Value of Information

FISH 558 Decision Analysis in Natural Resource Management

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Consulting

Review of Decision Analysis and Expected Value

Hilborn's Gamble

Action	**Outcome**		**Expected results**
	Red	Blue	
Probability	0.2	0.8	
Bet on Red	**$100**	**-$5**	$16
Bet of Blue	**-$20**	**$40**	$28
Don't play	**$0**	**$0**	$0

- There is an opaque box with 1000 balls in it. 200 balls are red and 800 are blue. You can bet on the color of a ball selected at random from the box. A bet on blue costs $20 and you win $60 if a blue ball is selected, whereas a bet on red costs $5 and you win $105 if a red ball is selected.

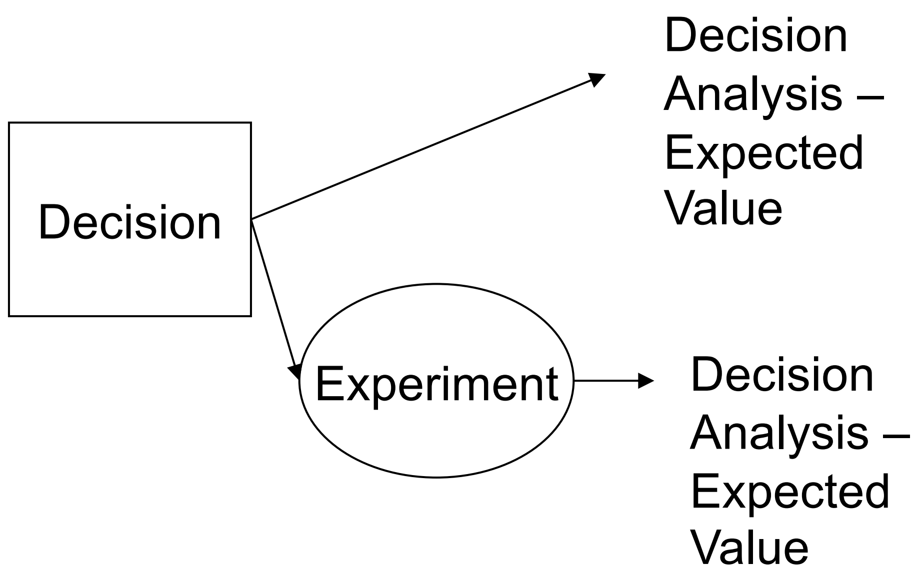
Review Decision Analysis II

- Hilborn's gamble highlights the four key elements of a decision analysis:
  1. The outcome (or "state of nature") - "red" or "blue".
  2. The alternative actions - "bet on red", "bet on blue", "don't play".
  3. The consequences of each action if each state of nature is true.
  4. The probability of each state of nature.
- Calculating the "probability of something bad happening" could be part of Step 3.

Types of additional information
(additional relative to information at current point in time)

- Collect more data using existing methods, which *may* lead to an improved understanding of the system.
- Improve the precision of existing method, e.g., increase sample size.
- Initiate new sampling methods, e.g., video surveys.
- Conduct a study that reduces the uncertainty in specific rates that are important to the population, e.g., acoustic or satellite tagging for estimating movement, survival.
- Force system to states that reveal information about competing underlying mechanisms - active adaptive management.

Example 2 – run an experiment?



- The results of running an experiment are used in the decision problem
- Thus have two possible scenarios – decision making with the results of the experiment or decision making without it
- Note: Expected Value (with Exp) $\geq$ Expected Value (without Exp)

But at what cost?

- Collecting additional information has a cost
- Can the cost be justified in relation to the value of the new information?
- Begs question of valuation
  - Economic settings - will the information have a net present value greater than 0 – i.e., will the investment "pay" for itself via capital markets
  - Conservation settings – less clear, as the value can not be determined from an existing market and thus other methods must be used, e.g., utility

Back to Hilborn's Gamble

- What if conducted an experiment to estimate the ball color before placing your bet?

