EPFL

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LEURE

ECOLOGICAL ECONOMICS
Env-610

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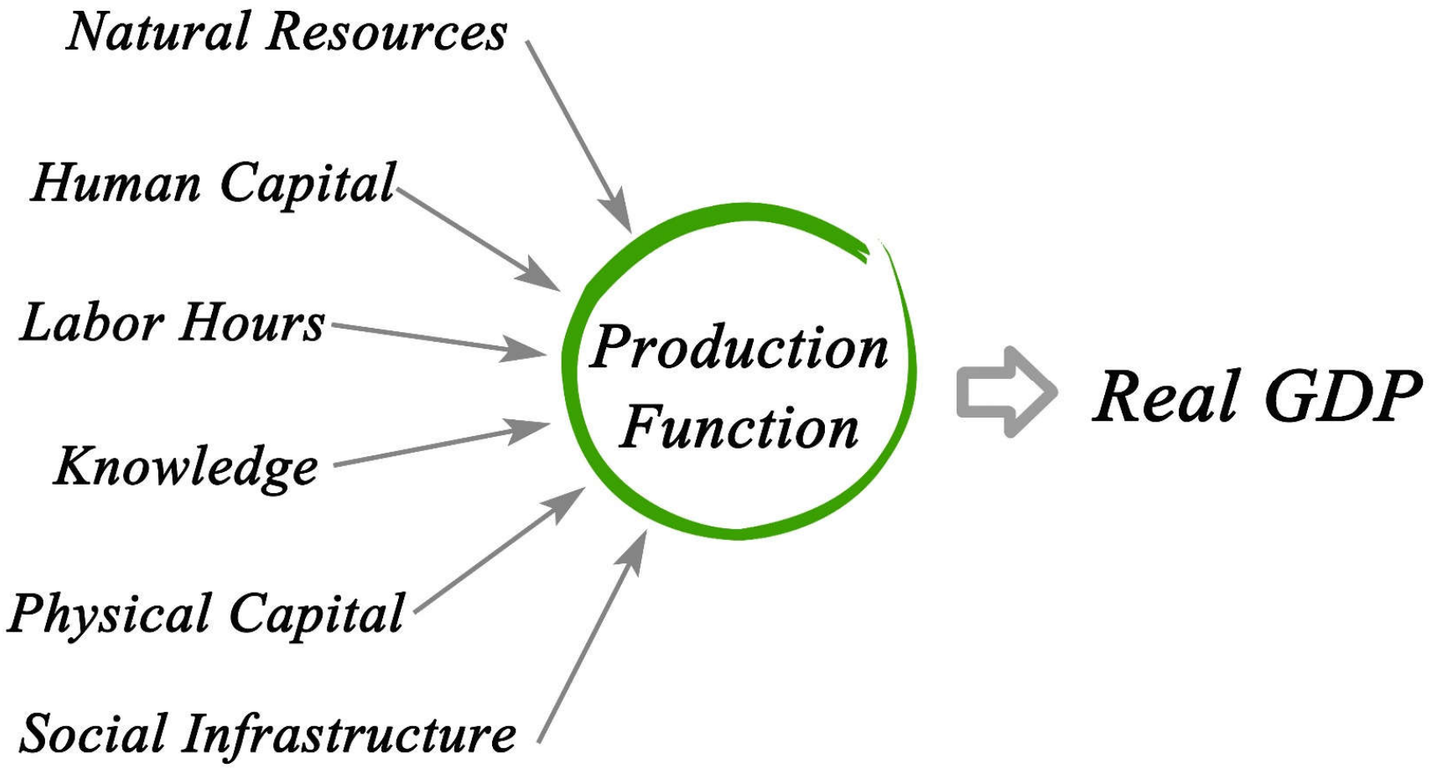
Sustainability

CAPITALS



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5 categories of capital

- **Natural capital** (K_N): natural resources and ambient absorption capacity
- Man-made or **manufactured capital** (K_M): infrastructures, buildings, urbanised soil, machines, tools
- **Human capital** (K_H): manpower with its health, know-how and skills
- **Immaterial capital** (K_I): social capital of individuals, organisational capital of enterprises, institutional capital of societies (legal and financial system)
- **Financial capital** (K_F): receivables against third parties, which can be converted into goods and services

