A Decision-Theoretic Approach to Setting Buffers Between Fishery Management Targets and Limits

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Decision theory basics

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Key features of decision theory (DT)

- Supported by vast, rigorous literature
  - Most of this is not directly related to fisheries
- Although theory is rigorous, mechanics simple
- Probabilities are incorporated
- Utilities are incorporated
  - Major difference from "probability-only" (PO) approach
- In application to fisheries:
  - Limit F corresponds to risk-neutral optimum
  - Target F corresponds to risk-averse optimum
  - Buffer ($\equiv 1 - F_{tar}/F_{lim}$) increases with "uncertainty"

Some "fair bets"

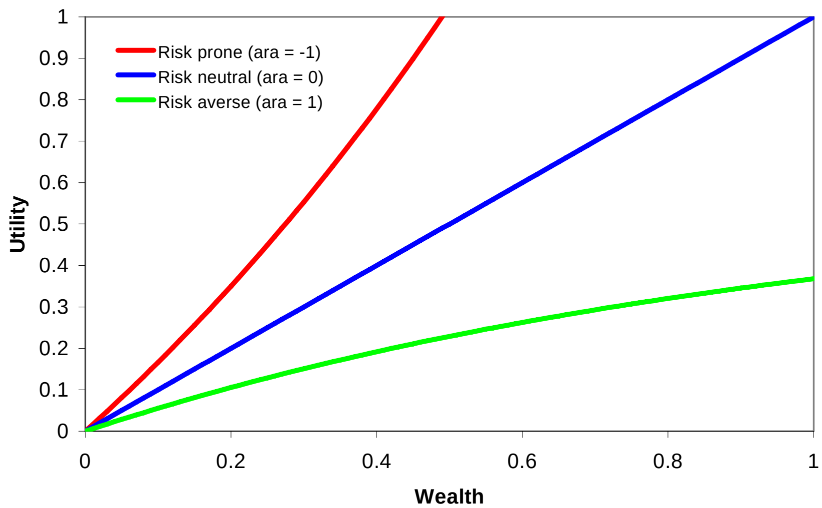
1. You increase your net worth by 100% with probability 0.50 and decrease your net worth by 100% with probability 0.50
2. You increase your net worth by 300% with probability 0.25 and decrease your net worth by 100% with probability 0.75
3. You increase your net worth by 9900% with probability 0.01 and decrease your net worth by 100% with probability 0.99

- In all cases, expected net worth is unchanged

Most people decline fair bets—but why?

- Cramer (1728) and Bernoulli (1738) said that people's *feelings* about money are nonlinear
- If you had twice as much money, would you be twice as happy?
- Objective should be to maximize expected *utility* (EU), not expected *wealth*
  - EU: Multiply probability by utility, sum across outcomes
- Conversely, if loss ≡ –utility and risk ≡ expected loss, objective is to *minimize risk*
- Risk aversion is *not* a probability; it is an attribute of the utility (or loss) function

Example utility functions



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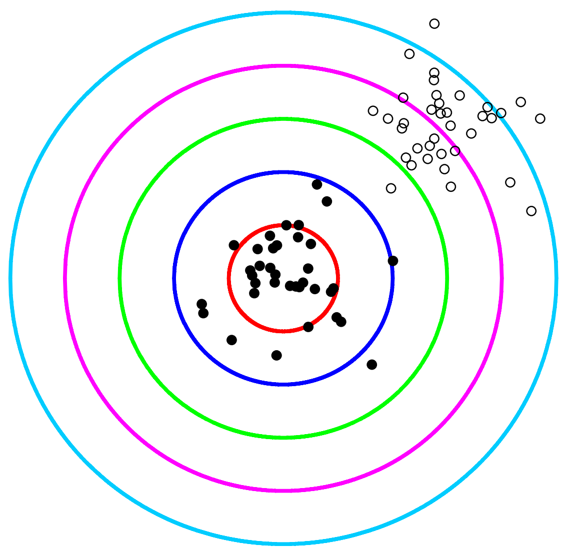
How to choose utility function

- Option 1: Estimation
  - Utility functions are real, observable quantities
  - Thus amenable to statistical estimation
  - Large literature on estimation techniques
  - E.g., “certainty equivalents” for hypothetical wagers
  - Problem of whose utility function to estimate
- Option 2: Specification
  - If time or other resources are insufficient to permit estimation, choose a utility function that seems appropriate based on performance in simulations or previous studies

