Environmental Economics

Prof. Philippe Thalmann

EPFL ENAC LEUrE

ENV-471

Master semester 2 or 4

The importance of interest rates

High interest rates, which drive up the cost of borrowing money, have an outsize effect on renewable energy projects. That's because the cost of building and operating a renewable energy generator like a wind farm is highly concentrated in its construction, as opposed to operations, thanks to the fact that it doesn't have to pay for fuel in the same way that a natural gas or coal-fired power plant does. This leaves developers highly exposed to the cost of borrowing money, which is directly tied to interest rates. "Our fuel is free, we say, but our fuel is really the cost of capital because we put so much capital out upfront," Orsted America's chief executive David Hardy said in June.

Matthew Zeitlin, Heatmap, 18 September 2024

Philippe Thalmann

Investment choice

INTRODUCTION TO FINANCIAL CALCULUS

Outline

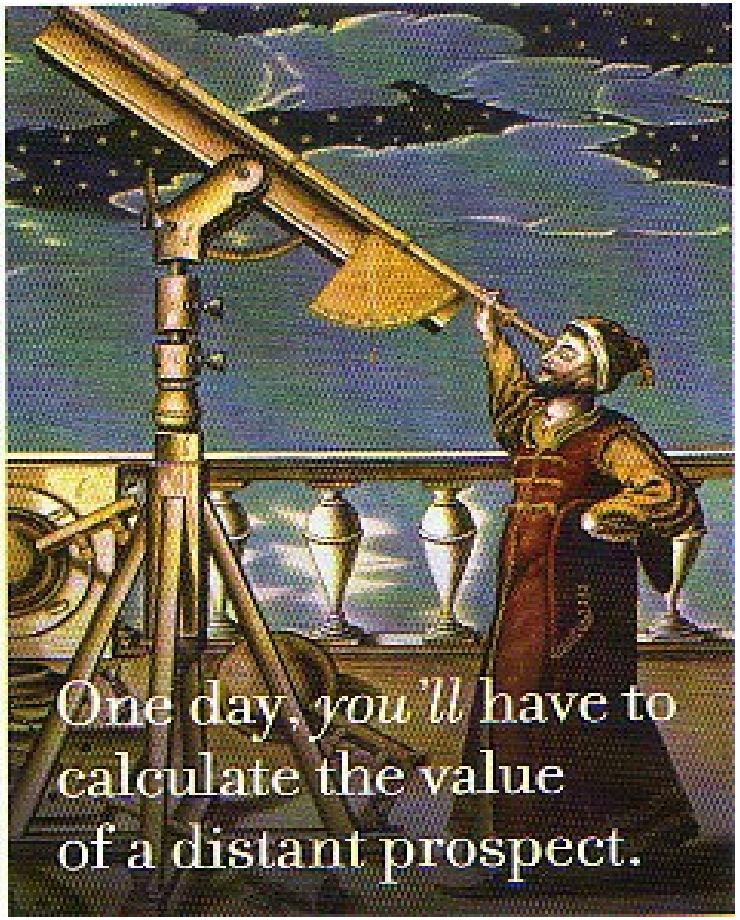
- Cost and benefits spread over time → intertemporal arbitrage
- Rate of return and discount rate
- Flows of ‘payments’
- Choosing the right discount rate
- Determinants of discount rate
- Useful for capital assessment, project evaluation…

