

# 程序代写代做 CS编程辅导

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Financial Econometrics



Slides-02

Regression

Review of Financial Applications in Finance

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R. Ouyssse

Economics<sup>1</sup>

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# Linear Regression

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- A model where one variable  $y_t$  is linearly explained by a group of variables  $(X_{1t}, \dots, X_{kt}), t = 1, \dots, T$ 
  - Easy to Implement
  - Versatile for financial data analysis
  - Foundation for more advanced models
- General formulation
 

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  - $Y_t = \beta_1 + \beta_2 X_{t1} + \beta_3 X_{t2} + \dots + \beta_K X_{tK} + \mu_t, t = 1, \dots, T$
  - $Y_t$ : dependent variable
  - $X_{t1}, \dots, X_{tK}$ : explanatory variables, regressors
  - $\beta_1, \beta_2, \dots, \beta_K$ : parameters (to be estimated)
  - $\mu_t$ : error term
  - $T$ : number of observations

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# Application 1: Capital Asset Pricing Model aka CAPM

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One of the most important concepts of modern financial economics is the **quantification of the trade-off between risk and expected return**. Common sense suggests risky investments (e.g. stock market) will generally yield higher returns than investments in bonds.



- Markowitz (1995) casts the investors' portfolio selection problem in terms of expected return and variance of the return.
- Investors optimally hold a mean-variance efficient portfolio: a portfolio with the highest expected return for a given level of variance.

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- Capital Asset Pricing Model is concerned with the pricing of assets in equilibrium. In equilibrium, all assets must be held by someone.
- How investors determine the expected returns—and thereby asset prices—as a function of risk.

⇒ [The Security Market Line](https://tutorcs.com)

## CAPM

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- Given that: some risks are diversifiable, diversification is easy and costless, and rational investors diversify
- There should be no premium associated with diversifiable risk.
- The question becomes: What is the equilibrium relation between systematic risk and expected return in the capital markets?
- The CAPM is the best-known and most-widely used equilibrium model of the risk/return (systematic risk/return) relation.

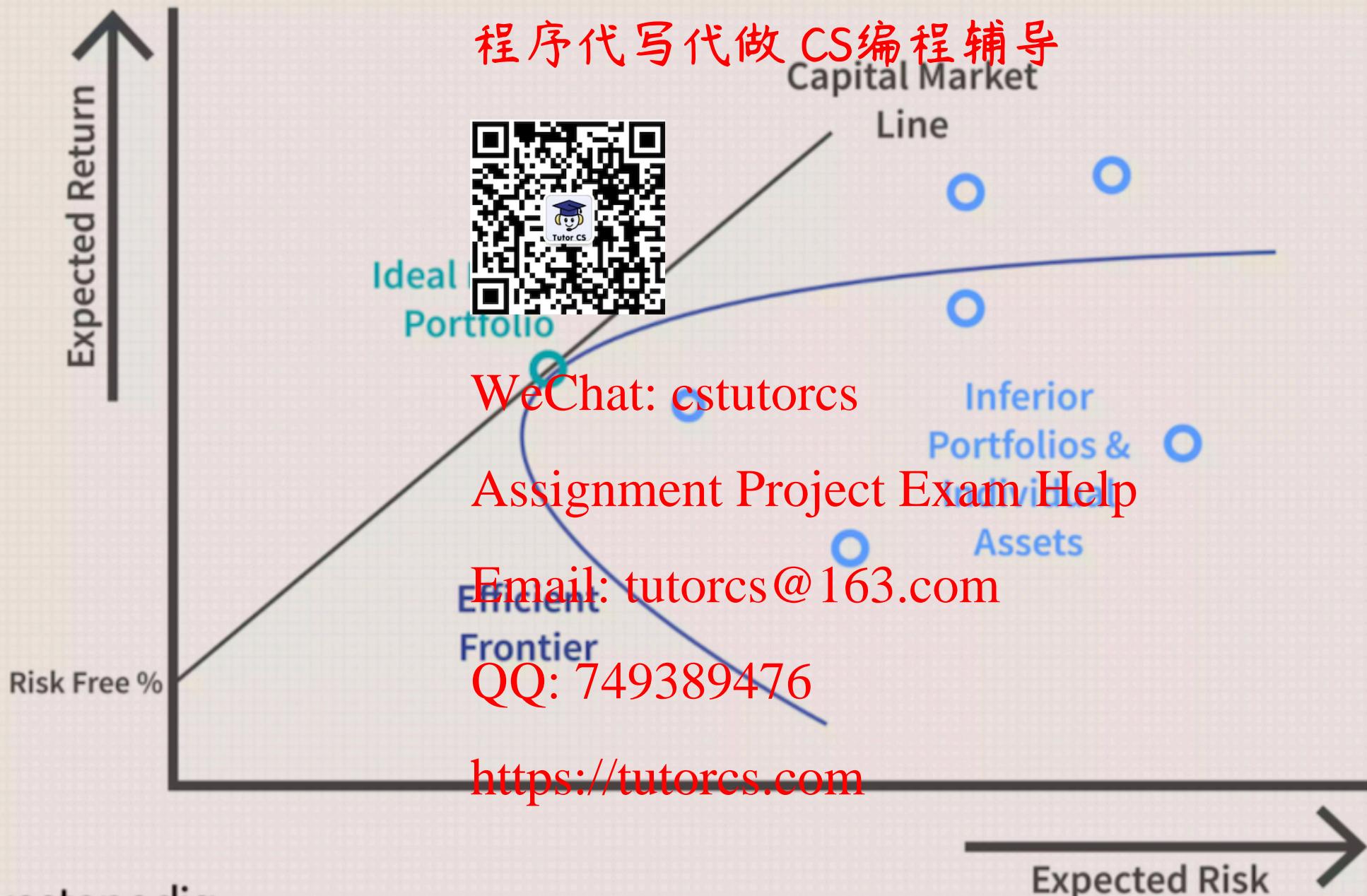
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# CAPM Intuition

