The economics of climate change

C 175 - Christian Traeger

Part 4: Discounting

Background reading in our textbooks (very short):

Kolstad, Charles D. (2000), "Environmental Economics", Oxford University Press, New York. Pages 72-74.

Varian, Hal R. (any edition…), "Intermediate Microeconomics – a modern approach", W. W. Norton & Company, New York. Edition 6: Pages 182-187.

Both only very partial match. Varian a bit more of a graphical intuition.

Required Reading:

Hepburn, Cameron (2006), "Discounting climate change damages: Working note for the Stern review".

The problem of intertemporal decisions

Problem:

- How to compare costs and benefits that occur at different points in time?

Examples:

- Compare costs for abating CO_2 emissions today, with the benefits that accrue in later decades. Which costs are worth what benefits?
- Do you prefer ***$100** today* or ***$130** in **10 years**?*

We start analyzing the second example because it is simpler.

Our goal is to answer the first example in the section on integrated assessment.

Discounting

Economic solution concept:

- **Discounting:** Describes the valuation in present day terms of future outcomes (damages, costs, benefits, utility values)
- **Discount factor *D***: Gives the value of one unit in the future (generally in one year) in present value terms
- **Discount rate *r***: Gives the rate at which future value is discounted

It holds $$D = \frac{1}{1+r}$$

Remark: That relation corresponds approximately to $r = -\ln D$

Discounting

Economic solution concept:

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It holds $D = \frac{1}{1+r}$

Example (discounting money with bank interest rate):

- ***r*:** yearly interest paid on money in a bank
- I have a ***$1000*** bill to pay **in one year**. What is it worth today?
- If rate of interest in a bank is *5%*, I could deposit today *$952*, and would receive next year (including interests)

$$\$952\ (1+0.05) = \$1000$$

- The present value of *$1000* in one year is therefore

$$\$1000\ D = \$1000\ /\ (1+0.05) = \mathbf{\$952}$$

Discounting

Example (interest rates, two years):

- ***r=5%:*** yearly interest paid on (or for) money in a bank
- I have a ***$1000*** bill to pay **in two years**. What is it worth today?
- I could deposit today *$907*, and would receive in one year (including interests)

$$\$907\ (1+0.05) = \$952$$

- ...and in two years (reinvesting interests)

$$\$952\ (1+0.05) = \$907\ (1+0.05)^2 = \$1000$$

- The present value of $1000 in two years today is therefore

$$\$1000\ D^2 = \$1000\ /\ (1+0.05)^2 = \mathbf{\$907}$$

Analogous reasoning holds for benefits which accrue in the future.

Cost Benefit Analysis (also Benefit Cost Analysis or Benefit-Cost analysis…)

In general we want to evaluate a project or a cash flows that gives rise to benefits in some periods and costs in other periods.

Economic solution concept:

Cost Benefit analysis:

- Assess costs and benefits (in different periods) in monetary units
- Express all benefits and costs in present value terms
- Support a project (only) if benefits exceed costs

Tool:

Net present value *NPV*:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t}$$

where B_t are benefits and C_t are costs in period t

Invest in project if $NPV \geq 0$

Cost Benefit Analysis

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t}$$

Example Cost Benefit analysis:

- Consider two projects and a discount rate of 5%.

	Benefits (in $)			
Year	**0**	**1**	**2**	**3**
Project A	**-30**	**20**	**20**	**20**
Project B	**-30**	**10**	**10**	**10**

- NPV_A=-\$30+\$20/(1.05) +\$20/(1.05)^2 +\$20/(1.05)^3 = **\$24.46**
- NPV_B=-\$30+\$10/(1.05) +\$10/(1.05)^2 +\$10/(1.05)^3 = **- \$2.77**

Only project A worth investing!

Cost Benefit Analysis

Example II Cost Benefit analysis: HOMEWORK !

- Consider the two modified projects and a discount rate of 5%.

