Uncertainty and Value of Information when Allocating Resources Within and Between Multiple Healthcare Programmes

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Overview

- Current decision rules for cost-effectiveness analysis
- Value of information analysis
- The allocation problem
- Stochastic mathematical programming formulation
- Empirical application
- Conclusions

Current Methods

Current decision rules for cost-effectiveness analysis:

- Set a threshold WTP for additional health benefits, λ
- Employ the league table rule
- Set the budget and maximise health benefits subject to the budget constraint

Arbitrary threshold λ is generally used

Current Methods

Current decision rules for cost-effectiveness analysis:

- Set a threshold WTP for additional health benefits, λ
- Employ the league table rule
- Set the budget and maximise health benefits subject to the budget constraint

Mathematical Programming gives optimal allocation

Uncertainty vs. Variability

Uncertainty (2nd order uncertainty):

- Represents the lack of knowledge about the distribution of the parameter values
- Reducible with additional information

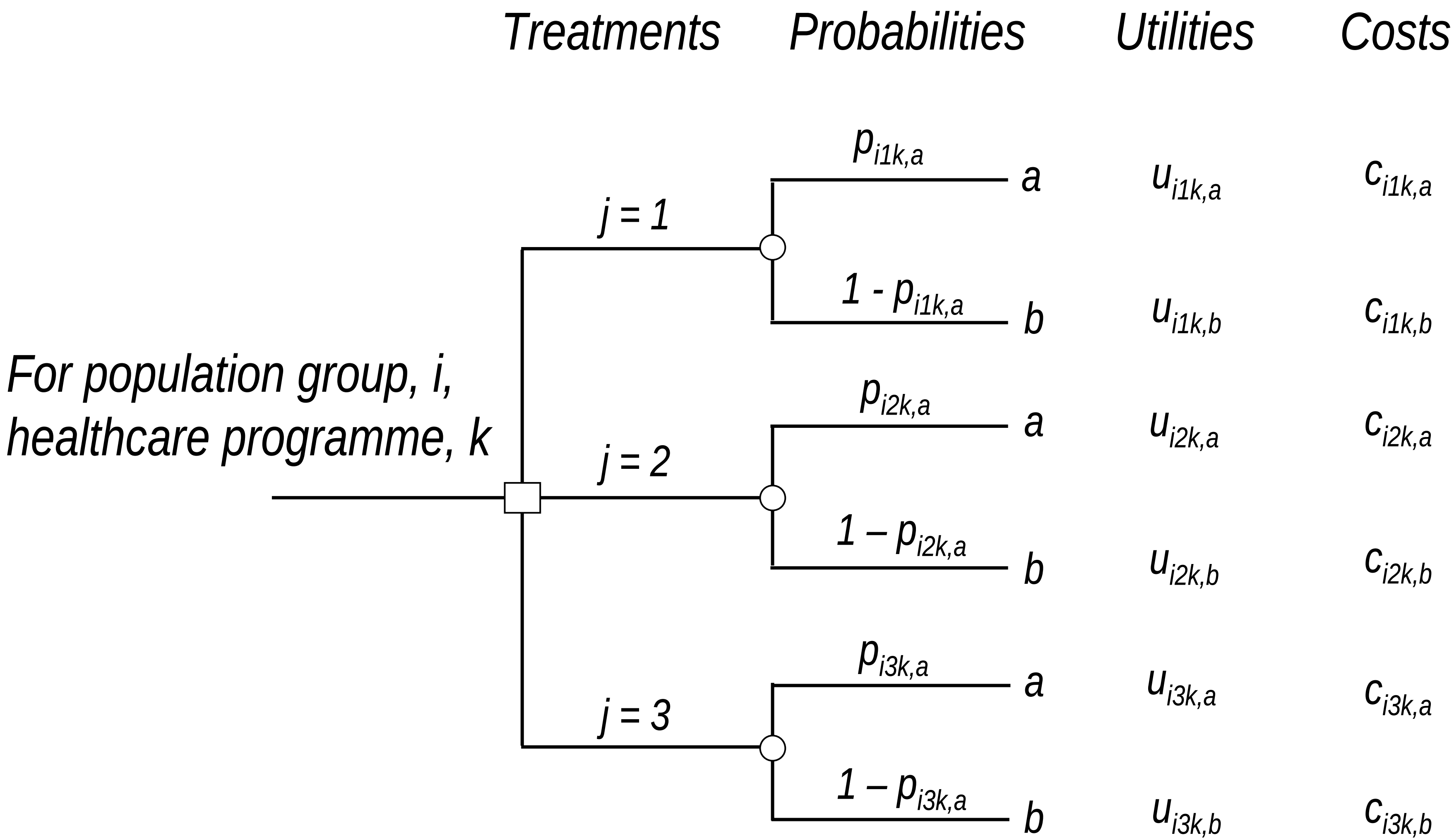
Variability (1st order uncertainty):