EPFL

Philippe Thalmann

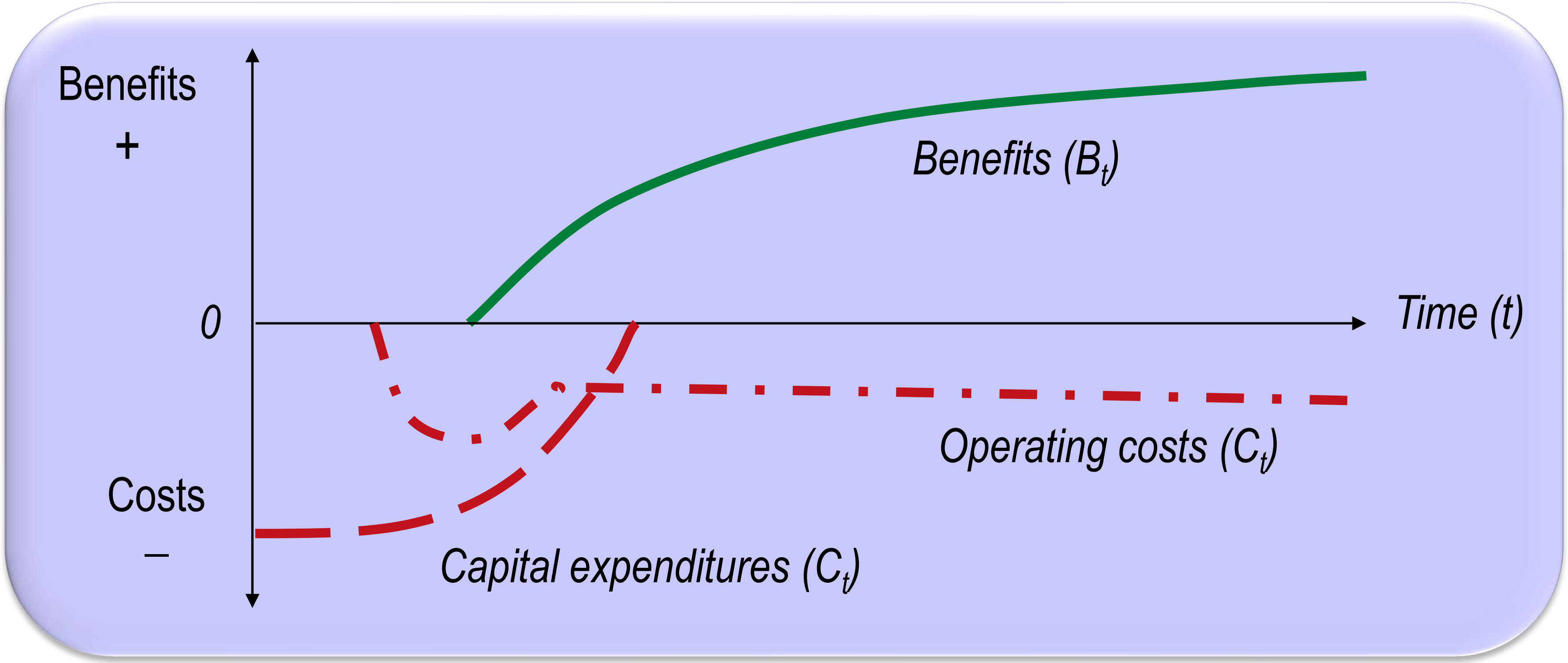
LEURE

INTERTEMPORAL ARBITRAGE



Source : Advertisement Campaign of the University of Chicago School of Business (2008)

Costs and benefits do not all occur simultaneously



What we need: A procedure for comparing benefits and costs that arise at any given time

Time preference

A bird in hand is worth two in the bush.
Mas vale pajaro en mano que cien volando.
Un tiens vaut mieux que deux tu l'auras.
عصفور فى اليد خير من عشرة على الشجرة

- Observation and folk wisdom: **we prefer good things now, bad things later**
- Earlier returns on investments are preferred over later returns
- Paying costs later is preferred to paying them earlier
- Possible **equivalence** between a sum S_0 now and a **larger** sum S_t in t years
- Examples:
  - We are willing to renounce an income B_t in t years for a smaller income B_0 now
  - We accept to wait t years for an income B_t if it is sufficiently larger than the income B_0 we would get now
  - We accept to pay a bill now rather than in t years when it is sufficiently smaller
  - We accept to pay more if we can pay later

Basic arbitrage (equivalence)

Philippe Thalmann

- Suppose that you put CHF 100 on January 1st into a bank account that entails no risk and pays a rate of interest of 2% on the balance on December 31st, and suppose that you do not add or withdraw anything from this account
- After one year, the balance of your account is CHF 100 + 100×2% = 100×(1+0.02) = CHF 102
- This investment option creates an equivalence between receiving CHF 100 on January 1st and receiving CHF 102 one year later
- This investment option creates an equivalence between paying CHF 100 on January 1st and paying CHF 102 one year later

Compounding

- Consider what happens with the bank account over the years
- After two years, the balance is CHF 102 + 102×2% = 102×(1+0.02) = [100×(1+0.02)]×(1+0.02) = 100×$(1+0.02)^2$ = CHF 104.04
- After three years: 100×$(1+0.02)^3$ = CHF 106.12
- After ten years: 100×$(1+0.02)^{10}$ = CHF 121.90
- Note the difference between 121.90 and 100 + 10×(100×2%): **compound interest**
- After t years: 100×$(1+0.02)^t$
- More generally: $S_t = S_0 \times (1+i)^t$
- This calculation is referred to as **compounding to future values**, because the result indicates to what CHF 1 today will have grown in the future

Future and present value

- $S_t = S_0 \times (1+i)^t$ is the **future value** of S_0 after t years with compound interest i
- It answers the question: how much will I have in t years if I invest S_0 at rate i?
- Inverse question: how much do I need to invest today at rate i if I want to have S_t in t years (e.g., to pay a future bill)?
- Answer: $S_0 = S_t/(1+i)^t$
- $S_0 = S_t/(1+i)^t$ is the **present value** of S_t in t years at rate of interest i

