ECON 180

Introduction to Principles of Microeconomics and Financial Project Evaluation

Lecture 24: Switching Values

November 2, 2021

Version 1.

Required Reading

- Riley, J. (n.d.). Breakeven Point (GCSE) [Web Page]. Retrieved from https://www.tutor2u.net/business/reference/breakeven-point
  - A short discussion of **break-even points** intended for UK high schoolers.

Sources

- Hammer, J. (1997). Economic Analysis for Health Projects. *The World Bank Research Observer, 12*(1), 47-71. Retrieved from https://www-jstor-org.ezproxy.library.uvic.ca/stable/3986358
- Liu, G. & Sun, B. (2007). Multi-product Dynamic Break-even Analysis and Its Application. *2007 International Conference on Management Science and Engineering*, 2164-2169. Retrieved from https://ieeexplore-ieee-org.ezproxy.library.uvic.ca/document/4422160
- Sritrakul, N., Santhadkha, T., Hudakorn, T. & Jaruyanon, P. (2019). Feasibility Study of an Electric Shuttle Bus in Silpakorn University, Sanam Chandra Palace Campus, *2019 7th International Electrical Engineering Congress (iEECON)*, 1-4. Retrieved from https://ieeexplore-ieee-org.ezproxy.library.uvic.ca/document/8939026

Switching Value Case Studies I

- Atkins, S. L. (1999). The Economics of Smallholder Irrigation Systems in Swaziland. *Agrekon*, 38(S1), pp. 269 – 283. Retrieved from https://doi-org.ezproxy.library.uvic.ca/10.1080/03031853.1999.9524921
  - **Sprinkler table example**
- De Graaf, N.R., Filius, A.M. & Huesca Santos, A.R. (2003). Financial analysis of sustained forest management for timber: Perspectives for application of the CELOS management system in Brazilian Amazonia. *Forest Ecology and Management*, 177, pp. 287 - 299. Retrieved from https://doi-org.ezproxy.library.uvic.ca/10.1016/S0378-1127(02)00323-7
  - **Timber example**
- Kennedy, D. (2007). New nuclear power generation in the UK: Cost benefit analysis. *Energy Policy*, 35, pp. 3701 – 3716. Retrieved from https://doi-org.ezproxy.library.uvic.ca/10.1016/j.enpol.2007.01.010
  - **Scenario-specific switching value graph example.**
- Yu, S. & Ting, J. (2008). Life cycle simulation-based economic and risk assessment of biomass-fuel ethanol (BFE) projects in different feedstock planting areas. *Energy*, 33, pp. 375 – 384. Retrieved from https://doi-org.ezproxy.library.uvic.ca/10.1016/j.energy.2007.10.009
  - **Switching values as deviations from baseline example.**

Switching Value Case Studies II

- Brown, J. & Macfayden, G. (2007). Ghost fishing in European waters: Impacts and management responses. *Marine Policy*, 31, 488 – 504. Retrieved from https://doi-org.ezproxy.library.uvic.ca/10.1016/j.marpol.2006.10.007
  - Uses **switching values** to investigate 'ghost fishing'.
- European Union. (2014). *Guide to Cost-Benefit Analysis of Investment Projects for Cohesion Policy 2014-2020*. Retrieved from https://ec.europa.eu/regional_policy/en/information/publications/guides/2014/guide-to-cost-benefit-analysis-of-investment-projects-for-cohesion-policy-2014-2020
  - A **free textbook** with many case studies and worked examples.

Learning Objectives

- Understand the use of switching values, and be able to create and interpret break-even graphs.
- Understand the importance of incorporating the time value of money and other relevant opportunity costs into break-even and switching value analysis.

ESSENTIALS (20 slides)

Break-Even (Switching Value) Analysis

- We saw in our sensitivity graph that slight changes in a variable could affect the outcome of our present worth evaluation.
- A natural question is: holding everything else at baseline, at what level of each value does the present worth of the project become zero?
- These values are called **switching values**.
- The investigation of switching values for the NPV is sometimes called break-even analysis, since you're examining the conditions under which the project just breaks even compared to your fallback project (NPV = 0).

Switching Value

- When all other variables are constant…
- The value of a variable that makes the BCR = 1
- The value of a variable that makes the NPV = 0
- On either side of this value, the project switches between being recommended and not recommended.
- The switching value is the value at which our recommendation for the project *switches*.
- Useful when we don’t have good values for Min/Max, or when asking ’what would it take for this project to be/not be worthwhile?’
- Also good at letting you know whether the project is resistant to shocks.

