Empirical Methods in CF

Lecture 4 – Instrumental Variables

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Background readings

- Roberts and Whited
  - *Section 3*
- Angrist and Pischke
  - *Sections 4.1, 4.4, and 4.6*
- Wooldridge
  - *Chapter 5*
- Greene
  - *Sections 8.2-8.5*

Outline for Instrumental Variables

- Motivation and intuition
- Required assumptions
- Implementation and 2SLS
  - Weak instruments problem
  - Multiple IVs and overidentification tests
- Miscellaneous IV issues
- Limitations of IV

Motivating IV *[Part 1]*

- Consider the following estimation

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k + u$$

where $\text{cov}(x_1, u) = \ldots = \text{cov}(x_{k-1}, u) = 0$

$\text{cov}(x_k, u) \neq 0$

  - **If we estimate this model, will we get a consistent estimate of β_k?**
  - **When would we get a consistent estimate of the other β's, and is this likely?**

Motivation *[Part 2]*

- **Answer #1:** No. We will not get a consistent estimate of β_k
- **Answer #2:** Very unlikely. We will only get consistent estimate of other β if x_k is uncorrelated with all other x

- Instrumental variables provide a *potential* solution to this problem…

Instrumental variables – *Intuition*

- Think of x_k as having 'good' and 'bad' variation
  - Good variation is <u>not</u> correlated with u
  - Bad variation is correlated with u
- An IV (let's call it z) is a variable that explains variation in x_k, but doesn't explain y
  - I.e. it only explains the "good" variation in x_k
- Can use the IV to extract the "good" variation and replace x_k with only that component!

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Instrumental variables – *Formally*

- IVs must satisfy two conditions
  - Relevance condition
  - Exclusion condition
    - What are these two conditions?
    - Which is harder to satisfy?
    - Can we test whether they are true?

To illustrate these conditions, let's start with the simplest case, where we have one instrument, z, for the problematic regressor, x_k

Relevance condition *[Part 1]*

How can we test this condition?

- The following must be true…
  - In the following model

$$x_k = \alpha_0 + \alpha_1 x_1 + \ldots + \alpha_{k-1} x_{k-1} + \gamma z + v$$

z satisfies the relevance condition if $\gamma \neq 0$

  - **What does this mean in words?**
    - **Answer:** z is relevant to explaining the problematic regressor, x_k, after partialling out the effect of **all** of the other regressors in the original model

Relevance condition *[Part 2]*

- Easy to test the relevance condition!
  - Just run the regression of x_k on all the other x's and the instrument z to see if z explains x_k
  - As we see later, this is what people call the 'first stage' of the IV estimation

Exclusion condition *[Part 1]*

How can we test this condition?

- The following must be true…
  - In the original model, where

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k + u$$

    z satisfies the exclusion condition if cov(z, u)=0

  - **What does this mean in words?**
    - **Answer:** z is uncorrelated with the disturbance, u… i.e. z has no explanatory power with respect to y after conditioning on the other x's;

Exclusion condition *[Part 2]*

- Trick question! You <u>**cannot**</u> test the exclusion restriction ***[Why?]***
  - **Answer:** You can't test it because u is <u>unobservable</u>
  - You must find a convincing ***economic*** argument as to why the exclusion restriction is not violated

Side note – What's wrong with this?

- I've seen many people try to use the below argument as support for the exclusion restriction… **what's wrong with it?**
  - Estimate the below regression…

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k + \gamma z + u$$

  - If $\gamma=0$, then exclusion restriction likely holds... i.e. they argue that z doesn't explain y after conditioning on the other x's

Side note – *Answer*

- If the original regression doesn't give consistent estimates, then neither will this one!
  - $\text{cov}(x_k, u) \neq 0$, so the estimates are still biased
  - Moreover, if we believe the relevance condition, then the coefficient on z is certainly biased because z is correlated with x_k

What makes a good instrument?

