Appropriately Controlling for Cost Interactions, Water Scarcity and Operating Environment in Regulatory Water Cost Assessment

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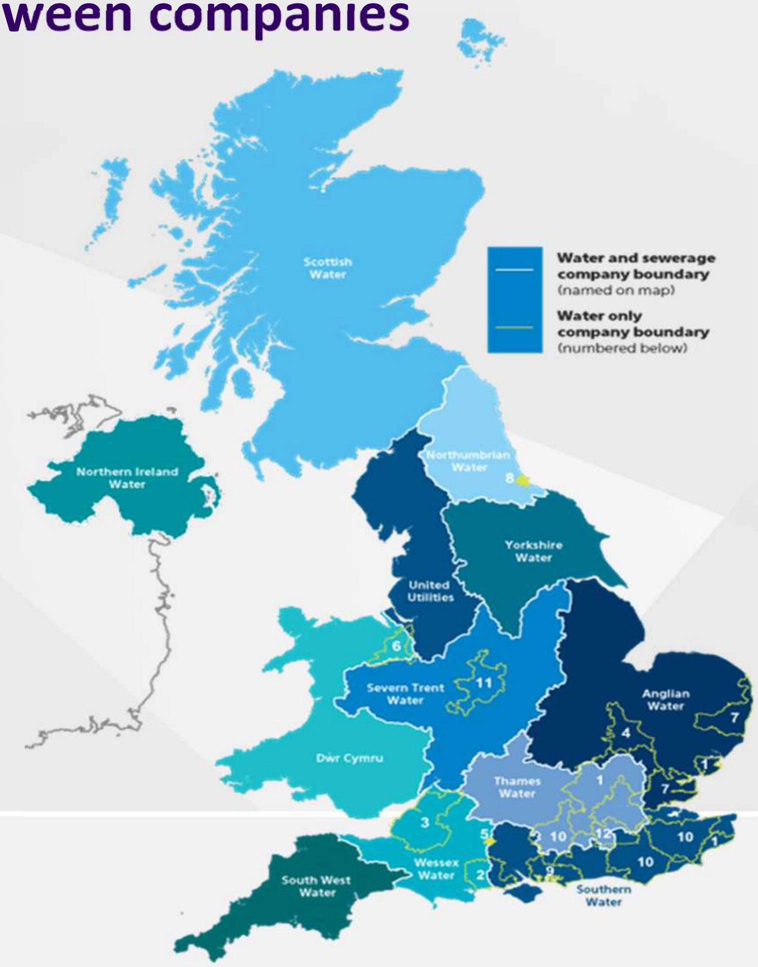
Understanding the Operating and Regulatory Context for Wholesale Water Cost Modelling in England and Wales

In PR 2019 We must Model with Company Level Data, but there is much complex difference both within and between companies

- Required unit of analysis is at company level (determined by Ofwat)
- 7 years of data
- 16 companies for 7 Years
- SWT and BWH for 5 years each
- SWB for 2 years
- 124 very colinear observations

HOW CAN WE MODEL COMPLEXITY WITH SUCH LIMITED DATA?



Complexity of Water Supply Systems

- Multi-output network industry
- Economies of size determined by complex cost interactions between
  - volume of output (water delivered)
  - transportation (length of main is standard proxy)
  - water resource availability, type, quality, and distance from settlements
  - Topography (more than pumping!)
  - Trade-off Network Losses, Transportation Distance, Network maintenance costs and Distribution Losses
  - Other operating characteristics

Complexity of Water Supply Systems (cont'd)

- Each system's configuration involves a complex trade-off between
  1. The location and size of population settlements
  2. The location and scale of available water resources
  3. Storage of water (seasonally and daily?)
  4. potential benefits of plant size cost economies in treatment, which differ by type of water and treatment requirements?
  5. Transportation costs
     - The length of network transportation required to bring water to served population
     - Costs related to population density and topography (pumping)
     - Distribution losses
  6. Geographic, environmental, water availability, etc that influence
     - demand for,
     - siting and
     - potential scale of water treatment works

Ofwat's Approach to Wholesale Water Cost Modelling in England and Wales

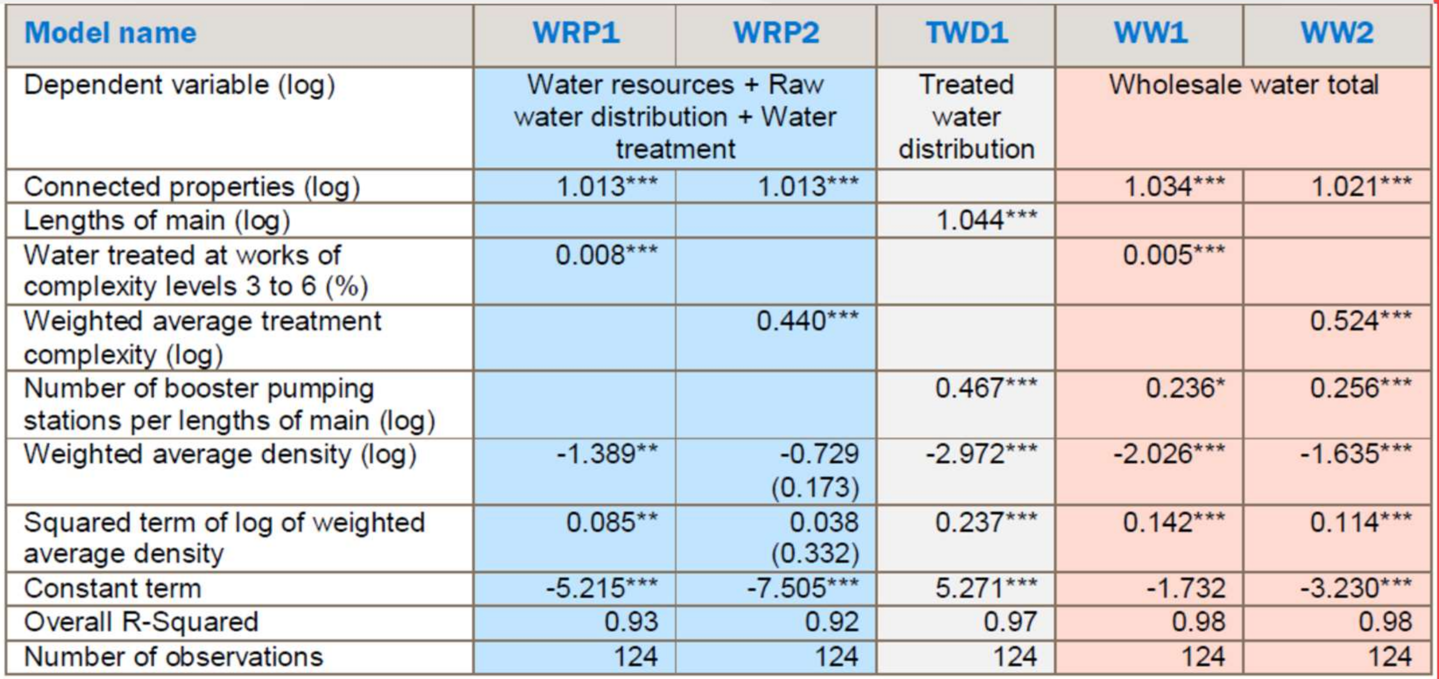
In PR2019 Ofwat seeks to foster competition and has changed its cost assessment accordingly

- **retail separation and "competitive retail market" for non households**
- **Disaggregated Price Caps within Wholesale Business**
    - Water Resources (Water Abstraction)
    - Water Network Plus (Treatment and Distribution)
    - Wastewater Network Plus (Collection and Treatment)
    - Bioresources (Sludge Treatment, Transportation and Disposal)
    - Household Retail (remains integrated within wholesale businesses)

Ofwat’s Approach to Cost Assessment for PR 2019: Effectively Assumes that Cost Interactions can be Ignored or Simply Captured by “noninteractive control variables”

- Appears to limit all models to the use of a single scale variable
- Allows only limited noninteractive control variables for “complexity” “topography” and “density”
- Relies heavily on separable controls for **population density**, to capture differences between firms
- Ofwat Does not appear to rigorously test the parameter restrictions it imposes because of its modelling approach (two examples below)

Ofwat Water Modelling- July 2019 DD



Model name	WRP1	WRP2	TWD1	WW1	WW2
Dependent variable (log)	Water resources + Raw water distribution + Water treatment		Treated water distribution	Wholesale water total	
Connected properties (log)	1.013***	1.013***		1.034***	1.021***
Lengths of main (log)			1.044***		
Water treated at works of complexity levels 3 to 6 (%)	0.008***			0.005***	
Weighted average treatment complexity (log)		0.440***			0.524***
Number of booster pumping stations per lengths of main (log)			0.467***	0.236*	0.256***
Weighted average density (log)	-1.389**	-0.729 (0.173)	-2.972***	-2.026***	-1.635***
Squared term of log of weighted average density	0.085**	0.038 (0.332)	0.237***	0.142***	0.114***
Constant term	-5.215***	-7.505***	5.271***	-1.732	-3.230***
Overall R-Squared	0.93	0.92	0.97	0.98	0.98
Number of observations	124	124	124	124	124

Note: Chosen Modelling is Not Consistent with the Price Control Level, but is more consistent with recognized upstream and downstream definitions of the water system

Where’s the Water?

Ofwat models Integrated Water, with a single output and control variables!

All models rely on a separable density specification

Only variation in models is treatment complexity (more on that below)

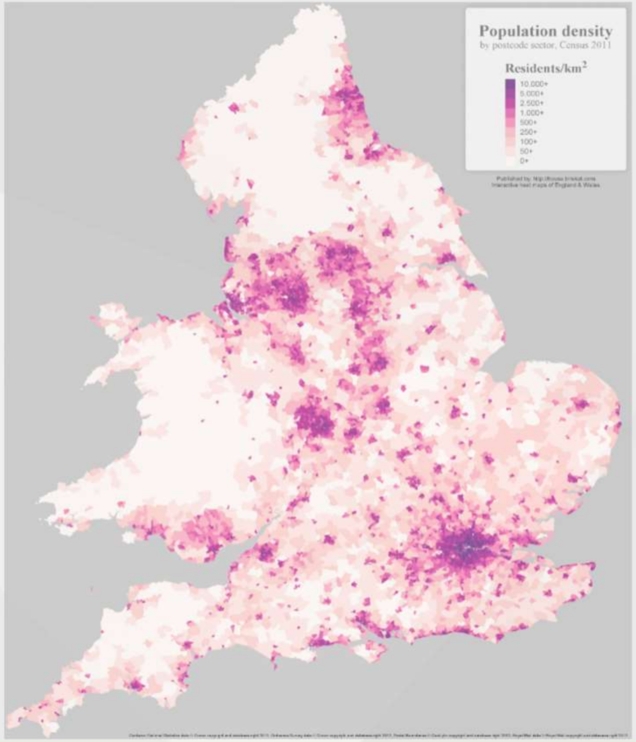
All Models employ only ln(boosterperlengh) as a proxy for “topography” but Ofwat is really treating pumping as an output in models with a negative elasticity for length

Do Ofwat's Models Adequately Account for Water System Complexity and the Resulting Relevant Cost Interactions?

If so, Are its Models Uniquely Appropriate ?

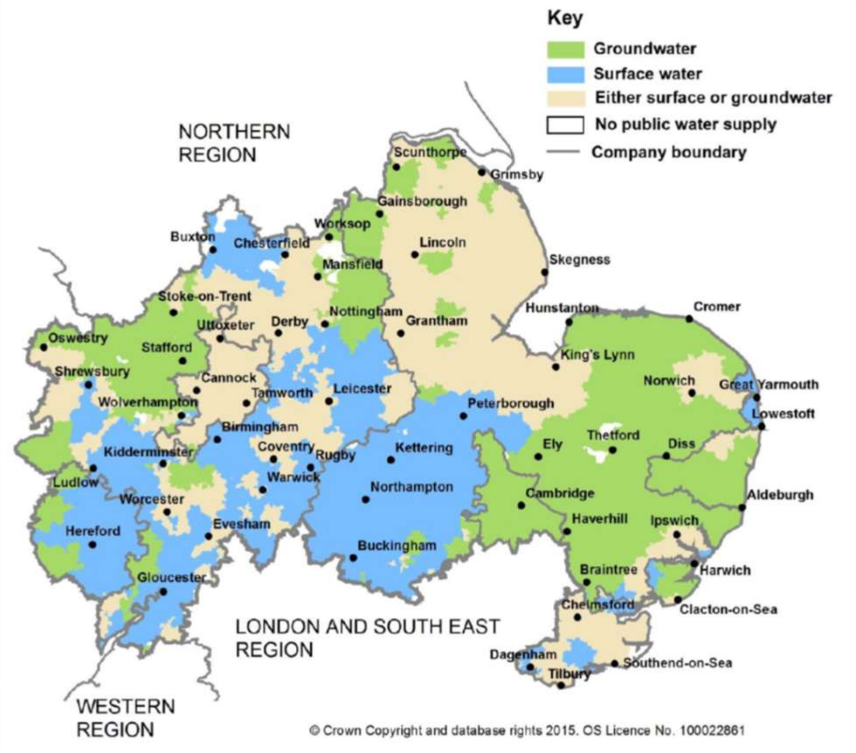
Population Density Is an Important but not a Sufficient Control for System Complexity

- Well known to have a non-linear impact on costs
- Typically addressed by including transportation output proxies (network length) and squared terms and interactions with other output variables to capture this impact on overall size economies and costs
- A Separable Density Specification Alone is Insufficient to explain how the water system designs that have been chosen by managers and engineers as the least-cost solution to a given population settlement pattern resulting from demographic, economic, planning, environmental and geographic factors influences costs



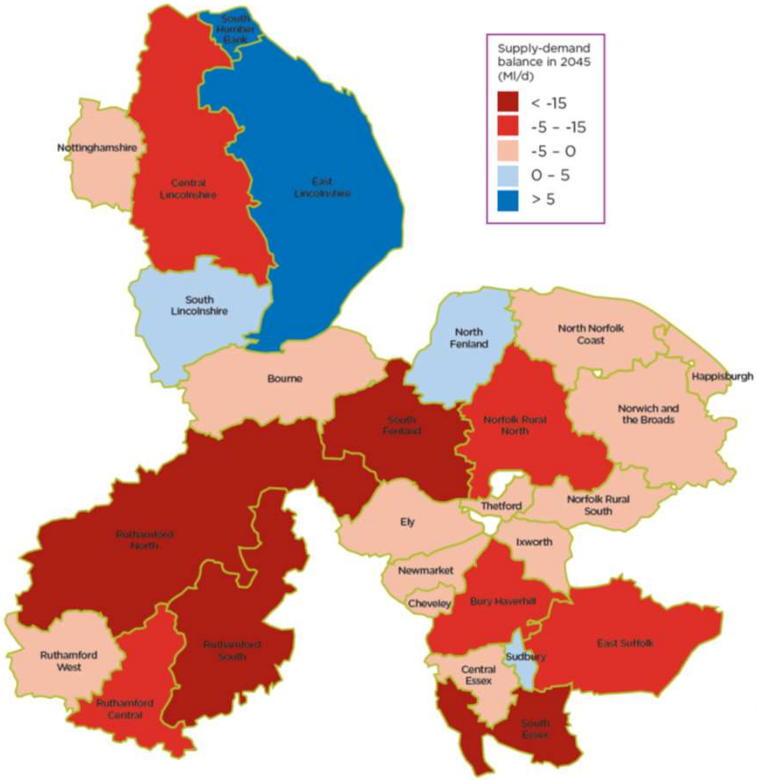
Water Availability and Type of Water of Abstraction Also Vary Significantly, Influence System Costs and May not be concurrent with population location

Figure 4: Map illustrating sources of drinking water by zone across the region



Source: Drinking Water Inspectorate

Baseline supply-demand balance in 2044-45 (DYAA scenario)



Source: Anglian Water Resource Management Plan

We therefore Need to Build an Intuitively Understandable but Sophisticated Model of Whole System Costs if We Wish to Build an Appropriate Model of Regulatory Costs

1. **Water System Costs are influenced by water scarcity** and the resulting cost trade off faced by all firm between saving Distribution Network Costs at the expense of Increased Leakage
2. **Water Demand Management is an activity that Firms Engage in Because it Reduces Whole System Costs** as they strive to balance water resource availability and water demand in the face of water scarcity
3. **Type of Water Source** (Ground and Surface), as well as treatment Complexity Matter and influence system configuration and hence whole system costs
4. **Topography, geography, and density influence network configurations in complex ways** that "noninteractive controls", which effectively impose untenable cost relationships, cannot appropriately control for.
5. **Cost Interactions between Water Production and Distribution Networks are Fundamental and are best Modelled by Allowing For them in a Multiple Output Model, rather than simply assuming that a density control adequately captures them.**

1. Water System Costs are influenced by water scarcity and the resulting cost trade off faced by all firm between saving Distribution Network Costs at the expense of Increased Leakage

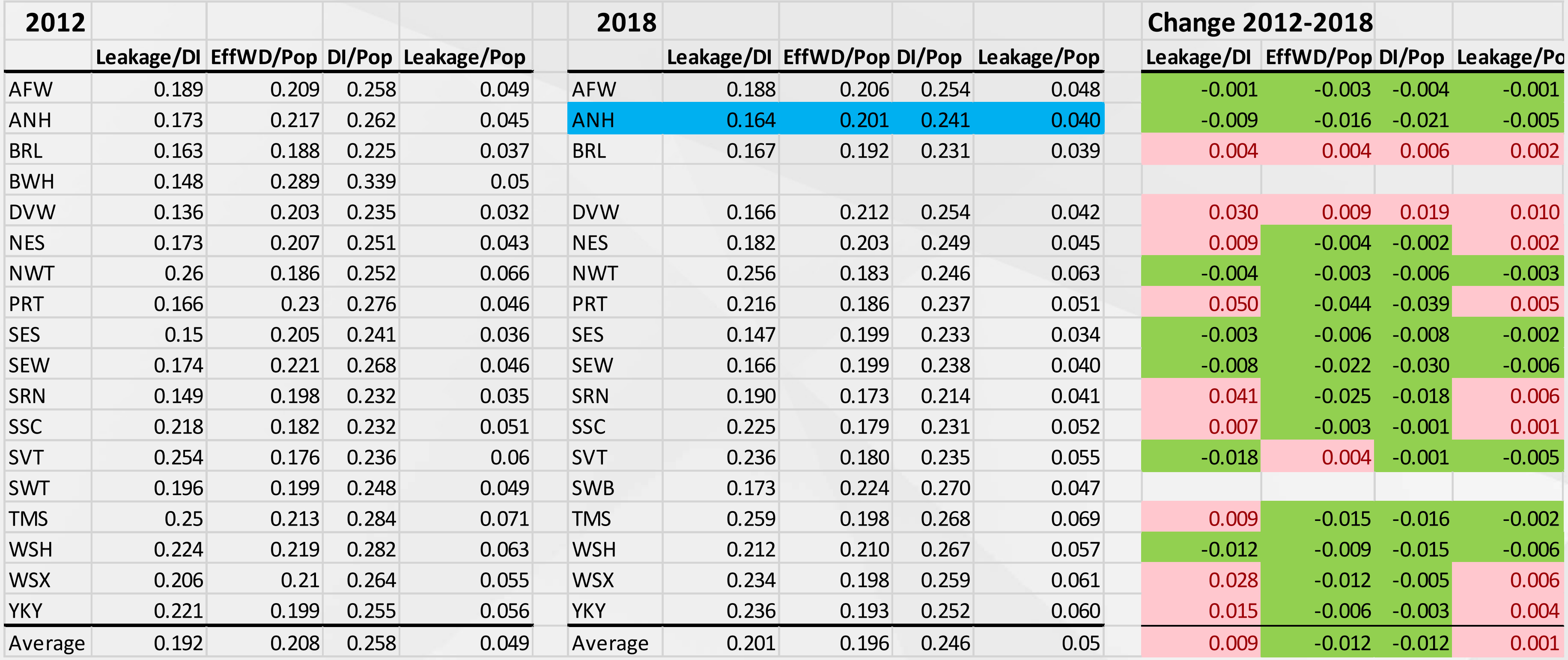
Effective Water= Distribution Input – Leakage

- Effective Water captures a measure that of the water actually used by customers
- Effective Water Provides an Appropriate Proxy of the Incentive Compatible Final Output Proxy for a Water Company seeking to serve its customers, while also appropriately and cost effectively employing water demand management and leakage controls as needed to maintain water supply balance
- Conceptually Firms Choose a distribution input and leakage level that minimise their whole system cost of effective water provision

Distribution Input= Effective Water+ Leakage

- While the relationship is mathematically identical it now indicates the upstream distribution input required by a company to deliver its effective water once its chosen leakage level is taken into account
- E.g it measures the amount of upstream water resource abstraction and treatment required to provide its effective demand given the leakage level it has chosen.

