For Online Publication

Appendix to:

Identification in Macroeconomics

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A The Effects of Monetary Shocks: Romer and Romer versus VARs

Coibion (2012) has drawn attention to the fact that Romer and Romer's (2004) results about the impact of monetary shocks contrast sharply with those of standard monetary VARs. The peak responses of industrial production and unemployment to a change in the federal funds rate are roughly six times larger in Romer and Romer (2004) than in a standard monetary VAR. Furthermore, while the contribution of monetary policy shocks to fluctuations in unemployment and inflation is quite modest according to a standard monetary VAR, monetary policy shocks account for a very large portion of fluctuations in these variables according to Romer and Romer's results.

Figure A.1 presents six different estimates of the response of industrial production and the real interest rate to monetary shocks. The two columns present results based on different monetary shocks: results in the left column are based on monetary shocks from a standard monetary VAR (the VAR used in Coibion (2012)), while results in the right column are based on Romer and Romer's (2004) monetary shocks.[1] In the three rows, different methods are used to construct impulse responses: in the top row impulse responses are constructed using VAR dynamics, in the middle row using the Jorda specification, and in the bottom row using the single-equation method employed by Romer and Romer (2004).[2] The sample period is 1970-1996—the same sample period as in Romer and Romer (2004). Figure A.2 presents analogous reponses for the CPI and the nominal interest rate.

There are two things we would like to emphasize about the results presented in Figure A.1. First, both the shocks used and the method used to construct impulse responses matters a great deal for the conclusions reached. The Romer-Romer shocks generate much larger effects than the VAR shocks. The VAR impulse responses suggest that the standard errors are substantially smaller than the other methods for constructing impulse responses. Finally, the Romer-Romer method for constructing impulse response generated much larger effects than the other two. Clearly, it matters a great deal which methods are used both for constructing shocks and estimating impulse

[1] Coibion's (2012) VAR is a monthly VAR that includes the logarithm of industrial production, the unemployment rate, the logarithm of CPI, the logarithm of a commodity price index, and the effective federal funds rate, in that order. Twelve lags are included. Standard errors are constructed using a wild bootstrap (Goncalves and Kilian, 2004; Mertens and Ravn, 2013). For Romer and Romer's (2004) shocks, we use a version of compiled by Wieland and Yang (2017).

[2] Romer and Romer regress industrial production on 36 lags of their monetary shocks as well as 24 lags of industrial production and month dummies. They then construct an impulse response function by iterating forward the response of industrial production to a shock (including the effects of the lagged dependent variables). In the Jorda specification, we include two lags of the five variables in Coibion's VAR as controls. The standard errors in the top row are constructed using a wild bootstrap (Goncalves and Kilian, 2004; Mertens and Ravn, 2013). In the middle panel, we use Newey and West (1987) standard errors with a lag length equal to 1 plus the horizon in question. The standard errors in the bottom two panels are constructed based on estimates of the asymptotic distribution of the parameters as in Romer and Romer (2004).