Natural capital

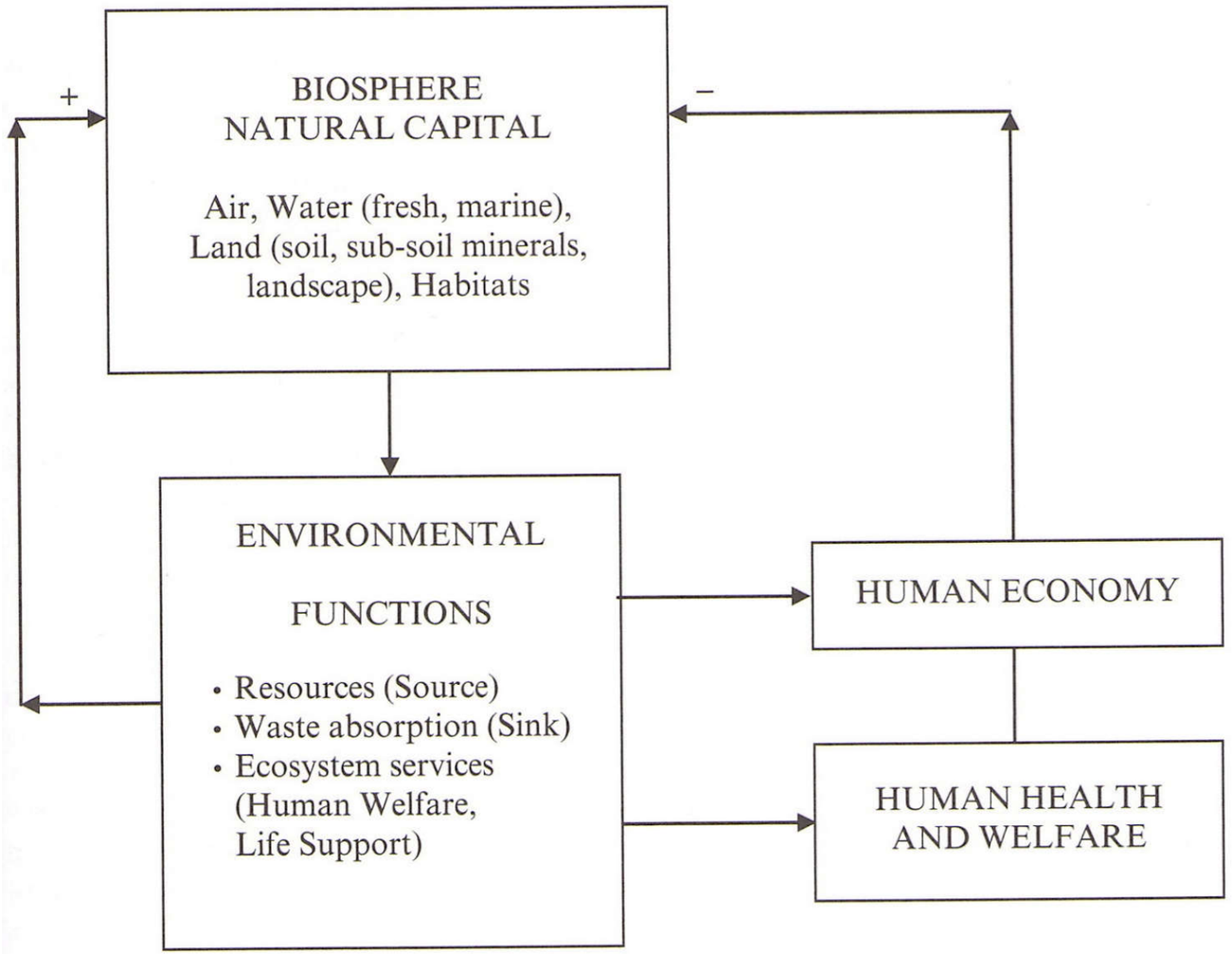


Figure 4.1 The relationship between environmental functions and human benefits

- Environmental functions contribute to human health and welfare directly (e.g. recreation) and to the economy
- Economic activity degrades the biosphere
- Environmental functions are also essential to preserve the biosphere
- These are harder to grasp but no less essential

Etkins, Paul, "Strong sustainability and critical natural capital", Atkinson, G. D., et al., Eds. (2014), Handbook of Sustainable Development. Cheltenham, UK; Northampton, MA, USA, Edward Elgar Publishing

Weak condition for SD (Environmental economics)

- **Weak condition**: $K_G = K_N + K_M + K_H + K_I + K_F$ does not decrease
- $GDP_t = f(K_{Nt}, K_{Mt}, K_{Ht}, K_{It}, K_{Ft}) = f(K_{Nt} + K_{Mt} + K_{Ht} + K_{It} + K_{Ft}) = f(K_{Gt})$
- Substitution possibilities (isoquants)
- NB: nature (K_N) at the sole service of mankind…
- The natural environment can be degraded, provided there is enough accumulation of other capital … assuming that this accumulation is possible in a degraded natural environment

Weak SD condition with growing population

- How much global capital should we bequeath to the next generation?
  - As much as we received from the previous generation (our parents)?
  - More, to account for demographic growth (keep K_G/Population constant)?
  - Enough capital for the next generation to cover its (subsistence) needs?
  - Enough capital for the next generation to live as well as we do?
- Technical progress: $Q_t = A_t \times f(K_{Gt})$ with A growing through time
- What if the next generation poorly uses its K_G?
- Will it leave enough of it for the following generation?

Problems with weak condition for SD

- Some parts of K_N are essential to our survival (e.g. ozone layer)
- Some parts of K_N cannot be replaced by other types of capital (impossible or very expensive substitution)
- Some parts of K_N cannot be restored once destroyed (irreversibility, e. g. extinct species)
- Some parts of K_N, left on their own, can maintain and regenerate themselves (which the other K cannot)
- Many parts of K_N belong to all (non-appropriable, free use), which is not the case for the other K

Strong condition for SD (Ecological economics)

- **Strong condition**: weak condition + K_N does not decrease
- Therefore, substitutability between K_N and other forms of capital is not accepted
- Higher incomes for the next generation do not compensate for an impoverished planet
- Do we not also need a strong condition for other types of capital?
- Substitutability between components of K_N?