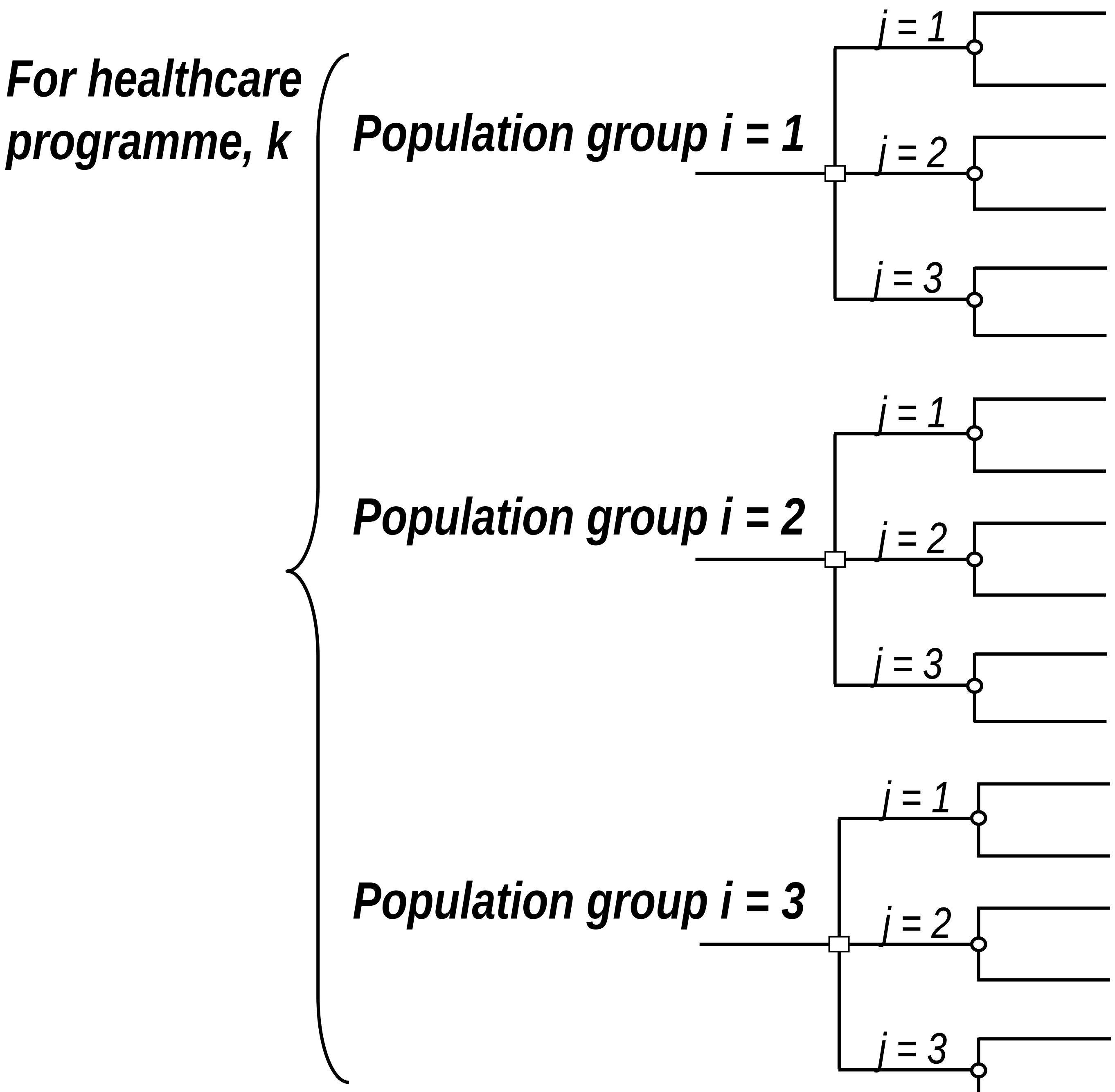
- Natural patient heterogeneity
- Irreducible with additional information

