

Lecture # 19 – Benefit-Cost Analysis

I. Discounting

- The costs and benefits we've discussed often occur at different times. To compare them fairly, it is important to discount costs and benefits that occur in the future.
 - The idea is to compare a flow of benefits and costs into a single value.
- The present value of a future amount of money is the maximum amount you would be willing to pay today for the right to receive that money in the future.
 - Present value accounts for the opportunity cost of not investing the money elsewhere.
 - Example:
 - You have \$100 now
 - If you put it in the bank, you will get 5% interest
 - Next year, that money is worth $(1 + 0.05) \times 100 = \105
 - After two years, it is worth $(1.05)(1.05)(100) = (1.05)^2(100) = \110.25
 - General rule:
 - FV = future value, PV = present value, r = interest rate
 - $FV = PV(1 + r)^t$
 - As a result, you wouldn't give up \$100 now for \$100 next year, because you could invest the money and get \$105 next year.
 - The present value of \$100 next year is the most you would give up today to get \$100 next year
 - $FV \Rightarrow PV(1.05) = \$100(1.05)$
 - $PV = FV/r = 100/1.05 = \$95.24$
 - General rule
 - $PV = FV/(1 + r)$
 - For a stream of payments:
 - $PV = x + X/(1+r) + X/(1+r)^2 + \dots + X/(1+r)^t$
 - Please see the spreadsheet from class for additional examples.

- To proceed, we need to know what value to use for r . This is the discount rate.
- The discount rate reflects the relative value a person places on future consumption compared to current consumption.
 - Lower values show a greater preference for future consumption.
 - If your discount rate is greater than the interest rate, you will be willing to borrow money.
 - A high discount rate says that current consumption is important to you.
 - If your discount rate is lower than the interest rate, you will be willing to loan money.
 - A low discount rate says that future consumption is important to you.
 - Since the market interest rate reflects an equilibrium of lenders and borrowers, we can use the market interest rate as a measure of the discount rate.
- There are several market interest rates. Which should we use?
 - Typically, economists use a risk-free rate.
 - Investors looking for a safe return invest in U.S. Treasury bills. Thus, the return on T-bills is a measure of the nominal risk-free rate.
 - To purchase assets that are riskier, investors need to be compensated with a higher rate of return.
 - This additional return is known as a risk premium.
 - The most commonly used rates in government reports are 3% and 7%
 - 3% represents the risk-free rate
 - It is the average real rates on US Treasury bills from 1973-2003
 - 7% represents the returns on private capital, which are higher due to taxes and increased risk.
- Why the discount rate matters
 - Discounting affects the value placed on future benefits and costs.
 - Higher discount rates place less importance on future returns.
 - Note, for example, how this is a particular problem for long-term problems such as climate change.
 - Because the benefits of climate protection extend far into the future, calculations of the social cost of carbon are very sensitive to the choice of discount rates
 - 2%: \$121/ton
 - 3%: \$51/ton
 - 7%: \$6/ton

- Prest *et al.* give three reasons why a 3% rate is no longer appropriate for climate change
 - Since 2003, average real rates on US Treasury bills have fallen. Would suggest a discount rate of 2%
 - Uncertainty about future discount rates suggests using lower rates for longer time horizons
 - A 7% rate assumes costs of climate protection fall on private capital. But benefits of protection can also help private capital
- Because we use higher discount rates when growth is higher, uncertainty about future economic growth (e.g. because damages may reduce growth), discount rates also become uncertain
 - E.g. future discount rates should be linked to future growth
- Note also how the discount rate relates to economic growth theory
 - discount rate = pure rate of time preference + growth rate of income x elasticity of marginal utility for income
 - Represented as $r = a + bg$.
 - The first term, a , captures the relative weight placed on the future versus today
 - Involves ethical judgments
 - The second term acknowledges that, due to economic growth, we expect future generations to be richer
 - If the marginal utility of income falls as we get richer, than additional money is less valuable when we are richer
- How to choose the parameters a and b
 - Descriptive approach
 - Find parameters that match observed market rates
 - But note that different combinations of a and b can yield the same rate
 - Thus, theory also matters
 - Prescriptive approach
 - Based on:
 - ethical decisions (e.g. is a positive a appropriate)
 - surveys

- Might the social discount rate deviate from the market rate?
 - The above estimates use market data to determine the discount rate. Are their reasons to believe that the market rate is flawed?
 - Some economists argue that the opportunity cost of foregone future consumption might differ from the opportunity cost revealed in the markets.
 - In this case, it might make sense to use a social discount rate which is lower than the rates observed in the marketplace.
 - The social discount rate represents the willingness of society to trade off present and future consumption.
 - If there are market failures, this may differ from discount rates observed from market behavior.
 - Why might market rates not be appropriate?
 - Long term projects involve benefits or costs for future generations.
 - However, future generations are not represented in the market.
 - People may be myopic, and thus not save sufficiently.
 - There may also be other externalities that cause the market rate of return on investments to deviate from the social discount rate, such as positive externalities from research and development.
 - Uncertainty may be a concern
 - Therefore, risk aversion may justify using a lower discount rate. However, uncertainty is not an excuse to do nothing.
- [Drupp et al. \(2018\)](#) survey economists on the social discount rate.
 - They asked economists who have published on the topic.
 - Survey had 262 responses
 - They ask about each component of $r = \delta + g\eta$.
 - Also asked what social discount rate they would recommend for a global public project with intergenerational consequences.
 - Mean risk-free rate: 2.38
 - Mean social discount rate: 2.27
 - 68% of responses between 1 & 3 percent
 - Most common response: 2%
 - Mean rate of time preference 1.1%
 - Mean elasticity of marginal utility 1.35%
 - Should normative weights be used for SDR?
 - 80% think both normative and positive matter, and that normative matters should get more weight

