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Application: Operationalization of Utilitarian and Egalitarian Objectives for Optimal Allocation of Health Care Resources

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Operationalization of Utilitarian and Egalitarian Objectives for Optimal Allocation of Health Care Resources

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Outline

1. Problem + model overview
2. Optimization phase I
3. Optimization phase II
4. Applications, pros and cons
5. Summary

Problem overview

- Available resources in health care (and in general) are always limited
- How should the limited resources then be allocated to achieve maximum benefit?
- How should benefit be defined?

Overview: Model for optimal resource allocation (1/3)

- Resources = total budget
  - Tests and treatments each have some cost associated with them
- Only one disease considered in the model
- Population divided into segments
  - Segments defined only by disease risk, 0% … 100%, discretized
  - Other factors not considered in division
- Strategy = the set of decisions about testing and treatment
  - A separate (optimal) strategy for each population segment

Overview: Model for optimal resource allocation (2/3)

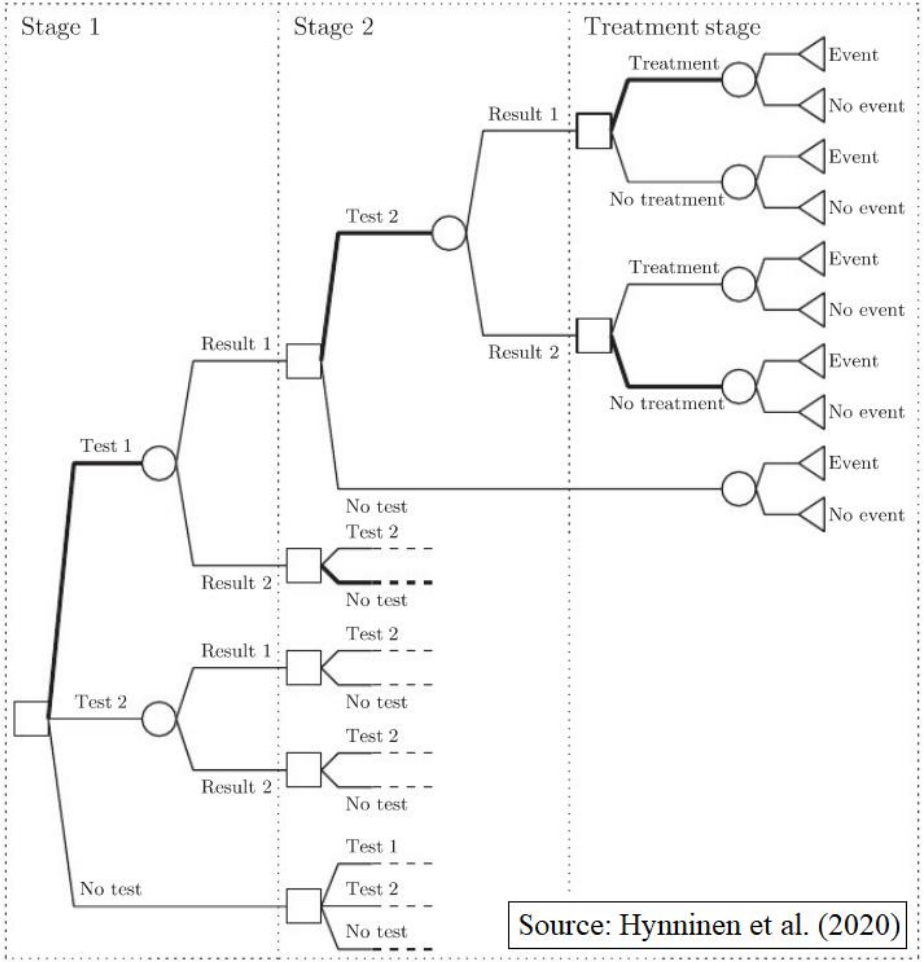
- Two objectives, optimized separately
  - Two “definitions of benefit”
  - Utilitarian objective: maximize expected health outcome over whole population
  - Egalitarian objective: limit differences in health outcomes between population segments
    - In practice: Maximize health outcome of those who are worst off