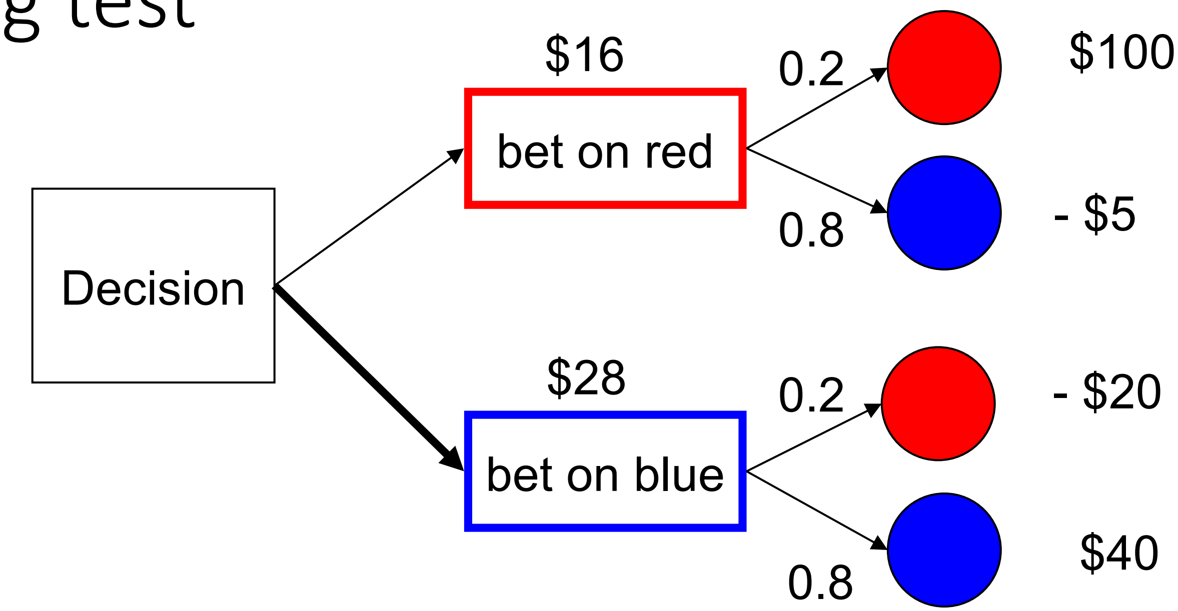
- How much would you be willing to pay for the experiment (test for color)?

Perfect test – 100% Accuracy

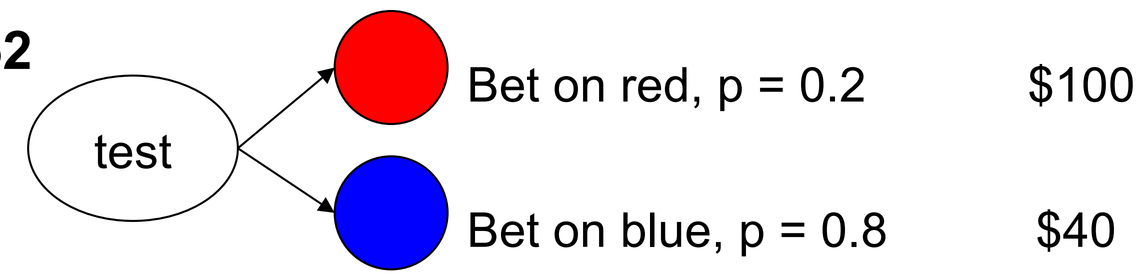
- If the test was 100% accurate, then we can calculate the expected value of perfect information (EVPI) – a hypothetical concept
- Definition of EVPI: the price that one would be willing to pay in order to gain access to **perfect information**
- EVPI thus forms the upper bound on the expected value of information
- EVPI = EV (with test) – EV (without test)

EVPI – gambling test

EV (no test) = $28



EV (with test) =
0.2*$100 + 0.8*$40 = $52



EVPI = EV(with test) – EV(no test) = $52 - $28 = $24

What affects EVPI?

- The expected value under current decision making (i.e., without the test) – if you can make decisions that are close to optimal now, then there isn't much increase in value to be had.

- The relative payoffs - one can justify even slightly better information if lucrative resources are being evaluated (relates to the slope of the utility function).

Thank you

If you will begin with certainties, you shall end in doubts, but if you will be content to begin with doubts, you shall end in almost certainties. -- Francis Bacon

Additional questions?
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…but no test is perfect!

- Expected value of sample information (EVSI)
  $0 \leq EVSI \leq EVPI$
- For example, what if test was only 90% accurate?
- Now we have to factor in the probability of the test giving us accurate information
  - Probability of test results P(test)
  - Revise priors given test Pr(theta|test)
  - Make decision based on test result
  - Calculate EV (with test)
  - Value of test = EV (with test) – EV (without test)

Calculating EVSI

- Test specifics
  - Two outcomes from the test:
    - Test predicts red ball = PR
    - Test predicts blue ball = PB
  - Test has error, though
    - Probability of a correct test is 0.9

$$pr(PB|B) = pr(PR|R) = 0.9$$

$$pr(PB|R) = pr(PR|B) = 0.1$$

Calculating EVSI - II

- Next we calculate the probability of the test predicting blue and the probability of predicting red:

pr(PB) = pr(PB|B)*pr(B) + pr(PB|R)*pr(R)
= 0.9*0.8 + 0.1*0.2 = 0.74

Pr(PR) = pr(PR|R)*pr(R) + pr(PR|B)*pr(B)
= 0.9*0.2 + 0.1*0.8 = 0.26
…also equal to 1 – pr(PB)