Modelling with Effective Water as the primary upstream output proxy, therefore not only provides an incentive compatible output measure, but will also embody how companies trade off higher (or lower) upstream water abstraction and treatment costs for lower (or higher) downstream network maintenance and water demand management costs in order to minimise whole system costs given water availability, demand, transportation costs, and settlement patterns

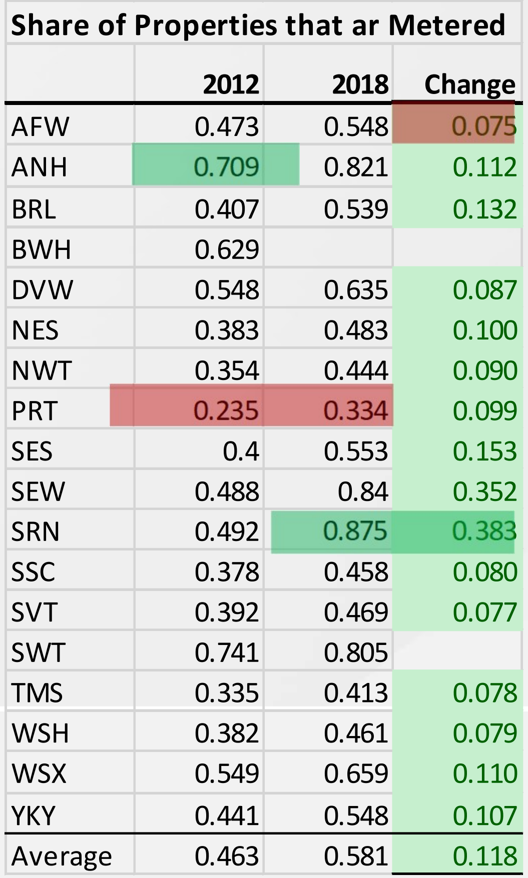


2012					2018					Change 2012-2018			
	Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Pop		Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Pop	Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Po
AFW	0.189	0.209	0.258	0.049	AFW	0.188	0.206	0.254	0.048	-0.001	-0.003	-0.004	-0.001
ANH	0.173	0.217	0.262	0.045	ANH	0.164	0.201	0.241	0.040	-0.009	-0.016	-0.021	-0.005
BRL	0.163	0.188	0.225	0.037	BRL	0.167	0.192	0.231	0.039	0.004	0.004	0.006	0.002
BWH	0.148	0.289	0.339	0.05									
DVW	0.136	0.203	0.235	0.032	DVW	0.166	0.212	0.254	0.042	0.030	0.009	0.019	0.010
NES	0.173	0.207	0.251	0.043	NES	0.182	0.203	0.249	0.045	0.009	-0.004	-0.002	0.002
NWT	0.26	0.186	0.252	0.066	NWT	0.256	0.183	0.246	0.063	-0.004	-0.003	-0.006	-0.003
PRT	0.166	0.23	0.276	0.046	PRT	0.216	0.186	0.237	0.051	0.050	-0.044	-0.039	0.005
SES	0.15	0.205	0.241	0.036	SES	0.147	0.199	0.233	0.034	-0.003	-0.006	-0.008	-0.002
SEW	0.174	0.221	0.268	0.046	SEW	0.166	0.199	0.238	0.040	-0.008	-0.022	-0.030	-0.006
SRN	0.149	0.198	0.232	0.035	SRN	0.190	0.173	0.214	0.041	0.041	-0.025	-0.018	0.006
SSC	0.218	0.182	0.232	0.051	SSC	0.225	0.179	0.231	0.052	0.007	-0.003	-0.001	0.001
SVT	0.254	0.176	0.236	0.06	SVT	0.236	0.180	0.235	0.055	-0.018	0.004	-0.001	-0.005
SWT	0.196	0.199	0.248	0.049	SWB	0.173	0.224	0.270	0.047				
TMS	0.25	0.213	0.284	0.071	TMS	0.259	0.198	0.268	0.069	0.009	-0.015	-0.016	-0.002
WSH	0.224	0.219	0.282	0.063	WSH	0.212	0.210	0.267	0.057	-0.012	-0.009	-0.015	-0.006
WSX	0.206	0.21	0.264	0.055	WSX	0.234	0.198	0.259	0.061	0.028	-0.012	-0.005	0.006
YKY	0.221	0.199	0.255	0.056	YKY	0.236	0.193	0.252	0.060	0.015	-0.006	-0.003	0.004
Average	0.192	0.208	0.258	0.049	Average	0.201	0.196	0.246	0.05	0.009	-0.012	-0.012	0.001

Many companies have improved water resource management, leakage and demand management , but many others have seen declines in at least some of these performance indicators

Is Ofwat's assumption that modelling with properties served can control for differences in company efforts to deal with water scarcity appropriate?

2. Water Demand Management is an activity that Firms Engage in Because it Reduces Whole System Costs as they strive to balance water resource availability and water demand in the face of water scarcity



Share of Properties that ar Metered

	2012	2018	Change
AFW	0.473	0.548	0.075
ANH	0.709	0.821	0.112
BRL	0.407	0.539	0.132
BWH	0.629		
DVW	0.548	0.635	0.087
NES	0.383	0.483	0.100
NWT	0.354	0.444	0.090
PRT	0.235	0.334	0.099
SES	0.4	0.553	0.153
SEW	0.488	0.84	0.352
SRN	0.492	0.875	0.383
SSC	0.378	0.458	0.080
SVT	0.392	0.469	0.077
SWT	0.741	0.805	
TMS	0.335	0.413	0.078
WSH	0.382	0.461	0.079
WSX	0.549	0.659	0.110
YKY	0.441	0.548	0.107
Average	0.463	0.581	0.118

Are Companies' Water Demand Management and Leakage Improvements best understood as an Inconsequential Issue for Regulatory Cost Assessment as Ofwat's models assume or are they better understood as an important options in whole system management, which firms pursue to different degrees because of differences in water scarcity?

3. Type of Water Source (Ground and Surface), as well as treatment Complexity Matter and influence system configuration and hence whole system costs

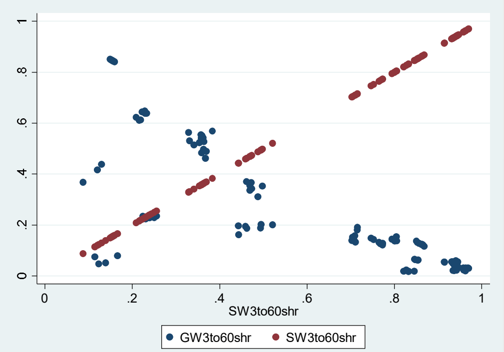
- **Ofwat’s treatment complexity indicator uses arbitrary weights**, and also conflates ground and surface water and is therefore not appropriate on an engineering, managerial, or economic basis
- **Ofwat’s complexity share indicator conflates groundwater and surface water** despite known operational differences as well as statistical correlations suggesting that this is inappropriate
  - It therefore appears to ignore important differences in network configuration that may exist between systems that rely on groundwater as opposed to surface water.
  - **E.g. based on how its definition focusses exclusively on treatment level while ignoring water source characteristics, Ofwat imposes potentially inappropriate parameter restrictions on these variables**

2018 Share of Treated Water by Type and Treamtent Level

	All Level 3 to 6	Ground Level 3 to 6	Surface Level 3 to 6	Ground Level 0 to 2	Surface Level 0 to 2	All Ground Water
AFW	0.952	0.569	0.383	0.048	0.00	0.617
ANH	0.798	0.311	0.487	0.202	0.00	0.513
BRL	0.987	0.122	0.865	0.013	0.00	0.135
DVW	1	0.055	0.945	0	0.00	0.055
NES	0.982	0.048	0.935	0.018	0.00	0.065
NWT	0.981	0.023	0.958	0.019	0.00	0.042
PRT	0.568	0.439	0.129	0.432	0.00	0.871
SES	1	0.845	0.155	0	0.00	0.845
SEW	0.876	0.648	0.229	0.124	0.00	0.771
SRN	0.892	0.563	0.329	0.108	0.00	0.671
SSC	0.721	0.201	0.521	0.279	0.00	0.479
SVT	0.906	0.191	0.715	0.094	0.00	0.285
SWB	0.968	0.055	0.914	0.032	0.00	0.086
TMS	0.901	0.128	0.773	0.099	0.00	0.227
WSH	1	0.032	0.968	0	0.00	0.032
WSX	0.48	0.237	0.244	0.52	0.00	0.756
YKY	0.958	0.154	0.804	0.042	0.00	0.196
Total	0.881	0.272	0.609	0.119	0.00	0.391

	All Level 3 to 6	Ground Level 3 to 6	Surface Level 3 to 6	Ground Level 0 to 2	Surface Level 0 to 2	All Ground Water
All Level 3 to 6	1					
Ground Level 3 to 6	0.02	1				
Surface Level 3 to 6	0.61	-0.79	1			
Ground Level 0 to 2	-0.99	0.01	-0.62	1		
Surface Level 0 to 2	0.01	-0.21	0.17	-0.15	1	
All Ground Water	-0.60	0.79	-1.00	0.62	-0.25	1

1. Ofwat's complexity share measure conflates two shares that are strongly negatively correlated with each other



2. Moreover as very little surface water treatment is carried out below level 0 to 2, its measure may primarily capture a difference between high level treatment of both ground and surface water relative to ground water treated to a lower level

```
    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
  GW0to20shr |        124    .1432896    .1879789          0   .8298138
  GW3to60shr |        124    .2422497    .2386856   .0177049   .8510226
  SW0to20shr |        124    .0056545    .0258702          0   .1388247
  SW3to60shr |        124    .6088061    .3001659   .0873236   .9699386
```

Is Ofwat's Complexity Measure Arbitrary? Particularly, as it does not test if the use of a single aggregate treatment measure is appropriate and the impact of the break chosen to define the measure.

2018 Share of Treated Water by Type and Treamtent Level

	All Level 4 to 6	Ground Level 4 to 6	Surface Level 4 to 6	Ground Level 0 to 3	Surface Level 0 to 3	All Ground Water
AFW	0.88	0.497	0.383	0.12	0	0.617
ANH	0.714	0.226	0.487	0.286	0	0.513
BRL	0.987	0.122	0.865	0.013	0	0.135
DVW	0.971	0.055	0.916	0	0.029	0.055
NES	0.938	0.028	0.91	0.038	0.024	0.065
NWT	0.661	0.023	0.638	0.019	0.32	0.042
PRT	0.568	0.439	0.129	0.432	0	0.871
SES	0.928	0.773	0.155	0.072	0	0.845
SEW	0.61	0.381	0.229	0.39	0	0.771
SRN	0.75	0.539	0.211	0.132	0.118	0.671
SSC	0.696	0.175	0.521	0.304	0	0.479
SVT	0.805	0.191	0.614	0.094	0.101	0.285
SWB	0.569	0.055	0.515	0.032	0.399	0.086
TMS	0.881	0.108	0.773	0.119	0	0.227
WSH	0.769	0.032	0.738	0	0.231	0.032
WSX	0.477	0.233	0.244	0.523	0	0.756
YKY	0.561	0.115	0.446	0.081	0.358	0.196
Total	0.751	0.235	0.516	0.156	0.093	0.391

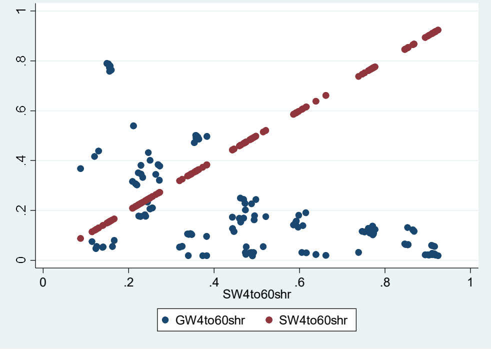
	All Level 4 to 6	Ground Level 4 to 6	Surface Level 4 to 6	Ground Level 0 to 3	Surface Level 0 to 3	All Ground Water
All Level 4 to 6	1					
Ground Level 4 to 6	0.23	1				
Surface Level 4 to 6	0.67	-0.57	1			
Ground Level 0 to 3	-0.51	0.15	-0.55	1		
Surface Level 0 to 3	-0.55	-0.39	-0.17	-0.43	1	
All Ground Water	-0.19	0.75	-0.74	0.77	-0.54	1

We will proceed by testing the inclusion of controls for

1. Complexity - Breaking the data between treatment at level 0 to 3 and level 4 to 6 illustrated in this slide,

2. Also breaking the data by Ground and Surface Source by Using the full set of share variables capturing complexity and ground or surface water sources

3. While also testing the statistical validity of parameter restrictions on these variables before imposing them.



4. Topography, geography, and density influence network configurations in complex ways that "noninteractive control variables", which actually impose untenable cost relationships, cannot appropriately control for

$$\ln(Botex) = \alpha + \delta \ln(lproperties) + \beta \ln\left(\frac{booster\ stations}{length}\right) + \gamma \ln(weighed\ pop\ density) + \theta(\ln(weighed\ pop\ density))^2 + \vartheta \ln(wac) \quad \text{(M1)}$$

This is mathematically and empirically equivalent to a Cobb-Douglas model that treats properties, booster pumping stations, and length as multiple outputs**,** but imposes the restriction that the elasticity of length is equal to the negative of the elasticity of boosters

$$\boldsymbol{ln(Botex) = \alpha + \delta\, ln(lproperties) + \beta\, ln(booster\ stations) - \beta\, ln(length) + \gamma\, ln(weighed\ pop\ density) + \theta(ln(weighed\ pop\ density))^2 + \vartheta\, ln(wac)} \quad \textbf{(M1')}$$

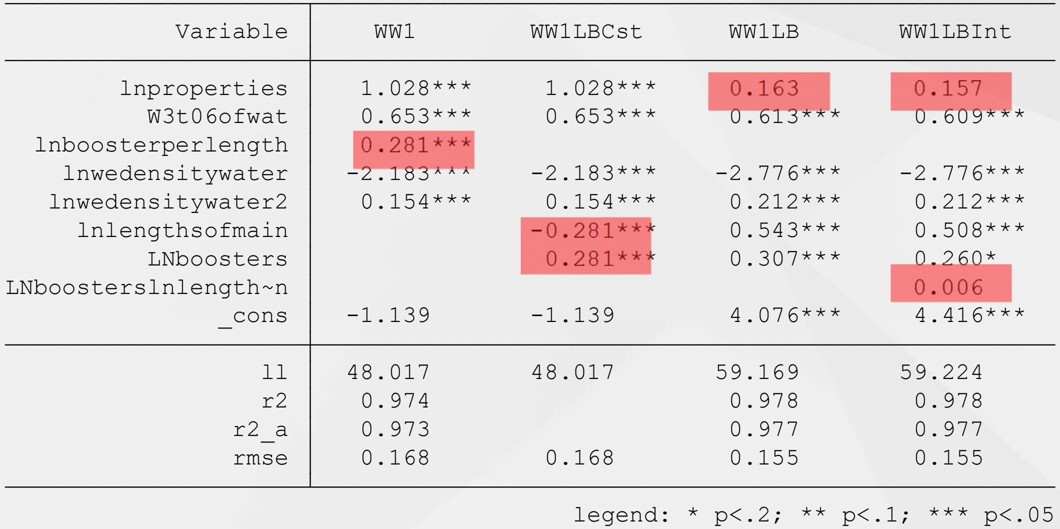
Or equivalently the following Cobb Douglas Cost Function where the restriction $\phi = -\beta$ has been imposed before estimation as Ofwat implicitly does

$$\ln(Botex) = \alpha + \delta \ln(lproperties) + \beta \ln(booster\ stations) + \phi \ln(length) + \gamma \ln(weighed\ pop\ density) + \theta(\ln(weighed\ pop\ density))^2 + \vartheta \ln(wac) \quad \text{(CD1')}$$

As this restriction implies that if an increases in booster station has a positive impact on costs, an increase in mains MUST HAVE A NEGATIVE IMPACT ON COSTS, it is highly inconsistent with engineering and managerial expectations of cost relationships

***I*t should be transparent that Ofwat's models impose a restriction that would be untenable if it was not disguised as an apparently innocuous control variable for pumping.**

It is Straightforward to Demonstrate that Ofwat's booster station based specification is a severe misspecification that not only treats boosters as an output but imposes a highly inappropriate restriction on the lengths of main coefficient



```
                Variable |     WW1       WW1LBCst      WW1LB      WW1LBInt
-------------------------+--------------------------------------------------
            lnproperties |   1.028***    1.028***      0.163       0.157
              W3t06ofwat |   0.653***    0.653***      0.613***    0.609***
      lnboosterperlength |   0.281***
        lnwedensitywater |  -2.183***   -2.183***     -2.776***   -2.776***
       lnwedensitywater2 |   0.154***    0.154***      0.212***    0.212***
         lnlengthsofmain |              -0.281***      0.543***    0.508***
              LNboosters |               0.281***      0.307***    0.260*
   LNboosterslnlength~n  |                                          0.006
                   _cons |  -1.139      -1.139         4.076***    4.416***
-------------------------+--------------------------------------------------
                      ll |  48.017      48.017        59.169      59.224
                      r2 |   0.974                     0.978       0.978
                    r2_a |   0.973                     0.977       0.977
                    rmse |   0.168       0.168         0.155       0.155
----------------------------------------------------------------------------
                                     legend: * p<.2; ** p<.1; *** p<.05
```

- WW1LBCst demonstrates that Ofwat's WW1 specification imposes a highly restrictive parameter constraint that implies an inappropriate coefficient for length of mains
- WW1LB and statistical test demonstrating the rejection of this restriction demonstrates that boosters are treated as an output in Ofwat's model, and its model should be rejected because it clearly imposes a restriction that should be statistically rejected, and that relaxing this constraint also causes the property variable to become insignificant
- **WW1LBInt further shows via insignificance of the interaction parameter that Ofwat's interpretation of this variable as capturing cost interaction between length and boosters is not correct**

```
             | lnpro~es lnleng~n LNboos~s
-------------+---------------------------
lnproperties |   1.0000
lnlengthso~n |   0.9739   1.0000
  LNboosters |   0.9069   0.9649   1.0000
```

```
.   estimates store WW1LB

.   test _b[lnlengthsofmain] + _b[LNboosters] = 0, coef

 ( 1)  lnlengthsofmain + LNboosters = 0

       F(  1,   117) =   23.06
            Prob > F =    0.0000
```

Note: We have illustrated the above with OLS estimation, to quickly facilitate demonstration of how Ofwat's specification is theoretically equivalent to a model which imposes the constrain demonstrated by WW1LBCst . This constraint is imposed regardless of what estimation method is employed

Average Pumping Head (APHTOT) Provides a Conceptually More Appropriate Control for Pumping than Ofwat's booster/Mains measure

- Ofwat's specification provides a count of the number of pumping stations required in the network thereby effectively included another scale proxy, which is strongly correlated to network length (and other scale of company variables).
- Moreover as the booster station count is uncorrected for station pumping capacity it does not actually measure the amount of pumping work required in the system, or relate to the volume of water output actually delivered in the system.
- Furthermore, as booster stations/mains is -0.55 correlated with Ofwat's density measure, Ofwat's chosen pumping control adds information which is "similar" to its density measure rather than providing a strongly distinct control variable
- **In contrast APHTOT provides a more appropriate proxy indicative of the amount of pumping work required per unit of distribution input consistent with a whole system perspective, e.g. the average amount of pumping effort required to move raw water, treat it, and distribute it to the final consumers.**
- Moreover, APH clearly conveys different information than boosters/Mains given the 0.22 correlation between these alternative controls for pumping .

Correlations			
	APHTOT	**boosters/ Mains**	**wedensity water**
APHTOT	1		
boosters/Mains	0.22	1	
wedensitywater	-0.25	-0.55	1

Our Below Models have therefore been developed with the conceptually more appropriated Average Pumping Head (APHTOT) Variable

5. Cost Interactions between Water Resource Plus and Distribution Network Costs are Fundamental and are best Modelled by Allowing for them in the Model

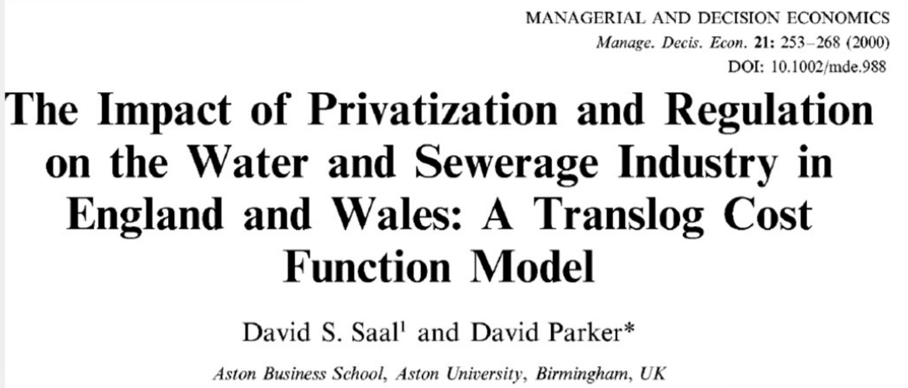
Do Models that Take this Approach provide a viable and appropriate alternatives to models which make the *a priori* assumption that density controls alone are sufficient?

