

Week 1

The Gross Domestic Product (GDP) of a country is a measure of the aggregate income (or value added) earned by all inhabitants of that country in a particular year.

	Ag
Ag	6
Mi	0
Man	14

We can see in the input-output Table 1 that the agricultural sector (row 3, column 1) is demanding €14 billion of intermediate inputs (for example, fertilisers, plastics, chemicals) produced by the manufacturing industry (列需要行的量)

- GDP = total value added = value of total final demand (FD)
- =FD=C+G+I+E - M

Macro-economists are finding it hard to give a reasonable forecast of GDP growth in the next few years, because they have no experience of a macro-crisis caused by both **supply-side disruptions** (the breakdown of global production chains, the closure of restaurants, hotels, museums, etc., the sudden stop of international trade and transportation due the lock-down) and **demand deficiency** (which is caused by higher unemployment, lower incomes and massive uncertainties)

Macro-economists generally use the symbol Y for nominal GDP; let us use lower-case 'y' for real GDP and the symbol 'p' for (the index of) the general price level (in the base year p=1).

this), where the growth rate of nominal GDP $\dot{Y} = \Delta \log(Y) = \Delta \log(P) + \Delta \log(y)$, we can write:

(13) $\dot{Y} = \dot{p} + \dot{y}$

Unemployment

The official definition of an unemployed person is a person aged at least 16, who is without work during the reference week, available to start work within the next two weeks (i.e. was available for paid employment or self-employment) and is actively seeking work (i.e. has actively sought employment at some time during the previous four weeks) or has already found a job to start later, i.e. within a period of at most three months. The official unemployment rate (known as U3) is defined as the number of unemployed persons as a share (or a percentage) of the total active population (= the labour force). The labour force is the number of people (in the age bracket 16-65 years) employed and unemployed. People who after becoming unemployed do not actively search for a new job: discouraged workers/persons marginally attached to the labour force ((which includes discouraged workers) is called U6.)

Recession

Recessions are generally defined as two consecutive quarters of negative economic growth.

Fiscal policy

the means by which a government adjusts its spending levels (public current expenditure G in equation (9) and public investment (which is part of investment I in eq. (9)) and **tax rates** in order to influence the level of activity in a nation's economy. The level of economic activity is expressed by the level of GDP.

Expansionary fiscal policy (fiscal stimulus): G+, I of the public+, tax-from C+

Contractionary fiscal policy (fiscal austerity): 通胀高了反正来

Monetary policy

through which a **central bank** attempts to influence inflation and GDP.

- the interest rate 需求+ Money supply 供给

increase in the public debt-to-GDP ratio

$\Delta debt = \text{fiscal deficit} + (i - g) \times debt$

Δdebt = the change in the public debt-to-GDP ratio; the fiscal deficit (as a percentage of GDP) does not include interest payments; i = the nominal rate of interest; g = the growth of nominal GDP; and debt = the initial public debt-to-GDP ratio.

The **average annual growth rate of real GDP y over a period of time** can be calculated as a **compound rate of growth**: assume that the period is n number of years and the starting year is year "zero", then the average annual growth rate of y is defined as:

(A.3) $\dot{y} = \left(\left[\frac{y_n}{y_0} \right]^{1/n} - 1 \right) \times 100\%$

Example: real GDP of the Netherlands (in constant 2015 prices) was €152.6 billion in 1960 and €757.2 billion in 2019. The average annual growth rate of Dutch real GDP during the 59-year period 1960-2019 is:

(A.4) $\dot{y} = \left(\left[\frac{757.2}{152.6} \right]^{\frac{1}{59}} - 1 \right) \times 100\% = 2.75\%$

Week 2: NEOCLASSICAL MACRO-ECONOMICS

neoclassical markets:

在新古典经济学中，经济被假设已经在最大（充分就业）产能下运作。

not change in response to changes in the real wage (W/p). In Figure 1, L^S is a vertical line. **Labour demand** (in the economy as a whole) is a function of output (x) and the real wage (W/p), or $L^D = \alpha x \left(\frac{W}{p} \right)^{-1}$, where L^D = the demand for labour, and α is a constant. The labour demand function is based on profit-maximising decision-making by firms.