Critical components of natural capital

Critical natural capital: NC whose functions are important and irreplaceable, so that it must be preserved

In the logic of the strong condition, critical components of K_N are not substitutable by other ones

Natural capital	Function ("ecosystem service")
Stratospheric ozone layer	Protection against UV radiation
Pollinating insects	Pollination
Mangroves	Coastal protection
An urban forest	Air purification and cooling

"To put it drastically, it would be strange to assume that more man-made capital cannot substitute for a bigger hole in the ozone layer, but an increased number of whales can." (Neumayer, E. (2013). Weak Versus Strong Sustainability - Exploring the Limits of Two Opposing Paradigms. Cheltenham, UK, Northampton, MA, USA. Edward Elgar, p.26)

Implementation of strong condition for SD (1)

Conditions for critical components of K_N:

- The use of renewable resources should not exceed their rates of renewal (maximum sustainable yield)
- Their exploitation must not contribute to the degradation of the environment
- (Waste, pollution) emissions must not exceed the assimilative capacity of the environment, in other words, use the environment as a sink for pollution only to the extent that its natural absorptive capacity does not decrease

"This is what sustainability means. It means eating the fruits without harming the trees, and in fact making the trees more along the way, so that over time everybody will be able to enjoy more fruit." (Yunus, Muhammad (2016) A World of Three Zeroes, The new economics of zero poverty, zero unemployment, and zero carbon emissions, London, U.K.: Scribe Publications, p. 125)

Implementation of strong condition for SD (2)

Conditions for other critical components of K_N:

- Extraction of exhaustible resources must not exceed the discovery of new deposits or the potential to replace them by renewable resources that are functionally equivalent
- Avoid taking risks that could permanently damage the environment (**precautionary principle**)
- Promote technical progress that allows better use of resources rather than one that uses more resources
- Preserve the diversity of species (biodiversity)

Precautionary principle

PRINCIPLE 15

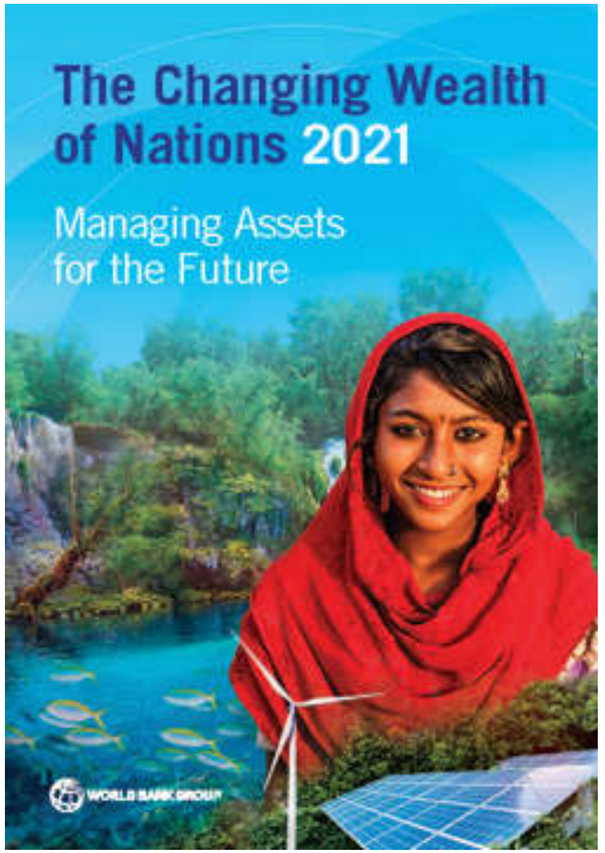
In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation. (The Rio declaration on environment and development, 1992)

- When an activity threatens human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.
- The proponent of such an activity, and not the public, must prove that it is not dangerous.
- The process of the application of the precautionary principle must be open, informed, and democratic, and include all parties likely to be affected.
- This process must involve a review of all of the alternatives, including no action

Wealth accounting by The World Bank

The World Bank is an international financial institution created in 1944 (together with the IMF) to provide loans and grants to the governments of low- and middle-income countries for the purpose of pursuing capital projects for their economic development. The World Bank also collects and processes large amounts of data related to development.

- Estimations for 1995 (World Bank, 1997), 2000 (World Bank, 2006), 2005 (World Bank, 2011), 1995-2014 (World Bank, 2018) and 1995-2018 (World Bank, 2021)
- Every time, the methods are improved
- The aim is to complement the information on GDP by projecting it towards the future
- Uses national accounts data as much as possible



Wealth accounting in 2021

Weak condition: $K_G/Pop = (K_N + K_M + K_H + K_I + K_F)/Pop$ does not decrease

rent = net sales price – extraction or production cost

- K_N: discounted value of natural resource rents
- K_M: permanent inventory
- K_H: discounted value of foreseeable labour incomes of the current working-age population
- K_I : not estimated but present in the interpretation
- K_F: recorded financial assets – financial liabilities
- $K_G = K_N + K_M + K_H + K_F$ (**total wealth**)

DISCOUNTING

Discounting for…

- Calculation of capitals (wealth)
- Decision on mitigation measures that involve long-lived "assets" (could be know-how and skills)
- Cost-benefit analysis when costs and benefits are spread through time

Rate of return and interest rate

- Investment: a sum of money reserved for some productive use for a period of time that can be short or long
- Rate of return: % increase in invested sum over 1 year due to the utilization of this sum
- Interest rate: rate of return promised for an investment
- Compound interest: when the increment corresponding to the rate of return remains invested, this amounts to an increased investment that can potentially generate additional return

Example 1

- 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 2

- 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 during **two years**
- On December 31st, **2020**, the start-up was sold for 260
- What was the rate of return on this investment?

