Causal Inference, Time Series and Economic History

6. Instrumental Variables and Natural Experiments

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Overview

- Instrumental variables
- Natural experiments
- *Class discussion paper:* Velde, F. R., 'Chronicle of a deflation unforetold', *Journal of Political Economy*, 117 (2009), pp. 591-634

$Cov(u_t, x_t) = 0$

- We know that OLS is biased when the zero conditional mean assumption is violated
- This may occur because of reverse causality, measurement error or omitted variable bias
- VARs are a possible solution to reverse causality but require potentially dubious assumptions
- Narrative methods are a possible solution to reverse causality and omitted variable bias but can be subjective and labour intensive

Instrumental Variables

- Instrumental variables (IV) can be used to resolve endogeneity stemming from reverse causality, measurement error and omitted variable bias
- Early pioneers were John Snow (1855) and Philip G. Wright (1928)
- Similar to the logic of narrative methods, the idea is that a variable, x_t, has two parts: one that is endogenous and correlated with the residual, u_t, and one that is exogenous
- IV uses an instrument, a variable that is correlated with x_t but uncorrelated with u_t, to isolate the exogenous component

Instrumental Variables: Validity

In a time series context, a valid instrument, z_t, must satisfy at least two conditions (Stock and Watson, 2018):

1. **Relevance**: $Cov(z_t, x_t) \neq 0$
2. **Contemporaneous exogeneity**: $Cov(z_t, u_t) = 0$

Instrumental Variables: 2SLS

- Returning to our simple bivariate example:

$$y_t = \alpha + \beta x_t + u_t$$

- We suspect that $Cov(u_t, x_t) \neq 0$
- However, we have a valid instrument, z_t, that satisfies the relevance and exogeneity conditions:
  - $Cov(z_t, x_t) \neq 0$
  - $Cov(z_t, u_t) = 0$

Instrumental Variables: 2SLS

- As the name suggests, 2 stage least squares (2SLS) involves 2 stages
- First stage:

$$x_t = \pi_0 + \pi_1 z_t + v_t$$

  - The exogenous component is $\hat{x}_t = \hat{\pi}_0 + \hat{\pi}_1 z_t$
  - The endogenous component is v_t

Instrumental Variables: 2SLS

- Second stage:

$$y_t = \alpha + \beta \hat{x}_t + u_t$$

- $\hat{\beta}$ is unbiased as $Cov(u_t, \hat{x}_t) = 0$
- The two stages can be estimated by OLS
- However, standard errors differ between OLS and 2SLS because of uncertainty in first stage

Instrumental Variables: 2SLS

Derivation

- Let:

$$y_t = \alpha + \beta x_t + u_t$$

- Therefore:

$$Cov(z_t, y_t) = Cov(z_t, \alpha + \beta x_t + u_t)$$

$$Cov(z_t, y_t) = \beta Cov(z_t, x_t) + Cov(z_t, u_t)$$

- Assuming $Cov(z_t, u_t) = 0$, the instrument exogeneity condition:

$$Cov(z_t, y_t) = \beta Cov(z_t, x_t)$$

$$\frac{Cov(z_t, y_t)}{Cov(z_t, x_t)} = \beta$$

Instrumental Variables: 2SLS

With control variables

- In the case of a single endogenous variable, x_t, a single instrument, z_t, and a single exogenous control variable, w_t:

$$y_t = \alpha + \beta x_t + \gamma w_t + u_t$$

- The first stage is:

$$x_t = \pi_0 + \pi_1 z_t + \pi_2 w_t + v_t$$

- The second stage is:

$$y_t = \alpha + \beta \hat{x}_t + \gamma w_t + u_t$$

- where $\hat{x}_t = \hat{\pi}_0 + \hat{\pi}_1 z_t + \hat{\pi}_2 w_t$
- More generally, any control variable included in the second stage must also be included in the first

Instrumental Variables: 2SLS

Instrument relevance

- The more relevant the instrument(s) - the more variation in x_t explained by the instrument(s) - the more information available for the second stage
- Instruments that explain little of the variation in x_t are called *weak instruments*
- If the instrument(s) is weak, 2SLS can be badly biased in the direction of OLS

Instrumental Variables: 2SLS

Instrument relevance

- There are tests of instrument relevance
- With homoscedastic and serially uncorrelated errors
  - Use the first-stage F-statistic, which tests the hypothesis that the coefficients on the instruments $z_{1t}, ..., z_{mt}$ equal zero
  - A statistic below 10 is indicative of a weak instrument problem (Staiger and Stock, 1997)
- With heteroscedastic and/or serially correlated errors
  - Use a robust test such as Olea and Pflueger (2013)

