International Institute
for Technology and Management

Unit 76: Management Mathematics

Handout #9

Calculus Applications

Taylor's Expansion

The Taylor polynomial for the function f(x) about x=a is

$$f(x)=f(a)+\frac{x-a}{1!}f'(a)+\frac{(x-a)^2}{2!}f''(a)+\frac{(x-a)^3}{3!}f'''(a)+\dots\dots\dots$$

Maclaurin's Expansion

With a = 0 , $f(x)=f(0)+\frac{x}{1!}f'(0)+\frac{x^2}{2!}f''(0)+\frac{x^3}{3!}f'''(0)+\dots\dots\dots$

Example: Expand f(x) = Arctanx = $\tan^{-1}x$

f(0) = Arctan 0 = 0 ; f′(x) = $\frac{1}{1+x^2}$ ⇒ f′(0) = 1 ; f″(x) = $\frac{-2x}{(1+x^2)^2}$ ⇒ f″(0)= 0

f‴(x) = -2 ,substituting all these in the Maclaurin's formula:

Arctanx = 0 + x(1) + $\frac{x^2}{2!}$(0) + $\frac{x^3}{3!}$(-2) …. = x - $\frac{x^3}{3}$ + $\frac{x^5}{5}$ - $\frac{x^7}{7}$ + …………

Famous Expansions :

e^x = 1 + x + $\frac{x^2}{2!}$ + $\frac{x^3}{3!}$ + ……….; sinx = x - $\frac{x^3}{3!}$ + $\frac{x^5}{5!}$ - $\frac{x^7}{7!}$ ……….

cosx = 1 - $\frac{x^2}{2!}$ + $\frac{x^4}{4!}$ - $\frac{x^6}{6!}$ ……….; ln(a+x) = lna + $\frac{x}{a}$ - $\frac{x^2}{2a^2}$ + $\frac{x^3}{3a^3}$ -…………

Note that expansion of lnx is not possible by Maclaurin's since the derivatives of lnx at x = 0 ,do not exist : f′(x) = 1/x then f′(0) = 1/0??
However, the expansion of lnx about x = a (a≠0) using **Taylor's** is possible :

lnx = lna + $\frac{1}{a}$(x-a) - $\frac{1}{2a^2}$(x-a)^2 + $\frac{1}{3a^3}$(x-a)^3 - ……; **e.g. lnx about x = 1**

ln x = ln1 + $\frac{1}{1}$(x-1) - $\frac{1}{2}$(x-1)^2 + $\frac{1}{3}$(x-1)^3 - ….= (x-1)- $\frac{1}{2}$(x-1)^2+ $\frac{1}{3}$(x-1)^3 - ….

Deducing Expansions Suppose we need the expansion of e^{-x} or e^{2x} or e^{-x^2} ,we can do this using the expansion of e^x without doing any computation : we have :

$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots$ to get the expansion of e^{-x} simply replace x by −x in the expansion of e^x : $e^{-x} = 1 + (-x) + \frac{(-x)^2}{2!} + \frac{(-x)^3}{3!} + \ldots = 1 - x + \frac{x^2}{2!} - \frac{x^3}{3!} + \ldots$

Example: Find the expansion of $e^{\cos x - 1}$ up to the term x^4 ,deduce the expansion of $e^{\cos x}$;we have $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots$ and $\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} \ldots \Rightarrow \cos x - 1 = -\frac{x^2}{2!} + \frac{x^4}{4!} - \ldots$ Now replace the whole expansion of (cosx−1) by x in the expansion of e^x :

$$e^{\cos x-1} = 1 + \left(-\frac{x^2}{2!} + \frac{x^4}{4!} - \ldots\right) + \frac{1}{2!}\left(-\frac{x^2}{2!} + \frac{x^4}{4!} - \ldots\right)^2 + \frac{1}{4!}\left(-\frac{x^2}{2!} + \frac{x^4}{4!} - \ldots\right)^4$$

Note : for the square : find the first two terms only as in $(a-b)^2 = a^2 - 2ab$ for the Cube and up : cube only the first term .

