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BA Economics Honours | Semester 3 | Calicut University

Analytical Tools for Economics I

Course Code: ECO3CJ201 • Module 2

Module II: Differential Calculus

Differential calculus is the indispensable mathematical engine of microeconomic optimization. Economics is fundamentally a science of marginal choices; because marginal concepts (marginal cost, marginal revenue, marginal utility, marginal product) represent instantaneous rates of change, they are mathematically defined as the first derivatives of their corresponding total functions.

Unit 3: Limits, Continuity, and the Derivative

The derivative of a function $y = f(x)$ measures the instantaneous rate of change of the dependent variable y with respect to an infinitesimal change in the independent variable x:

Definition of Derivative

$$\frac{dy}{dx} = f'(x) = lim_{Deltax \to 0} \frac{f(x + Deltax) - f(x)}{Deltax}$$

Where: $f'(x)$ represents the instantaneous rate of change of y with respect to x evaluated at the limit as increment Δx approaches zero.

Rules of Differentiation

- **Constant Rule:**

Constant Rule

$$\frac{d}{dx}(c) = 0$$

- **Power Function Rule:**

Power Function Rule

$$\frac{d}{dx}(x^n) = nx^{n-1}$$

Where: The derivative of variable x raised to power n equals the exponent multiplied by x raised to power $(n - 1)$.

- **Constant Multiple Rule:**

Constant Multiple Rule

$$\frac{d}{dx}[c \cdot f(x)] = c \cdot f'(x)$$

- **Sum-Difference Rule:**

Sum-Difference Rule

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

- **Product Rule:**

Product Rule

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

- **Quotient Rule:**

Quotient Rule

(d) / (dx)left[(f(x)) / (g(x))right] = (g(x) f'(x) - f(x) g'(x)) / ([g(x)]^2)

Where: The derivative of ratio *u(x) / v(x)* equals the denominator times the derivative of numerator minus numerator times derivative of denominator, divided by denominator squared.

- **Chain Rule (Function of a Function):** If $y = f(u)$ and $u = g(x)$, then $\frac{dy}{dx} = \frac{dy}{du} \cdot \frac{du}{dx}$

Unit 4: Economic Applications of Derivatives

Every fundamental marginal concept in economics represents a first derivative:

- **Marginal Revenue (MR):** First derivative of Total Revenue (TR) with respect to output (Q): $MR = \frac{d(TR)}{dQ}$.
- **Marginal Cost (MC):** First derivative of Total Cost (TC) with respect to output: $MC = \frac{d(TC)}{dQ}$.
- **Price Elasticity of Demand ($epsilon_p$):** Expressed using derivatives: $epsilon_p = -\frac{dQ}{dP} \cdot \frac{P}{Q}$.

Unit 5: Optimization: Maxima and Minima

Economic agents are optimizers

consumers maximize utility, firms maximize profits, and governments minimize social costs. For a single-variable function $y = f(x)$, optimization requires two conditions:

1. **First-Order Condition (FOC - Necessary Condition):** The first derivative must equal zero:

$$\frac{dy}{dx} = f'(x) = 0$$

Points satisfying the FOC are designated as stationary or critical points.

2. **Second-Order Condition (SOC - Sufficient Condition):** Evaluated via the sign of the second derivative:
   - For a **Relative Maximum**: $\frac{d^2y}{dx^2} = f''(x) < 0$ (the function is strictly concave).
   - For a **Relative Minimum**: $\frac{d^2y}{dx^2} = f''(x) > 0$ (the function is strictly convex).
   - If $f''(x) = 0$, the test is inconclusive (possible point of inflection).

Mathematical Derivation of Firm Profit Maximization

Let total profit be $pi(Q) = TR(Q) - TC(Q)$.
FOC: $\frac{dpi}{dQ} = \frac{d(TR)}{dQ} - \frac{d(TC)}{dQ} = 0 \implies MR = MC$.
SOC: $\frac{d^2pi}{dQ^2} = \frac{d(MR)}{dQ} - \frac{d(MC)}{dQ} < 0 \implies \frac{d(MC)}{dQ} > \frac{d(MR)}{dQ}$.
The second-order condition establishes that at the profit-maximizing output, the slope of the Marginal Cost curve must be strictly greater than the slope of the Marginal Revenue curve (MC must cut MR from below).

Partial Differentiation and Constrained Optimization

When an economic variable depends on multiple inputs ($z = f(x,y)$), the **partial derivative** $\frac{\partial z}{\partial x}$ measures the rate of change of z with respect to x, holding y strictly constant. In production theory, $\frac{\partial Q}{\partial L} = MP_L$ and $\frac{\partial Q}{\partial K} = MP_K$.

When economic optimization is subject to equality constraints (e.g., maximizing utility $U(x,y)$ subject to budget constraint $P_x x + P_y y = M$), economists formulate the **Lagrange Function**:

$$\mathrm{L}(x, y, lambda) = U(x,y) + lambda[M - P_x x - P_y y]$$

Setting partial derivatives with respect to x, y, and the Lagrange multiplier $lambda$ to zero yields the tangency equilibrium condition: $\frac{MU_x}{P_x} = \frac{MU_y}{P_y} = lambda$.

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