Instrumental Variables: 2SLS

Instrument exogeneity

- With as many instruments as endogenous regressors (the coefficients are *exactly identified*), it is not possible to test the exogeneity condition
- With more instruments than endogenous regressors (the coefficients are *over identified*), it is possible to test the exogeneity condition
- The overidentifying restrictions test involves:
  - First, estimate: $y_t = \alpha + \beta x_t + \gamma w_t + u_t$
  - Second, estimate: $\hat{u}_t = \delta + \phi_1 z_{1t} + \ldots + \phi_m z_{mt} + \psi w_t + e_t$
  - Third, calculate the F-statistic for the null hypothesis that $\phi_1 + \ldots + \phi_m = 0$
  - Fourth, calculate $J = mF$
  - Valid if e_t is well behaved

Instrumental Variables: 2SLS

Dynamic effects

- As a result of lagged effects, we are not only interested in the causal effect of x_t on y_t but also in x_t on y_{t+h}
- To do so, there are IV equivalents of two methods we've already covered in the course

Instrumental Variables: 2SLS

LP-IV

- First stage: $x_t = \pi_0 + \pi_1 z_t + v_t$
- Second stage: $y_{t+h} = \alpha_h + \beta_h \hat{x}_t + u_{t+h}$
- However, requires a third assumption
  - **Lead-lag exogeneity**: $Cov(z_t, u_{t+j}) = 0$ for $j \neq 0$
- Applications
  - Ramey (2016), Fieldhouse et al. (2018), Ramey and Zubairy (2018), Stock and Watson (2018), Jordà et al. (2020)

Instrumental Variables: 2SLS

SVAR-IV

- VAR identified with external instruments
- Also known as a proxy SVAR
- Involves estimating a reduced form VAR and using external instruments to uncover the structural shocks
- More efficient than LP-IV (Stock and Watson, 2018)
- Does not require lead-lag exogeneity
- The details are beyond the scope of this course
- Applications
  - Stock and Watson (2008, 2012, 2018), Ramey (2016), Mertens and Ravn (2013, 2014)

Pros and Cons

Pro

- Possible to establish causality

Con

- Difficult to find valid instruments

Natural Experiments

- In economics, we are often unable to run experiments
- Therefore, we rely on observational, as opposed to, experimental data
- The issue with observational data is that "treatment" is not often randomly assigned
- In a natural experiment, or quasi-experiment, randomness is introduced by variations in circumstances that make it appear as if the treatment is randomly assigned (Stock and Watson, 2020, p. 490)

Natural Experiments

- OLS is not valid when the zero conditional mean assumption is violated, $Cov(u_t, x_t) \neq 0$
- A valid natural experiment is one in which $Cov(u_t, x_t) = 0$
- Therefore, we are looking for variation in x_t that is uncorrelated with u_t
- This exogenous variation, z_t, can be used with:
  - OLS: $y_t = \alpha + \beta z_t + u_t$
  - 2SLS: $y_t = \alpha + \beta x_t + u_t$, where z_t is used as an instrument for x_t

Pros and Cons

Pro

- Possible to establish causality

Cons

- Difficult to find valid quasi-experiments
- External validity
  - "The analysis is said to have external validity if its inferences and conclusions can be generalized from the population and setting studied to other populations and settings" (Stock and Watson, 2020, p. 331)

Class Discussion Paper: Velde (2009)

Research Question

- How do prices and output respond to a major shift in the money supply?
- The setting:
  - 1720s France
  - 45 per cent cumulative reduction in the money supply

Class Discussion Paper: Velde (2009)

Model

- The logic is that the money supply is endogenous to both prices and output
  - $q_t = \alpha + \beta m_t + u_t$
  - $Cov(u_t, m_t) \neq 0$
  - According to the quantity theory of money, for example, the money supply depends on prices and output and prices and output depend on the money supply ($m \times v = p \times q$)
  - The objective of the policy "was a kind of long-term price level targeting"
- The empirical strategy is:
  - To show a number of time series around the reductions
  - To report qualitative evidence from contemporaries around the reductions

Class Discussion Paper: Velde (2009)

Data

- Exchange rates (on Paris in London and Hamburg)
- Exports and imports
- Commodity prices
- Output
- Interest rates
- Qualitative evidence

Class Discussion Paper: Velde (2009)

Results

- Exchange rates reacted instantly and completely
- Goods prices reacted slowly and incompletely
- Industrial output contracted
- This evidence is incompatible with the neutrality of money

Further Material

- Velde, F. R., 'Experiments with money and people', *Economic History Podcast*
- Ramey (2016)
- Nakamura and Steinsson (2018)
- Stock and Watson (2018)
- Stock and Watson (2020), ch. 12 and 13