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1 Overlapping Generations model

The overlaping generations (OLG) model was first developed by **Allais (1947)**, **Samuelson (1958)** and **Diamond (1965)**. Here I present the simple, classic version of the model where agents live for two periods: in the first they are "young" and work, and in the second they are "old" or "retired" and have to finance their consumption from previously accumulated savings. I also later discuss social security (pensions) issues.

1.1 Basic model

Households

Each household lives for two periods. In period t there are N_t^y young households born and each of them supplies one unit of labor, so that the total labor supply L_t is equal to the number of young households N_t^y. The rate of growth of young agents is assumed to be constant for simplicity and denoted with n:

$$\frac{L_{t+1}}{L_t} = \frac{N_{t+1}^y}{N_t^y} = \frac{(1+n)\,N_t^y}{N_t^y} = 1+n$$

The number of old agents in period t is denoted with N_t^o. All young survive into the old age, but all old die with certainty. Therefore, the number of old agents in period $t+1$ is equal to the number of young agents in period t. The rate of growth of the entire population (denoted with N_t) is also equal to n:

A household born in period t faces the following utility maximization problem:

$$\begin{aligned} \max_{c_t^y,\, c_{t+1}^o,\, a_{t+1}} \quad & U = \ln c_t^y + \beta \ln c_{t+1}^o \\ \text{subject to} \quad & c_t^y + a_{t+1} = w_t \\ & c_{t+1}^o = (1+r_{t+1})\, a_{t+1} \end{aligned}$$

where c_t^y denotes consumption of household born in period t when young, and c_{t+1}^o denotes consumption of household born in period t when old (consumption takes place in period $t+1$). It is assumed that young households receive wage income w_t and the old households sell their assets to consume. Note that both wage w_t and interest rate r_{t+1} are time-dependent and will be determined in the market equilibrium.

The lifetime budget constraint of a household born in period t is:

$$c_t^y + \frac{c_{t+1}^o}{1+r_{t+1}} = w_t$$

The present discounted value (PDV) of consumption has to equal to the PDV of income, the latter being equal to the wage income earned while young.

Set up the Lagrangian:

$$\mathcal{L} = \ln c_t^y + \beta \ln c_{t+1}^o + \lambda \left[w_t - c_t^y - \frac{c_{t+1}^o}{1+r_{t+1}} \right]$$

First order conditions:

$$\begin{aligned} c_t^y &: \quad \frac{1}{c_t^y} - \lambda = 0 & \rightarrow \quad & \lambda = \frac{1}{c_t^y} \\ c_{t+1}^o &: \quad \beta \frac{1}{c_{t+1}^o} - \frac{\lambda}{1+r_{t+1}} = 0 & \rightarrow \quad & \lambda = \beta\,(1+r_{t+1})\,\frac{1}{c_{t+1}^o} \end{aligned}$$

We obtain the familiar Euler equation:

$$\frac{1}{c_t^y} = \beta\,(1+r_{t+1})\,\frac{1}{c_{t+1}^o} \quad \rightarrow \quad c_{t+1}^o = \beta\,(1+r_{t+1})\,c_t^y \tag{1}$$

Plug the optimality condition into the lifetime budget constraint:

$$\begin{aligned}
c_t^y + \frac{c_{t+1}^o}{1+r_{t+1}} &= w_t \\
c_{t+1}^o &= \beta\left(1+r_{t+1}\right)c_t^y \\
c_t^y + \frac{\beta\left(1+r_{t+1}\right)c_t^y}{1+r_{t+1}} &= w_t \\
\left(1+\beta\right)c_t^y &= w_t
\end{aligned}$$

$$\begin{aligned}
c_t^y &= \frac{1}{1+\beta}w_t \\
a_{t+1} &= w_t - c_t^y = \frac{\beta}{1+\beta}w_t \\
c_{t+1}^o &= \frac{\beta}{1+\beta}\left(1+r_{t+1}\right)w_t
\end{aligned}$$

Note that the consumption of young and their savings are independent of the interest rate, which greatly simplifies the following analysis. This is a consequence of the substitution and income effects canceling out due to the assumption of logarithmic utility and zero retirement income.

Firms

For simplicity let's assume that the behavior of the entire firms sector is summarized by a single representative firm. This firm hires capital K and labor L and produces goods Y according to the following Cobb-Douglas production function:

$$Y_t = K_t^\alpha L_t^{1-\alpha}$$

where $\alpha \in (0,1)$ is the elasticity of output with respect to capital.