Multiple Output Modelling of Network Industries Allowing for Cost Interactions as an Appropriate and Parsimonious Alternative

- **Regulatory modelling needs to carefully consider how complex cost interactions and operating characteristics influence water system costs**

- **A vast academic literature on multiple output network infrastructure** industries has found considerable evidence of important **cost interactions** between the upstream and downstream components that Ofwat seeks to separately assess costs for
- This includes my own research and consulting work for both Ofwat and companies (Anglian Water, Severn Trent Water, and Untied Utilities)

My own work began with a paper that opened the path to becoming an “expert” in water and wastewater cost modelling



MANAGERIAL AND DECISION ECONOMICS
Manage. Decis. Econ. **21:** 253–268 (2000)
DOI: 10.1002/mde.988

The Impact of Privatization and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Model

David S. Saal[1] and David Parker*

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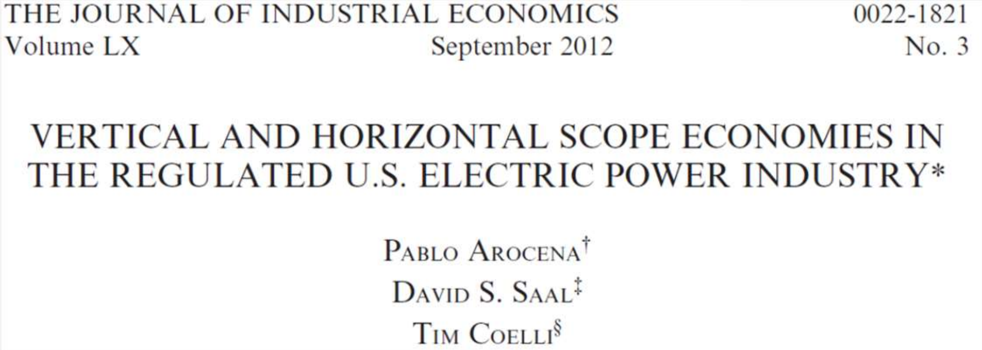
- Translog Model -
- “Separability of inputs and outputs is rejected, thereby demonstrating that it is inappropriate to evaluate WASC costs without using a multiple-output cost function.”
- “These results demonstrate that the costs of water and sewerage services are intricately linked, suggesting that Ofwat’s preference to model WASC water and sewerage costs separately may be inappropriate”

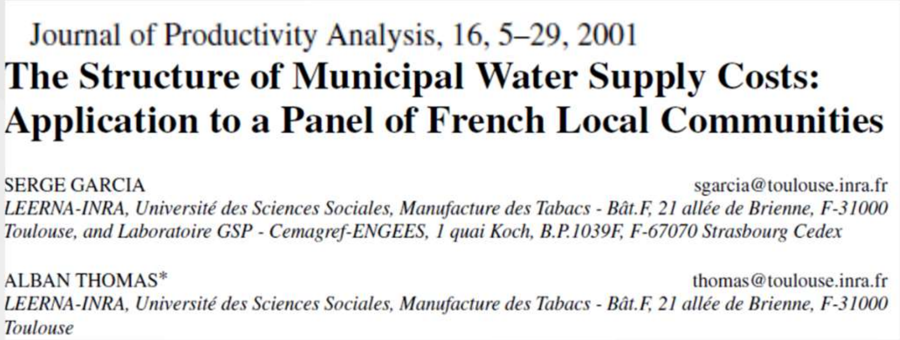
A Few More Relevant Examples from that Vast Academic Literature Considering Cost Interactions in Multiple Output Network Infrastructure Industries



THE JOURNAL OF INDUSTRIAL ECONOMICS 0022-1821
Volume LX September 2012 No. 3

VERTICAL AND HORIZONTAL SCOPE ECONOMIES IN THE REGULATED U.S. ELECTRIC POWER INDUSTRY*

Pablo Arocena[†]
David S. Saal[‡]
Tim Coelli[§]



Journal of Productivity Analysis, 16, 5–29, 2001

The Structure of Municipal Water Supply Costs: Application to a Panel of French Local Communities

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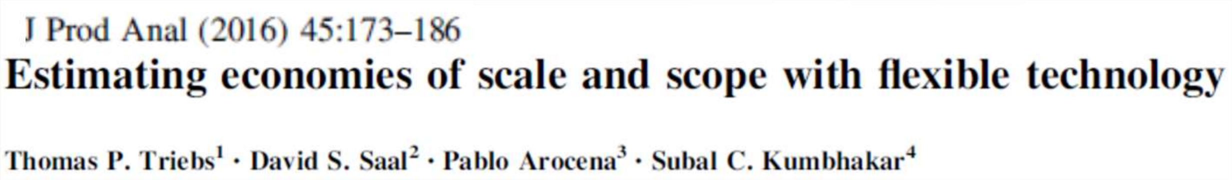
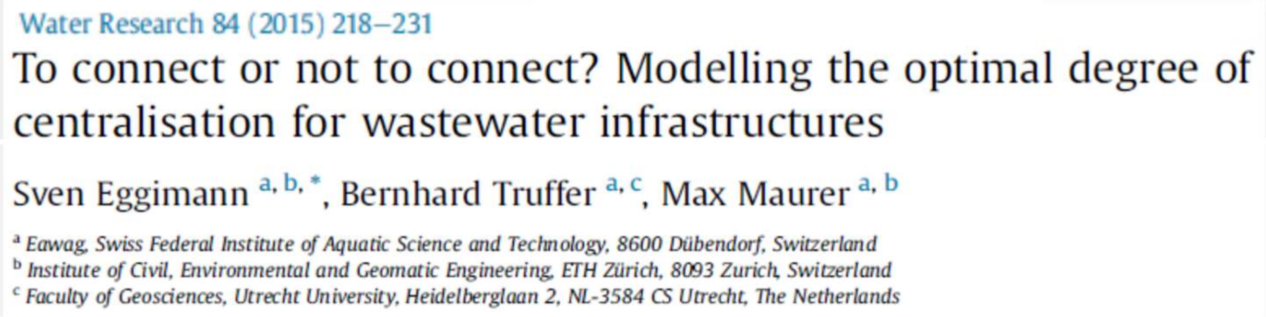


J Prod Anal (2016) 45:173–186

Estimating economies of scale and scope with flexible technology

Thomas P. Triebs[1] · David S. Saal[2] · Pablo Arocena[3] · Subal C. Kumbhakar[4]



Water Research 84 (2015) 218–231

To connect or not to connect? Modelling the optimal degree of centralisation for wastewater infrastructures

Sven Eggimann [a, b, *], Bernhard Truffer [a, c], Max Maurer [a, b]

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Modelling Approach

Translog Models with Testing Down from General to Specific Model

- Allows Modelling of the Complex Cost Interactions that Must be Controlled for in Water Systems, that are precluded in Ofwat’s approach to modelling
- Allows for Restriction to Both a Multiple Output “Cobb-Douglas Specification”, more consistent with Ofwat's modelling framework , and rejection of these models as underspecified and therefore resulting in omitted variables bias due to omitting Interacted Water System Network Characteristic Variables

Requires Normalisation of Data Around Sample Means

- Ofwat’s criticism that translog models lead to models that are difficult to interpret is disingenuous – This standard technique can be applied and is almost always applied in academic literature
- Direct parameter estimates reflect the elasticities with regard to logged variables for a typical sample average firm
- Interacted variable coefficients indicate how elasticity of costs are influenced by differences across firms

Variables

Interacted Basic Outputs

- **Effective Water(EffWD) = Ditribution Input – Leakage**
- **Network Transportation – Mains Length (Mains) -** best available proxy for the amount of network transportation required, and tradeoffs with location and amount of required upstream water production and defined to include raw water mains in addition to distribution mains to be consistent with whole system modelling

Non-Interacted System Characteristics

- **Share of Properties Metered (Pmetshr) -** Indicative of Effort in Water Demand Management and Impct on Whole System Costs
- **Share of Water by Type (Ground v. Surface) and Treatment Level (0 to 3 versus 4 to 6) -** To better capture how treatment complexity as well as type of water sources influences costs
- **Ofwat's density (density) and density squared (density) variables** - to test if Ofwat's density variables remain statistically significant when a whole system specification is employed, but squared term dived by 2 as is standard practice in translog modelling to aid interpretation
- **Average Pumping Head (APHTOT) -** To further capture how managers consider pumping costs in whole water system design, and the resulting trade-offs faced by water company managers in system design

Estimation Approach – Random Effects – As Ofwat Does, but

1. **We estimate the models with statistically significant time dummies**

as given strong time trends in the underlying data this is necessary to avoid bias in both backward looking cost assessment and forward looking cost projection (as we have demonstrated elsewhere)

2. **We prefer estimating the models using 2014 -18 as required for consistent cost-efficiency estimation for 2014-18 with random effects**

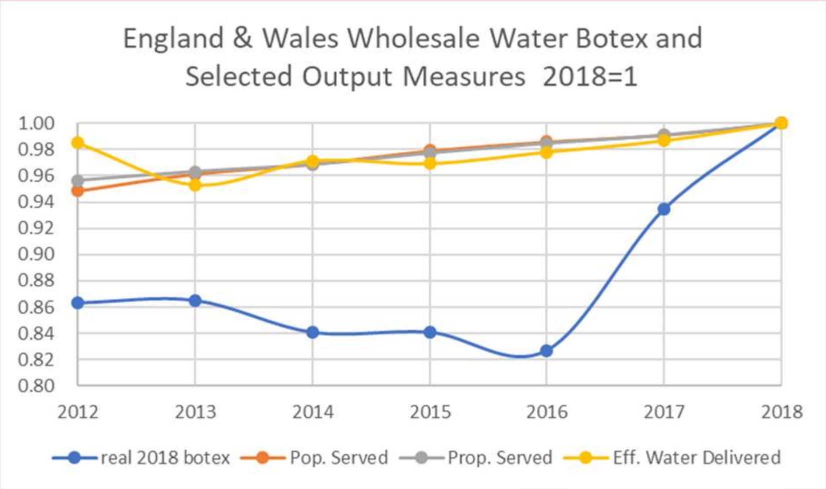
We have argued elsewhere that cost efficiency estimation for the 2014-18 period with random effects is not consistent with a random effects model using data for 2012-18 as done by Ofwat, as this effectively assumes a single random effect for each company for the entire 2012-18 period, thereby conflating and biasing the cost-efficiency estimate for the 2014-18 period with cost-efficiency conditions for 2012-13.

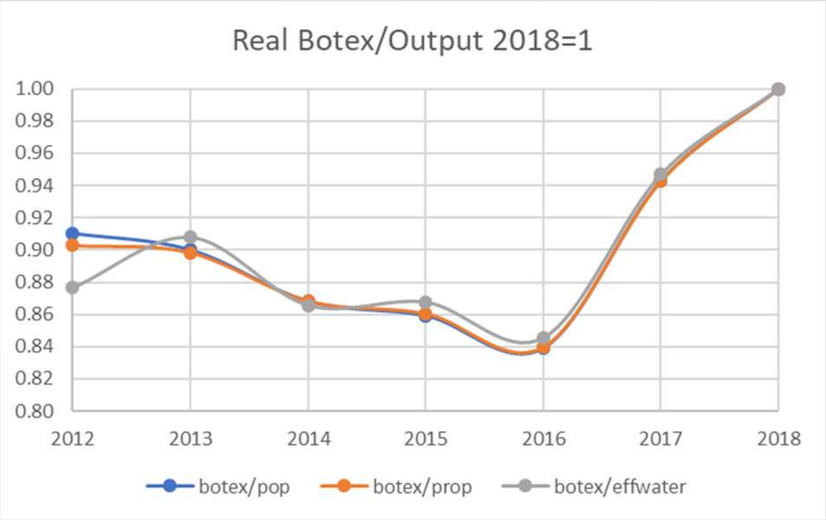
3. Reported Models, Including Ofwat's Models, are estimated with a definition of cost consistent with Ofwat's Botex definition in its January 2019 Initial Assessment of Plans and not the expanded cost definition it used in July 2019 Draft Determinations

We have demonstrated elsewhere that there are Important Implications with Regard to the Appropriateness of Ofwat's backward looking cost assessment and its forward looking assessment of company business plans, given that it simply ignores these differences across time in its cost assessment

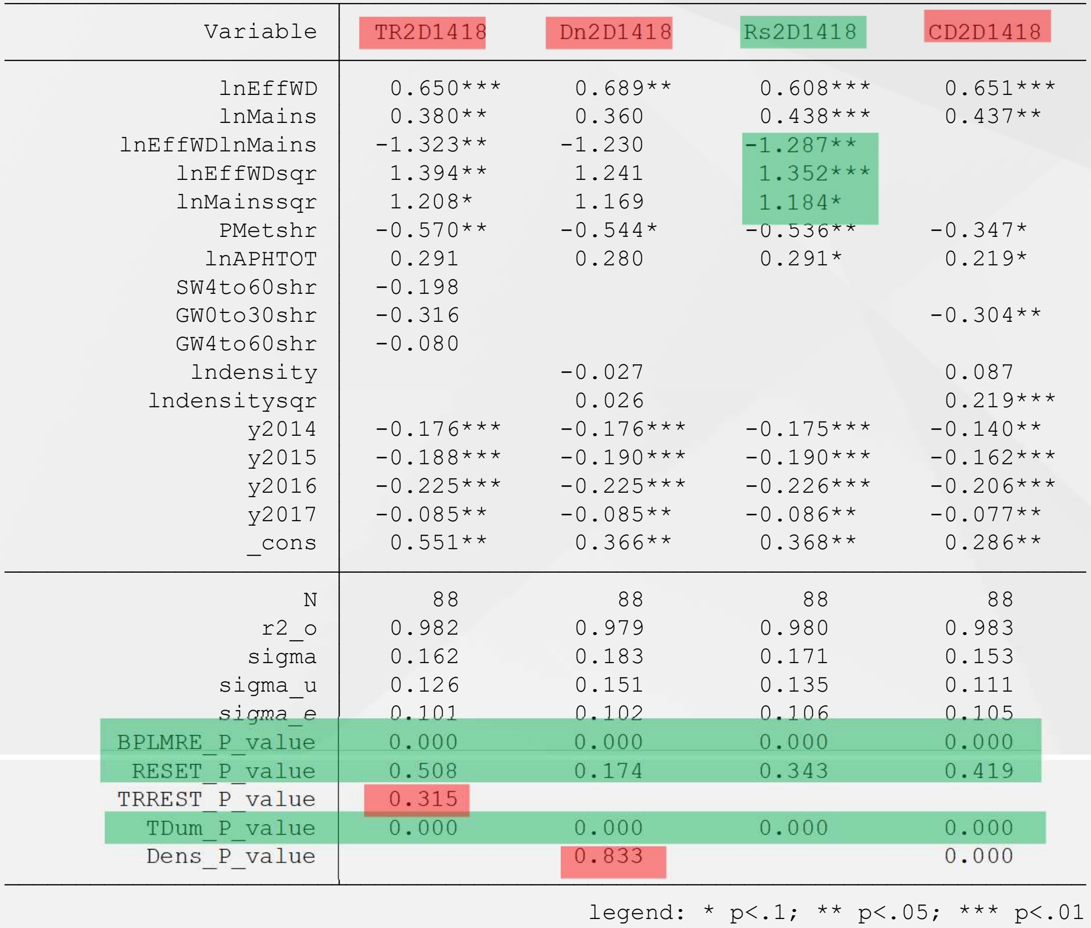
Aggregate Wholesale Water Botex and Selected Output Measures

year	real 2018 botex (000,000)	Pop. Served (000)	Prop. Served (000)	Eff. Water Delivered (Ml/day?)
2012	3,054.3	55,798.8	24,845.2	11,257.4
2013	3,060.8	56,555.9	25,023.7	10,894.1
2014	2,974.9	56,991.8	25,162.2	11,103.8
2015	2,975.2	57,590.6	25,391.6	11,079.2
2016	2,926.2	57,990.2	25,586.2	11,179.7
2017	3,306.1	58,297.1	25,750.2	11,279.2
2018	3,537.2	58,822.3	25,979.9	11,429.2


England & Wales Wholesale Water Botex and Selected Output Measures 2018=1


Real Botex/Output 2018=1

Effective Water 2014-2018 Translog Restriction Tests



Variable	TR2D1418	Dn2D1418	Rs2D1418	CD2D1418
lnEffWD	0.650***	0.689**	0.608***	0.651***
lnMains	0.380**	0.360	0.438***	0.437**
lnEffWDlnMains	-1.323**	-1.230	-1.287**	
lnEffWDsqr	1.394**	1.241	1.352***	
lnMainssqr	1.208*	1.169	1.184*	
PMetshr	-0.570**	-0.544*	-0.536**	-0.347*
lnAPHTOT	0.291	0.280	0.291*	0.219*
SW4to60shr	-0.198			
GW0to30shr	-0.316			-0.304**
GW4to60shr	-0.080			
lndensity		-0.027		0.087
lndensitysqr		0.026		0.219***
y2014	-0.176***	-0.176***	-0.175***	-0.140**
y2015	-0.188***	-0.190***	-0.190***	-0.162***
y2016	-0.225***	-0.225***	-0.226***	-0.206***
y2017	-0.085**	-0.085**	-0.086**	-0.077**
_cons	0.551**	0.366**	0.368**	0.286**
N	88	88	88	88
r2_o	0.982	0.979	0.980	0.983
sigma	0.162	0.183	0.171	0.153
sigma_u	0.126	0.151	0.135	0.111
sigma_e	0.101	0.102	0.106	0.105
BPLMRE_P_value	0.000	0.000	0.000	0.000
RESET_P_value	0.508	0.174	0.343	0.419
TRREST_P_value	0.315			
TDum_P_value	0.000	0.000	0.000	0.000
Dens_P_value		0.833		0.000

legend: * p<.1; ** p<.05; *** p<.01

Cobb Douglas Model (CD2D1418) demonstrates a feasible noninteractive modelling approach to Ofwat's modelling which allows for statistically significant water scarcity, demand management, density, and pumping controls

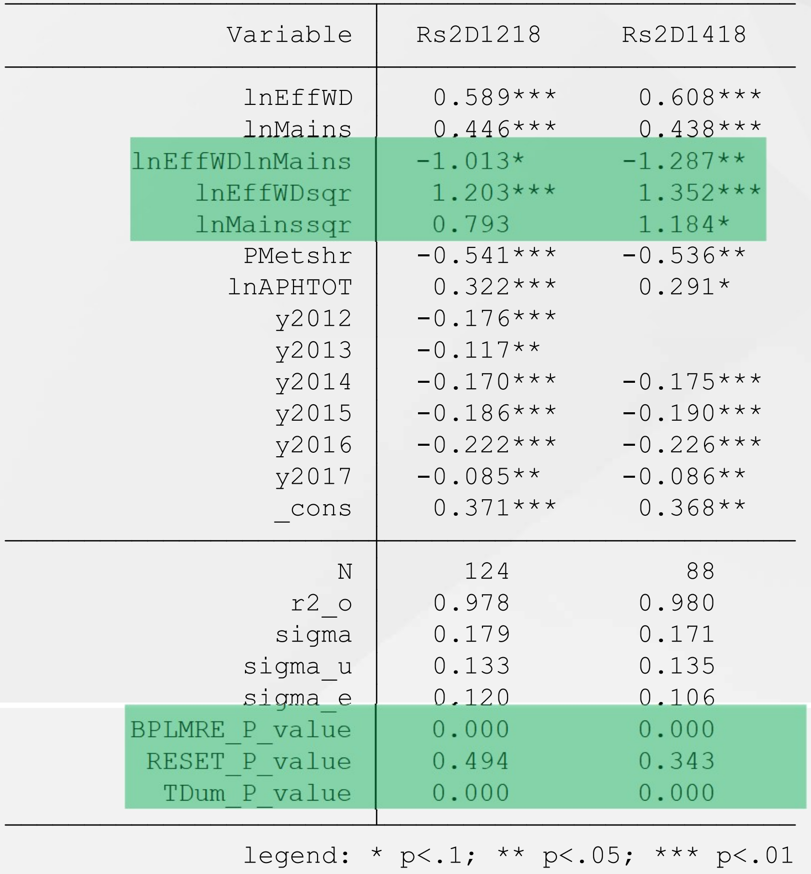
Supports engineering and operational understanding that low treatment groundwater has lower costs, ceteris paribus than other types of water

- **Translog Model (RS2D1418)**

Demonstrates a parsimonious alternative to Ofwat's density specification, which demonstrates the relevance of cost interactions between water production and distribution activities

Suggests that once cost interactions between water production and distribution activities are allowed, water type and treatment controls are no longer required – e.g they are controlled for by the models allowed cost interactions