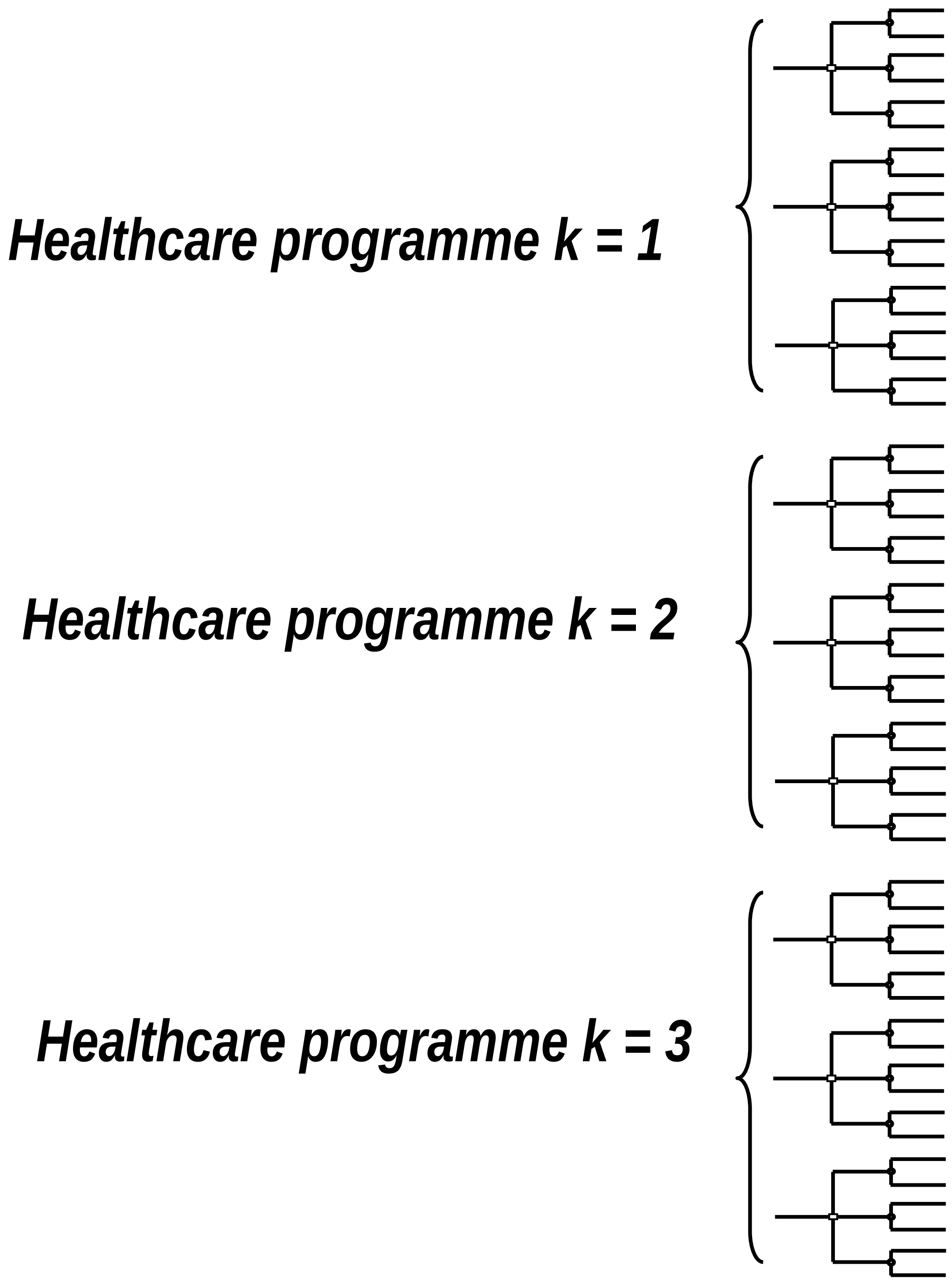
Expected Value of Perfect Information (EVPI)

- EVPI is the difference between a decision made with perfect information and one made with current information
- Sets an upper limit on the societal returns to further research
- Traditional EVPI for a single healthcare programme is based on an arbitrary threshold WTP, λ
- EVPI for the allocation problem as a whole incorporates the true opportunity costs

The Allocation Problem




For healthcare programme, k
Population group i = 1
j = 1
j = 2
j = 3
Population group i = 2
j = 1
j = 2
j = 3
Population group i = 3
j = 1
j = 2
j = 3



Healthcare programme k = 1
Healthcare programme k = 2
Healthcare programme k = 3

The Allocation Problem

Total of 3 x 3 x 3 = 27 decision variables

$$X = (x_{ijk},\ \text{for}\ i, j, k = 1, .., 3)$$

x_{ijk} proportion of population group *i* in healthcare programme *k* that is allocated treatment *j*

Set of uncertain parameters:

$$\Phi = (p_{ijk,a},\ \text{for}\ i, j, k = 1, .., 3)$$ ~ Beta

Set of variable parameters:

$$\Delta = (n_{ijk,a},\ \text{for}\ i, j, k = 1, .., 3)$$ ~ Binomial

Total set of random parameters:

$$Z = \Phi \cup \Delta = (p_{ijk,a},\ n_{ijk,a},\ \text{for}\ i, j, k = 1, .., 3)$$

A Two-Stage Stochastic MP Formulation

The solution is divided into 4 steps:

(1) Distinguish between uncertain and variable parameters

(2) Determine the optimal allocation based on current information and calculate the expected health benefit

(3) Determine the optimal allocation based on perfect information and calculate the expected health benefit