- Bottom line, an instrument must be justified largely on economic arguments
  - Relevance condition can be shown formally, but you should have an economic argument for why
  - Exclusion restriction <u>cannot</u> be tested… you need to provide a convincing economic argument as to why it explains y, but only through its effect on x_k

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Implementing IV estimation

- You've found a good IV, now what?
- One can think of the IV estimation as being done in two steps
  - **First stage:** regress x_k on <u>other</u> x's & z
  - **Second stage:** take predicted x_k from first stage and use it in original model instead of x_k

  This is why we also call IV estimations two stage least squares (2SLS)

First stage of 2SLS

- Estimate the following

$$x_k = \alpha_0 + \alpha_1 x_1 + \ldots + \alpha_{k-1} x_{k-1} + \gamma z + v$$

Problematic regressor [i.e. cov(x_k, u)≠0]

All other non-problematic variables that explain *y*

Instrumental variable

  - Get estimates for the α's and γ
  - Calculate predicted values, $\hat{x}_k$, where

$$\hat{x}_k = \hat{\alpha}_0 + \hat{\alpha}_1 x_1 + \ldots + \hat{\alpha}_{k-1} x_{k-1} + \hat{\gamma} z$$

Second stage of 2SLS

- Use predicted values to estimate

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_k \hat{x}_k + u$$

Predicted values replace the problematic regressor

- Can be shown (see textbook for math) that this 2SLS estimation yields **consistent** estimates of all the β when both the relevance and exclusion conditions are satisfied

Intuition behind 2SLS

- Predicted values represent variation in x_k that is 'good' in that it is driven only by factors that are uncorrelated with u
  - Specifically, predicted value is linear function of variables that are uncorrelated with u
- Why not just use other x's? Why need z?
  - **Answer:** Can't just use other x's to generate predicted value because then predicted value would be collinear in the second stage

Reduced Form Estimates *[Part 1]*

- The "reduced form" estimation is when you regress y directly onto the instrument, z, and other non-problematic x's

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_{k-1} x_{k-1} + \delta z + u$$

  - It is an unbiased and consistent estimate of the effect of z on y (presumably through the channel of z's effect on x_k)

Reduced Form Estimates *[Part 2]*

- It can be shown that the IV estimate for x_k , $\hat{\beta}_k^{IV}$, is simply given by…

$$\hat{\beta}_k^{IV} = \frac{\hat{\delta}}{\hat{\gamma}}$$

Reduced form coefficient estimate for *z*

First stage coefficient estimate for *z*

  - I.e. if you don't find effect of z on y in reduced form, then IV is unlikely to work
    - IV estimate is just scaled version of reduced form

Practical advice *[Part 1]*

- Don't state in your paper's intro that you use an IV to resolve an identification problem, unless…
  - You also state what the IV you use is
  - ***And***, provide a strong economic argument as to why it satisfies the necessary conditions

Don't bury the explanation of your IV! Researchers that do this almost <u>always</u> have a bad IV. If you really have a good IV, you'll be willing to defend it in the intro!

Practical advice *[Part 2]*

- Don't forget to justify why we should be believe the exclusion restriction holds
  - Too many researchers only talk about the relevance condition
  - Exclusion restriction is equally important

Practical Advice *[Part 3]*

- Do **not** do two stages on your own!
  - Let the software do it; e.g. in Stata, use the IVREG or XTIVREG (for panel data) commands

- Three ways people will mess up when trying to do 2SLS on their …

  #1 – Standard errors will be wrong

  #2 – They try using nonlinear models in first stage

  #3 – They will use the fitted values incorrectly

Practical Advice *[Part 3-1]*

- Why will standard errors be wrong if you try to do 2SLS on your own?
  - **Answer:** Because the second stage uses 'estimated' values that have their own estimation error. This error needs to be taken into account when calculating standard errors!

Practical Advice *[Part 3-2]*

- People will try using predicted values from non-linear model, e.g. Probit or Logit, in a 'second stage' IV regression
  - But, **only** linear OLS in first stage guarantees covariates and fitted values in second stage will be uncorrelated with the error
    - I.e. this approach is **NOT** consistent
    - This is what we call the "forbidden regression"

Practical Advice *[Part 3-3]*

- In models with quadratic terms, e.g.

$$y = \beta_0 + \beta_1 x + \beta_2 x^2 + u$$

people often try to calculate one fitted value $\hat{x}$ using one instrument, z, and then plug in $\hat{x}$ and $\hat{x}^2$ into second stage…

  - Seems intuitive, but it is **NOT** consistent!
  - Instead, you should just use z and z^2 as IVs!