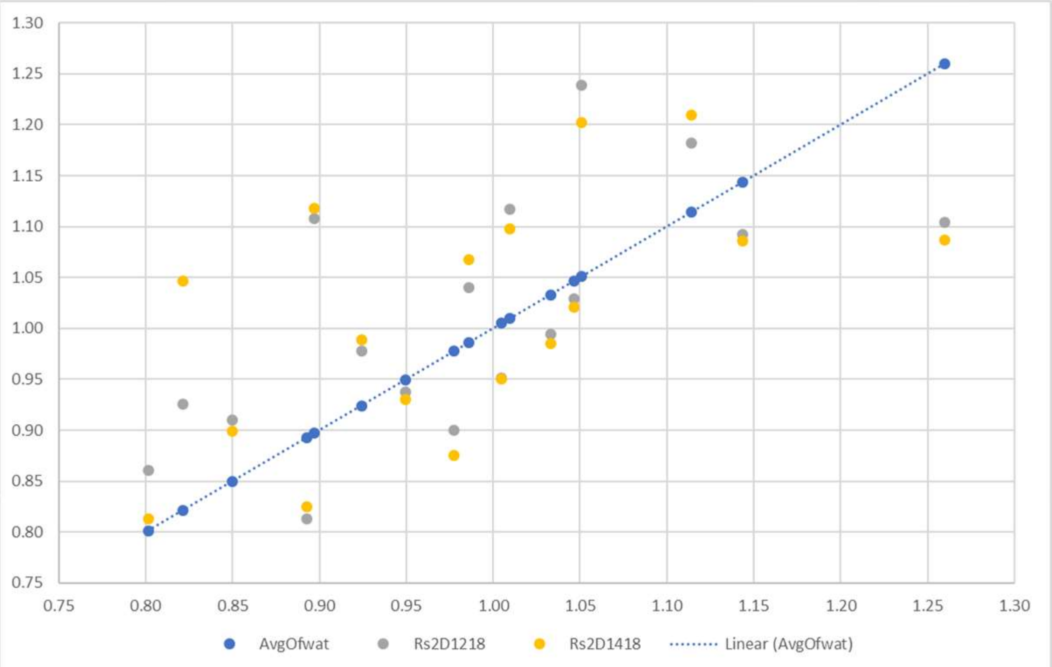
Comparison of 2012-2018 and 2014-18 Preferred Regressions demonstrates that estimation is robust in both databases and interaction parameters are jointly significant as required in translog modelling



```
                Variable     Rs2D1218      Rs2D1418
--------------------------------------------------
                 lnEffWD    0.589***      0.608***
                 lnMains    0.446***      0.438***
         lnEffWDlnMains   -1.013*       -1.287**
            lnEffWDsqr    1.203***      1.352***
            lnMainssqr    0.793         1.184*
                 PMetshr   -0.541***     -0.536**
                lnAPHTOT    0.322***      0.291*
                   y2012   -0.176***
                   y2013   -0.117**
                   y2014   -0.170***     -0.175***
                   y2015   -0.186***     -0.190***
                   y2016   -0.222***     -0.226***
                   y2017   -0.085**      -0.086**
                   _cons    0.371***      0.368**
--------------------------------------------------
                       N     124            88
                    r2_o    0.978         0.980
                   sigma    0.179         0.171
                 sigma_u    0.133         0.135
                 sigma_e    0.120         0.106
          BPLMRE_P_value    0.000         0.000
           RESET_P_value    0.494         0.343
            TDum_P_value    0.000         0.000
--------------------------------------------------
            legend: * p<.1; ** p<.05; *** p<.01
```

Use of a parsimonious multiple output model allowing for cost interactions and specified with effective water as an incentive compatible output controlling for water scarcity, as well as metering and pumping head controls, **yields a model that should be considered robust for regulatory application, when compared to Ofwat's own models.**

These Alternative Models Also Suggest Substantially Different Estimates of 2014-18 Costs Relative to Ofwat's Models



	2014-2018 Actual/Pred. Cost			Dif. from Ofwat	
	Avg. of Ofwat M1 & M2	Rs2D1218	Rs2D1418	Rs2D1218	Rs2D1418
AFW	1.01	1.12	1.10	0.11	0.09
ANH	0.98	0.90	0.88	-0.08	-0.10
BRL	1.11	1.18	1.21	0.07	0.10
DVW	0.82	0.93	1.05	0.10	0.22
NES	0.95	0.94	0.93	-0.01	-0.02
NWT	1.05	1.24	1.20	0.19	0.15
PRT	0.80	0.86	0.81	0.06	0.01
SES	1.14	1.09	1.09	-0.05	-0.06
SEW	0.92	0.98	0.99	0.05	0.06
SRN	0.90	1.11	1.12	0.21	0.22
SSC	0.89	0.81	0.82	-0.08	-0.07
SVT	1.05	1.03	1.02	-0.02	-0.03
SWB	1.00	0.95	0.95	-0.05	-0.05
TMS	1.03	0.99	0.99	-0.04	-0.05
WSH	1.26	1.10	1.09	-0.16	-0.17
WSX	0.99	1.04	1.07	0.05	0.08
YKY	0.85	0.91	0.90	0.06	0.05
Min	0.80	0.81	0.81	-0.16	-0.17
Avg.	0.99	1.01	1.01	0.02	0.03
Median	0.99	0.99	1.02	0.05	0.01
Max	1.26	1.24	1.21	0.21	0.22
Range	0.46	0.43	0.40		
Correlations					
With Ofwat Model		0.66	0.57		
Between Models			0.95		

Conclusions on Ofwat’s PR2019 Modelling Approach

- Ofwat’s Integrated and Disaggregated Modelling Ignore Cost Interactions Between Upstream and Downstream Activities which are fundamental to understanding water system costs
- Ofwat’s integrated (as well as its distribution only) models employ a specification that can be demonstrated to impose cost relationships that are not consistent with managerial, economic, and engineering understanding of cost relationships in the water industry.
- Ofwat’s reliance on a limited number of models complying with its rigid modelling approach implies that it does not provide a set of “uniquely appropriate” regulatory cost assessment models for PR2019.
- This failure to appropriately “triangulate” its modelling suggests that Ofwat should urgently reconsider the robustness of its cost assessment modelling before its Final Determinations due on Dec 16th, and should develop more appropriate modelling for PR2024.

Conclusions on the Multiple Output Modelling Approach

- It is more than feasible to develop suitably parsimonious and robust regulatory cost assessment models while also respecting the academic literature, which supports the modelling of network infrastructure industry costs with multiple output cost models that allow for cost interactions between outputs.
- We have also demonstrated how defining an incentive compatible measure of “effective water demand” and allowing for water demand management provides a model where water, and managerial response to relative water scarcity are fundamental to water cost modelling.
- We have also demonstrated that the definition, appropriateness and statistical significance of control variables such as population density, pumping controls , water source type and treatment levels are dependent on the underlying model specification, thereby further reinforcing that Ofwat’s rigid modelling approach does not provide “uniquely appropriate” regulatory cost assessment models.

Appropriately Controlling for Cost Interactions, Water Scarcity and Operating Environment in Regulatory Water Cost Assessment

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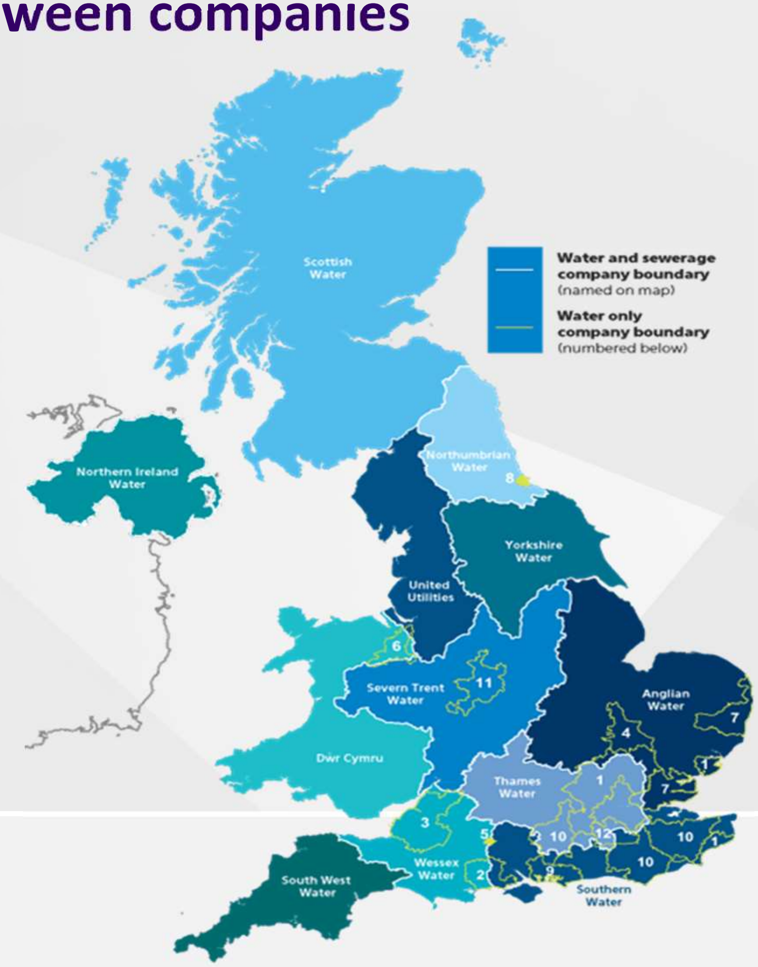
Understanding the Operating and Regulatory Context for Wholesale Water Cost Modelling in England and Wales

In PR 2019 We must Model with Company Level Data, but there is much complex difference both within and between companies

- Required unit of analysis is at company level (determined by Ofwat)
- 7 years of data
- 16 companies for 7 Years
- SWT and BWH for 5 years each
- SWB for 2 years
- 124 very colinear observations

HOW CAN WE MODEL COMPLEXITY WITH SUCH LIMITED DATA?



Complexity of Water Supply Systems

- Multi-output network industry
- Economies of size determined by complex cost interactions between
    - volume of output (water delivered)
    - transportation (length of main is standard proxy)
    - water resource availability, type, quality, and distance from settlements
    - Topography (more than pumping!)
    - Trade-off Network Losses, Transportation Distance, Network maintenance costs and Distribution Losses
    - Other operating characteristics

Complexity of Water Supply Systems (cont’d)

- Each system‘s configuration involves a complex trade-off between
  1. The location and size of population settlements
  2. The location and scale of available water resources
  3. Storage of water (seasonally and daily?)
  4. potential benefits of plant size cost economies in treatment, which differ by type of water and treatment requirements?
  5. Transportation costs
     - The length of network transportation required to bring water to served population
     - Costs related to population density and topography (pumping)
     - Distribution losses
  6. Geographic, environmental, water availability, etc that influence
     - demand for,
     - siting and
     - potential scale of water treatment works

Ofwat's Approach to Wholesale Water Cost Modelling in England and Wales

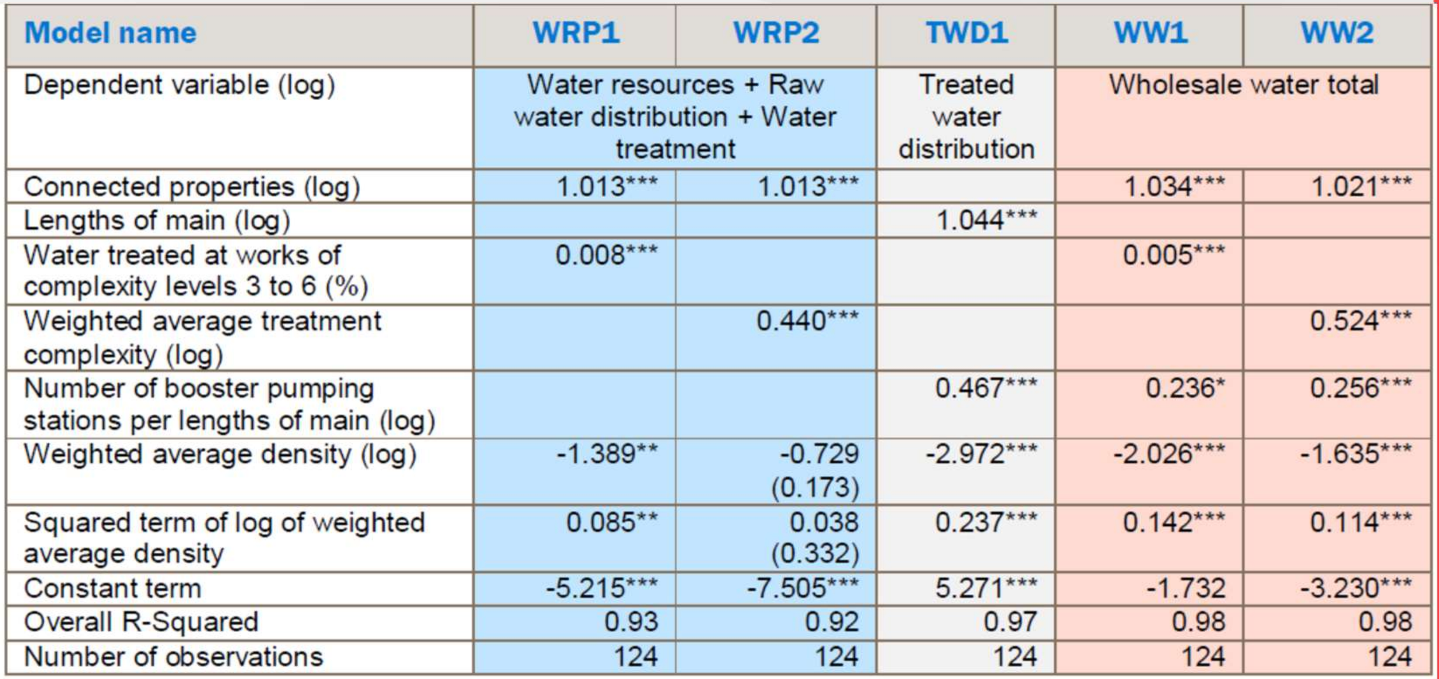
In PR2019 Ofwat seeks to foster competition and has changed its cost assessment accordingly

- **retail separation and “competitive retail market” for non households**
- **Disaggregated Price Caps within Wholesale Business**
  - Water Resources (Water Abstraction)
  - Water Network Plus (Treatment and Distribution)
  - Wastewater Network Plus (Collection and Treatment)
  - Bioresources (Sludge Treatment, Transportation and Disposal)
  - Household Retail (remains integrated within wholesale businesses)

Ofwat’s Approach to Cost Assessment for PR 2019: Effectively Assumes that Cost Interactions can be Ignored or Simply Captured by “noninteractive control variables”

- Appears to limit all models to the use of a single scale variable
- Allows only limited noninteractive control variables for “complexity” “topography” and “density”
- Relies heavily on separable controls for **population density**, to capture differences between firms
- Ofwat Does not appear to rigorously test the parameter restrictions it imposes because of its modelling approach (two examples below)

Ofwat Water Modelling- July 2019 DD



Model name	WRP1	WRP2	TWD1	WW1	WW2
Dependent variable (log)	Water resources + Raw water distribution + Water treatment		Treated water distribution	Wholesale water total	
Connected properties (log)	1.013***	1.013***		1.034***	1.021***
Lengths of main (log)			1.044***		
Water treated at works of complexity levels 3 to 6 (%)	0.008***			0.005***	
Weighted average treatment complexity (log)		0.440***			0.524***
Number of booster pumping stations per lengths of main (log)			0.467***	0.236*	0.256***
Weighted average density (log)	-1.389**	-0.729 (0.173)	-2.972***	-2.026***	-1.635***
Squared term of log of weighted average density	0.085**	0.038 (0.332)	0.237***	0.142***	0.114***
Constant term	-5.215***	-7.505***	5.271***	-1.732	-3.230***
Overall R-Squared	0.93	0.92	0.97	0.98	0.98
Number of observations	124	124	124	124	124

Note: Chosen Modelling is Not Consistent with the Price Control Level, but is more consistent with recognized upstream and downstream definitions of the water system

Where's the Water?

Ofwat models Integrated Water, with a single output and control variables!

All models rely on a separable density specification

Only variation in models is treatment complexity (more on that below)

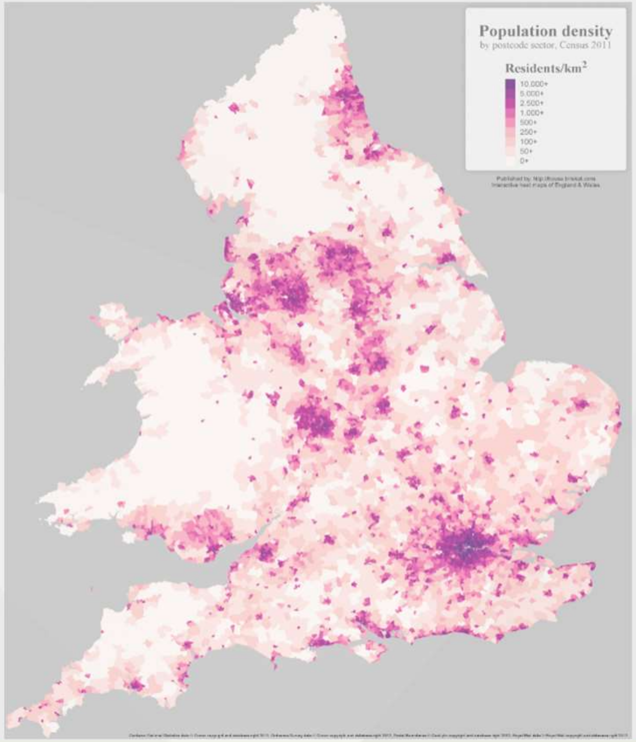
All Models employ only ln(boosterperlengh) as a proxy for "topography" but Ofwat is really treating pumping as an output in models with a negative elasticity for length

Do Ofwat’s Models Adequately Account for Water System Complexity and the Resulting Relevant Cost Interactions?

If so, Are its Models Uniquely Appropriate ?

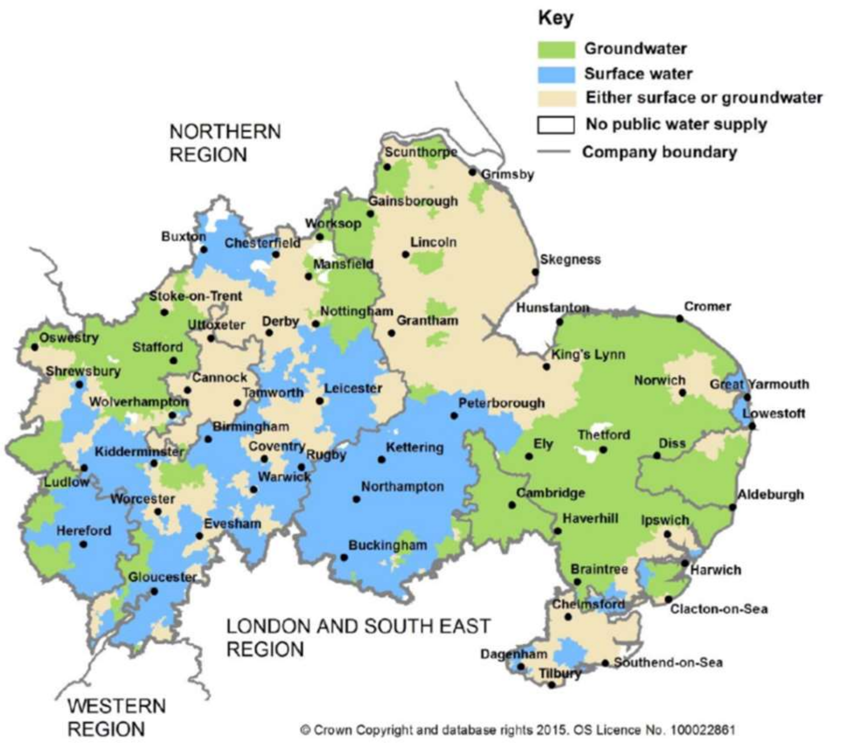
Population Density Is an Important but not a Sufficient Control for System Complexity

- Well known to have a non-linear impact on costs
- Typically addressed by including transportation output proxies (network length) and squared terms and interactions with other output variables to capture this impact on overall size economies and costs
- A Separable Density Specification Alone is Insufficient to explain how the water system designs that have been chosen by managers and engineers as the least-cost solution to a given population settlement pattern resulting from demographic, economic, planning, environmental and geographic factors influences costs



Water Availability and Type of Water of Abstraction Also Vary Significantly, Influence System Costs and May not be concurrent with population location

Figure 4: Map illustrating sources of drinking water by zone across the region



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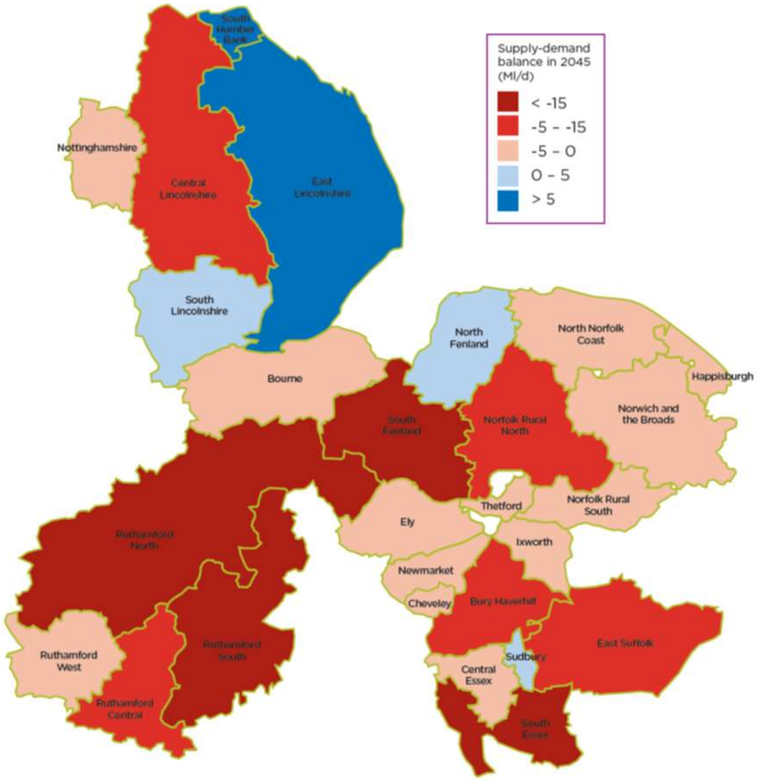
Source: Drinking Water Inspectorate