	Benefits (in $)			
Year	**0**	**1**	**2**	**3**
Project A	**-30**	**20**	**10**	**10**
Project B	**-30**	**10**	**20**	**20**

- $NPV_A = ?$
- $NPV_B = ?$

Assume you only have $30 that you can invest in the first period.

Which project would you invest in?

Discounting and Cost Benefit Analysis

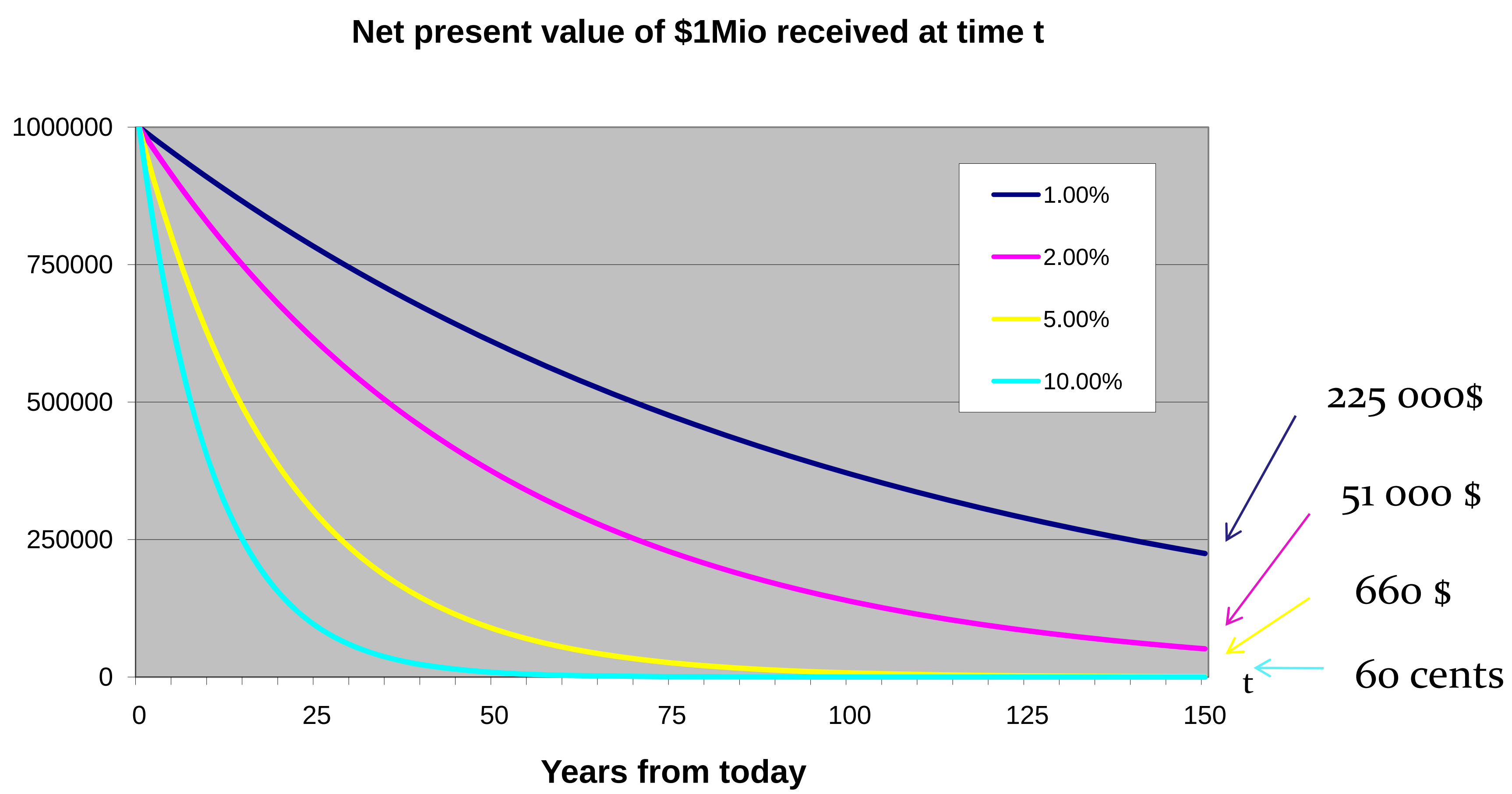
How important is the discount rate for cost benefit analysis?