Overview: Model for optimal resource allocation (3/3)

- Optimization divided into two phases
- Phase I
  - Separately for each population segment: determine the strategies that are Pareto optimal in terms of expected health benefit and cost
  - Solved with dynamic optimization
- Phase II
  - Determine which strategy to apply for each population segment when maximizing the utilitarian or egalitarian objective and subject to an overall resource constraint
  - Solved by binary linear programming

Strategy: idea (1/3)

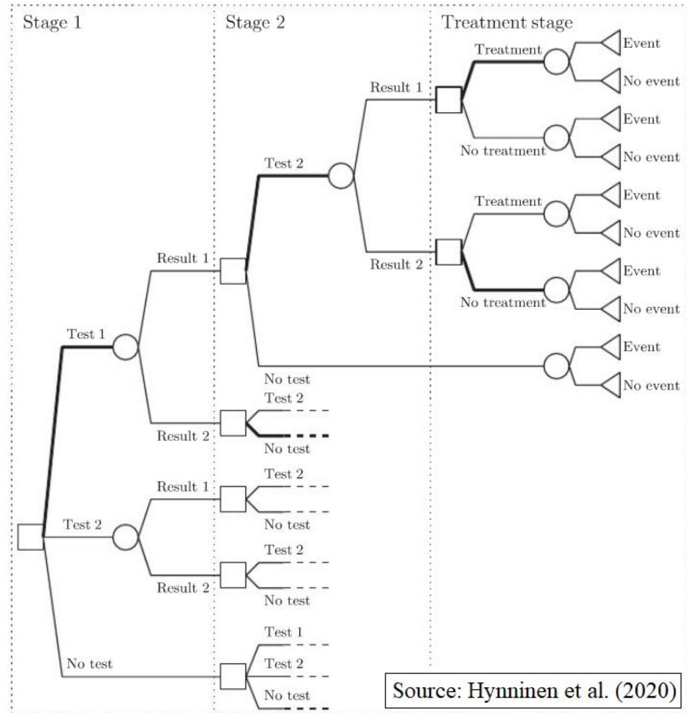
- Strategy = the set of decisions about testing and treatment
- i.e. a path through the decision tree
- Same for each patient in a population segment
- Expected cost C
- Expected health outcome H



Source: Hynninen et al. (2020)

Strategy: idea (2/3)

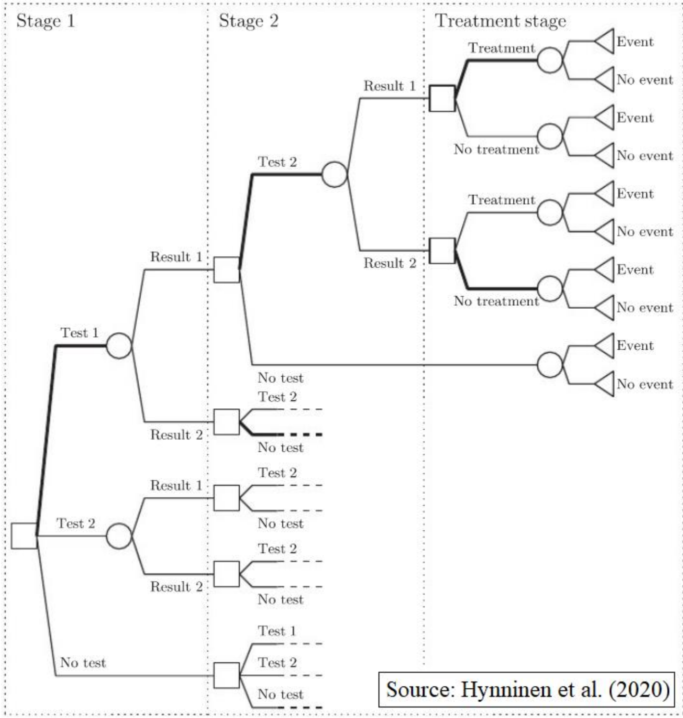
- Patient with state $S = \{sick, not\ sick\}$
  - Probability of having disease $p = P(S = 1)$
- Treatments $A = \{0, a_1, \dots\ a_n\}$
  - Health outcome $h(a \mid s)$ known for all actions a, states s (e.g. QALY)
- Tests $\mathcal{T} = \{0, t_1, \dots, T\}$
  - Testing stages $k = 1, \dots, K$
  - Tests at stage k: $\boldsymbol{t}^k = (t_1^k, \dots, t_{n(k)}^k)$
- Test results at stage k: $\boldsymbol{r}^k = (r_{t_1^k}, \dots, r_{t_{n(k)}^k})$
  - Gives information about patient state: update probability $p_{k-1} \to p_k$