Practical Advice *[Part 3]*

- Bottom line… if you find yourself plugging in fitted values when doing an IV, you are probably doing something wrong!
  - Let the software do it for you; it will prevent you from doing incorrect things

Practical Advice *[Part 4]*

- All x's that are not problematic, need to be included in the first stage!!!
  - You're **not** doing 2SLS, and you're **not** getting consistent estimates if this isn't done
  - This includes things like firm and year FE!
- Yet another reason to let statistical software do the 2SLS estimation for you!

Practical Advice *[Part 5]*

- Always report your first stage results & R^2
- There are two good reasons for this… ***[What are they?]***
  - **Answer #1:** It is direct test of relevance condition… i.e. we need to see $\gamma \neq 0$!
  - **Answer #2:** It helps us determine whether there might be a weak IV problem…

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Consistent, but biased

- IV is a consistent, but biased, estimator
  - For any finite number of observations, N, the IV estimates are biased toward the biased OLS estimate
  - But, as N approaches infinity, the IV estimates converge to the true coefficients
- This feature of IV leads to what we call the weak instrument problem…

Weak instruments problem

- A weak instrument is an IV that doesn't explain very much of the variation in the problematic regressor
- Why is this an issue?
  - Small sample bias of estimator is greater when the instrument is weak; *i.e. our estimates, which use a finite sample, might be misleading…*
  - *t*-stats in finite sample can also be wrong

Weak IV bias can be severe *[Part 1]*

- Hahn and Hausman (2005) show that finite sample bias of 2SLS is ≈

$$\frac{j\rho(1-r^2)}{Nr^2}$$

  - j = number of IVs [we'll talk about multiple IVs in a second]
  - ϱ = correlation between x_k and u
  - $r^2 = R^2$ from first-stage regression
  - N = sample size

Weak IV bias can be severe *[Part 2]*

$$\frac{j\rho(1-r^2)}{Nr^2}$$

More instruments, which we'll talk about later, need not help; they help increase r^2, but if they are weak (i.e. don't increase r^2 much), they can still increase finite sample bias

A low explanatory power in first stage can result in large bias even if *N* is large

Detecting weak instruments

- Number of warning flags to watch for…
  - Large standard errors in IV estimates
    - You'll get large SEs when covariance between instrument and problematic regressor is low
  - Low F statistic from first stage
    - The higher F statistic for excluded IVs, the better
    - Stock, Wright, and Yogo (2002) find that an F statistic above 10 likely means you're okay…

Excluded IVs – *Tangent*

- Just some terminology…
  - In some ways, can think of all non-problematic *x*'s as IVs; they all appear in first stage and are used to get predicted values
  - But, when people refer to **excluded** IVs, they refer to the IVs (i.e. *z's*) that are excluded from the second stage

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More than one problematic regressor

- Now, consider the following…

$$y = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k + u$$

where $\text{cov}(x_1, u) = \ldots = \text{cov}(x_{k-2}, u) = 0$

$\text{cov}(x_{k-1}, u) \neq 0$

$\text{cov}(x_k, u) \neq 0$

  - There are two problematic regressors, x_{k-1} and x_k
  - Easy to show that IVs can solve this as well

Multiple IVs *[Part 1]*

- Just need one IV for each problematic regressor, *e.g.* z_1 *and* z_2
- Then, estimate 2SLS in similar way…
  - Regress x_k on all other x's (except x_{k-1}) and both instruments, z_1 and z_2
  - Regress x_{k-1} on all other x's (except x_k) and both instruments, z_1 and z_2
  - Get predicted values, do second stage

Multiple IVs *[Part 2]*

- Need at least as many IVs as problematic regressors to ensure predicted values are not collinear with the non-problematic x's
  - If # of IVs match # of problematic x's, model is said to be "**Just Identified**"

"Overidentified" Models

- Can also have models with more IVs than # of problematic regressors
  - E.g. m instruments for h problematic regressors, where $m > h$
  - This is what we call an overidentified model
- Can implement 2SLS just as before…