The representative firm aims to maximize its profits. The price of the good is normalized to 1 (so that all other prices are expressed in units of the final good) and the profit maximization problem is given by:

$$\begin{aligned}
\max_{K_t,\,L_t} \quad & \Pi_t = Y_t - \left(r_t+\delta\right)K_t - w_t L_t \\
\text{subject to} \quad & Y_t = K_t^\alpha L_t^{1-\alpha}
\end{aligned}$$

where $\delta \in (0,1)$ is the capital depreciation rate. Here it is convenient to directly include the constraint in the objective function:

$$\max_{K_t,\,L_t} \quad \Pi_t = K_t^\alpha L_t^{1-\alpha} - \left(r_t+\delta\right)K_t - w_t L_t$$

First order conditions:

$$\begin{aligned}
K_t \quad &: \quad \alpha K_t^{\alpha-1}L_t^{1-\alpha} - \left(r_t+\delta\right) = 0 \quad \rightarrow \quad r_t = \alpha\left(\frac{K_t}{L_t}\right)^{\alpha-1} - \delta \\
L_t \quad &: \quad \left(1-\alpha\right)K_t^\alpha L_t^{-\alpha} - w_t = 0 \quad \rightarrow \quad w_t = \left(1-\alpha\right)\left(\frac{K_t}{L_t}\right)^{\alpha}
\end{aligned}$$

The prices of factors of production depend on the level of capital per worker, defined as:

$$k_t \equiv \frac{K_t}{L_t}$$

The factor prices can then be rewritten as:

$$\begin{aligned}
r_t &= \alpha k_t^{\alpha-1} - \delta \\
w_t &= \left(1-\alpha\right)k_t^\alpha
\end{aligned}$$

General Equilibrium

We now know how the households and firms behave in isolation. However, they are obviously interconnected: how much the households save will matter for how much capital gets accumulated in the economy, while the prices of factors of production matter for the households' choices. The way to combine this information is to impose that the economy is in general equilibrium and all markets clear.

The capital that will be available for production in period $t+1$ is equal to the end-of-period savings of time period t young:

$$K_{t+1} = N_t^y a_{t+1}$$

We can express the above relationship in per worker terms:

$$\frac{K_{t+1}}{L_t} = \frac{N_t^y}{L_t} a_{t+1}$$
$$\frac{K_{t+1}}{L_{t+1}} \frac{L_{t+1}}{L_t} = a_{t+1}$$
$$k_{t+1}(1+n) = a_{t+1}$$

From the solution of the households problem we obtained already the expression for assets of the young:

$$a_{t+1} = \frac{\beta}{1+\beta} w_t$$

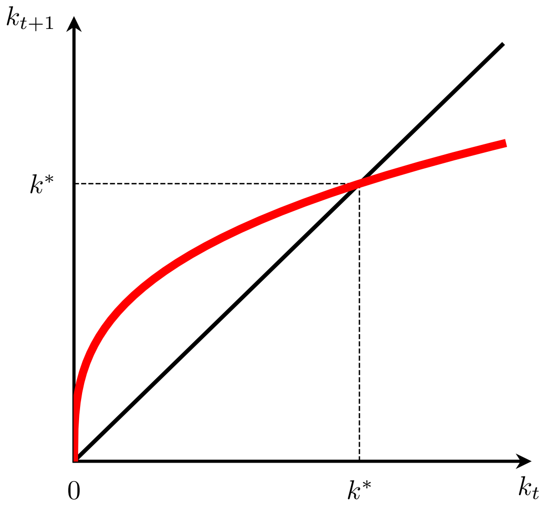
From the problem of the firms we also obtained the expression for the real wage:

$$w_t = (1-\alpha) k_t^\alpha$$

Combine all pieces of information:

$$k_{t+1} = \frac{\beta(1-\alpha)}{1+\beta} \frac{1}{1+n} k_t^\alpha$$

The above is a dynamic equation that describes the evolution of capital per worker over time:



with the steady state value of capital per worker equal to:

$$k^* = \left[\frac{\beta(1-\alpha)}{1+\beta} \frac{1}{1+n}\right]^{1/(1-\alpha)}$$

Note that under our assumptions the behavior of the model closely resembles that of the Solow-Swan model. In fact, we can show that the expression $\frac{\beta(1-\alpha)}{1+\beta}$ corresponds to the constant saving rate.

1.2 Saving rate of the simple OLG economy

We can also derive the saving rate of this economy, and show that it is constant, just like in the Solow-Swan case. In this context, one of the advantages of the OLG model is in providing the link between households' preferences and the saving rate.

