between the h-period response of output to a monetary policy shock occurring during expansions and the h-period response of output to a monetary policy shock occurring during recessions. A test of the null hypothesis of no state dependence at horizon h can then be conducted via a simple t-test of $\alpha^h = 0$. The analogous transformation is used to test for state dependence in Eq. (2):

$$y_{t+h} - y_{t-1} = \beta_r^h \varepsilon_t + (\theta_r^h)' z_t + \left(1 - F_t\right)\left(\alpha^h \varepsilon_t + (\theta^h)' z_t\right) + u_{t+h}. \tag{4}$$

2.2. Non-linear (Romer & Romer, 2004) monetary policy shocks

To measure ε_t in Eqs. (1) and (2), we use monetary policy shocks based on those developed in Romer and Romer (2004). Romer and Romer (2004) propose a two-step process to derive a measure of monetary policy shocks that controls for the endogenous and anticipatory movements that plague traditional monetary policy measures such as the money supply or the Federal funds rate. First, the intended Federal Funds rate for a given Federal Open Market Committee (FOMC) meeting is constructed by reading the narrative record of each FOMC meeting. Second, the change in the intended funds rate series at each FOMC meeting is regressed on output and inflation forecasts from the Federal Reserve's Greenbook forecasts for the corresponding meeting. The Greenbook forecast is produced prior to each FOMC meeting by the research staff of the Board of Governors. The forecasts contain projections of many macroeconomic variables of output, prices, employment, and investment. By regressing the intended funds rate on these forecasts, the residuals from this regression are free of anticipatory movements. These residuals are then the Romer and Romer (2004) monetary policy shock series.

We follow Tenreyro and Thwaites (2016) in the use of non-linear (Romer & Romer, 2004) shocks. Given that the premise of this study is to estimate non-linearities in the response of monetary policy, assuming the reaction function of the Federal Reserve to be linear may add some state dependent measurement error, causing state dependence in the estimated effects of shocks to show up where there is none. The original (Romer & Romer, 2004) regression is written as follows:

$$\begin{aligned} \Delta ff_m = {} & \alpha + \beta ffb_m + \sum_{i=-1}^{2} \gamma_i \widetilde{\Delta y}_{m,i} + \sum_{i=-1}^{2} \lambda_i (\widetilde{\Delta y}_{m,i} - \widetilde{\Delta y}_{m-1,i}) \\ & + \sum_{i=-1}^{2} \phi_i \widetilde{\pi}_{m,i} + \sum_{i=-1}^{2} \theta_i (\widetilde{\pi}_{m,i} - \widetilde{\pi}_{m-1,i}) + \rho \widetilde{u}_{m,0} + \varepsilon_m \end{aligned}$$

[6] For a specific value of h, Eqs. (1) and (2) are in-sample regressions, and the h-horizon impulse response is the estimate of β_r^h and β_e^h from these regressions. If the maximum horizon shown in a figure is H, then there are H separate in-sample regressions estimated to form the entire impulse response function. In estimating these regressions we keep the sample size the same across horizons by limiting the sample size to that used for the maximum value of h considered.

[7] See Herbst and Johannsen (2024), Kilian and Kim (2011) and Piger and Stockwell (2023).

where Δff_m is the change in the intended funds rate around FOMC meeting m, ffb_m is the level of the intended funds rate before any changes were made at the associated FOMC meeting, and $\widetilde{\Delta y}_{m,i}$, $\widetilde{\pi}_{m,i}$, and $\widetilde{u}_{m,i}$ are the forecasts of real output growth, inflation, and the unemployment rate at horizon i found in the Greenbook for FOMC meeting m. Collecting the right hand side variables in the vector X_m, we write the original (Romer & Romer, 2004) regression compactly as:

$$\Delta ff_m = B' X_m + \varepsilon_m$$

The state-dependent reaction function is then:

$$\Delta ff_m = F_t \left(B_r' X_m\right) + \left(1 - F_t\right)\left(B_e' X_m\right) + \varepsilon_{m,nl} \tag{5}$$

The residuals from this regression, $\varepsilon_{m,nl}$, represent the non-linear monetary policy shock for FOMC meeting m. For our analysis that requires monthly monetary policy shocks we set the monthly shock to $\varepsilon_{m,nl}$ if FOMC meeting m occurred in that month, and zero if there was no FOMC meeting in that month. For our analysis that requires quarterly monetary policy shocks we aggregate the monthly monetary policy shocks by quarter.

2.3. Measuring the business cycle

To measure the business cycle state variable, F_t, Tenreyro and Thwaites (2016) use a continuous, smoothly transitioning, measure created by applying a logistic function to the seven quarter lagging moving average of the growth rate of U.S. quarterly real GDP. Labeling this moving average as z_t, and the standard deviation of z_t as σ, this function is defined as:

$$F_t = 1 - \frac{exp(\kappa(\frac{z_t - c}{\sigma}))}{1 + exp(\kappa(\frac{z_t - c}{\sigma}))}.$$

This function varies between zero and one, with high values indicating lower growth periods and low values indicating higher growth periods. Tenreyro and Thwaites (2016) calibrate the values of c and κ such that F_t matches closely the periods of expansion and recession defined for the United States by the National Bureau of Economic Research (NBER) Business Cycle Dating Committee. To simplify the interpretation of our results, here we instead define F_t as a binary variable that is zero during economic expansions and one during economic recessions as defined by the NBER. However, our results are robust to the definition of F_t used by Tenreyro and Thwaites (2016).[8]

2.4. Data and sample period

We consider several different measures of output for the response variable y_t. Our baseline model, which follows Tenreyro and Thwaites (2016), uses quarterly log U.S. real GDP (FRED code: GDPC1) as the response variable. We also consider the log of real U.S. industrial production index (FRED code: INDPRO) and log real U.S. personal consumption expenditures[9] as alternative response variables, which allows us to estimate impulse response functions at the monthly frequency. Each of these variables was collected from the St. Louis Federal Reserve Bank's FRED database. The federal funds rate variable is measured as the Effective Federal Funds Rate series (FRED code: EFFR) available from FRED. The NBER recession indicator was collected from the National Bureau of Economic Research. Finally, the Greenbook forecasts used to generate the Romer and Romer (2004) monetary policy shocks were collected from the Philadelphia Federal Reserve Bank's Greenbook data set.[10]

The main sample period for our quarterly dataset follows Tenreyro and Thwaites (2016) and runs from 1969:Q1–2008:Q4. For consistency, our monthly dataset runs from 1969:03–2008:12. We restrict our sample period to prior to the Great Recession for two main reasons. One, the papers we are comparing our results to were either written prior to the Great Recession or restrict their sample as is the case in Tenreyro and Thwaites (2016). Two, the federal funds rate was lowered to the zero lower bound in 2008 and stayed there until 2015. This lack of variation combined with the unconventional monetary policy tools employed by the Federal Reserve make using the federal funds rate to evaluate policy difficult.[11,12]

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8 The NBER produces business cycle peak and trough dates at the monthly frequency, while we will produce results regarding the state-dependent effects of monetary policy shocks at both the monthly and quarterly frequency. In mapping the NBER classification to the variable F_t at the monthly frequency, we define the NBER peak month as the last month of an expansion, and the NBER trough month as the last month of a recession. At the quarterly frequency, we define a quarter as in recession if at least two of the months of that quarter are in recession as defined by our monthly measure of F_t, and in expansion otherwise.