(4) Calculate the EVPI, the upper bound on the return of resolving all the uncertainties within the allocation problem as a whole

Current Information

1st Stage

$$\text{Max.} \quad E_Z(B(Z,X))$$

health benefits

$$\text{s.t.} \quad E_Z(C(Z,X)) \leq \Psi$$

budget constraint

$$\sum_{j=1}^{3} x_{ijk} = 1 \quad \text{for} \quad i,j,k = 1,..,3$$

Current Information

1st Stage

$$\text{Max.} \quad E_Z(B(Z,X))$$ health benefits

$$\text{s.t.} \quad E_Z(C(Z,X)) \leq \Psi$$ budget constraint

$$\sum_{j=1}^{3} x_{ijk} = 1 \quad \text{for} \quad i,j,k = 1,..,3$$

Optimal solution:

$$B^*, \; C^*, \; X^* = (x_{ijk}, \text{ for } i,j,k = 1,..,3)$$

Current Information

2nd Stage

$$\text{for all } Z \quad \left\{ \begin{array}{ll} \text{Min.} & (B^* - B(Z,Y)) \\ \text{s.t.} & C(Z,Y) \leq \Psi \\ & y_{i1k} \geq x^*_{i1k} \quad \text{for} \quad i,k = 1,..,3 \\ & \sum_{j=1}^{3} y_{ijk} = 1 \quad \text{for} \quad i,j,k = 1,..,3 \end{array} \right.$$

Current Information

2nd Stage

$$\text{for all } Z \quad \left\{ \begin{array}{ll} \text{Min.} & (B^* - B(Z,Y)) \\ \text{s.t.} & C(Z,Y) \leq \Psi \\ & \boxed{y_{i1k} \geq x^*_{i1k} \quad \text{for} \quad i,k = 1,..,3} \\ & \sum_{j=1}^{3} y_{ijk} = 1 \quad \text{for} \quad i,j,k = 1,..,3 \end{array} \right.$$

Current Information

2nd Stage

$$\text{for all } Z \quad \left\{ \begin{array}{ll} \text{Min.} & (B^* - B(Z,Y)) \\ \text{s.t.} & C(Z,Y) \leq \Psi \\ & y_{i1k} \geq x^*_{i1k} \quad \text{for} \quad i,k = 1,..,3 \\ & \sum_{j=1}^{3} y_{ijk} = 1 \quad \text{for} \quad i,j,k = 1,..,3 \end{array} \right.$$

Expected health benefits: $E_Z(B(Z, Y^*(Z)))$

Optimal allocation: $Y^*(Z) = (y_{ijk}, \text{ for } i,j,k = 1,..,3)$

Perfect Information

1st Stage

$$\text{for all } \Phi \begin{cases} \text{Max.} & E_{\Delta|\Phi}(B(\Phi,\Delta,X)) \\ \text{s.t.} & E_{\Delta|\Phi}(C(\Phi,\Delta,X)) \leq \Psi \\ & \displaystyle\sum_{j=1}^{3} x_{ijk} = 1 \quad \text{for} \quad i,j,k = 1,..,3 \end{cases}$$

Optimal solution:

$$B^{**}(\Phi), \quad C^{**}(\Phi), \quad X^{**}(\Phi) = (x_{ijk}, \text{ for } i,j,k = 1,..,3)$$

Perfect Information

2nd Stage

$$\text{for all } \Phi \left\{ \text{for all } \Delta \left\{ \begin{array}{ll} \text{Min.} & (B^{**}(\Phi) - B(\Phi, \Delta, Y)) \\ \text{s.t.} & C(\Phi, \Delta, Y) \leq \Psi \\ & y_{i1k} \geq x_{i1k}^{**} \quad \text{for} \quad i, k = 1, .., 3 \\ & \sum_{j=1}^{3} y_{ijk} = 1 \quad \text{for} \quad i, j, k = 1, .., 3 \end{array} \right. \right.$$

Expected health benefits: $E_{\Phi}(E_{\Delta|\Phi}(B(\Phi, \Delta, Y^{**}(\Delta|\Phi))))$

Optimal allocation: $Y^{**}(\Delta|\Phi) = (y_{ijk}, \text{ for } i, j, k = 1, .., 3)$

Expected Value of Perfect Information (EVPI)

- EVPI = Expected benefits$_{\textit{\textbf{perfect}}}$ – Expected benefits$_{\textit{\textbf{current}}}$

Converting EVPI in health gains into a monetary value:

- Decrease the budget with perfect information to generate the same benefits as current information

Empirical Application

Threshold Net Benefit Approach

vs.