- Say "you" receive ***1* million** US dollar in ***150* years** from now.
- Say your discount rate is ***r=10%***.

How much will the *$ 1,000,000* be worth to you today?

Guess!

Importance of the Discount Rate



Choice of the discount rate

- High discount rate implies
  - A dollar today is much more valuable than a dollar tomorrow
  - Hard to justify climate policy where costs occur today but benefits (abated damages) accrue later
- Note different interest rates
  - Nominal (seen in the market)
  - Real (adjusted for inflation)
- We will generally consider real interest rates.
- When we talk about money:
  We will think of it as expressing the value of a consumption bundle
  (or an environmental damage, or an investment…)
  in a particular period
  (adjusted for inflation).
- Remark: Compare to money metric utility function, where we expressed all other consumption but one good in terms of the corresponding money value

Choice of the discount rate

But how do we find the discount rate for cost benefit analysis?

Option 1: Simple take the market rate
= real interest paid on certain investment
represents productivity of capital in the market equilibrium

Difficulties:

In the context of climate change evaluation and long time horizons the market rate might not reflect preferences of society correctly because of

- **Market failures and market imperfections**
(e.g. externalities, distortions, market power)
- **Super-responsibility of government**: Government might have to represent future generations as well as current generations
(while only current generations are represented on the market)
- **Dual-role of individuals**: In their political role individuals are more concerned about future generations than in their day to day activities
(which are reflected in the market)

Choice of the discount rate

Option 2: Social discounting

- Find the determinants of the discount rate from economic (or ethical) considerations

Reasons to discount (on preference/utility side)**:**

- Pure rate of time preference (***time discounting,*** *also: utility discounting*)
  - Pure impatience: Rather consume /get utility now than later
- Economic growth (***growth discounting,*** *also: consumption smoothing*)
  - If someone is richer in ten years, a dollar today might be worth more than a dollar in ten years (utility function concave)
- Uncertainty -> Later

Determinants of Social Discount Rate

- How do we formalize these reasons for discounting?

Let's start with two periods and a situation where markets function.

- Define welfare $$W(x_0, x_1) = U(x_0) + \frac{1}{1+\rho} U(x_1)$$
- where $\boldsymbol{x_0}$ is consumption in the present (*t*=0) and $\boldsymbol{x_1}$ is consumption in the future period (*t*=1). You can think of x either as real consumption or as consumption expressed in monetary terms. Consumption can include environmental damages and benefits.
- where $\boldsymbol{U}(x_t)$ characterizes utility obtained from consuming x_t in period *t*
  (same utility function for all periods, corresponds to stationarity assumption)
- where the discount rate $\boldsymbol{\rho}$ characterizes pure time preference (also utility discount rate). It makes utility in the future be worth less than utility in the present (impatience).

Determinants of Social Discount Rate

- So at what rate do we discount consumption?
  (if you like expressed in monetary terms)

Go back to good old necessary conditions for an equilibrium:

Marginal rate of substitution (MRS)
= Rate at which a consumer is just willing to substitute one good for the other

has to equal the **price ratio** of the two goods which again has to equal

Marginal Rate of Transformation (MRT)
= Rate at which we can technically transform one good into the other

- However:
  This time we take the first good to be consumption in period $t=0$ and the second good to be consumption in period $t=1$.