9 This was calculated from nominal PCE (FRED code: PCE) and the PCE price index (FRED code: PCEPI).

10 This data can be found at https://www.philadelphiafed.org/surveys-and-data/real-time-data-research/greenbook. It is listed under the Tealbook data sets, as the Greenbook was combined with the Bluebook to form the Tealbook in 2010.

11 One solution would be to make use of the recent work by Choi and Doh (2016), Krippner (2013), Lombardi and Zhu (2018), and Wu and Xia (2016) to calculate shadow rates for the effective federal funds rate during this period. However, this would complicate our comparison to the previous monetary policy asymmetry literature.

12 A recent paper by Stockwell (2023) showed that including post-2008 data in the sample has a negligible effect on monetary policy asymmetry results in a similar local projections model.

3. Results

In this section, we present the estimated state-dependent impulse response functions. We begin with a baseline model that mirrors closely that in Tenreyro and Thwaites (2016). We then move through a variety of robustness checks in attempt to identify the key factors driving conflicting results in the existing literature. For all impulse response functions presented, the impulse response is to a one standard deviation non-linear (Romer & Romer, 2004) shock as constructed in Section 2.2.

3.1. Baseline results

We begin with a baseline specification that closely follows that in Tenreyro and Thwaites (2016). Specifically, we estimate Eq. (1), where the response variable is U.S. quarterly log real GDP. Fig. 1a shows the point estimate for the impulse response of log real GDP to a positive (Romer & Romer, 2004) monetary policy shock taken during both an expansion (blue line) and recession (red line). These results strongly suggest that the effects of a monetary policy shock are stronger when the shock takes place during an expansion. The peak response for a shock taken during expansions occurs at the 10 quarter horizon, and this peak response is more than twice as large as the effect for a shock taken during a recession. Aside from a brief period at the earliest horizons, the expansion effect is larger than the recession effect. Indeed, for most horizons, the response to a shock taken during recessions is near zero. These results closely match the results found in Tenreyro and Thwaites (2016), who found the impulse response of output in expansions reached its peak about ten quarters from the time of the shock, and the recession response was smaller for most horizons.

Fig. 1b and c provide point-wise Newey–West standard errors for the impulse response at each horizon. The response of output to a monetary policy shock taken during expansions is significantly different from zero over most horizons considered, while the response to a shock taken during recessions is significantly different from zero only in the early part of the horizon. To test the null hypothesis that the recession and expansion responses are equal, Fig. 1d shows the p-value for a test of the significance of α^h from Eq. (3). These p-values fall below 0.10 from horizons 9–15, which corresponds to the horizons with the largest estimated difference between the expansion and the recession response. Overall, the evidence from the point estimates and measures of statistical significance largely mirror the findings of Tenreyro and Thwaites (2016) that the response of output to a monetary policy shock taken during expansions is larger than the response to a shock taken during recessions. We now study the robustness of this result to a variety of deviations from the baseline model specification.

3.2. Robustness to estimation in long differences

There is variability in the broad literature regarding the choice of whether to use models specified in levels vs. some variety of differencing to estimate impulse response functions. The literature studying state-dependence in output responses to monetary policy shocks is no exception. Most early papers in this literature estimated empirical models in terms of the difference of the output measure.[13] More recent papers in the state dependence literature use models specified in log levels. This is especially true among papers using local projections to estimate impulse response functions.[14]

At the same time, there is a recent and growing literature, exemplified by Herbst and Johannsen (2024), that documents significant finite sample bias in local projection regressions, where this literature has focused on models specified in levels. In contrast, Piger and Stockwell (2023) show that estimates of impulse response functions from local projections with an externally identified shock and estimated in a long-differenced specification display less bias and better coverage properties than estimates from local projections estimated in levels. Further, these improvements in estimation and inference performance are larger in smaller sample sizes, making the long-differenced specification especially relevant when investigating business cycle state dependence, which effectively splits the sample across business cycle regimes. Given these recent results, it seems natural to evaluate the robustness of findings regarding state dependence in the effects of monetary policy to specification of the local projection in levels vs. long differences.

Fig. 2a shows the point estimate for the impulse response of log real GDP to a positive (Romer & Romer, 2004) monetary policy shock taken during both an expansion (blue line) and recession (red line), where the estimates are constructed using the long-differenced specification in Eq. (2). This figure tells a striking story: estimation in long differences erases the conclusion that monetary policy shocks taken during expansions have larger effects than those taken during recessions, and provides some evidence to the contrary. Specifically, the peak responses in expansions and recessions are now roughly equal. However, the response in the recession regime reaches its peak response more quickly and stays there for longer than the expansion regime. This result is in contrast to Tenreyro and Thwaites (2016) but in agreement with much of the rest of the related literature.

Fig. 2d shows the p-value for a test of the significance of α^h from Eq. (4). These p-values fall below 0.10 briefly at shorter horizons, with the impulse response estimates suggesting the real GDP response to shocks taken during recessions is larger than to those taken during expansions. For longer horizons, there is no statistically significant evidence of business cycle state-dependence in the response to monetary policy shocks.[15]

[13] Examples include the early literature mentioned in Section 1 such as Garcia and Schaller (2002), Kaufmann (2002), Lo and Piger (2005), Peersman and Smets (2002), and Thoma (1994).

[14] Examples include more recent papers mentioned in Section 1 such as Ramey and Zubairy (2018) and Tenreyro and Thwaites (2016).

[15] We ran this same specification using real GDP per capita in place of real GDP and found similar results.

