

Linear Models Lecture 16: IV

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2SLS and IV

- iv_robust(Y ~ D + X | Z + X, data = dat)

- IV formula:

$$\hat{\beta}_{IV} = (Z'X)^{-1}Z'y$$

- Two stage least squares:

- Suppose in the first stage we regress

$$X = Z\gamma + v$$

- In the second stage, we use $\hat{X} = Z\hat{\gamma} = Z(Z'Z)^{-1}Z'X = P_ZX$,

$$\hat{\beta}_{2SLS} = (\hat{X}'\hat{X})^{-1}\hat{X}'y$$

Equivalence Between 2SLS and IV

- 2SLS is exactly identical to IV when $I = k$

$$\begin{aligned}\hat{\beta}_{2SLS} &= (\hat{X}'\hat{X})^{-1}\hat{X}'y \\ &= (X'Z(Z'Z)^{-1}Z'Z(Z'Z)^{-1}Z'X)^{-1}X'Z(Z'Z)^{-1}Z'y \\ &= (X'Z(Z'Z)^{-1}Z'X)^{-1}X'Z(Z'Z)^{-1}Z'y \\ &= (Z'X)^{-1}(Z'Z)(X'Z)^{-1}X'Z(Z'Z)^{-1}Z'y \quad ((ABC)^{-1} = C^{-1}B^{-1}A^{-1}) \\ &= (Z'X)^{-1}(Z'Z)(Z'Z)^{-1}Z'y \\ &= (Z'X)^{-1}Z'y = \hat{\beta}_{IV}\end{aligned}$$

Control Function Regression

- Assume that x_2 is endogenous:

$$Y = \mathbf{x}'_1 \beta_1 + \mathbf{x}'_2 \beta_2 + e$$

$$\mathbf{x}_2 = \Gamma'_{12} \mathbf{z}_1 + \Gamma'_{22} \mathbf{z}_2 + \mathbf{u}_2$$

- The control function approach directly models the error:

$$e = u'_2 \alpha + v$$

$$\alpha = (E[\mathbf{u}_2 \mathbf{u}'_2])^{-1} E[\mathbf{u}_2 e]$$

$$E[\mathbf{u}_2 v] = 0$$

Control Function Regression

- We then plug this in to the original structural form equation, controlling for the error.

$$Y = \mathbf{x}'_1 \beta_1 + \mathbf{x}'_2 \beta_2 + e$$

$$Y = \mathbf{x}'_1 \beta_1 + \mathbf{x}'_2 \beta_2 + u'_2 \alpha + v$$

$$E[X_1 v] = 0$$

$$E[X_2 v] = 0$$

$$E[u_2 v] = 0$$

- After we control for u_2 , the error is uncorrelated with \mathbf{x}
- We estimate this new control with the reduced form residual:

$$\hat{u}_{2i} = x_{2i} - \hat{\Gamma}'_{12} \mathbf{z}_1 + \hat{\Gamma}'_{22} \mathbf{z}_2$$

- It is like subtracting off the endogenous part.

$$Y = \mathbf{X} \hat{\beta} + \hat{\mathbf{U}}_e \hat{\alpha} + \hat{v}$$

Application: Heterogenous Returns to Education

- Consider the canonical returns to education model:

$$lwage_i = z_{i1}\delta_1 + g_{i1}educ_i + u_{i1}$$

- The returns to schooling for the population is $\gamma_i = E[g_{i1}]$

$$g_{i1} = \gamma_1 + v_{i1}$$

- Plugging in:

$$lwage_i = z_{i1}\delta_1 + \gamma_1 educ_i + v_{i1}educ_i + u_{i1}$$

$$educ_i = z_i\pi_2 + v_{i2}$$

Control function approach assumes that unobservables are linearly related to v_{i2}

- We then proceed estimation by controlling for \hat{v}_{i2} and the interaction between \hat{educ}_i and the estimated \hat{v}_{i2} .