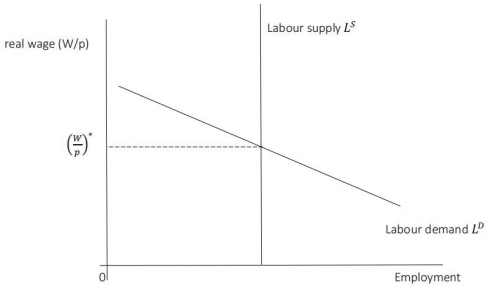


Figure 1: The Neoclassical Labour Market

market for capital goods (machines)的图像长得一样，L换成K，W换成π，α换成β the neoclassical economy operates at **full employment**

新古典的 **savings** 一直有 **leakage** 在 **circular** 中，但是有 **market for loanable funds** 银行将储蓄作为存款接收。在新古典模型中，银行是利润最大化的企业，利润最大化的银行将利用储蓄（或可贷资金）向企业提供贷款，以使它们能够购买生产资料。也就是说，可贷资金的供给（即储蓄）用于向企业提供它们投资所需的资金。银行的中介角色被概念化为一个市场——一个可贷资金市场（见图 5）。这个市场也是一个完美的市场，在这个市场中，实际利率（即可贷资金的价格）使市场达到均衡。供给一直是 y^*FE 即完全就业

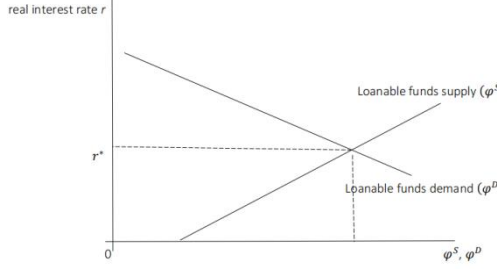
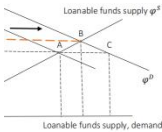


Figure 5: The Neoclassical Market for Loanable Funds

当 $\phi^S > \phi^D$ 时，即当储蓄过剩时，银行（作为中介机构）资金充裕，唯一使这些资金对它们有利可图的方法是将其这些资金转化为向企业发放的（带息）贷款。企业只有在预期其投资项目（足够）有利可图时才会接受额外贷款。因此，银行将降低利率，响应利率 \downarrow 的下降，投资和 ϕ^D 将会上升，而储蓄 ϕ^S 将会下降，直到达到均衡。可贷资金市场对新古典经济学方法至关重要。一个关键的新古典假设是，储蓄总是会回归经济体系，因为在可贷资金市场上，所有储蓄都会转化为投资。利率的变化将确保这一点。因此，如果储蓄 $(s = 20\%)$ ，那么投资也将等于 20%；结果，需求 $d = 100\%$ ，经济系统将继续以充分就业运转，即 $\lambda(x, FE) = y, FE$ 。

Fiscal policy in the neoclassical model: public spending crowds out private spending
crowded out

$\Delta d = 0 = \downarrow c + \downarrow i_p + \uparrow i_g$



Monetary policy in the neoclassical model: inflation targeting and the 'money-growth rule'
the **money supply** is supposed to be **exogenous** 即直接被央行控制

The demand for money varies with the level of GDP, the overall price level, and the velocity of money circulation (v): $M^D = \left(\frac{1}{p} \right) p \times y$, where v is generally assumed constant. M^D increases when economic activity (y) and/or the general price level (p) increase; in both cases, more money is needed for carrying out economic transactions.

inflation is **decided (exogenous) money supply growth (instantaneous) growth rates: $\dot{p} = \dot{M}^S - \dot{y}$**
and real GDP growth 等式又被叫做 **monetary policy rule**. 钱是 **neutral** 的。央行控制钱的供给来防止通胀。

Week 3: KEYNESIAN MACRO-ECONOMICS

- Below full employment
- emphasizes the role of aggregate demand (and especially investment demand) as the key driver of economic growth
- the view is always forward, uncertainty future
- 有波动的 business-cycle, investment demand and aggregate demand are not stable
- 消费是稳定且相对可预测的，因为家庭被发现会消费其（可支配）收入的固定比例。与作为经济驱动力的投资不同，私人消费是“被动的”passive，是一个被驱动的数量。
- 拒绝新古典的 **loanable funds market**，即 **banks are money-creating institutions (and not just intermediaries)**，钱不是 **neutral** 的
- 运作核心机制是**乘数效应 multiple process**
- 政府的财政政策可以用来保持（和引导）实际 GDP 接近其充分就业水平。在凯恩斯模型中，公共支出**不会挤出私人支出**（这与新古典模型相反）。
- 货币政策没有财政政策有效因为 **private investment** 是和期待有关而不是 **real interest rate**

Keynesian circular flow of income

- (1) $d = c + i$ aggregate demand = consumption + investment
- (2) $c = (1 - \sigma) \times y$ real consumption is a function of real GDP
- (3) $s = \sigma \times y$ real savings are a fixed proportion σ of y
- (4) $i = i_0$ real investment is autonomous real investment i_0
- (5) $y = x = d$ real GDP is determined by real aggregate demand
- (6) $y = x = d = c + i = (1 - \sigma) \times y + i_0 \rightarrow y^* = \frac{1}{\sigma} \times i_0 < y^{FE}$

The reduced-form equation states that equilibrium (real) GDP is a function of the multiplier (1/ σ) and autonomous real investment. We can write eq. (6) in first differences as follows:

(7) $\Delta y^* = \frac{1}{\sigma} \times \Delta i_0$

In our example, $\sigma = 0.2$. This means that the **multiplier** (1/ σ) equals 5 (see the Appendix for a formal derivation of the multiplier.)