Baseline supply-demand balance in 2044-45 (DYAA scenario)



Source: Anglian Water Resource Management Plan

We therefore Need to Build an Intuitively Understandable but Sophisticated Model of Whole System Costs if We Wish to Build an Appropriate Model of Regulatory Costs

1. **Water System Costs are influenced by water scarcity** and the resulting cost trade off faced by all firm between saving Distribution Network Costs at the expense of Increased Leakage
2. **Water Demand Management is an activity that Firms Engage in Because it Reduces Whole System Costs** as they strive to balance water resource availability and water demand in the face of water scarcity
3. **Type of Water Source** (Ground and Surface), as well as treatment Complexity Matter and influence system configuration and hence whole system costs
4. **Topography, geography, and density influence network configurations in complex ways** that “noninteractive controls”, which effectively impose untenable cost relationships, cannot appropriately control for.
5. **Cost Interactions between Water Production and Distribution Networks are Fundamental and are best Modelled by Allowing For them in a Multiple Output Model, rather than simply assuming that a density control adequately captures them.**

1. Water System Costs are influenced by water scarcity and the resulting cost trade off faced by all firm between saving Distribution Network Costs at the expense of Increased Leakage

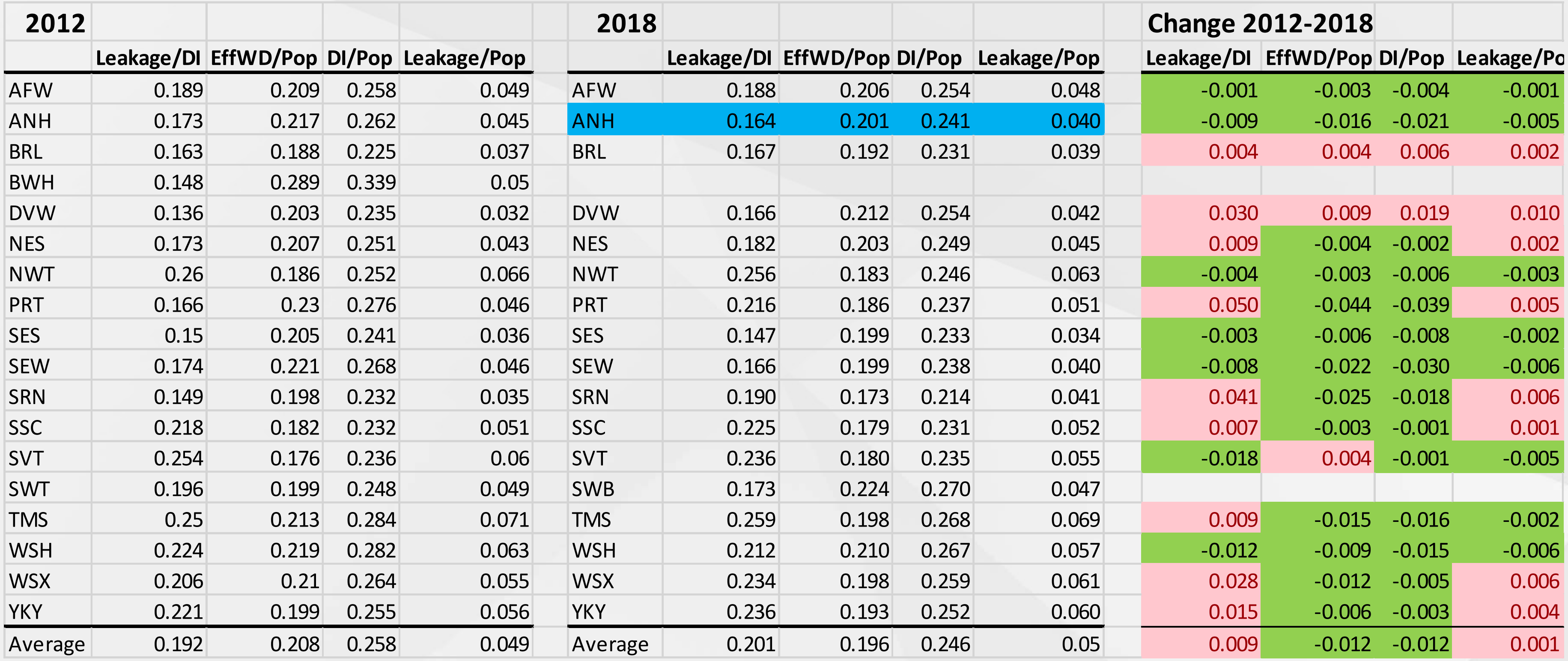
Effective Water= Distribution Input – Leakage

- Effective Water captures a measure that of the water actually used by customers
- Effective Water Provides an Appropriate Proxy of the Incentive Compatible Final Output Proxy for a Water Company seeking to serve its customers, while also appropriately and cost effectively employing water demand management and leakage controls as needed to maintain water supply balance
- Conceptually Firms Choose a distribution input and leakage level that minimise their whole system cost of effective water provision

Distribution Input= Effective Water+ Leakage

- While the relationship is mathematically identical it now indicates the upstream distribution input required by a company to deliver its effective water once its chosen leakage level is taken into account
- E.g it measures the amount of upstream water resource abstraction and treatment required to provide its effective demand given the leakage level it has chosen.

Modelling with Effective Water as the primary upstream output proxy, therefore not only provides an incentive compatible output measure, but will also embody how companies trade off higher (or lower) upstream water abstraction and treatment costs for lower (or higher) downstream network maintenance and water demand management costs in order to minimise whole system costs given water availability, demand, transportation costs, and settlement patterns

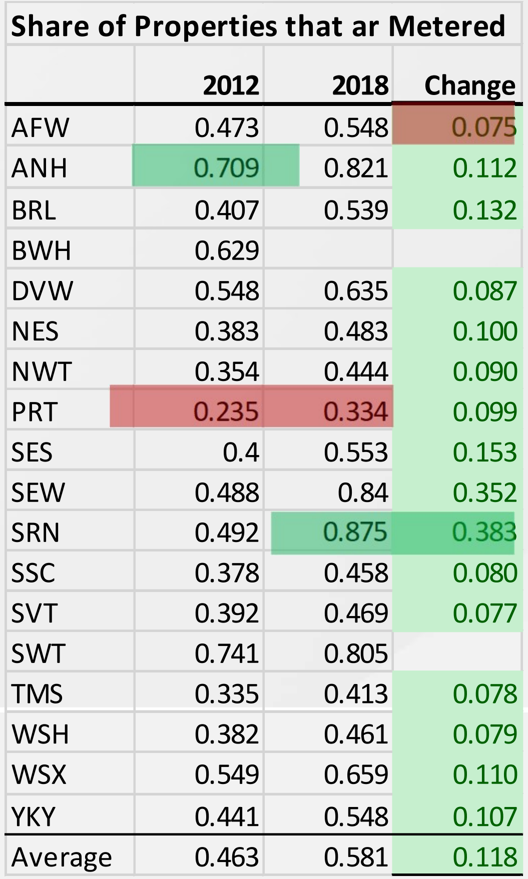


2012					2018					Change 2012-2018			
	Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Pop		Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Pop	Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Po
AFW	0.189	0.209	0.258	0.049	AFW	0.188	0.206	0.254	0.048	-0.001	-0.003	-0.004	-0.001
ANH	0.173	0.217	0.262	0.045	ANH	0.164	0.201	0.241	0.040	-0.009	-0.016	-0.021	-0.005
BRL	0.163	0.188	0.225	0.037	BRL	0.167	0.192	0.231	0.039	0.004	0.004	0.006	0.002
BWH	0.148	0.289	0.339	0.05									
DVW	0.136	0.203	0.235	0.032	DVW	0.166	0.212	0.254	0.042	0.030	0.009	0.019	0.010
NES	0.173	0.207	0.251	0.043	NES	0.182	0.203	0.249	0.045	0.009	-0.004	-0.002	0.002
NWT	0.26	0.186	0.252	0.066	NWT	0.256	0.183	0.246	0.063	-0.004	-0.003	-0.006	-0.003
PRT	0.166	0.23	0.276	0.046	PRT	0.216	0.186	0.237	0.051	0.050	-0.044	-0.039	0.005
SES	0.15	0.205	0.241	0.036	SES	0.147	0.199	0.233	0.034	-0.003	-0.006	-0.008	-0.002
SEW	0.174	0.221	0.268	0.046	SEW	0.166	0.199	0.238	0.040	-0.008	-0.022	-0.030	-0.006
SRN	0.149	0.198	0.232	0.035	SRN	0.190	0.173	0.214	0.041	0.041	-0.025	-0.018	0.006
SSC	0.218	0.182	0.232	0.051	SSC	0.225	0.179	0.231	0.052	0.007	-0.003	-0.001	0.001
SVT	0.254	0.176	0.236	0.06	SVT	0.236	0.180	0.235	0.055	-0.018	0.004	-0.001	-0.005
SWT	0.196	0.199	0.248	0.049	SWB	0.173	0.224	0.270	0.047				
TMS	0.25	0.213	0.284	0.071	TMS	0.259	0.198	0.268	0.069	0.009	-0.015	-0.016	-0.002
WSH	0.224	0.219	0.282	0.063	WSH	0.212	0.210	0.267	0.057	-0.012	-0.009	-0.015	-0.006
WSX	0.206	0.21	0.264	0.055	WSX	0.234	0.198	0.259	0.061	0.028	-0.012	-0.005	0.006
YKY	0.221	0.199	0.255	0.056	YKY	0.236	0.193	0.252	0.060	0.015	-0.006	-0.003	0.004
Average	0.192	0.208	0.258	0.049	Average	0.201	0.196	0.246	0.05	0.009	-0.012	-0.012	0.001

Many companies have improved water resource management, leakage and demand management , but many others have seen declines in at least some of these performance indicators

Is Ofwat's assumption that modelling with properties served can control for differences in company efforts to deal with water scarcity appropriate?

2. Water Demand Management is an activity that Firms Engage in Because it Reduces Whole System Costs as they strive to balance water resource availability and water demand in the face of water scarcity



Share of Properties that ar Metered

	2012	2018	Change
AFW	0.473	0.548	0.075
ANH	0.709	0.821	0.112
BRL	0.407	0.539	0.132
BWH	0.629		
DVW	0.548	0.635	0.087
NES	0.383	0.483	0.100
NWT	0.354	0.444	0.090
PRT	0.235	0.334	0.099
SES	0.4	0.553	0.153
SEW	0.488	0.84	0.352
SRN	0.492	0.875	0.383
SSC	0.378	0.458	0.080
SVT	0.392	0.469	0.077
SWT	0.741	0.805	
TMS	0.335	0.413	0.078
WSH	0.382	0.461	0.079
WSX	0.549	0.659	0.110
YKY	0.441	0.548	0.107
Average	0.463	0.581	0.118

Are Companies’ Water Demand Management and Leakage Improvements best understood as an Inconsequential Issue for Regulatory Cost Assessment as Ofwat’s models assume or are they better understood as an important options in whole system management, which firms pursue to different degrees because of differences in water scarcity?

3. Type of Water Source (Ground and Surface), as well as treatment Complexity Matter and influence system configuration and hence whole system costs

- **Ofwat's treatment complexity indicator uses arbitrary weights**, and also conflates ground and surface water and is therefore not appropriate on an engineering, managerial, or economic basis
- **Ofwat's complexity share indicator conflates groundwater and surface water** despite known operational differences as well as statistical correlations suggesting that this is inappropriate
  - It therefore appears to ignore important differences in network configuration that may exist between systems that rely on groundwater as opposed to surface water.
  - **E.g. based on how its definition focusses exclusively on treatment level while ignoring water source characteristics, Ofwat imposes potentially inappropriate parameter restrictions on these variables**

2018 Share of Treated Water by Type and Treamtent Level

	All Level 3 to 6	Ground Level 3 to 6	Surface Level 3 to 6	Ground Level 0 to 2	Surface Level 0 to 2	All Ground Water
AFW	0.952	0.569	0.383	0.048	0.00	0.617
ANH	0.798	0.311	0.487	0.202	0.00	0.513
BRL	0.987	0.122	0.865	0.013	0.00	0.135
DVW	1	0.055	0.945	0	0.00	0.055
NES	0.982	0.048	0.935	0.018	0.00	0.065
NWT	0.981	0.023	0.958	0.019	0.00	0.042
PRT	0.568	0.439	0.129	0.432	0.00	0.871
SES	1	0.845	0.155	0	0.00	0.845
SEW	0.876	0.648	0.229	0.124	0.00	0.771
SRN	0.892	0.563	0.329	0.108	0.00	0.671
SSC	0.721	0.201	0.521	0.279	0.00	0.479
SVT	0.906	0.191	0.715	0.094	0.00	0.285
SWB	0.968	0.055	0.914	0.032	0.00	0.086
TMS	0.901	0.128	0.773	0.099	0.00	0.227
WSH	1	0.032	0.968	0	0.00	0.032
WSX	0.48	0.237	0.244	0.52	0.00	0.756
YKY	0.958	0.154	0.804	0.042	0.00	0.196
Total	0.881	0.272	0.609	0.119	0.00	0.391

	All Level 3 to 6	Ground Level 3 to 6	Surface Level 3 to 6	Ground Level 0 to 2	Surface Level 0 to 2	All Ground Water
All Level 3 to 6	1					
Ground Level 3 to 6	0.02	1				
Surface Level 3 to 6	0.61	-0.79	1			
Ground Level 0 to 2	-0.99	0.01	-0.62	1		
Surface Level 0 to 2	0.01	-0.21	0.17	-0.15	1	
All Ground Water	-0.60	0.79	-1.00	0.62	-0.25	1

1. Ofwat's complexity share measure conflates two shares that are strongly negatively correlated with each other

2. Moreover as very little surface water treatment is carried out below level 0 to 2, its measure may primarily capture a difference between high level treatment of both ground and surface water relative to ground water treated to a lower level

```
    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
  GW0to20shr |        124    .1432896    .1879789          0   .8298138
  GW3to60shr |        124    .2422497    .2386856   .0177049   .8510226
  SW0to20shr |        124    .0056545    .0258702          0   .1388247
  SW3to60shr |        124    .6088061    .3001659   .0873236   .9699386
```

Is Ofwat's Complexity Measure Arbitrary? Particularly, as it does not test if the use of a single aggregate treatment measure is appropriate and the impact of the break chosen to define the measure.

2018 Share of Treated Water by Type and Treamtent Level

	All Level 4 to 6	Ground Level 4 to 6	Surface Level 4 to 6	Ground Level 0 to 3	Surface Level 0 to 3	All Ground Water
AFW	0.88	0.497	0.383	0.12	0	0.617
ANH	0.714	0.226	0.487	0.286	0	0.513
BRL	0.987	0.122	0.865	0.013	0	0.135
DVW	0.971	0.055	0.916	0	0.029	0.055
NES	0.938	0.028	0.91	0.038	0.024	0.065
NWT	0.661	0.023	0.638	0.019	0.32	0.042
PRT	0.568	0.439	0.129	0.432	0	0.871
SES	0.928	0.773	0.155	0.072	0	0.845
SEW	0.61	0.381	0.229	0.39	0	0.771
SRN	0.75	0.539	0.211	0.132	0.118	0.671
SSC	0.696	0.175	0.521	0.304	0	0.479
SVT	0.805	0.191	0.614	0.094	0.101	0.285
SWB	0.569	0.055	0.515	0.032	0.399	0.086
TMS	0.881	0.108	0.773	0.119	0	0.227
WSH	0.769	0.032	0.738	0	0.231	0.032
WSX	0.477	0.233	0.244	0.523	0	0.756
YKY	0.561	0.115	0.446	0.081	0.358	0.196
Total	0.751	0.235	0.516	0.156	0.093	0.391

	All Level 4 to 6	Ground Level 4 to 6	Surface Level 4 to 6	Ground Level 0 to 3	Surface Level 0 to 3	All Ground Water
All Level 4 to 6	1					
Ground Level 4 to 6	0.23	1				
Surface Level 4 to 6	0.67	-0.57	1			
Ground Level 0 to 3	-0.51	0.15	-0.55	1		
Surface Level 0 to 3	-0.55	-0.39	-0.17	-0.43	1	
All Ground Water	-0.19	0.75	-0.74	0.77	-0.54	1

We will proceed by testing the inclusion of controls for

1. Complexity - Breaking the data between treatment at level 0 to 3 and level 4 to 6 illustrated in this slide,

2. Also breaking the data by Ground and Surface Source by Using the full set of share variables capturing complexity and ground or surface water sources

3. While also testing the statistical validity of parameter restrictions on these variables before imposing them.

4. Topography, geography, and density influence network configurations in complex ways that "noninteractive control variables", which actually impose untenable cost relationships, cannot appropriately control for

$$\ln(Botex) = \alpha + \delta\ln(lproperties) + \beta\ln\left(\frac{booster\ stations}{length}\right) + \gamma\ln(weighed\ pop\ density) + \theta(\ln(weighed\ pop\ density))^2 + \vartheta\ln(wac) \quad \text{(M1)}$$

This is mathematically and empirically equivalent to a Cobb-Douglas model that treats properties, booster pumping stations, and length as multiple outputs**,** but imposes the restriction that the elasticity of length is equal to the negative of the elasticity of boosters

$$\boldsymbol{ln(Botex) = \alpha + \delta\, ln(lproperties) + \beta\, ln(booster\ stations) - \beta\, ln(length) + \gamma\, ln(weighed\ pop\ density) + \theta(ln(weighed\ pop\ density))^2 + \vartheta\, ln(wac)} \quad \textbf{(M1')}$$

Or equivalently the following Cobb Douglas Cost Function where the restriction $\phi = -\beta$ has been imposed before estimation as Ofwat implicitly does

$$\ln(Botex) = \alpha + \delta\ln(lproperties) + \beta\ln(booster\ stations) + \phi\ln(length) + \gamma\ln(weighed\ pop\ density) + \theta(\ln(weighed\ pop\ density))^2 + \vartheta\ln(wac) \quad \text{(CD1')}$$

As this restriction implies that if an increases in booster station has a positive impact on costs, an increase in mains MUST HAVE A NEGATIVE IMPACT ON COSTS, it is highly inconsistent with engineering and managerial expectations of cost relationships

***I*t should be transparent that Ofwat's models impose a restriction that would be untenable if it was not disguised as an apparently innocuous control variable for pumping.**

It is Straightforward to Demonstrate that Ofwat's booster station based specification is a severe misspecification that not only treats boosters as an output but imposes a highly inappropriate restriction on the lengths of main coefficient

```
------------------------------------------------------------------------
            Variable |    WW1       WW1LBCst      WW1LB      WW1LBInt
---------------------+--------------------------------------------------
        lnproperties |  1.028***    1.028***     0.163       0.157
           W3t06ofwat|  0.653***    0.653***     0.613***    0.609***
  lnboosterperlength |  0.281***
    lnwedensitywater | -2.183***   -2.183***    -2.776***   -2.776***
   lnwedensitywater2 |  0.154***    0.154***     0.212***    0.212***
     lnlengthsofmain |             -0.281***     0.543***    0.508***
          LNboosters |              0.281***     0.307***    0.260*
LNboosterslnlength~n |                                       0.006
               _cons | -1.139      -1.139        4.076***    4.416***
---------------------+--------------------------------------------------
                  ll | 48.017      48.017       59.169      59.224
                  r2 |  0.974                    0.978       0.978
                r2_a |  0.973                    0.977       0.977
                rmse |  0.168       0.168        0.155       0.155
------------------------------------------------------------------------
                                  legend: * p<.2; ** p<.1; *** p<.05
```

- WW1LBCst demonstrates that Ofwat's WW1 specification imposes a highly restrictive parameter constraint that implies an inappropriate coefficient for length of mains
- WW1LB and statistical test demonstrating the rejection of this restriction demonstrates that boosters are treated as an output in Ofwat's model, and its model should be rejected because it clearly imposes a restriction that should be statistically rejected, and that relaxing this constraint also causes the property variable to become insignificant
- **WW1LBInt further shows via insignificance of the interaction parameter that Ofwat's interpretation of this variable as capturing cost interaction between length and boosters is not correct**

```
             | lnpro~es lnleng~n LNboos~s
-------------+---------------------------
lnproperties |   1.0000
lnlengthso~n |   0.9739   1.0000
  LNboosters |   0.9069   0.9649   1.0000
```

```
.   estimates store WW1LB

.   test _b[lnlengthsofmain] + _b[LNboosters] = 0, coef

 ( 1)  lnlengthsofmain + LNboosters = 0

       F(  1,   117) =   23.06
            Prob > F =    0.0000
```

Note: We have illustrated the above with OLS estimation, to quickly facilitate demonstration of how Ofwat's specification is theoretically equivalent to a model which imposes the constrain demonstrated by WW1LBCst . This constraint is imposed regardless of what estimation method is employed

Average Pumping Head (APHTOT) Provides a Conceptually More Appropriate Control for Pumping than Ofwat's booster/Mains measure

- Ofwat's specification provides a count of the number of pumping stations required in the network thereby effectively included another scale proxy, which is strongly correlated to network length (and other scale of company variables).
- Moreover as the booster station count is uncorrected for station pumping capacity it does not actually measure the amount of pumping work required in the system, or relate to the volume of water output actually delivered in the system.
- Furthermore, as booster stations/mains is -0.55 correlated with Ofwat's density measure, Ofwat's chosen pumping control adds information which is "similar" to its density measure rather than providing a strongly distinct control variable
- **In contrast APHTOT provides a more appropriate proxy indicative of the amount of pumping work required per unit of distribution input consistent with a whole system perspective, e.g. the average amount of pumping effort required to move raw water, treat it, and distribute it to the final consumers.**
- Moreover, APH clearly conveys different information than boosters/Mains given the 0.22 correlation between these alternative controls for pumping .