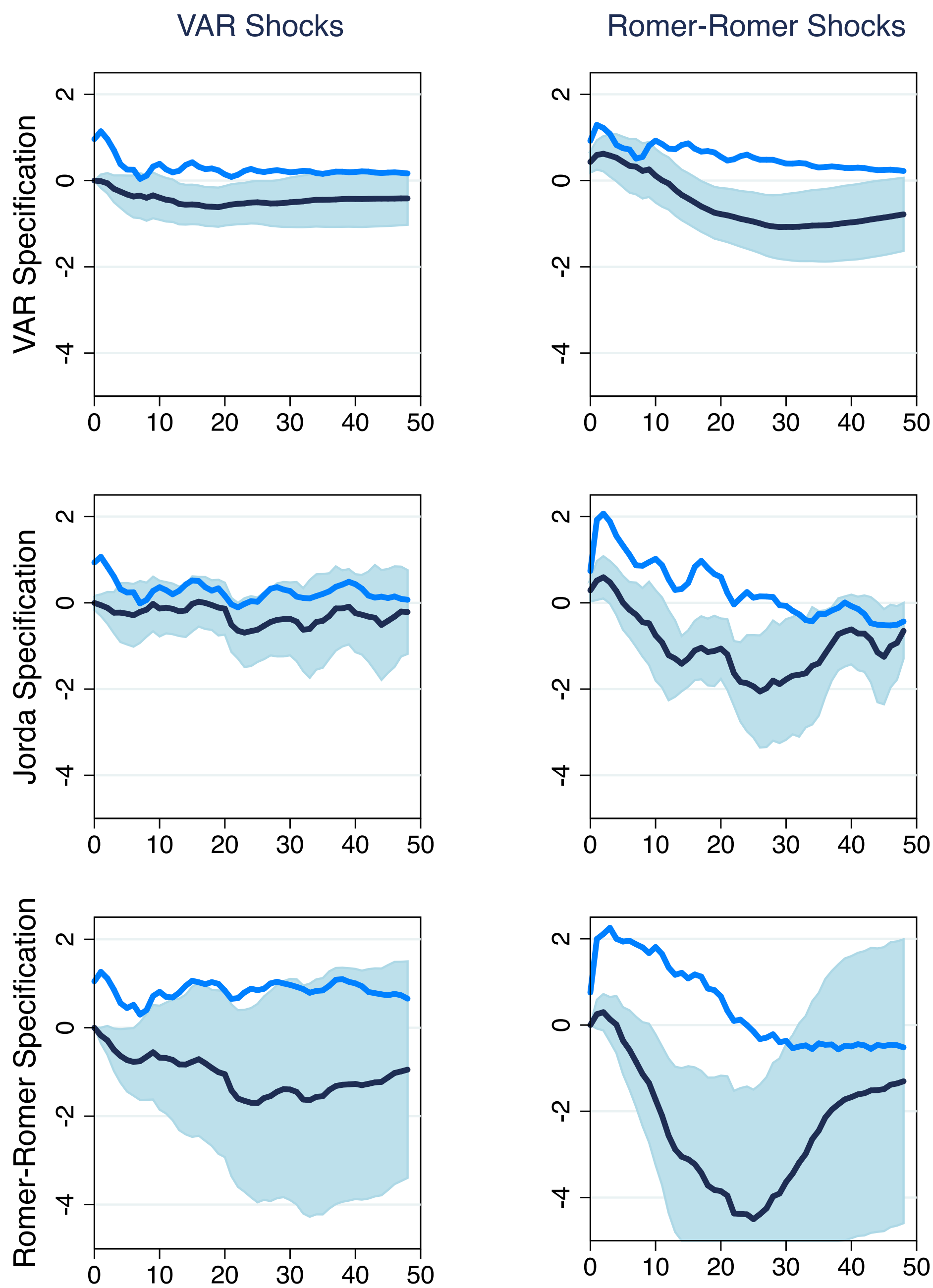

Figure A.1: Response of Industrial Production and the Real Interest Rate to Monetary Shocks

Note: The figure plots the response of industrial production (black line) and the real interest rate (blue line) to monetary shocks calculated in six different ways. The light-blue area represents a 95% confidence band for industrial production. The three panels on the left use the monetary shocks produced by Coibion's (2012) monthly VAR, while the three panels on the right use Romer and Romer's (2004) monetary shocks. The top two panels use Coibion's (2012) VAR specification to construct the impulse response, while the middle two panels use the Jorda specification and the bottom two panels use Romer and Romer's (2004) specification. The sample period is 1970 to 1996, the same as the sample period in Romer and Romer (2004). The top panel on the right uses the Romer-Romer shocks as external instruments in Coibion's VAR.

