(Log-Approximation)



Log-approximation to growth rates

▶ Recall that  $g_X = \ln X_{t+1} - \ln X_t$ .

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ► Suppose X = YZ. Taking logs

$$\ln X = \ln YZ$$

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ► Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t$$

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t$$

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\Longrightarrow g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

▶ Suppose X = Y/Z.

#### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ► Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

$$\ln X = \ln \frac{Y}{7}$$

#### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

$$\ln X = \ln \frac{Y}{Z} = \ln Y - \ln Z$$

#### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ► Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

$$\ln X = \ln \frac{Y}{Z} = \ln Y - \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t$$

#### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

$$\ln X = \ln \frac{Y}{Z} = \ln Y - \ln Z$$
  
 $\Longrightarrow g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} - \ln Z_{t+1} - \ln Y_t + \ln Z_t$ 

#### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

$$\ln X = \ln \frac{Y}{Z} = \ln Y - \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} - \ln Z_{t+1} - \ln Y_t + \ln Z_t = g_Y - g_Z.$$

#### Log-approximation to growth rates

- ▶ Recall that  $g_X = \ln X_{t+1} \ln X_t$ .
- ▶ Suppose X = YZ. Taking logs

$$\ln X = \ln YZ = \ln Y + \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} + \ln Z_{t+1} - \ln Y_t - \ln Z_t = g_Y + g_Z.$$

▶ Suppose X = Y/Z. Taking logs

$$\ln X = \ln \frac{Y}{Z} = \ln Y - \ln Z$$

$$\implies g_X = \ln X_{t+1} - \ln X_t = \ln Y_{t+1} - \ln Z_{t+1} - \ln Y_t + \ln Z_t = g_Y - g_Z.$$

Note that  $(1+g_X)(1+g_Y) \approx 1+g_X+g_Y$ .

(Solow Model)



▶ Production Function: Y = F(K, AN).



- ▶ Production Function: Y = F(K, AN).
- ▶ Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .



- ▶ Production Function: Y = F(K, AN).
- ▶ Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .
- ightharpoonup Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.



- ▶ Production Function: Y = F(K, AN).
- Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN}, 1) = f(k)$ .
- ▶ Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- ▶ Then, to keep K/AN constant, K must grow at the same rate as AN.

- ▶ Production Function: Y = F(K, AN).
- ▶ Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .
- ▶ Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- ▶ Then, to keep K/AN constant, K must grow at the same rate as AN.
- ▶ Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .

- ▶ Production Function: Y = F(K, AN).
- ▶ Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F\left(\frac{K}{AN},1\right) = f(k)$ .
- $\blacktriangleright$  Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- ▶ Then, to keep K/AN constant, K must grow at the same rate as AN.
- ► Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .
- ► Capital per effective worker accumulation equation:

$$\frac{K_{t+1}}{A_t N_t} - \frac{K_t}{A_t N_t} = s \frac{Y_t}{A_t N_t} - \delta \frac{K_t}{A_t N_t}$$

- ▶ Production Function: Y = F(K, AN).
- Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .
- $\triangleright$  Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- $\blacktriangleright$  Then, to keep K/AN constant, K must grow at the same rate as AN.
- ▶ Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .
- ► Capital per effective worker accumulation equation:

$$\frac{K_{t+1}}{A_t N_t} - \frac{K_t}{A_t N_t} = s \frac{Y_t}{A_t N_t} - \delta \frac{K_t}{A_t N_t} \implies \frac{K_{t+1}}{A_{t+1} N_{t+1}} \cdot \frac{A_{t+1} N_{t+1}}{A_t N_t} - k_t = s y_t - \delta k_t$$

- ▶ Production Function: Y = F(K, AN).
- Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .
- $\triangleright$  Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- ▶ Then, to keep K/AN constant, K must grow at the same rate as AN.
- ▶ Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .
- Capital per effective worker accumulation equation:

$$\frac{K_{t+1}}{A_t N_t} - \frac{K_t}{A_t N_t} = s \frac{Y_t}{A_t N_t} - \delta \frac{K_t}{A_t N_t} \implies \frac{K_{t+1}}{A_{t+1} N_{t+1}} \cdot \frac{A_{t+1} N_{t+1}}{A_t N_t} - k_t = s y_t - \delta k_t$$

$$\implies (1 + g_A + g_N) k_{t+1}$$

- ▶ Production Function: Y = F(K, AN).
- ► Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN}, 1) = f(k)$ .
- ightharpoonup Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- ▶ Then, to keep K/AN constant, K must grow at the same rate as AN.
- ▶ Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .
- Capital per effective worker accumulation equation:

$$\frac{K_{t+1}}{A_t N_t} - \frac{K_t}{A_t N_t} = s \frac{Y_t}{A_t N_t} - \delta \frac{K_t}{A_t N_t} \implies \frac{K_{t+1}}{A_{t+1} N_{t+1}} \cdot \frac{A_{t+1} N_{t+1}}{A_t N_t} - k_t = s y_t - \delta k_t$$

$$\implies (1 + g_A + g_N) k_{t+1} - (1 + g_A + g_N) k_t = s f(k_t) - (\delta + g_A + g_N) k_t$$

- ▶ Production Function: Y = F(K, AN).
- ▶ Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .
- $\blacktriangleright$  Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- ▶ Then, to keep K/AN constant, K must grow at the same rate as AN.
- ▶ Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .
- ► Capital per effective worker accumulation equation:

$$\frac{K_{t+1}}{A_t N_t} - \frac{K_t}{A_t N_t} = s \frac{Y_t}{A_t N_t} - \delta \frac{K_t}{A_t N_t} \implies \frac{K_{t+1}}{A_{t+1} N_{t+1}} \cdot \frac{A_{t+1} N_{t+1}}{A_t N_t} - k_t = s y_t - \delta k_t 
\implies (1 + g_A + g_N) k_{t+1} - (1 + g_A + g_N) k_t = s f(k_t) - (\delta + g_A + g_N) k_t 
\implies (1 + g_A + g_N) (k_{t+1} - k_t) = s f(k_t) - (\delta + g_A + g_N) k_t$$

- ▶ Production Function: Y = F(K, AN).
- Output per effective worker:  $y \equiv Y/AN = \frac{F(K,AN)}{AN} = F(\frac{K}{AN},1) = f(k)$ .
- $\triangleright$  Assume that A and N grow at constant rates  $g_A$  and  $g_N$  respectively.
- $\blacktriangleright$  Then, to keep K/AN constant, K must grow at the same rate as AN.
- ► Capital Accumulation Equation:  $K_{t+1} K_t = sY_t \delta K_t$ .
- ► Capital per effective worker accumulation equation:

$$\frac{K_{t+1}}{A_t N_t} - \frac{K_t}{A_t N_t} = s \frac{Y_t}{A_t N_t} - \delta \frac{K_t}{A_t N_t} \Longrightarrow \frac{K_{t+1}}{A_{t+1} N_{t+1}} \cdot \frac{A_{t+1} N_{t+1}}{A_t N_t} - k_t = s y_t - \delta k_t$$

$$\Longrightarrow (1 + g_A + g_N) k_{t+1} - (1 + g_A + g_N) k_t = s f(k_t) - (\delta + g_A + g_N) k_t$$

$$\Longrightarrow (1 + g_A + g_N) (k_{t+1} - k_t) = s f(k_t) - (\delta + g_A + g_N) k_t$$

• Steady state condition:  $sf(k^*) = (\delta + g_A + g_N)k^*$ .