Overidentified model conditions

- Necessary conditions very similar
  - **Exclusion restriction** = none of the instruments are correlated with u
  - **Relevance condition**
    - Each first stage (there will be h of them) must have at least one IV with non-zero coefficient
    - Of the m instruments, there must be at least h of them that are partially correlated with problematic regressors [otherwise, model isn't identified]

E.g. you can't just have one IV that is correlated with all the problematic regressors and all the other IVs are not

Benefit of Overidentified Model

- Assuming you satisfy the relevance and exclusion conditions, you will get more asymptotic efficiency with more IVs
    - **Intuition:** you are able to extract more 'good' variation from the first stage of the estimation

But, Overidentification Dilemma

- Suppose you are a very clever researcher…
  - You find not just *h* instruments for *h* problematic regressors, you find $m > h$
    - First, you should consider yourself very clever [a good instrument is hard to come by]!
    - **But, why might you not want to use the *m-h* extra instruments?**

Answer – Weak instruments

- Again, as we saw earlier, a weak instrument will increase likelihood of finite sample bias and misleading inferences!
  - If have one really good IV, not clear you want to add some extra (less good) IVs…

Practical Advice – Overidentified IV

- Helpful to always show results using "just identified" model with your best IVs
  - It is least likely to suffer small sample bias
  - In fact, the just identified model is median-unbiased making weak instruments critique less of a concern

Overidentification "Tests" *[Part 1]*

- When model is overidentified, you can supposedly "test" the quality of your IVs
- The logic of the tests is as follows…
  - If all IVs are valid, then we can get consistent estimates using any subset of the IVs
  - So, compare IV estimates from different subsets; if find they are similar, this suggests the IVs okay

Overidentification "Tests" *[Part 2]*

- But, I see the following <u>all</u> the time…
  - Researcher has overidentified IV model
  - <u>All</u> the IVs are highly questionable in that they lack convincing economic arguments
  - But, authors argue that because their model passes some "overidentification test" that the IVs must be okay
- **What is wrong with this logic?**

Overidentification "Tests" *[Part 3]*

- **Answer** = All the IVs could be junk!
  - The "test" implicitly assumes that some subset of instruments is valid
  - <u>This may not be the case!</u>
- **To reiterate my earlier point…**
  - There is **no** test to prove an IV is valid! Can only motivate that the IV satisfies exclusion restriction using <u>economic</u> theory

“Informal” checks – *Tangent*

- It is useful, however, to try some “informal” checks on validity of IV
  - E.g. One could show the IV is uncorrelated with other non-problematic regressors or with y that pre-dates the instrument
    - Could help bolster economic argument that IV isn’t related to outcome y for other reasons
    - But, don’t do this for your actual outcome, y, why?

      Answer = It would suggest a weak IV (at best)

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Miscelleneous IV issues

- IVs with interactions
- Constructing additional IVs
- Using lagged y or lagged x as IVs
- Using group average of x as IV for x

IVs with interactions

- Suppose you want to estimate

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2 + u$$

where $\begin{aligned} &\text{cov}(x_1, u) = 0 \\ &\text{cov}(x_2, u) \neq 0 \end{aligned}$

  - Now, both x_2 and $x_1 x_2$ are problematic
  - Suppose you can only find one IV, z.
    Is there a way to get consistent estimates?

IVs with interactions *[Part 2]*

- **Answer** = Yes! In this case, one can construct other instruments from the one IV
  - Use z as IV for x_2
  - Use $x_1 z$ as IV for $x_1 x_2$
- Same <u>economic argument</u> used to support z as IV for x_2 will carry through to using $x_1 z$ as IV for $x_1 x_2$

Constructing additional IV

- Now, suppose you want to estimate

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + u$$

where
$$\mathrm{cov}(x_1, u) = 0$$
$$\mathrm{cov}(x_2, u) \neq 0$$
$$\mathrm{cov}(x_3, u) \neq 0$$

Now, both x_2 and x_3 are problematic

  - Suppose you can only find one IV, z, and you think z is correlated with both x_2 and x_3… **Can you use z and z^2 as IVs?**