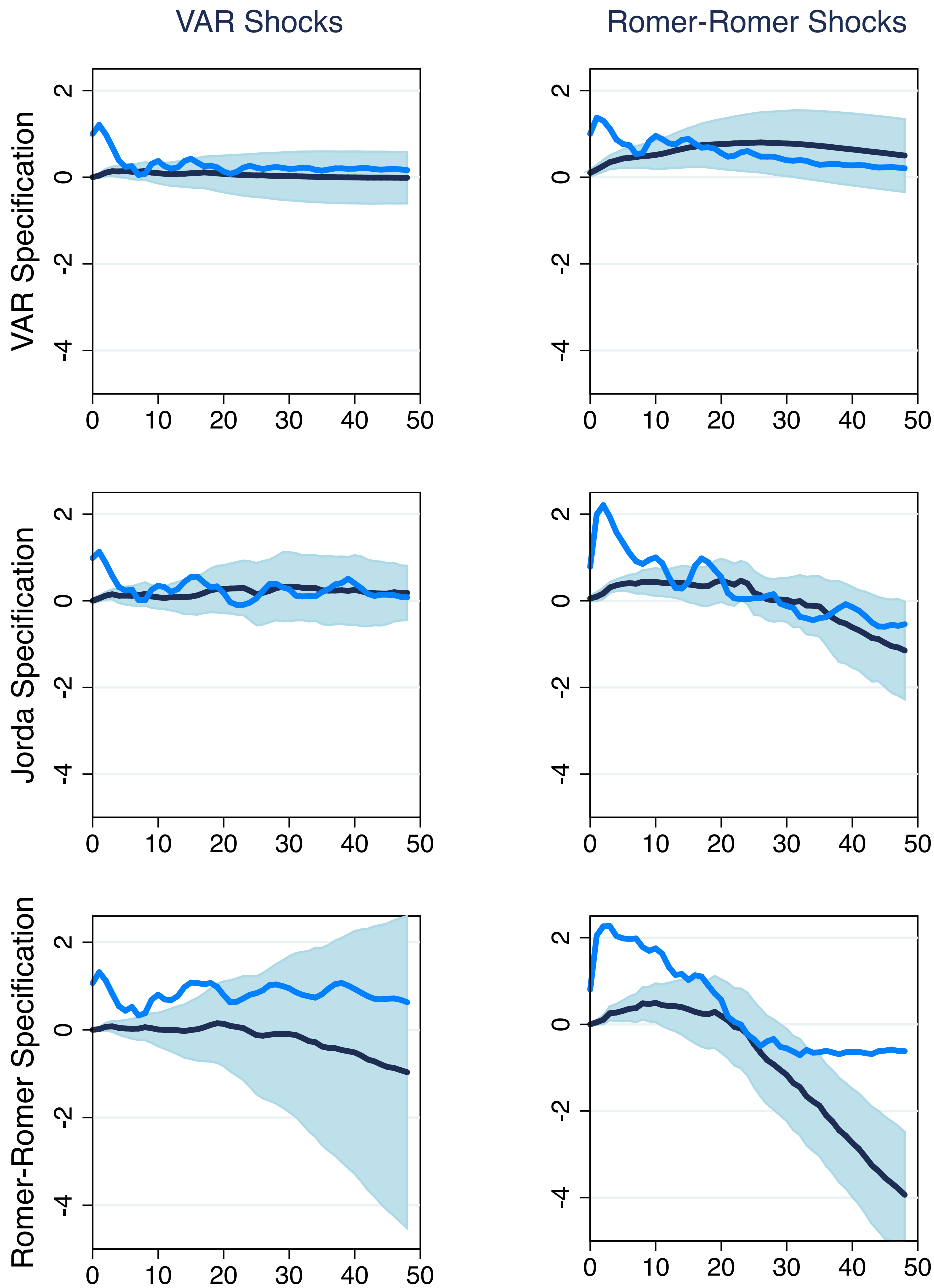

Figure A.2: Response of the CPI and the Nominal Interest Rate to Monetary Shocks

Note: The figure plots the response of the CPI (black line) and the nominal interest rate (blue line) to monetary shocks calculated in six different ways. The light-blue area represents a 95% confidence band for the CPI. The three panels on the left use the monetary shocks produced by Coibion's (2012) monthly VAR, while the three panels on the right use Romer and Romer's (2004) monetary shocks. The top two panels use Coibion's (2012) VAR specification to construct the impulse response, while the middle two panels use the Jorda specification and the bottom two panels use Romer and Romer's (2004) specification. The sample period is 1970 to 1996, the same as the sample period in Romer and Romer (2004). The top panel on the right uses the Romer-Romer shocks as external instruments in Coibion's VAR.