Benefits/Costs of a Fishing Gear Retrieval Program

Sensitivity analysis of cost/benefit model

Ghost fishing: fish deaths from abandoned/lost fishing gear

This particular program is unlikely to be worth it…

Variable (Brown & Macfayden, 2007)	Base case	Resulting benefit/cost ratio[a]	Switching value[b]
Base case		0.49	
Vessel numbers	40	0.73	82
% of lost gear found	50%	0.73	>100%
Vessel numbers	40	0.51	N/a
% of lost gear found[c]	50%		
Cost of retrieval programme	€46,500	0.3	€22,664
Total ghost catch over 1 year by one fleet[d]	3.65 tonnes	0.52	10.7 tonnes
Ghost catch by lost fleet as a % of all active vessel fleets	5%	0.52	14%
Number of days after net loss that daily ghost catches = 5% of active catches	90	0.52	262
Number of nets lost per year per vessel	1	0.73	2.1
Number of nets per fleet	100 net panels/fleet	0.24	N/a
Fleets used	3 fleets		
Cost of nets and markers/floats for one fleet	€9500	0.73	€19,475

[a] A benefit/cost ratio of <1 indicates that benefits do not outweigh costs.
[b] The value of the variable that would result in a positive benefit/cost ratio with all other variables remaining constant.

When are switching values most useful?

- When the number you ideally want to calculate isn't available with precision, or controversial – e.g., the value of a human life.
- Consider a highway improvement project that will reduce the number of accidents.
- You have VERY good data on costs, and on how many fatal accidents will, in expectation, be prevented.
- Problem: costs are in $, and the avoided fatalities are in terms of human lives. No matter what method you use to calculate the value of a human life, someone will have an objection to it.

One way (not the only way) around it:

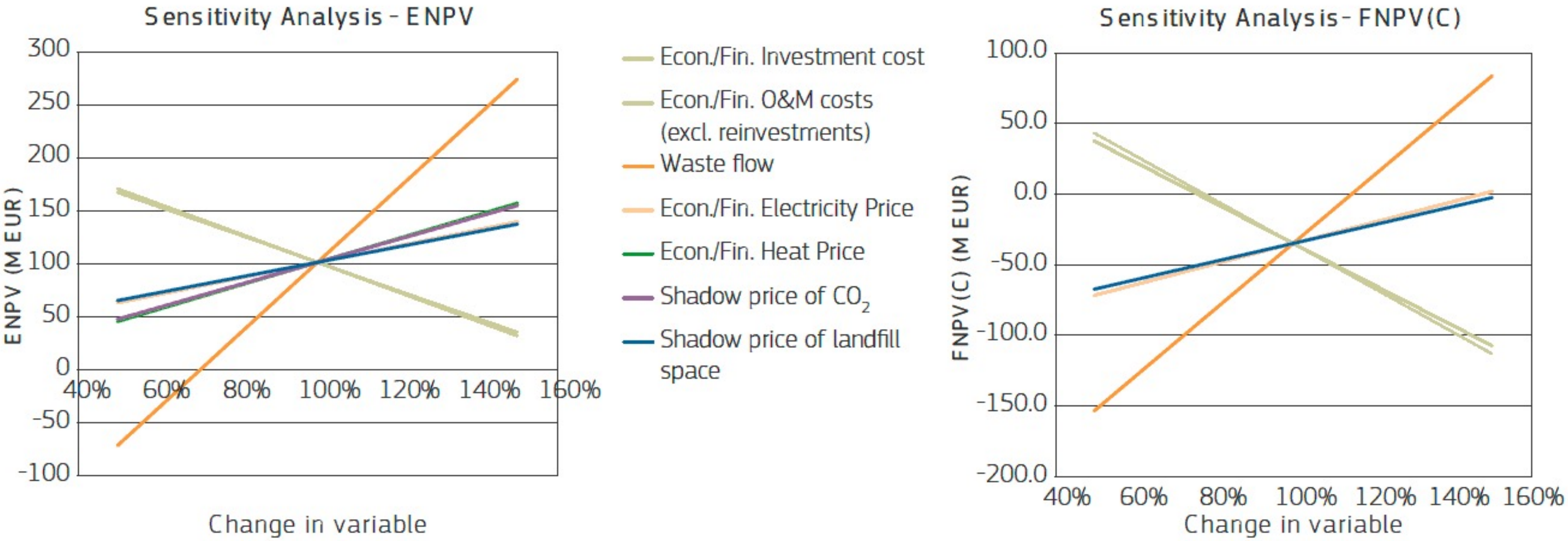
- Calculate the switching value:
- What would the value of a human life have to be for the project NOT to be worthwhile?
- If this value is huge, say, $1 trillion, then whatever the value of a (statistical) human life is, you're pretty sure it's below that.
- If the value is very low, say, $5,000, then you can be fairly sure that whatever the value of a human life is, it's above that.
- That can help you provide reasonable guidance on whether the project should be pursued or not, even if you can't comfortably commit to a single, precise calculation in $ of the value of interest.