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What would be a "fair" return on any stock?

- $E(R_{it}) = R_{ft}$  (risk Premium)
- Risk free assets earn the risk-free rate (think of this as a rental rate on capital). The risk free compensate for time.
- If the asset is risky, we need to add a risk premium.
- The size of the risk premium depends on the amount of systematic risk for the asset (stock, bond, or investment project) and the price per unit risk.
- $R_{it} - R_{ft}$ : Excess return

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# CAPM Intuition Formalized

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$$E[R_{it}] = \frac{\rho v(R_{it}, R_{mt})}{Var(R_{mt})} [E[R_{mt}] - R_{ft}]$$

$$E[R_{it}] = R_{ft} + \beta_i [E[R_{mt}] - R_{ft}]$$

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The expression above is referred to as the "Security Market Line".

- $E[R_{mt}] - R_{ft}$  Market Risk premium (compensation for risk) or the price per unit of risk
- $\beta_i$ : number of units of systematic risk
  - $\beta_i > 1$  (or  $< 1$ ): the asset is more (less) risky than the market portfolio
  - $\beta_i < 0$  : the asset is a hedge against the market portfolio
  - $\beta_i$  how sensitive the asset to market movement

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# CAPM Formalized

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Three inputs are required:



- ① An estimate of the risk-free interest rate. The current yield on short term treasury bills is one measure. Practitioners tend to favor the current yield on longer-term treasury bonds but this may be a fix for a problem we don't fully understand.

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- ② An estimate of the market risk premium,  $E[R_{mt}] - R_{ft}$ . Expectations are not observable. Generally use a historically estimated value.

The market is defined as a portfolio of all wealth including real estate, human capital, etc. In practice, a broad based stock index, such as the S&P 500 or the portfolio of all NYSE stocks, is generally used.

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- ③ An estimate of beta.

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# CAPM: Econometric model

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Let  $X_{mt} = R_{mt} - R_{ft}$  and  $\mu_{it} = R_{it} - R_{ft}$  and consider the econometric model:

$$X_{it} = \alpha_i + \beta_i X_{mt} + \mu_{it}$$

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- The CAPM can be examined by testing  $H_0: \alpha_i = 0$
- If  $\alpha_i > 0$ , asset  $i$  beats the market by earning more than  $\beta_i E[X_{mt}]$
- This has been used to test the performance of mutual funds (application in the Brooks textbook)

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# CAPM: Application

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What determines the expected return of an asset?  
Example: Mobil (a US petro-



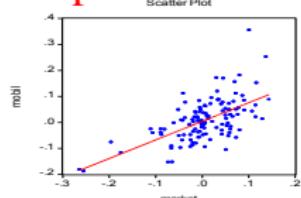
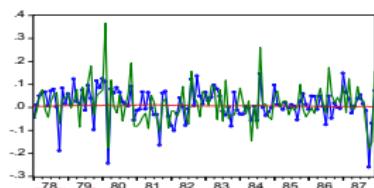
1978:01-1987:12 with  $T = 120$ .