Challenges with IV

- The IV estimator is among the most common tools of econometrics.
- However, it has several weaknesses.
 - Imprecision
 - Small sample Bias
 - Sensitivity to Weak Instruments

Problems with IV estimator: Imprecision

- Suppose Z and X are mean 0, $y = X\beta + e$,

$$Z'X = X'Z = \sum z_i x_i = n * cov(z, x)$$

$$Z'Z = \sum z_i^2 = n * var(z)$$

$$X'X = \sum x_i^2 = n * var(x)$$

$$\hat{\beta}_{IV} = (Z'X)^{-1}Z'y$$

$$\hat{\beta}_{OLS} = (X'X)^{-1}X'y$$

$$Avar(\hat{\beta}_{OLS}) = \sigma_e^2 (X'X)^{-1}$$

$$Avar(\hat{\beta}_{IV}) = \sigma_e^2 (Z'X)^{-1}Z'Z(X'Z)^{-1}$$

Problems with IV estimator: Imprecision

$$Avar(\hat{\beta}_{OLS}) = \sigma_e^2 (X'X)^{-1} = \frac{\sigma_e^2}{n} \frac{1}{var(x)}$$

$$\begin{aligned} Avar(\hat{\beta}_{IV}) &= \sigma_e^2 (Z'X)^{-1} Z' Z (X'Z)^{-1} = \frac{\sigma_e^2}{n^2} \frac{n * var(z)}{cov(x, z)^2} \\ &= \frac{\sigma_e^2}{n} \frac{1}{var(x)} \frac{var(x) var(z)}{cov(x, z)^2} \\ &= \frac{\sigma_e^2}{n} \frac{1}{var(x)} \frac{1}{\rho_{xz}^2} \\ &= Avar(\hat{\beta}_{OLS}) \frac{1}{\rho_{xz}^2} \end{aligned}$$

- As $\rho_{xz}^2 \rightarrow 0$, $Avar(\hat{\beta}_{IV}) \rightarrow \infty$

Problems with IV estimator: Bias

- IV is often neither biased nor unbiased because it does not even have an expectation.
- Kiviet has shown that the IV estimator has M moments, the number of overidentifying restrictions. If $q = 0$, IV has no expectation.

$$y = X\beta + e$$

$$X = Z\pi + v$$

$$\begin{aligned}\hat{\beta}_{IV} &= (X'P_Z X)^{-1} X' P_z y \\&= \beta + (X'P_Z X)^{-1} X' P_z e \\&= \beta + (X'P_Z X)^{-1} (\pi' Z' + v') P_z e \\&= \beta + (X'P_Z X)^{-1} (\pi' Z' + v') P_z e \\&= \beta + (X'P_Z X)^{-1} \pi' Z' P_z e + (X'P_Z X)^{-1} v' P_z e \\&= \beta + (X'P_Z X)^{-1} \pi' Z' e + (X'P_Z X)^{-1} v' P_z e\end{aligned}$$

Form of small sample bias

$$\begin{aligned} E(\hat{\beta}_{IV}) - \beta &\approx E(X'P_ZX)^{-1}E(\pi'Z'e) + E(X'P_ZX)^{-1}E(v'P_ze) \\ &= E(X'P_ZX)^{-1}\pi'E(Z'e) + E(X'P_ZX)^{-1}E(v'P_ze) \\ &= (E(X'P_ZX))^{-1}E(v'P_ze) \\ &= (E(\pi'Z' + v')P_z(Z\pi + v)))^{-1}E(v'P_ze) \\ &= (E(\pi'Z'Z\pi + \pi'Z'v + v'Z\pi + v'P_zv))^{-1}E(v'P_ze) \\ &= (E(\pi'Z'Z\pi) + E(v'P_zv))^{-1}E(v'P_ze) \quad (\text{b/c } E(Z'e) = E(Z'v) = 0) \\ &= (E(\pi'Z'Z\pi) + \sigma_v^2 p)^{-1}\sigma_{ev}^2 p \\ &= \frac{1}{\left(\frac{E(\pi'Z'Z\pi)/p}{\sigma_v^2} + 1\right)} \frac{\sigma_{ev}^2}{\sigma_v^2} \end{aligned}$$