Calculating EVSI – III

Calculate posterior probabilities using Bayes theorem

- Finally, we want the probability that the selected ball is blue given that the test predicts blue, and probability of red given that test predicts red:
- pr(B|PB)

  pr(B|PB) = pr(PB|B)*pr(B) / pr(PB)

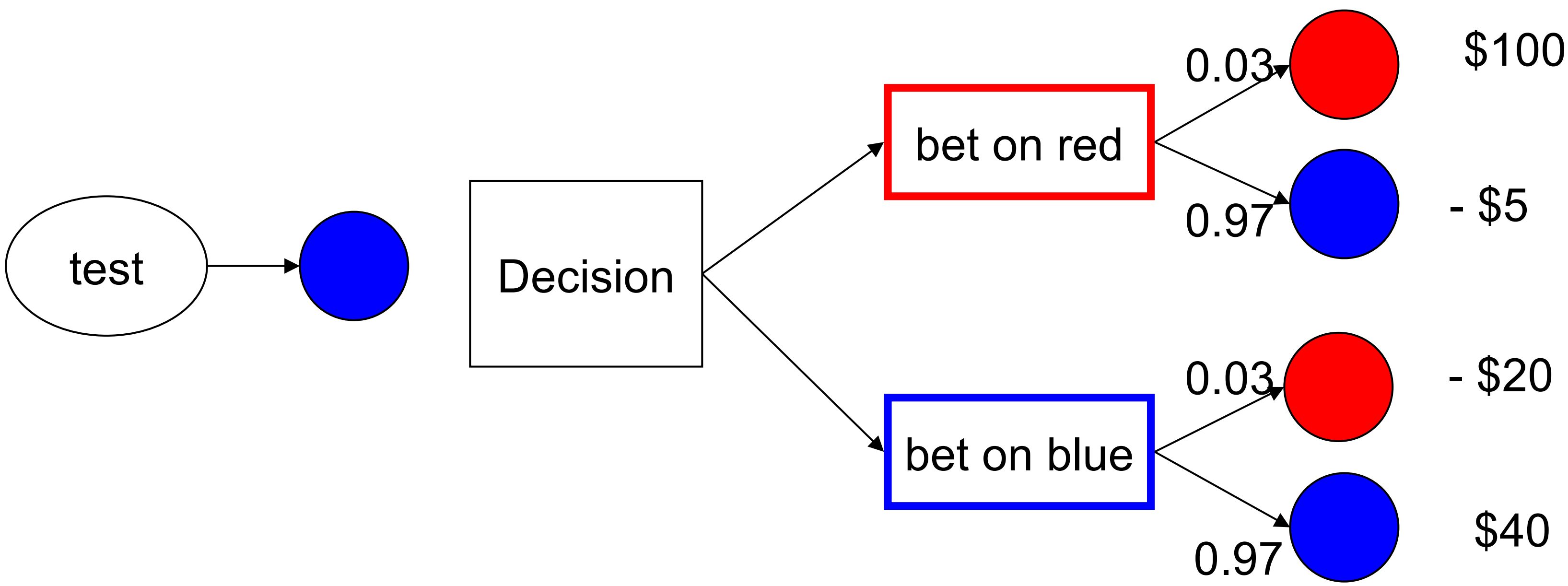
  = 0.9*0.8/0.74 = 0.97
- pr(R|PR)

  pr(R|PR) = pr(PR|R)*pr(R) / pr(PR)