Broader arbitrage

- If a sum S_0 can be invested at a yearly rate of interest i, it compounds to the future value of $S_t = S_0 \times (1+i)^t$ after t years
- For somebody who has access to this investment option, S_0 now and S_t in t years are equivalent
- This is only true from a purely financial perspective
- There may be other elements considered when comparing S_0 and S_t
- These could be represented by a **required rate of interest** i_r
- For somebody whose required rate of interest is i_r, S_0 now and $S_t = S_0 \times (1+i_r)^t$ in t years are equivalent
- For somebody whose required rate of interest is i_r, $S_0 = S_t/(1+i_r)^t$ now and S_t in t years are equivalent

Philippe Thalmann

LEURE

Philippe Thalmann

(INTERNAL) RATE OF RETURN

Rate of return and interest rate

- **Investment**: a sum of money given up for some productive use for a period that can be short or long; a kind of ‘sacrifice’
- **Rate of return**: % increase in invested sum over 1 year derived from the investment
- **Interest rate**: rate of return promised for an investment
- **Required rate of return** (or of interest): rate of return expected from the investment in compensation for the ‘sacrifice’
- **Compound interest**: when the increment corresponding to the rate of return remains invested, this is the same as an increased investment that can potentially generate additional return

Example 1: start-up, one year

- Sum of 100 was invested in a start-up on January 1st, 2019; it was used to pay for equipment, room rent, salaries and consumables during the year
- On December 31st, 2019, the start-up was sold for 130
- What was the rate of return on this investment?

Example 2a: start-up, two years

- Sum of **200** was invested in a start-up on January 1st, 2019; it was used to pay for equipment, room rent, salaries and consumables for **two years**
- On December 31st, **2020**, the start-up was sold for 260
- What was the rate of return on this investment?

Example 2a (answered)

- 200 → 260 over two years, so total rate of return of 30%
- What is the equivalent <u>yearly</u> rate of return?
- Assumption:

  $$200 \rightarrow 200\times(1+r) \rightarrow [200\times(1+r)]\times(1+r) = 260$$

- Hence:

  $$200\times(1+r)^2 = 260 \Rightarrow r = (260/200)^{1/2} - 1 = 14.0\%$$

- This is also called the **internal rate of return (IRR)**

Arbitrage between investments

- Investment in previous example yielded an average rate of return of 14% over two years
- Was it a good investment?
- Not if a comparable investment yielded a higher rate of return
- Arbitrage amounts to comparing alternative investment opportunities and selecting the one for which the highest rate of return is expected
- For some types of investment (bank accounts, bonds and other fixed-rate credits), the expected return is set in the terms of the contract: interest rate
- Only invest when the expected return exceeds the interest rate on a comparable investment

Example 2b

- Investor **expects** that with his investment of 200 in the start-up he will get 260 back after 2 years
- Alternatively, he could invest his money at an interest rate of 10% per year
- Should he put his stake into the start-up?

Example 2b (answered)

- Investor **expects** that with his investment of 200 in the start-up he will get 260 back after 2 years
- Alternatively, he could invest his money at an interest rate of 10% per year
- Should he put his stake into the start-up?
- With alternative investment, his stake becomes:

$$200 \rightarrow 200 \times (1+10\%)^2 = 242$$

- The start-up is the better investment

Example 3a

- You are given the choice between receiving 200 today and 250 in two years: which do you choose?

Example 3a (answered)

- You are given the choice between receiving 200 today and 250 in two years: which do you choose?
- It depends on what you can do with the 200 received today:
  - If the best alternative investment is the one with 10% interest, 200 becomes 242, so wait for 250
  - If investment in start-up is possible, that transforms 200 into 260, so take the 200 now
- IRR for 200 $\rightarrow$ 250 in 2 years is given by $200\times(1+IRR)^2 = 250$, hence $IRR = (250/200)^{1/2} - 1 = 11.8\%$
- Compare IRRs
- What if you need the money now?

Example 3b

- You are given the choice between receiving 250 in two years and receiving a smaller sum today already: what is the sum you would accept today?
- Assumption: you can invest at 10%

Example 3b (answered)

- You are given the choice between receiving 250 in two years and receiving a smaller sum today already: what is the sum you would accept today?
- Assumption: you can invest at 10%
- The answer is a <u>minimum</u> sum (WTA) equivalent to 250 in 2 years
- A sum S_0 such that $S_0 \times (1+10\%)^2 = 250$
- $S_0 = 250 / (1+10\%)^2 = 206.61$