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Dependent Variable: E_MQAD					
Method: Least Squares					
Sample: 1978M01 1987M12					
Included observations: 120					
Variable	Coefficient	Std. Error	t Statistic	P> t	Prob.
C	0.714695	0.085615	8.347761	0.0000	
E_MARKET	0.371287	Mean dependent var	0.009353		
R-squared	0.365959	S.D. dependent var	0.080468		
Adjusted R-squared	0.365407	Nakkeran Criterion	-2.641019		
S.E. of regression	0.434455	Chi-square statistic	-2.594561		
Sum squared resid	160.4612	F-statistic	69.68511		
Log likelihood		Prob(F-statistic)			
Durbin-Watson stat	2.087124	Prob(F-statistic)	0.000000		

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## Application 2: The term structure of interest rates

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- Interest rates are the cost of money and, in equilibrium, interest rates equate the amount of borrowing to the amount of saving.
- The Term Structure of Interest Rates shows the relation between interest rates for different term-to-maturity loans.
- In the most basic sense, theories to explain the term structure are still based on interest rates equating the supply and demand for loanable funds.
- Different rates may exist over different terms because of expectations of changing inflation and differing preferences regarding longer-term vs. shorter-term saving.

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# The term structure of interest rate

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The relation of long and short bond returns?

- Monthly return on the long bond at time  $n$ :  $R_{n,t}$ ,  $n = 1, 3$

Rule of one price ( $E_t R_{1,t+1} = E_t R_{1,t+2}$ ) Hypothesis)

$$(1 + R_{3,t})^3 = (1 + R_{1,t})(1 + E_t R_{1,t+1})(1 + E_t R_{1,t+2})$$

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$$R_{3,t} \approx [R_{1,t} + E_t R_{1,t+1} + E_t R_{1,t+2}] / 3$$

where  $E_t$  is expectation formed at time  $t$

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- If  $R_{1,t}$  follows a random walk:  $R_{1,t+1} = R_{1,t} + v_{t+1}$  with  $E_t v_{t+1} = 0$  then  $E_t R_{1,t+1} = E_t R_{1,t+2} = R_{1,t}$  and

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- Test the null  $H_0 : \beta_0 + \beta_1 R_{1,t} = \beta_0 + \beta_1 R_{1,t} + u_t$ .

# Term structure of interest rate: example

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- Consider that given expectations for inflation over the next year, investors require 4% for a one-year loan.
- Suppose investors currently expect inflation for the next year (the second year) to be higher so that they expect to require 6% for a one year loan (starting one year from now).
- Then, the Pure-Expectations Hypothesis, is consistent with the current 2-year spot rate defined as follows:

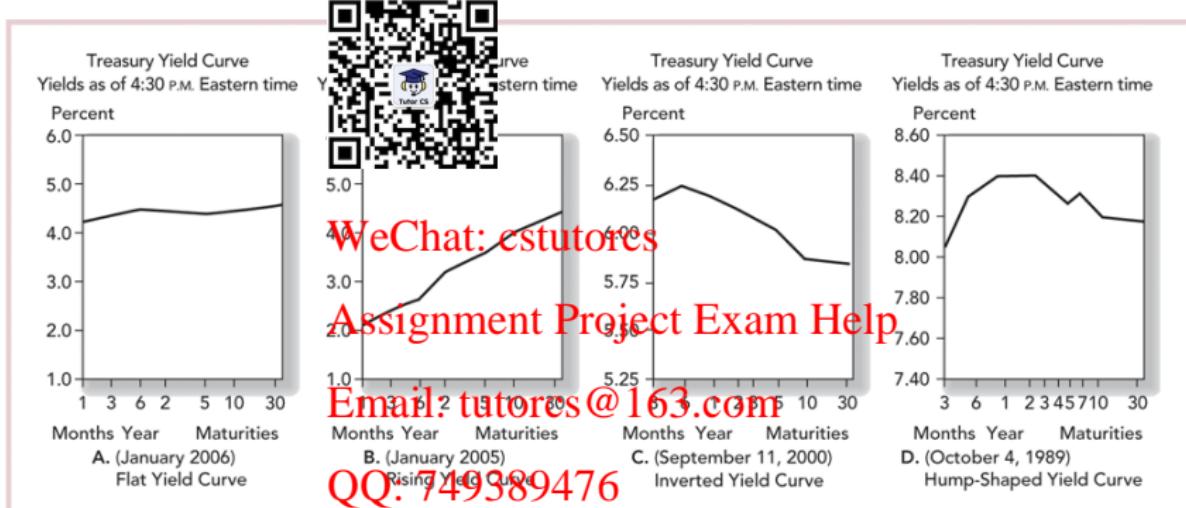
$$(1 + R_{2,t})^2 = (1 + R_{1,t})(1 + E_t[R_{1,t+1}]) = (1.04)x(1.06)$$