Example 2 (answered)

- 200 $\rightarrow$ 260 over two years, so total rate of return of 30%
- What is the equivalent yearly 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

- 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

- 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 (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:

$$200 \rightarrow 200\times(1+10\%) \rightarrow [200\times(1+10\%)]\times(1+10\%) = 242$$

- The start-up is the better investment

Example

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

Example (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 → 250 in 2 years is $(250/200)^{1/2} - 1 = 11.8\%$
- Compare IRRs
- What if you need the money now?

Example

- 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 (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 minimum sum (WTA) equivalent to 250 in 2 years
- A sum S such that $S \times (1+10\%)^2 = 250$
- $S = 250 / (1+10\%)^2 = 206.61$

Intertemporal arbitrage and discounting

- S_0 now and S_N in N years are equivalent, by arbitrage, if

  $S_0 \times (1+r)^N = S_N$

- Equivalently:

  $S_0 = S_N / (1+r)^N$

- $S_N / (1+r)^N$ is the **present value** of S_N in N years at **discount rate** r
- Calculating the present value is called **discounting**, whereas calculating the future value is called **capitalisation**

Estimating a stock of capital (1)

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

$$\mathbf{K_1 \rightarrow R_1, R_2, R_3, \ldots, R_n}$$

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

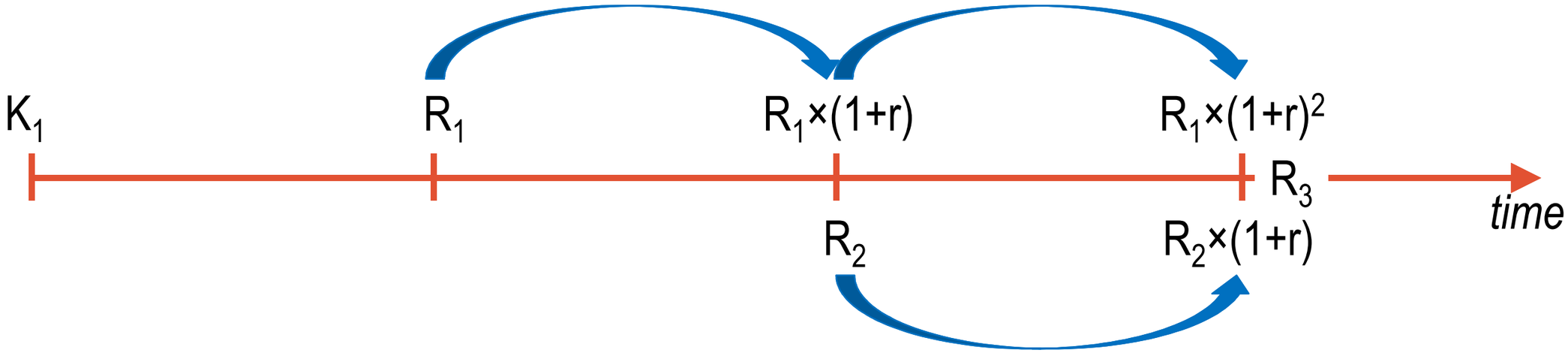
With this option, she has:

$K_1 + rK_1 = (1+r)K_1$	in one year
$(1+r)K_1 + r(1+r)K_1 = (1+r)^2K_1$	in two years
$\mathbf{(1+r)^nK_1}$	in n years

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 interest rate 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)

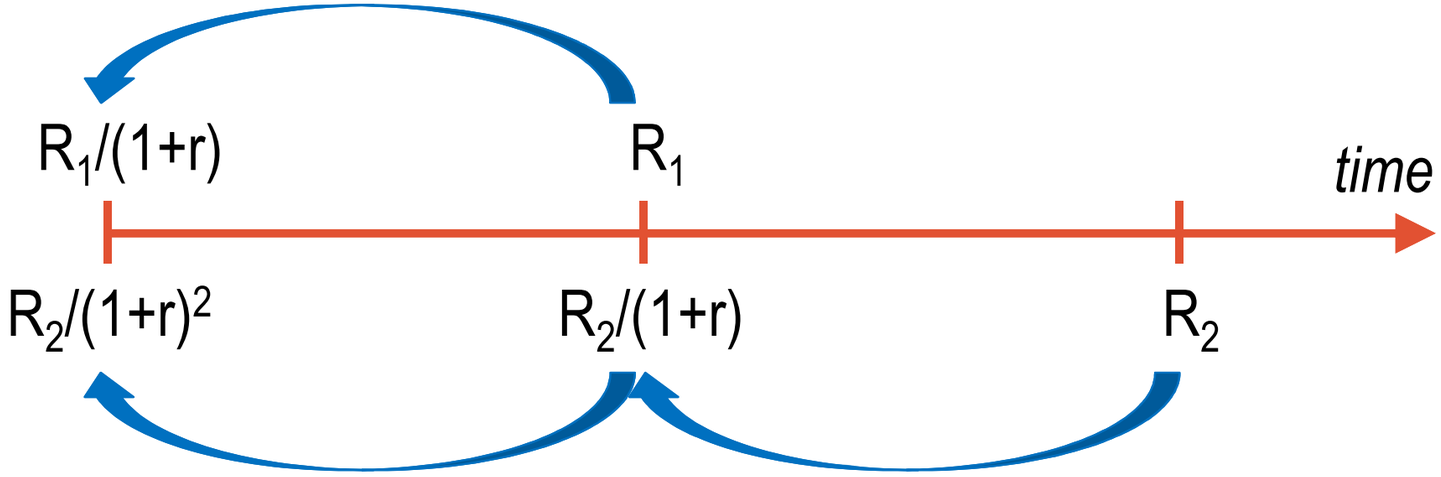
The equivalence between the capital owner's two options determines the value of her capital:

$$(1+r)^n K_1 = (1+r)^{n-1} R_1 + (1+r)^{n-2} R_2 + (1+r)^{n-3} R_3 + \ldots + (1+r) R_{n-1} + R_n$$

$$K_1 = \frac{R_1}{1+r} + \frac{R_2}{(1+r)^2} + \frac{R_3}{(1+r)^3} + \ldots + \frac{R_n}{(1+r)^n}$$

