11.1 Our aim is to estimate the parameters of the simultaneous equations model

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$$y_1 = \alpha_1 y_2 + e_1$$

$$y_2 = \alpha_2 y_1 + \beta_1 x_1 + \beta_2 x_2 + e_2$$

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We assume that x_1 and x_2 are exogenous and uncorrelated with the error terms e_1 and e_2.

a. Solve the two structural equations for the reduced-form equation for y_2, that is, $y_2 = \pi_1 x_1 + \pi_2 x_2 + v_2$. Express the reduced-form parameters in terms of the **structural parameters** and the reduced-form error in terms of the structural parameters and e_1 and e_2. Show that y_2 is correlated with e_1.

b. Which equation parameters are consistently estimated using OLS? Explain.

c. Which parameters are "identified," in the simultaneous equations sense? Explain your reasoning.

(a) $y_2 = \alpha_2(\alpha_1 y_2 + e_1) + \beta_1 x_1 + \beta_2 x_2 + e_2$

$\Rightarrow y_2(1-\alpha_1\alpha_2) = \beta_1 x_1 + \beta_2 x_2 + (\alpha_2 e_1 + e_2)$

$\Rightarrow y_2 = \left(\frac{\beta_1}{1-\alpha_1\alpha_2}\right) x_1 + \left(\frac{\beta_2}{1-\alpha_1\alpha_2}\right) x_2 + \left(\frac{\alpha_2 e_1 + e_2}{1-\alpha_1\alpha_2}\right) = \pi_1 x_1 + \pi_2 x_2 + v_2$

$$\begin{aligned}
\operatorname{cov}(y_2, e_1|x) &= E(y_2 e_1|x) = E\left[\left(\frac{\beta_1}{1-\alpha_1\alpha_2} x_1 + \frac{\beta_2}{1-\alpha_1\alpha_2} x_2 + \frac{\alpha_2 e_1 + e_2}{1-\alpha_1\alpha_2}\right) e_1 \Big| x\right] \\
&= E\left[\left(\frac{\beta_1}{1-\alpha_1\alpha_2} x_1 e_1\right)\Big|x\right] + E\left[\left(\frac{\beta_2}{1-\alpha_1\alpha_2} x_2 e_1\right)\Big|x\right] + E\left[\left(\frac{\alpha_2 e_1 + e_2}{1-\alpha_1\alpha_2} e_1\right)\Big|x\right] \\
&= 0 + 0 + E\left[\left(\frac{\alpha_2 e_1 + e_2}{1-\alpha_1\alpha_2} e_1\right)\Big|x\right]
\end{aligned}$$

$\rightarrow \operatorname{cov}(y_2, e_1|x) = E(y_2 e_1|x) = \dfrac{E(e_1 e_2|x) + \alpha_2 E(e_1^2|x)}{1-\alpha_1\alpha_2} = \dfrac{\alpha_2 \cdot \sigma_1^2}{1-\alpha_1\alpha_2}$

by consider the error of two equation are uncorrelated.

$\operatorname{cov}(y_2, e_1|x)$ isn't zero unless $\alpha_2 = 0$.

(b) Since equation (1) and (2) have an endogenous variable on the right-hand side, the OLS is biased and inconsistent.

(c) $M=2$ At least $M-1=1$ variable needs to be omitted from equation.

Equation (1) omitted two exogenous variables larger than one variable → "identified"

Equation (2) omitted no variables. → "not identified"

d. To estimate the parameters of the reduced-form equation for y_2 using the method of moments (MOM), which was introduced in Section 10.3, the two moment equations are

$$N^{-1}\sum x_{i1}(y_2 - \pi_1 x_{i1} - \pi_2 x_{i2}) = 0$$

$$N^{-1}\sum x_{i2}(y_2 - \pi_1 x_{i1} - \pi_2 x_{i2}) = 0$$

Explain why these two moment conditions are a valid basis for obtaining consistent estimators of the reduced-form parameters.

