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

$$y_1 = \alpha_1 y_2 + e_1 \quad (1)$$

$$y_2 = \alpha_2 y_1 + \beta_1 x_1 + \beta_2 x_2 + e_2 \quad (2)$$

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.

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

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

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

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 $\sum \hat{y}_{i2}\left(y_{i1} - \alpha_1 y_{i2}\right) = 0$ 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).

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

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

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

$y_2 = \dfrac{\beta_1}{1-\alpha_1\alpha_2} x_1 + \dfrac{\beta_2}{1-\alpha_1\alpha_2} x_2 + \dfrac{\alpha_2 e_1 + e_2}{1-\alpha_1\alpha_2}$

$= \pi_1 x_1 + \pi_2 x_2 + v_2$

$\text{cov}(y_2, e_1)$

$= \text{cov}(\pi_1 x_1 + \pi_2 x_2 + v_2, e_1)$

$= \pi_1 \underbrace{\text{cov}(x_1, e_1)}_{=0} + \pi_2 \underbrace{\text{cov}(x_2, e_1)}_{=0} + \text{cov}(v_2, e_1)$

$\text{cov}(v_2, e_1) = \text{cov}\left(\dfrac{\alpha_2 e_1 + e_2}{1-\alpha_1\alpha_2}, e_1\right)$

$= \dfrac{1}{1-\alpha_1\alpha_2}\text{cov}(\alpha_2 e_1, e_1) = \dfrac{\alpha_2}{1-\alpha_1\alpha_2}\text{Var}(e_1)$

只要 $\alpha_2 \neq 0$

b. Neither of the structural equations.

Both equation (1) & (2) have an endogenous variable on right-hand side.

$\Rightarrow$ OLS is biased and inconsistent.

Reduced form equation parameters can be estimated consistently using OLS because only exogenous variables appear on the right-hand side.

c. There are $M=2$ equations.

Identification requires that $M-1$ variables be omitted from each equation.

(1): x_1, x_2 被排除，排除的外生变量 $=2 > M-1=1 \Rightarrow$ identified

(2): 排除的外生变数 $=0 < M-1=0 \Rightarrow$ not identified

d. These moment conditions arise from the assumptions that x's are exogenous.

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

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

$$E[x_{ik} v_2 | x]$$

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

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

$$= 0 + 0$$

当 $N \to \infty$ 弱大数法则 $N^{-1}\sum x_{i1} v_{2i} = 0 \Rightarrow E(x_{i1} v_{2i}) = 0 \Rightarrow$ 一致性

樣本平均数 收斂至期望值

有 2 未知数、2 moment conditions $\rightarrow$ identified

e. OLS 估計式目標

$$\min SSE: S(\pi_1, \pi_2 | y, x) = \sum (y_2 - \pi_1 x_1 - \pi_2 x_2)^2$$

F.O.C $\frac{\partial SSE}{\partial \pi_1} = -2 \sum x_{1i}(y_{2i} - \pi_1 x_{1i} - \pi_2 x_{2i}) = 0$

$\frac{\partial SSE}{\partial \pi_2} = -2 \sum x_{2i}(y_{2i} - \pi_1 x_{1i} - \pi_2 x_{2i}) = 0$

f.

$\sum x_{i1}(y_{2i} - \pi_1 x_{i1} - \pi_2 x_{i2}) = 0 \Rightarrow \sum x_{i1} y_{2i} - \pi_1 \sum x_{i1}^2 - \pi_2 \sum x_{i1} x_{i2} = 0$

$3 - \pi_1 \times 1 - \pi_2 \times 0 = 0$

$\pi_1 = 3$

$\sum x_{i2}(y_{2i} - \pi_1 x_{i1} - \pi_2 x_{i2}) = 0 \Rightarrow \sum x_{i2} y_{2i} - \pi_1 \sum x_{i2} x_{i1} - \pi_2 \sum x_{i2}^2 = 0$

$4 - \pi_1 \times 0 - \pi_2 \times 1 = 0$

$\pi_2 = 4$

g.

$\sum \hat{y}_{i2}(y_{i1} - \alpha_1 y_{i2}) = 0 \qquad \sum \hat{y}_{i2} y_{i1} = \alpha_1 \sum \hat{y}_{i2} y_{i2} \Rightarrow \alpha_1 = \dfrac{\sum \hat{y}_{i2} y_{i1}}{\sum \hat{y}_{i2} y_{i2}}$

$\hat{y}_2 = \hat{\pi}_1 x_1 + \hat{\pi}_2 x_2 = 3x_1 + 4x_2$

$\sum \hat{y}_{i2} y_{i1} = \sum (3x_{i1} + 4x_{i2}) y_{i1} = 3\sum x_{i1} y_{i1} + 4 \sum x_{i2} y_{i1}$

$= 3\times 2 + 4\times 3 = 18$

$\sum \hat{y}_{i2} y_{i2} = \sum (3x_{i1} + 4_{i2}) y_{i2} = 3\sum x_{i1} + y_{i2} + 4\sum x_{i2} y_{i2} = 3\times 3 + 4\times 4$

