Module 8: Benefit-Cost Analysis and Dynamic Decision-Making

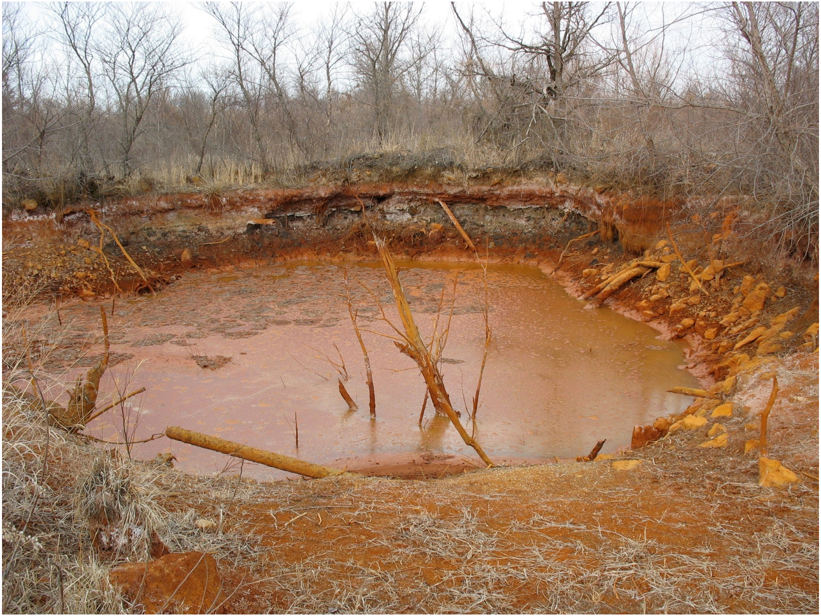
So far in this class we have talked about:

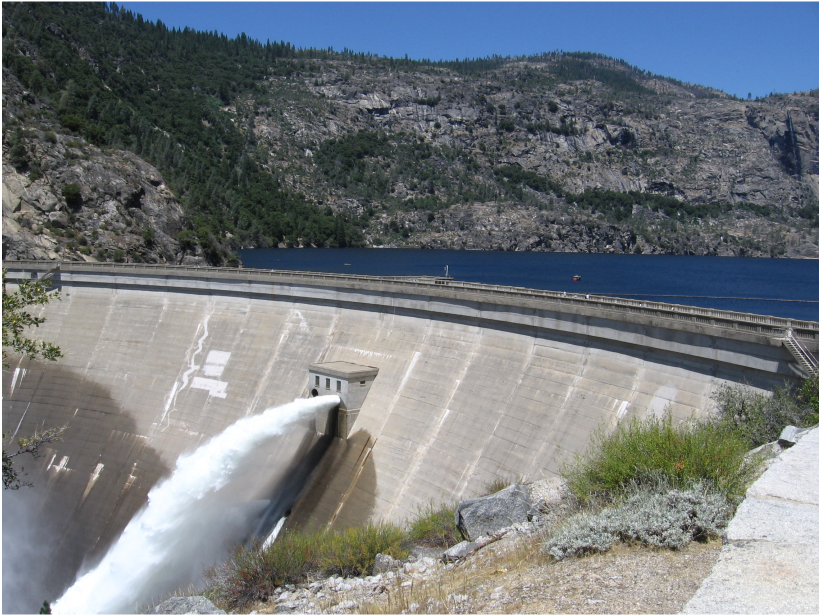
- How to measure benefits from environmental protection
  - Revealed preference vs. stated preference
  - Use value, option value, and non-use value
- How to measure costs of environmental protection
  - Engineering cost vs. opportunity cost
  - Productivity effect
  - Employment effect

