

Instrumental Variables in a Market Model

Class Notes

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Model

- Consider the following market model. The demand equation is

$$q_d = \alpha + \beta p + u \quad (1)$$

where q_d is demand (for fish, say), p is price, and u is a preference shifter.

- The supply equation is

$$q_s = \delta + \psi p - \gamma z + \varepsilon \quad (2)$$

where q_s is supply, z is rain at sea, and ε is a production shifter.

- In equilibrium $q_d = q_s = q$.
- The model determines q and p whereas z , u , and ε are determined outside the model.
- So q and p are endogenous or internal to the model, whereas z , u , and ε are exogenous or external to the model.

Reduced form

- Now imagine realizations of these variables (for the same market over time or for a cross-section of markets).
- Values of z , u , and ε occur according to some probability distribution.
- Given these values, the model produces realizations of q and p given by the reduced form:

$$\begin{aligned}(\psi - \beta) q &= (\alpha\psi - \beta\delta) + \beta\gamma z + (\psi u - \beta\varepsilon) \\(\psi - \beta) p &= (\alpha - \delta) + \gamma z + (u - \varepsilon).\end{aligned}$$

Econometric problem

- Next, we formulate the following econometric problem:
- ① We have data on p , q , and z but not on u and ε .
 - ② We believe model (1)-(2) is correct but we do not know the values of the parameters.
 - ③ We want to use data and the model to infer the slope β of the demand equation.

Endogeneity

- In the econometric sense, we say that p is an *endogenous* explanatory variable in the demand equation if its *realized values* are correlated with those of the error term.
- Endogeneity in the econometric sense does not imply nor is it implied by endogeneity in the economic sense (of being a variable internally determined by the model) e.g. z is external but it would be endogenous in the supply equation if correlated to ε .
- The implication of endogeneity in the econometric sense is that the equation of interest, as it applies to realized values, is not a regression (which by construction would have lack of correlation between error and regressor).
- We do not really know empirically if the realized values of p are correlated with those of u because we do not have data on u , but the model lets us expect such correlation.
- If p and u were in fact uncorrelated then β would coincide with the OLS coefficient, but in general

$$\frac{\text{Cov}(p, q)}{\text{Var}(p)} = \beta + \frac{\text{Cov}(p, u)}{\text{Var}(p)}.$$

- So our theory lets us suspect that as a measure of β , the quantity $\text{Cov}(p, q) / \text{Var}(p)$ has a bias.

Instrumental variables

- In the econometric sense, z is exogenous in the demand equation if it is uncorrelated with the error term (again, we do not observe it, we assume it if we believe there is no association between variation in preferences for fish and rain at sea).
- Moreover, there is an *exclusion restriction* since the theory tells us that z has no effect on demand given u and p . In other words, if we write demand as

$$q = \alpha + \beta p + \varphi z + u,$$

the theory tells us that $\varphi = 0$.

- Given this exclusion, the orthogonality condition $Cov(z, u) = 0$, or equivalently

$$Cov(z, q) = \beta Cov(z, p),$$

implies that, as long as $Cov(z, p) \neq 0$, β is determined as a ratio of data covariances:

$$\beta = \frac{Cov(z, q)}{Cov(z, p)}.$$

- If so we say that β is *identified* in the econometric problem that we posed. Otherwise, if $Cov(z, p) = 0$ then β is not identified.
- Essentially $Cov(z, p) \neq 0$ if $\gamma \neq 0$. Thus, *identification of demand depends on a property of supply*.
- If $Cov(z, u) = 0$ (orthogonality) and $Cov(z, p) \neq 0$ (relevance) hold, z is a valid *instrumental variable*.

A graphical representation

- Suppose that demand is inelastic ($\beta = 0$), $\psi = 1$, and $Cov(\varepsilon, u) = 0$. The model is

$$q = \alpha + u$$

$$q = \delta + p - \gamma z + \varepsilon.$$

with reduced form

$$q = \alpha + u$$

$$p = (\alpha - \delta) + \gamma z + (u - \varepsilon).$$

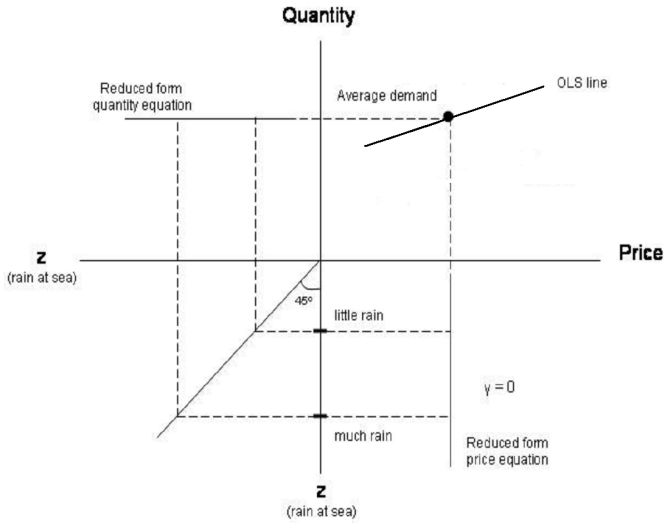
- The “first-stage regression” is a regression of p on z and has slope γ .
- The reduced-form quantity equation is a regression of q on z and has slope zero ($\beta\gamma$).
- The OLS regression of q on p has positive slope unless $Var(u) = 0$ (a perfect fit):

$$\frac{Cov(p, u)}{Var(p)} = \frac{Var(u)}{Var(u) + Var(\gamma z - \varepsilon)}.$$