$= 25$

$\frac{18}{25} = 0.72$

h. 證明 $\hat{\alpha}_{1,2SLS} = \dfrac{\sum \hat{y}_{i2} y_{i1}}{\sum \hat{y}_{i2}^2} = \hat{\alpha}_{1,IV} = \dfrac{\sum \hat{y}_{i2} y_{i1}}{\sum \hat{y}_{i2} y_{i2}} \Rightarrow \sum \hat{y}_{i2}^2 = \sum \hat{y}_{i2} y_{i2}$

$\because \hat{v}_2 = y_2 - \hat{y}_2 \Rightarrow \hat{y}_2 = y_2 - \hat{v}_2$

代入 $\hat{y}_2 = y_2 - \hat{v}_2 \Rightarrow \sum \hat{y}_{i2}^2 = \sum \hat{y}_{i2}(y_{i2} - \hat{v}_{i2}) = \sum \hat{y}_{i2} y_{i2} - \underbrace{\sum \hat{y}_{i2} \hat{v}_{i2}}$

$\hookrightarrow \sum (\hat{\pi}_1 x_{i1} + \hat{\pi}_2 x_{i2}) \hat{v}_{i2} = \hat{\pi}_1 \sum x_{i1} \hat{v}_{i2} + \hat{\pi}_2 \sum x_{i2} \hat{v}_{i2} = 0$

11.16 Consider the following supply and demand model

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

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.

TABLE 11.7 **Data for Exercise 11.16**

Q	P	W	$\hat{P}_i = 2.4 + W_i$
4	2	2	4.4
6	4	3	5.4
9	3	1	3.4
3	5	1	3.4
8	8	3	5.4

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.

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

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

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

$\Rightarrow P_i = \pi_1 + \pi_2 W_i + V_1$

$Q_i = \alpha_1 + \alpha_2 P_i + e_{di}$

$= \alpha_1 + \alpha_2(\pi_1 + \pi_2 W_i + V_1) + e_{di}$

$= (\alpha_1 + \alpha_2 \pi_1) + \alpha_2 \pi_2 W_i + (\alpha_2 V_1 + e_{di})$

$\Rightarrow Q = \theta_1 + \theta_2 W + V_2$

b.

Demand: identified (排除的外生变量 $= 1 = M - 1 = 1$) 可解出 α_1, α_2

Supply: not identified ($= 0 < M - 1 = 1$) 无法解出 $\beta_1, \beta_2, \beta_3$

c.

$\hat{Q} = \underset{\theta_1}{5} + \underset{\theta_2}{0.5} W$ $\qquad \hat{P} = \underset{\pi_1}{2.4} + \underset{\pi_2}{1} W$

$\theta_1 = \alpha_1 + \alpha_2 \pi_1 \qquad 5 = \alpha_1 + 0.5 \times 2.4 \qquad \alpha_1 = 3.8$

$\theta_2 = \alpha_2 \pi_2$

$0.5 = \alpha_2$

d.

$$Q_i = a_1 + a_2 \hat{P}_i + e_i$$

$$a_2 = \frac{\sum (Q_i - \bar{Q})(\hat{P}_i - \bar{\hat{P}})}{\sum (\hat{P}_i - \bar{\hat{P}})^2}$$

$\bar{Q} = 6$ $\bar{\hat{P}} = 4.4$

$$= \frac{0 + 0 - 3 + 3 + 2}{0 + 1 + 1 + 1 + 1} = \frac{2}{4} = 0.5$$

$$a_1 = \bar{Q} - a_2 \cdot \bar{P} = 6 - 0.5 \cdot 4.4 = 6 - 2.2 = 3.8$$

$$Q_i = 3.5 + 0.5 P_i$$

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?

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

Investment equation : $I_t = \beta_1 + \beta_2 P_t + \beta_3 P_{t-1} + \beta_4 K_{t-1} + e_{2t}$

wage equation : $W_{1t} = \gamma_1 + \gamma_2 E_t + \gamma_3 E_{t-1} + \gamma_4 TIME_t + e_{3t}$

$W_t = W_{1t} + W_{2t}$

$E_t = CN_t + I_t + (G_t - W_{2t})$

$TIME_t = YEAR_t - 1931$

a. $M=8$，至少排除 $M-1=7$ 个外生变数，才能满足「最小識別條件」

共16个

			Identified
consumption	6个变数	，排除10个	✓
investment	5	11	✓
wage	5	11	✓

b. 要識別，排除的外生变数数量必须 ≥ 右边的内生变数数量

consumption	5	≥	2	✓
investment	5	≥	1	✓
wage	5	≥	1	✓

⇒ all satisfied

c. 所有外生变数和预决变数的线性组合

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

d. ① $\hat{W}_{1t} = \pi_{11} + \pi_{12} G_t + \pi_{13} W_{2t} + \pi_{14} TX_t + \pi_{15} TIME_t + \pi_{16} P_{t-1} + \pi_{17} K_{t-1} + \pi_{18} E_{t-1}$

$\hat{P}_t = \pi_{21} + \pi_{22} G_t + \pi_{23} W_{2t} + \pi_{24} TX_t + \pi_{25} TIME_t + \pi_{26} P_{t-1} + \pi_{27} K_{t-1} + \pi_{28} E_{t-1}$

② $CN_t = \alpha_0 + \alpha_1 (\hat{W}_{1t} + W_{2t}) + \alpha_2 \hat{P}_t + \alpha_3 P_{t-1} + u_t$

e. 估计值会相同

t值不同 ∵ OLS估计的SE不同