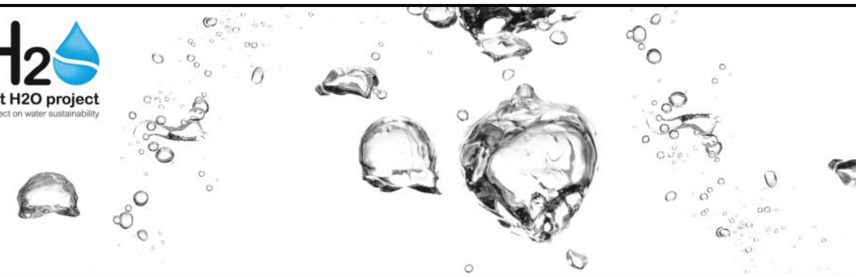
sH2 the smart H2O project
A European project on water sustainability



Dynamic water pricing, consumer behaviour, & evaluating their impacts on water systems

Julien Harou, Charles Rougé, and many collaborators
University of Manchester, etc.

SEVENTH FRAMEWORK PROGRAMME

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sH2 the smart H2O project
A European project on water sustainability

Outline

1. Should smart-meters change the price of water? If so how?

2. How do consumers respond to changing prices?

   Few utilities ready for dynamic pricing, so how to predict impacts?

   - Meta-analysis of price elasticity studies
   - Online questionnaires
   - Online experiment

3. Should smart meters influence today's water supply investment decisions? What imact could they have?

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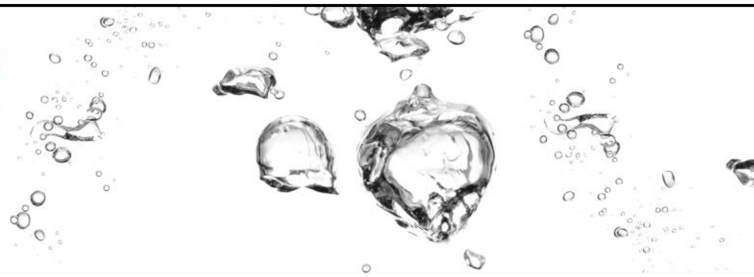

1. Smart meter enabled dynamic pricing of water

Charles Rougé, Julien Harou

Overview

- What's 'economic engineering' opportunities for smart meters?
- How could they reduce or shift demand?
- Conceptual framework for evaluating the impacts & benefits of smart-meter enabled dynamic pricing
- Proof of concept application to London's water supply system
- Discussion

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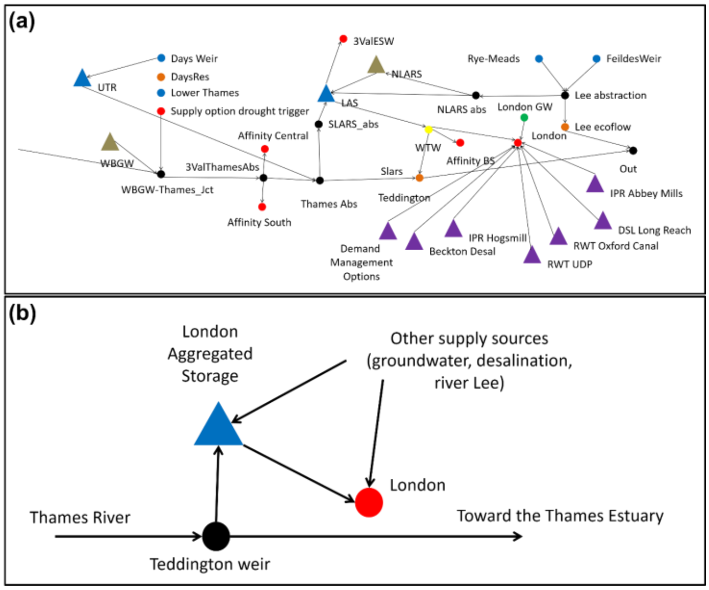
London case study: The system



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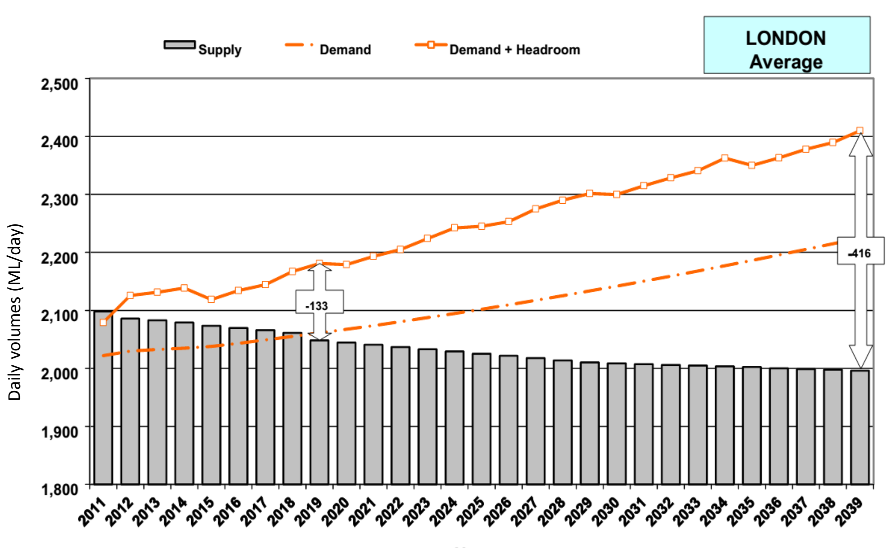
London case study: Supply & demand



Dynamic water pricing

- Smart metering possibilities :
  - Frequent measurements
  - Communicate with customers in real time
- Constraint on dynamic pricing: rates communicable to consumers, water managers

Dynamic water pricing

- Smart metering possibilities :
  - Frequent measurements
  - Communicate with customers in real time
- Constraint on dynamic pricing: rates communicable to consumers, water managers

1) Scarcity pricing	**2) Peak pricing**
Drought-time demand reduction	Demand shifting
Aims at overall economic efficiency	Increases cost-efficiency of smart metering
Weekly to seasonal timescale	Sub-daily to weekly timescale

1) Scarcity pricing

- Increase urban consumer volumetric prices commensurate with water stress
- Goal: to achieve an appropriate balance between sectors:
  - An efficient one, that allows for the largest societal economic gain from water use)
  - One where an incremental unit of water used by each sector is worth the same
- Sends a tangible signal to consumers:
  - 'The environment is now being strongly impacted by our water use'
  - 'We have increased prices to reflect this'
- Challenges: acceptability, securing and maintaining impact

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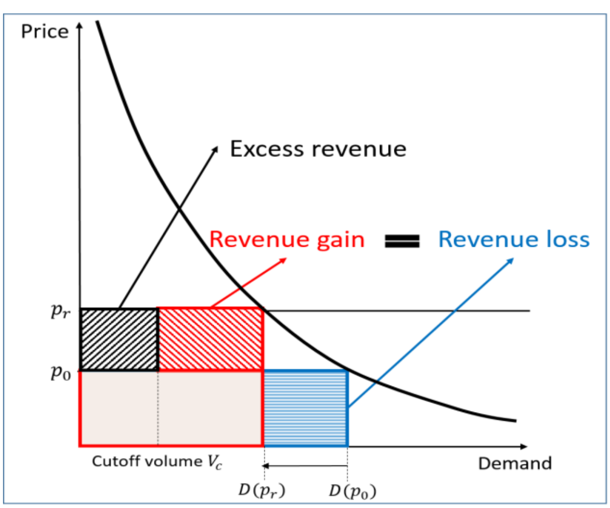
How to reduce demand via scarcity pricing?