但是这个等式取决于题目

paradox of thrift

虽然个人增加储蓄倾向（如为了退休金或购买耐用消费品）可能是合理的，但如果每个人都这样做，将适得其反。

For Keynes, Δi_0 comes first (**ex-ante**), while ΔS follows as an outcome of the multiplier process (**ex-post**). Keynes thus rejects the neoclassical savings-constraint.

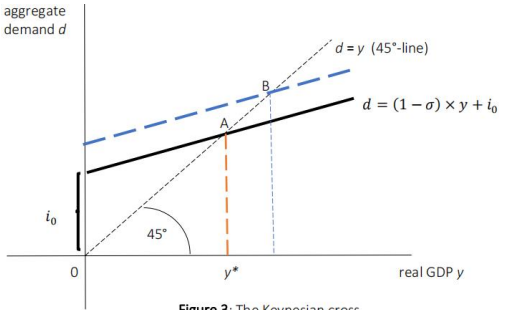


Figure 3: The Keynesian cross

考虑到 t, e, m 等 mu 是进入占 y 比例，结论：

$y^* = \frac{1}{\sigma + t - (\sigma \times t) + \mu} \times [g + i_0 + e_0]$

对 g, i_0, e_0 的偏导数都大于 0

Fiscal policy in the Keynesian model

对上面那个公式把 i_0 展开成 $ig + ip$ ，对 ig 求偏导一样的

没有挤出效应：银行不必提高利率以吸引更多的储蓄（可贷资金），以便能够为国家提供增加 ig 的资金。毕竟，银行可以创造新货币并向国家提供贷款来资助更高的 ig 。换句话说，没有储蓄约束。我们将在第七周讨论商业银行的货币创造。第二个因素是，经济运行处于未充分利用产能的状态。

Counter-cyclical fiscal policy tries to dampen the business cycle, i.e. to reduce the amplitude of the usual upswings and downswings

- government budget deficit may be desirable in a downswing or a recession
- government budget surplus may be desirable in an upswing or a boom, because it will slow down growth and prevent the economy from over-heating

如果 $ip = ip_0 - \theta r_t$ ：把上面那个等式的括号替换 $(g + i_0 = ip_0 - \theta r + e_0)$

$\Delta y^* = \frac{-\theta}{\sigma + t - (\sigma \times t) + \mu} < 0$ **Real interest rate** 加则 **real GDP** 减

流动性陷阱是指在经济衰退时期，尽管中央银行降低利率并增加货币供应量，但投资和消费需求仍然低迷，导致货币政策无效的现象。此时，公众和企业对未来经济前景极度悲观，倾向于持有现金而非投资或消费，使得进一步降息也无法刺激经济增长。在这种情况下，传统的货币政策工具失去作用，而要靠财政政策或其他非常规措施来促进经济增长。

$c + g + i + e - m = c + t + s \Rightarrow y = (t + g) + (m - e) = s + g + sf$ 这里是 **private public foreign savings trade surplus: $e - m > 0$**

Week 5: IS-LM

Hicks 这个模型和凯恩斯的理论有一点不一样：ISLM 假设货币外源，凯恩斯假设货币供给内生(现实中是内生的)；忽略不确定性

We know from the circular flow of income that

$y = d = c + i$ real GDP = aggregate demand for goods & services = $c + i$

and

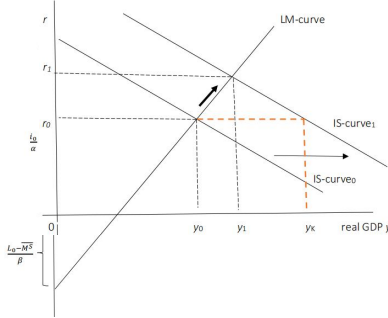
$y = c + s$ real GDP is either used for consumption or for savings