Stochastic Mathematical Programming

Threshold approach

Programme 1	Pop. 1	Tx. 1
		2
		3
	2	1
		2
		3
	3	1
		2
		3
Programme 2	1	1
		2
		3
	2	1
		2
		3
	3	1
		2
		3
Programme 3	1	1
		2
		3
	2	1
		2
		3
	3	1
		2
		3

Threshold approach

Programme 1	Pop. 1	Tx. 1
		2
		3
	2	1
		2
		3
	3	1
		2
		3
Programme 2	1	1
		2
		3
	2	1
		2
		3
	3	1
		2
		3
Programme 3	1	1
		2
		3
	2	1
		2
		3
	3	1
		2
		3

Threshold approach λ = *£10,000*

Programme 1	Pop. 1	Tx. 1
		2
		3
	2	1
		2
		3
	3	1
		2
		3
Programme 2	1	1
		2
		3
	2	1
		2
		3
	3	1
		2
		3
Programme 3	1	1
		2
		3
	2	1
		2
		3
	3	1
		2
		3

0
0
1

Threshold approach *λ = £10,000* *Benefits* *Costs*

Programme	Pop.	Tx.		*Benefits*	*Costs*
Programme 1	Pop. 1	Tx. 1	0	-	-
		2	0	-	-
		3	1	660.5	£1,149,381
	2	1			
		2			
		3			
	3	1			
		2			
		3			
Programme 2	1	1			
		2			
		3			
	2	1			
		2			
		3			
	3	1			
		2			
		3			
Programme 3	1	1			
		2			
		3			
	2	1			
		2			
		3			
	3	1			
		2			
		3			

Threshold approach λ = *£10,000* *Benefits* *Costs*

Programme	Pop.	Tx.		Benefits	Costs
Programme 1	Pop. 1	Tx. 1	0	-	-
		2	0	-	-
		3	1	660.5	£1,149,381
	2	1	0	-	-
		2	1	539.2	£690,203
		3	0	-	-
	3	1			
		2			
		3			
Programme 2	1	1			
		2			
		3			
	2	1			
		2			
		3			
	3	1			
		2			
		3			
Programme 3	1	1			
		2			
		3			
	2	1			
		2			
		3			
	3	1			
		2			
		3			

Threshold approach *λ = £10,000* *Benefits* *Costs*

Programme	Pop.	Tx.		Benefits	Costs
Programme 1	Pop. 1	Tx. 1	0	-	-
		2	0	-	-
		3	1	660.5	£1,149,381
	2	1	0	-	-
		2	1	539.2	£690,203
		3	0	-	-
	3	1	0	-	-
		2	1	543.1	£1,358,839
		3	0	-	-
Programme 2	1	1			
		2			
		3			
	2	1			
		2			
		3			
	3	1			
		2			
		3			
Programme 3	1	1			
		2			
		3			
	2	1			
		2			
		3			
	3	1			
		2			
		3			

Threshold approach *λ = £10,000*

Programme	Pop.	Tx.		*Benefits*	*Costs*
Programme 1	Pop. 1	Tx. 1	0	-	-
		2	0	-	-
		3	1	660.5	£1,149,381
	2	1	0	-	-
		2	1	539.2	£690,203
		3	0	-	-
	3	1	0	-	-
		2	1	543.1	£1,358,839
		3	0	-	-
Programme 2	1	1	0	-	-
		2	0	-	-
		3	1	566.8	£1,155,251
	2	1	0	-	-
		2	1	479.3	£690,217
		3	0	-	-
	3	1	1	362.5	£0
		2	0	-	-
		3	0	-	-
Programme 3	1	1	0	-	-
		2	1	421.5	£398,065
		3	0	-	-
	2	1	0	-	-
		2	1	423.2	£688,421
		3	0	-	-
	3	1	1	340.9	£0
		2	0	-	-
		3	0	-	-

Threshold approach *λ = £10,000 Benefits Costs*

				Benefits	*Costs*
Programme 1	Pop. 1	Tx. 1	0	-	-
		2	0	-	-
		3	1	660.5	£1,149,381
	2	1	0	-	-
		2	1	539.2	£690,203
		3	0	-	-
	3	1	0	-	-
		2	1	543.1	£1,358,839
		3	0	-	-
Programme 2	1	1	0	-	-
		2	0	-	-
		3	1	566.8	£1,155,251
	2	1	0	-	-
		2	1	479.3	£690,217
		3	0	-	-
	3	1	1	362.5	£0
		2	0	-	-
		3	0	-	-
Programme 3	1	1	0	-	-
		2	1	421.5	£398,065
		3	0	-	-
	2	1	0	-	-
		2	1	423.2	£688,421
		3	0	-	-
	3	1	1	340.9	£0
		2	0	-	-
		3	0	-	-

Total Benefits:

4337.1

Threshold approach *λ = £10,000 Benefits Costs*

Programme	Pop.	Tx.	Selected	Benefits	Costs
Programme 1	Pop. 1	Tx. 1	0	-	-
		2	0	-	-
		3	1	660.5	£1,149,381
	2	1	0	-	-
		2	1	539.2	£690,203
		3	0	-	-
	3	1	0	-	-
		2	1	543.1	£1,358,839
		3	0	-	-
Programme 2	1	1	0	-	-
		2	0	-	-
		3	1	566.8	£1,155,251
	2	1	0	-	-
		2	1	479.3	£690,217
		3	0	-	-
	3	1	1	362.5	£0
		2	0	-	-
		3	0	-	-
Programme 3	1	1	0	-	-
		2	1	421.5	£398,065
		3	0	-	-
	2	1	0	-	-
		2	1	423.2	£688,421
		3	0	-	-
	3	1	1	340.9	£0
		2	0	-	-
		3	0	-	-

Total Benefits:

4337.1

Total Costs:

£6,130,377

λ = £10,000   Budget = £6,130,377

Programme 1	Pop. 1	Tx. 1	0	0
		2	0	0
		3	1	1
	2	1	0	0
		2	1	1
		3	0	0
	3	1	0	0
		2	1	1
		3	0	0
Programme 2	1	1	0	0
		2	0	0
		3	1	1
	2	1	0	0
		2	1	1
		3	0	0
	3	1	1	1
		2	0	0
		3	0	0
Programme 3	1	1	0	0
		2	1	1
		3	0	0
	2	1	0	0
		2	1	1
		3	0	0
	3	1	1	1
		2	0	0
		3	0	0

SMP approach

Total Benefits: 4337.8

Total Costs: £6,130,377

Threshold approach

Total Benefits: 4337.1

Total Costs: £6,130,377

SMP approach

For the budget of £6,130,377, the expected benefits under

Current Information

1st stage	=	4337.8	
2nd stage	=	4390.4	

Perfect Information

1st stage	=	4403.8	
2nd stage	=	4404.3	

EVPI (health gains)

4404.3 – 4390.4 = 13.8

EVPI (monetary terms)

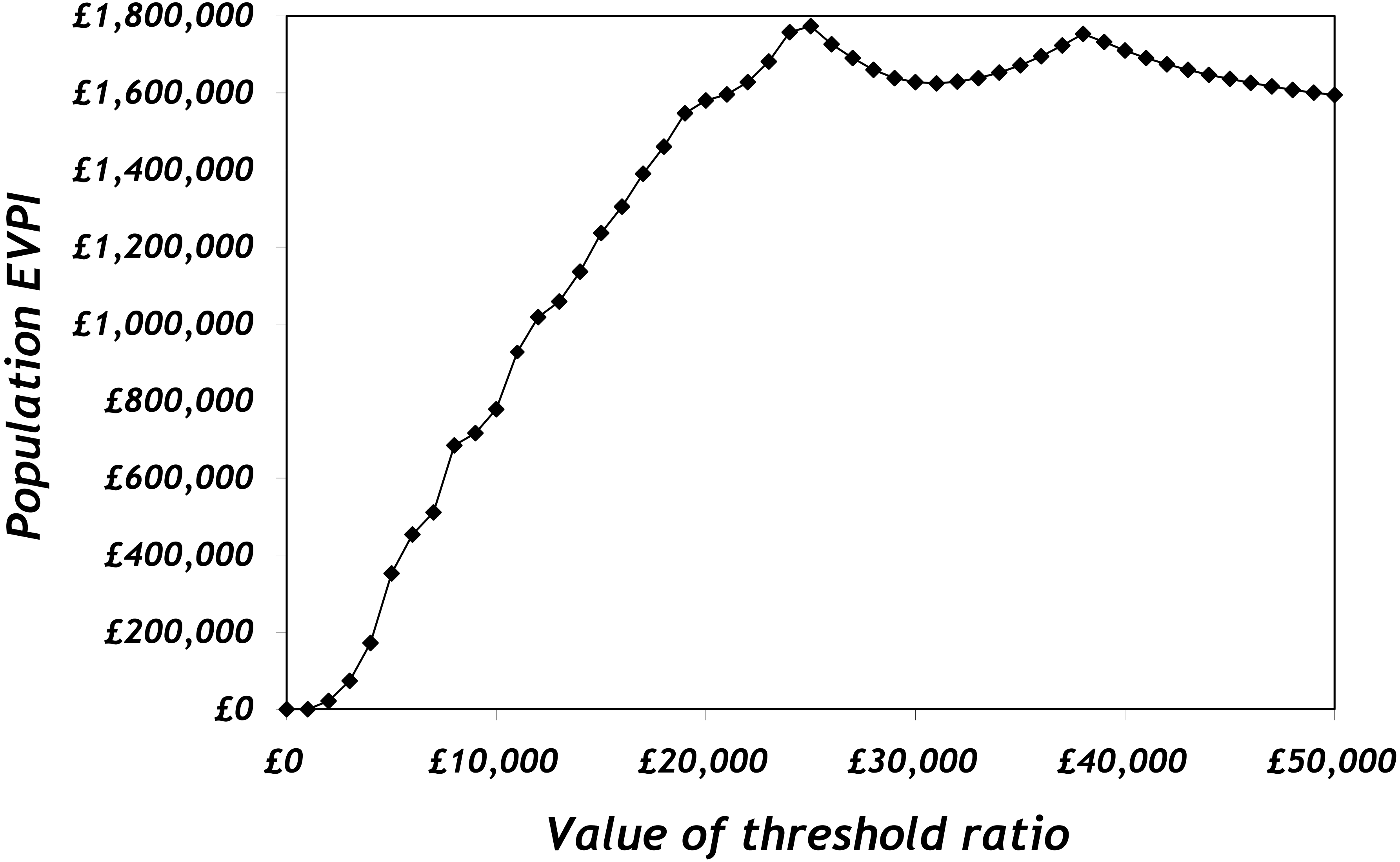
Budget	Current	Perfect	EVPI (benefits)
£5,995,377	4373.6	4390.4	16.8
£6,130,377	4390.4	4404.3	13.8