The further in the future, the less important:

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



This is the **net present value method (NPV)**

THE IMPORTANCE OF THE DISCOUNT RATE

Example

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

Example (corrected)

- 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 long residence time in 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						Dammages 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.”

Cost-benefit analysis for climate policy?

It is far from easy to assess the value of ecosystem changes and other impacts of climate change:

- Great uncertainties about the consequences of climate changes
- Everything must be expressed in the same unit, typically money (not energy: how do you evaluate human distress in energy terms?)
- The loss of marketed goods can be estimated quite easily, they have a price; for non-market goods, values must be revealed; different possible approaches
- Adaptation blurs the picture; it reduces the benefits of mitigation since it reduces damages
- Costs now, benefits in the future. Discounting? Intergenerational equity

Limitations of CBA (1)

- Next to the difficulties of assessing costs and benefits, there are more fundamental problems with CBA:
  - Only outcomes are considered, not how they were obtained (consequentialism), “the end justifies the means”
  - No sensitivity to rights and duties
- Problems of adding up costs and benefits:
  - Equity: Costs for whom? Benefits for whom?
  - People often think in lexicographic terms, i.e., no trade-off, absolute aversion to losing something such as a species
  - People think asymmetrically about gains and losses, about what they receive and what they pay

Limitations of CBA (2)

- Many of those objections can be overcome by weighing costs and benefits depending on who gets them and how they are valued; cf. social utility functions
- Still, CBA is a rather technocratic approach
- Yet, is it possible to be rigorous and systematic without being technocratic?
- If the environmental costs of climate change or the environmental benefits of mitigation are not valued or valued poorly, **only the costs of mitigation will be taken into account** and little will be done

"The American way of life is not up for negotiations. Period."
President George W. Bush, at the first Earth Summit in Rio de Janeiro in 1992

DETERMINANTS OF DISCOUNT RATE

Example

- How much would I have to return to you in 10 years in exchange of 1,000 francs today?

Example (answered)

- How much would I have to return to you in 10 years in exchange of 1,000 francs today?
- If you answer 2,000 francs, your implicit **required rate of return** is 7.2%

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

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%

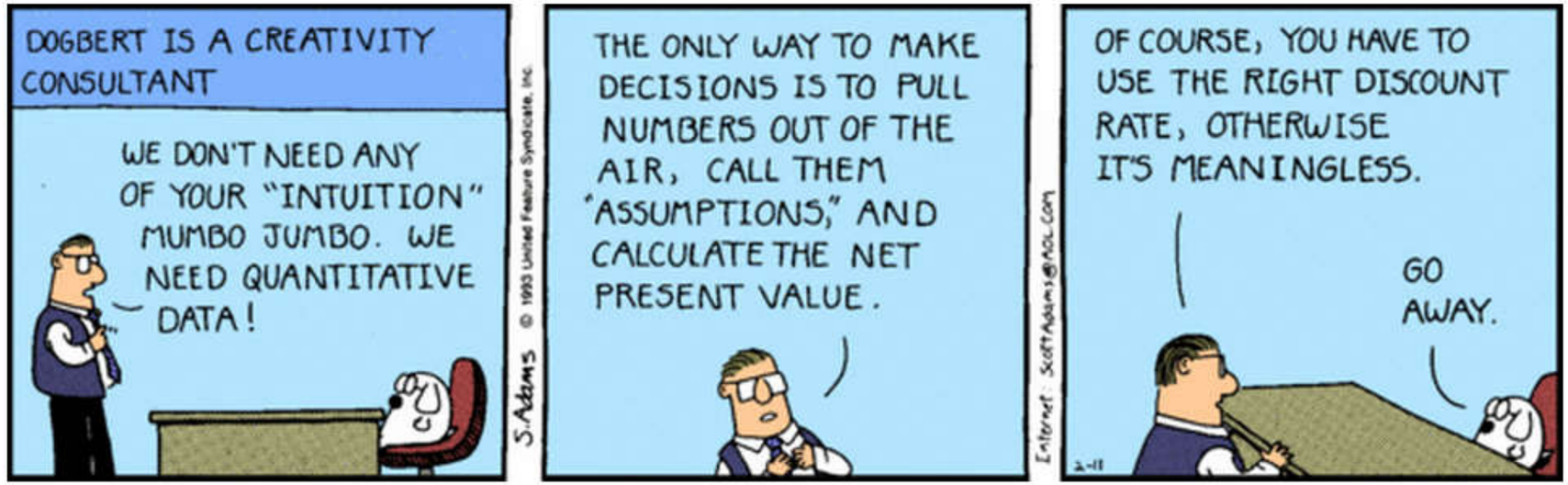
Risk aversion

State of nature	Benefit	Cost	Net benefit	Probability
"good"	200	100	100	9/10
"bad"	200	1000	-800	1/10