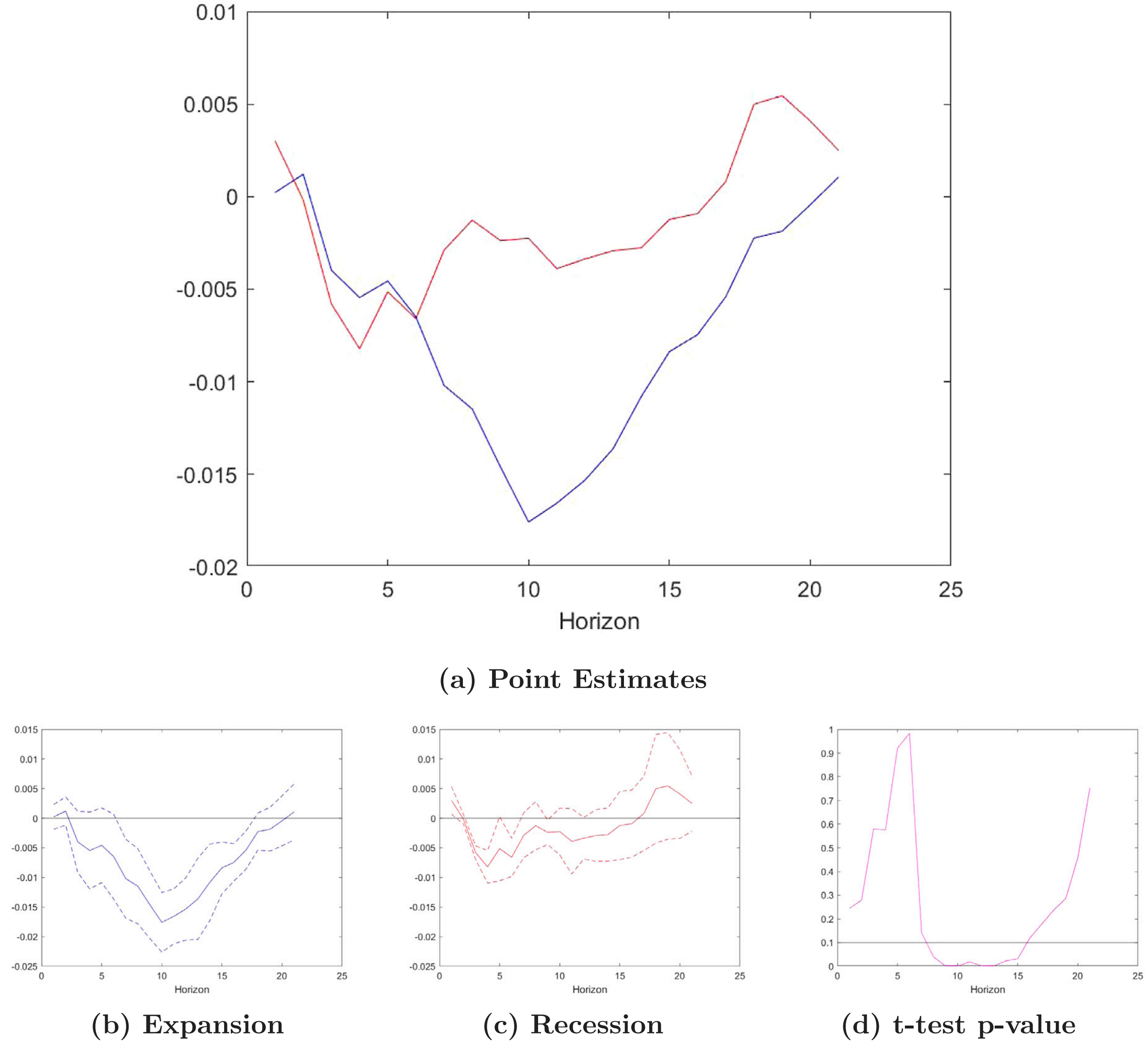


Fig. 1. Impulse response function of quarterly real GDP using the Levels specification. *Notes:* This figure shows the impulse response of log real GDP to a one standard deviation positive (Romer & Romer, 2004) monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with log real GDP as the left-hand side variable. The sample is quarterly from 1969:Q1–2008:Q4. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse responses with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to 10% significance. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

These results suggest that the specification of the response variable in the local projection in long differences vs. log levels is enough to eradicate the finding that monetary policy shocks taken during expansions have larger output effects than those taken during recessions. The responses between the two phases of the business cycle are roughly equal but larger during recessions than expansions at shorter time horizons. These two sections taken together suggests that there is mixed evidence regarding which phase of the business cycle sees larger effects of monetary policy on output. We next turn to evaluating the importance of outliers in investigating business cycle dependence of the output effects of monetary policy shocks.

3.3. Robustness to outliers

Most commonly used measures of monetary policy shocks display significant outliers during the early years of the Volcker chairmanship of the Federal Reserve when the FOMC briefly experimented with non-borrowed reserves targeting. During this period, commonly dated from November 1979 to September 1982, the FOMC dropped its targeting of the federal funds rate, and shifted its focus to targeting the quantity of nonborrowed reserves. This corresponded to extreme swings in the federal funds rate, and makes