-£135,000

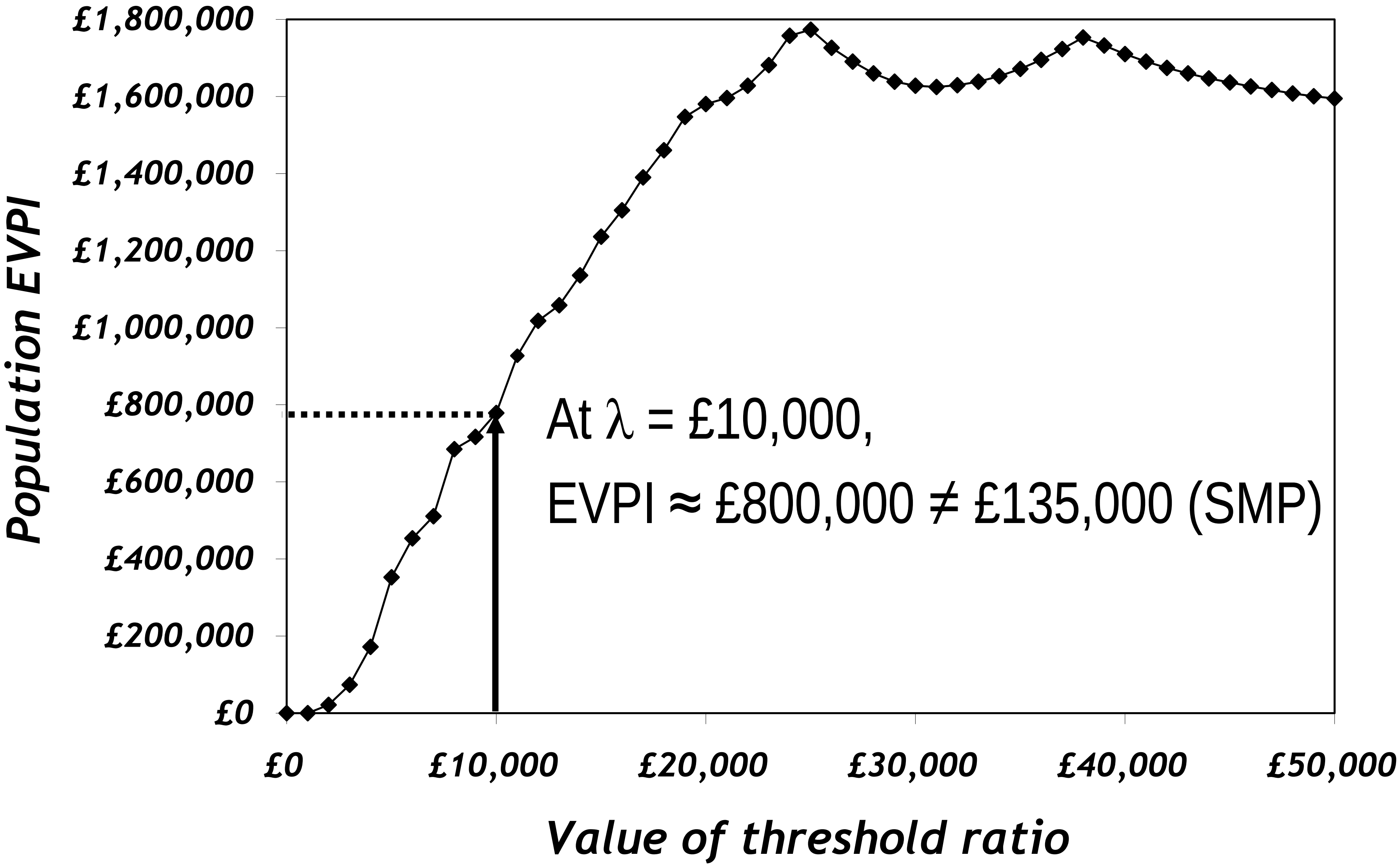
At £6,130,377, EVPI = £135,000

Corresponding threshold λ = £135,000/13.8 = £9,783 per additional QALY gained

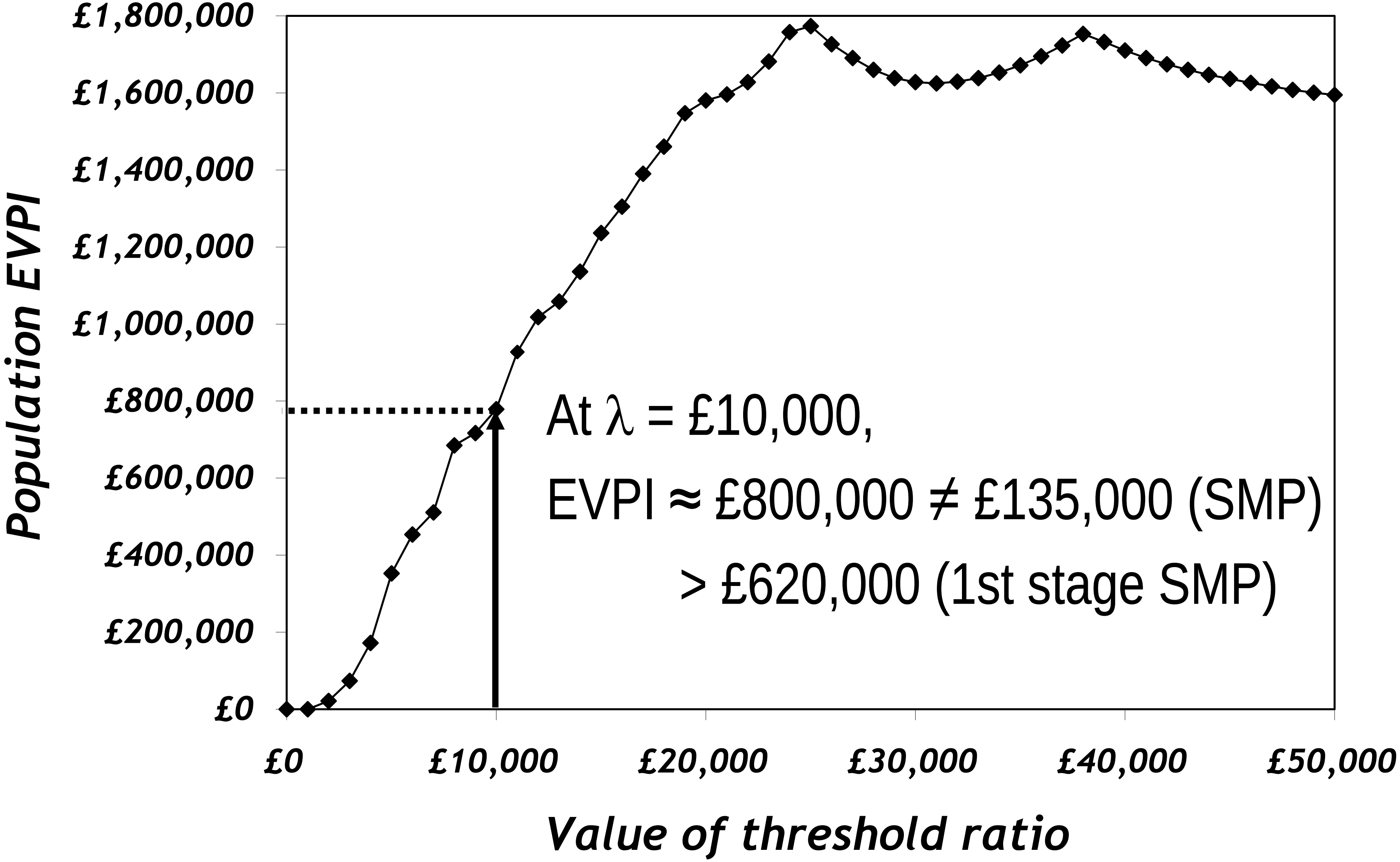
Comparison with traditional EVPI approach



Comparison with traditional EVPI approach



Comparison with traditional EVPI approach



Conclusions

- We can evaluate actual budgetary policies eg. strict constraint
- The opportunity costs of violating the constraint are endogenous
- By distinguishing between uncertainty and variability, the value of information for the whole allocation problem is obtained
- The EVPI based on the analysis of each of the decision problems separately substantially overestimates the value of research

Decisions regarding allocation of resources and the value of acquiring further evidence to inform these decisions must be made in the context of the whole allocation problem