$$e^{\cos x-1} = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \ldots + \frac{1}{2!}\left(\frac{x^4}{(2!)^2} - 2\frac{x^6}{2!4!} \ldots\right) + \frac{1}{4!}\left(\frac{x^8}{(2!)^4} \ldots\right)$$

$$= 1 - \frac{x^2}{2!} + \frac{x^4}{4!} + \frac{1}{2!}\left(\frac{x^4}{(2!)^2}\right) = 1 - \frac{x^2}{2!} + \frac{x^4}{6} + \ldots \text{(only up to } x^4\text{)}$$

$$e^{\cos x} = e(e^{\cos x-1}) = e\left(1 - \frac{x^2}{2!} + \frac{x^4}{6} + \ldots\right)$$

Example : find the expansion of $e^x \sin x$ up to x^5

we have $e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots$ and $\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} \ldots$

$e^x \sin x$ **=** $\left(1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots\right)\left(x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} \ldots\right)$ **Multiply :**

= $x - \frac{x^3}{3!} + \frac{x^5}{5!} \ldots + x^2 - \frac{x^4}{3!} \ldots + \frac{x^3}{2!} - \frac{x^5}{2!3!} = x + x^2 + \frac{x^3}{3} - \frac{x^5}{30} \ldots$

Simpson's rule : is used to approximate definite integrals:

$$\int_a^b f(x)dx \approx \frac{h}{3}\left[f(a)+4f(a+h)+2f(a+2h)+4f(a+3h)......+f(b)\right]$$

FETO : Four times even ordinates ; two times odd ordinates.

Simpson's rule with ***n*** ordinates : h = $\frac{b-a}{n-1}$.

Example: Use Simpson's rule with **7** ordinates to determine an approximate value for $\int_{-2}^{+2}\frac{dx}{4+x^2}$ Compare your answer with a precise answer obtained by integration by substitution or otherwise.

$$\int_a^b f(x)dx \approx \frac{h}{3}\left[f(a)+4f(a+h)+2f(a+2h)+......+f(b)\right]$$

where h = b – a / 6 = 2-(-2)/6 = 2/3

$$\int_a^b f(x)dx \approx \frac{2}{9}\left[f(-2)+4f(-2+2/3)+2f(-2+4/3)+......+f(2)\right]$$

7 ordinates

f(a) = f(-2) = $\frac{1}{4+(-2)^2}$ = 1/8 ,etc……

$$\int_{-2}^{+2}\frac{dx}{4+x^2} \approx 0.7853$$

Using $\int \frac{dx}{a^2+x^2} = \frac{1}{a}\tan^{-1}\left(\frac{x}{a}\right)+C$

$$\int_{-2}^{+2}\frac{dx}{4+x^2} = \frac{1}{2}\tan^{-1}\left(\frac{x}{2}\right)\Big|_{-2}^{2} = \frac{1}{2}\tan^{-1}\left(\frac{2}{2}\right)-\frac{1}{2}\tan^{-1}\left(\frac{-2}{2}\right)$$