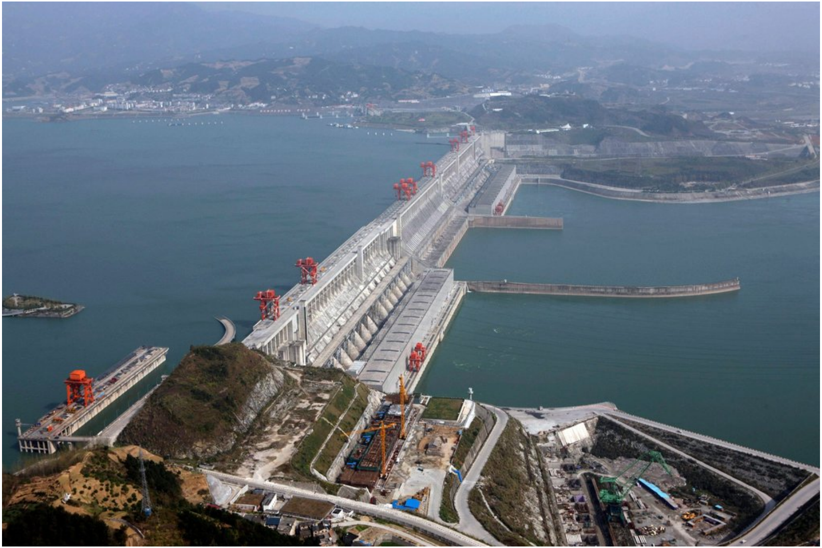
In this module, we are going to look at how to compare between benefits and costs. We will talk about:

- Benefit-cost analysis
- Discounting and present value
  - Private vs. Public discount rates
- Dynamic decision-making
- Decision-making under uncertainty

One of the most important reasons to environmental benefits and costs is to evaluate public policy decisions:







And these projects need to be funded by the public

- Free-riding problem: private entities will under-private public goods
- One of the major functionalities of the government is public good provision:
  - Education
  - Health
  - Environment

The Decision Rule

Let B be the benefits from a proposed policy, and C be the costs. The decision rule is:

If B>C, do it. Otherwise, don't do it.

Alternatively,

If the benefit-cost ratio B/C>1, do it.

Benefit-cost Analysis

Benefit-cost analysis provides a **normative** criteria to evaluate **public** policy **decisions**

- Normative: entails a value judgment
  - That the societal welfare is measured by the TOTAL economic benefits and costs
- Public: Benefit-cost analysis only applies to decisions that involves a public project
  - Private companies will automatically evaluate decisions based on revenue and cost
  - Public projects do not face the scrutiny of economic(accounting) calculus
- Decision
  - Whether to do the project or not
  - Need a decision rule that is clear-cut

Of course, benefit-cost analysis is NOT the only decision rule:

- Impact analysis
  - What are the environmental impacts of a proposed action?
  - If there is harm, then could it be mitigated?
  - Environmental Impact Analysis, Wetland Permit, Endangered Species Act
- Cost-effectiveness
  - Wish to achieve some normative societal outcome (social justice, universal healthcare)
  - What is the way that involes the least cost to achieve the policy target?

And there is this

Executive Order 13771 (1/30/2017): "*(c) . . . any new incremental costs associated with new regulations shall, to the extent permitted by law, be offset by the elimination of existing costs associated with at least two prior regulations.*"

- The Milton Friedman tradition: too much existing regulation are hurting businesses
- Total costs of the regulation should remain the same (or lower)
- But what about benefits?

And benefit-cost analysis does not guarantee economic efficiency

- BCA essentially evaluates whether total benefit is larger than total costs
  - Or, whether net benefit is larger than zero
- That does not guarantee that the proposed policy MAXIMIZES societal welfare

Mike Pompeo on the Paris Agreement, 11/4/2019

https://finance.yahoo.com/video/mike-pompeo-explains-why-us-002029088.html

Where does the Secretary of State get wrong?

What does benefit-cost analysis look like?