From a World Bank research paper

- From (Hammer, 1997): "One way around the **valuation of life** issue is provided by the National Schistosomiasis Control project for Egypt”
- Schistosomiasis, or ”snail fever,” is an illness caused by parasites.
- “For this project the [internal] rate of return was calculated under the assumption that the ‘**switching value**’ that would make the project fail to pass a 10 percent rate-of-return test can be calculated and shown to be unreasonably low”.
- (In other words, the value that would make IRR > MARR when MARR = 10%.)
- “This method will not always give clear answers, however. Sometimes the value of life so obtained will be within a reasonable range for such a number. At the least, though, this calculation could give the policymaker something to discuss."

Switching values are built into spider diagrams: we're switching focus, not really doing anything new.

Spider diagrams illustrating the elasticities and switching values for the above mentioned variables are depicted below.



The sensitivity analysis shows that in the economic analysis, only the waste input, and to a lesser extent the investment and operating cost as well as the economic cost of heat and the shadow price of CO_2, constitute critical variables. In the financial analysis, on the other hand, most of the tested variables are critical for the FNPV(C)[243]. This can be explained by the fact that the FNPV(C) is not far from 0 (in which case the project investment would be sufficiently profitable without any external support).

(European Commission Textbook, p. 207)

How do you calculate switching values?

- Write down the equation you are using to measure the worth of your project, e.g.
- NPV = PV Benefits – PV Costs, or BCR = PV Benefits/PV Costs
- Set these equal to the value at which a project is barely worthwhile – for NPV, this is $0, for BCR, this is 1.
- Set all parameters except the one whose switching value you want to solve for, to their baseline values.
- Leave the remaining parameter as a variable.
- Solve for that variable. That's your switching value.

Looking at Lunch again

- Suppose your lunch today costs \$11.
- Benefits = WTP for Lunch
- Recall: WTP = Willingness to Pay
- Cost = \$11
- B/C = WTP/11 → Switching Value of WTP = \$11
- If WTP > 11, BCR > 1, NPV > 0 → Lunch is worth it
- NPV = WTP – 11 → Switching Value of WTP = \$11
- If WTP < 11, BCR < 1, NPV < 0 → Lunch is not worth it
- The switching value for our WTP is \$11.

The IRR is a switching value!

- Suppose we pay \$100 today for \$200 in one year, and our MARR is currently 25%/year.
- How high can the MARR get, and still have the project break even?
- NPV = -100 + 200/(1 + MARR)
- Setting NPV – 0, -100 + 200/(1 + MARR) = 0
- Solving for $MARR_S$ (S for 'Switching'):
- -\$100 + \$200/(1 + $MARR_S$) = 0 → $MARR_S$ = 100%
- This is also the IRR of the project (recall that we find the IRR by setting the NPV = 0 and solving for the MARR).