Table A.1: Scaled Cumulative Response of Industrial Production to Monetary Shocks over 36 Months

	VAR Shocks	Romer-Romer Shocks
VAR Specification	1.4	0.7
Jorda Specification	1.0	2.0
Romer-Romer Specification	1.3	3.5

Notes: Each number in the figure is the (negative of the) cumulative response of industrial production divided by the cumulative response of the real interest rate over the first 36 months after a monetary shock.

responses.

The second important lesson illustrated by Figure A.1 has to do with how to best measure the size of the response. The direct comparison between Romer and Romer's (2004) results and those from a standard monetary VAR can be seen by comparing the top-left panel (VAR) with the bottom-right panel (Romer-Romer). The response of industrial production is clearly much bigger for Romer-Romer than VAR. But notice that the response of the real interest rate is also much bigger. Loosely speaking, this means that the "treatment" in the Romer-Romer panel is much bigger. It stands to reason that this contributes substantially to the bigger response of industrial production in the Romer-Romer panel.

To get a meaningful measure of the effect of a treatment, one must divide the size of the response with the size of the treatment in each case. One way to do this is to sum up the response of industrial production over some time horizon, sum up the response of the real interest rate over the same horizon, and divide the cumulative response of one by the other. This is what is done in Table A.1 using a horizon of 36 months. While the peak response of industrial production is roughly 6 times larger in Romer-Romer than VAR, the cumulative response of industrial production scaled by the cumulative response of real interest rates is only 2.5 times larger (3.5 versus 1.4). This illustrates well the point we made earlier in this article that different dynamics of different shocks can make it tricky to apply the estimates from one setting to another without the aid of a model.

B External Instruments in VARs

A recent innovation in dynamic causal inference is the use of "external instruments" in VARs (Stock and Watson, 2012; Mertens and Ravn, 2013; Stock and Watson, 2017). Gertler and Karadi (2015) use this method to estimate the effects of exogenous monetary shocks on output, inflation, and credit spreads. Their measure of exogenous variation in monetary policy is the surprise movement in the 3-month-ahead fed funds rate futures contract in a 30-minute window around FOMC announcements. They then run a monthly VAR and instead of viewing the reduced form error in the interest rate equation as the monetary shock, they regress all the reduced form residuals on their "external" monetary policy shock. This yields a vector of contemporaneous responses of the variables in the VAR to the monetary shock (non of which is constrained to be zero). Finally, they construct an impulse response by iterating forward the VAR dynamics starting with this contemporaneous response. Figure B.1 reproduces Figure 1 from Gertler and Karadi (2015). The column on the left gives impulse responses using external instruments, while the column on the right uses a standard Cholesky decomposition (see the figure note for details).

An important advantage of the external instruments approach relative to standard monetary VARs that rely on a Cholesky ordering is that it is possible to include fast-moving financial variables—such as stock prices, exchange rates, and credit spreads—in the VAR. In a standard monetary VAR, one must make a stark choice regarding the direction of contemporaneous causation of each variable with the policy variable: either it runs only from the policy variable to the variable in question or it runs only the other way. This is clearly unsatisfactory for variables such as stock prices, exchange rates, and credit spreads. The notion that the contemporaneous values of stock prices, exchange rates, and credit spreads do not contain useful information about the endogenous component of monetary policy (even conditional on the other variables in the VAR) is highly dubious. This would suggest including them in the policy equation so as to get a cleaner measure of exogenous policy actions. However, if this is done, one cannot use the VAR dynamics to iterate forward the impulse response without assuming that these variables do not react to exogenous policy actions contemporaneously, which is inconsistent with much evidence (see, e.g., Gurkaynak, Sack, and Swanson, 2005; Bernanke and Kuttner, 2005, for stock prices).