II. Example: Benefit-Cost Analysis of Hybrid Delivery Vehicles

- We finished class discussing Krutilla and Graham's article in the *Journal of Policy Analysis* as an example of benefit-cost analysis.
- As a reminder, these are the steps to benefit-cost analysis that we discussed earlier. Note how the work in this article matches up with each of these steps.
 - 1) Specify clearly the project or program.
 - 2) Determine quantitatively the inputs and outputs of the program.
 - 3) Estimate the social costs and benefits of these inputs and outputs.
 - 4) Compare these costs and benefits.
- **Specify the project or program:** What is the project and/or policy analyzed?
 - In 2011, the National Highway Traffic Safety Administration (NHTSA) and Environmental Protection Agency (EPA) implemented new rules on fuel consumption and CO₂ emissions from medium- and heavy-duty trucks.
 - This analysis does a cost-benefit analysis of diesel-electric hybrid technology as a potential response to the new rules.
 - Specifically consider technology to propel urban pickup and delivery vehicles (PUADs).
 - PUADs operate at low speeds and stop-and-start frequently, making them good candidates for hybrid technology.
 - Companies such as FedEx and UPS use them
 - Hybrids have larger up-front costs and battery replacement costs, but save money on fuel
 - Incremental cost of about \$33,000 in 2012 for hybrid purchase.
 - Note that discounting is thus important!

- **What are the inputs and outputs of using this technology?** What are the benefits and costs?
 - What are the benefits of hybrid technology?
 - Value of fuel savings
 - Depends on market adjustments to reduced diesel demand
 - Paper assumes diesel prices set in global market, and thus not affected by increased hybrid usage
 - Value is thus market price of diesel net fuel taxes
 - Taxes are a transfer Ignores scarcity rents lost by domestic suppliers
 - Externalities
 - Environmental damages from CO₂
 - Tailpipe emissions that affect local air pollution
 - Function of miles traveled and fuel economy
 - National security issues with imported oil
 - Congestion, accidents, and roadway maintenance
 - Function of miles traveled
 - Not included, since occur even if a hybrid not used
 - Note importance of *marginal analysis* here
 - Assumes little rebound effect for delivery vehicles
 - What are the costs of hybrid technology?
 - Incremental technology costs
 - Additional capital costs
 - May improve over time, since the technology is immature
 - Cost of eventual battery replacement
 - Other changes in operating and maintenance costs
 - May be positive or negative

- **Estimate social costs and benefits:** How do the authors estimate social costs and benefits of these inputs and outputs?
 - Operational performance and fuel savings
 - Begin with a reference hybrid model
 - Assume both it and the conventional model would be driven for 20 years
 - Assumptions
 - Fuel efficiency: Hybrid gets 9.8 MPG, compared to 7.5 for conventional
 - Assume 1% improvement over time for hybrid
 - But, model future MPG probabilistically
 - Future MPG of conventional expected to improve in response to new regulations
 - 7.85 MPG in 2014
 - 8.2 MPG in 2017
 - Note that *Business as Usual (BAU)* (e.g. what happens with no intervention) is different than simply assuming the status quo continues forever
 - Miles driven: Assume driven 20,000 miles/year
 - Leads to fuel savings of 639 gallons per year
 - Assume mileage increase to 20,267 in 2017, because of rebound effect due to new fuel economy standards
 - Increases fuel savings
 - Fuel prices
 - Use projections from Annual Energy Outlook
 - Extend projections to 2050 for hybrids purchased in 2030
 - **Table 1** shows projections
 - Externality valuation (#s in **Table 1**)
 - Global climate benefit
 - Develop CO₂ equivalents for all emissions saved
 - Use social cost of carbon to monetize
 - Assumes SCC increases over time as CO₂ emissions increase over time
 - Include uncertainty analysis using a lognormal distribution based on Interagency Working Group on the Social Cost of Carbon report (2010)
 - Energy security
 - Costs of imports include potential disruptions and military costs with securing imported oil
 - Use Oak Ridge National Laboratory estimate of energy security benefits
 - Local air pollution
 - Includes reduction of NO_x, CO, and PM
 - Use an EPA study on the benefits of new air quality standards to get benefits