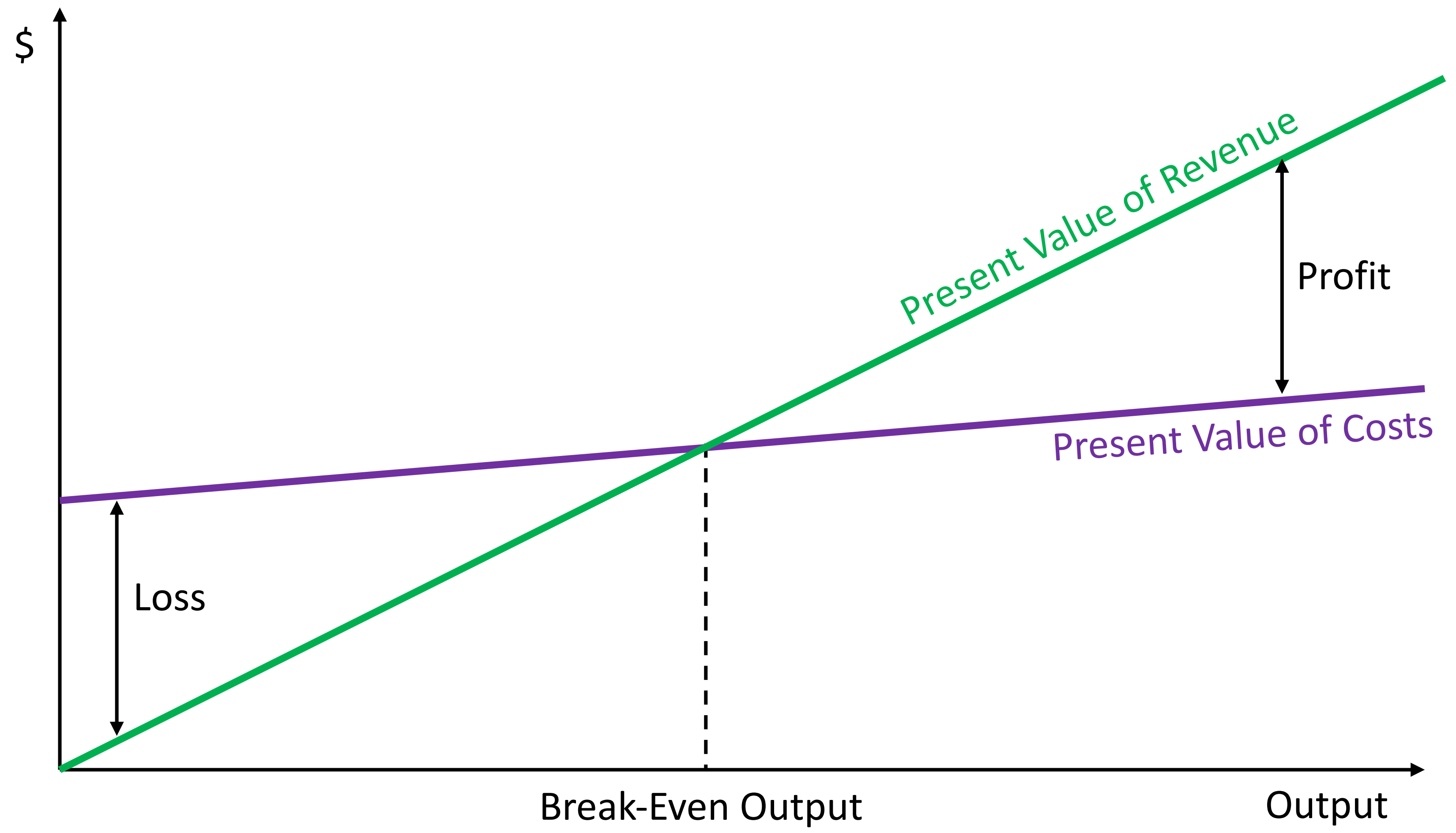
The other switching values…

- Let's find switching values for the other two parameters, Cost and Benefit.
- Cost: -$Cost_S$ + \$200/(1 + 25%) = 0 → Cost = \$160
- Benefit: -100 + $Benefit_S$/(1 + 25%) = 0 → $Benefit_S$ = \$125
- Note that each time, we kept all the parameters we weren't solving for at their usual numerical levels.

Break even graphs

- Uses a graph to show what values a project parameter can take and have the project still break even.
- Vertical Axis: same units as project worth (usually $)
- Horizontal Axis: relevant parameter.
- Plot benefits and costs separately, then see where they cross.
- These graphs are useful for eyeballing how bad things can get in any one dimension and still have the project pay off.
- These are very commonly used in business, where they often look like the example on the following slide.