Constructing additional IV *[Part 2]*

- **Answer** = Technically, yes. But probably not advisable…
  - Absent an economic reason for why z^2 is correlated with either x_2 or x_3 after partialling out z, it's probably not a good IV
    - Even if it satisfies the relevance condition, it might be a 'weak' instrument, which can be very problematic *[as seen earlier]*

Lagged instruments

- It has become common in CF to use lagged variables as instruments
- This usually takes two forms
  - Instrumenting for a lagged y in dynamic panel model with FE using a lagged lagged y
  - Instrumenting for problematic x or lagged y using lagged version of the same x

Example where lagged IVs are used

- As noted in 1st half, we cannot estimate models with both a lagged dep. var. and unobserved FE

$$y_{i,t} = \alpha + \rho y_{i,t-1} + \beta x_{i,t} + f_i + u_{i,t}, \quad |\rho| < 1$$

  - The lagged y independent variable will be correlated with the error, u
  - One proposed solution is to use lagged values of y as IV for problematic $y_{i,t-1}$

Using lagged *y* as IV in panel models

- Specifically, papers propose using first differences combined with lagged values, like $y_{i,t-2}$, as instrument for $y_{i,t-1}$
  - *Could* work in theory, …
    - Lagged *y* will likely satisfy relevance criteria
    - But, exclusion restriction requires lagged values of *y* to be <u>uncorrelated</u> with differenced residual, $u_{i,t} - u_{i,t-1}$

Is this plausible in corporate finance?

Lagged *y* values as instruments?

- Probably not…
  - Lagged values of *y* will be correlated with changes in errors if errors are serially correlated
  - This is common in corporate finance, suggesting this approach is **not** helpful

[See Holtz-Eakin, Newey, and Rosen (1988), Arellano and Bond (1991), Blundell and Bond (1998) for more details on these type of IV strategies]

Lagged *x* values as instruments? *[Part 1]*

- Another approach is to make assumptions about how $x_{i,t}$ is correlated with $u_{i,t}$
  - Idea behind relevance condition is *x* is persistent and predictive of future *x* or future *y* *[depends on what you're trying to instrument]*
  - And exclusion restriction is satisfied if we assume $x_{i,t}$ is uncorrelated with future shocks, *u*

Lagged x values as instruments? *[Part 2]*

- Just not clear how plausible this is…
  - Again, serial correlation in *u (which is very common in CF)* all but guarantees the IV is invalid
  - An <u>economic argument</u> is generally lacking, [*and for this reason, I'm very skeptical of these strategies]*

    [See Arellano and Bond (1991), Arellano and Bover (1995) for more details on these type of IV strategies]

Using group averages as IVs *[Part 1]*

- Will often see the following…

$$y_{i,j} = \alpha + \beta x_{i,j} + u_{i,j}$$

  - $y_{i,j}$ is outcome for observation i (e.g., firm) in group j (e.g., industry)
  - Researcher worries that cov(x,u)≠0
  - So, they use group average, $\bar{x}_{-i,j}$, as IV

$$\bar{x}_{-i,j} = \frac{1}{J-1} \sum_{\substack{i \in j \\ k \neq i}} x_{k,j}$$

***J* is # of observations in the group**

Using group averages as IVs *[Part 2]*

- They say…
  - "group average of x is likely correlated with own x" – i.e. relevance condition holds
  - "*but,* group average doesn't directly affect y" – i.e., exclusion restriction holds
- Anyone see a problem?

Using group averages as IVs *[Part 3]*

- **Answer =**
  - Relevance condition implicitly assumes some common group-level heterogeneity, f_j, that is correlated with x_{ij}
  - But, if model has f_j (i.e. group fixed effect), then $\bar{x}_{-i,j}$ must violate exclusion restriction!
- **This is a really bad IV** *[see Gormley and Matsa (2014) for more details]*

?