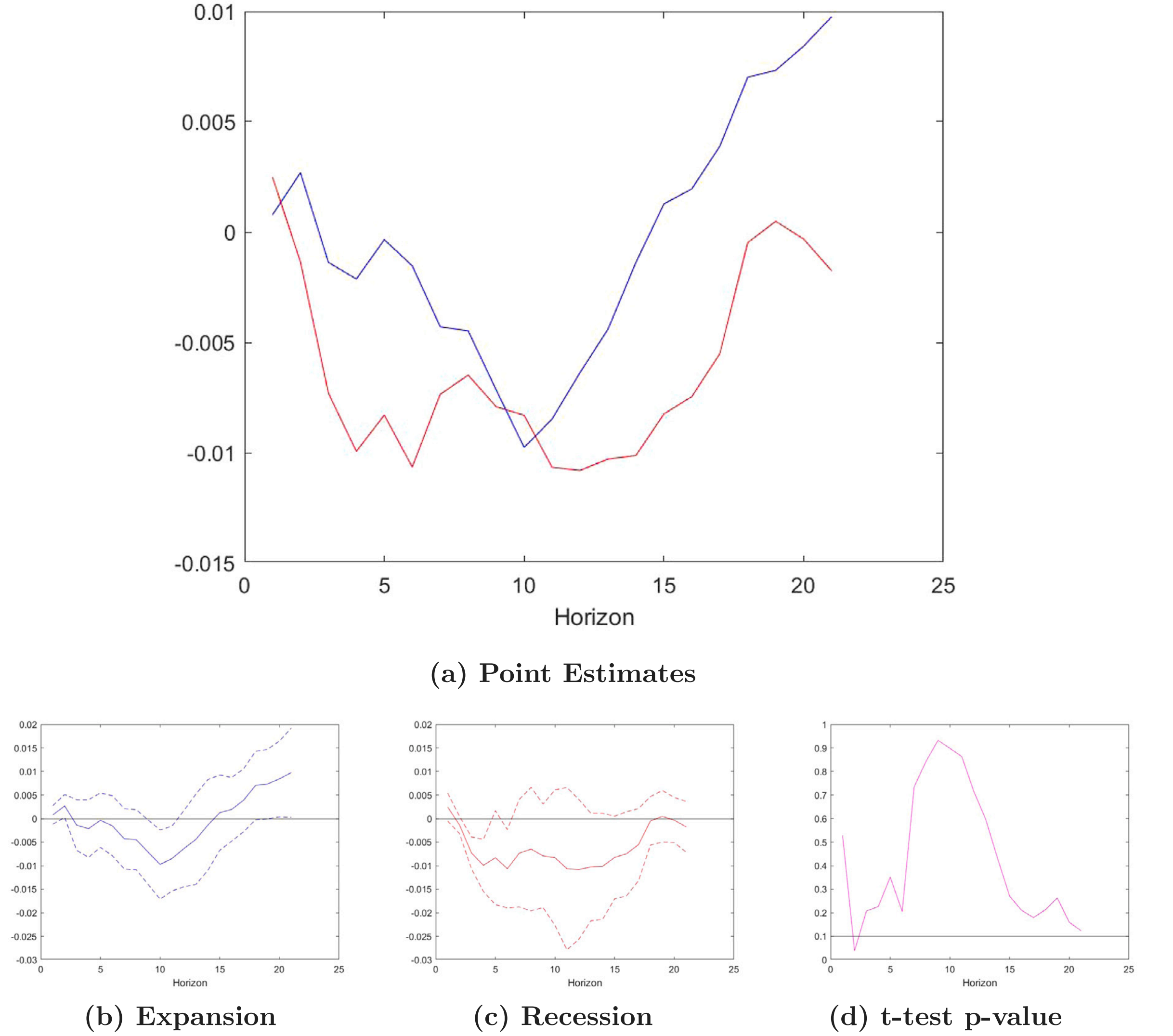


Fig. 2. Impulse response function of quarterly real GDP using the long-differenced specification. *Notes:* This figure shows the impulse response of log real GDP to a one standard deviation positive (Romer & Romer, 2004) monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with a long difference of log real GDP as the left-hand side variable. The sample is quarterly from 1969:Q1-2008:Q4. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse responses with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to the 10% significance level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

measurement of monetary policy shocks over this period particularly difficult. Indeed, Coibion (2012) shows that the Romer and Romer (2004) monetary policy shocks can be predicted using lagged macroeconomic fundamentals, but this predictability disappears when the period of non-borrowed reserves targeting is dropped from the sample. Romer and Romer (2004) also note some concern with the inclusion of shocks during this period when measuring the effects of monetary policy shocks, and present robustness checks where this period is excluded. In this section, we demonstrate how the results change for business cycle state-dependent impulse response functions when we remove the outliers in the Romer and Romer (2004) monetary policy shocks during the early periods of the Volcker chairmanship.

Fig. 3 plots the non-linear (Romer & Romer, 2004) monetary policy shocks generated according to Eq. (5), while Table 1 contains the values of the ten largest (Romer & Romer, 2004) monetary policy shocks in absolute value. The largest shocks happen during the Volcker chairmanship at the Fed, with three of the quarters from 1980 being among the four largest values. This was a feature of the shocks produced in the original (Romer & Romer, 2004) paper as well. It is also important to note that the first three quarters of 1980 were recessions according to our classification. This is problematic since of the 160 quarters in our sample, only 27 are counted as recessions. Since there are so few data points in recessions, results for the recession regime are likely highly susceptible to outliers.

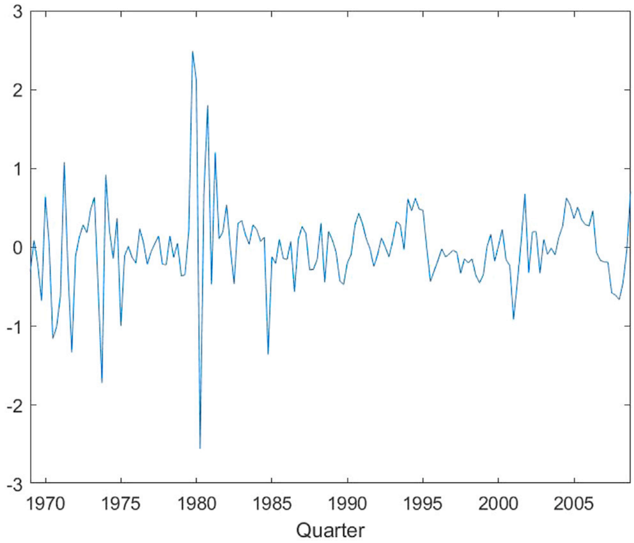


Fig. 3. Quarterly non-linear (Romer & Romer, 2004) shocks. *Notes:* This figure plots the quarterly non-linear (Romer & Romer, 2004) shocks constructed as in Section 2.2 over the sample 1969:Q1-2008:Q4.

Table 1
Largest quarterly non-linear (Romer & Romer, 2004) shocks.

Quarter	Value	$NBER$
1980:Q2	−2.6377	1
1979:Q4	2.6151	0
1980:Q1	2.1771	1
1980:Q4	1.9366	0
1973:Q4	−1.6411	0
1981:Q2	1.3189	0
1971:Q4	−1.2106	0
1970:Q3	−1.1734	1
1984:Q4	−1.1583	0
1975:Q1	−1.1531	1

Notes: This table contains the values of the ten largest shocks (in absolute value) of the nonlinear (Romer & Romer, 2004) monetary policy shock series constructed as described in Section 2.2. The column $NBER$ indicates U.S. recession quarters as established by the National Bureau of Economic Research.

To evaluate the influence of these outliers on the estimated impulse response functions, we re-estimate the model in the long-differenced specification in Eq. (2), including dummy variables to remove the influence of shocks that occur from 1979:Q4 to 1982:Q4. Fig. 4a shows these estimated impulse response functions, and demonstrates the very significant effect outliers had on the previously shown results. The response to a policy shock occurring during a recession is now always larger than the response for shocks occurring during expansions, and the peak response in recessions is approximately three times larger than in Fig. 2. The outliers observed during the Volker period also have an effect on the results for policy shocks taken during expansions as the response is now smaller and has a counter-intuitive sign.

From Fig. 4b and c, we see that the response of output to a policy shock that occurs in expansions is not significantly different from zero at almost all horizons, while the response to a policy shock that occurs in recessions is significant at most horizons. Finally, Fig. 4d shows that there is a significant difference between the response of output to monetary policy during recessions and expansions. The result from Section 3.1 has flipped to monetary policy being more effective in recessions than expansions, a finding opposite from most of the recent literature.[16]

3.4. Robustness to alternative measures of output

Many papers studying output effects of U.S. monetary policy shocks use monthly industrial production as the measure of output, including those that evaluate various types of state-dependence in these effects. For example, Garcia and Schaller (2002), Lo and Piger (2005), Peersman and Smets (2002), Romer and Romer (2004), and Weise (1999) all use industrial production in their baseline

[16] We ran this same specification using real GDP per capita in place of real GDP and found similar results.