However, while VARs identified with external instruments relax the Cholesky timing assumptions for contemporaneous responses, they do not relax the assumptions embedded in using the VAR system to construct the impulse response. This methodology still must assume that the VAR is a correct representation of the dynamics of all the variables in the system (the model is correct).

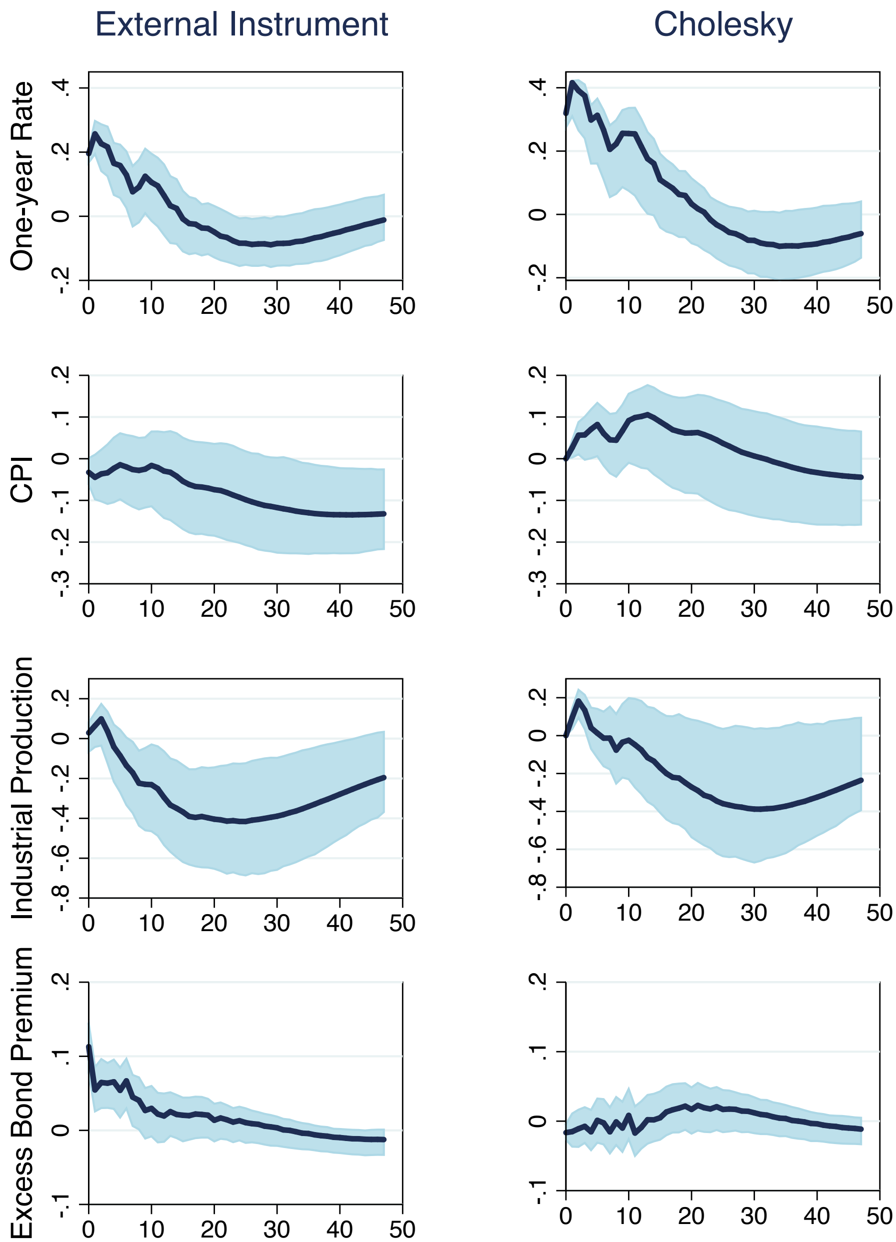

Figure B.1: Responses to Monetary Shocks from Gertler and Karadi (2015)

