

# The Solow (1956) growth model

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These are notes corresponding to derivations made on the board on May 7, 2018. The Solow (1956) growth model considers an economy whose production function has constant returns to scale with respect to capital and labor, and the saving rate is constant. Time is discrete with  $t = 0, 1, 2, \dots$ , and the economy starts with an amount of capital  $K_0$  at  $t = 0$ . Capital depreciates at a rate  $\delta$ . Section 1 considers the case of a general production function. Section 2 looks at the case of a Cobb-Douglas production function.

## 1 General production function

We started from the following production function, with constant returns to scale with respect to capital and labor:

$$\frac{Y}{N} = F\left(\frac{K}{N}, 1\right) = f\left(\frac{K}{N}\right)$$

with  $f(x) \equiv F(x, 1)$ .

There is no public saving, therefore total saving, which is equal to private saving at time  $t$   $S_t$  equals investment at time  $t$   $I_t$ :

$$S_t = I_t$$

Saving is assumed to be a constant fraction  $s$  of output  $Y_t$ , therefore:

$$S_t = sY_t$$

Depreciation of capital is given by  $\delta$ . Therefore, the capital stock evolves according to:

$$K_{t+1} = (1 - \delta) K_t + I_t \tag{1}$$

Replace investment in equation (1) and divide both sides by  $N$ :

$$\frac{K_{t+1}}{N} = (1 - \delta) \frac{K_t}{N} + s \frac{Y_t}{N} \quad \Rightarrow \quad \boxed{\frac{K_{t+1}}{N} - \frac{K_t}{N} = s \frac{Y_t}{N} - \delta \frac{K_t}{N}}$$

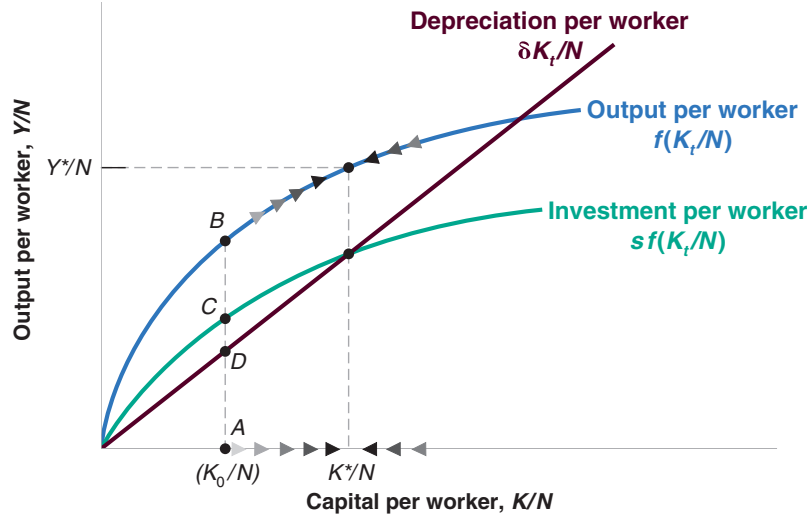
$$\underbrace{\frac{K_{t+1}}{N} - \frac{K_t}{N}}_{\text{Change in capital}} = \underbrace{s f\left(\frac{K_t}{N}\right)}_{\text{Investment}} - \underbrace{\delta \frac{K_t}{N}}_{\text{Depreciation}}$$

The steady state level of the capital stock  $K^*$  is such that  $K_{t+1} = K_t = K^*$ , and it verifies:

$$sf\left(\frac{K^*}{N}\right) = \delta \frac{K^*}{N}$$

The steady-state value of output per worker  $Y^*/N$ , as a function of  $K^*/N$  is given by:

$$\frac{Y^*}{N} = f\left(\frac{K^*}{N}\right)$$



## 2 Cobb and Douglas (1928) production function

Assume now that the production function is a Cobb-Douglas production function, so that:

$$F(K, N) = K^\alpha L^{1-\alpha}$$

This implies then that:

$$f(x) = x^\alpha$$

The law of motion for capital is given by:

$$\frac{K_{t+1}}{N} = \frac{K_t}{N} + s \left( \frac{K_t}{N} \right)^\alpha - \delta \frac{K_t}{N}.$$

Note that given  $N$ ,  $K_0$ ,  $\alpha$ ,  $s$ ,  $\delta$ , you are able to calculate  $K_1$ ,  $K_2$ , ..., as well as  $K_t$  for any  $t$ , by calculating the quantities of capital successively from the formula above. If you do so, you will notice that  $K_t$  indeed converges to a steady state value  $K^*$ . However, you do not need to perform an infinity of operations to get at this  $K^*$ . Instead, you should see that capital per worker in steady-state  $K^*/N$  solves:

$$s \left( \frac{K^*}{N} \right)^\alpha = \delta \frac{K^*}{N} \Rightarrow \frac{K^*}{N} = \left( \frac{s}{\delta} \right)^{\frac{1}{1-\alpha}}$$

The steady-state level of output per worker is then:

$$\frac{Y^*}{N} = \left(\frac{s}{\delta}\right)^{\frac{\alpha}{1-\alpha}}$$

**Golden Rule.** The Golden Rule level of capital accumulation is such that the level of steady state consumption per capita is maximized. It is given by:

$$\frac{C^*}{N} = (1-s)\frac{Y^*}{N} = (1-s)\left(\frac{s}{\delta}\right)^{\frac{\alpha}{1-\alpha}} = \frac{(1-s)s^{\frac{\alpha}{1-\alpha}}}{\delta^{\frac{\alpha}{1-\alpha}}}$$

Maximizing this steady state consumption over the level of steady state saving gives:

$$\begin{aligned} -s^{\frac{\alpha}{1-\alpha}} + \frac{\alpha}{1-\alpha}(1-s)s^{\frac{\alpha}{1-\alpha}-1} &= 0 \quad \Rightarrow \quad \frac{\alpha}{1-\alpha} \frac{1-s}{s} = 1 \\ \Rightarrow \quad \alpha - \alpha s &= s - \alpha s \quad \Rightarrow \quad \boxed{s = \alpha}. \end{aligned}$$

Therefore, the saving rate corresponding to the Golden Rule level of capital accumulation is equal to  $\alpha$ . The Golden Rule level of capital accumulation is then such that:

$$\frac{K^*}{N} = \left(\frac{\alpha}{\delta}\right)^{\frac{1}{1-\alpha}} \quad \Rightarrow \quad K^* = N \left(\frac{\alpha}{\delta}\right)^{\frac{1}{1-\alpha}}$$

The level of GDP corresponding to this Golden rule level is:

$$Y^* = N \left(\frac{\alpha}{\delta}\right)^{\frac{\alpha}{1-\alpha}}$$

## References

**Cobb, Charles W. and Paul H. Douglas**, “A Theory of Production,” *The American Economic Review*, 1928, 18 (1), 139–165.

**Solow, Robert M.**, “A Contribution to the Theory of Economic Growth,” *The Quarterly Journal of Economics*, 1956, 70 (1), 65–94.