- Increase price from p_0 to p_r during drought
- Utility revenue neutrality
  - Increasing block tariffs (IBTs)
  - Re-allocate excess revenue (social tariff, environmental fund, etc)

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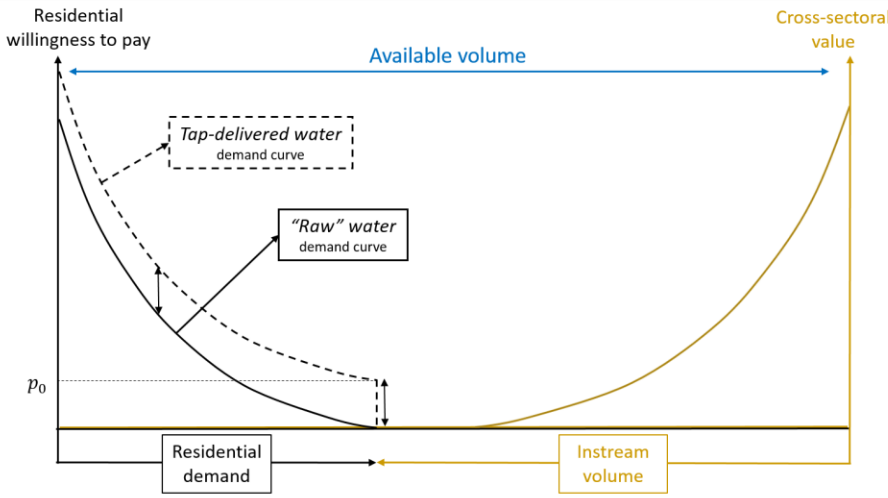
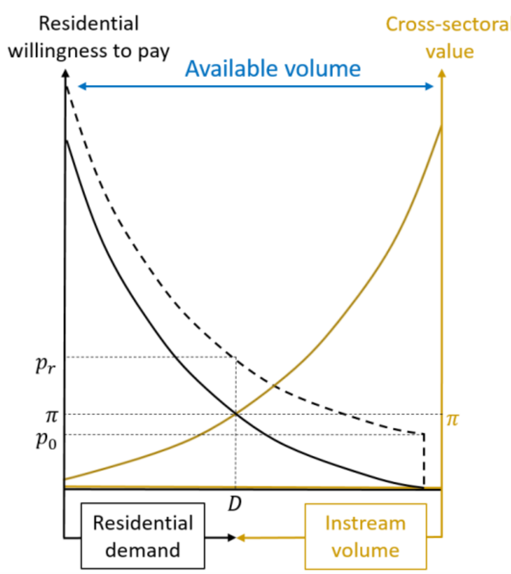
Efficient water pricing (1/2)



Efficient water pricing (2/2)



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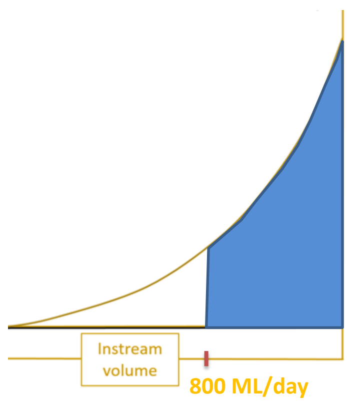
London application



- Minimum environmental flows (800 ML/day upstream of London)
- Published environmental value (blue area) for ecosystem services:

  £250 M/yr (from 2 WTP studies)
- Other benefits: tourism, property valuation (non-evaluated)
- 2 valuation scenarios tested: £250 and £500 M/yr

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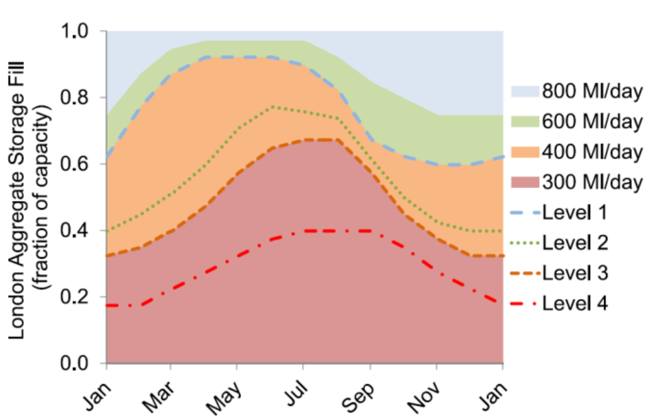
Three 80 year weekly Simulations



Next plot will look at environmental water shortages under 3 scenarios:

1. Current control rule (no scarcity pricing)
2. Scarcity pricing with Current valuation (£250M/yr)
3. Scarcity pricing with High valuation (£500M/yr)

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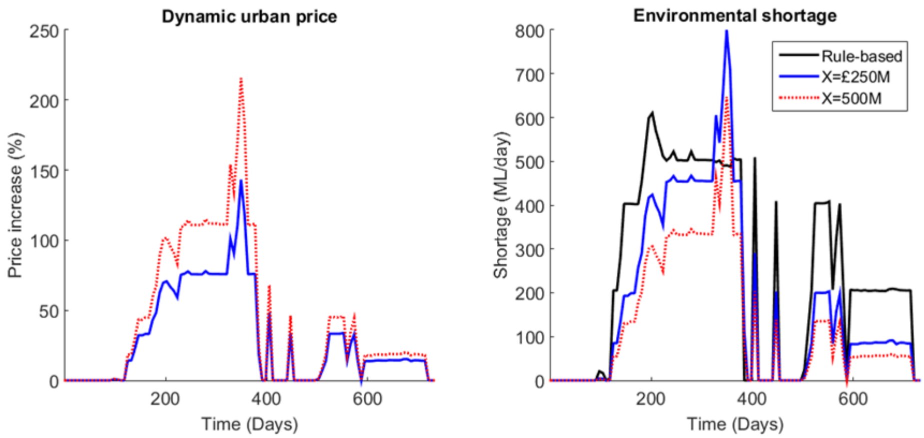
Results:

Price and environmental shortage during 1922 drought



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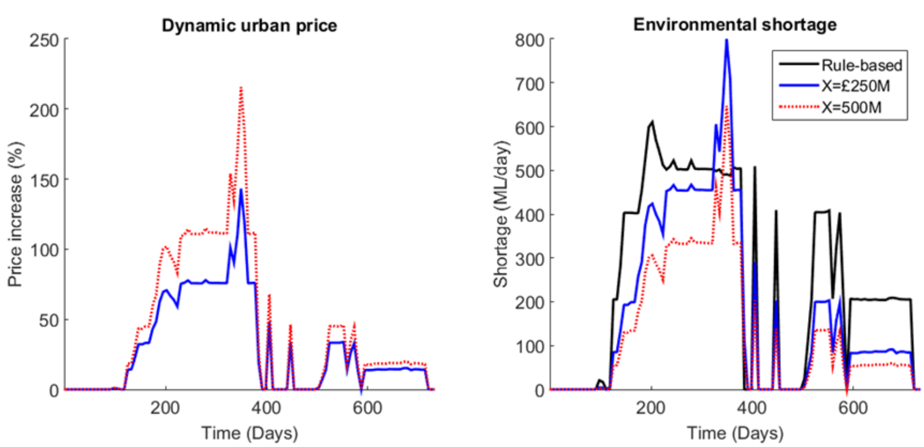
Results:

