

EE320 (2/2012)

INTRODUCTORY MATHEMATICAL ECONOMICS

NONLINEAR MODEL AND DIFFERENTIAL CALCULUS
IN ECONOMIC THEORY

(Part 1 – Nonlinear Model and Calculus Review)

Topics

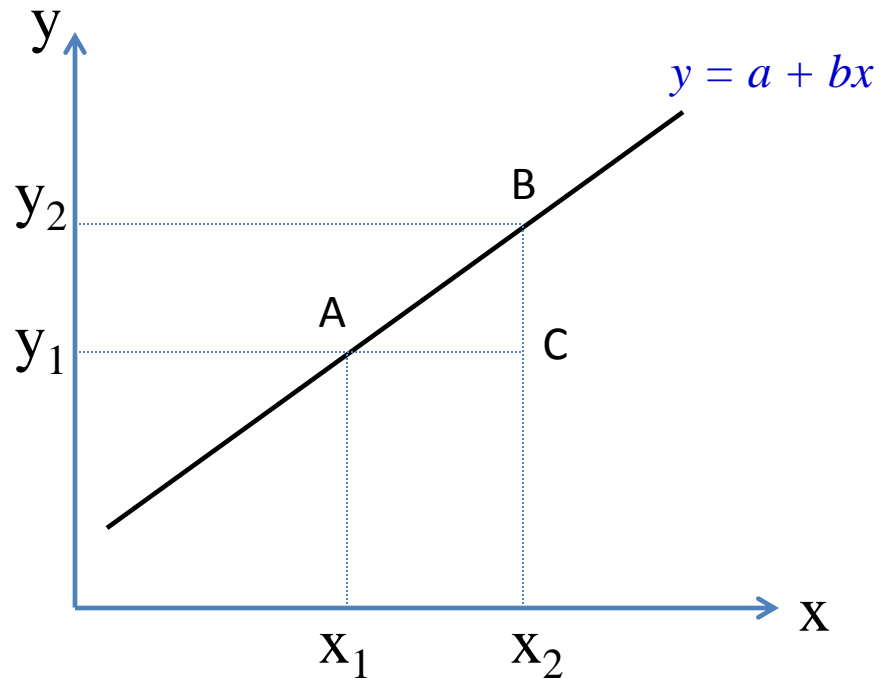
- Slopes of Curves
 - Linear model
 - Non-linear model
- Rate of Change and the Derivative
- The Derivative and the Slope of a Curve
- Differentiability of a Function
- Rules of Differentiation

Introduction

- This lecture focuses *the rate of change* of the equilibrium value of an endogenous variable with respect to the change in a particular exogenous variable.
- Geometrically, this rate of change is referred to as the *slope of a curve*.
- **Examples:**
 - Slope of a *total cost* function is the *marginal cost*.
 - Slope of a *utility* function is *marginal utility*.
- The slope of a function tells the characteristics of the function.
 - **Linear functions:** Slope is constant.
 - **Nonlinear functions:** Slopes vary at different values of x .

Linear Function

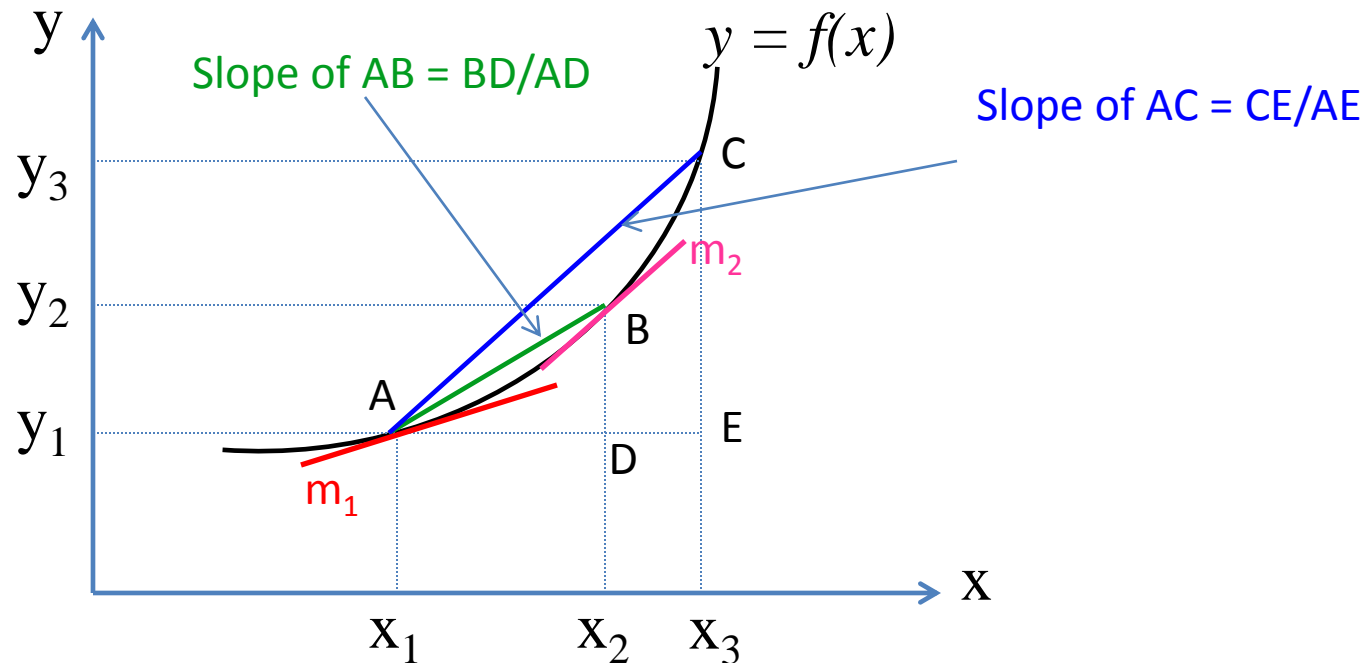
- Consider a linear function: $y = a + bx$.
- Graph



