Endogenous and Exogenous Uncertainty in Adaptive Water Resource Planning

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Endogenous and Exogenous Uncertainty

Staged water infrastructure capacity expansion optimization models help create flexible plans under uncertainty:

- Exogenous uncertainty can be incorporated into the optimization using an a priori hydrological and demand scenario ensemble

- Endogenous or ‘decision-dependent’, i.e., the optimized timing and selection of interventions determines when and which uncertainties must be considered

Endogenous Uncertainty & Real Options

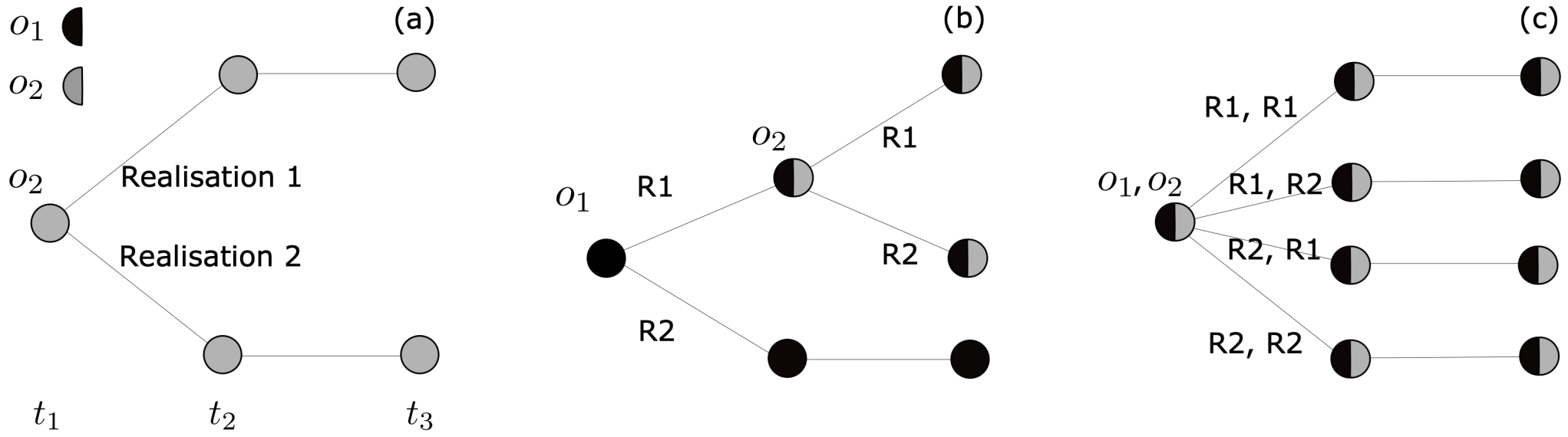
- We formulate a multistage real-options water supply capacity expansion optimization model incorporating endogenous uncertainty and describe its effect on cost and option selection.

- We show how endogenous uncertainty propagates when making planning decisions over time on a synthetic case study.

- The results are contrasted with the deterministic formulation in terms of option activations and the expected present value of the cost.