Correlations			
	APHTOT	boosters/ Mains	wedensity water
APHTOT	1		
boosters/Mains	0.22	1	
wedensitywater	-0.25	-0.55	1

Our Below Models have therefore been developed with the conceptually more appropriated Average Pumping Head (APHTOT) Variable

5. Cost Interactions between Water Resource Plus and Distribution Network Costs are Fundamental and are best Modelled by Allowing for them in the Model

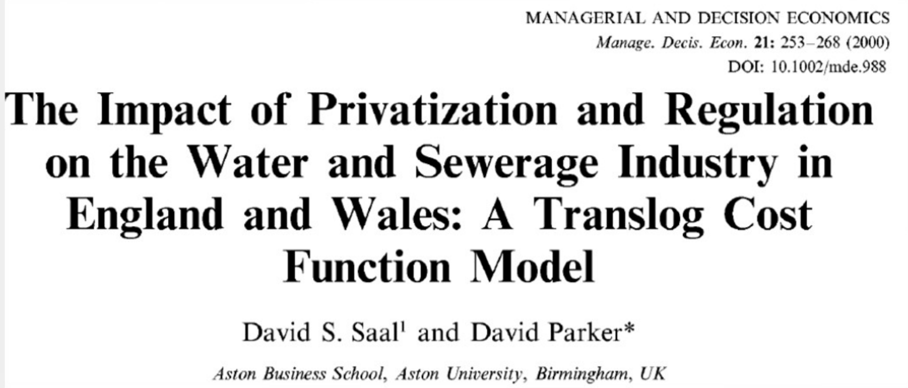
Do Models that Take this Approach provide a viable and appropriate alternatives to models which make the *a priori* assumption that density controls alone are sufficient?

Multiple Output Modelling of Network Industries Allowing for Cost Interactions as an Appropriate and Parsimonious Alternative

- **Regulatory modelling needs to carefully consider how complex cost interactions and operating characteristics influence water system costs**

- **A vast academic literature on multiple output network infrastructure** industries has found considerable evidence of important **cost interactions** between the upstream and downstream components that Ofwat seeks to separately assess costs for
- This includes my own research and consulting work for both Ofwat and companies (Anglian Water, Severn Trent Water, and Untied Utilities)

My own work began with a paper that opened the path to becoming an “expert” in water and wastewater cost modelling



MANAGERIAL AND DECISION ECONOMICS
Manage. Decis. Econ. **21:** 253–268 (2000)
DOI: 10.1002/mde.988

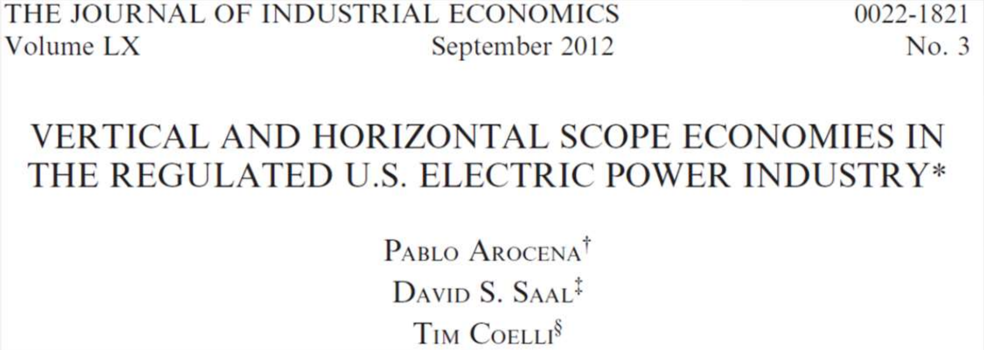
The Impact of Privatization and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Model

David S. Saal[1] and David Parker*

Aston Business School, Aston University, Birmingham, UK

- Translog Model -
- “Separability of inputs and outputs is rejected, thereby demonstrating that it is inappropriate to evaluate WASC costs without using a multiple-output cost function.”
- “These results demonstrate that the costs of water and sewerage services are intricately linked, suggesting that Ofwat’s preference to model WASC water and sewerage costs separately may be inappropriate”

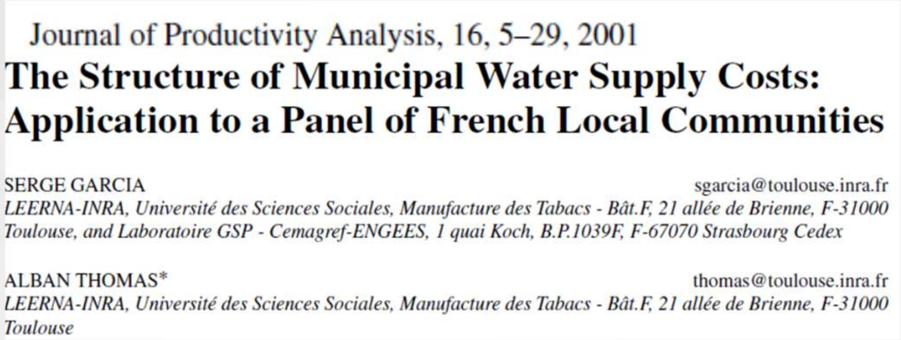
A Few More Relevant Examples from that Vast Academic Literature Considering Cost Interactions in Multiple Output Network Infrastructure Industries



THE JOURNAL OF INDUSTRIAL ECONOMICS 0022-1821
Volume LX September 2012 No. 3

VERTICAL AND HORIZONTAL SCOPE ECONOMIES IN THE REGULATED U.S. ELECTRIC POWER INDUSTRY*

PABLO ARORENA[†]
DAVID S. SAAL[‡]
TIM COELLI[§]



Journal of Productivity Analysis, 16, 5–29, 2001

The Structure of Municipal Water Supply Costs: Application to a Panel of French Local Communities

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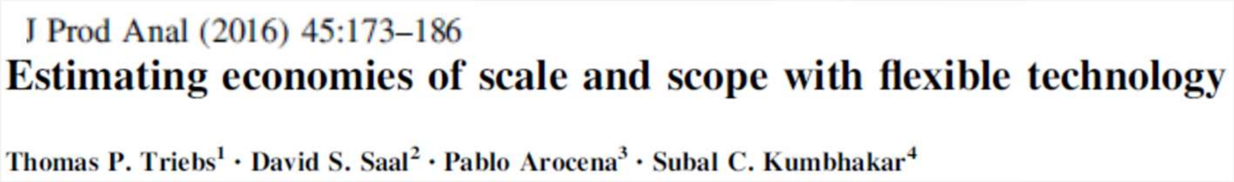
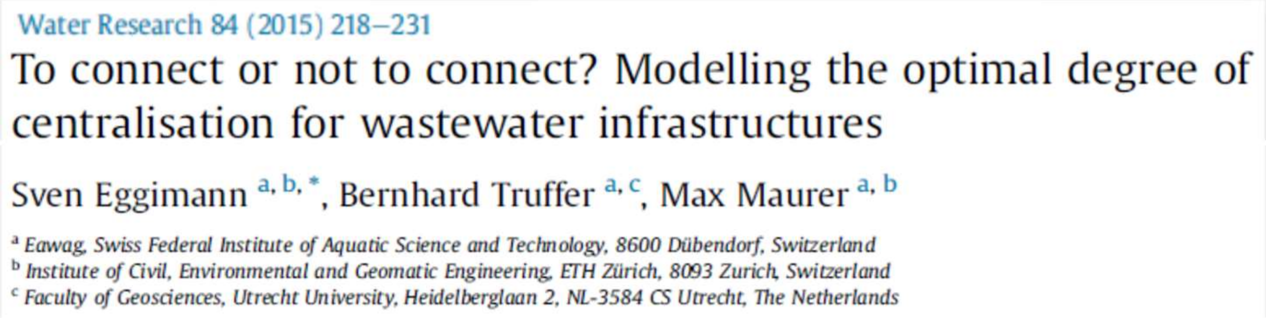


J Prod Anal (2016) 45:173–186

Estimating economies of scale and scope with flexible technology

Thomas P. Triebs[1] · David S. Saal[2] · Pablo Arocena[3] · Subal C. Kumbhakar[4]



Water Research 84 (2015) 218–231

To connect or not to connect? Modelling the optimal degree of centralisation for wastewater infrastructures

Sven Eggimann [a, b, *], Bernhard Truffer [a, c], Max Maurer [a, b]

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Modelling Approach

Translog Models with Testing Down from General to Specific Model

- Allows Modelling of the Complex Cost Interactions that Must be Controlled for in Water Systems, that are precluded in Ofwat's approach to modelling
- Allows for Restriction to Both a Multiple Output "Cobb-Douglas Specification", more consistent with Ofwat's modelling framework , and rejection of these models as underspecified and therefore resulting in omitted variables bias due to omitting Interacted Water System Network Characteristic Variables

Requires Normalisation of Data Around Sample Means

- Ofwat's criticism that translog models lead to models that are difficult to interpret is disingenuous – This standard technique can be applied and is almost always applied in academic literature
- Direct parameter estimates reflect the elasticities with regard to logged variables for a typical sample average firm
- Interacted variable coefficients indicate how elasticity of costs are influenced by differences across firms

Variables

Interacted Basic Outputs

- **Effective Water(EffWD) = Ditribution Input – Leakage**
- **Network Transportation – Mains Length (Mains) -** best available proxy for the amount of network transportation required, and tradeoffs with location and amount of required upstream water production and defined to include raw water mains in addition to distribution mains to be consistent with whole system modelling

Non-Interacted System Characteristics

- **Share of Properties Metered (Pmetshr) -** Indicative of Effort in Water Demand Management and Impct on Whole System Costs
- **Share of Water by Type (Ground v. Surface) and Treatment Level (0 to 3 versus 4 to 6) -** To better capture how treatment complexity as well as type of water sources influences costs
- **Ofwat's density (density) and density squared (density) variables** - to test if Ofwat's density variables remain statistically significant when a whole system specification is employed, but squared term dived by 2 as is standard practice in translog modelling to aid interpretation
- **Average Pumping Head (APHTOT) -** To further capture how managers consider pumping costs in whole water system design, and the resulting trade-offs faced by water company managers in system design

Estimation Approach – Random Effects – As Ofwat Does, but

1. **We estimate the models with statistically significant time dummies**

as given strong time trends in the underlying data this is necessary to avoid bias in both backward looking cost assessment and forward looking cost projection (as we have demonstrated elsewhere)

2. **We prefer estimating the models using 2014 -18 as required for consistent cost-efficiency estimation for 2014-18 with random effects**

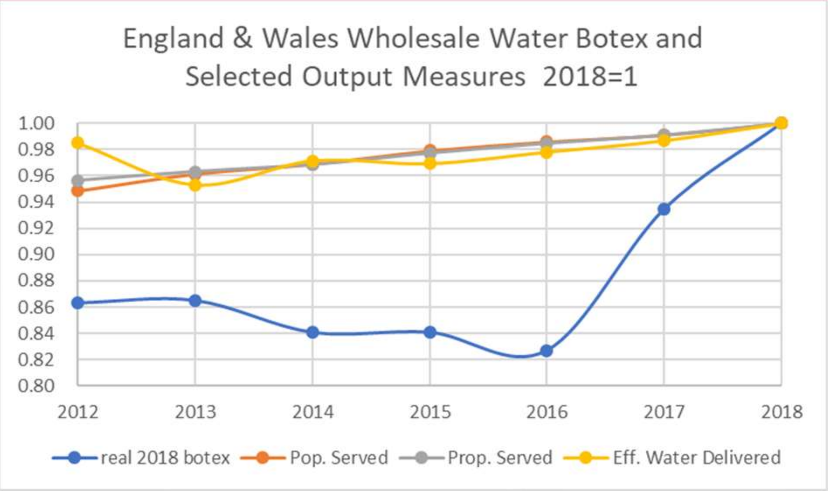
We have argued elsewhere that cost efficiency estimation for the 2014-18 period with random effects is not consistent with a random effects model using data for 2012-18 as done by Ofwat, as this effectively assumes a single random effect for each company for the entire 2012-18 period, thereby conflating and biasing the cost-efficiency estimate for the 2014-18 period with cost-efficiency conditions for 2012-13.

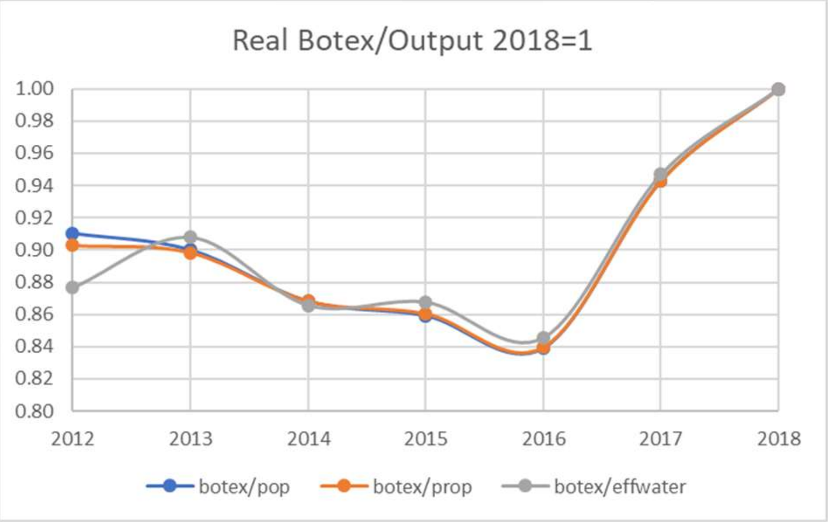
3. Reported Models, Including Ofwat's Models, are estimated with a definition of cost consistent with Ofwat's Botex definition in its January 2019 Initial Assessment of Plans and not the expanded cost definition it used in July 2019 Draft Determinations

We have demonstrated elsewhere that there are Important Implications with Regard to the Appropriateness of Ofwat's backward looking cost assessment and its forward looking assessment of company business plans, given that it simply ignores these differences across time in its cost assessment

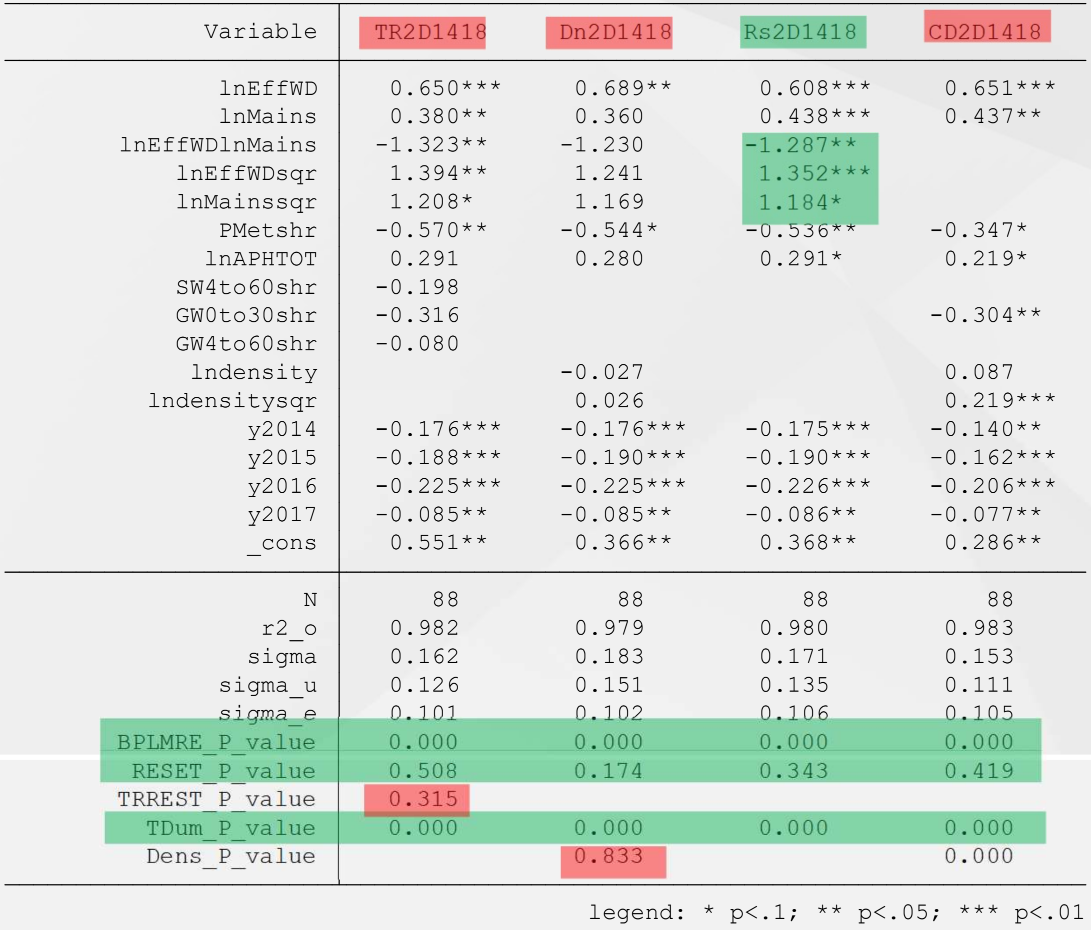
Aggregate Wholesale Water Botex and Selected Output Measures

year	real 2018 botex (000,000)	Pop. Served (000)	Prop. Served (000)	Eff. Water Delivered (Ml/day?)
2012	3,054.3	55,798.8	24,845.2	11,257.4
2013	3,060.8	56,555.9	25,023.7	10,894.1
2014	2,974.9	56,991.8	25,162.2	11,103.8
2015	2,975.2	57,590.6	25,391.6	11,079.2
2016	2,926.2	57,990.2	25,586.2	11,179.7
2017	3,306.1	58,297.1	25,750.2	11,279.2
2018	3,537.2	58,822.3	25,979.9	11,429.2





Effective Water 2014-2018 Translog Restriction Tests



Variable	TR2D1418	Dn2D1418	Rs2D1418	CD2D1418
lnEffWD	0.650***	0.689**	0.608***	0.651***
lnMains	0.380**	0.360	0.438***	0.437**
lnEffWDlnMains	-1.323**	-1.230	-1.287**	
lnEffWDsqr	1.394**	1.241	1.352***	
lnMainssqr	1.208*	1.169	1.184*	
PMetshr	-0.570**	-0.544*	-0.536**	-0.347*
lnAPHTOT	0.291	0.280	0.291*	0.219*
SW4to60shr	-0.198			
GW0to30shr	-0.316			-0.304**
GW4to60shr	-0.080			
lndensity		-0.027		0.087
lndensitysqr		0.026		0.219***
y2014	-0.176***	-0.176***	-0.175***	-0.140**
y2015	-0.188***	-0.190***	-0.190***	-0.162***
y2016	-0.225***	-0.225***	-0.226***	-0.206***
y2017	-0.085**	-0.085**	-0.086**	-0.077**
_cons	0.551**	0.366**	0.368**	0.286**
N	88	88	88	88
r2_o	0.982	0.979	0.980	0.983
sigma	0.162	0.183	0.171	0.153
sigma_u	0.126	0.151	0.135	0.111
sigma_e	0.101	0.102	0.106	0.105
BPLMRE_P_value	0.000	0.000	0.000	0.000
RESET_P_value	0.508	0.174	0.343	0.419
TRREST_P_value	0.315			
TDum_P_value	0.000	0.000	0.000	0.000
Dens_P_value		0.833		0.000

legend: * p<.1; ** p<.05; *** p<.01

Cobb Douglas Model (CD2D1418) demonstrates a feasible noninteractive modelling approach to Ofwat's modelling which allows for statistically significant water scarcity, demand management, density, and pumping controls

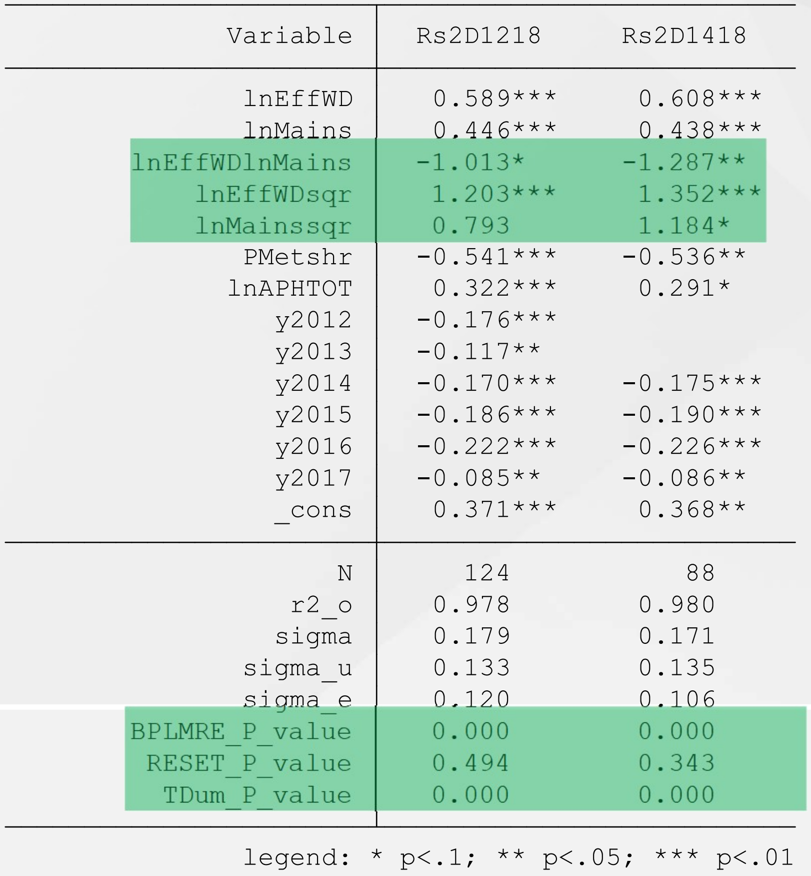
Supports engineering and operational understanding that low treatment groundwater has lower costs, ceteris paribus than other types of water