  = 0.9*0.2/0.26 = 0.69

… and pr(R|PB) = 0.03 and pr(B|PR) = 0.31

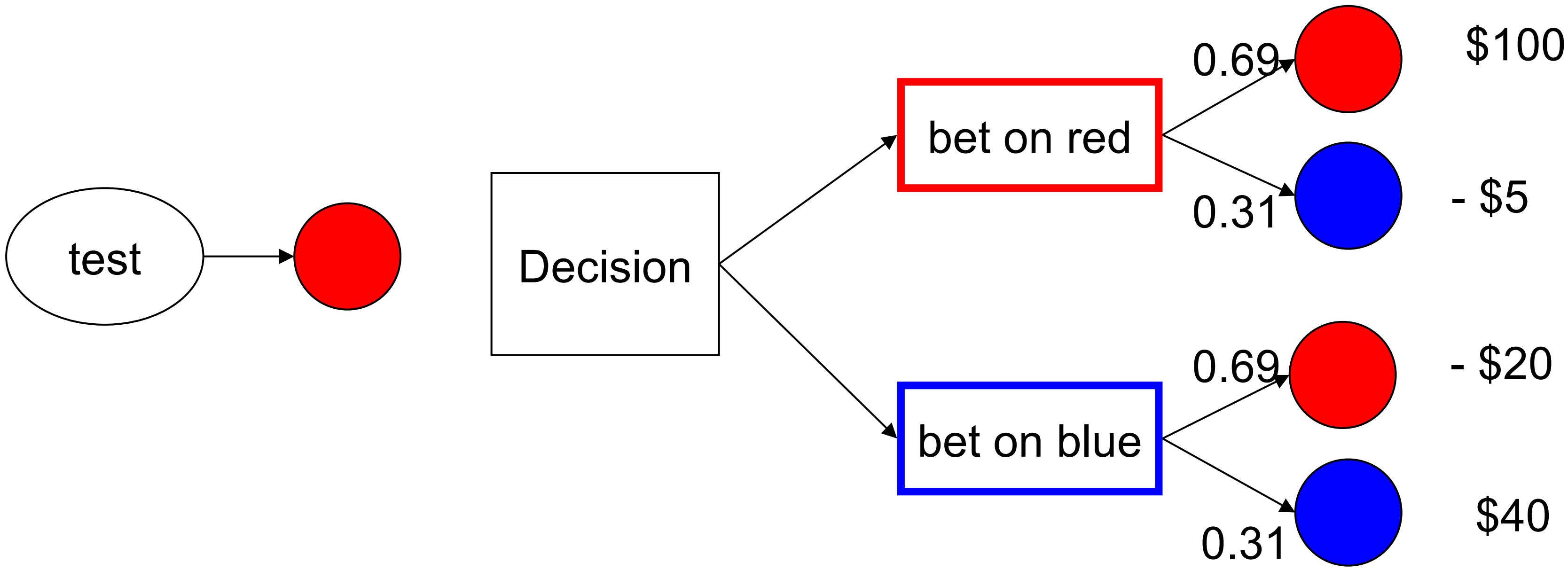
Test says that ball is Blue



EV(bet on red) = \$3 – \$4.85 = - \$1.85

EV(bet on blue) = \$38.80 – \$0.60 = \$38.20

Test says that ball is Red



EV(bet on red) = \$69.00 – \$1.55 = \$67.45

EV(bet on blue) = -\$13.80 + \$12.40 = -\$1.40

Calculation of EVSI and EV of test

- EV of test with 90% accuracy =
  pr(PB)*EV(bet on blue|PB) + pr(PR)*EV(bet on red|PR)
  = 0.74*$38.20 + 0.26*$67.45 = $45.80

- EV (no test) = $28

- EVSI (90% accuracy) = $45.80 - $28 = $17.80

- Note, EVPI = $52 - $28 = $24.00

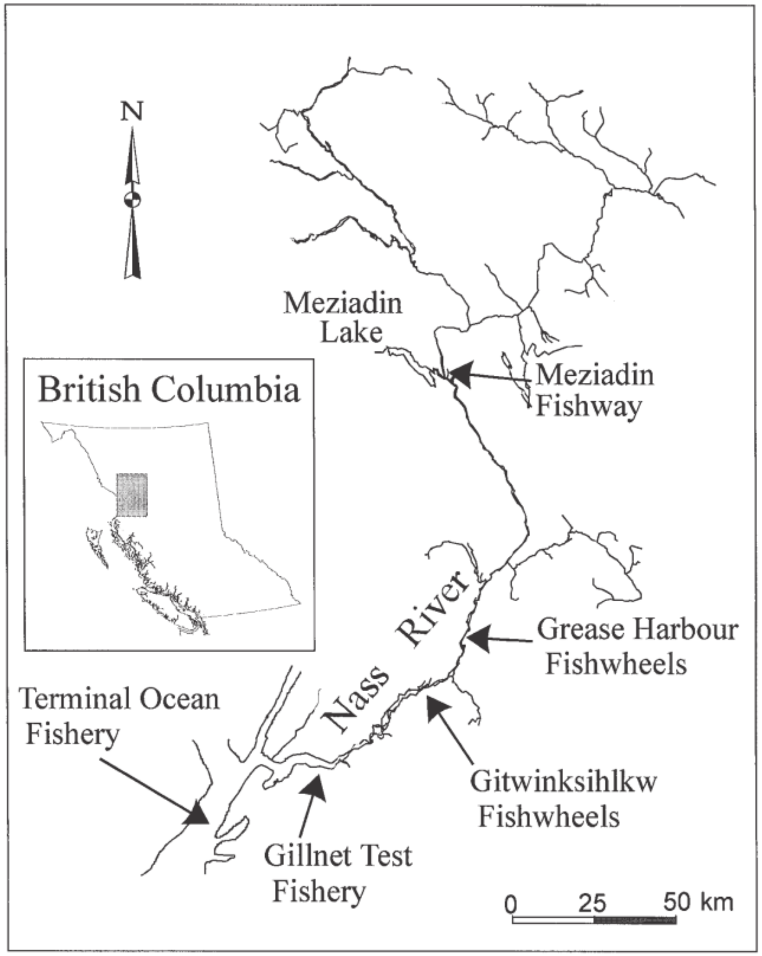
Usually want to determine whether it "pays" to run a test