- Time savings in refueling
 - Apply a gallon pumped per minute value to fuel savings
 - Value time savings at relevant wage rate
 - Data from both taken from NHTSA (2011)
 - Comes to 3.8 cents/gallon saved
- Costs of hybrids
 - Current difference in costs is \$33,085
 - But future hybrid costs expected to fall
 - Use NRC report for the new rulemaking as a guide
 - Batteries replacement
 - Battery lifetime is 7 years
 - Sensitivity analysis showed little impact on results
 - Batteries currently cost \$10,353, assumed to improve over time at same rate as other hybrid technology
 - Assume O&M costs will be similar for hybrids and other vehicles
- Taxes
 - While taxes are transfers, they do impact private returns
 - Moreover, there are potential changes to revenues for different levels of governments (e.g. state vs. federal)
 - Consider fuel taxes, sales taxes, and corporate income taxes
 - E.g. value of fuel savings is after tax
 - Capital costs can be depreciated
 - There are thus additional tax savings for purchasers
 - The federal government loses tax revenues
- Discount rate
 - Use both 3% and 7%
 - 7% recommended by Office of Management and Budget (OMB)
 - Represents before-tax rate of return on private capital
 - 3% as example of social discount rate

- How do the authors address uncertainty?
 - Simulate NPV annually for hybrids purchased each year between 2012-2030
 - Account for fuel price, environmental, and technology trends
 - What assumptions must be made?
 - Assume a distribution of possible values for uncertain values, including:
 - Future fuel economy
 - Future fuel price
 - Future costs of hybrids
 - For these variables, the distribution includes minimum, maximum, and most likely values
 - These are the PERT distributions discussed on page 506
 - For other variables, they parameterize a wider distribution of potential values
 - Social cost of carbon (Weibull distribution, p. 509)
 - Air quality benefits
 - They run simulations using different values of these variables from each of their distributions
 - **Table 2** shows the combinations for three key variables using PERT
 - For each combination in Table 2, they run multiple simulations based on other uncertain variables.
 - These are the Monte Carlo simulations they describe on page 514.
 - What information do they use to inform their assumptions?
 - Used an expert panel to make projections, then used probabilistic modeling to characterize key variables

- **Compare costs and benefits:** What are their results?
 - Present results for four different stakeholders:
 - Private hybrid purchaser
 - State government
 - Federal government
 - Parties impacted by external costs
 - Net society includes all of these
 - **Tables 3 & 4** shows results for a single year – a hybrid purchased in 2014
 - Using a 7% discount rate (**Table 3**), the NPV is negative
 - Using a 7% discount rate for private costs and benefits, and 3% for social costs and benefits (**Table 4**), the NPV is positive
 - The column “Evaluator adjustor for differential discounting” converts the 7% discounted private costs and benefits into 3% discounted values for the social returns.
 - It is the extra benefit or cost if discounted at 3%, so that the total in Net Society is a total discounted at 3%
 - Why do results change?
 - Value of external benefits increase
 - Adjustment for fuel savings is also large (\$9,141). Why might it make sense to consider social value of this, and not just the private value?
 - Could be that more fuel is available for other uses.
 - **Figures 1 & 2** show the path of NPV over time
 - Show the most and least optimistic assumptions
 - Can see when NPV becomes positive for each group and for society
 - Preregulation Societal 3% represents a counterfactual simulation on baseline assumptions of the fuel efficiency of medium duty and heavy duty trucks
 - In early years, benefits smaller because new fuel economy standards implemented in 2014 & 2017
 - These reduce the relative gains from diesel-electric hybrids, as other vehicles become more efficient
 - NPV of Diesel-electric hybrid for society at 3% is around \$1,196, but would be \$17,773 without new fuel economy regulations on medium- and heavy-duty trucks
 - Expected NPV increases after 2017 for all scenarios because of projected technology improvements

- Key results
 - NPV for society at 3% always positive with optimistic assumptions (Figure 1), but is negative until 2025 with low assumptions (Figure 2)
 - For private investors, NPV doesn't become positive until 2024 in Figure 1, and never becomes positive in Figure 2
 - Private and social diverge over time because of changes in taxes over time (p. 520-521).
- *Is the long-term benefit worth the short term costs?* E.g. should early hybrid development be subsidized to encourage future cost savings?
 - Discount the NPV of a purchase in each year back to the initial year
 - Tables show mean of each simulation, as well as the probability that NPV is positive for each set of assumptions. Note standard deviations and 90% confidence intervals also included.
 - **Table 5** shows societal perspective
 - mean NPV never positive with 7% discount rate
 - mean NPV positive for 5 of 8 cases with 3% social discount rate
 - **Table 6 & 7** show effect on state and federal revenues
 - States gain money (presumably sales taxes), federal government loses money (corporate income taxes)
 - **Table 8** shows total fiscal impact
- Conclusions
 - The authors argue that most studies ignore tax distortions, but that they do matter
 - Changes in sales and corporate income tax revenue dominate effect on fuel taxes
 - Given that NPV only positive for social returns when using 3% rate, and isn't positive for private citizens, does this justify policy to support hybrid-diesel technology?