A one-project business break-even graph



- NPV = Present Value of Revenue – Present Value of Costs

C. Break-even point analysis

The break-even point analysis (BEP) can be calculated as:

$$Sale\ price = \frac{Fixed\ cost + Variable\ cost}{Number\ of\ pieces} \qquad (1)$$

D. Project evaluation method

The project evaluation method consists of:

- Payback period (PB)

$$PB = \frac{Initial\ investment\ of\ the\ project}{Net\ cash\ flow\ of\ the\ project} \qquad (2)$$

- Net present value (NPV)

$$NPV = \left(\sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} \right) - CF_0 \qquad (3)$$

where: CF_0 = Initial investment of the project

CF_t = Net cash flow of the project in each period

t = Project duration

n = Project age of the investment

i = Discount rate of the project

A common problem

- Shockingly often, even in the peer-reviewed literature, practitioners calculate break-even values *without taking the time value of money into account.*
- This is even the case when they calculate other measures of project worth, that *do* take these into account!
- Case in point on the left (Sritrakul et al., 2019).
- Let's fix it.

What’s the situation?

- Want to see how feasible it is to run an electric shuttle at a university in Thailand.
- In particular: want to know how much they’d need to charge per ride to break even.
- The bus will last 5 years.
- The relevant MARR is 7.8018% per year (average bank rate)
- Total passengers over 5 years = 709,280
- Some of the information I would like to have is not in the paper, or is contradictory (e.g. working days/year not specified, though it looks they used ~258, kWh/trip listed as 1/trip, but also 25.78/day, when there are 52 trips per day), so I’ll use the *totals* given and work backward.

Calculating monthly costs

- 5 x 12 = 60 months, and assuming first payment at Time 0,
- PV (Monthly Costs) = A + A x (P/A,MARR,59)
- MARR = $(1+7.8018\%)^{1/12} - 1$ = 0.6280% per month
- Total costs over 5 years (60 months) for…
- Energy: 135,181.65
- Labour: 516,240.78
- Energy + Labour = 641,422.43
- →A = 641,422.43/60 = 10,857.04
- **→PV = 10,857.04 + 10,857.04 x (P/A,0.6280%,59) = 544,761.64**

Other costs

- **Initial (Month 0) cost of 963,000**
- Maintenance costs of 260,000
- Maintenance is done every other year – assume Year 2, 4.
- Costs 260,000/2 = 130,000 per maintenance
- MARR = $(1+7.8018\%)^2 - 1 = 16.21\%$ per two years
- **PV Maintenance = 130,000 x (P/A,16.21%,2) = $208,122.80**
- Total costs = Fixed + PV of A + PV of Maintenance
- **Total costs = 963,000 + 544,761.64 + 208,122.80 = 1,715,884.44**

Revenue

- To keep things manageable, I’ll assume revenue is paid monthly.
- Why? I don’t know their ‘working days per year’ assumption, or how those working days are distributed throughout the year.
- I also don’t know which months have more or less passengers: GIGO.
- Total passengers across 5 years = 709,280
- Average passengers/month = 709,280/60 = 11,821 (to nearest passenger).
- Revenue per month = F x 11,821, where F is fare
- Let’s assume fares are collected at the *end* of the month, not in advance: we have a well-behaved, 60 payment annuity.
- PV Revenue = F x 11,821 x (P/A,0.6280%,60) = F x 5889,427.57

Breaking Even

- At the Break Even point, NPV = 0
- NPV = F x 589,427.57 – 1,715,884.44
- →Switching value of F is
- **F_{switch} = 1,715,884.44/589,427.57 = 2.91 baht**
- This is 10% higher than the paper's 2.64 baht, calculated while ignoring the time value of money.
- Ideally: more accurate and frequent compounding for fares (per day, taking the distribution of passengers across seasons, etc.).
- (I'd also have liked information on *exactly* how and when electricity s paid for – are there peak/off-peak rates? Paid monthly? Immediately on use?)

A 2007 paper nails it

- From (Liu & Sun, 2007):
- “[T]raditional break-even analysis takes zero-profit as the break-even point, [but] does not consider the time value of money, and is a kind of static analysis”.
- “Zero-profit-based break-even actually means that the project has lost income at the basis profit level, and has potential losses.”
- Calculating a ‘break-even’ point while ignoring the time value of money does not take into account the *opportunity cost* of those resources.
- You can more than break even, and still be worse off, *compared to the next-best use of those resources.*
- If, instead, you calculate the break-even point as the point at which NPV=0, then at that point you’re *just as well off as with the fallback project your MARR was derived from*.