- Calculate EVSI
  - EVSI > cost of test, then run test
  - But calculating EVSI is not a trivial task!
- Calculate EVPI
  - EVPI > cost of test, then consider running test
  - Rule of thumb*: EVPI > 2 X cost of test, then run test
  - Tests never accurate and estimates of accuracy may be uncertain themselves

*Industry rule of thumb – Engineering systems analysis for design by DeNeufville, Clark, and Field, MIT

A Fisheries Example…

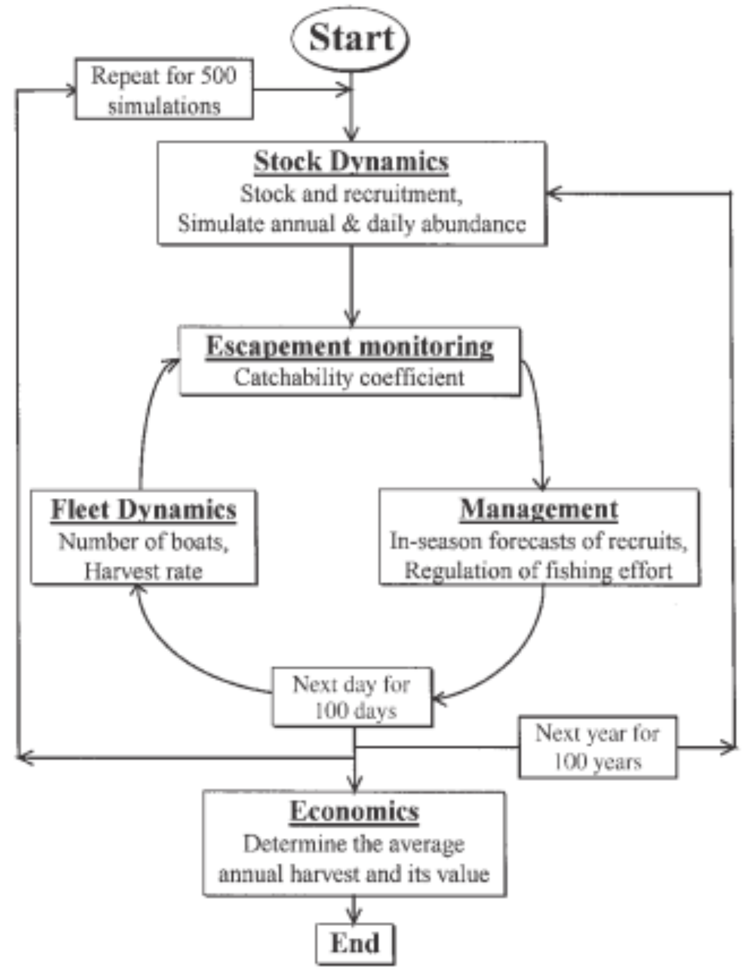
A more realistic problem - value of in-season estimates of abundance of sockeye salmon



Link and Peterman. 1998, Estimating the value of in-season estimates of abundance of sockeye salmon. CJFAS 55: 1408 – 1418.

Value of in-season estimates of abundance of sockeye salmon

- Evaluate whether it is financially prudent to use a fishwheel versus gillnet for in-season data collection
- Gill net test fishery saturates at high abundance, whereas fishwheel does not
- Incorporate uncertainty in stock recruit relationship and fleet dynamics
- Summary: reducing bias of in-season returns leads to higher catch that more than pays for costs of the additional sampling