Price and environmental shortage during 1922 drought

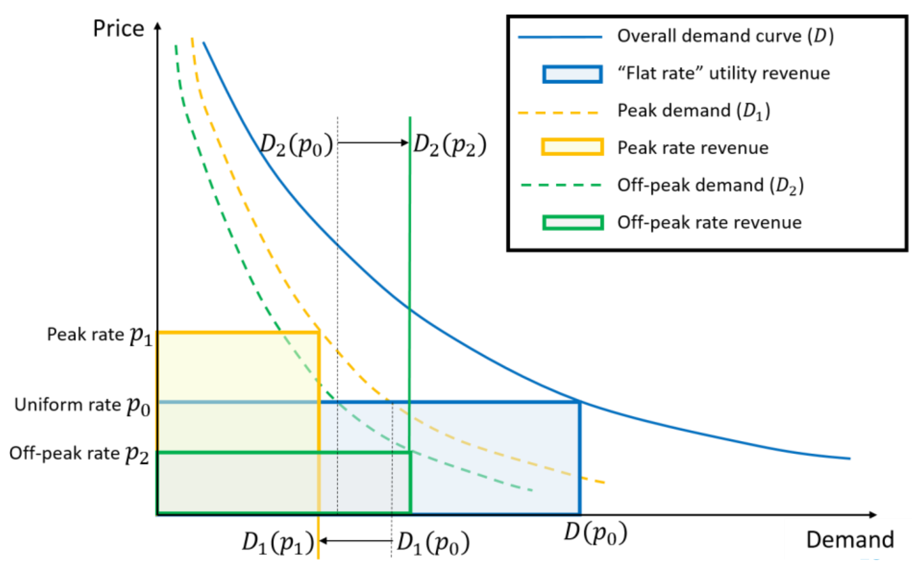


	Rule-based allocation	Scarcity pricing $X = £250M/year$	Scarcity pricing $X = £500M/year$
Frequency of price doubling (%)	0	0.47	2.0
Frequency of price tripling (%)	0	0.34	0.38
Average environmental flow shortage (ML/day)	202	157	111

2) Peak pricing

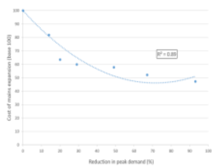
- Increase urban consumer volumetric prices at certain times of the day
- Goal: reduce peak consumption will enable financial savings through:
  - Delayed capacity expansion
  - Delayed maintenance
  - Reduced peak energy consumption -> reduced energy cost
- Sends a tangible signal to consumers:
  - 'Use at this time leads to increasing costs on our future network'
  - 'We have increased prices to reflect this'
- Challenges: acceptability, securing and maintaining impact

Displacing demand via peak pricing



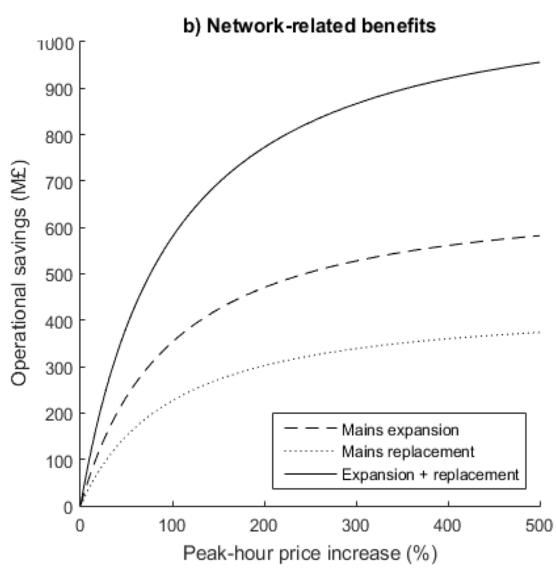
London application

- Annual population growth expected 0.6%: will require network expansion



- Quadratic relationship between peak usage reduction and cost of investing in new mains in a residential suburb in Sydney, Australia. Data from Lucas et al. (2010)
- Extrapolate relationship to network expansion and replacement given an average per-property cost of mains installation or replacement £2,000
- Financial savings associated with different levels of peak-hour price increases can then be computed (3.5% discount rate, elasticity of 40%)

Potential London benefits



Dynamic pricing conclusions

Scarcity pricing

- **Managing demand by:**
  Demand reduction
- **Potential for:**
  Reducing drought vulnerability (environmental flow shortage)
- **Financial impact:**
  Preserves utility's finances compared with usage restrictions
- **Further research:**
  Valuation of environmental flows

Peak pricing

- **Managing demand by:**
  Demand shifting
- **Potential for:**
  Financial operational savings (network, energy)
- **Financial impact:**
  Aimed at financial operational savings (network, energy)
- **Further research:**
  Estimating savings from peak pricing (network impacts, pressure management)

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   - Online experiment

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2. Predicting consumer responses to pricing

A. Meta-analysis of price elasticity
B. Online surveys
C. Online experiment

A. Meta-analysis of price elasticity

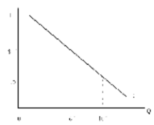
Riccardo Marzano, Paola Garrone

Water price elasticity

Meta-analysis of water demand studies

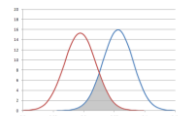
DATA GATHERING
Price elasticity estimates from previous studies of water demand

PRICE ELASTICITIES
How much does water demand decrease in response to a price increase?



ROLE OF LOCAL CONTEXT AND METHODOLOGY
Geography, price regulation, socio-economic characteristics, sampling method, model specification, estimator

SIMULATION OF PRICE ELASTICITIES
E.g. price regulation scenarios (utility-level characteristics)



PREDICTION PURPOSES
Price and income elasticities statistics (input to WP3)

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Water price elasticity

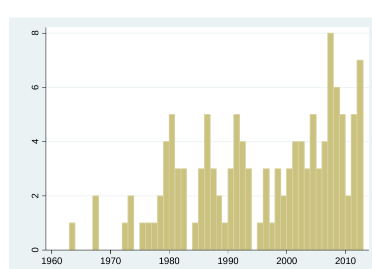
Sampled water demand studies

– 198 studies collected (26 European studies)
  - Coverage: US, Europe, rest of the world