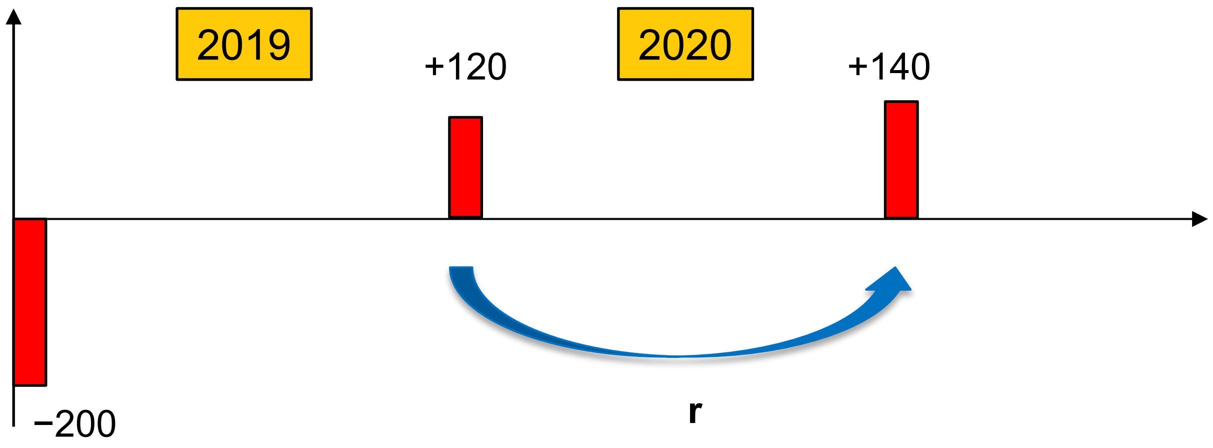
Philippe Thalmann

FLOWS OF PAYMENTS

Example 2c

- A sole investor invests **200** in a start-up on January 1st, 2019; the start-up uses it to pay for equipment, room rent, salaries and consumables for **two years**
- On December 31st, **2019**, the investor sells half of the shares of the start-up for **120**
- On December 31st, **2020**, he sells the other half of the shares for **140**
- What is the rate of return on this investment?

Example 2c (answered)



- The fact that the payments rewarding the investment are not concentrated at the end of the investment complicates the analysis
- What is the advantage of earning 120 already after one year?
- Arbitrage defining IRR: $200 \times (1+r)^2 = 120 \times (1+r) + 140 \rightarrow r = 18.9\%$
- *When 260 were concentrated at end:* $200 \times (1+r)^2 = 260 \rightarrow r = 14.0\%$

Example 3c

- You are given the choice between (a) receiving 120 in one year and 130 in two years, and (b) receiving a smaller sum today already: what is the sum you would accept today?
- Assumption: you can invest at 10%

Example 3c (answered)

- You are given the choice between (a) receiving 120 in one year and 130 in two years, and (b) receiving a smaller sum today already: what is the sum you would accept today?
- Assumption: you can invest at 10%
- Comparison at the end of investment period:
$S_0 \times (1+10\%)^2 = 120 \times (1+10\%) + 130$
- Hence: $S_0 = \frac{120}{1+10\%} + \frac{130}{(1+10\%)^2} = 216.53$
- In comparison: $250 / (1+10\%)^2 = 206.61$
- S_0 is the **present value of the flow of future payments**

Discounted cash flow

- A flow of payments, positive or negative, can be summarized as an **equivalent present value** by discounting all payments for the number of years until they occur:

$$S_0 = \frac{P_1}{1+r} + \frac{P_2}{(1+r)^2} + \cdots + \frac{P_n}{(1+r)^n} = \sum_{t=1}^{n} \frac{P_t}{(1+r)^t}$$

- This sum is commonly called '**discounted cash flow**' (DCF)
- Paying S_0 for the right to this cash flow implies a rate of return of r over n years…

Estimating a stock of capital (1)

A common approach to estimating the stock of capital assumes that it will generate incomes for a given number (n) of years:

$$\mathbf{K_0 \rightarrow R_1, R_2, R_3, \ldots, R_n}$$

The owner of this capital could sell it at price K_0 and invest the proceeds for an interest rate equal to r