这意味着在（事后）均衡中，必须满足 ies ，即投资等于储蓄。这个条件在凯恩斯宏观模型（投资通过乘数效应决定收入，而收入决定储蓄）以及新古典宏观模型（储蓄作为可贷资金存入银行，然后银行将这些资金作为投资重新引入循环流动）中都成立。Let us now assume that (a) real investment is partly **autonomous** (i.e. determined by 'animal spirits', or i_0) and partly influenced by the **cost of capital** (= the real rate of interest r); and (b) that real savings are a fixed proportion σ of real income (y). This gives:

(1) $i = i_0 - \alpha r = s = \sigma \times y$

$r = \left(\frac{1}{\alpha} \right) \times (i_0 - \sigma \times y) \rightarrow \text{the IS-curve}$

The standard IS-LM Model



LM 中的 $M^D = L1 + L2$
L1 代表交易动机和预防动机的货币需求。即，人们持有货币用于日常交易和预防意外支出的需求。这部分需求主要受收入水平（Y）影响，收入越高，交易和预防需求也越高，因此 **L1** 是收入的增函数。
L1 = v * p * y v 是常数
L2 代表投机动机 speculative 的货币需求。即，人们持有货币以便在未来利率变化时进行投机活动。**L2** 主要受利率（i）影响，当利率较低时，人们预期未来利率会上升，从而增加对货币的需求，反之亦然。因此，**L2** 是利率的减函数
 $L2 = L0 - \beta r$

带入前面的等式让 $M^S = \bar{M}^S = M^D$

$r = \left(\frac{1}{\beta} \right) \times (v \times p \times y + L_0 - \bar{M}^S) \rightarrow \text{the LM-curve}$

The macro-economic impacts of fiscal policy

Fiscal stimulus does lead to **partial crowding out** of business investment in this version of the IS-LM model. 如图

The macro-economic impacts of monetary policy

现在让我们考虑货币紧缩的情况：中央银行增加货币供应 **LM** 曲线将向右移动。由于货币供应的（外生）增加，货币市场出现了超额供给： $\phi^S > \phi^D$ 。经济最初在 $(y_0, 0)$ 水平运作，这一实际 GDP 水平决定了交易货币需求 ϕ^D 。这意味着货币供应的增加不会被 ϕ^D “吸收”，而必须由投机性货币需求 ϕ^L 来吸收。金融投资者只有在利率降低时才会愿意持有更多的现金。因此，为应对超额货币供给，银行降低了利率。这有两个后果。首先，投机者增加了对流动性的需求： ϕ^L 上升。其次，较低的（实际）利率将导致商业投资增加： ϕ^I 上升。较高的商业投资对实际 GDP 产生乘数效应，较高的 ϕ^I 提高了交易货币需求。因此， ϕ^D 也会上升，最终结果是经济增长：图 4 中实际 GDP 从 y_0 增加到 y_1 。均衡实际利率从 r_0 下降到 r_1 。货币扩张（即 ϕ^S 的增加）导致利率下降，进而吸引商业投资。因此，虽然财政刺激导致私人投资的挤出效应，货币刺激则导致私人投资的吸入效应。货币扩张也被发现有效地提高了实际 GDP（和降低失业率）。

The IS-LM Model: a first special case

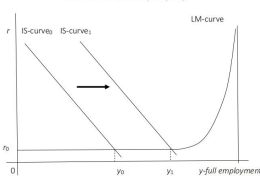
$\alpha = 0$ ，即 **IS** 曲线垂直向上
This gives the following **'equilibrium relationship'** for real GDP:

(2) $y = \left(\frac{1}{\sigma} \right) \times i_0 \rightarrow \text{the IS-curve}$

We see that (equilibrium) real GDP now depends on the (Keynesian) multiplier (1/ σ) and autonomous investment i_0 . The IS-curve becomes **vertical** – as in Figure 6.
fiscal policy becomes very effective, because there is no longer any crowding out (of business investment, caused by the higher interest rate).

The IS-LM Model: a second special case

The IS-LM Model: the Liquidity Trap



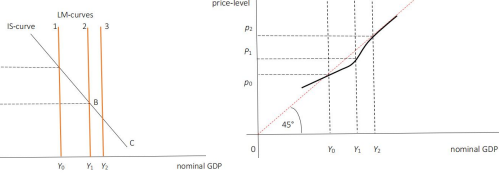
沿水平部分的 **LM** 曲线，实际利率是恒定的。系数 **beta** 和 **v** 也是恒定的，即使 **p** 保持不变。如果市场情绪不变，实际 GDP 也不会变化。因为实际利率被认为是恒定的，当中央银行增加 ϕ^S 时会发生什么？答案是：没有变化。**LM** 曲线不会因为 ϕ^S 的增加而向右移动。原因是货币供应的增加被金融投资者的投机性现金持有量 ϕ^L 吸收。 ϕ^L 是 **LM** 曲线方程中唯一可以吸收货币供应增加的变量。因此，沿水平部分的 **LM** 曲线假定 $\Delta L_0 = \Delta L$
 $\phi^S = \phi^D$ ：实际利率不会（需要）变化。
因为经济处于低迷状态，没有人期望经济会很快复苏。利率很低，资产价格相对较高。投机者愿意持有（新）货币，预期一旦经济增长开始加速，利率将再次上升，他们就有现金购买金融资产（届时价格会下降）。这种停滞被称为 **流动性陷阱**。投资停滞，充斥着货币（流动性），但货币闲置（在投机者的银行账户中），未用于交易目的。