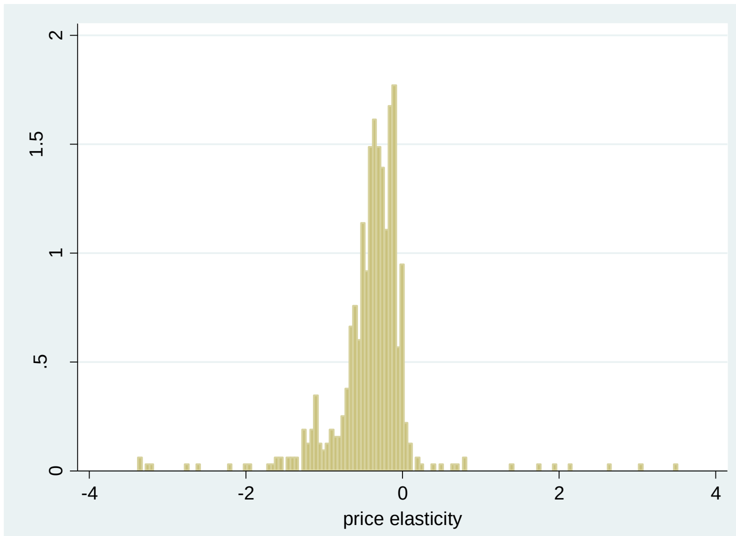
Sampled studies

Sample					
Studies in the sample = 125 Observations = 635		Studies		Observations	
Location	*United States*	64	51.2%	414	65.2%
	Europe	26	20.8%	111	17.5%
	Other locations	35	28.0%	110	17.3%
Publication status	*Published*	113	90.4%	570	89.8%
	Unpublished	12	9.6%	65	10.2%

Water demand studies overtime



Distribution of price elasticity of demand



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Water price elasticity

The meta-regression model

– Dependent variable: Estimated price elasticity
– Independent variables
  - Water demand specification
    – Type of estimated price elasticity (point, segment, long-run)
    – Price measure used in the water demand estimation (marginal, average, Shin)
    – Conditioning vars (income, HH size, temperature, rainfall,…)
    – Functional form (linear, semi-log, log-log,…)
  - Data
    – Disaggregation over time (yearly, monthly, daily data)
    – Disaggregation over users (HH-level, aggregate-level
    – Data period (summer, winter)
    – Data structure (cross-section, time series, panel data)

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Water price elasticity

The meta-regression model

- Independent variables
  - Methodology
    - Estimator (OLS, IV, 2SLS, 3SLS)
    - Innovative method (DCC)
  - Publishing status
    - Published study
  - Location-specific controls
    - Location (Europe, US, rest of the world)
    - Socio-economic factors (GDP per capita)
    - Tariff structure (flat, IBR, DBR)
    - Water scarcity (Water Stress Indicator, WSI)
    - Regulatory framework (Independent regulator)

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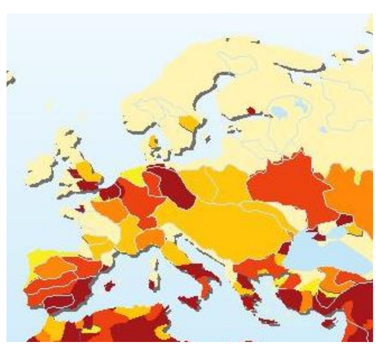
Water price elasticity

Three case studies



- The three case studies differ in:
  - Water scarcity level
  - Regulatory framework
  - Socio-economic aspects (GDP per capita,…)

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Case study simulation of price elasticity

Average price elasticity	Baseline	IBR
London	-.32	-.4
Ticino	-.32	-.4
Valencia	-.34	-.6

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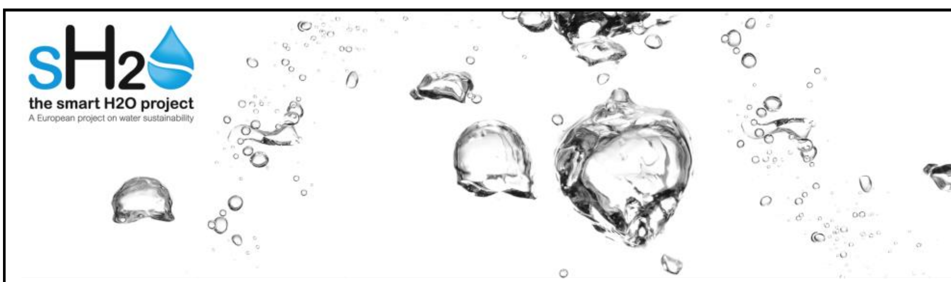

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B. Water consumers’ responses to incentives: Results from SmartH2O surveys

Paola Garrone, Riccardo Marzano

SEVENTH FRAMEWORK PROGRAMME

SmartH2O online surveys: Objectives

- Empirical evidence on customers' response to **dynamic pricing** schemes enabled by smart meters
  - Do residents reduce consumption if price varies with water scarcity?
  - Do they shift temporally demand if price varies with time of use?
- Empirical evidence on the performance of **other forms of incentive** compared to price
  - Symbolic rewards (badges)?
  - Monetary rewards (vouchers, rebates)?

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Why an online survey of residents

- Other options to get **insights on dynamic pricing & rewards**?
  - Revealed preferences & demand models? Unfeasible
  - Lab experiments? Unfit to inform policy
  - Field experiments? Open option
- A few **advantages** of online surveys
  - Feasible, adaptable to the context, administrable
  - Strategies for closing the gap with revealed preferences

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Enhancement strategies

- **Randomization** of incentives and scenarios
  - Control / Baseline sample
  - Treatment samples
- **Checks**
  - Certainty on statements
  - Internet use
- **Controls**
  - Respondent characteristics and attitudes
  - Household and property characteristics
  - Water uses, Appliances, Fixtures
  - Actual consumption (Valencia)

Sample and surveys administration

- **Ticino (Switzerland)**: October-November 2015
  - Administered by SUPSI
  - Paper invitation to 70,000 customers of SES (power utility & sH2O partner)
  - Drawn 3 mini Ipads as a prize
  - 462 filled questionnaires (Italian, German, English versions; 0.7% response)
- **Valencia (Spain):** May 2016 – Ongoing
  - Hosted by SmartH2O Consumer Portal
  - Email invitation to 80,000 customers of Emivasa + Banner on paper invoice to all customers + School workshop (+ Media campaign)
  - SmartH2O points as a prize (about half of a Drop! game)

Ticino survey: Sample & randomization

- Incentives and scarcity scenarios are randomized across respondents

Treatments	Incentives		Scarcity scenarios		#Respondents	
	Badge°	Bill increase^	Regular	Critical*	#	%
Baseline			X		65	14.07
Pricing		X	X		86	18.61
Badge	X		X		82	17.75
Scarcity				X	79	17.10
Dyn. Pricing		X		X	82	17.75
Dyn. Badge	X			X	68	14.72
Total					**462**	**100.00**

In order to get the badge:
° Users who undertake water saving actions are rewarded with a "Best friend of environment" badge that is advertised in the town; ^ Users who do not undertake water saving actions have the semester water bill increased by 40CHF/semester-household (23.3-43.5% of the reference bill range); *The district is facing a severe water supply issue/water shortage

SmartH2O surveys (Ticino + Valencia)

Incentives

No incentive, Price increase, Badge, Rebate, Voucher

Scenarios

Regular, Water shortage, Peak time issues, Severe drought

Changes in water uses

Shower time reduction, Watering time reduction, Shifting washing machine to off-peak time, …