We are going to assume that the depreciation rate δ is equal to 1. This is justified by the fact that each period of time represents decades in real world. Just think about how few machines and pieces of equipment that were used in 1990 are still in use today. Then the capital accumulation equation implies:

$$K_{t+1} = I_t + (1-\delta) K_t \underbrace{\rightarrow}_{\delta=1} K_{t+1} = I_t$$

We already know that the next period capital stock is given by:

$$K_{t+1} = N_t^y a_{t+1}$$

By definition, the economy's saving rate is the ratio between total savings (investment) and output:

$$s \equiv \frac{S_t}{Y_t} = \frac{I_t}{Y_t} = \frac{N_t^y a_{t+1}}{Y_t} = \frac{N_t^y \frac{\beta(1-\alpha)}{1+\beta} K_t^\alpha L_t^{-\alpha}}{K_t^\alpha L_t^{1-\alpha}} = \frac{\beta (1-\alpha)}{1+\beta}$$

As expected, the saving rate s depends positively on households' discount factor β:

$$\frac{\partial s}{\partial \beta} = (1-\alpha) \frac{(1+\beta)-\beta}{(1+\beta)^2} = \frac{1-\alpha}{(1+\beta)^2} > 0$$

The more patient the households are, the higher is the aggregate saving rate in the OLG economy.

The formula for the saving rate allows us to express the dynamic equation for capital per worker in a more convenient fashion:

$$k_{t+1} = \frac{\beta}{(1+\beta)} \frac{(1-\alpha)}{(1+n)} k_t^\alpha = \frac{s}{1+n} k_t^\alpha$$

And the steady state level of capital per worker is given by:

$$k^* = \left(\frac{s}{1+n} \right)^{1/(1-\alpha)}$$

which is identical to the formula for the steady state level of capital per worker in the Solow-Swan model without technological progress and assuming $\delta = 1$.

1.3 Optimality and dynamic efficiency

We already know which decisions households and firms will make. It is interesting to see whether those decisions are optimal. To find this out, we first need to obtain those optimal decisions. Obviously, the economy needs to satisfy the resource constraint:

$$C_t + I_t = Y_t$$
$$N_t^y c_t^y + N_t^o c_t^o + K_{t+1} = K_t^\alpha L_t^{1-\alpha}$$

In per worker terms:

$$N_t^y c_t^y + N_{t-1}^y c_t^o + K_{t+1} = K_t^\alpha L_t^{1-\alpha} \quad | \quad : L_t$$
$$\frac{N_t^y}{L_t} c_t^y + \frac{N_{t-1}^y}{N_t^y} \frac{N_t^y}{L_t} c_t^o + \frac{K_{t+1}}{L_{t+1}} \frac{L_{t+1}}{L_t} = K_t^\alpha L_t^{-\alpha}$$
$$c_t^y + \frac{c_t^o}{1+n} + (1+n) k_{t+1} = k_t^\alpha$$

We are going to focus on the case where the economy is in the steady state, as then we can get rid of time subscripts and the welfare of an individual is time-independent. Let us now maximize utility of a representative household living in the steady state:

$$\max_{c^y,\,c^o} \quad \ln c^y + \beta \ln c^o$$
$$\text{subject to} \quad c^y + \frac{c^o}{1+n} = k^\alpha - (1+n)\,k$$

Lagrangian:

$$\mathcal{L} = \ln c^y + \beta \ln c^o + \lambda \left[k^\alpha - (1+n)\,k - c^y - \frac{c^o}{1+n} \right]$$

First order conditions:

$$\begin{aligned} c^y &: \quad \frac{1}{c^y} - \lambda = 0 \\ c^o &: \quad \frac{\beta}{c^o} - \frac{\lambda}{1+n} = 0 \\ k &: \quad \lambda \left[\alpha k^{\alpha-1} - (1+n) \right] = 0 \end{aligned}$$

The FOC with respect to capital tells us that welfare is maximized when:

$$\alpha k^{\alpha-1} = 1+n$$

This implies that, similar to the Solow-Swan model, the level of capital per worker that maximizes agents' welfare in the steady state is given by:

$$k^*_{GR} = \left(\frac{\alpha}{1+n} \right)^{1/(1-\alpha)}$$

and the golden rule savings rate (see **Phelps, 1961**) is equal to:

$$s_{GR} = \alpha$$

Combining FOCs for consumption yields:

$$c^o = \beta\,(1+n)\,c^y$$

which implies that the interest rate that households receive should be equal to the "biological" interest rate (see **Samuelson, 1958**).

It is easy to show that if the economy accumulates more capital than implied by the golden rule, the situation is dynamically inefficient: we could improve the well-being of at least one agent without decreasing the well-being of other agents.

In the more general case, where we allow for the technological progress, we can offer the following criterion to examine whether an economy is dynamically inefficient. If the rate of growth of aggregate real GDP exceeds the real interest rate, then the economy is dynamically inefficient.

1.4 Pensions

The considerations from the previous sections are very relevant for the construction of the retirement systems. We will analyze two types: “fully funded” and “pay-as-you-go” systems. In both cases the government will collect a social security contribution τ_t from young agents and pay pensions p_t to the retired. The modified budget constraints are:

$$\begin{aligned} c_t^y + a_{t+1} &= w_t - \tau_t \\ c_{t+1}^o &= (1 + r_{t+1})\, a_{t+1} + p_{t+1} \end{aligned}$$

The difference between the systems stems from the different relationships between τ and p.