- Slope between point A and B is: $\frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{BC}{AC}$

Nonlinear Function

- Consider the following non-linear function



- The slope between any two points vary along the curve.
- The slope of the curve must be measured at the tangency of a particular point.

Rate of Change and the Derivative (1)

- Given the function $y = f(x)$, the **difference quotient** is the change in y per unit of change in x :

$$\frac{\Delta y}{\Delta x} = \frac{f(x_0 + \Delta x) - f(x_0)}{\Delta x}$$

- i.e. the difference quotient measures the average rate of change of y .
- Example:** Given $y = f(x) = x^2 + 3x$, we can write:

$$f(x_0) = x_0^2 + 3x_0$$

$$f(x_0 + \Delta x) = (x_0 + \Delta x)^2 + 3(x_0 + \Delta x)$$

→
$$\frac{\Delta y}{\Delta x} = 2x_0 + \Delta x + 3$$

Rate of Change and the Derivative (2)

- When Δx is *infinitesimally small*, the rate of change of y is called the **derivative**:

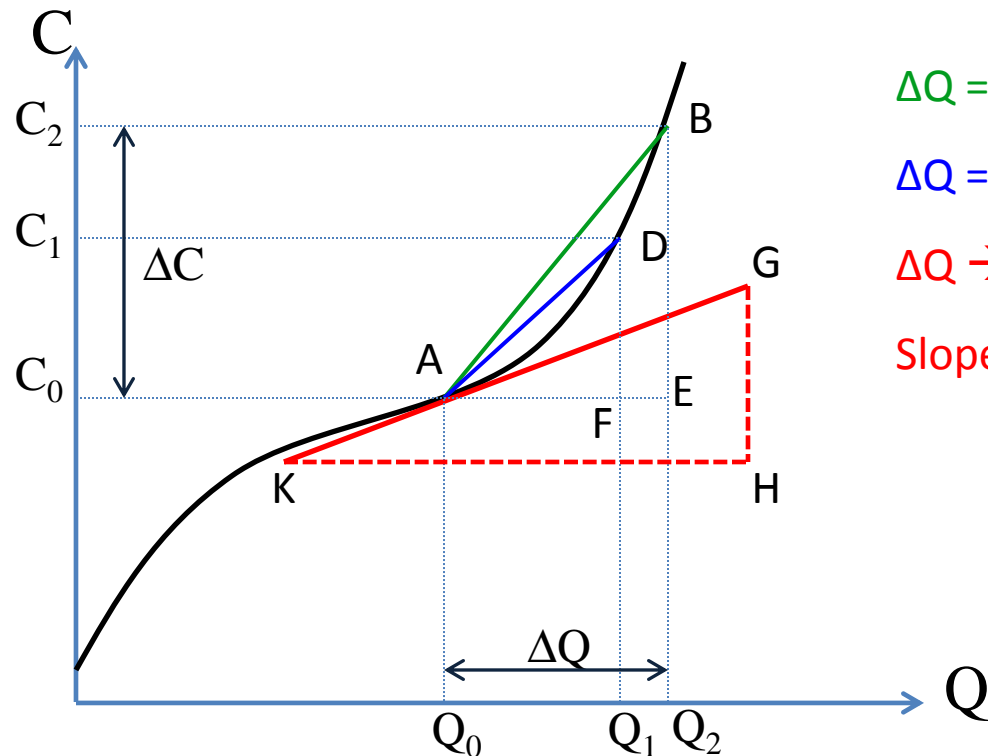
$$\frac{dy}{dx} \equiv f'(x) \equiv \lim_{\Delta x \rightarrow 0} \frac{\Delta y}{\Delta x}$$