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Limitations of IV

- There are two main limitations to discuss
  - Finding a good instrument is really hard; even the seemingly best IVs can have problems
  - External validity can be a concern

Subtle violations of exclusion restriction

- Even the seemingly best IVs can violate the exclusion restriction
  - Roberts and Whited (pg. 31, 2011) provide a good example of this in description of Bennedsen et al. (2007) paper

Bennedsen et al. (2007) example *[Part 1]*

- Paper studies effect of family CEO succession on firm performance
  - IVs for family CEO succession using gender of first-born child
    - Families where the first child was a boy are more likely to have a family CEO succession
    - Obviously, gender of first-born is totally random; seems like a great IV…

Any guesses as to what might be wrong?

Bennedsen et al. (2007) example *[Part 2]*

- Problem is that first-born gender may be correlated with disturbance u
  - Girl-first families may only turnover firm to a daughter when she is very talented
  - Therefore, effect of family CEO turnover might depend on gender of first born
  - I.e. gender of first born is correlated with u because it includes interaction between problematic x and the instrument, z!

External vs. Internal validity

- External validity is another concern of IV [and other identification strategies]
  - **Internal validity** is when the estimation strategy successfully uncovers a causal effect
  - **External validity** is when those estimates are predictive of outcomes in <u>other</u> scenarios
    - IV (done correctly) gives us internal validity
    - But, it doesn't necessarily give us external validity

External validity *[Part 1]*

- Issue is that IV estimates only tell us about subsample where the instrument is predictive
  - Remember, you're only making use of variation in x driven by z
  - So, we aren't learning effect of x for observations where z doesn't explain x!
- It's a version of LATE (local average treatment effect) and affects interpretation

External validity *[Part 2]*

- Again, consider Bennedsen et al (2007)
  - Gender of first born may only predict likelihood of family turnover in certain firms…
    - I.e. family firms where CEO thinks females (including daughters) are less suitable for leadership positions
  - Thus, we only learn about effect of family succession for these firms
  - Why might this matter?

External validity *[Part 3]*

- **Answer:** These firms might be different in other dimensions, which limits the external validity of our findings
  - E.g. Could be that these are poorly run firms…
    - If so, then we only identify effect for such poorly run firms using the IV
    - And, effect of family succession in well-run firms might be quite different…

External validity *[Part 4]*

- Possible test for external validity problems
  - Size of residual from first stage tells us something about importance of IV for certain observations
    - Large residual means IV didn't explain much
    - Small residual means it did
  - Compare characteristics (i.e. other x's) of observations of groups with small and large residuals to make sure they don't differ much

External validity – *Example*

- Angrist (1990) used randomness of Vietnam draft to study effect of military service on Veterans' earnings
  - Person's draft number (which was random) predicted likelihood of serving in Vietnam
  - He found, using draft # as IV, that serving in military reduced future earnings

Question: What might be a concern about the <u>external</u> validity of his findings, and why?

External validity – *Example*

- **Answer =** IV only identifies effect of serving on those that served <u>because</u> of being drafted
  - E.g., his finding doesn't necessarily tell us what the effect of serving is for people that would serve *regardless* of whether they are drafted or not
  - Must keep this **local average treatment effect** (LATE) in mind when interpreting IV

Summary of IVs *[Part 1]*

- IV estimation is one possible way to overcome identification challenges
- A good IV needs to satisfy two conditions
  - Relevance condition
  - Exclusion condition
- Exclusion condition cannot be tested; must use economic argument to support it

Summary of IVs *[Part 2]*

- IV estimations have their limits
  - Really hard to come up with good IV
  - Weak instruments can be a problem
  - External validity can be an concern

Quick Review *[Part 1]*

- **Question:** Are more instruments necessarily a good thing? If not, why not?
  - **Answer** = Not necessarily. Weak instrument problem (i.e. bias in finite sample) can be much worse with more instruments, particularly if they are weaker instruments

Quick Review *[Part 2]*

- **Question:** How can overidentification tests be used to prove the IV is valid?
  - **Answer** = Trick question! They cannot be used in such a way. They rely on the assumption that at least one IV is good. You must provide a convincing economic argument as to why your IVs make sense!

In Next Class

- Natural experiments
  - How do they help with identification?
  - What assumptions are necessary to make causal inferences?
  - What are their limitations?

Some nice IV papers to look at…

- Gormley (JFI 2010)
  - Foreign bank entry and credit access
- Bennedsen, et al. (QJE 2007)
  - CEO family succession and performance