so  $R_{2,t} = 4.995238\%$  QQ: 749389476

- Restated, if we observe  $R_{1,t} = 4\%$  and  $R_{2,t} = 4.995238\%$ , then, under the Pure-Expectations Hypothesis, we would have  $E_t[R_{1,t+1}]$  to be 6%.

# Term Structure

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**FIGURE 15.1** Treasury yield curves  
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# Application 3: Present Value (Gordon) Model

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- The price of the asset today is a discounted sum of all possible future cash flows (or dividends)

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$$P_t = \sum_j^{\infty} \frac{E_t(D_{t+j})}{(1 + R)^j}$$

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# Present Value (Gordon) Model

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$$\begin{aligned}
 P_t &= \left[ \frac{D_t}{R} + \frac{1}{(1+R)^2} + K \right] \\
 &= \frac{D_t}{R} \left[ 1 + \frac{1}{1+R} + \frac{1}{(1+R)^2} + K \right] \\
 &= \frac{D_t}{R} \left[ \frac{1}{1/(1+R)} \right] \\
 &= \frac{D_t}{R}
 \end{aligned}$$

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- we used the property of the infinite converging geometric progression series:  $\sum_{k=0}^{\infty} a^k = 1/(1-a)$

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# Present Value (Gordon) Model

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- the model is still nonlinear, but we may take the logs:  
 $\log(P_t) = -\log(R_t) + \log(D_t)$
- And once again use OLS to test whether the model is correct

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 $\log(P_t) = \alpha + \beta \log(D_t) + u_t$

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# Ordinary Least Squares (OLS) Estimation

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Consider a *K*-varia



regression model

$$Y_i = \beta_1 + \beta_2 X_{i2} + \beta_3 X_{i3} + \dots + \beta_K X_{iK} + \mu_i, \quad i = 1, \dots, N$$

The OLS estimator minimises the sum of squared residuals of the sample regression function, i.e.

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$$\min_{\hat{\beta}_1, \dots, \hat{\beta}_K} \sum \hat{\mu}_i^2 = \sum \left( Y_i - \hat{\beta}_1 \hat{\beta}_2 X_{i2} - \hat{\beta}_3 X_{i3} - \dots - \hat{\beta}_K X_{iK} \right)^2$$

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This yields a system of *K* equations (first order conditions) in *K* unknowns which can be solved for the OLS estimator.

# Model in matrix Form

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The equation above is



expression for the system

$$Y_1 = \beta_1 + \beta_2 X_{12} + \dots + \beta_K X_{1K} + \mu_1$$

$$Y_2 = \beta_1 + \beta_2 X_{22} + \dots + \beta_K X_{2K} + \mu_2$$

$\vdots$

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$$Y_N = \beta_1 + \beta_2 X_{N2} + \beta_3 X_{N3} + \dots + \beta_K X_{NK} + \mu_N$$

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Alternatively, this system can be written in matrix notation

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_N \end{bmatrix} = \begin{bmatrix} 1 & X_{12} & X_{13} & \dots & X_{1K} \\ 1 & X_{22} & X_{23} & \dots & X_{2K} \\ \vdots & \vdots & \vdots & & \vdots \\ 1 & X_{N2} & X_{N3} & \dots & X_{NK} \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_K \end{bmatrix} + \begin{bmatrix} \mu_1 \\ \mu_2 \\ \vdots \\ \mu_N \end{bmatrix}$$

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# Model in matrix Form

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This matrix notation can be extended to



by defining

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- ▶  $y$  is a  $N \times 1$  column vector holding  $N$  observations on  $Y$
- ▶  $X$  is a  $N \times K$  matrix holding  $N$  observations on the  $K$  explanatory variables
- ▶  $\beta$  is a  $K \times 1$  vector holding  $K$  unknown parameters
- ▶  $\mu$  is a  $N \times 1$  column vector holding  $N$  disturbances  $\mu$

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# Deriving OLS Estimator

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The OLS estimator can be obtained by minimising the sum of squared residuals from the regression function. In matrix notation, this amounts to minimising  $\hat{\mu}'\hat{\mu}$  since:



$$\hat{\mu}'\hat{\mu} = [\hat{\mu}_1 \quad \hat{\mu}_2 \quad \cdots \quad \hat{\mu}_N] \begin{bmatrix} \hat{\mu}_1 \\ \hat{\mu}_2 \\ \vdots \\ \hat{\mu}_N \end{bmatrix} = \hat{\mu}_1^2 + \hat{\mu}_2^2 + \cdots + \hat{\mu}_N^2 = \sum \hat{\mu}_i^2$$

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with  $\hat{\mu} = y - X\hat{\beta}$ .