在流动性陷阱中，货币政策（增加 $\overline{(M, S)}$ ）无效： $\overline{(M, S)}$ 的增加不会降低实际利率，因此对商业投资或实际 GDP 没有影响。摆脱流动性陷阱的唯一出路是财政刺激：增加公共支出，使 IS 曲线向右移动（如图 7 所示），提高实际 GDP（并减少失业），（最初）对实际利率没有任何影响。只有当实际 GDP 超过 $\overline{(y_1)}$ 后，利率才会上升。

The IS-LM Model: a third and final special case

货币主义经济学家（如米尔顿·弗里德曼）拒绝凯恩斯关于“流动性偏好”的观点。根据货币主义经济学家，因为金融市场运作高效且没有显著的交易成本，理性的投机者没有理由持有大量货币余额。在他们看来，持有现金的机会成本很高，这就促使理性的金融投资者持有资产，而不是货币。L2=0, LM 曲线垂直向上， $p^*y = Y = M^s/v$

The IS-LM Model: the monetarist version – Phillips-curve

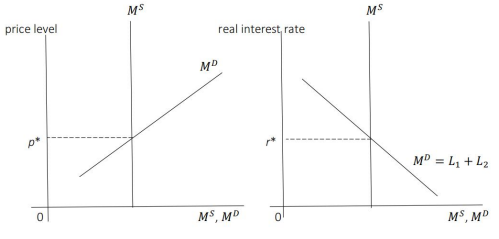


考虑货币主义版本的 IS-LM 模型中财政刺激的宏观效果。与以前一样，由于公共投资的增加，向下倾斜的 IS 曲线将向右移动。然而，垂直的 LM 曲线不会移动。因此，经济将从旧均衡 A 转移到新均衡 B：实际 GDP 保持不变，但利率上升。利率的上升压低了私人支出——公共支出完全挤出了私人需求。在货币主义的 IS-LM 模型中，财政刺激是无效的。

下半部分显示了（名义）GDP 与物价水平 ppp 之间的关系：这是实践。由于 $\overline{M^s}$ 的增加，名义 GDP 从 YOY_0YO 增加到 YIY_1YI 。实际经济活动增加，失业率下降，工资和物价将开始上涨。根据我们对（名义）经济活动和通货膨胀之间经验关系（菲利普斯曲线）的了解，我们知道物价水平从 pOp_0p_0 上升到 pIp_1p_1 。最初，随着 GDP（和货币供应）的增加，物价水平的上升幅度小于比例。这意味着随着名义 GDP 从 YOY_0YO 增加到 YIY_1YI ，名义收入增长部分是由于（a）实际 GDP 增长和（b）通货膨胀。货币刺激（提高 M^s ）可能在短期内提高实际 GDP 和通货膨胀，但随着时间的推移（从长远来看）， M^s 的增加只会专门提高物价水平——实际 GDP 将保持停滞。因此，货币刺激不能在长期内提高实际 GDP，但会在长期内引发通货膨胀。

Week 7: EXOGENOUS MONEY versus ENDOGENOUS MONEY

“exogenous money” view



The money market in the neoclassical model The money market in the IS-LM model

Note that $(\frac{1}{p})$ is the money multiplier. The demand for currency (cash held in our wallets) is assumed to be constant (or stable). From the point of view of a central bank and assuming that commercial banks are fully loaned-up, money supply can be seen as a function of the cash-
缺点：not stable or predictable

“endogenous money” view

Money supply determined by whatever is the demand for money, and cannot be directly and predictably determined by central banks. Central banks can at best influence M^s indirectly, by using the interest rate as the instrument of monetary policy, but this influence is neither straightforward nor predictable. The “endogenous money” view is consistent with the Keynesian macro-model. 图像就是 ISLM 图像没有 MS 的样子

commercial banks have the ability to create money ex-nihilo, without having received money deposited in their accounts.