- The expected value of the project above is equal to 10
- A decision maker who is indifferent between this project and a project that yields net benefit of 10 with certainty is **risk neutral**
- **Risk averse** decision makers prefer the safe project
- They would even prefer a safe project with a lower net benefit, but not any lower benefit
- Suppose that they are indifferent between the risky project and a safe project with net benefit of 1; this is the **certainty equivalent** of the risky project for them; their **risk premium** is 10 – 1 = 9; they are willing to give this amount up to get rid of the risk

Discounting with risk premia

date of occurrence	Benefit	Cost	B-C	discount rate	
50	1'000'000	-1'000'000	0		
0	228'107	-228'107	0	3%	riskless rate
0	87'204	-87'204	0	5%	+2% risk premium
0	87'204	-608'039	-520'835	5%	for B 1% for C



CHOOSING THE DISCOUNT RATE

Public vs private

- For private firms, the discount rate r clearly represents the opportunity cost of capital, because it is the rate of return that stockholders could have earned on their savings
- It is not so clear how to interpret the term for public investment

Other views

- Public investments give rise to services that are consumed by the public
  - The appropriate discount rate depends on the way that society views the marginal rate of substitution between current and future consumption of such services (the marginal social rate of time preference)
- The two different methods give rise to very different values for the public discount rate and it is not clear which is more correct …

The Opportunity Cost View

- Recall that (assuming X and M are roughly equal)

  GDP = C + I + G

- Under the assumption of full-employment, long-run GDP can be assumed to be constant
- Because GDP is constant, more public spending G leads to less consumption C and/or private investment I (*crowding out*)
- The "cost" of the decrease in private investment is the productivity of private investment on the margin, which is equal to the real rate of return
- The "cost" of the decrease in private consumption at the margin is the rate of return that individuals receive on their savings, because that is the compensation for which they voluntarily lower their consumption (save more)

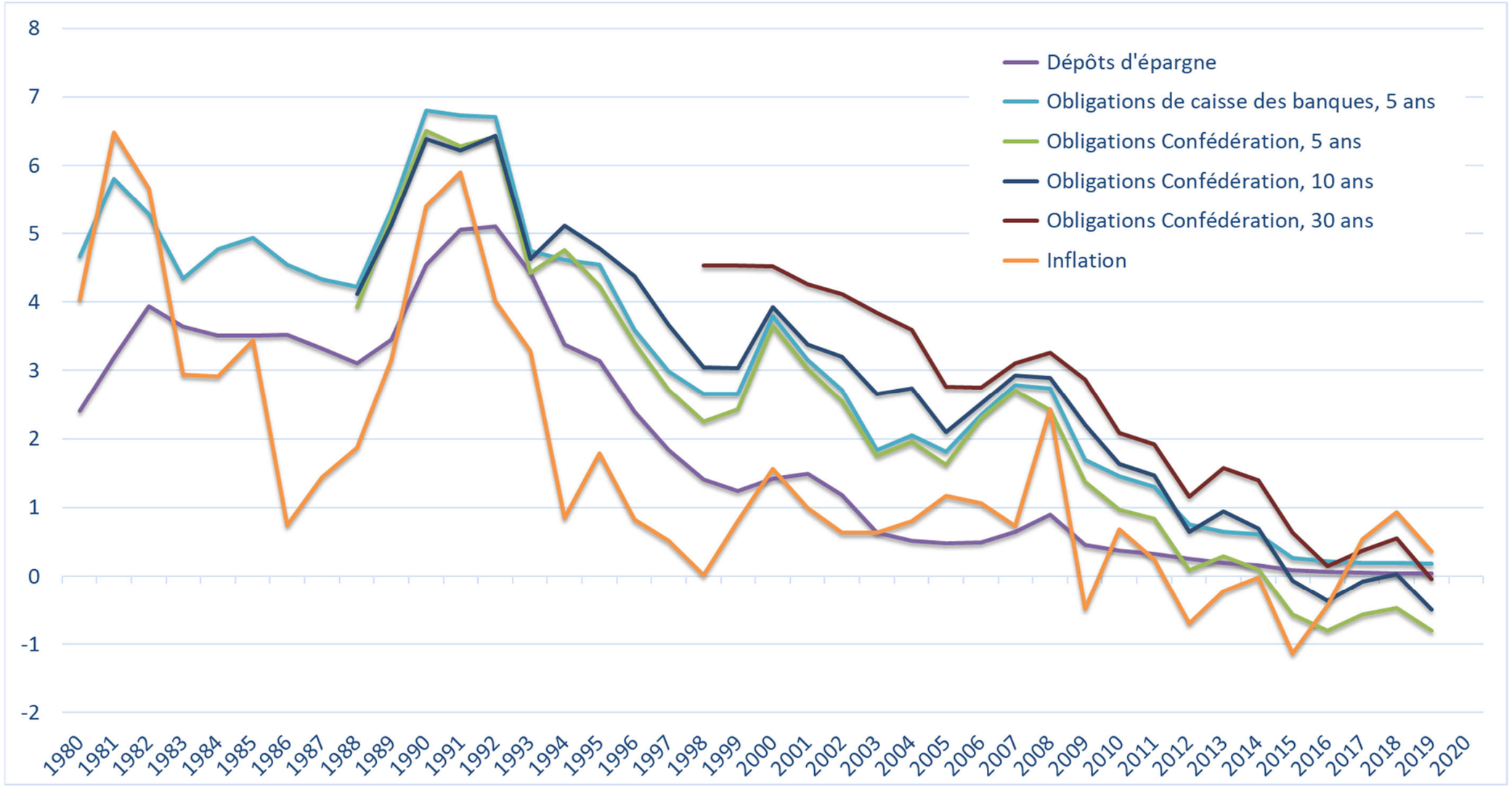
The Opportunity Cost View (continued)