A very simple example

- Pay \$10,000 today, get \$F in a century (100 years from now).
- Under traditional break-even analysis, the break-even value is such that Income – Costs = 0 → \$F - \$10,000 = 0, → F_{switch} = 10,000.
- So, if F = 10,001, you're more than "breaking even"…
- But suppose your MARR is 2.5% per year, and you consider you've 'broken even' if NPV=0.
- NPV = -10,000 + F x (P/F,2.5%,100)
- →F_{switch} = 10,000/(P/F,2.5%,100) = 118,137.16
- Anything less than F=\$118,137.16, and you'd have been better off with your fallback project.
- Using NPV=0 as your threshold for breaking even helps you make better decisions by telling you when you break even *with respect to your fallback project*.

AFTER HOURS

- Published examples (6 slides)

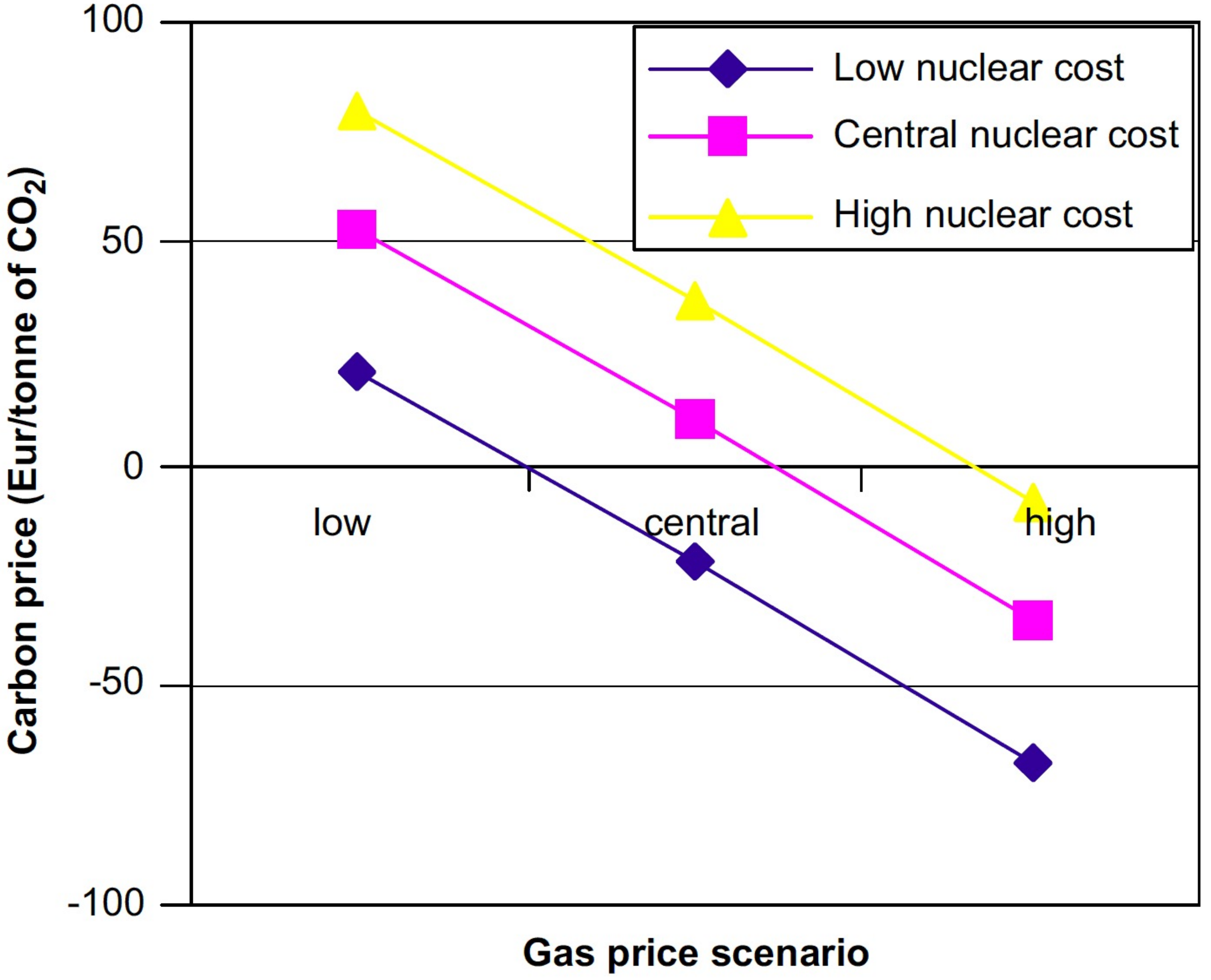


Fig. 1. Switching values for varying gas prices/carbon prices/nuclear costs. (Kennedy, 2007)

Sometimes, Switching Values are plotted on their own.