- **Translog Model (RS2D1418)**

Demonstrates a parsimonious alternative to Ofwat's density specification, which demonstrates the relevance of cost interactions between water production and distribution activities

Suggests that once cost interactions between water production and distribution activities are allowed, water type and treatment controls are no longer required – e.g they are controlled for by the models allowed cost interactions

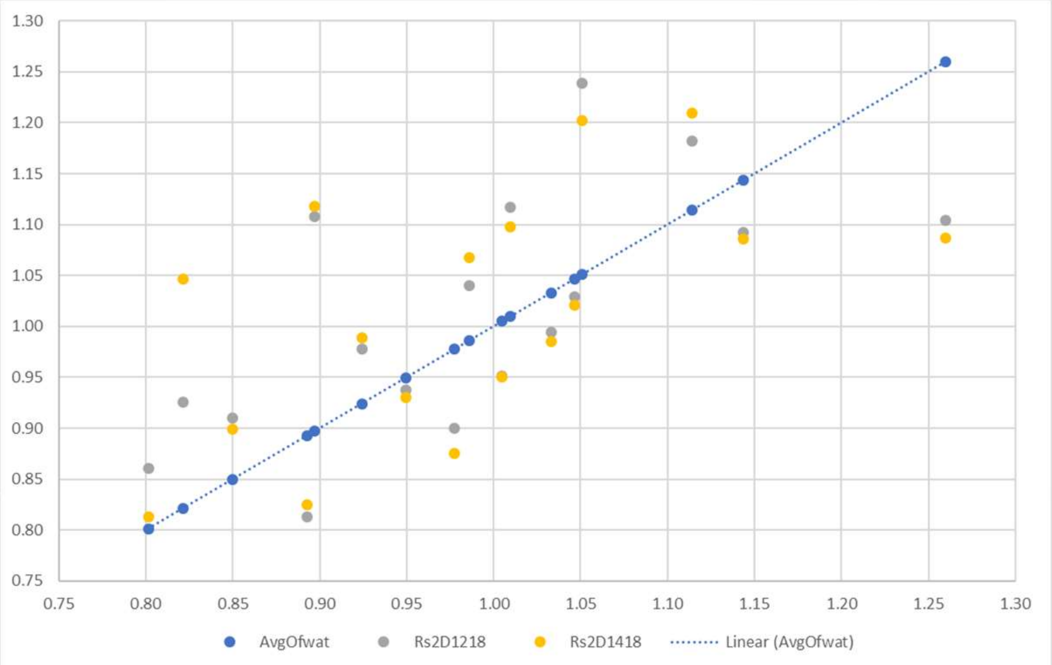
Comparison of 2012-2018 and 2014-18 Preferred Regressions demonstrates that estimation is robust in both databases and interaction parameters are jointly significant as required in translog modelling



```
------------------------------------------------
         Variable |    Rs2D1218      Rs2D1418
------------------------------------------------
          lnEffWD |    0.589***      0.608***
          lnMains |    0.446***      0.438***
   lnEffWDlnMains |   -1.013*       -1.287**
       lnEffWDsqr |    1.203***      1.352***
      lnMainssqr  |    0.793         1.184*
          PMetshr |   -0.541***     -0.536**
         lnAPHTOT |    0.322***      0.291*
            y2012 |   -0.176***
            y2013 |   -0.117**
            y2014 |   -0.170***     -0.175***
            y2015 |   -0.186***     -0.190***
            y2016 |   -0.222***     -0.226***
            y2017 |   -0.085**      -0.086**
            _cons |    0.371***      0.368**
------------------------------------------------
                N |     124            88
             r2_o |    0.978         0.980
            sigma |    0.179         0.171
          sigma_u |    0.133         0.135
          sigma_e |    0.120         0.106
   BPLMRE_P_value |    0.000         0.000
    RESET_P_value |    0.494         0.343
     TDum_P_value |    0.000         0.000
------------------------------------------------
             legend: * p<.1; ** p<.05; *** p<.01
```

Use of a parsimonious multiple output model allowing for cost interactions and specified with effective water as an incentive compatible output controlling for water scarcity, as well as metering and pumping head controls, **yields a model that should be considered robust for regulatory application, when compared to Ofwat's own models.**

These Alternative Models Also Suggest Substantially Different Estimates of 2014-18 Costs Relative to Ofwat's Models



	2014-2018 Actual/Pred. Cost			Dif. from Ofwat	
	Avg. of Ofwat M1 & M2	Rs2D1218	Rs2D1418	Rs2D1218	Rs2D1418
AFW	1.01	1.12	1.10	0.11	0.09
ANH	0.98	0.90	0.88	-0.08	-0.10
BRL	1.11	1.18	1.21	0.07	0.10
DVW	0.82	0.93	1.05	0.10	0.22
NES	0.95	0.94	0.93	-0.01	-0.02
NWT	1.05	1.24	1.20	0.19	0.15
PRT	0.80	0.86	0.81	0.06	0.01
SES	1.14	1.09	1.09	-0.05	-0.06
SEW	0.92	0.98	0.99	0.05	0.06
SRN	0.90	1.11	1.12	0.21	0.22
SSC	0.89	0.81	0.82	-0.08	-0.07
SVT	1.05	1.03	1.02	-0.02	-0.03
SWB	1.00	0.95	0.95	-0.05	-0.05
TMS	1.03	0.99	0.99	-0.04	-0.05
WSH	1.26	1.10	1.09	-0.16	-0.17
WSX	0.99	1.04	1.07	0.05	0.08
YKY	0.85	0.91	0.90	0.06	0.05
Min	0.80	0.81	0.81	-0.16	-0.17
Avg.	0.99	1.01	1.01	0.02	0.03
Median	0.99	0.99	1.02	0.05	0.01
Max	1.26	1.24	1.21	0.21	0.22
Range	0.46	0.43	0.40		
Correlations					
With Ofwat Model		0.66	0.57		
Between Models			0.95		

Conclusions on Ofwat’s PR2019 Modelling Approach

- Ofwat’s Integrated and Disaggregated Modelling Ignore Cost Interactions Between Upstream and Downstream Activities which are fundamental to understanding water system costs
- Ofwat’s integrated (as well as its distribution only) models employ a specification that can be demonstrated to impose cost relationships that are not consistent with managerial, economic, and engineering understanding of cost relationships in the water industry.
- Ofwat’s reliance on a limited number of models complying with its rigid modelling approach implies that it does not provide a set of “uniquely appropriate” regulatory cost assessment models for PR2019.
- This failure to appropriately “triangulate” its modelling suggests that Ofwat should urgently reconsider the robustness of its cost assessment modelling before its Final Determinations due on Dec 16th, and should develop more appropriate modelling for PR2024.

Conclusions on the Multiple Output Modelling Approach

- It is more than feasible to develop suitably parsimonious and robust regulatory cost assessment models while also respecting the academic literature, which supports the modelling of network infrastructure industry costs with multiple output cost models that allow for cost interactions between outputs.
- We have also demonstrated how defining an incentive compatible measure of "effective water demand" and allowing for water demand management provides a model where water, and managerial response to relative water scarcity are fundamental to water cost modelling.
- We have also demonstrated that the definition, appropriateness and statistical significance of control variables such as population density, pumping controls , water source type and treatment levels are dependent on the underlying model specification, thereby further reinforcing that Ofwat's rigid modelling approach does not provide "uniquely appropriate" regulatory cost assessment models.

Appropriately Controlling for Cost Interactions, Water Scarcity and Operating Environment in Regulatory Water Cost Assessment

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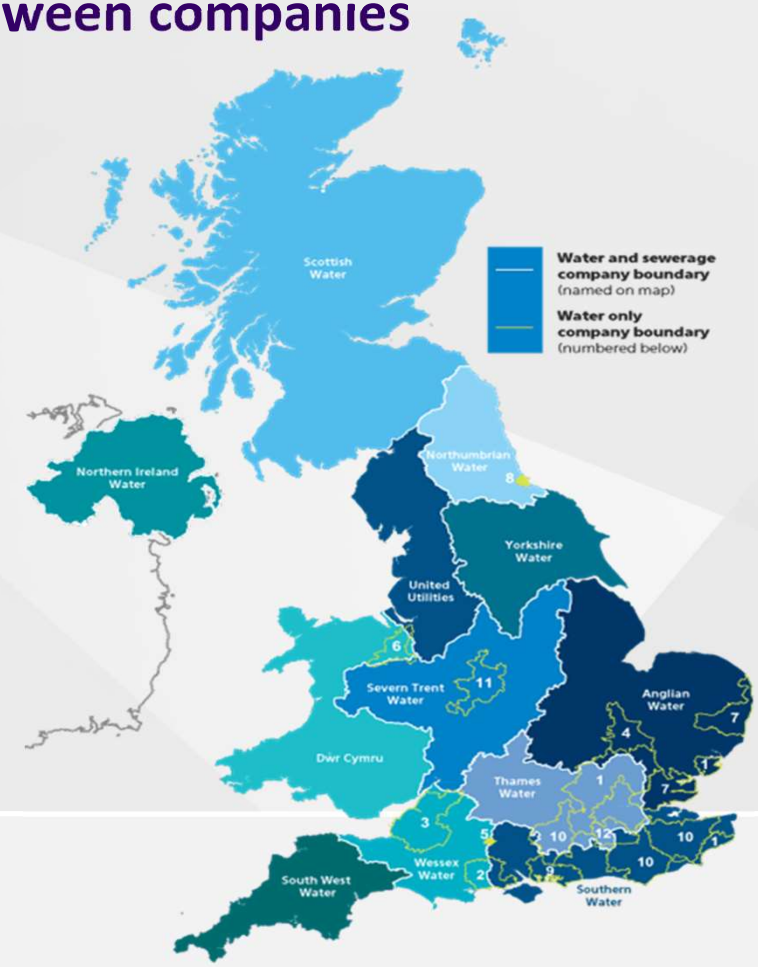
Understanding the Operating and Regulatory Context for Wholesale Water Cost Modelling in England and Wales

In PR 2019 We must Model with Company Level Data, but there is much complex difference both within and between companies

- Required unit of analysis is at company level (determined by Ofwat)
- 7 years of data
- 16 companies for 7 Years
- SWT and BWH for 5 years each
- SWB for 2 years
- 124 very colinear observations

HOW CAN WE MODEL COMPLEXITY WITH SUCH LIMITED DATA?



Complexity of Water Supply Systems

- Multi-output network industry
- Economies of size determined by complex cost interactions between
  - volume of output (water delivered)
  - transportation (length of main is standard proxy)
  - water resource availability, type, quality, and distance from settlements
  - Topography (more than pumping!)
  - Trade-off Network Losses, Transportation Distance, Network maintenance costs and Distribution Losses
  - Other operating characteristics

Complexity of Water Supply Systems (cont'd)

- Each system's configuration involves a complex trade-off between
  1. The location and size of population settlements
  2. The location and scale of available water resources
  3. Storage of water (seasonally and daily?)
  4. potential benefits of plant size cost economies in treatment, which differ by type of water and treatment requirements?
  5. Transportation costs
     - The length of network transportation required to bring water to served population
     - Costs related to population density and topography (pumping)
     - Distribution losses
  6. Geographic, environmental, water availability, etc that influence
     - demand for,
     - siting and
     - potential scale of water treatment works

Ofwat's Approach to Wholesale Water Cost Modelling in England and Wales

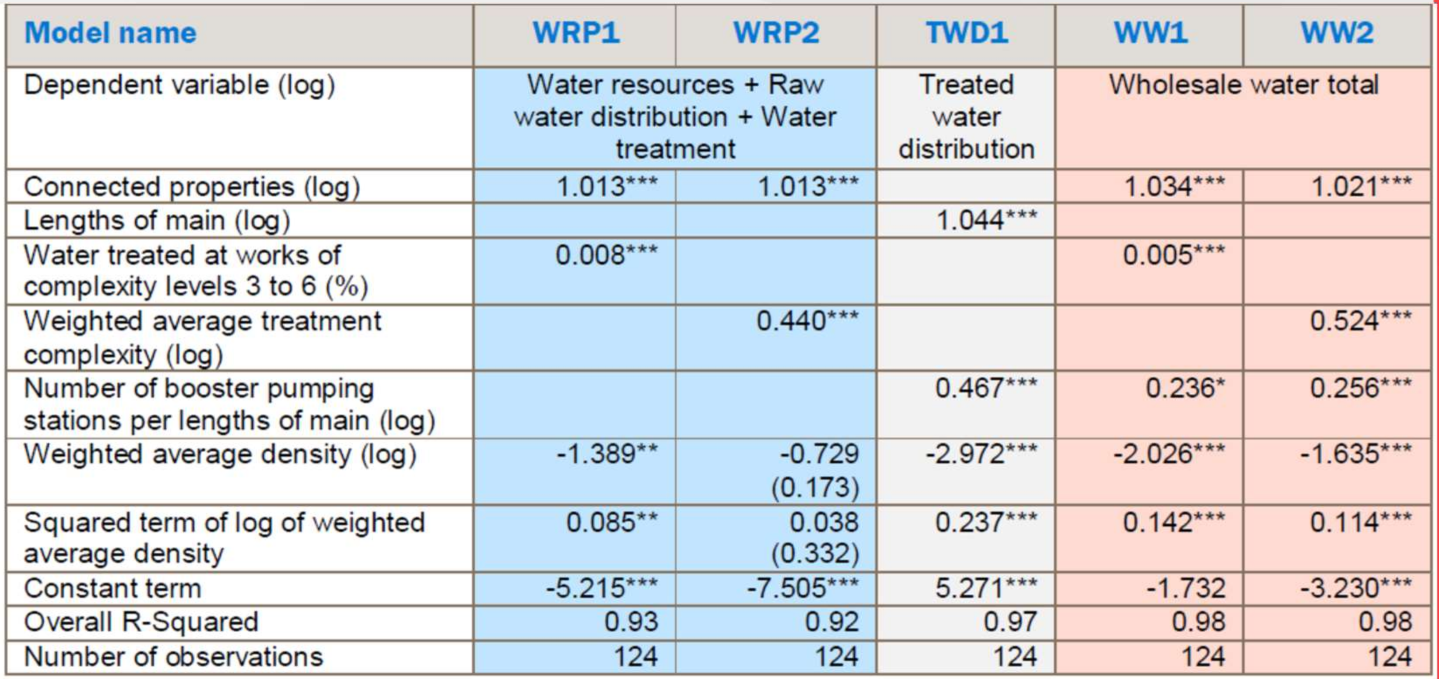
In PR2019 Ofwat seeks to foster competition and has changed its cost assessment accordingly

- **retail separation and “competitive retail market” for non households**
- **Disaggregated Price Caps within Wholesale Business**
  - Water Resources (Water Abstraction)
  - Water Network Plus (Treatment and Distribution)
  - Wastewater Network Plus (Collection and Treatment)
  - Bioresources (Sludge Treatment, Transportation and Disposal)
  - Household Retail (remains integrated within wholesale businesses)

Ofwat’s Approach to Cost Assessment for PR 2019: Effectively Assumes that Cost Interactions can be Ignored or Simply Captured by “noninteractive control variables”

- Appears to limit all models to the use of a single scale variable
- Allows only limited noninteractive control variables for “complexity” “topography” and “density”
- Relies heavily on separable controls for **population density**, to capture differences between firms
- Ofwat Does not appear to rigorously test the parameter restrictions it imposes because of its modelling approach (two examples below)

Ofwat Water Modelling- July 2019 DD



Model name	**WRP1**	**WRP2**	**TWD1**	**WW1**	**WW2**
Dependent variable (log)	Water resources + Raw water distribution + Water treatment		Treated water distribution	Wholesale water total	
Connected properties (log)	1.013***	1.013***		1.034***	1.021***
Lengths of main (log)			1.044***		
Water treated at works of complexity levels 3 to 6 (%)	0.008***			0.005***	
Weighted average treatment complexity (log)		0.440***			0.524***
Number of booster pumping stations per lengths of main (log)			0.467***	0.236*	0.256***
Weighted average density (log)	-1.389**	-0.729 (0.173)	-2.972***	-2.026***	-1.635***
Squared term of log of weighted average density	0.085**	0.038 (0.332)	0.237***	0.142***	0.114***
Constant term	-5.215***	-7.505***	5.271***	-1.732	-3.230***
Overall R-Squared	0.93	0.92	0.97	0.98	0.98
Number of observations	124	124	124	124	124

Note: Chosen Modelling is Not Consistent with the Price Control Level, but is more consistent with recognized upstream and downstream definitions of the water system

Where’s the Water?

Ofwat models Integrated Water, with a single output and control variables!

All models rely on a separable density specification

Only variation in models is treatment complexity (more on that below)

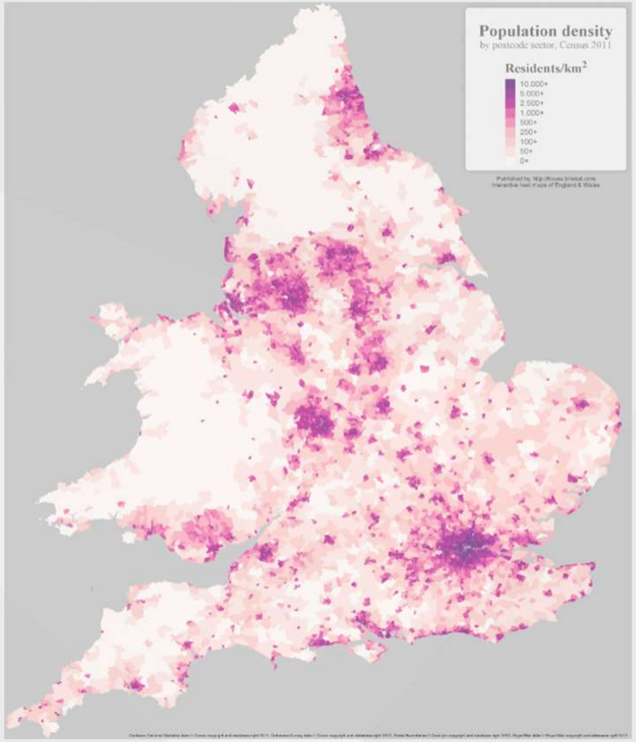
All Models employ only ln(boosterperlengh) as a proxy for “topography” but Ofwat is really treating pumping as an output in models with a negative elasticity for length

Do Ofwat’s Models Adequately Account for Water System Complexity and the Resulting Relevant Cost Interactions?

If so, Are its Models Uniquely Appropriate ?