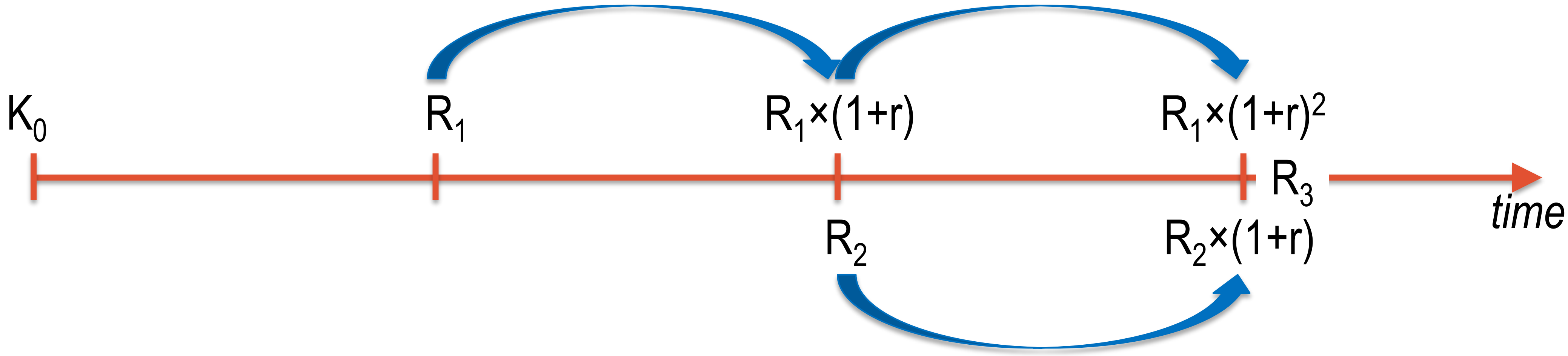
If she chose to sell, she would have $\mathbf{(1+r)^n K_0}$ in n years

What if she chooses not to sell?

Estimating a stock of capital (2)

If the owner keeps her capital and uses it to generate the flow of income R, this is what she has after n years (observing that incomes also grow at the rate of return when in possession of the owner) :

$$(1+r)^{n-1}R_1+(1+r)^{n-2}R_2+(1+r)^{n-3}R_3+\ldots+(1+r)R_{n-1}+R_n$$



Estimating a stock of capital (3)

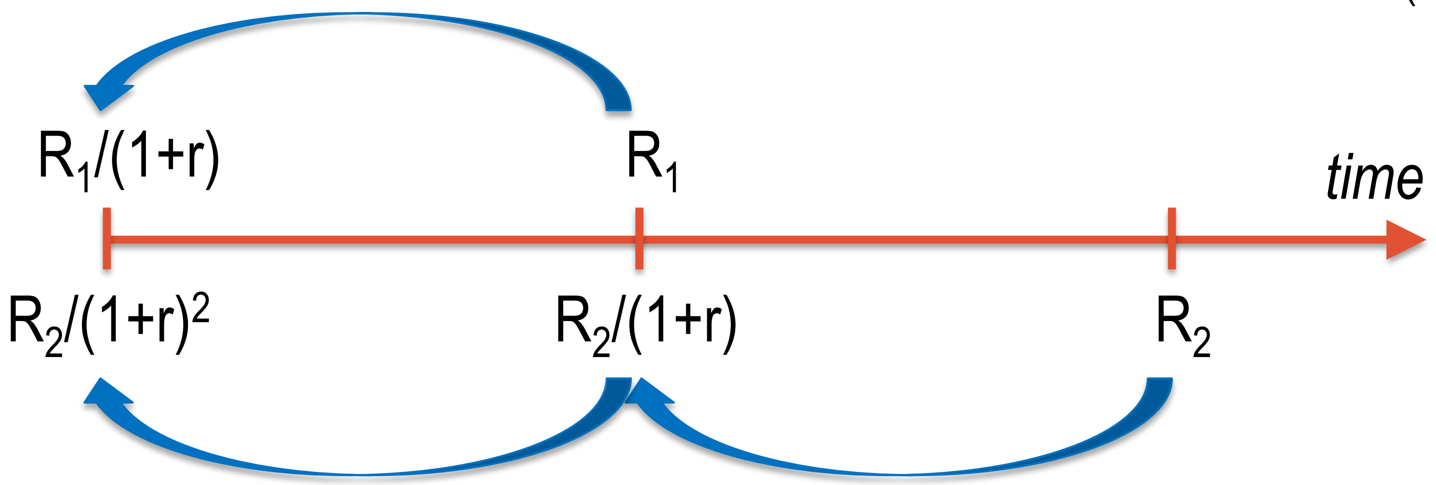
The equivalence between the capital owner's two options determines the value of her capital:

$$(1+r)^n K_0 = (1+r)^{n-1} R_1 + (1+r)^{n-2} R_2 + (1+r)^{n-3} R_3 + \ldots + (1+r) R_{n-1} + R_n$$

$$K_0 = \frac{R_1}{1+r} + \frac{R_2}{(1+r)^2} + \frac{R_3}{(1+r)^3} + \ldots + \frac{R_n}{(1+r)^n}$$

The further in the future, the less important:

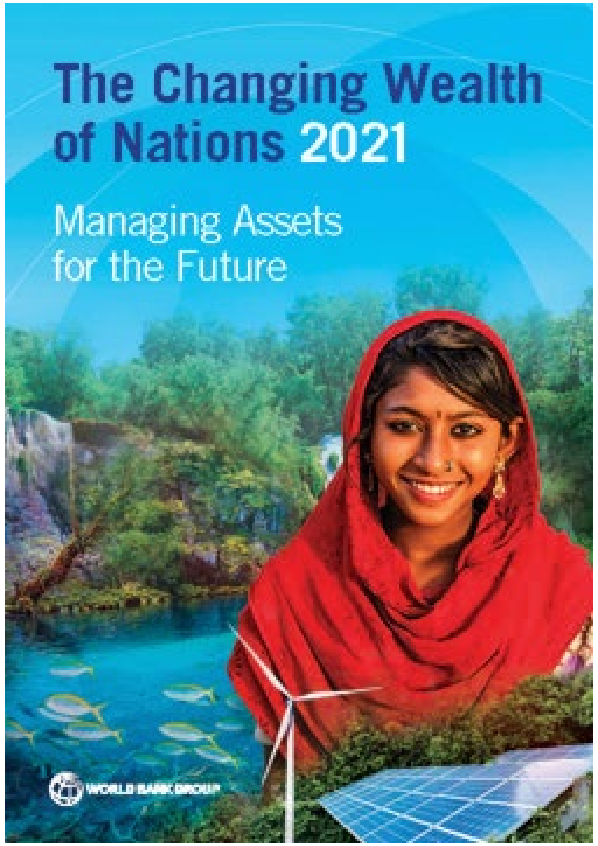
$$\frac{1}{(1+0.05)^{25}} = \frac{1}{3.4} \qquad \frac{1}{(1+0.08)^{50}} = \frac{1}{47}$$



EPFL
Philippe Thalmann
LEURE

Estimating a stock of capital (4)

- This is how natural capital and human capital are estimated by the World Bank for its ‘Wealth of Nations’ reports
- For natural capital, the future rents (world sales price − extraction costs) from fossil energy reserves, metals and minerals, agricultural areas, forests, mangroves and protected land areas (providing ecosystem services and generating tourism income), and fisheries are discounted at a rate of 4%; for renewable resources, rents are capped at 100 years; for non-renewable resources, the lifetime is based on reserves and extraction paths
- For human capital, expected future labor incomes that could be generated over the lifetime of all women and men currently living in a country are discounted at 4%; this prediction includes the effects of training and life expectancy



THE IMPORTANCE OF THE DISCOUNT RATE

Example

- What is the present value of 1000 in 20 years when discounting at 0%, 5%, 10%?

Example (answered)

- What is the present value of 1000 in 20 years when discounting at 0%, 5%, 10%?
- $1000 / (1+0\%)^{20} = 1000$
- $1000 / (1+5\%)^{20} = 377$
- $1000 / (1+10\%)^{20} = 149$
- This is the mirror effect of compound interest

Discounting can be cruel for future generations

Climate change mitigation involves taking costly measures now to reduce impacts spread over decades, due to the long residence time in the atmosphere of CO_2 and other GHG

$$\max_{\Delta} \quad -C_{\Delta}(\Delta)+\frac{G_1(\Delta)}{1+r}+\frac{G_2(\Delta)}{(1+r)^2}+\frac{G_3(\Delta)}{(1+r)^3}+\frac{G_4(\Delta)}{(1+r)^4}+\ldots$$

1 million CHF						Damages in 50 years
0%	1%	3%	5%	7%	9%	Discount rate
1 000 000	608 000	228 000	87 000	34 000	13 500	Equivalent present value

Choosing the right discount rate matters

"Policy issues often involve intergenerational trade-offs. One highly publicized and polarizing example concerns the appropriate response to global warming. While Nordhaus (1994) concluded that there was no need to enact draconian policies to reduce CO_2 emissions immediately, Stern (2006) insisted that the situation was in fact dire. The difference in position can be attributed almost exclusively to the rates of time preference assumed by these two authors – Nordhaus used a few percent, based on estimates deriving from private economic behavior, while Stern essentially set it equal to zero, on the basis of a philosophical stance. It then becomes clear that CO_2 emissions should be taken seriously if for some reason private rates of time preference are too high when applied to public decisions, since such decisions should then be made on the basis of a lower rate."

Arthur J. Robson and Balázs Szentes, "A biological theory of social discounting", *American Economic Review* 104(11), Nov. 2014, pp. 3481-97

DETERMINANTS OF DISCOUNT RATES

Example

- How much would I have to return to you in 10 years in exchange of you lending me 1000 francs today?