F-test

$$E(\hat{\beta}_{IV}) - \beta \approx \frac{1}{\left(\frac{E(\pi' Z' Z \pi)/p}{\sigma_v^2} + 1 \right)} \frac{\sigma_{ev}^2}{\sigma_v^2} \approx \frac{1}{(1 + F_{p,n-p})} \frac{\sigma_{ev}^2}{\sigma_v^2}$$

- F is the test where the null is that all instrument coefficients are 0.
- The bias of IV only goes away if $F \rightarrow \infty$
- The bias of IV is the OLS bias as $F \rightarrow 0$.
- Adding useless instruments increases p, which decreases F and increases the bias.

Weak instruments

Suppose we have a single x and a single instrument z . An instrument is weak if ρ_{zx} is small.

$$\begin{aligned} p\lim \hat{\beta}_{OLS} &= p\lim \frac{cov(x, y)}{var(x)} \\ &= p\lim \frac{cov(x, \alpha + \beta + e)}{var(x)} \\ &= \beta + p\lim \frac{cov(x, e)}{var(x)} \\ &= \beta + p\lim \frac{cov(x, e)}{\sqrt{var(x)}\sqrt{var(e)}} \frac{\sqrt{var(e)}}{\sqrt{var(x)}} \\ &= \beta + \rho_{xe} \frac{\sigma_e}{\sigma_x} \end{aligned}$$

Weak instruments

$$\begin{aligned} p\lim \hat{\beta}_{IV} &= \beta + p\lim \frac{cov(z, e)}{cov(z, x)} \\ &= \beta + p\lim \frac{\frac{cov(z, e)}{\sqrt{var(x)}\sqrt{var(e)}}}{\frac{cov(z, x)}{\sqrt{var(x)}\sqrt{var(z)}}} \frac{\sqrt{var(e)}}{\sqrt{var(x)}} \\ &= \beta + \frac{\rho_{ze}}{\rho_{zx}} \frac{\sigma_e}{\sigma_x} \\ &= \beta + \frac{\rho_{ze}}{\rho_{zx}\rho_{xe}} \rho_{xe} \frac{\sigma_e}{\sigma_x} \\ &= \beta + \frac{\rho_{ze}}{\rho_{zx}\rho_{xe}} ABias(\hat{\beta}_{OLS}) \end{aligned}$$

Weak/Bad instruments are worse than OLS

$$\frac{ABias(\hat{\beta}_{OLS})}{ABias(\hat{\beta}_{IV})} > 1 \rightarrow \frac{\rho_{ze}}{\rho_{zx}\rho_{xe}} > 1$$

If $\frac{\rho_{ze}}{\rho_{zx}\rho_{xe}} \geq 1$, then IV is more biased than OLS.

Suppose $\rho_{xu} = .5$, so X is super endogenous, Z is barely endogenous: $\rho_{zu} = 0.01$.

Small $\rho_{zx} = 0.019$ gives $\frac{ABias(\hat{\beta}_{OLS})}{ABias(\hat{\beta}_{IV})} = 1.052$.

Testing power of instruments

$$\frac{ABias(\hat{\beta}_{OLS})}{ABias(\hat{\beta}_{IV})} \approx \frac{1}{F}$$

F statistic of 100 means IV is 1% as biased as OLS.

Testing endogeneity via Durbin-Hausman-Wu test

- If X is exogenous, then both OLS and IV are consistent, but OLS is BLUE.
- Asymptotically, the difference between OLS and IV should converge to zero.

$$H = (\hat{\beta}_{IV} - \hat{\beta}_{OLS})' [Avar(\hat{\beta}_{IV}) - Avar(\hat{\beta}_{OLS})]^{-1} (\hat{\beta}_{IV} - \hat{\beta}_{OLS}) \sim \chi^2_{\dim(\beta)}$$

- Rejecting null says that OLS and IV are not close to one another, so either X is endogenous or Z is an invalid instrument.