assets = ‘active’		liabilities = ‘passive’	
cash reserves = €100 m		deposits	= €1000 + 100 m
loans = €1200 + 100 m		inter – bank loans	= €200 m
govt. bonds = €200 m		equity	= €300 m
total = €1600 m		total	= €1600 m

这里可以先有 loans 再加到 liability 上面但是外源的不行，而对 liquidity short 就卖 government bonds 或者去其他银行借钱

Week 8: THE ECONOMICS OF GLOBAL WARMING

Climate-change economics uses the theories and tools of economics and mathematical modeling to analyse efficient and inefficient approaches to slowing global warming. The Intergovernmental Panel on Climate Change (IPCC) uses the outcomes of various economy climate impact Assessment Models (IAMs) which have been built by economists in the past 30 years or so. The most widely used IAM is the Dynamic Integrated model of Climate and the Economy (DICE), a neoclassical model of economic growth and climate change developed by William Nordhaus. Nordhaus received the 2018 Nobel Memorial Prize in Economic Sciences “for integrating climate change into long-run macroeconomic analysis.” 诺德豪斯的模型是一个动态优化模型，其中一个全能且全知的全球社会规划者代表世界人口的所有成员选择最优的、效用最大化的储蓄倾向——问题在于，我们“今天”消费得越多，储蓄和投资于未来增长的就越少，这意味着未来的消费会更少。这种“今天消费”与“明天消费”之间的权衡是错误且虚假的，因为它基于可贷资金市场的谬误，即银行只有先为负债储蓄或可贷资金才能进行投资贷款。在第七周我们学到了银行是货币创造机构——投资并不受事前储蓄不足的限制，而是通过乘数效应事后产生必要的储蓄。我们通过假设一个固定的平均储蓄倾向来简化 DICE 模型，并将模型转变为一个模拟模型（而不是优化模型）。

Neoclassical model of (long-run) economic growth
constant-returns-to-scale Cobb-Douglas production function for global output or world real GDP:

$$(1) \quad y_t = a \times L_t^{(1-\alpha)} \times K_t^{(\alpha)}$$

瞬时增长率:

$$(2) \quad g_Y = g_a + (1 - \alpha) \times g_L + \alpha \times g_K$$

where $g_Y = \dot{Y} = \frac{dY}{Y}$ is the annual growth rate of real-world GDP; g_K is the annual growth rate of the global capital stock; g_a is the annual growth rate of the global labour force; and the growth of the constant term $g_L = \hat{a} = \frac{da}{a}$ = total factor productivity growth. In neoclassical economic thinking, g_a is interpreted as a measure of exogenous (neutral disembodied) technological progress. In the neoclassical model, the macro-economy works at full

global real income growth depends on (i) ‘demography’ (i.e. exogenous g_L), (ii) technological progress (i.e. exogenous TFP growth or g_a), and (iii) endogenous capital accumulation, or the growth of the capital stock g_K .

depreciation 记作字母 (4) $K_{t+1} = (1 - \delta) \times K_t + i_t$

$$(5) \quad K_{t+1} = K_t - \delta \times K_t + i_t \rightarrow$$

$$K_{t+1} - K_t = \Delta K = i_t - \delta \times K_t \rightarrow g_K = \frac{\Delta K}{K_t} = \frac{i_t}{K_t} - \delta$$

世界资本存量的增长是全球实际投资的函数，如公式(5)所示。在新古典理论中，实际投资由可贷资金市场中的实际储蓄融资。可贷资金市场是一个完全运作（竞争）市场，通过实际利率的调整实现市场出清。如果实际储蓄（=可贷资金的供给）超过实际投资（=可贷资金的需求），实际利率将下降——投资将增加（因为借贷变得更便宜），直到储蓄等于投资。如果我们假设存在这样一个完美运作的可贷资金市场，我们可以立即得出最终结果：当实际储蓄超过实际投资时，实际利率下降，导致投资增加，直到储蓄等于投资。反之，当实际投资超过实际储蓄时，实际利率上升，导致储蓄增加，投资减少，直到投资等于储蓄。这种均衡机制表明，在一个理想的可贷资金市场中，实际储蓄和实际投资通过实际利率的调整实现市场出清，从而使资本存量的增长可以稳定在一个均衡水平。

$$(6) \quad s_t = \sigma \times y_t = i_t$$

We assume that real savings are a fixed proportion σ of real income; and that all savings are channelled – through the market for loanable funds – into investment. This means, in turn, that we can forget about investment, since savings are all that matter for the rate of growth of the global capital stock g_K :

$$(7) \quad g_K = \sigma \times \kappa - \delta$$

where κ = the output-capital ratio $\frac{Y_t}{K_t}$, which we assume to be constant (in the long-run steady state). Using (3) and (7), we can derive the following equation for the growth rate of real global GDP:

$$(8) \quad g_Y = g_a + (1 - \alpha) \times \overline{g_L} + \alpha \times (\sigma \times \kappa - \delta)$$