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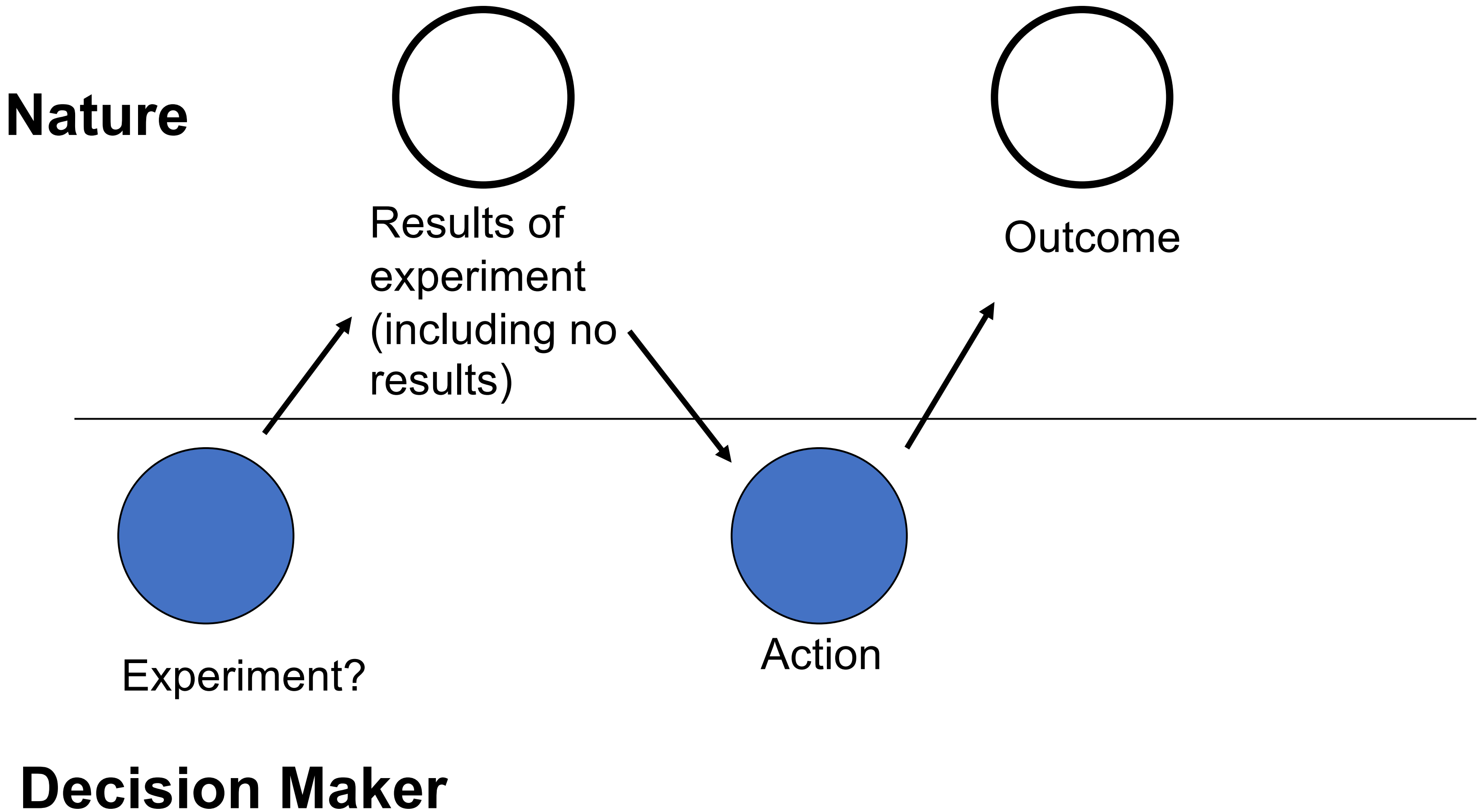
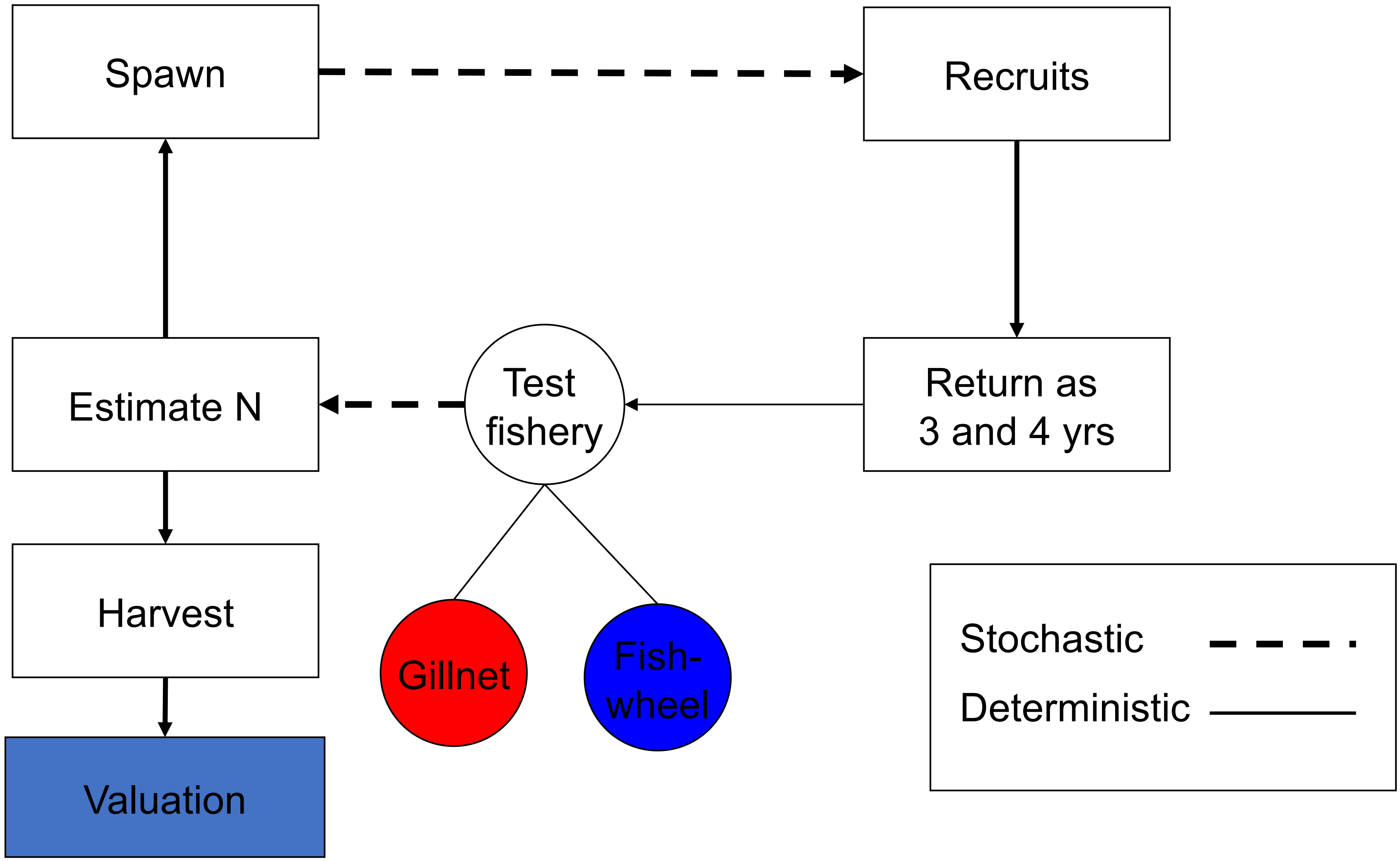
A framework for more realistic problems: Raiffa (1968) decision analysis: a two-player game