DT versus PO: Marksmanship analogy



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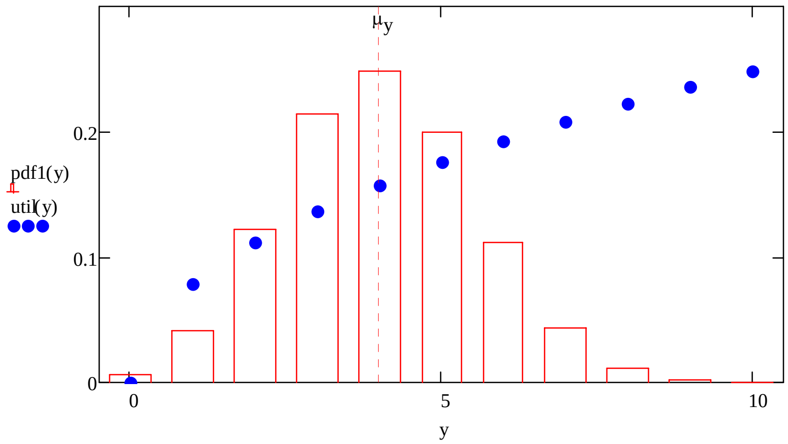
DT versus PO: Another example

- You are offered a wager where one outcome involves winning money and the other involves losing money.
  - Probability-only: “I don't want to lose money. Therefore, I will take the bet only if the probability of losing is small; say, less than 25%.”
  - Decision theory: “I am interested not only in the *probability* of losing/winning, but *how much* money I might lose/win.”
- You then learn that the bet guarantees a 20% chance of losing $1 million and an 80% chance of winning $1.
  - Probability-only: “I’ll take the bet!”
  - Decision theory: “Are you crazy?”

How about some fishery examples?

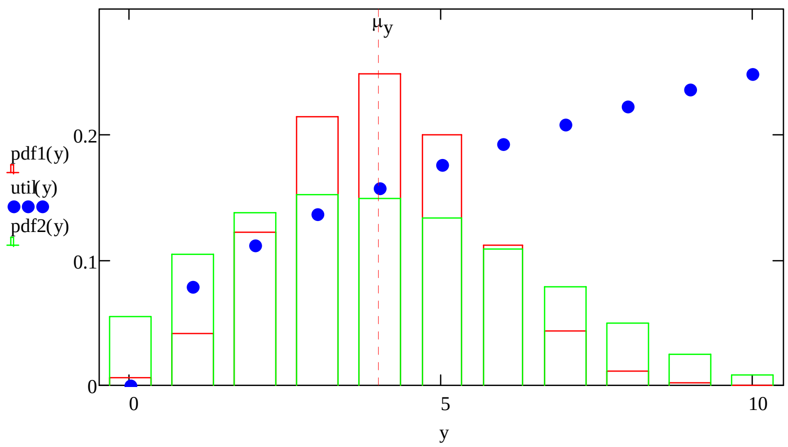
Calculating expected utility

- Multiply probability by utility, then sum



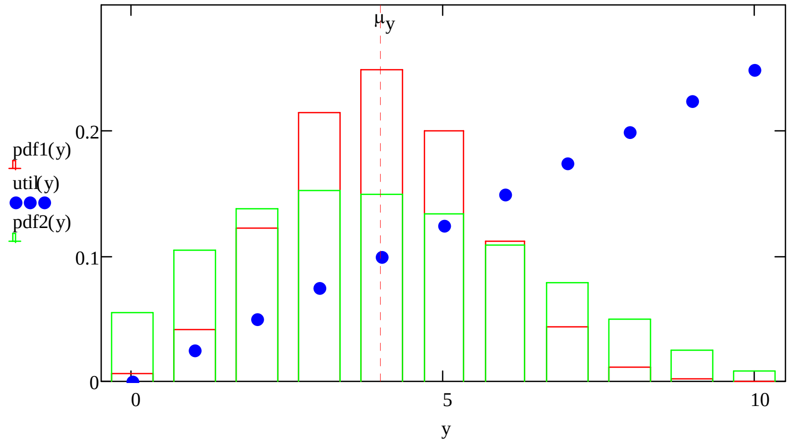
Maximizing EU: risk aversion

- Different pdf for each F; here, red pdf has higher EU



Maximizing EU: risk neutrality

- Here, both pdfs have the same EU (mean yields equal)