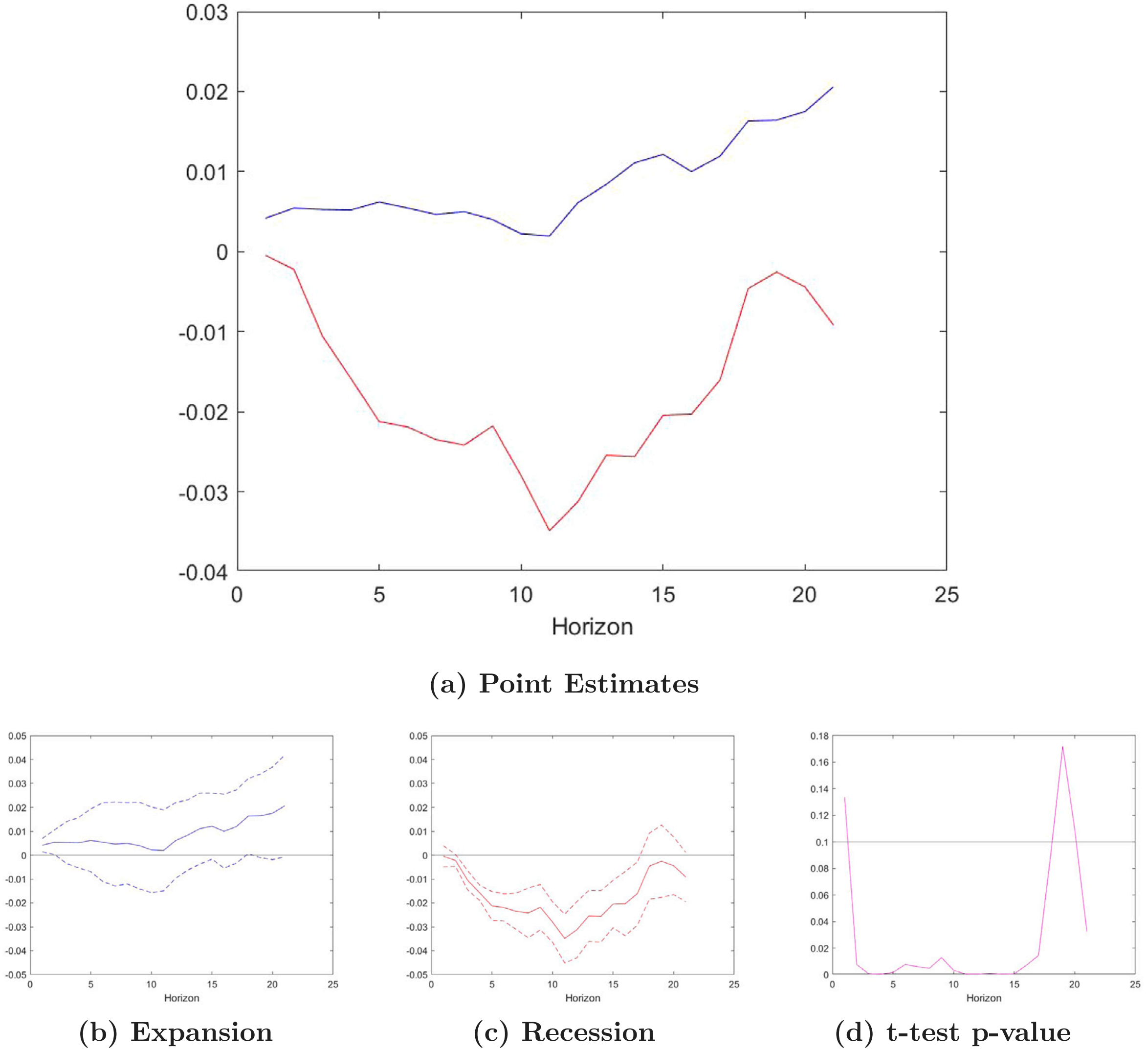


Fig. 4. Impulse response function of quarterly real GDP using the long-differenced specification and controlling for outliers. *Notes:* This figure shows the impulse response of log real GDP to a one standard deviation positive (Romer & Romer, 2004) monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with a long difference of log real GDP as the left-hand side variable. The sample is quarterly from 1969:Q1-2008:Q4 with the quarters 1979:Q4-1982:Q4 dummied out. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse response of log real GDP with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to the 10% significance level.

specifications. While industrial production is a narrower measure of output than real GDP, it has the appeal of being more sensitive to interest rates. It is also available at a monthly frequency. This allows us to exactly match the business cycle state variable used in our empirical models to the NBER recession and expansion chronology.

Fig. 5a shows the point estimate for the impulse response of log monthly industrial production to a positive (Romer & Romer, 2004) monetary policy shock taken during both an expansion (blue line) and recession (red line), where the estimates are constructed using the long-differenced specification in Eq. (2), but without controlling for outliers. Comparing the point estimates in Fig. 5a to those in Fig. 2a shows similar results. The tests for state-dependent effects at alternative horizons presented in Fig. 5d follows a similar pattern to the case when using quarterly log real GDP as the output measure in Fig. 2d, though there are a few horizons where asymmetry is statistically significant when using monthly log industrial production. Overall, Fig. 5 suggests that the response of output to monetary policy is equal between expansions and recessions (as it was in Fig. 2), with weak evidence pointing to a stronger response during recessions.

Fig. 6 repeats the analysis with industrial production now controlling for outliers in the Romer and Romer (2004) monetary policy shock from November 1979 to September 1982. The results in this case are similar to those when using real GDP as the