Fully funded

In the fully funded system the government collects the social security contributions and invests them in financial markets, just as the households do. The rate of return on those “mandatory” savings is assumed to be equal to the rate of return on households’ savings. Thus the pensions are determined by:

$$p_{t+1} = (1 + r_{t+1})\, \tau_t$$

Include this information in the households’ budget constraints:

$$\begin{aligned} c_t^y + a_{t+1} &= w_t - \tau_t \\ c_{t+1}^o &= (1 + r_{t+1})\, a_{t+1} + (1 + r_{t+1})\, \tau_t \end{aligned}$$

And produce the lifetime budget constraint:

$$\begin{aligned} a_{t+1} &= \frac{c_{t+1}^o}{1 + r_{t+1}} - \tau_t \\ c_t^y + \frac{c_{t+1}^o}{1 + r_{t+1}} - \tau_t &= w_t - \tau_t \\ c_t^y + \frac{c_{t+1}^o}{1 + r_{t+1}} &= w_t \end{aligned}$$

The lifetime budget constraint is identical to the case of no retirement system. The optimality condition is still given by the Euler equation 1. Thus, the chosen consumption level will be unchanged:

$$c_t^y = \frac{1}{1 + \beta} w_t$$

However, since the young have less disposable income, their private savings will be equal to:

$$a_{t+1} = w_t - c_t^y - \tau_t = \frac{\beta}{1 + \beta} w_t - \tau_t$$

The capital in the next period will be the sum of voluntary (private) and mandatory (public) savings:

$$K_{t+1} = N_t^y \,(a_{t+1} + \tau_t) = N_t^y \left(\frac{\beta}{1 + \beta} w_t - \tau_t + \tau_t \right) = N_t^y \left(\frac{\beta}{1 + \beta} w_t \right)$$

and be invariant to the retirement system.

Pay-as-you-go (PAYG)

In the pay-as-you-go system the government collects the social security contributions and immediately spends them on the pensions of the currently old:

$$
\begin{aligned}
N_t^o p_t &= N_t^y \tau_t \\
p_t &= \frac{N_t^y}{N_{t-1}^y} \tau_t \\
p_t &= (1+n)\,\tau_t
\end{aligned}
$$

Include this information in the households' budget constraints:

$$
\begin{aligned}
c_t^y + a_{t+1} &= w_t - \tau_t \\
c_{t+1}^o &= (1+r_{t+1})\,a_{t+1} + (1+n)\,\tau_{t+1}
\end{aligned}
$$

To analyze the PAYG system easily, assume that $\tau_t = \tau_{t+1} = \tau$. The lifetime budget constraint becomes:

$$
\begin{aligned}
a_{t+1} &= \frac{c_{t+1}^o - (1+n)\,\tau}{1+r_{t+1}} \\
c_t^y + \frac{c_{t+1}^o - (1+n)\,\tau}{1+r_{t+1}} &= w_t - \tau \\
c_t^y + \frac{c_{t+1}^o}{1+r_{t+1}} &= w_t + \frac{(n - r_{t+1})\,\tau}{1+r_{t+1}}
\end{aligned}
$$

The optimality condition is still given by the Euler equation [1] and the chosen level of consumption when young and savings will be given by:

$$
\begin{aligned}
c_t^y &= \frac{1}{1+\beta}\left[w_t + \frac{(n-r_{t+1})\,\tau}{1+r_{t+1}}\right] \\
a_{t+1} &= w_t - \tau - \frac{1}{1+\beta}\left[w_t + \frac{(n-r_{t+1})\,\tau}{1+r_{t+1}}\right] \\
a_{t+1} &= \frac{\beta}{1+\beta}\,(w_t - \tau) - \frac{1}{1+\beta}\frac{1+n}{1+r_{t+1}}\tau
\end{aligned}
$$

Accordingly, the capital in the next period is given by:

$$
K_{t+1} = N_t^y a_{t+1} = N_t^y \left[\frac{\beta}{1+\beta}\,(w_t - \tau) - \frac{1}{1+\beta}\frac{1+n}{1+r_{t+1}}\tau\right]
$$

It is trivial to verify that the right hand side depends negatively on τ. That is, compared to the no retirement system case, the economy will accumulate less capital. We have seen the situation when that would be beneficial: when the households save "too much", leading to the dynamically inefficient situation.

As many countries experience low fertility rates, and as a consequence low (or even negative) n, it would be optimal to switch from the PAYG to the fully funded system. However such a switch involves redirecting the social security contributions away from financing the pensions of currently old to the financial markets. This creates the need to find some other source of financing those pensions, which might involve welfare losses outweighing the benefits of switching systems.