Findings

Estimates of consumers' responses to different incentives under different scenarios

Consumers' characteristics and water uses

Example from Valencia survey. *Imagine that your water supplier measures in detail household water consumption through smart meters and your city is facing a very severe drought period. Your municipality, in order to deal with the water shortage issue, increases the bi-monthly water bill by 5€ for households who do not undertake water saving actions.*

Results (Ticino): Effects of pricing

- **Showertime reduction**: Response of the «average» respondent to a **bill increase** of 40 CHF/semester-household ^

	Predicted reduction [min]#	Standard error	95% conf. interval
Pricing=1	0.8***	0.1307	0.5143 - 1.0288
Pricing=0	0.5***	0.0902	0.3111 - 0.6660
Difference	**0.3***	0.1718	-0.0537 – 0.6198
Observations		362	

Note: ^23.3-43.5% of the reference bill range; # 5.9 [min] showertime reference; *, **, ***: 10%, 5% and 1% significance levels

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Results (Ticino): Effects of «dynamic» pricing

- **Showertime reduction**: Response of the «average» respondent to a **bill increase** of 40 CHF/semester-household **under water shortage**^

	Predicted reduction [min]#	Standard error	95% conf. interval
Pricing=0&Scarcity=0	0.45***	0.1334	0.1763 - 0.7015
Pricing=1&Scarcity=1	1***	0.1886	0.6134 - 1.3557
Difference	**0.55****	0.2312	0.0926 – 0.9988
Observations		362	

Note: ^23.3-43.5% of the reference bill range; # 5.9 [min] showertime reference; *, **, ***: 10%, 5% and 1% significance levels

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Results (Ticino): Effects of pricing

- **Showertime reduction**: Response of various consumer types to a **bill increase of 40** CHF/semester-household ^

Consumer type	Predicted reduction [min]	Standard error	95% conf. interval
Sample mean	0.3*	0.1718	-0.0537 – 0.6198
Sample mean under scarcity	0.55**	0.2312	0.0926 – 0.9988
Education= Less than apprenticeship	0.9**	0.4189	0.0517 – 1.6939
Education= University degree	-0.07	0.2881	-0.6394 – 0.4900
Env.attitude=Not env. friendly at all	-0.72	0.7000	-2.0362 – 0.7078
Env.attitude=Extremely env. friendly	0.8**	0.4316	-0.0005 – 1.6912
...other types	...	...	... - ...

Note: ^23.3-43.5% of the reference bill range; # 5.9 [min] showertime reference; 41
*, **, ***: 10%, 5% and 1% significance levels

Results (Ticino): Effects of badges

- **Showertime reduction**: Response of various consumer types to to the «Best Friend of Environment» **badge**^

Consumer type	Predicted reduction [min]	Standard error	95% conf. interval
Sample mean	0.1097	0.1777	-0.2386 – 0.4581
Sample mean under scarcity	0.3261	0.2406	-0.1454 – 0.7976
Education= Less than apprenticeship	0.0499	0.4427	-0.8178 – 0.9176
Education= University degree	0.1439	0.3004	-0.4448 – 0.7326
Env.attitude=Not env. friendly at all	-1.1371	0.6979	-2.5049 – 0.2307
Env.attitude=Extremely env. friendly	0.8499**	0.4239	0.0190 – 1.6808
...other types	...	...	... - ...

Note: ^23.3-43.5% of the reference bill range; # 5.9 [min] showertime reference; 42
*, **, ***: 10%, 5% and 1% significance levels

Conclusions

- «Average» Ticino consumer
  - Pricing effect: Slight (5%) shower time reduction
  - «Dynamic pricing» effect (bill increase under scarcity): Larger (9%) shower time reduction
  - Badge effect: Moving washing machine on night
  - Age, education, environmental attitude, property tenure: possible moderators
- Looking forward to Valencia survey data…
  - Possibly a larger sample
  - Control of actual consumption
  - Peak-time pricing, Rebates (along with bill increase)

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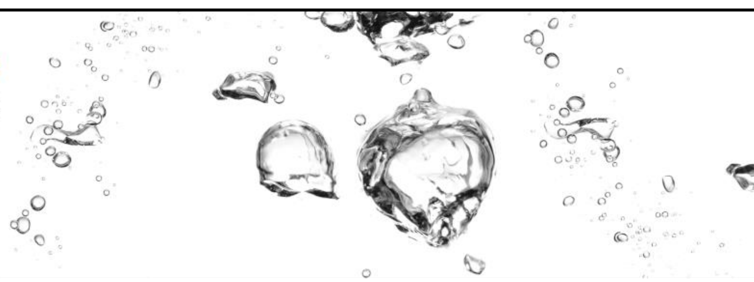

C. Online experiments

Riccardo Marzano, Charles Rouge, Paola Garrone, Julien Harou, Manuel Pulido

Goal

- Aim: evaluating price response by asking people to state their trade-off between water price and shower time
- The experiment starts with questions about the respondents' socio-demographics
- Introduces notion of "satisfaction" for using the shower and "hassle cost" for shorter shower times

Proposed experiment

- The experiment is conceived as a game where players are asked to decide how much time they are going to spend in the shower.
- They are endowed with a fixed sum, which they can use to buy the water they need for the shower, having full info about the unit price of the water litre.
- Final payoff would be the residual endowment (after having paid for water) plus an additional component (that could be negative) that will take into account disutility of a short shower (to prevent people from maximizing the payoff, this function will be kept hidden).
- This design relies on randomization to test the effect of price surge. Different people are exposed to different prices. Assuming that we will have a fairly large amount of participants, we can match them ex-post (based on their demographic characteristics) to obtain the effect of a change in water price. We can randomize the scarcity scenario.

Introductory statement

- This is an online experiment about water conservation.
- You will be asked a series of preliminary questions on your socio-economic characteristics and water usage.
- Then you will be asked to answer a question regarding your water use depending on water price.
- Upon completing this questionnaire, you are guaranteed $1.3, but depending on how you answer questions, you may be able to win between $2 and $3 in total.

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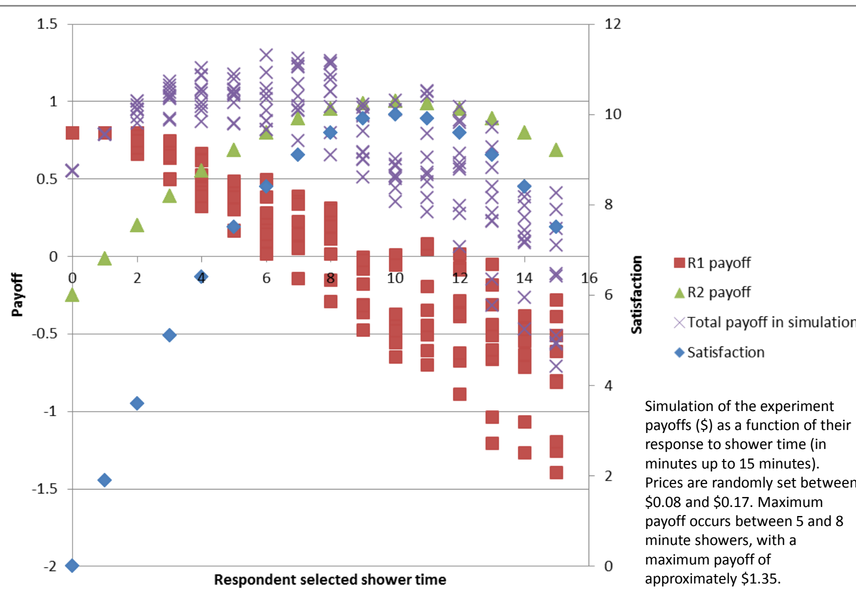
Monte Carlo simulation of the experiment



Simulation of the experiment payoffs ($) as a function of their response to shower time (in minutes up to 15 minutes). Prices are randomly set between $0.08 and $0.17. Maximum payoff occurs between 5 and 8 minute showers, with a maximum payoff of approximately $1.35.