A simplified fishwheel analysis

- Uncertainty in Stock-Recruit relationship
- Uncertainty in catchability of two sampling methods used to estimate abundance
  - Gillnet – less precise and less expensive
  - Fishwheel – more precise and more expensive
- Set harvest rate based on abundance estimate
- Value catch

Flow chart of simplified analysis



Stock Recruit relationship

- Ricker stock – recruit function

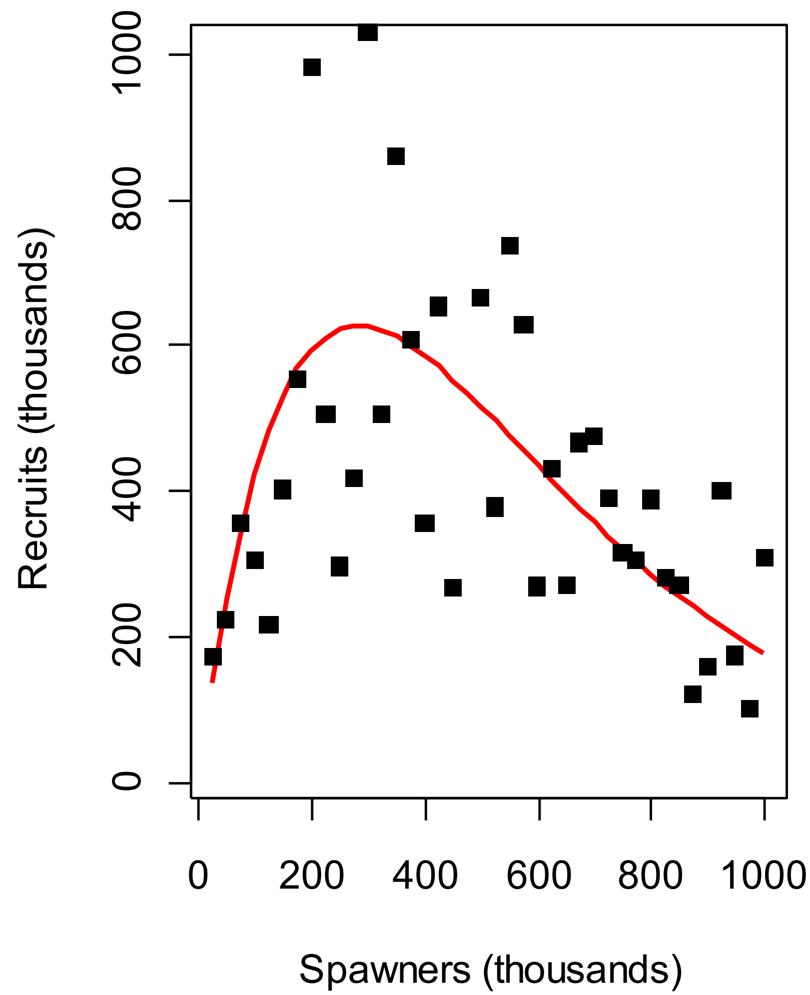
$R_t = S_t * exp\{a(1-S_t/b) + vt\}$

S_t = stock size at time t

a = productivity (1.78)

b = equilibrium stock size (508,000)

v_t = random noise at time t N(mean=0, sd=0.458)