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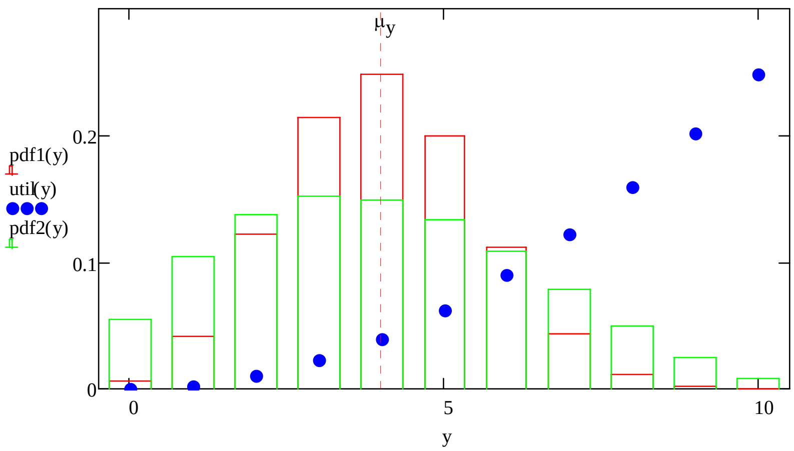
Maximizing EU: risk proclivity

- Here, choose the F associated with green pdf (higher EU)



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What if pdfs have different means?

- The math of computing EU is exactly the same
- Optimization will involve a weighted function of mean *and* variance (not just variance)
  - Mean yield weighted positively in all cases
- Sign of variance weight depends on risk attitude
  - Risk averse: Variance weighted negatively
  - Risk neutral: Variance unweighted
  - Risk prone: Variance weighted positively
- Ratio of weights (variance:mean) is proportional to the level of risk aversion in some models

How big are buffers likely to be?

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Parameter inputs (factorial design)

- Uncertainty, spawning per recruit, natural mortality

cv_m	cv_p	cv_r	$rspr_{msy}$	v
0.10	0.05	0.20	0.35	0.10
0.20	0.10	0.30	0.40	0.20
0.30	0.15	0.40	0.45	0.30

- Fishing mortality at MSY

	v =0.1			v =0.2			v =0.3		
$rspr_{msy}$	25%	50%	75%	25%	50%	75%	25%	50%	75%
0.35	0.124	0.135	0.146	0.220	0.237	0.254	0.304	0.322	0.340
0.40	0.103	0.112	0.121	0.187	0.201	0.216	0.262	0.278	0.294
0.45	0.086	0.094	0.101	0.158	0.171	0.184	0.225	0.239	0.254

MSE results

- Ranges and averages:

Statistic	ara =0.25	ara =0.50	ara =0.75	ara =1.00
minimum f_{tar}/f_{msy}	0.34	0.26	0.23	0.20
average f_{tar}/f_{msy}	0.65	0.56	0.50	0.47
maximum f_{tar}/f_{msy}	0.94	0.90	0.87	0.84
maximum buffer	0.66	0.74	0.77	0.80
average buffer	0.35	0.44	0.50	0.53
minimum buffer	0.06	0.10	0.13	0.16

- For case-specific buffer size, handy regressions permit rapid estimation *on a pocket calculator*

What about the NS1 guidelines?

- If used to compute ABC, the decision-theoretic approach does not fit the guidelines very well
  - "The determination of ABC should be based, when possible, on the probability that an actual catch equal to the stock's ABC would result in overfishing...."
  - If used to compute ABC, probably best to exclude implementation error from "uncertainty"
- Could be used to set some other target instead
  - ACT, OY, or some other target (see Comment 4)
- PO approach could be used as a constraint
  - Set ABC based on decision theory unless it results in a probability of overfishing greater than P*

Conclusions

- In decision theory, risk is expected loss ($\equiv -$EU)
  - *Not* a probability
  - Risk *aversion* is a property of the utility function
- Decision theory sets buffer optimally
  - Manage fishery so as to maximize something *good*
  - Not to achieve a fixed probability of something *bad*
- Math is no harder than probability-only approach
- Regressions provide shortcut if needed
- Creativity required to comply with NS1 guidelines

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