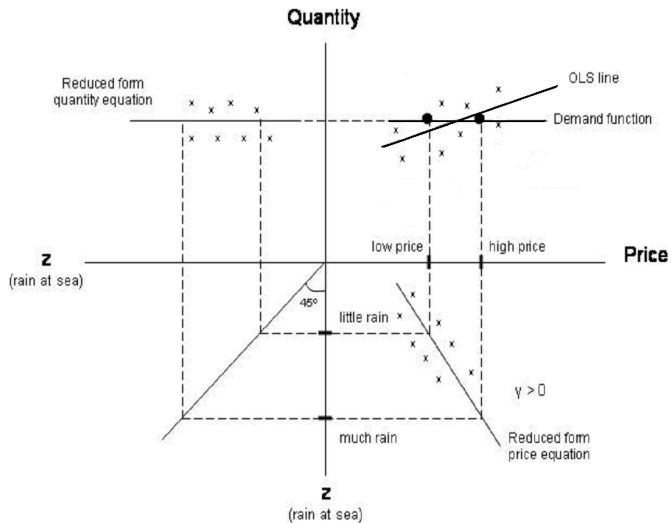
- The relation between predicted q and p given z traces average demand for conjectural values of p if $\gamma \neq 0$ (Figure 1):

$$E^*(q | z) = \alpha + \beta E^*(p | z).$$

- If $\gamma = 0$, $E^*(p | z) = E(p)$ and $E^*(q | z) = \alpha + \beta E(p)$ for all z , so demand is not identified (Figure 2).
- Data points cluster along regression lines but not along the demand function (Fig. 3).



2. Underidentification



3. Scatters of data points

Endogenous prices that are econometrically exogenous

- Suppose the observed quantity is measured with an error v :

$$q = q^* + v,$$

but the market model has no preference shifter:

$$q^* = \alpha + \beta p$$

$$q^* = \delta + \psi p - \gamma z + \varepsilon$$

- The observed demand is

$$q = \alpha + \beta p + v.$$

- The reduced form price equation is

$$(\psi - \beta) p = (\alpha - \delta) + \gamma z - \varepsilon.$$

- Contrary to the preference-shifter model, in the mismeasured demand model p does not directly depend on the demand equation error.
- Thus, if $Cov(v, \varepsilon) = 0$, p is econometrically exogenous in the demand equation even if p remains endogenous or internal to the model.
- In any case p is econometrically endogenous in the supply equation.

Identifying supply: Unobserved demand shifter as instrument

- If in the original model $Cov(u, \varepsilon) \neq 0$, the supply equation is not identified because there is no observed demand shifter that could be used as an instrumental variable.
- All we know is that the true values of (δ, ψ, γ) satisfy the two equations

$$\begin{aligned} E(q) &= \delta + \psi E(p) - \gamma E(z) \\ E(zq) &= \delta E(z) + \psi E(zp) - \gamma E(z^2), \end{aligned}$$

but since there are three unknowns the system admits a multiplicity of solutions.

- However, if $Cov(u, \varepsilon) = 0$ the supply is identified because u can be used as an instrument.
- Intuitively, u is “observable” since the demand parameters are identified. Moreover, u is a relevant instrument in general subject to a rank condition.
- The full set of moment equations is:

$$E \left(\begin{array}{c} \left(\begin{array}{c} 1 \\ z \end{array} \right) (q - \alpha - \beta p) \\ \left(\begin{array}{c} 1 \\ z \\ q - \alpha - \beta p \end{array} \right) (q - \delta - \psi p + \gamma z) \end{array} \right) = 0,$$

so that there are five equations for five unknowns.

The language of structural equations and statistical relationships

- Let F be the joint distribution of quantities, prices and rain at sea in a population of markets.
- Parameters of statistical relationships (e.g. regressions, IV estimands) are characteristics of F .
- Parameters of structural equations (e.g. demand and supply equations) are not in themselves characteristics of F . They are used to describe a set of hypothetical experiments.
- The traditional notation employed in econometrics has often failed to make a sharp distinction between the two.
- The potential outcome notation of Rubin (1974) and the do-calculus of Pearl (1994) have made this distinction explicit in their approaches to causality.