Note: This figure replicates Figure 1 in Gertler and Karadi (2015). The figure plots the response of the one-year Treasury bond yield, the CPI, industrial production, and a measure of the excess bond premium in response to monetary policy shocks identified in two different ways. The left column uses external instruments to identify the contemporaneous response to the monetary shocks. The right column uses a Cholesky decomposition with the one-year yield considered the policy instrument and this variable ordered second to last with the excess bond premium ordered last. In both cases, the responses after the initial period are calculated by iterating forward a VAR with these four variables.

Consider the response of industrial production in Figure B.1. The external instruments approach allows the contemporaneous response of industrial production to be non-zero. In fact, however, it is estimated to be very close to zero (i.e., not very different from the Cholesky case). The fact that the response of industrial production is different at later horizons is therefore mainly due to dynamic influences of other variables on industrial production as estimated in the VAR (most notably differences in the response of the excess bond premium and its estimated effect on output in the VAR). In other words, while the contemporaneous responses are estimated more freely, the VAR dynamics are still doing a lot of the work when it comes to the inference about responses at future horizons.

C A Problem Set on Misspecification in VARs

Consider the following simple New Keynesian model.

Phillips curve:	$\pi_t = \beta E_t \pi_{t+1} + \kappa(y_t - y_t^n)$
Aggregate demand:	$\Delta M_t = \Delta y_t + \pi_t$
Monetary shock:	$\Delta M_t = \rho \Delta M_{t-1} + \epsilon_t$
Productivity shock:	$y_t^n = \eta_t$

Assume ϵ_t and η_t are i.i.d. normal. Set the parameters to $\beta = 0.99$, $\kappa = 0.13$, $\rho = 0.8$, $\sigma_\epsilon = 0.00066$, $\sigma_\eta = 0.007$. The last two are chosen so that the contribution of ΔM_t and y_t^* to the variance of y_t is equal.

1. Show that the solution for output in this model takes the form $y_t = a y_{t-1} + b \Delta M_{t-1} + c\epsilon_t + d\eta_t$ (hint: method of undetermined coefficients).

2. Calculate the true impulse response of output to a monetary shock.

3. Simulate 500 time series from the model each of length 500 data points. Estimate the following three misspecified empirical models for output for each of these series: a model with the contemporaneous monetary shock and one lag of output, a model with the contemporaneous monetary shock and four lag of output, a model with the contemporaneous monetary shock and twelve lag of output. Plot the median impulse response for each misspecified empirical model. Notice that adding 12 lags of output doesn't help at all in matching the true impulse response even though the true impulse response "looks like" an AR(2).

4. Do the same for a model with one lag of output, the contemporaneous monetary shock, and 6 lags of the monetary shock. Notice that this matches the true impulse response out to horizon 6 (but is biased after that).

5. Finally, do the same using the Jorda specification (with or without controls). Notice that this matches the true impulse response almost perfectly.

Table D.1: Romer-Romer Dates and Oil-Shock Dates

Romer and Romer Dates	Oil Shock Dates
October 1947	December 1947
	June 1953
September 1955	June 1956
	February 1957
December 1968	March 1969
	December 1970
April 1974	January 1974
August 1978	March 1978
October 1979	September 1979
	February 1981
	January 1987
December 1988	December 1988
	August 1990

Notes: Romer-Romer dates are dates are identified by Romer and Romer (1989) and Romer and Romer (1994). Oil-shock dates up to 1981 are taken from Hoover and Perez (1994), who refine the narrative identification of these shocks by Hamilton (1983). The last three oil shock dates are from Romer and Romer (1994).

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