Source: Hynninen et al. (2020)

Strategy: idea (3/3)

- Solve optimal path through decision tree with dynamic optimization
- Maximize expected health outcome H w.r.t actions (choices about tests and treatments), subject to a cost constraint
- Obtain strategy (C, H)
  - $C =$ expected cost of strategy at root of tree
  - $H =$ expected health outcome of strategy at root of tree



Source: Hynninen et al. (2020)

Pareto optimality

Definition 1: *Let* (C, H) *be a test and treatment strategy with expected cost* C *and expected health outcome* H*. Strategy* (C, H) Pareto dominates *strategy* (C', H')*, denoted* $(C, H) \succ (C', H')$*, if*

$$C \leq C' \text{ and } H \geq H',$$

where at least one of the inequalities is strict.

Definition 2: *Strategy* (C, H) *is* Pareto optimal, *if* $\nexists$ (C', H') *such that* $(C', H') \succ (C, H)$.

Source: Hynninen et al. (2020)

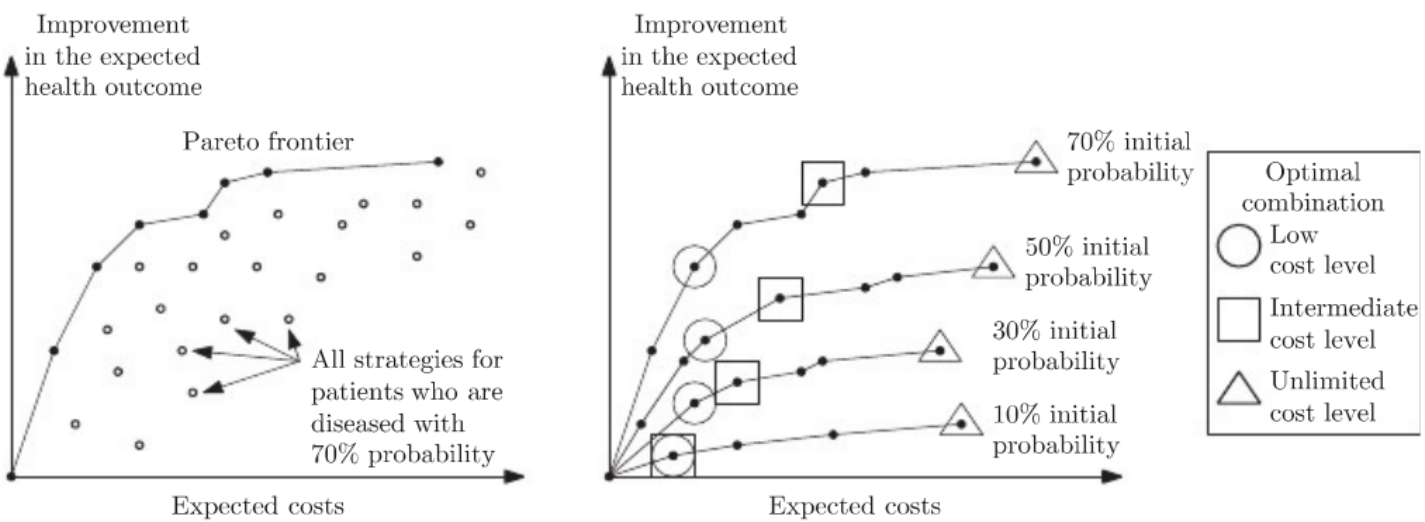
Phase I illustration

Pareto optimal strategies for each population segment

Phase II illustration

Optimal combination of strategies given overall resource constraint

Figure 1: Two-phase optimization process. First, identify Pareto optimal strategies for each patient segment (left). Pareto optimal strategies are depicted with the symbol • and Pareto dominated strategies with the symbol ∘. Second, identify the optimal combination of Pareto optimal strategies for patient segments subject to a cost constraint (right).