Determinants of Social Discount Rate

- Then with $$W(x_0, x_1) = U(x_0) + \frac{1}{1+\rho} U(x_1)$$
- we calculate

$$MRS = \frac{\Delta X_1}{\Delta X_0} = -\frac{MW_{X_0}}{MW_{X_1}} = -\frac{\frac{\partial W}{\partial X_0}}{\frac{\partial W}{\partial X_1}} = -\frac{U'(X_0)}{\frac{1}{1+\rho} U'(X_1)} = -(1+\rho)\frac{U'(X_0)}{U'(X_1)} \qquad \left(= -\frac{p_{X_0}}{p_{X_1}} \right)$$

On the production side we assume for simplicity that

- The only input to production is capital, let *M* be our available capital in the present
(you can add a fixed amount of labor to the production process if you like)
- In $t=0$ we have $X_0=M$
- In $t=1$ we have $X_1=(1+r)$ M   because capital is productive
(it became more due to investment in/productivity of firm)

$$MRT = -\frac{\frac{\partial X_1}{\partial M}}{\frac{\partial X_0}{\partial M}} = -(1+r) \qquad \left(= -\frac{p_{X_0}}{p_{X_1}} \right)$$

Determinants of Social Discount Rate, Example

- Example:

$$U(x) = \ln x$$

- Then

$$W(x_0, x_1) = \ln x_0 + \frac{1}{1+\rho} \ln x_1$$

  and

$$MRS = -(1+\rho)\frac{U'(X_0)}{U'(X_1)} = \ldots$$

  -> Blackboard

- So that market equilibrium (and Pareto optimum) condition *MRT*=*MRS* implies
- r=...
- -> Blackboard

Determinants of Social Discount Rate, general case

$$MRS = -(1+\rho)\frac{U'(X_0)}{U'(X_1)} = -(1+\rho)\frac{U'(X_0)}{U'(X_0+gX_0)}$$

$$= -(1+\rho)\frac{U'(X_0)}{U'(X_0)+U''(X_0)gX_0}$$

$$= -(1+\rho)\left(1+\frac{U''(X_0)X_0}{U'(X_0)}g\right)^{-1}$$

Magic!
(assumes
g is small)

Define: $$\theta = -\frac{U''(X_0)X_0}{U'(X_0)} = -\frac{dU'(X_0)}{dX_0}\frac{X_0}{U'(X_0)} = -\frac{dU'(X_0)}{U'(X_0)} \Bigg/ \frac{dX_0}{X_0}$$

- The parameter $\boldsymbol{\theta}$ describes by how many percent marginal utility changes if consumption increases by one percent.
- $\boldsymbol{\theta}$ is called the **consumption elasticity of marginal utility**

Determinants of Social Discount Rate, general case

- With this definition we have:

$$MRS = -(1+\rho)\left(1+\frac{U''(X_0)X_0}{U'(X_0)}g\right)^{-1} = -(1+\rho)(1-\theta\, g)^{-1}$$

- On the other hand we have

$$MRT = -(1+r)$$

- Therefore we find from *-MRT= - MRS* that

$$1+r = (1+\rho)(1-\theta\, g)^{-1}$$
$$\Leftrightarrow (1+r)(1-\theta\, g) = (1+\rho)$$
$$\Leftrightarrow 1+r-\theta\, g - r\,\theta\, g = 1+\rho$$
$$\Leftrightarrow r = \rho + \theta\, g + r\,\theta\, g \approx \rho + \theta\, g$$

Determinants of Social Discount Rate, general case

- The resulting equation

  $$r = \rho + \theta g$$

  is known as the “Ramsey equation” after Frank Ramsey (1928)
- The equation states that in an optimal intertemporal allocation:
- the productivity of capital (interest rate) = the return on investment is the sum of
  - The rate of pure time preference (describing impatience)
  - And the product of
    - the consumption elasticity of marginal utility $\boldsymbol{\theta}$ (describing how fast marginal consumption decreases in consumption)
    - the growth rate $\boldsymbol{g}$ (describing how fast consumption increases)