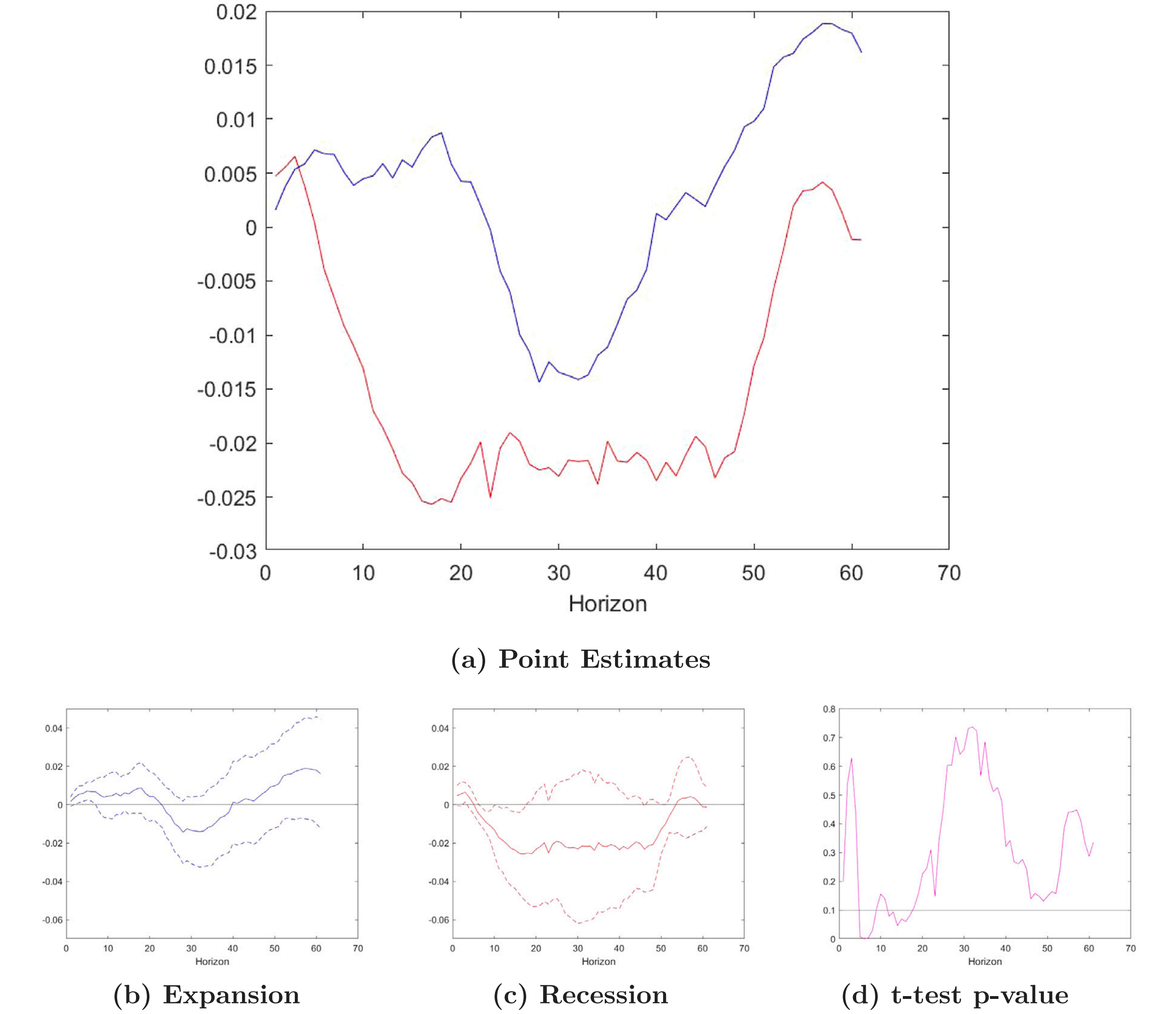


Fig. 5. Impulse response function of monthly industrial production using the long-differenced specification. *Notes:* This figure shows the impulse response of log monthly industrial production to a one standard deviation positive (Romer & Romer, 2004) monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with a long difference of log monthly industrial production as the left-hand side variable. The sample is monthly from 1969:03-2008:12. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse responses with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to the 10% significance level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

output variable and controlling for outliers. Fig. 6 is very similar to Fig. 4 in that the response during recessions is always larger than the response during expansions, and the expansion response is statistically insignificant. Also, the p-values from the t-tests support the conclusion that the output response is larger when the monetary policy shock takes place during recessions. Specifically, these tests show a statistically significant difference between the expansion and recession response from monthly horizons 5–52. Finally, comparing Figs. 5 to 6 shows that removing the outliers in the monetary policy shock strengthens the evidence in favor of policy shocks taken during recessions having larger effects than those taken during expansions. As just one example, the peak response of industrial production to a monetary policy shock taken during recessions in Fig. 6a is much larger than in Fig. 5a, by a factor of between three and four, while the response to policy shocks taken during an expansion is smaller in absolute value and has a counterintuitive sign. This again is consistent with the results for real GDP and flips the results from Section 3.1.

In addition to monthly log industrial production, we also consider the log of monthly U.S. real personal consumption expenditures (PCE) as an additional measure of output. Fig. 7 shows these results estimated over the sample 1969:03-2008:12. To avoid a proliferation of figures, we focus on the case where the model is estimated in long differences (Eq. (2)) and dummies are included to control for the outliers in the Romer and Romer (2004) monetary policy shock during 1979–1982 period. Similar to the results for