e. Are the MOM estimators in part (d) the same as the OLS estimators? Form the sum of squared errors function for $y_2 = \pi_1 x_1 + \pi_2 x_2 + v_2$ and find the first derivatives. Set these to zero and show that they are equivalent to the two equations in part (d).

f. Using $\sum x_{i1}^2 = 1$, $\sum x_{i2}^2 = 1$, $\sum x_{i1}x_{i2} = 0$, $\sum x_{i1}y_{1i} = 2$, $\sum x_{i1}y_{2i} = 3$, $\sum x_{i2}y_{1i} = 3$, $\sum x_{i2}y_{2i} = 4$, and the two moment conditions in part (d) show that the MOM/OLS estimates of π_1 and π_2 are $\hat{\pi}_1 = 3$ and $\hat{\pi}_2 = 4$.

g. The fitted value $\hat{y}_2 = \hat{\pi}_1 x_1 + \hat{\pi}_2 x_2$. Explain why we can use the moment condition $\sum \hat{y}_{i2}(y_{i1} - \alpha_1 y_{i2}) = 0$ as a valid basis for consistently estimating α_1. Obtain the IV estimate of α_1.

h. Find the 2SLS estimate of α_1 by applying OLS to $y_1 = \alpha_1 \hat{y}_2 + e_1^*$. Compare your answer to that in part (g).

(d) $E(x_{i1}v_{i1}|x) = E(x_{i2}v_{i2}|x) = 0$

$\rightarrow E\left[x_{ik}\left(\frac{\alpha_1 e_1 + e_2}{1-\alpha_1\alpha_2}\right)\Big|x\right]$

$= E\left[\frac{\alpha_1}{1-\alpha_1\alpha_2} e_1 x_{ik}\Big|x\right] + E\left[\frac{1}{1-\alpha_1\alpha_2} e_2 x_{ik}\Big|x\right] = 0.$

e. $\min \sum (y_2 - \pi_1 x_1 - \pi_2 x_2)^2$

對π_1偏微分: $2\sum(y_2 - \pi_1 x_1 - \pi_2 x_2) \times (-x_1) = 0$

對π_2偏微分: $2\sum(y_2 - \pi_1 x_1 - \pi_2 x_2) \times (-x_2) = 0$

↳ $\div 2$, $\times N^{-1}$

So they are equivalent to the two equations.

f. $N^{-1}\sum x_{i1}(y_2 - \pi_1 x_{i1} - \pi_2 x_{i2}) = 0 \Rightarrow \sum x_{i1}y_2 - \pi_1 \sum x_{i1}^2 - \pi_2 \sum x_{i1}x_{i2} = 0$

$N^{-1}\sum x_{i2}(y_2 - \pi_1 x_{i1} - \pi_2 x_{i2}) = 0 \Rightarrow \sum x_{i2}y_2 - \pi_1 \sum x_{i1}x_{i2} - \pi_2 \sum x_{i2}^2 = 0$

$$\Rightarrow \begin{cases} 3 - \hat{\pi}_1 \times 1 - \pi_2 \times 0 = 0 \\ 4 - \hat{\pi}_1 \times 0 - \pi_2 \times 1 = 0 \end{cases} \Rightarrow \begin{cases} \hat{\pi}_1 = 3 \\ \hat{\pi}_2 = 4 \end{cases}$$

g. $\because y_1 = \alpha_1 y_2 + e_1$ $\qquad \hat{y}_2 = \hat{\pi}_1 x_1 + \hat{\pi}_2 x_2$

moment condition $(y_2, e_1) \Rightarrow \sum \hat{y}_2 (y_1 - \alpha_1 y_2) = 0 \Rightarrow \sum \hat{y}_2 y_1 - \alpha_1 \sum \hat{y}_2 y_2 = 0 \Rightarrow \alpha_1 = \dfrac{\sum \hat{y}_2 y_1}{\sum \hat{y}_2 y_2}$