Estimated Annual US Benefits and Costs of the SO_2 Allowance Trading Program; Title IV, Clean Air Amendments of 1990

(billions of US 2000 Dollars)

Benefits	
Mortality	50–100
Morbidity	3–7
Recreational visibility	2–3
Residential visibility	2–3
Ecosystem effects	0.5
Total	**59–116**
Costs	**0.5–2.0**
Net benefits	**58–114**

Table 1
Benefits and Costs of Federal Regulations

	Surface water (1)	*Drinking water (2)*	*Air (3)*	*Greenhouse gases (4)*	*All other (5)*	*All (6)*
A: Total US expenditures (trillions of 2017 dollars)						
1970 to 2014	2.83	1.99	2.11	–	–	–
1973 to 1990	0.94	0.49	0.85	–	–	–
B: Estimated benefits and costs of regulations analyzed in years 1992–2017						
Total benefits / total costs	0.79	4.75	12.36	2.98	1.97	6.31
Mean benefits / mean costs	0.57	8.26	15.18	3.64	21.79	16.17
Share with benefits < costs	0.67	0.20	0.08	0.00	0.19	0.15

Table 3.3 Summary Comparison of Benefits and Costs from the Clean Air Act 1990–2020 (Estimates in Million 2006$)

	Annual Estimates			*Present Value Estimate*
	2000	*2010*	*2020*	*1990–2020*
Monetized Direct Costs:				
Low[1]				
Central	$20,000	$53,000	$65,000	$380,000
High[1]				
Monetized Direct Benefits:				
Low[2]	$90,000	$160,000	$250,000	$1,400,000
Central	$770,000	$1,300,000	$2,000,000	$12,000,000
High[2]	$2,300,000	$3,800,000	$5,700,000	$35,000,000
Net Benefits:				
Low	$70,000	$110,000	$190,000	$1,000,000
Central	$750,000	$1,200,000	$1,900,000	$12,000,000
High	$2,300,000	$3,700,000	$5,600,000	$35,000,000
Benefit/Cost Ratio:				
Low[3]	5/1	3/1	4/1	4/1
Central	39/1	25/1	31/1	32/1
High[3]	115/1	72/1	88/1	92/1

An inherent puzzle with public investments

- Many public projects involve a large sum of investment in the current period
  - Three-gorge dam
  - Superfund cleanup
  - Climate change mitigation
- The streams of benefit come at a later point
- How do we evaluate benefits and costs over different time horizons
  - Do we sacrifice future generations?
  - Do we sacrifice current economic development opportunities?

Cleaning up a waste site near Kingslanding costs \$25 million in year 2019. Starting from 2020, it provides economic benefits of \$10 million per year for the next three years, before another cleanup is due.

How to evaluate the benefits and the costs?

Discounting the future

In general, we might want to value more heavily with money on hand. This is true for several reasons:

- Opportunity cost of money: investment generates returns
- Time preference: the desire to enjoy now more than later in the future
- Inflation: future money is less valuable

This leads to a positive **discount rate** of r

Present value of benefits & costs

With the discount rate established, we can now evaluate the benefits and costs for the waste cleanup problem.

Assuming the base year is 2019, and a discount rate of 5%. Our problem is to put every benefit stream occuring in the future back into 2019 terms. For example, a benefit of $10 million in 2020 is worth:

$10 million in 2020 = $10 million / (1+5%) = $9.52 million in 2019
$10 million in 2021 = $10 million / (1+5%)ˆ2 = $9.07 million in 2019
$10 million in 2022 = $10 million / (1+5%)ˆ3 = $8.64 million in 2019

The present value benefits and costs for the project is:

The present value benefits:

$$PVB = 10 * \frac{1}{(1+5\%)} + 10 * \frac{1}{(1+5\%)^2} + 10 * \frac{1}{(1+5\%)^3}$$

$= 9.52 + 9.07 + 8.64$
$= \$27.23$ million

The present value costs: PVC $= \$25$ million

Present value net benefits

The **present value net benefits** is thus:

PVNB = PVB - PVC
=27.23-25 = \$2.23 million

- PVNB is equivalent to the idea of net benefit in the one time-period problems
- Decision rule for a BCA becomes: ** PVNB $>$ 0: do it; PVNB $<$0: don't do it**