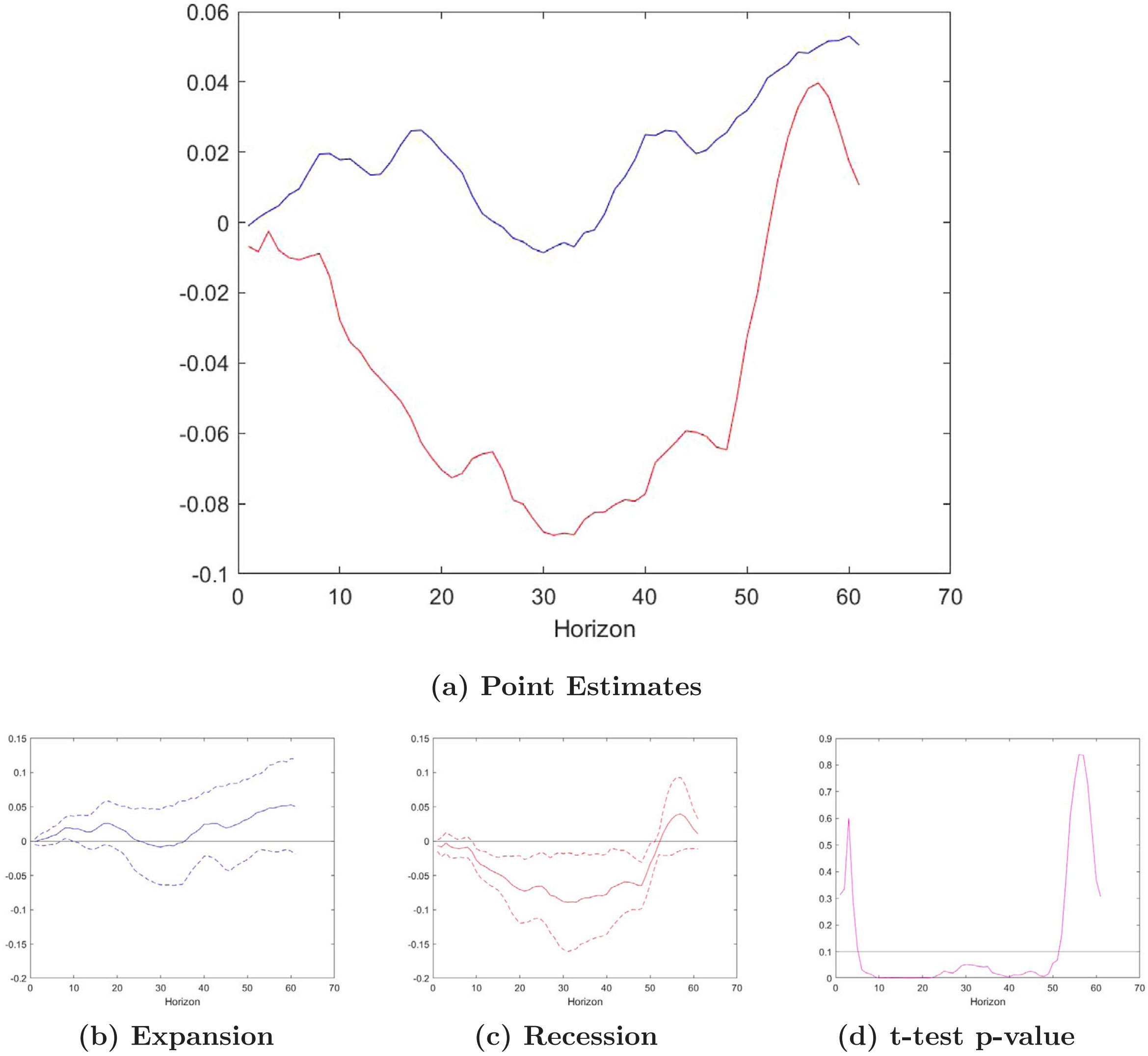


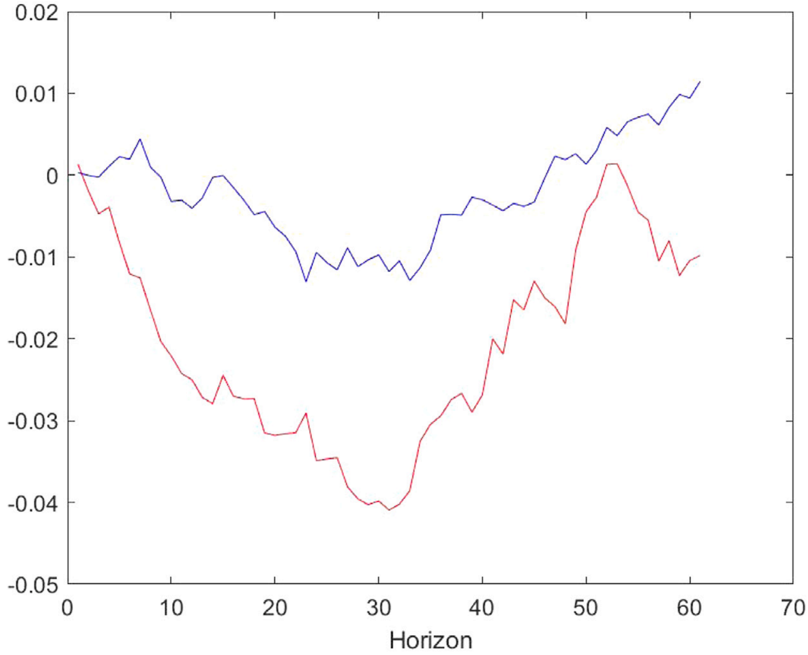
Fig. 6. Impulse response function of monthly industrial production using the long-differenced specification and controlling for outliers. *Notes:* This figure shows the impulse response of log monthly industrial production to a one standard deviation positive (Romer & Romer, 2004) monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with a long difference of log monthly industrial production as the left-hand side variable. The sample is monthly from 1969:03–2008:12 with the months 1979:10–1982:12 dummied out. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse response of log real GDP with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to the 10% significance level.

real GDP and industrial production, these results show strong evidence in favor of monetary policy shocks taken during recessions having much larger effects than those taken during expansions. The tests in 7d show that there are significant differences between the responses in expansions and recessions.

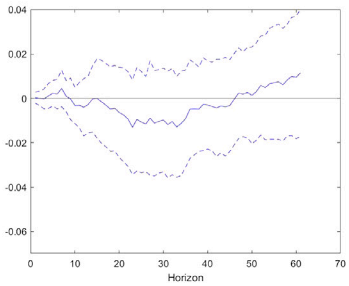
Taken together, the results in this section demonstrate that the measure of output used, be it quarterly real GDP, monthly industrial production or real PCE, yields similar results for the estimated response of output to monetary policy shocks taken during expansions vs. recessions. In particular, when the local projection models are estimated in long-differences there is weak evidence in favor or shocks taken during recessions having larger effects. This evidence becomes very strong once we account for the large outliers occurring during the early years of the Volcker chairmanship of the Federal Reserve.

3.5. Robustness to an alternative measure of policy shocks

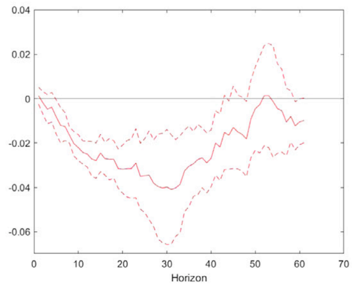
Fig. 8 explores the robustness of the previously presented results to a different measure of monetary policy shocks. In particular, we measure monetary policy shocks using a non-linear monetary structural VAR containing real GDP growth, PCE inflation, and the



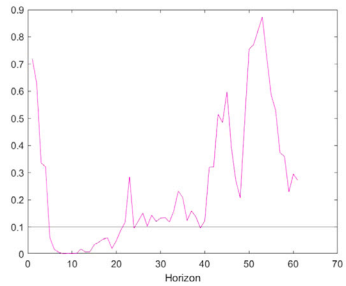
(a) Point Estimates



(b) Expansion



(c) Recession



(d) t-test p-value

Fig. 7. Impulse response function of monthly real personal consumption expenditures using the long-differenced specification and controlling for outliers. ***Notes:*** This figure shows the impulse response of log monthly real personal consumption expenditures to a one standard deviation positive (Romer & Romer, 2004) monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with a long difference of log monthly real personal consumption expenditures as the left-hand side variable. The sample is monthly from 1969:03-2008:12 with the months 1979:10-1982:12 dummied out. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse response of log real GDP with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to the 10% significance level.

Federal Funds rate, where the Federal Funds rate is ordered last in the VAR. The residuals from the Federal Funds rate equation from this VAR were then used in place of the Romer and Romer (2004) shocks in Eq. (2). Fig. 8 shows the estimated impulse response function of log real GDP to a VAR shock, where the local projection is estimated in long differences and we control for outliers in the early years of the Volcker period.