- The two rates are equal: the return on investment is the return to savings
- It follows that public investment must at least match this rate of return to be worth the sacrifice of consumption or investment
- This means that public investment should earn the same return as private investment
- This demonstration rests on a number of critical assumptions, among which:
  - Full employment of all resources
  - Efficient capital markets
  - Investors and consumers have time horizons as long as the public investment, incorporating, if needed, the interests of future generations

Pragmatic View

- Weitzman (2001) surveyed 2,160 economists in 48 countries
  - Mean recommended public rate of discount under 4%
  - Range of variation : —3% to +27%
  - Majority between 1 and 6%
- The U.S. Office of Management and Budget recommends a rate of 7% for intra-generational projects, as a measure of pretax real rates of return on private investments (in 2003), and a rate of 3%, as a social rate of time preference
- Use the rate at which the public sector can borrow its funds, with a temporal horizon equal to that of the project
- Use a range of rates and analyze the sensitivity

Some Possible Rates of Reference in Switzerland



Declining discount rates

- Technical arguments derived from Ramsey discounting formula: $\rho_t = \delta + \eta \cdot g_t$

  ρ_t is the rate at which society discounts consumption at date t to the present

  δ is the pure rate of time preference, i.e. the rate at which future welfare is discounted

  η is (minus) the elasticity of marginal welfare wrt consumption, i.e. the % decrease in welfare for a 1% increase in consumption

  g_t is the growth rate of aggregate consumption

- If g_t is uncertain and shocks are positively correlated, then ρ_t decreases through time

Source : Arrow, K. J., et al. (2014). "Should Governments Use a Declining Discount Rate in Project Analysis?" *Review of Environmental Economics and Policy* 8(2): 145-163.

Declining discount rates in practice

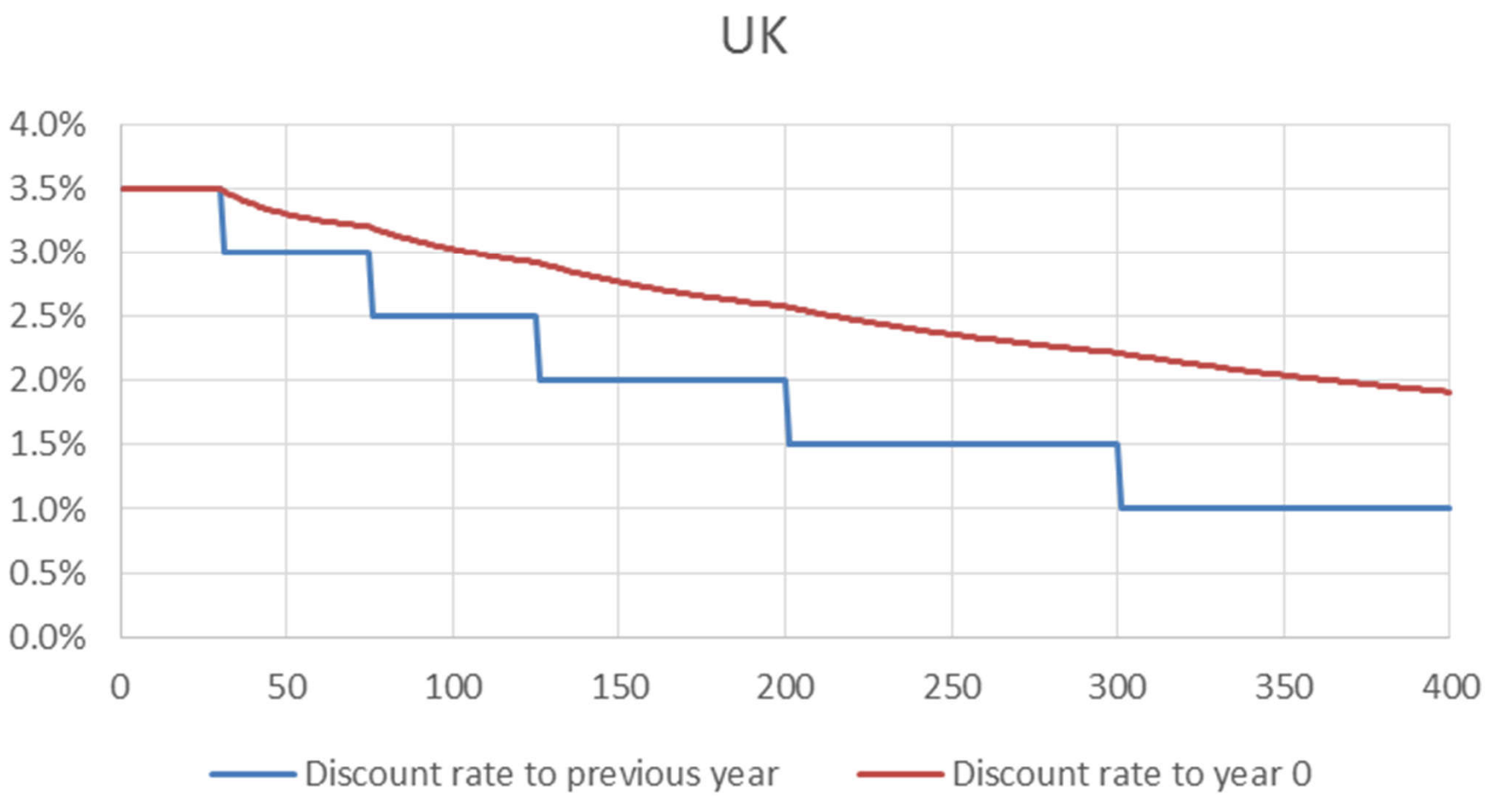
- France and the UK use since 2003 discount rate schedules that have declining discount rates through time