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   - Online experiment

3. Should smart meters influence today's water supply investment decisions? What imact could they have?

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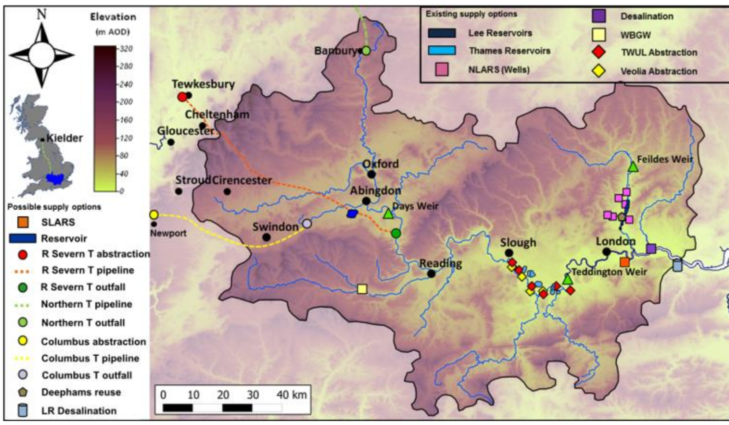
3. Should smart meters impact water supply investment programs? How to decide?

SEVENTH FRAMEWORK PROGRAMME

River Thames basin water resource system planning - decisions



Demand management options
Active Leakage Control (**ALC**)
Pipe repair campaign (**Mains**)
Efficiency Improvements (**Efficiency**)
Installation of Smart Meters (**Meters**)
Seasonal Tariffs (**Tariffs**)

Which assets? At **what capacity**? **When**?

sH2 the smart H2O project

Aggregate demand management interventions

Intervention	Description	Capacity or release
	Demand management interventions	
Active Leakage Control (ALC)	Enhanced levels of "Find and Fix", implementation of further pressure management, and trunk main leakage management	0 – 50 Ml/day reduction in demand
Pipe repair campaign	Replacement of water mains, communication pipes and supply pipes to reduce leakage in the distribution system.	165.1 Ml/day reduction in demand
Enhanced efficiency improvements (EFI)	Water efficiency campaigns, retrofitting and household and commercial customer audit programmes	11.6 Ml/day reduction in demand
Installation of smart meters (Meters) with seasonal tariffs (Tariffs)	Installing smart meters in properties with application of seasonal tariffs. Tariffs are considered as a decision conditional on implementing Meters.	88.7 Ml/day reduction in demand

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Many-objective optimization and visual analytics reveal key trade-offs for London's water supply

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Infrastructure system design
Evolutionary multi-objective optimization

SUMMARY

In this study, we link a water resource management simulator to multi-objective search to reveal the key trade-offs inherent in planning a real-world water resource system. We consider new supplies and demand management (conservation) options while seeking to elucidate the trade-offs between the best portfolios of schemes to satisfy projected water demands. Alternative system designs are evaluated using performance measures that minimize capital and operating costs and energy use while maximizing resilience, engineering and environmental metrics, subject to supply reliability constraints. Our analysis shows many-objective evolutionary optimization coupled with state-of-the art visual analytics can help planners discover more diverse water supply system designs and better understand their inherent trade-offs. The approach is used to explore future water supply options for the Thames water resource system (including London's water supply). New supply options include a new reservoir, water transfers, artificial recharge, wastewater reuse and brackish groundwater desalination. Demand management options include leakage reduction, compulsory metering and seasonal tariffs. The Thames system's Pareto approximate portfolios cluster into distinct groups of water supply options; for example implementing a pipe refurbishment program leads to higher capital costs but greater reliability. This study highlights that traditional least-cost reliability constrained design of water supply systems masks asset combinations whose benefits only become apparent when more planning objectives are considered.

What type of solution are we searching for?

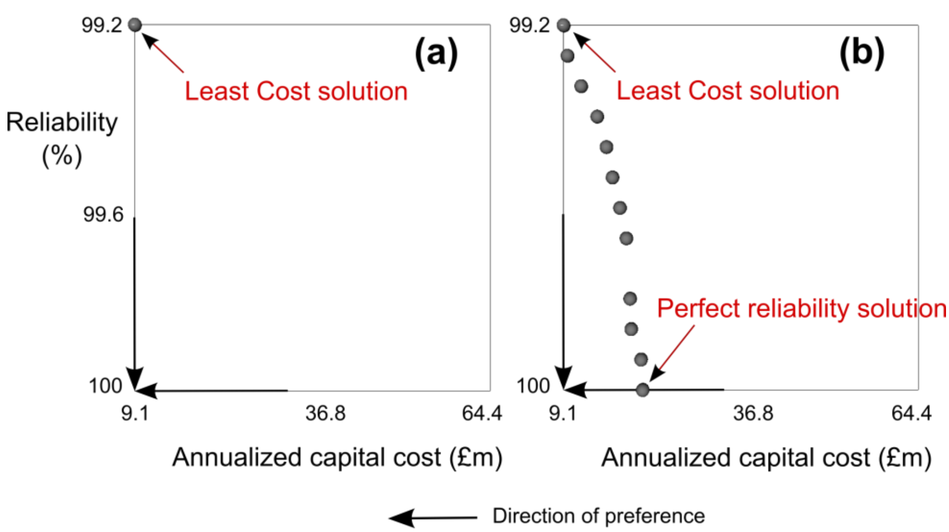
Our objectives:

- **Capital cost** – *Annualized capital cost of implementing new supply and demand options based on option's design life (£m)*
- **Supply deficit** – *Average annual experienced by London WRZ (%)*
- **Supply resilience** – *Maximum duration failure* (weeks)*
- **Supply reliability** – *Frequency of failures* (%)*
- **Eco-deficit** – *Difference between natural and simulated low flows (%)*
- **Energy cost** – *Annual average operating cost (£M/a)*