The discount rate for which the NPV = 0, is called the internal rate of return (irr) of the project. We can calculate the irr. It follows that if our chosen discount rate $\delta > irr \rightarrow NPV < 0$; if we select $\delta < irr \rightarrow NPV > 0$; and if we choose $\delta \rightarrow NPV = 0$.

discount factor

$\frac{1}{(1+\delta)^n}$, where delta is social discount rate and n is the years

social cost of carbon (SCC)

The present value of the future global warming damage in year t per tonne of CO₂eq emissions in year t.GHG
1 GtCO₂e = 10⁹ tCO₂e

碳库兹涅茨曲线（CKC）是一种用于描述碳排放与人均实际GDP之间关系的模型。具体而言，它基于以下二次关系：

$$\ln(cop) = \beta_0 + \beta_1 \ln y + \beta_2 (\ln y)^2$$

其中，cop 表示人均二氧化碳排放，y 表示人均实际GDP。

碳库兹涅茨曲线的形状

CKC 的形状为倒 U 形。其表示如下阶段：

- 低收入水平**：在低人均收入水平时，人均碳排放较低。这种情况通常出现在低收入国家，平均消费水平低，制造业规模小。
- 中等收入水平**：在人均收入较高时，人均碳排放增加。这种情况通常出现在新兴工业化国家，如中国，此时生活水平提高，碳密度增加，工业化进程加快。
- 高收入水平**：在人均收入最高时（如OECD国家），人均碳排放开始下降。

经济增长和碳排放之间存在一种复杂的关系。在经济发展的不同阶段，碳排放和经济增长之间可能会出现相对脱钩或绝对脱钩。相对脱钩意味着经济增长与碳排放增长同步，但碳排放增长速度较慢；绝对脱钩则意味着经济增长的同时，碳排放量下降。然而，必须注意人口增长对总碳排放的影响，即使人均碳排放下降，总碳排放量仍可能增加。

Week 6: Input-Output Model, IOM

输入-输出模型（Input-Output Model, IOM）由瓦西里·里昂季夫（Wassily Leontief）在 1940 年代开发，主要用于研究经济活动中各产业之间的关系。

输入-输出表

输入-输出表格记录了经济中不同产业之间的商品和服务流动。以假设的2产业（农业和制造业）模型为例：

	农业	制造业	最终需求	总需求
农业	8	5	3	16
制造业	4	2	6	12
增加值	4	5		
总产出	16	12		

公式推导

从上述表格，可以推导出以下公式：

$$\mathbf{x} = \mathbf{Zi} + \mathbf{y}$$

其中， \mathbf{x} 是产业总产出向量， \mathbf{Z} 是中间投入输出矩阵， \mathbf{i} 是一个元素全为1的向量， \mathbf{y} 是最终需求向量。

具体计算如下：

$$\mathbf{Z} = \begin{bmatrix} 8 & 5 \\ 4 & 2 \end{bmatrix}, \quad \mathbf{i} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}, \quad \mathbf{y} = \begin{bmatrix} 3 \\ 6 \end{bmatrix}$$

$$\mathbf{x} = \mathbf{Zi} + \mathbf{y} = \begin{bmatrix} 8 & 5 \\ 4 & 2 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} + \begin{bmatrix} 3 \\ 6 \end{bmatrix} = \begin{bmatrix} 16 \\ 12 \end{bmatrix}$$

计算技术系数矩阵 \mathbf{A} ：

$$\mathbf{A} = \mathbf{Z}\mathbf{x}^{-1} = \begin{bmatrix} 8 & 5 \\ 4 & 2 \end{bmatrix} \begin{bmatrix} \frac{1}{16} & 0 \\ 0 & \frac{1}{12} \end{bmatrix} = \begin{bmatrix} 0.50 & 0.42 \\ 0.25 & 0.17 \end{bmatrix}$$

3. 数学推导

求解模型

输入-输出模型的核心方程为：

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y}$$

通过矩阵运算，可以得到：

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$$

其中， \mathbf{I} 是单位矩阵， $(\mathbf{I} - \mathbf{A})^{-1}$ 称为里昂季夫逆矩阵（Leontief inverse）。