TABLE 6.1: THE DECLINING LONG TERM DISCOUNT RATE

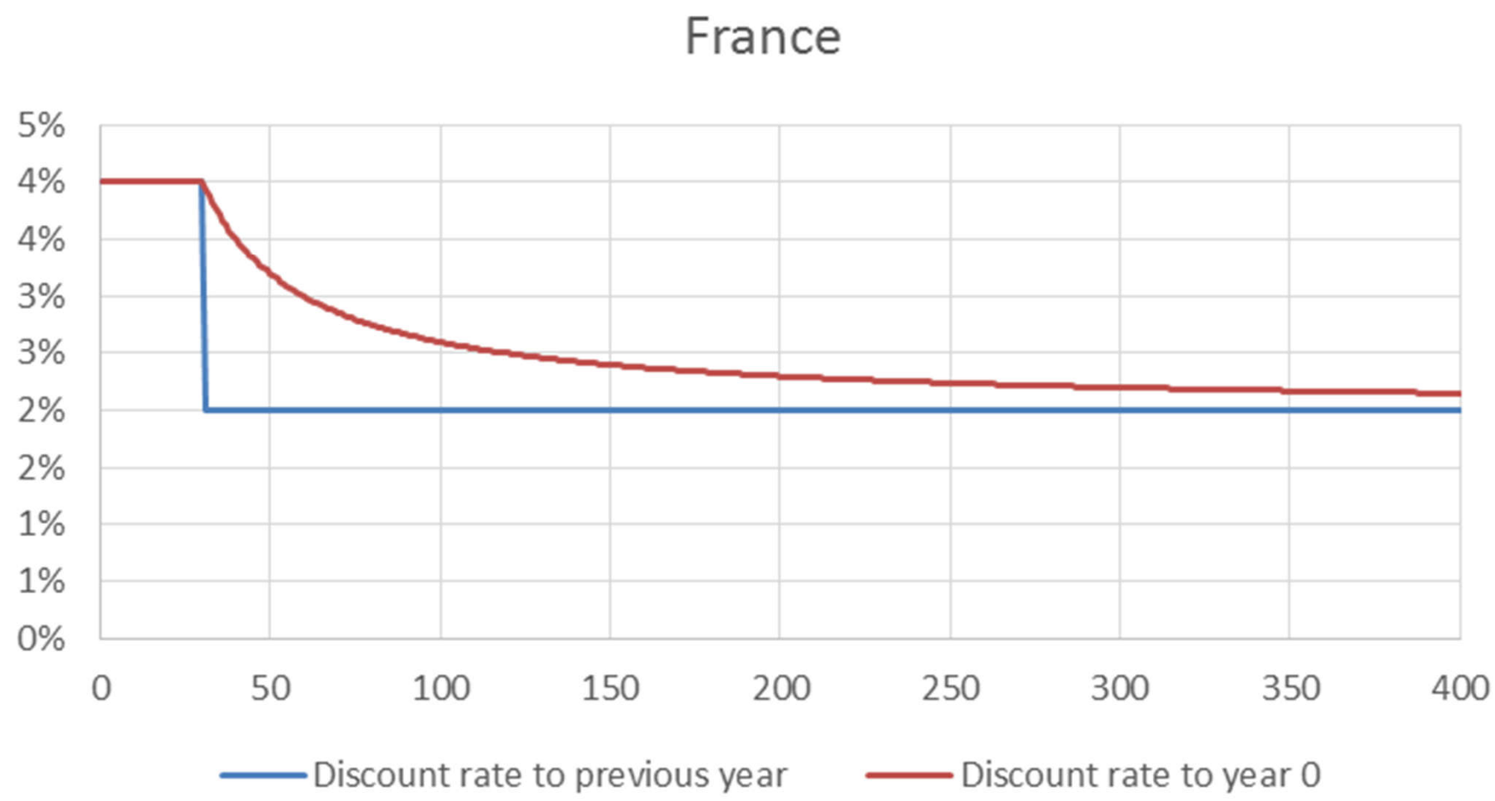
Period of years	0–30	31–75	76–125	126–200	201–300	301+
Discount rate	3.5%	3.0%	2.5%	2.0%	1.5%	1.0%

HM Treasury, THE GREEN BOOK - Appraisal and Evaluation in Central Government, 2003, rev. July 2011

Declining discount rates - UK



Declining discount rates - France



Agreement among most economists

- Future consumption should be discounted by society at a lower rate than private savings
  - Savings entail the positive externality that future earnings from savings provide future tax revenues
  - Current generation do not give enough weight to future generations
- Assuming a lower rate allows one to address both of these concerns by encouraging more public investment
- A popular theoretical model accounting for tax distortions suggests that the appropriate formula is actually much more complex than either of the above methods