- i.e. the derivative of the function $y = f(x)$ is the **limit of the difference quotient** $\Delta y/\Delta x$.
- The derivative measures the *instantaneous rate of change*.
- **Example**: Given $y = f(x) = x^2 + 3x$,

$$\lim_{\Delta x \rightarrow 0} \frac{\Delta y}{\Delta x} = \lim_{\Delta x \rightarrow 0} 2x_0 + \Delta x + 3 = 2x_0 + 3$$

Slope and Derivatives

- **Example:** Total cost curve and its slope



$\Delta Q = Q_2 - Q_0$: Slope of AB = BE/AE

$\Delta Q = Q_1 - Q_0$: Slope of AD = DF/AF

$\Delta Q \rightarrow 0$:

Slope at A = Slope of KG (tangent at A)
 = GH/KH
 = $\lim_{\Delta Q \rightarrow 0} (\Delta C / \Delta Q)$
 = $f'(Q_0)$

The tangency to the curve $y = f(x)$ at $x = a$ is the slope: $m = f'(a)$.

Differentiability of a Function

- The process of determining the derivative of a function is called “**differentiation**”
- A function is **differentiable** if it is **continuous** and **smooth**.
 - **Continuity** is a *necessary condition* for differentiability.
 - **Smoothness** is a *sufficient condition* for differentiability.

- **Definition:**

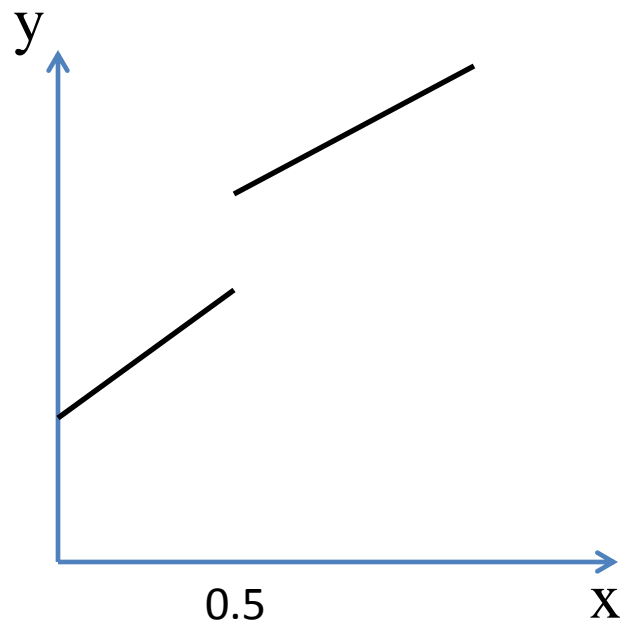
A function $y = f(x)$ is continuous at x_0 if the followings are true:

1. $f(x_0)$ is defined.
2. $\lim_{x \rightarrow x_0}$ exists.
3. $\lim_{x \rightarrow x_0} f(x) = f(x_0)$

Continuity

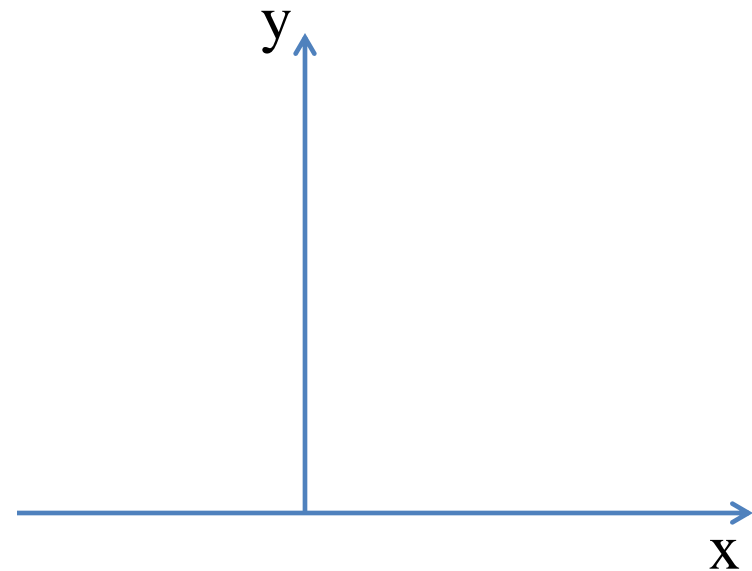
- **Example 1:**

$f(x)$ is discontinuous at 0.5.