These results yield similar but weaker conclusions to those in Section 3.3. From Fig. 8a, with the exception of the shortest horizons, the response of real GDP to a shock that occurs in recessions is larger than to a shock that occurs in expansions. The tests for state-dependent effects find some statistically significant differences between the effects for shocks that occur during recessions vs. expansions, although this evidence is weaker the case where (Romer & Romer, 2004) shocks were used.

4. Conclusion

There is substantial interest in whether the output effects of U.S. monetary policy shocks vary over the business cycle, with the existing literature containing conflicting results. In this paper we began with a baseline specification similar to Tenreyro and

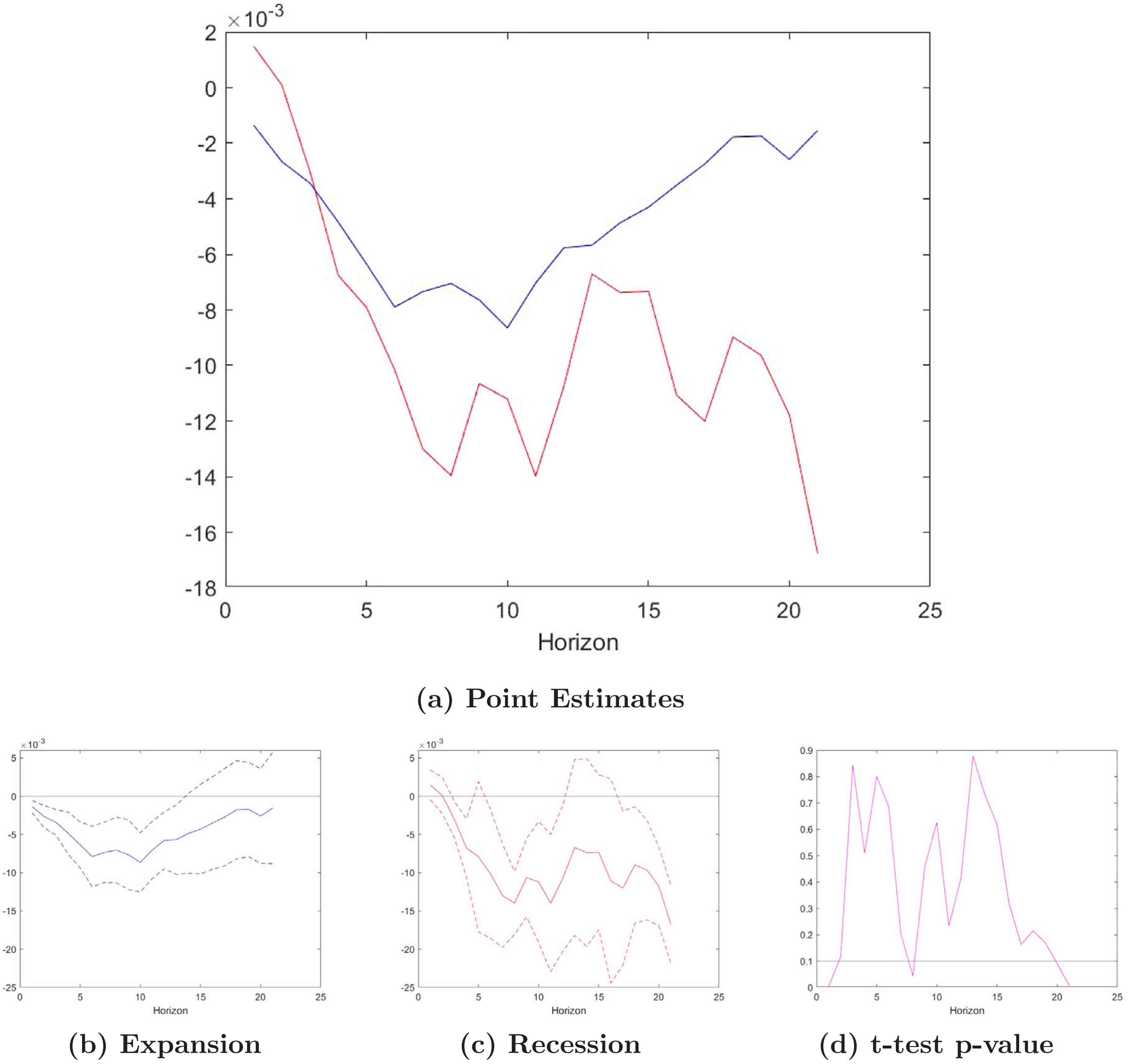


Fig. 8. Impulse response function of quarterly real GDP to a VAR-based shock using the long-differenced specification and controlling for outliers. *Notes:* This figure shows the impulse response of log real GDP to a one standard deviation positive VAR-based monetary policy shock that occurs during recessions (red) versus expansions (blue). The local projection regression is specified with a long difference of log real GDP as the left-hand side variable. The sample is quarterly from 1969:Q1–2008:Q4 with the quarters 1979:Q4–1982:Q4 dummied out. Panel (a) shows the impulse response point estimates for expansions and recessions. Panels (b) and (c) show the impulse responses with the Newey–West 90% confidence intervals for expansion and recession respectively. Panel (d) shows the *p*-value of the t-test of no difference between the impulse response to a shock taken during expansions vs. recessions, with the horizontal line in the figure corresponding to the 10% significance level.

Thwaites (2016) that yields evidence that monetary policy shocks taken during expansions have larger effects on output than those taken during recessions. We then explored a variety of robustness checks on this baseline model.

We find that the results from this baseline model are not robust, and that the combination of two key specification changes can reverse the results such that there is very strong evidence that monetary policy shocks taken during recessions have substantially larger effects on output than those taken during expansions. The first change relates to the choice of whether to estimate impulse response functions in a local projection regression that is specified in levels vs. long differences of the data. When the output effects are estimated using the long-differenced specification, the result from the baseline case disappears, and the response of output in recessions and expansions are roughly equal. The results suggest that when measured in long-differences, the response of output during recessions “closes the gap” with the response of output in expansions.

The second change involves accounting for outliers. The early years of the Volcker chairmanship of the Federal Reserve coincides with several extreme observations in commonly used measures of monetary policy shocks. These outliers can have a particularly outsized effect on regressions investigating business cycle state dependence in the effects of monetary policy shocks, as a disproportionate number occur during the small sample of data corresponding to recessions. When the influence of these outliers is controlled for, the response of output to shocks occurring during recessions increases in size and the response to shocks occurring during expansions disappears, flipping the result from the baseline case. We have also considered a variety of other factors, including the use of alternative output measures and measures of monetary policy shocks. Each of these changes yields results consistent with our primary analysis. Overall, in our preferred specification of using the long-difference and controlling for outliers, we conclude that the evidence is most supportive of monetary policy shocks occurring during recessions having larger output effects than those occurring during expansions.

CRediT authorship contribution statement

Jeremy Piger: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Thomas Stockwell:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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