Uncertainty in catchability of test gear

Abundance forecast:

N = q*C/E

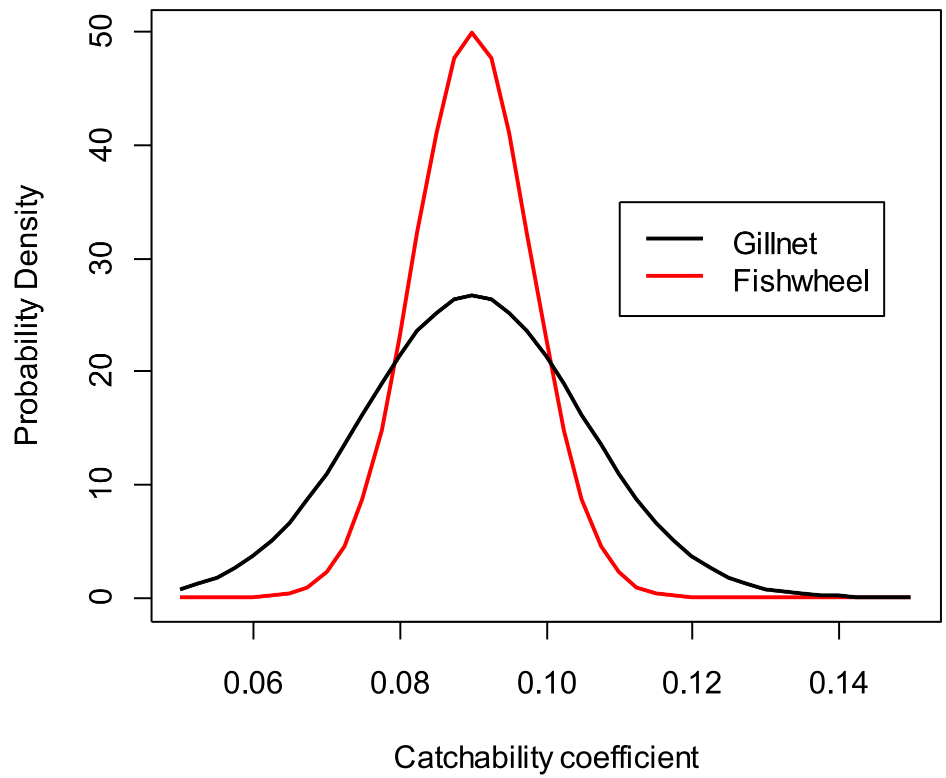
E = 5 days

Gillnet

q_{gn}~N(0.09,sd = 0.015)

Fishwheel

q_{fw}~N(0.09,sd = 0.008)



Harvest management and valuation

- Harvest Management
  - Target fish in excess of the escapement goal of 300,000
  - Desired catch = forecasted run – escapement target
  - Assume perfect control of harvest
- Valuation
  - Estimate of sockeye in 1991 was $21 CAN per 2.9 kg fish
  - Using estimates of inflation since 1991, assume a 1.6 multiplier on 1991 dollars. So, $33.6 CAN per fish.

Results of simulation

- Gillnet test fishery –
  - Average annual harvest of 354,000 sockeye
- Perfect management (information) -
  - Average annual harvest of 385,000 sockeye
- Fishwheel test fishery -
  - Average annual harvest of 377,000

Does the benefit of the fishwheel justify the cost?

- Cost of operating the fishwheel program was \$49K in 1991, so let's assume \$110K in 2019

- 23,000 more sockeye captured on average each year under fishwheel than gillnet test fishery for an annual value of 23,000 X \$33.6 = \$772,800 CAN

- EVSI = \$772,800 – \$110,000 = \$662,800 CAN

My interest in value of data streams

- Working on a couple projects where the rate of learning is important to achieving management objectives
  1. Glacier Bay National Park, Alaska developed speed restrictions to minimize whale – cruise ship interactions, how soon will we know if speed reduces the probability of a strike?
  2. Central Valley California are managing hydrology for agricultural and municipal diversions along with endangered Chinook recovery. How informative are abundance indices for detecting negative effects of water management?

Ship strikes in Glacier Bay National Park, AK