Present value vs. current value

- Current value: economic values that are generated in the future(current) year, before discounting
- Present value: the equivalent economic values generated in the future to the present year

And we have the following formula:

$$PV = \frac{CV}{(1+r)^t}$$

$$CV = PV * (1+r)^t$$

where
PV: Present value of benefits
CV: Current value of benefits
r: Discount rate
t: Number of periods

Present value benefits for the infinite horizon

In many circumstances, future benefit/cost streams will run for a long period of time, or indefinitely:

- Benefits from mitigating climate change
- Flood control and hydro-power generation from major dams
- Regulatory expenses to maintain a program

And how do we put that into account?

The construction of the Three Gorges Dam cost \$30 billion in year 0. Starting from year 1, it provides economic benefits of \$1 billion per year until the earth is occupied by the three-body civilization. Assume a discount rate of 5%.

Current value costs: \$30 billion in year 0
Current value benefits: \$1 billion starting in year 1, indefinitely

Present value costs: \$30 billion
Present value benefits:

$$1/1.05 + 1/1.05^2 + 1/1.05^3 + 1/1.05^4 + ...$$

using the summation rule of geometric sequences:

$$\sum_{s=1}^{t} A * \frac{1}{(1+r)^s} = A * \frac{1}{1+r} * \frac{1-(\frac{1}{1+r})^t}{1-\frac{1}{1+r}}$$

When t goes to infinity, we have:

$$\sum_{s=1}^{t} A * \frac{1}{(1+r)^s} = A * \frac{1}{1+r} * \frac{1}{\frac{r}{1+r}}$$

$$= \frac{A}{r}$$

Or:

PV of an infinite stream of payoff $= \frac{\text{CV of each year's payoff}}{r}$

And the PVB for the project is: $1/0.05 = \$20$ billion.
The PVNB is thus: 20-30 = \$-10 billion

The influence of discount rate

Discount rate has a critical impact on benefit-cost analysis. Suppose for the same project ($30B initial cost, $1B indefinite benefit), different discount rates are chosen:

```
##  Discount_rate PVB PVC  PVNB
##           0.01 100  30  70.0
##           0.02  50  30  20.0
##           0.03  33  30   3.3
##           0.05  20  30 -10.0
##           0.10  10  30 -20.0
##           0.20   5  30 -25.0
```

Internal Rate of Return

Another way to evaluate policy projects (or business ones) is to calculate the internal rate of return.

IRR = the discount rate when the project is just breaking even

	A	B	C	D	E
1	**Period**	**Cash flow**	**PV**		
2	Initial investment	-$1,000	-$1,000		
3	1	$300	$275.49	=B3/(1+$B$7)^A3	
4	2	$400	$337.31	=B4/(1+$B$7)^A4	
5	3	$500	$387.20	=B5/(1+$B$7)^A5	
6					
7	**IRR**	8.90%	=IRR(B2:B5)		
8	**NPV**	$0.00	=SUM(C2:C5)		

Put it in another way

- Climate change is going to cause \$5 trillion (5,000,000,000,000) in damage by 2100
- With 3% discount rate, this is \$382 billion in NPV
  - Half of the annual US military spending
- With 5% discount rate, this is \$72 billion
  - How much China invests in its high-speed rail system
- With 7% discount rate, this is \$13 billion
  - 4 months of Netflix subscription for the entire US

- Higher discount rate: welfare for the present is relatively more valuable
- Lower discount rate: welfare for the future is relatively more valuable

From the financial markets' perspective:

- Private markets establish equilibrium interest rates for savings and loans
  - 10-year treasury bill: 1.79%
  - Alipay's Tianhong Monetary Fund (Yu'e Bao): 2.25%
  - Prime-rate auto loan: 4%
  - Sub-prime mortgages: 8%
  - Average return on US stock market (S&P): 9.9%
- We call this **private discount rate**
- Risky assets will yield higher return
  - A "risk premium" for taking on extra risk