Philippe Thalmann

Example (answered)

- How much would I have to return to you in 10 years in exchange of you lending me 1000 francs today?
- If you answer 2000 francs, your implicit **required rate of return** is 7.2%

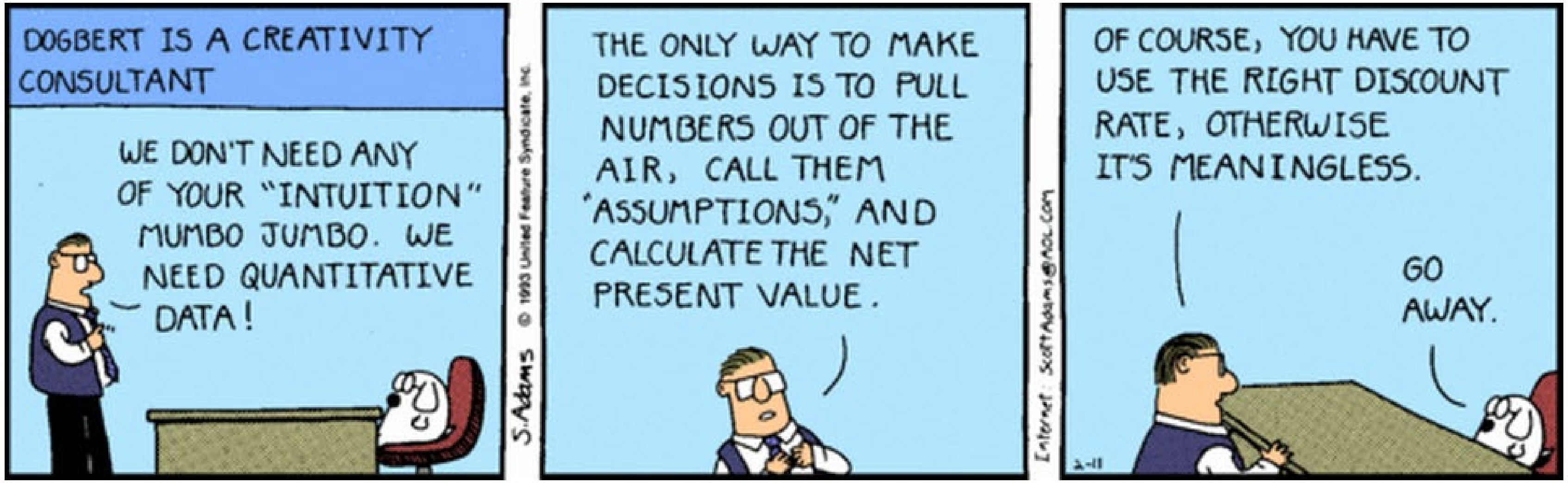
$$1000\times(1+7.2\%)^{10} = 2000$$

$$r = (X/1000)^{1/10} - 1$$

Your answer	Implicit required rate of return
1000	0.0%
1100	1.0%
1200	1.8%
1300	2.7%
1400	3.4%
1500	4.1%
1600	4.8%
1700	5.4%
1800	6.1%
1900	6.6%
2000	7.2%
2100	7.7%
2200	8.2%
2300	8.7%
2400	9.1%
2500	9.6%

Neuroscientists' view on discounting

- Our brain: striatum (instincts) vs cortex (reason)
- The striatum is survival oriented: food, reproduction, power, economy of effort, information
- It rewards us (dopamine) to get more and more of these, faster and faster
- For the striatum alone, grab the present reward, do not wait for tomorrow, even if it could be larger
- The cortex tries to control this, with some success (we see savings and investments)
- Thanks to the inventions of the cortex (innovation and technology), we can get (almost) everything immediately
- We forget the virtues of patience, we become increasingly short-sighted
- Commercial conditioning reinforces this (fast food, same day delivery)



CHOOSING A DISCOUNT RATE (REQUIRED RATE OF RETURN)

The opportunity cost of public investment (1)

- Gross domestic production is used for private consumption (C), private investment (I), government spending and investment (G) and the excess of exports (X) over imports (M)

$$GDP = C + I + G + (X - M)$$

- Under the assumption of full-employment, GDP is essentially given by the size of the working population and its productivity
- Because GDP is given, more public investment G requires a decrease in private consumption C and/or private investment I (*crowding out*)
- Public investment paid for through taxes tends to crowd out C
- Public investment paid for through borrowing tends to crowd out I
- The **opportunity cost of public investment** is equal to the "cost" of less C or less I