- **Example 2:**

$$g(x) = \begin{cases} x^2 & \text{if } x < 2 \\ x+1 & \text{if } x \geq 2 \end{cases}$$



Smoothness

- A function is **smooth** means that it is differentiable everywhere.

- Definition:

A function $f(x)$ is differentiable at point a if

$$f'(a) = \lim_{h \rightarrow 0} \frac{f(a+h) - f(a)}{h}$$

Alternatively, given that $x = a + h$, then $x \rightarrow a$ if $h \rightarrow 0$. Then,

$$f'(a) = \lim_{x \rightarrow a} \frac{f(x) - f(a)}{x - a}, x \neq a$$

- Theorem:

If a function $f(x)$ has a derivative at a , then it is continuous at a as well.

Non-Differentiable Functions

- Example: $f(x) = |x - 2| + 1$

Summary: All differentiable functions are continuous, but not all continuous functions are differentiable.

Rules of Differentiation: A Function of One Variable

- Constant-Function Rule:

$$y = f(x) = c, \text{ where } c \text{ is a constant}$$

$$\rightarrow f'(x) = 0.$$

- Power-Function Rule:

$$y = f(x) = x^n, \text{ where } n \text{ is a real number}$$

$$\rightarrow f'(x) = nx^{n-1}$$

- Exponential-Function Rule:

$$y = f(x) = e^x$$

$$\rightarrow f'(x) = e^x$$

- Logarithm-Function Rule:

$$y = f(x) = \ln(x)$$

$$\rightarrow f'(x) = 1/x$$

Rules of Differentiation:

Two or More Functions of the Same Variable

- Sum-Difference Rule:

$$y = f(x) + g(x) \rightarrow \frac{d}{dx}[f(x) + g(x)] = f'(x) + g'(x)$$

$$y = f(x) - g(x) \rightarrow \frac{d}{dx}[f(x) - g(x)] = f'(x) - g'(x)$$

- Product Rule:

$$y = f(x)g(x) \rightarrow \frac{d}{dx}[f(x)g(x)] = f(x)g'(x) + g(x)f'(x)$$

- Quotient rule:

$$y = \frac{f(x)}{g(x)}$$

$$\rightarrow \frac{d}{dx} \left[\frac{f(x)}{g(x)} \right] = \frac{g(x)f'(x) - f(x)g'(x)}{[g(x)]^2}$$

Examples

- Example 1:

$$f(x) = 2x^3 + 3x^2 - 5x + 1$$

$$f'(x) = 6x^2 + 6x - 5$$

- Example 2:

$$f(x) = 3x^{-2/3}$$

$$f'(x) = -2x^{-5/3}$$

- Example 3:

$$f(t) = e^{rt}$$

$$f'(t) = re^{rt}$$

Examples

- Example 4:

$$f(x) = (6x + 1)(x^2 - 2x)$$

$$f'(x) = 18x^2 - 22x - 2$$

- Example 5:

$$f(x) = (x + 1)/2x^2$$

$$f'(x) = -(x + 2)/2x^3, \quad \text{for } x \neq 0$$

- Example 6:

$$f(x) = x^5(3x)^2$$

$$f'(x) = 63x^6$$

Rules of Differentiation: Functions of Different Variables

- Chain Rule:

$$z = f(y) \text{ and } y = g(x) \rightarrow z = f(g(x))$$

$$\rightarrow \frac{dz}{dx} = \frac{dz}{dy} \frac{dy}{dx} = f'(y)g'(y)$$

- Inverse-Function Rule:

If the function $y = f(x)$ represents a one-to-one mapping, the function f will have an inverse function: $x = f^{-1}(y)$.

$$\rightarrow \frac{dx}{dy} = \frac{1}{dy/dx}$$

Examples

- Example 7:

$$f(x) = (x^2 - 4x)^3$$

$$f'(x) = 6x^5 - 60x^4 + 192x^3 - 192x^2$$

- Example 8:

$$f(x) = \ln(2x^2)$$

$$f'(x) = 2/x$$

- Example 9:

$$f(x) = 3x^5 + x^2$$

$$dx/dy = 1/(15x^4 + 2x)$$