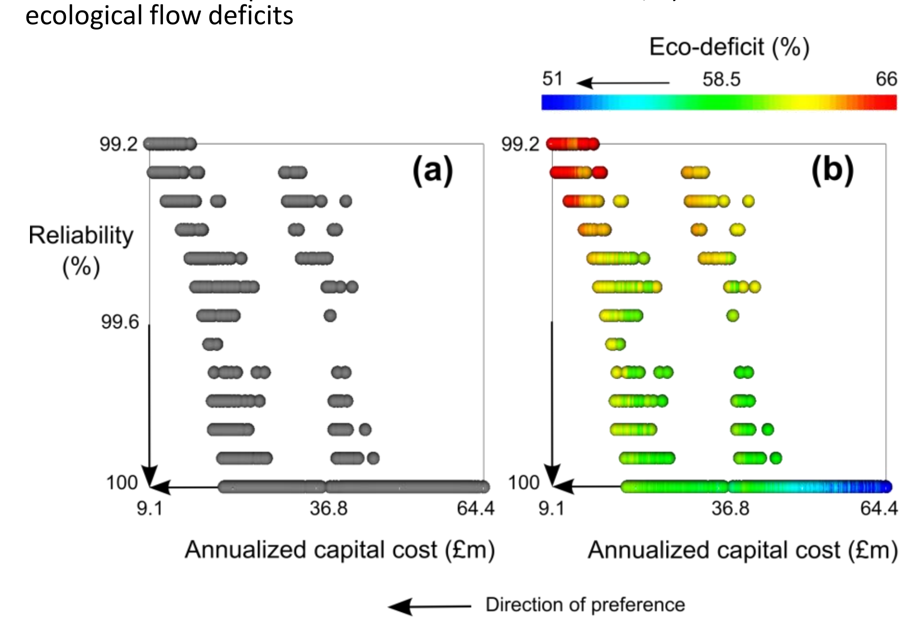
Our constraints

- **Levels of Service** *(max. frequency of imposing demand restrictions)*
- **Mutual exclusivity of some supply options**

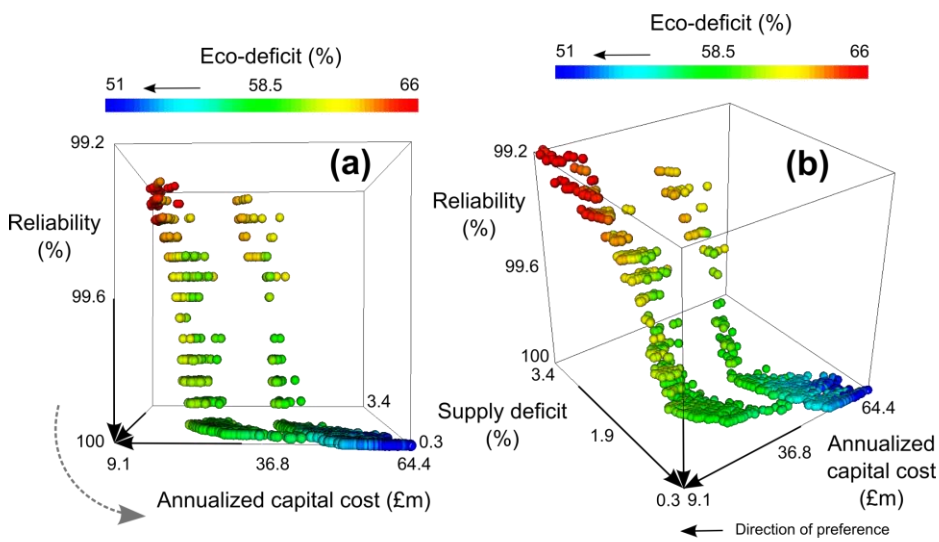
Single and two objective optimization; Currently UK utilities find a) they should consider b)



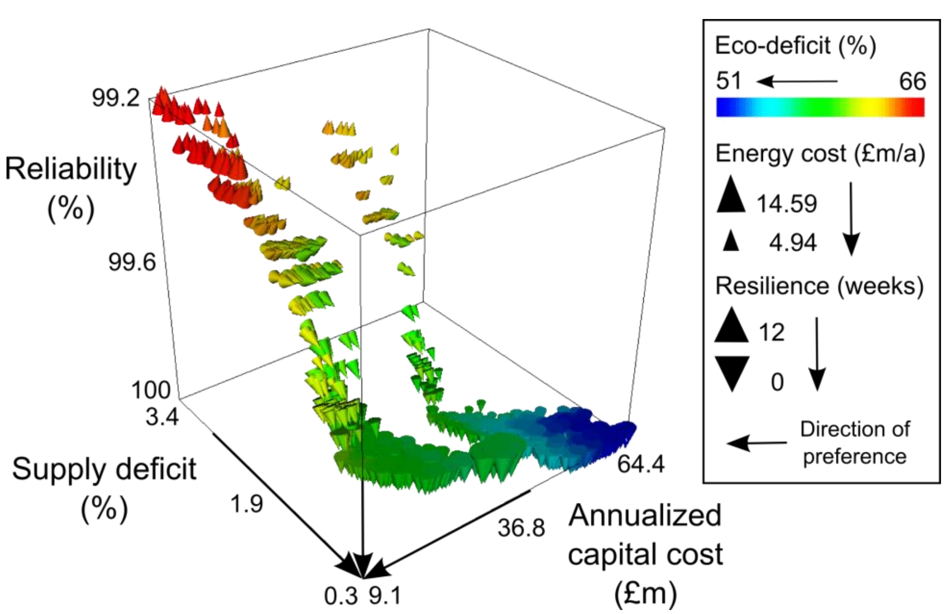
Many objectives implies many alternative solutions: a) plots 6 dimensions in a 2 dimensional plot - we need more dimensions!; b) adds color to show ecological flow deficits



Adding Supply deficit as "depth"



Six objective trade-offs



Here we do the same search, but consider performance over 88 different plausible futures …

- **Climate change**:

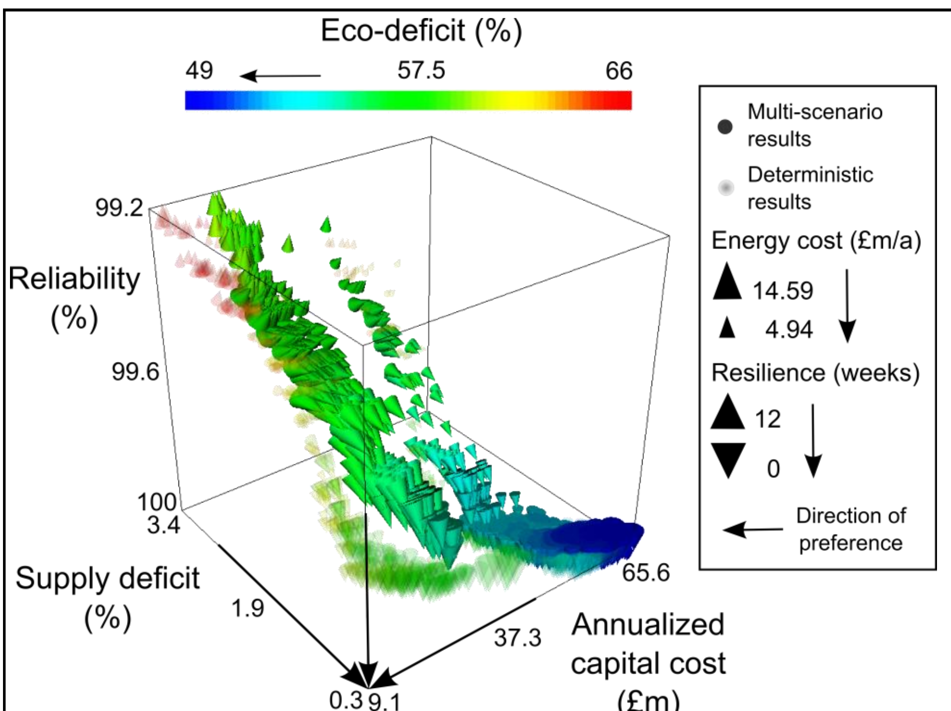
  11 Hydrology flows scenarios (using Future Flows[1] from NRFA)