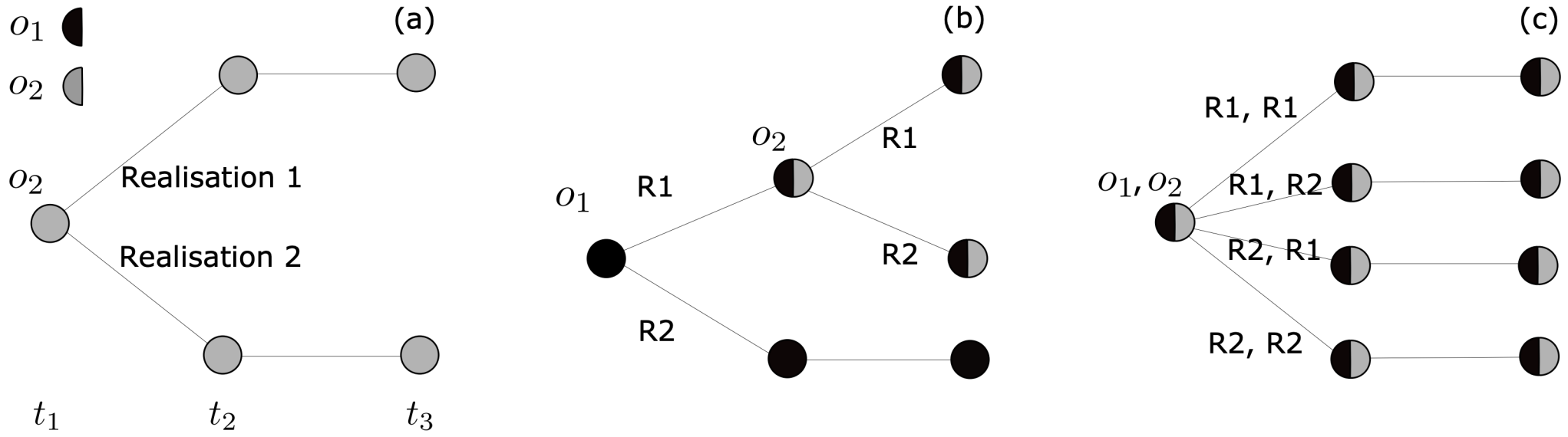
Problem description

The figure shows the uncertainty realization for two water development options (O_1 and O_2) as endogenous uncertain parameters.



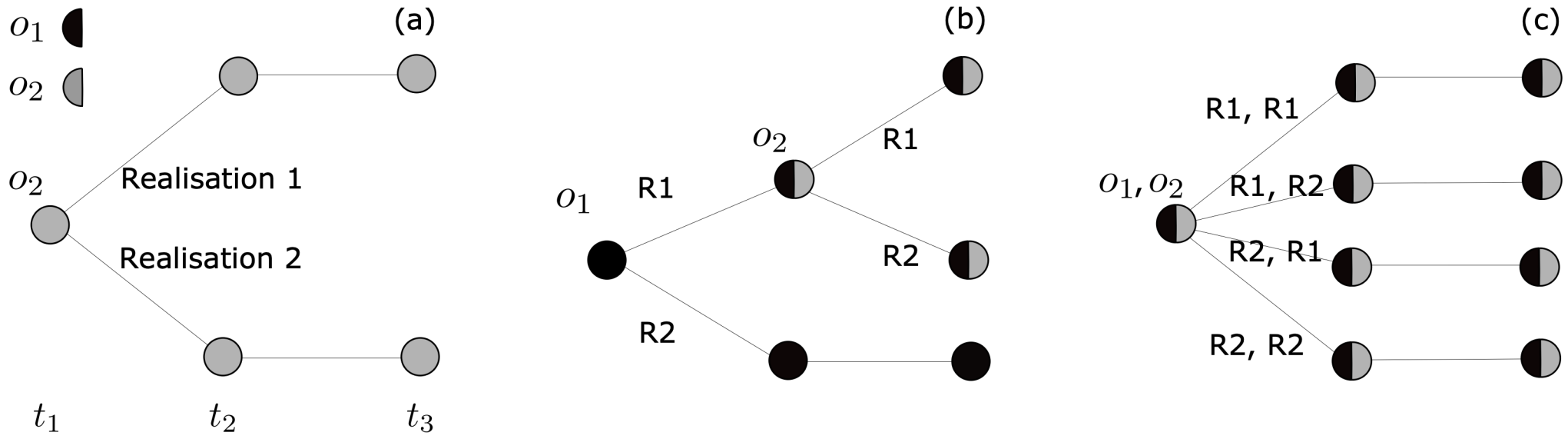
Problem description

In (a) O_2 is activated in t_1 with uncertainty over two possible realizations while O_1 is never activated accounting for two scenarios.