From consumers' perspective

There are (at least) two main reasons why an individual values present wealth more than future wealth:

- Time preference (the impatient desire)
  - Between consuming now and consuming later, individuals almost always desire to consume now
  - Think about going to your favorite restaurant, or a concert from your favorite singer
- Economic growth (money growing on trees)
  - By saving instead of consuming, more wealth could be generated in the future

Social vs. private discount rate

But the problem with a market-driven discount rate is, private discount rates are higher than the social discount rate

- Investors are more impatient than the society as a whole (higher time preference)
  - Make money in three years, otherwise I will not invest in your start-up
- Higher risk premium
  - Government can better shield institutional risks
  - Government can impose risks to private firms

By the same logic, developed countries may have lower interest rate than developing countries:

- Divergence in credit ratings of national debts (cost of raising capital)
- Divergence in institutional risks
- Divergence in growth rates

This is to say, while US should use a discount rate of 3%, Mozambique should use a discount rate of 8%.

What are the implications of this?

Frank Ramsey and the Ramsey equation

Frank Ramsey is NOT an economist. He was a philosophy/mathematician working with the great Wittgenstein. He was encouraged by John Maynard Keynes and Arthur Pigou(!) though.

Ramsey wrote only three economics papers in his life:

- A Contribution to the Theory of Taxation (landmark in public finance)
- Truth and Probability (the foundation of modern statistics)
- A Mathematical Theory of Saving (first chapter in every advanced macroeconomics book)

Paul Samuelson: “three great legacies – legacies that were for the most part mere by-products of his major interest in the foundations of mathematics and knowledge.”

John Maynard Keynes: “one of the most remarkable contributions to mathematical economics ever made, both in respect of the intrinsic importance and difficulty of its subject. . . ”

The Ramsey equation

Ramsey (1928): How to maximize present value benefits over time? Or rather, how should the society tradeoff current consumption with future ones?

2.4.1 The Problem that Households Face

The problem that the household solves is therefore:

$$\max_{\{C(t)\}} U = \int_{t=0}^{\infty} e^{-\rho t} u(C(t))L(t)dt$$

subject to the following dynamic budget constraint:

$$\dot{B}(t) = r(t)B(t) + W(t)L(t) - C(t)L(t) \tag{5}$$

From the dynamic budget constraint (5), we can derive an *intertemporal budget constraint*. To see this, let's take the dynamic budget constraint (5) and pre-multiply each side by $e^{-R(t)}$, then integrate between time t and time $T > t$:

$$\int_t^T e^{-R(s)} \dot{B}(s)ds = \int_t^T e^{-R(s)} r(s)B(s)ds + \int_t^T e^{-R(s)}(W(s) - C(s))L(s)ds$$

We can use the Integration by Part formula to replace the left hand side with

$$\int_t^T e^{-R(s)} \dot{B}(s)ds = B(T)e^{-R(T)} - B(t)e^{-R(t)} + \int_t^T e^{-R(s)} r(s)B(s)ds$$

where we use the fact that $dR(s)/ds = d(\int_0^s r(u)du)/ds = r(s)$.

Substituting this expression into the budget constraint and canceling terms, we obtain:

$$B(T)e^{-R(T)} - B(t)e^{-R(t)} = \int_t^T e^{-R(s)}(W(s) - C(s))L(s)ds$$

After some difficult (but elegant) math, it goes as simple as this:

$$r = \delta + \eta g$$

where:
r: discount rate
δ: pure time preference
η: elasticity of marginal utility of consumption
g: growth rate of the economy

In other words, discount rate consists of two part:

- Pure time preference: δ
- Future economic growth, weighted by the diminishing marginal utility of consumption: ηg

Some estimates of the social discount rate

- Obama Administration: 3% - 5%
- Nordhaus: Observe parameters on the market
  - $\delta = 1.5$; η=2
  - r = 4.5%-6.5%
- Stern: Choosing parameters from a moral stand point
  - $\delta = 0.1$; η=1
  - r = 1.4%