  – Not a reconstruction of past hydrology
- **Socio-economic**:

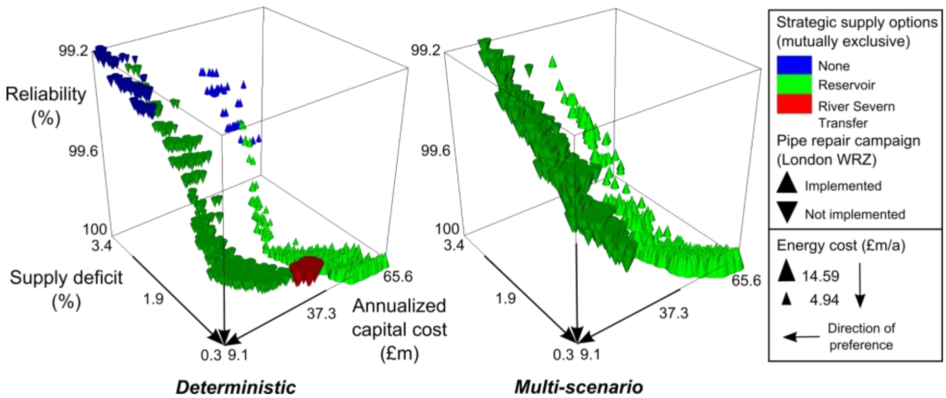
  2 Demand projection and

  2 Energy prices scenarios
- **Institutional**:

  2 Sustainability reductions scenarios
- 88 possible combinations



Where are specific investment options located in the performance trade-off space?



- The efficient portfolios found by searching with only historical conditions (left) recommend a range of options (do nothing, reservoir, transfer) whilst the search process which considered many plausible futures (right) shows only the reservoir option is robust.
- Both solution sets show two distinct fronts created by the implementation of London's Pipe repair campaign, which implies higher capital but lower operating (energy) costs.

Discussion

London Findings

- New reservoir and demand management schemes are likely no-regret options (provide benefits even in the absence of climate change)

Benefits

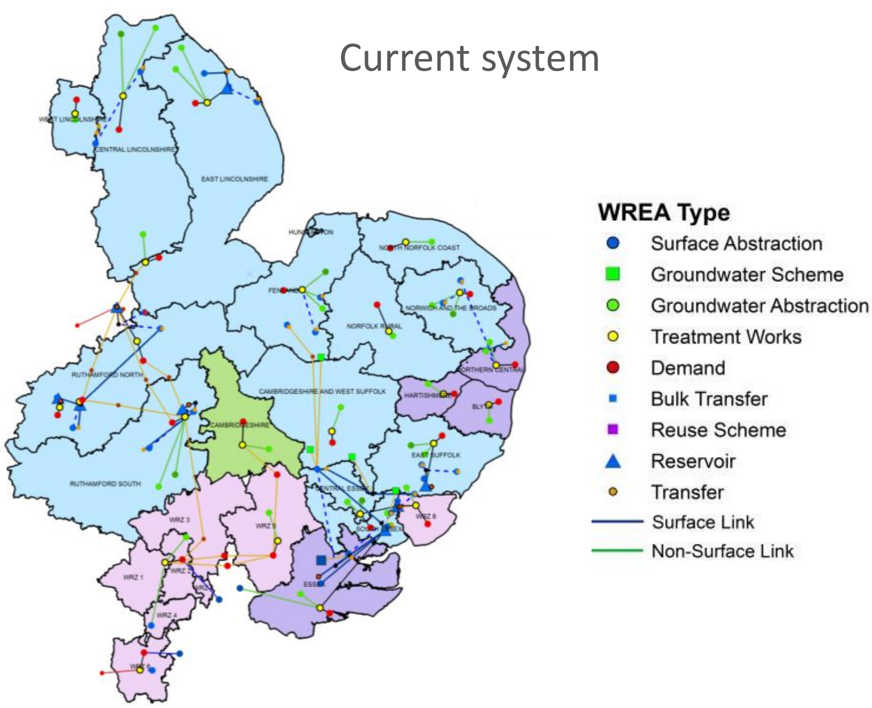
- Suggests many alternative promising system designs and identifies the performance trade-offs they imply
- Identifies robust plans given many plausible futures
- Recent work looks at scheduling of interventions – demand management options frequently introduced early

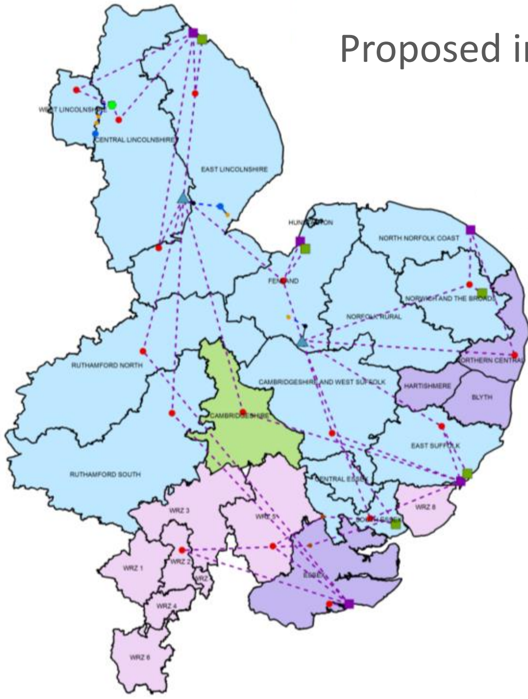
Other large scale case studies

'Water Resources of East England' (WRE)

'Water Resources of the South East' (WRSE)

Current system





Proposed interventions

- Demand management options including metering
- 5 desalination options
- 5 reuse options
- 2 reservoir options
- 1 artificial recharge scheme
- 2 transfers from existing reservoir
- 38 unique supply to demand transfer links

Outline

1. Should smart-meters change the price of water? If so how?

2. How do consumers respond to changing prices?

   Few utilities ready for dynamic pricing, so how to predict impacts?

   - Meta-analysis of price elasticity studies
   - Online questionnaires
   - Online experiment

3. Should smart meters influence today's water supply investment decisions? What imact could they have?

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Discussion

1. Smart-meters enable water price change over time which could increase economic benefits and decrease future financial costs

2. Utilities haven't yet adopted dynamic pricing; several methods available to estimate consumer reactions. Their accuracy is yet unclear.
   - Meta-analysis of price elasticity studies
   - Online questionnaires
   - Online experiment

3. Smart meters should be part of water supply investment decisions. For London demand managment is efficient in almost all situations, and applied early. This puts pressure to progress on 1 and 2.