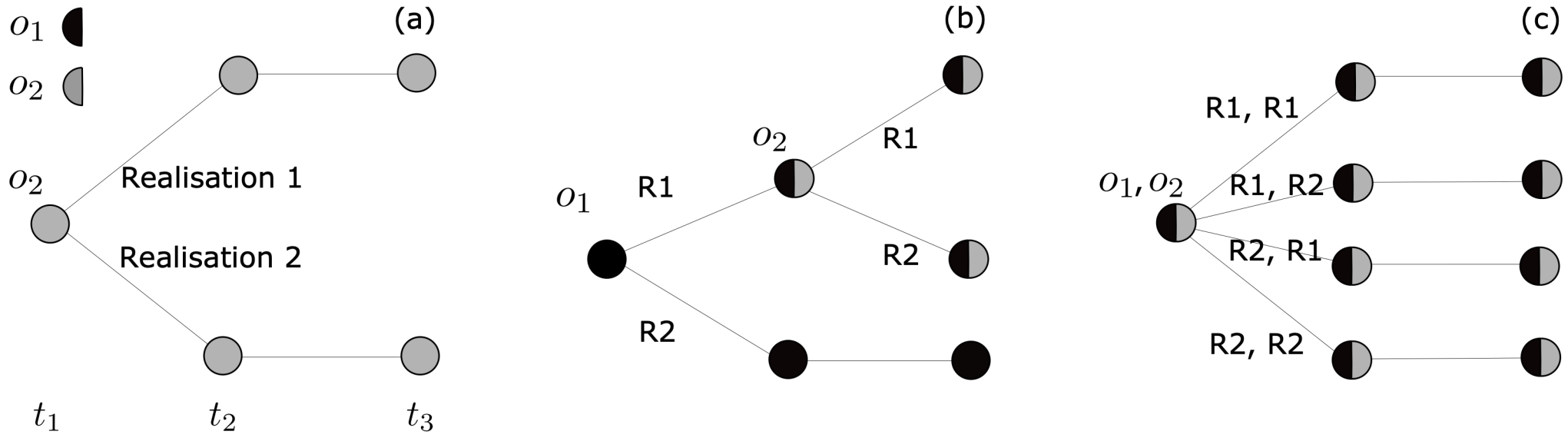
Problem description

In (b) O_1 is activated in t_1 and O_2 is activated in t_2 both with two possible realizations showing three scenarios.



Problem description

In (c) both options are activated in t_1 and hence produces four scenarios. These activations are during the course of optimization and are not known a priori.



Problem formulation

w is a scenario with probability of occurrence of p_w

t denotes time (stages)

i is a water resources development decision

r is the discount rate

Constraint 5 and 6 introduce the endogenous uncertainty

$$min\ e = \sum_{w\in\Omega,t\in T,i\in I} \frac{p_w}{(1+r)^t}[cC_i \times (dS^w_{t,i} - dS^w_{t-1,i}) + fC_i \times dS^w_{t,i} + vC_i \times S^w_{t,i}], \tag{1}$$

$$s.t.$$

$$\sum_{i\in I} S^w_{t,i} + eS^w_t \geq D_t, \quad \forall w \in \Omega, t \in T, \tag{2}$$

$$S^w_{t,i} \leq dS^w_{t,i} \times cS^w_i, \quad \forall w \in \Omega, t \in T, i \in I, \tag{3}$$

$$dS^w_{t+1,i} \leq dS^w_{t,i}, \quad \forall w \in \Omega, t \in T, i \in I, \tag{4}$$

$$dS^w_{1,i} = dS^v_{1,i}, \quad \forall w, v \in \Omega, i \in I, v \neq w \tag{5}$$

$$dS^w_{t+1,i} = dS^v_{t+1,i} \Leftrightarrow \bigwedge_{i\in D(w,v)} \bigwedge_{l<t} \left(1 - dS^w_{l,i}\right), \quad \forall w, v \in \Omega, i \in I, v \neq w \tag{6}$$

Application Water Resource Planning Problem

Table 1 shows demand growth and existing supply projection (assumed to be known)

Table 1: Existing water availability and demand growth projection

	t_1	t_2	t_3	t_4	t_5
Demand (Ml/d)	2010	2024	2042	2050	2060
Water availability (Ml/d)	2000	2000	2000	2000	2000