$$\Rightarrow \hat{\alpha}_1 = \frac{\sum (\hat{\pi}_1 x_1 + \hat{\pi}_2 x_2) y_1}{\sum (\hat{\pi}_1 x_1 + \hat{\pi}_2 x_2) y_2} = \frac{3\sum x_1 y_1 + 4 \sum x_2 y_1}{3 \sum x_1 y_2 + 4 \sum x_2 y_2} = \frac{3\times 2 + 4 \times 3}{3 \times 3 + 4 \times 4} = \frac{18}{25}$$

h. 原 $\hat{\alpha}_{1,2SLS} = \dfrac{\sum \hat{y}_2 y_1}{\sum \hat{y}_2^2}$

To prove $\hat{\alpha}_{1,2SLS} = \hat{\alpha}_1$ (by moment condition)

we need to prove $\sum \hat{y}_2^2 = \sum \hat{y}_2 y_2$

$\sum \hat{y}_2^2 = \sum \hat{y}_2 (y_2 - \hat{v}_2) = \sum \hat{y}_2 y_2 - \cancelto{0}{\sum \hat{y}_2 \hat{v}_2} = \sum \hat{y}_2 y_2$ ($\because$ 解釋變數和誤差無關)

11.16 Consider the following supply and demand model

$$\text{Demand: } Q_i = \alpha_1 + \alpha_2 P_i + e_{di}, \quad \text{Supply: } Q_i = \beta_1 + \beta_2 P_i + \beta_3 W_i + e_{si}$$

where Q is the quantity, P is the price, and W is the wage rate, which is assumed exogenous. Data on these variables are in Table 11.7.

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TABLE 11.7 Data for Exercise 11.16

Q	P	W
4	2	2
6	4	3
9	3	1
3	5	1
8	8	3

a. Derive the algebraic form of the reduced-form equations, $Q = \theta_1 + \theta_2 W + v_2$ and $P = \pi_1 + \pi_2 W + v_1$, expressing the reduced-form parameters in terms of the structural parameters.

b. Which structural parameters can you solve for from the results in part (a)? Which equation is "identified"?

c. The estimated reduced-form equations are $\hat{Q} = 5 + 0.5W$ and $\hat{P} = 2.4 + 1W$. Solve for the identified structural parameters. This is the method of **indirect least squares**.

d. Obtain the fitted values from the reduced-form equation for P, and apply 2SLS to obtain estimates of the demand equation.

a. reduced-form

Demand = Supply

$\Rightarrow \alpha_1 + \alpha_2 P_i + e_{di} = \beta_1 + \beta_2 P_i + \beta_3 W_i + e_{si}$

$(\alpha_2 - \beta_2) P_i = (\beta_1 - \alpha_1) + \beta_3 W_i + (e_{si} - e_{di})$

$\Rightarrow P_i = \dfrac{\beta_1 - \alpha_1}{\alpha_2 - \beta_2} + \dfrac{\beta_3}{\alpha_2 - \beta_2} W_i + \dfrac{e_{si} - e_{di}}{\alpha_2 - \beta_2}$

$Q_i = \alpha_1 + \alpha_2 \left(\dfrac{\beta_1 - \alpha_1}{\alpha_2 - \beta_2} + \dfrac{\beta_3}{\alpha_2 - \beta_2} W_i + \dfrac{e_{si} - e_{di}}{\alpha_2 - \beta_2} \right) + e_{di}$

$\Rightarrow Q_i = \alpha_1 + \dfrac{\beta_1 - \alpha_1}{\alpha_2 - \beta_2} \alpha_2 + \dfrac{\beta_3}{\alpha_2 - \beta_2} W_i \alpha_2 + \dfrac{e_{si} - e_{di}}{\alpha_2 - \beta_2} \alpha_2 + e_{di}$