Therefore

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$$\begin{aligned}\hat{\mu}'\hat{\mu} &= (y - X\hat{\beta})' (y - X\hat{\beta}) \\ &= y'y - \hat{\beta}'X'y - y'X\hat{\beta} + \hat{\beta}'X'X\hat{\beta} \\ &= y'y - 2y'X\hat{\beta} + \hat{\beta}'X'X\hat{\beta}\end{aligned}$$

— — — — —

# Deriving OLS Estimator

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The OLS estimator for  arrived from the first order conditions

$$\frac{\partial \hat{\mu}' / \hat{\beta}}{\partial \hat{\beta}} - 2X'X\hat{\beta} = 0$$

as

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$$\begin{aligned} X'X\hat{\beta} &= X'y \\ \hat{\beta} &= (X'X)^{-1}X'y \end{aligned}$$

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

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Features of the  $(X'X)$  matrix:

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- ▶ Symmetrical (see example below)
- ▶ Invertible if there is no exact multicollinearity

# Linear Regression: Basic Assumptions

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- ① No collinearity in  $X$



inverse of  $X'X$  to exist

Intuitively: all regressors non-redundant

- ② Zero conditional mean:  $E[\mu|X] = 0$  ( $\mu$  independent of  $X$ )

Violation means endogeneity, a serious problem

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$$\hat{\beta} = (X'X)^{-1}X'y = (X'X)^{-1}X'(X\beta + \mu)$$

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$$= (X'X)^{-1}X'X\beta + (X'X)^{-1}X'\mu = \beta + (X'X)^{-1}X'\mu$$

$$E(\hat{\beta}) = \beta + E[(X'X)^{-1}X'\mu]$$

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$$= \beta + (X'X)^{-1}X'E[\mu|X]$$

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The latter assuming  $X$  deterministic. Otherwise, we can use the law of iterated expectations.

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- ③ Homoskedasticity:  $Var(\mu_i|X) = \sigma^2$  for all  $i$

# Linear regression: variance-covariance

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$$\begin{aligned}
 \text{var}(\hat{\beta}) &= E[(\hat{\beta} - \beta)(\hat{\beta} - \beta)'] \\
 &= E[(X' \mu)(X' \mu)'] \\
 &= E[(X' X)^{-1} X' \mu \mu' X (X' X)^{-1}] \\
 &\quad \text{WeChat: cstutorcs} \\
 &= (X' X)^{-1} X' E[\mu \mu'] X (X' X)^{-1} \\
 &= (X' X)^{-1} X' \sigma^2 I_N X (X' X)^{-1} \\
 &= \sigma^2 (X' X)^{-1}
 \end{aligned}$$

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An unbiased estimator of  $\sigma^2$  is given by  
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$$\hat{\sigma}^2 = \frac{\sum \hat{\mu}_i^2}{N - K} = \frac{\hat{\mu}' \hat{\mu}}{N - K} = \frac{y'y - \hat{\beta}' X'y}{N - K}$$

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# Linear regression: Properties (BLUE)

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- ① **Unbiased:**  $E(\hat{\beta}) =$



- ② **Consistent:**  $\text{plim} \hat{\beta} = \beta$  as  $T$  goes to infinity ( $\infty$ ).

$$P(\hat{\beta} - \beta > \epsilon) \rightarrow 0 \text{ as } T \text{ goes to } \infty.$$

Intuitively  $\hat{\beta}$  gets closer and closer to  $\beta$  as  $T \rightarrow \infty$ .

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(does not imply unbiasedness, may still be that  $E(\hat{\beta}) \neq \beta$ )

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- ③ **Asymptotically normal (Why?):**  $\hat{\beta} = \beta + (X'X)^{-1}X'\mu$

(or Exact normality if  $\mu$  are normally distributed.)

$$\hat{\beta} \sim N(\beta, \sigma^2(X'X)^{-1})$$

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- ④ **Efficient among linear estimators:**

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OLS has smallest variance among linear estimators