Table 2 shows the uncertainties implied by the water supply-demand intervention options that follow a triangular distribution

Table 2: Decision dependent uncertainty implied by the investment options

	Water availability by expanding capacity (Ml/d)			
Intervention	high	medium	low	Mean
o_1	60	42	40	47
o_2	25	20	5	17
o_3	20	18	15	18

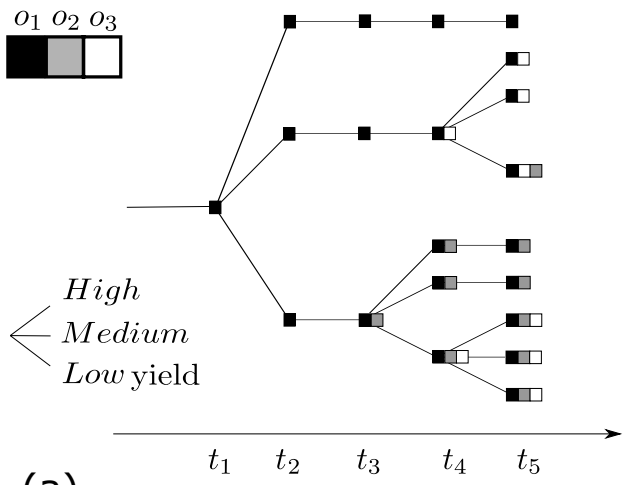
Results: Optimal activation of options

(a) Solution structure for capacity expansion by considering endogenous uncertainty

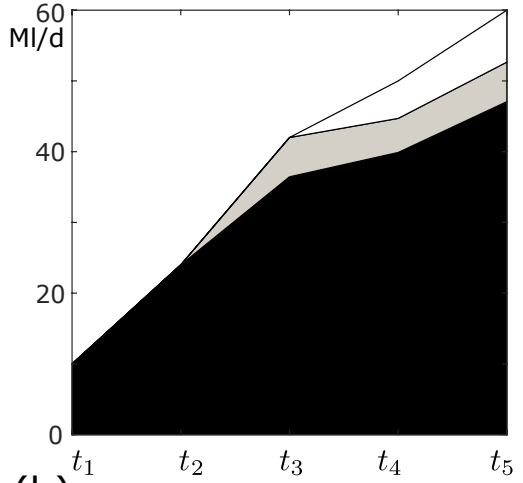
(b) Utilization of options by considering endogenous uncertainty

(c) Capacity expansion deterministic solution

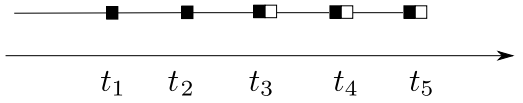
(d) Utilization of options activated in deterministic solution



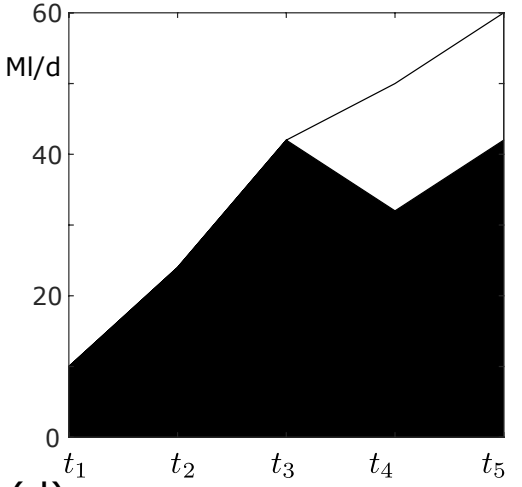
(a)



(b)



(c)



(d)

Conclusions

- Proposed an extension to an adaptive multistage real options water infrastructure planning optimization problem formulation for when some uncertainties are endogenous.
- Solved problems where water resource system intervention decisions control when additional uncertainties associated with new options must be introduced.
- The formulation with endogenous uncertainty saves 10% compared to deterministic formulation.

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