计算里昂季夫逆矩阵：

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} - \begin{bmatrix} 0.50 & 0.42 \\ 0.25 & 0.17 \end{bmatrix} = \begin{bmatrix} 0.50 & -0.42 \\ -0.25 & 0.83 \end{bmatrix}^{-1} = \begin{bmatrix} 2.68 & 1.35 \\ 0.81 & 1.61 \end{bmatrix}$$

最终得到：

$$\mathbf{x} = \mathbf{L}\mathbf{y} = \begin{bmatrix} 2.68 & 1.35 \\ 0.81 & 1.61 \end{bmatrix} \begin{bmatrix} 3 \\ 6 \end{bmatrix} = \begin{bmatrix} 16 \\ 12 \end{bmatrix}$$

Backward production linkages

4. 关联和乘数效应

向后生产关联

向后生产关联是指某一产业的最终需求变化对整个经济系统中总产出的影响。可以通过里昂季夫逆矩阵的列和来计算：

$$\text{农业的向后生产关联} = \sum_i L_{i1} = 2.68 + 0.81 = 3.49$$

$$\text{制造业的向后生产关联} = \sum_i L_{i2} = 1.35 + 1.61 = 2.96$$

5. 应用示例

东亚和太平洋地区的生产关联

1975年东亚和太平洋地区的生产关联研究显示，不同国家和地区间的产业关联和乘数效应：

	国内	国外	总计
印度尼西亚	2.29	1.55	3.84
马来西亚	2.22	1.87	4.09
泰国	2.23	1.69	3.92
韩国	3.10	2.17	5.27
日本	3.06	2.98	6.04
美国	2.19	2.14	4.33

6. 扩展应用

附加值乘数

附加值乘数反映某一产业的最终需求变化对总附加值的影响。

$$\mathbf{VA} = \mathbf{va} \times \mathbf{L} = \begin{bmatrix} 0.25 & 0.42 \end{bmatrix} \times \begin{bmatrix} 2.68 & 1.35 \\ 0.81 & 1.61 \end{bmatrix} = \begin{bmatrix} 1 & 1 \end{bmatrix}$$

就业乘数

就业乘数反映某一产业的最终需求变化对总就业的影响。

$$\mathbf{E} = \mathbf{e} \times \mathbf{L} = \begin{bmatrix} 0.75 & 0.25 \end{bmatrix} \times \begin{bmatrix} 2.68 & 1.35 \\ 0.81 & 1.61 \end{bmatrix} = \begin{bmatrix} 2.21 & 1.42 \end{bmatrix}$$

环境扩展输入-输出分析

环境扩展输入-输出分析用于评估经济活动对环境的影响，例如碳足迹。

$$\mathbf{F} = \mathbf{f} \times \mathbf{L} = \begin{bmatrix} 0.50 & 0.83 \end{bmatrix} \times \begin{bmatrix} 2.68 & 1.35 \\ 0.81 & 1.61 \end{bmatrix} = \begin{bmatrix} 2.0 & 2.0 \end{bmatrix}$$

7. 德国的实例分析

2015年德国的输入-输出表

以2015年德国的输入-输出表为例，展示了各产业的附加值强度、就业强度和温室气体强度。通过计算各产业的技术系数矩阵和里昂季夫逆矩阵，可以分析各产业之间的关联和乘数效应。

德国各产业就业强度 (I) 和温室气体强度 (F) 计算

假设我们有以下数据：

产业	总产出 (百万欧元)	就业人数 (千人)	温室气体排放量 (万吨)
农业	1600	17632	1492
矿业	1600	11376	625.8
制造业	1600	6912	94.3
电力、煤气和水供应	1600	4864	1926.4
建筑业	1600	15824	40.3
批发、零售和交通运输	1600	15728	135.2
信息和其他商业服务	1600	4768	10.6
金融、保险和房地产 (FIRE)	1600	3600	4.4
公共管理	1600	5840	8.3
其他服务 (教育、卫生、艺术和娱乐等)	1600	30432	28.4

我们可以计算出各产业的就业强度和温室气体强度：

$$I_{\text{农业}} = \frac{17632 \text{ 千人}}{1600 \text{ 百万欧元}} = 11.02 \text{ 人/百万欧元}$$

$$I_{\text{制造业}} = \frac{6912 \text{ 千人}}{1600 \text{ 百万欧元}} = 4.32 \text{ 人/百万欧元}$$

$$f_{\text{农业}} = \frac{1492 \text{ 万吨}}{1600 \text{ 百万欧元}} = 0.93375 \text{ 万吨/百万欧元}$$

$$f_{\text{制造业}} = \frac{94.3 \text{ 万吨}}{1600 \text{ 百万欧元}} = 0.0589375 \text{ 万吨/百万欧元}$$