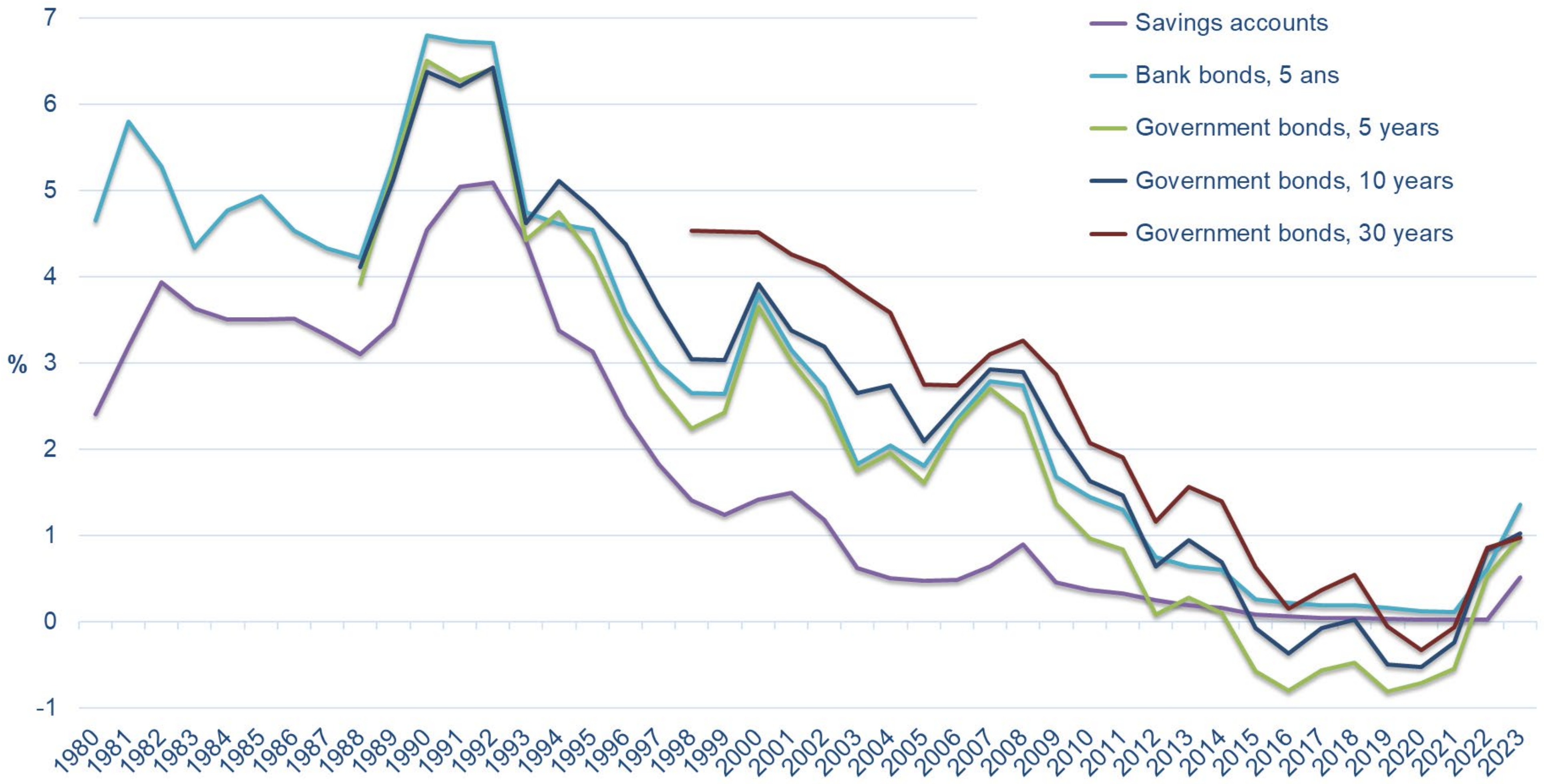
The opportunity cost of public investment (2)

- The "cost" of the decrease in private investment is related to the productivity of marginal private investment, i.e. the rate on return of private investment
- This depends on the level of private investment
- The "cost" of the decrease in private consumption is related to the satisfaction that households derive from their marginal consumption
- This depends on the level of private consumption
- Public investment entails consumption transfers between successive generations, which the current generation may not sufficiently consider
- The opportunity cost of public investment is much smaller in case of under-employment of (human) resources

A pragmatic view

- Weitzman (2001) surveyed 2,160 economists in 48 countries
  - Mean recommended public rate of discount 3.96%, sd = 2.94%
  - Range of variation : −3% to +27%
  - Majority between 1 and 6%
- Drupp, Freeman, Groom & Nesje (2018) surveyed over 200 experts: mean recommended public rate of discount 2.27%, sd = 1.62% (risk free)
- Gollier, van der Ploeg & Zheng (2022) surveyed 948 top-ranked economists in Feb.-March 2021: mean recommended public rate of discount 2.28%, sd = 2.22% (risk free)
- Use a range of rates and analyze the sensitivity
- Use the rate at which the public sector can borrow its funds, with a temporal horizon equal to that of the project

Some possible reference interest rates in Switzerland



Source of data: Swiss National Bank

Conclusions

- Decisions on long-term projects are very sensitive to the chosen discount rate
- A high discount rate gives very little weight to impacts far in the future (i.e., for future generations)
- This can be mitigated by a declining discount rate (rate used for discounting payment P_{t+1} smaller than rate used for discounting P_t)
- No agreement on the appropriate discount rate, particularly for projects affecting future generations
- Referring to market interest rates is complicated by the fact that they vary a lot through time