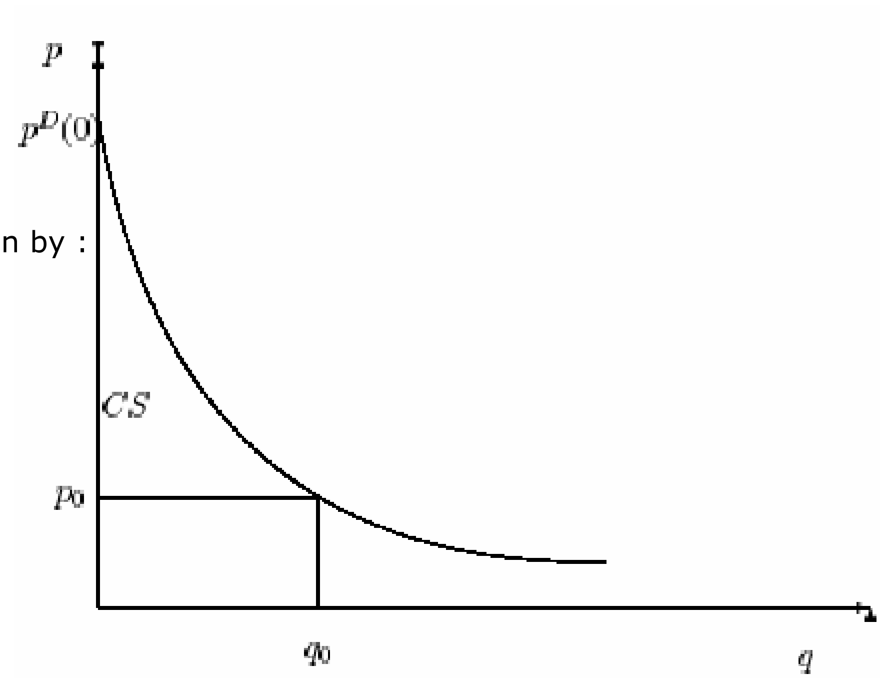
$$= \frac{1}{2}\tan^{-1}1-\frac{1}{2}\tan^{-1}(-1) = ½ (0.7853) – ½ (-0.7853) = 0.7853$$

Consumers & Producers surpluses

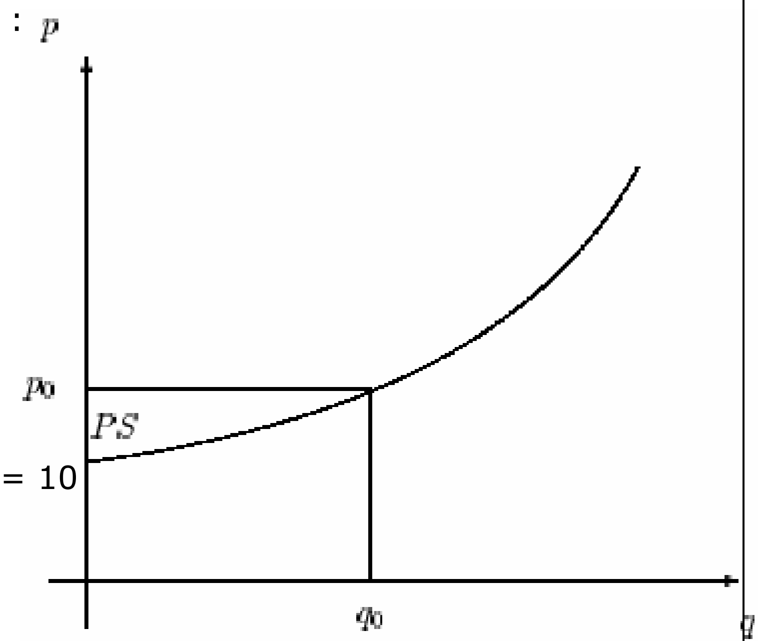
$$CS = \int_0^q P^D dq - pq \ ; \ PS = pq - \int_0^q P^S dq$$

Where p and q are Equilibrium price and quantity respectively.

Example:
The demand for a commodity is given by :p(q + 1)= 231 and the supply is given by : p – q = 11 .Find the consumers' and Producers' Surpluses.



Equilibrium price and quantity :



p(q + 1)= 231 $\Rightarrow$ p = $\frac{231}{q+1}$

p – q = 11 $\Rightarrow$ p = 11 + q

p = p $\Rightarrow$ $\frac{231}{q+1}$ = 11 + q $\Rightarrow$

$q^2 + 12q - 220 = 0$

$\Rightarrow$(q + 22)(q -10) = 0

since q can not be negative,q= 10

Hence p= 11 + q= 21

$$CS = \int_0^q P^D dq - pq = \int_0^{10} \frac{231}{q+1} dq - (21)(10) = 231\ln(q+1)\Big|_0^{10} - 210 = 231\ln(11) -$$

231ln1 – 210 = 231ln(11) – 210 Since ln1 = 0 $\approx$334.9

$$PS = pq - \int_0^q P^S dq = 210 - \int_0^{10} (q+11)dq = 210 - (q^2/2 + 11q)\Big|_0^{10} = 210 - (50+110) = 50$$