b. $M=2$, omitted at least one variable

equation (1) → one → "identified" → 可推出 α_1, α_2

equation (2) → zero. → "not identified" → 不可推出 $\beta_1, \beta_2, \beta_3$

c. $\hat{Q} = 5 + 0.5W$, $\hat{P} = 2.4 + 1W$

$5 + 0.5W = \alpha_1 + \alpha_2(2.4 + W)$

$= (\alpha_1 + \alpha_2 \times 2.4) + \alpha_2 W$

$\Rightarrow \alpha_2 = 0.5 \qquad 5 = \alpha_1 + 0.5 \times 2.4$

$\alpha_1 = 3.8$

d. $\hat{P} = 2.4 + W$

		$\hat{P} - \bar{\hat{P}}$	$Q - \bar{Q}$
$W=2$	$\hat{P} = 4.4$	0	−2
$W=3$	$\hat{P} = 5.4$	1	0
$W=1$	$\hat{P} = 3.4$	−1	3
$W=1$	$\hat{P} = 3.4$	−1	−3
$W=3$	$\hat{P} = 5.4$	1	2

$\bar{\hat{P}} = 4.4$

$\bar{Q} = 6$

$Q = \alpha_1 + \alpha_2 \hat{P} + e_i$

$\hat{\alpha}_2 = \dfrac{\sum(\hat{P}_i - \bar{\hat{P}})(Q_i - \bar{Q})}{\sum(\hat{P}_i - \bar{\hat{P}})^2} = \dfrac{-3+3+2}{4} = \dfrac{1}{2}$

$\hat{\alpha}_1 = \bar{Q} - \alpha_2 \bar{P} = 6 - 0.5 \times 4.4 = 3.8$

$\Rightarrow \hat{Q} = 3.8 + 0.5P$

11.17 Example 11.3 introduces Klein's Model I.

a. Do we have an adequate number of IVs to estimate each equation? Check the necessary condition for the identification of each equation. The necessary condition for identification is that in a system of M equations at least $M - 1$ variables must be omitted from each equation.

b. An equivalent identification condition is that the number of excluded exogenous variables from the equation must be at least as large as the number of included right-hand side endogenous variables. Check that this condition is satisfied for each equation.

c. Write down in econometric notation the first-stage equation, the reduced form, for W_{1t}, wages of workers earned in the private sector. Call the parameters $\pi_1, \pi_2, \ldots$

d. Describe the two regression steps of 2SLS estimation of the consumption function. This is not a question about a computer software command.

e. Does following the steps in part (d) produce regression results that are identical to the 2SLS estimates provided by software specifically designed for 2SLS estimation? In particular, will the t-values be the same?

P_{t-1}. Thus, the consumption function is

$$CN_t = \alpha_1 + \alpha_2(W_{1t} + W_{2t}) + \alpha_3 P_t + \alpha_4 P_{t-1} + e_{1t} \quad (11.17)$$

investment equation is

$$I_t = \beta_1 + \beta_2 P_t + \beta_3 P_{t-1} + \beta_4 K_{t-1} + e_{2t} \quad (11.18)$$

wage equation is

$$W_{1t} = \gamma_1 + \gamma_2 E_t + \gamma_3 E_{t-1} + \gamma_4 TIME_t + e_{3t} \quad (11.19)$$

a. $M=8$, requiring 7 omitted variables, total 16 variables.

The consumption function includes 6 variables and omits 10 variables

The investment function 5 11

The wage function 5 11

⇒ all satisfied necessary condition for identification.

b. Consumption function: 2 RHS endogenous variables and exludes 5 exogenous variables

Investment function: 1 RHS 5

Wage function: 1 RHS 5

⇒ all satisfied.

c. $W_{1t} = \pi_1 + \pi_2 G_t + \pi_3 W_{2t} + \pi_4 TX_t + \pi_5 TIME_t + \pi_6 P_{t-1} + \pi_7 K_{t-1} + \pi_8 E_{t-1} + v$

d. Get fitted value $\hat{W}_{1t}$ from (c), and using the same method $\hat{P}_t$, create $W_t^* = \hat{W}_{1t} + W_{2t}$

Regress CN_t by OLS.