Consequences of discount rate choices

Drastic differences on the social cost of carbon (price of a carbon tax):

- Obama Administration: $40 per ton
- Nordhaus (DICE): $8 per ton
- The Stern Report: $200 per ton

Discount rate as a political tool

And of course, discount rate is a power weapon if politicians want to “play with the numbers”:

- The Trump administration revisited the social cost of carbon
- Among other things, they chose a discount rate of 7%(!)
- Leads to a social cost of carbon of less than $1 per ton
  - Almost no climate policy will pass the BCA with that
  - Basis for revoking existing climate regulations

Nordhaus vs. Weitzman vs. Stern

- Nordhaus: simulation modeling
  - Investment in climate change has relatively low rate of return
  - Resource better spent on other projects with higher return: Child education, fighting poverty
  - Favors a carbon tax
- Weitzman: the fat tail problem
  - Need to avoid potential catastrophic events (with small probability, but fat tails)
  - Favors a cap-and-trade
- Stern: Discount rate should be a moral choice
  - Discount rate as low as possible

What do you think the discount rate should be?

- How should it be determined?
- How high should it be?
- Any problems with discounting in this way?
  - What about catastrophic risk in the future?
  - What about future growth rates?

Decision-making under uncertainty

In the real world, it is hard to state the consequence of a policy with certainty.

- Exposure to radioactive substances from the Fukushima Nuclear site is lethal to human 1 in 10,000 time, and non-lethal for the rest 9999 times.
- Climate change may cause massive damage to the society, or it may cause relatively small damage
- Mars-landing may cost NASA 100 billion dollars if everything goes right, but it may cost up to 1 trillion

How does benefit-cost analysis incorporate uncertainty?

A government can implement one of the three programs to restore a migratory bird habitat. Three plans have the same cost of $1000. The economic benefits from each strategy is the following:

	Outcome A	Outcome B	Outcome C
Economic Benefits	500	1000	2000
Plan A	30%	50%	20%
Plan B	10%	65%	25%
Plan C	20%	40%	40%

Which plan should the government pick?

Dominant policy

A **dominant policy** is one that confers higher net benefits for every outcome.

Also, a dominated policy is a policy that confers lower net benefits for every outcome comparing to another policy.

Is there a dominant strategy there? Is there a dominated strategy there?

Expected value maximization

If there is no dominant strategy, then we will have to rely on something else: **maximize the expected value of net benefits**

Expected Net Benefit of Choice j $= \sum_{i=1}^{I} p_i NB_{ij}$

Plan A: $E(NB) = 500 * 30\% + 1000 * 50\% + 2000 * 20\% = 1050$

Plan B: $E(NB) = 500 * 10\% + 1000 * 65\% + 2000 * 25\% = 1200$

Plan C: $E(NB) = 500 * 20\% + 1000 * 40\% + 2000 * 40\% = 1300$

Another example

Honduras is thinking of a national climate change adaptation plan that costs \$70 million. There is a 70% chance that the plan is successful, and create an annual benefit of \$4 million indefinitely. There is a 30% chance that the plan is unsuccessful, creating only \$1 million indefinitely.

Assuming a discount rate of 5%, should the government go through with the plan?

Maximizing expected present value net benefits

E(PVNB) $= 4{,}000{,}000/5\% * 70\% + 1{,}000{,}000/5\% * 30\% - 70{,}000{,}000$
$= -\$8{,}000{,}000$

Honduras should not go through with that plan.

- Using expected net value maximization implicitly assumes that the society is risk-neutral
  - i.e., the society is indifferent between a certain \$50 payoff and a 50% chance of getting \$100
- This may be a simplification
  - What if there is a catastrophic risk that we cannot bear?

Takeaways from the module

- Benefit-cost analysis
  - Normative, public decisions
- Dynamic decision-making
  - Present value vs. current value
- Discount rate
  - The Ramsey formula
  - Private vs. social discount rate
  - Implications for climate change # Decision-making under uncertainty