This allows the graph to combine scenario analysis and break-even analysis.

This graph shows how switching values change as a function of gas and carbon prices.

Each line is for a different scenario. Along each line, society's NPV is zero.

For each scenario, the line plots switching values as a function of gas and carbon prices.

Switching values for the key variables are presented in Fig. 1. The figure shows that the CO_2 price can fall to Euro 10 [£7]/t before the welfare balance is negative in a central gas price—central nuclear cost scenario. In a low gas price scenario, the CO_2 price must rise to Euro 54 [£37]/t in order for the nuclear welfare balance to be positive; this carbon price is within the range between DEFRA's central and high case estimates of the social cost of carbon. In a high nuclear cost scenario, the CO_2 price must rise to just above Euro 36 [£25]/t, or the gas levelised cost must rise to £34.80/MWh for a CO_2 price of Euro 36 [£25]/t, in order that the welfare balance is positive.

Nuclear generation is likely to be justified in a world where there is continued commitment to carbon emissions reduction and gas prices are at or above 37 pence/therm. (Kennedy, 2007)

How are switching values reported?

- Very often, switching values are presented as percentage deviations from baseline: this is useful, since the lower this value, the more sensitive the variable is.

According to switching value analysis, the NPV of WFE is most sensitive to wheat's market price, conversion rate of wheat, and gasoline price. If there is a 50.43% drop of wheat's market price (mean value of its distribution), from 1140 to 565 RMB/ton, or a 68.68% rise of gasoline's price (mean value of its distribution), from 3400 to 5700 RMB/ton, or a feedstock conversion rate improvement from 1:3.7 to 1:1.84, the expected NPV would be greater than zero. (Yu & Tao, 2008)

Table 5
Switching values of timber sale and cost at different discount rates

(De Graaf et al., 2003)

Discount rate (%)	Switching value timber sale		Switching value cost	
	Land-extensive option	Land-intensive option	Land-extensive option	Land-intensive option
5	43	53	7	111
8	35	49	55	194
10	30	46	42	86
15	16	41	19	70
20	1	36	1	56

Table 5 gives the outcomes of another type of sensitivity analysis, namely a breakeven analysis on base of switching values. The breakeven analysis gives an answer on the question at which value an option becomes critical; that is when the NPV becomes zero (total discounted benefits equal total discounted cost).

The switching values for timber sale give the percentage with which timber sale revenues can decrease before an option will be critical. According to Table 5, the timber sale revenue may decrease with 35% in the land-extensive option and even 49% in the land-intensive option at an 8% discount rate before the critical point will be reached. The switching value of cost gives the percentage with which the cost can increase before the NPV will be zero. At 8% discount rate this switching value is in the land-intensive option 94%. This breakeven analysis shows that from the point of view of uncertainty, the land-intensive option is much more acceptable than the land-extensive option. (De Graaf et al., 2003)

Table 5: Sensitivity analysis (switching values*) on discounted cash flows for five selected irrigation systems

Parameter	Irrigation System				
	Furrow	Dragline Sprinkler	Floppy Sprinkler	Centre Pivot	Drip
Capital costs of irrigation system	73%	**127%**	90%	109%	29%
Irrigation operating costs:					
Power tariff	Na	148%	**198%**	133%	66%
Irrigation labour	200%	325%	**925%**	900%	300%
Water consumption	Na	148%	**207%**	138%	66%
Equipment maintenance	693%	540%	**582%**	756%	108%
Capital cost of water to field	25%	40%	**41%**	30%	11%
Sugar-cane production:					
Fertilizer	93%	147%	**161%**	154%	44%
Labour (general)	100%	162%	**168%**	160%	46%
Transport to mill	60%	86%	**93%**	81%	24%
In-field maintenance	420%	660%	**702%**	688%	200%
Total production costs	14%	18%	**22%**	18%	5%
Sugar-cane production:					
Sugar-cane yields	-8%	-11%	**-12%**	-10%	-4%
Sucrose yields	-6%	-9%	**-10%**	-6%	-1%
Sucrose prices	-6%	-9%	**-10%**	-9%	-2%

Note: *The switching value is the change in a given parameter needed to bring the NPV to zero (or breakeven). N.a. is recorded twice against furrow irrigation water consumption as the model based this parameter on quantity of water pumped. (Atkins, 1999)