Source: Hynninen et al. (2020)

Utilitarian objective

$$U^* = \max_x \sum_{i=1}^{I} \sum_{j_i=1}^{J_i} x_{i,j_i} d_i h_{i,j_i}$$

$$\text{subject to} \sum_{i=1}^{I} \sum_{j_i=1}^{J_i} x_{i,j_i} d_i c_{i,j_i} \leq B$$

$$\sum_{j=1}^{J_i} x_{i,j_i} = 1 \text{ for all } i \in \{1, \ldots, I\}$$

$$x_{i,j_i} \in \{0, 1\} \text{ for all } i \in \{1, \ldots, I\},\ j_i \in \{1, \ldots, J_i\}$$

x_{i,j_i}: (decision variables) for segment i apply strategy j_i
d_i: amount of people in segment i
h_{i,j_i}: expected health outcome for segment i, strategy j_i
c_{i,j_i}: expected cost for segment i, strategy j_i
B: total budget

Source: Hynninen et al. (2020)

Egalitarian objective

$$E^* = \quad \operatorname{lex\,max}_{\boldsymbol{x}} f(\boldsymbol{x})$$

$$\text{subject to } \sum_{i=1}^{I} \sum_{j_i=1}^{J_i} x_{i,j_i} d_i c_{i,j_i} \leq B$$

$$\sum_{j=1}^{J_i} x_{i,j_i} = 1 \text{ for all } i \in \{1, \ldots, I\}$$

$$x_{i,j_i} \in \{0, 1\} \text{ for all } i \in \{1, \ldots, I\},\ j_i \in \{1, \ldots, J_i\}$$

x_{i,j_i}: (decision variables) for segment i apply strategy j_i
d_i: amount of people in segment i
h_{i,j_i}: expected health outcome for segment i, strategy j_i
c_{i,j_i}: expected cost for segment i, strategy j_i
B: total budget

Source: Hynninen et al. (2020)

Applications

- Preparing for emergencies and allocating resources to humanitarian health care
- Segmenting and prioritizing patients
- Predicting how much resources are needed for tests and treatments
- Assessing the cost-effectiveness of new tests and treatments

Advantages

- Model does not assume that population is homogeneous
- Pareto-optimal strategies
  - No need to convert health outcome to monetary values
- Model guides the interpretation of (imperfect) test results
  - Strategy gives optimal path through decision tree
- Two objective functions: utilitarian & egalitarian
  - Allows to see the effect of different objectives on the optimal strategies
  - Allows to introduce different values into population-level objectives

Disadvantages

- Test results assumed independent of each other
  - May cause inaccuracies
- State of a single patient is static
  - E.g. health deterioration over time is not modeled
- Population divided into segments only by disease risk
  - Other factors such as correlated diseases not considered
  - Individuals in the same risk group may respond to treatments differently
- Computationally expensive
  - Contributing factors: number of tests and test results, number of discretization points, Pareto set approximation

Summary

- Model for optimal health care resource allocation established
- Optimized in two phases
  - Phase I: Pareto-optimal strategies for each population segment
  - Phase II: Optimal combination of strategies given overall budget
- Two population-level objectives employed
  - Utilitarian
  - Egalitarian

References

Hynninen, Y., Vilkkumaa, E. and Salo, A. (2020), Operationalization of Utilitarian and Egalitarian Objectives for Optimal Allocation of Health Care Resources. Decision Sciences. doi:10.1111/deci.12448

Homework

Read pages 18-25 of the paper by Hynninen et al. that deal with the case study on coronary heart disease events. Summarize your thoughts briefly on the following:

- In this case study, what are the main concrete differences and similarities between the utilitarian and egalitarian approaches in terms of their resource allocation?

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Thank you for listening!