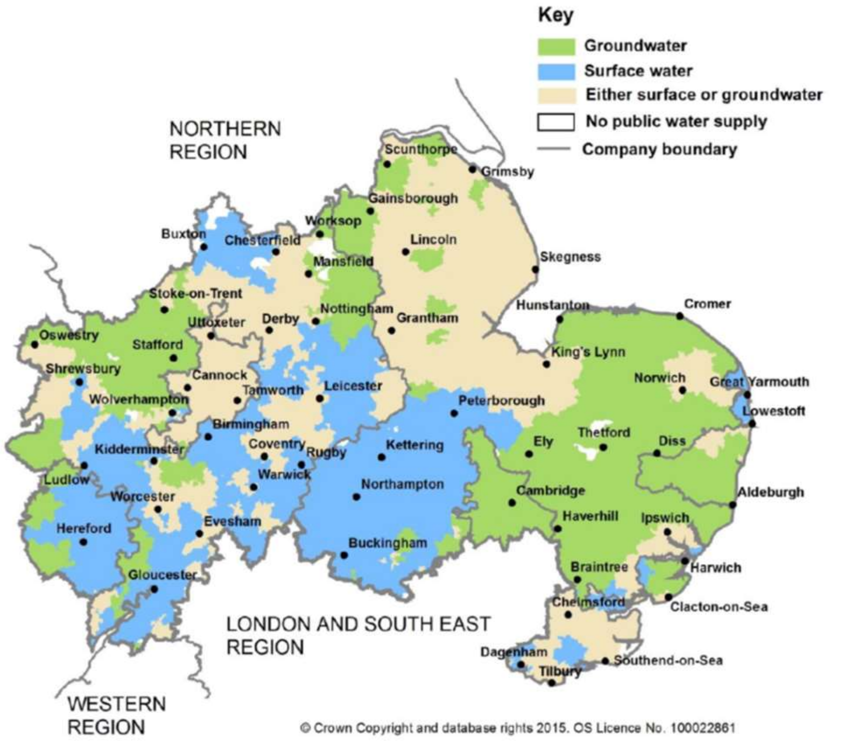
Population Density Is an Important but not a Sufficient Control for System Complexity

- Well known to have a non-linear impact on costs
- Typically addressed by including transportation output proxies (network length) and squared terms and interactions with other output variables to capture this impact on overall size economies and costs
- A Separable Density Specification Alone is Insufficient to explain how the water system designs that have been chosen by managers and engineers as the least-cost solution to a given population settlement pattern resulting from demographic, economic, planning, environmental and geographic factors influences costs

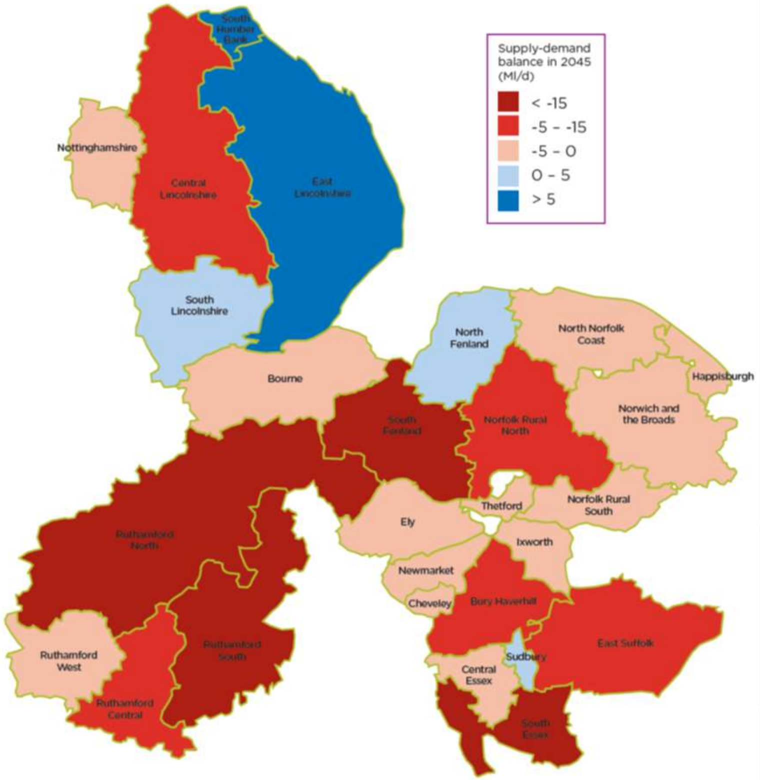


Water Availability and Type of Water of Abstraction Also Vary Significantly, Influence System Costs and May not be concurrent with population location

Figure 4: Map illustrating sources of drinking water by zone across the region



Baseline supply-demand balance in 2044-45 (DYAA scenario)



Source: Drinking Water Inspectorate

Source: Anglian Water Resource Management Plan

We therefore Need to Build an Intuitively Understandable but Sophisticated Model of Whole System Costs if We Wish to Build an Appropriate Model of Regulatory Costs

1. **Water System Costs are influenced by water scarcity** and the resulting cost trade off faced by all firm between saving Distribution Network Costs at the expense of Increased Leakage
2. **Water Demand Management is an activity that Firms Engage in Because it Reduces Whole System Costs** as they strive to balance water resource availability and water demand in the face of water scarcity
3. **Type of Water Source** (Ground and Surface), as well as treatment Complexity Matter and influence system configuration and hence whole system costs
4. **Topography, geography, and density influence network configurations in complex ways** that "noninteractive controls", which effectively impose untenable cost relationships, cannot appropriately control for.
5. **Cost Interactions between Water Production and Distribution Networks are Fundamental and are best Modelled by Allowing For them in a Multiple Output Model, rather than simply assuming that a density control adequately captures them.**

1. Water System Costs are influenced by water scarcity and the resulting cost trade off faced by all firm between saving Distribution Network Costs at the expense of Increased Leakage

Effective Water= Distribution Input – Leakage

- Effective Water captures a measure that of the water actually used by customers
- Effective Water Provides an Appropriate Proxy of the Incentive Compatible Final Output Proxy for a Water Company seeking to serve its customers, while also appropriately and cost effectively employing water demand management and leakage controls as needed to maintain water supply balance
- Conceptually Firms Choose a distribution input and leakage level that minimise their whole system cost of effective water provision

Distribution Input= Effective Water+ Leakage

- While the relationship is mathematically identical it now indicates the upstream distribution input required by a company to deliver its effective water once its chosen leakage level is taken into account
- E.g it measures the amount of upstream water resource abstraction and treatment required to provide its effective demand given the leakage level it has chosen.

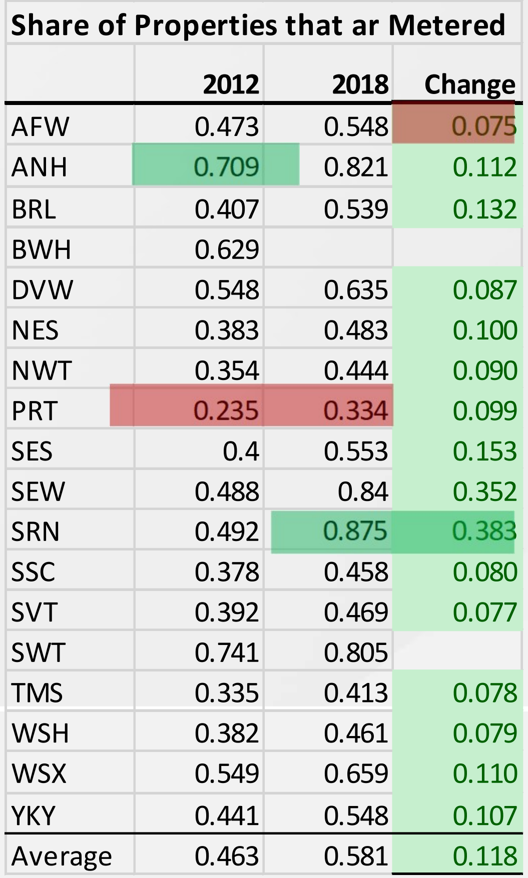
Modelling with Effective Water as the primary upstream output proxy, therefore not only provides an incentive compatible output measure, but will also embody how companies trade off higher (or lower) upstream water abstraction and treatment costs for lower (or higher) downstream network maintenance and water demand management costs in order to minimise whole system costs given water availability, demand, transportation costs, and settlement patterns

2012					2018					Change 2012-2018			
	Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Pop		Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Pop	Leakage/DI	EffWD/Pop	DI/Pop	Leakage/Po
AFW	0.189	0.209	0.258	0.049	AFW	0.188	0.206	0.254	0.048	-0.001	-0.003	-0.004	-0.001
ANH	0.173	0.217	0.262	0.045	ANH	0.164	0.201	0.241	0.040	-0.009	-0.016	-0.021	-0.005
BRL	0.163	0.188	0.225	0.037	BRL	0.167	0.192	0.231	0.039	0.004	0.004	0.006	0.002
BWH	0.148	0.289	0.339	0.05									
DVW	0.136	0.203	0.235	0.032	DVW	0.166	0.212	0.254	0.042	0.030	0.009	0.019	0.010
NES	0.173	0.207	0.251	0.043	NES	0.182	0.203	0.249	0.045	0.009	-0.004	-0.002	0.002
NWT	0.26	0.186	0.252	0.066	NWT	0.256	0.183	0.246	0.063	-0.004	-0.003	-0.006	-0.003
PRT	0.166	0.23	0.276	0.046	PRT	0.216	0.186	0.237	0.051	0.050	-0.044	-0.039	0.005
SES	0.15	0.205	0.241	0.036	SES	0.147	0.199	0.233	0.034	-0.003	-0.006	-0.008	-0.002
SEW	0.174	0.221	0.268	0.046	SEW	0.166	0.199	0.238	0.040	-0.008	-0.022	-0.030	-0.006
SRN	0.149	0.198	0.232	0.035	SRN	0.190	0.173	0.214	0.041	0.041	-0.025	-0.018	0.006
SSC	0.218	0.182	0.232	0.051	SSC	0.225	0.179	0.231	0.052	0.007	-0.003	-0.001	0.001
SVT	0.254	0.176	0.236	0.06	SVT	0.236	0.180	0.235	0.055	-0.018	0.004	-0.001	-0.005
SWT	0.196	0.199	0.248	0.049	SWB	0.173	0.224	0.270	0.047				
TMS	0.25	0.213	0.284	0.071	TMS	0.259	0.198	0.268	0.069	0.009	-0.015	-0.016	-0.002
WSH	0.224	0.219	0.282	0.063	WSH	0.212	0.210	0.267	0.057	-0.012	-0.009	-0.015	-0.006
WSX	0.206	0.21	0.264	0.055	WSX	0.234	0.198	0.259	0.061	0.028	-0.012	-0.005	0.006
YKY	0.221	0.199	0.255	0.056	YKY	0.236	0.193	0.252	0.060	0.015	-0.006	-0.003	0.004
Average	0.192	0.208	0.258	0.049	Average	0.201	0.196	0.246	0.05	0.009	-0.012	-0.012	0.001

Many companies have improved water resource management, leakage and demand management , but many others have seen declines in at least some of these performance indicators

Is Ofwat’s assumption that modelling with properties served can control for differences in company efforts to deal with water scarcity appropriate?

2. Water Demand Management is an activity that Firms Engage in Because it Reduces Whole System Costs as they strive to balance water resource availability and water demand in the face of water scarcity



Share of Properties that ar Metered

	2012	2018	Change
AFW	0.473	0.548	0.075
ANH	0.709	0.821	0.112
BRL	0.407	0.539	0.132
BWH	0.629		
DVW	0.548	0.635	0.087
NES	0.383	0.483	0.100
NWT	0.354	0.444	0.090
PRT	0.235	0.334	0.099
SES	0.4	0.553	0.153
SEW	0.488	0.84	0.352
SRN	0.492	0.875	0.383
SSC	0.378	0.458	0.080
SVT	0.392	0.469	0.077
SWT	0.741	0.805	
TMS	0.335	0.413	0.078
WSH	0.382	0.461	0.079
WSX	0.549	0.659	0.110
YKY	0.441	0.548	0.107
Average	0.463	0.581	0.118

Are Companies' Water Demand Management and Leakage Improvements best understood as an Inconsequential Issue for Regulatory Cost Assessment as Ofwat's models assume or are they better understood as an important options in whole system management, which firms pursue to different degrees because of differences in water scarcity?

3. Type of Water Source (Ground and Surface), as well as treatment Complexity Matter and influence system configuration and hence whole system costs

- **Ofwat's treatment complexity indicator uses arbitrary weights**, and also conflates ground and surface water and is therefore not appropriate on an engineering, managerial, or economic basis
- **Ofwat's complexity share indicator conflates groundwater and surface water** despite known operational differences as well as statistical correlations suggesting that this is inappropriate
  - It therefore appears to ignore important differences in network configuration that may exist between systems that rely on groundwater as opposed to surface water.
  - **E.g. based on how its definition focusses exclusively on treatment level while ignoring water source characteristics, Ofwat imposes potentially inappropriate parameter restrictions on these variables**

2018 Share of Treated Water by Type and Treamtent Level

	All Level 3 to 6	Ground Level 3 to 6	Surface Level 3 to 6	Ground Level 0 to 2	Surface Level 0 to 2	All Ground Water
AFW	0.952	0.569	0.383	0.048	0.00	0.617
ANH	0.798	0.311	0.487	0.202	0.00	0.513
BRL	0.987	0.122	0.865	0.013	0.00	0.135
DVW	1	0.055	0.945	0	0.00	0.055
NES	0.982	0.048	0.935	0.018	0.00	0.065
NWT	0.981	0.023	0.958	0.019	0.00	0.042
PRT	0.568	0.439	0.129	0.432	0.00	0.871
SES	1	0.845	0.155	0	0.00	0.845
SEW	0.876	0.648	0.229	0.124	0.00	0.771
SRN	0.892	0.563	0.329	0.108	0.00	0.671
SSC	0.721	0.201	0.521	0.279	0.00	0.479
SVT	0.906	0.191	0.715	0.094	0.00	0.285
SWB	0.968	0.055	0.914	0.032	0.00	0.086
TMS	0.901	0.128	0.773	0.099	0.00	0.227
WSH	1	0.032	0.968	0	0.00	0.032
WSX	0.48	0.237	0.244	0.52	0.00	0.756
YKY	0.958	0.154	0.804	0.042	0.00	0.196
Total	0.881	0.272	0.609	0.119	0.00	0.391

	All Level 3 to 6	Ground Level 3 to 6	Surface Level 3 to 6	Ground Level 0 to 2	Surface Level 0 to 2	All Ground Water
All Level 3 to 6	1					
Ground Level 3 to 6	0.02	1				
Surface Level 3 to 6	0.61	-0.79	1			
Ground Level 0 to 2	-0.99	0.01	-0.62	1		
Surface Level 0 to 2	0.01	-0.21	0.17	-0.15	1	
All Ground Water	-0.60	0.79	-1.00	0.62	-0.25	1

1. Ofwat's complexity share measure conflates two shares that are strongly negatively correlated with each other

2. Moreover as very little surface water treatment is carried out below level 0 to 2, its measure may primarily capture a difference between high level treatment of both ground and surface water relative to ground water treated to a lower level

```
    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
  GW0to20shr |        124    .1432896    .1879789          0   .8298138
  GW3to60shr |        124    .2422497    .2386856   .0177049   .8510226
  SW0to20shr |        124    .0056545    .0258702          0   .1388247
  SW3to60shr |        124    .6088061    .3001659   .0873236   .9699386
```

Is Ofwat's Complexity Measure Arbitrary? Particularly, as it does not test if the use of a single aggregate treatment measure is appropriate and the impact of the break chosen to define the measure.

2018 Share of Treated Water by Type and Treamtent Level						
	All Level 4 to 6	Ground Level 4 to 6	Surface Level 4 to 6	Ground Level 0 to 3	Surface Level 0 to 3	All Ground Water
AFW	0.88	0.497	0.383	0.12	0	0.617
ANH	0.714	0.226	0.487	0.286	0	0.513
BRL	0.987	0.122	0.865	0.013	0	0.135
DVW	0.971	0.055	0.916	0	0.029	0.055
NES	0.938	0.028	0.91	0.038	0.024	0.065
NWT	0.661	0.023	0.638	0.019	0.32	0.042
PRT	0.568	0.439	0.129	0.432	0	0.871
SES	0.928	0.773	0.155	0.072	0	0.845
SEW	0.61	0.381	0.229	0.39	0	0.771
SRN	0.75	0.539	0.211	0.132	0.118	0.671
SSC	0.696	0.175	0.521	0.304	0	0.479
SVT	0.805	0.191	0.614	0.094	0.101	0.285
SWB	0.569	0.055	0.515	0.032	0.399	0.086
TMS	0.881	0.108	0.773	0.119	0	0.227
WSH	0.769	0.032	0.738	0	0.231	0.032
WSX	0.477	0.233	0.244	0.523	0	0.756
YKY	0.561	0.115	0.446	0.081	0.358	0.196
Total	0.751	0.235	0.516	0.156	0.093	0.391

	All Level 4 to 6	Ground Level 4 to 6	Surface Level 4 to 6	Ground Level 0 to 3	Surface Level 0 to 3	All Ground Water
All Level 4 to 6	1					
Ground Level 4 to 6	0.23	1				
Surface Level 4 to 6	0.67	-0.57	1			
Ground Level 0 to 3	-0.51	0.15	-0.55	1		
Surface Level 0 to 3	-0.55	-0.39	-0.17	-0.43	1	
All Ground Water	-0.19	0.75	-0.74	0.77	-0.54	1

We will proceed by testing the inclusion of controls for

1. Complexity - Breaking the data between treatment at level 0 to 3 and level 4 to 6 illustrated in this slide,

2. Also breaking the data by Ground and Surface Source by Using the full set of share variables capturing complexity and ground or surface water sources

3. While also testing the statistical validity of parameter restrictions on these variables before imposing them.

4. Topography, geography, and density influence network configurations in complex ways that "noninteractive control variables", which actually impose untenable cost relationships, cannot appropriately control for

$$\ln(Botex) = \alpha + \delta\ln(lproperties) + \beta\ln\left(\frac{booster\ stations}{length}\right) + \gamma\ln(weighed\ pop\ density) + \theta(\ln(weighed\ pop\ density))^2 + \vartheta\ln(wac) \quad \text{(M1)}$$

This is mathematically and empirically equivalent to a Cobb-Douglas model that treats properties, booster pumping stations, and length as multiple outputs**,** but imposes the restriction that the elasticity of length is equal to the negative of the elasticity of boosters

$$\boldsymbol{ln(Botex) = \alpha + \delta\, ln(lproperties) + \beta\, ln(booster\ stations) - \beta\, ln(length) + \gamma\, ln(weighed\ pop\ density) + \theta(ln(weighed\ pop\ density))^2 + \vartheta\, ln(wac)} \quad \textbf{(M1')}$$

Or equivalently the following Cobb Douglas Cost Function where the restriction $\phi = -\beta$ has been imposed before estimation as Ofwat implicitly does

$$\ln(Botex) = \alpha + \delta\ln(lproperties) + \beta\ln(booster\ stations) + \phi\ln(length) + \gamma\ln(weighed\ pop\ density) + \theta(\ln(weighed\ pop\ density))^2 + \vartheta\ln(wac) \quad \text{(CD1')}$$

As this restriction implies that if an increases in booster station has a positive impact on costs, an increase in mains MUST HAVE A NEGATIVE IMPACT ON COSTS, it is highly inconsistent with engineering and managerial expectations of cost relationships

***I*t should be transparent that Ofwat's models impose a restriction that would be untenable if it was not disguised as an apparently innocuous control variable for pumping.**

It is Straightforward to Demonstrate that Ofwat's booster station based specification is a severe misspecification that not only treats boosters as an output but imposes a highly inappropriate restriction on the lengths of main coefficient

```
----------------------------------------------------------------------------
            Variable |     WW1        WW1LBCst       WW1LB        WW1LBInt
---------------------+------------------------------------------------------
        lnproperties |   1.028***     1.028***      0.163         0.157
          W3t06ofwat |   0.653***     0.653***      0.613***      0.609***
  lnboosterperlength |   0.281***
    lnwedensitywater |  -2.183***    -2.183***     -2.776***     -2.776***
   lnwedensitywater2 |   0.154***     0.154***      0.212***      0.212***
     lnlengthsofmain |               -0.281***      0.543***      0.508***
         LNboosters  |                0.281***      0.307***      0.260*
LNboosterslnlength~n |                                            0.006
               _cons |  -1.139       -1.139         4.076***      4.416***
---------------------+------------------------------------------------------
                  ll |  48.017       48.017        59.169        59.224
                  r2 |   0.974                      0.978         0.978
                r2_a |   0.973                      0.977         0.977
                rmse |   0.168        0.168         0.155         0.155
----------------------------------------------------------------------------
                                   legend: * p<.2; ** p<.1; *** p<.05
```

- WW1LBCst demonstrates that Ofwat's WW1 specification imposes a highly restrictive parameter constraint that implies an inappropriate coefficient for length of mains
- WW1LB and statistical test demonstrating the rejection of this restriction demonstrates that boosters are treated as an output in Ofwat's model, and its model should be rejected because it clearly imposes a restriction that should be statistically rejected, and that relaxing this constraint also causes the property variable to become insignificant
- **WW1LBInt further shows via insignificance of the interaction parameter that Ofwat's interpretation of this variable as capturing cost interaction between length and boosters is not correct**

```
.   estimates store WW1LB

.   test _b[lnlengthsofmain] + _b[LNboosters] = 0, coef

 ( 1)  lnlengthsofmain + LNboosters = 0

           F(  1,   117) =   23.06
                Prob > F =    0.0000
```

```
             | lnpro~es lnleng~n LNboos~s
-------------+---------------------------
lnproperties |   1.0000
lnlengthso~n |   0.9739   1.0000
  LNboosters |   0.9069   0.9649   1.0000
```

Note: We have illustrated the above with OLS estimation, to quickly facilitate demonstration of how Ofwat's specification is theoretically equivalent to a model which imposes the constrain demonstrated by WW1LBCst . This constraint is imposed regardless of what estimation method is employed

Average Pumping Head (APHTOT) Provides a Conceptually More Appropriate Control for Pumping than Ofwat's booster/Mains measure

- Ofwat's specification provides a count of the number of pumping stations required in the network thereby effectively included another scale proxy, which is strongly correlated to network length (and other scale of company variables).
- Moreover as the booster station count is uncorrected for station pumping capacity it does not actually measure the amount of pumping work required in the system, or relate to the volume of water output actually delivered in the system.
- Furthermore, as booster stations/mains is -0.55 correlated with Ofwat's density measure, Ofwat's chosen pumping control adds information which is "similar" to its density measure rather than providing a strongly distinct control variable
- **In contrast APHTOT provides a more appropriate proxy indicative of the amount of pumping work required per unit of distribution input consistent with a whole system perspective, e.g. the average amount of pumping effort required to move raw water, treat it, and distribute it to the final consumers.**
- Moreover, APH clearly conveys different information than boosters/Mains given the 0.22 correlation between these alternative controls for pumping .

Correlations			
	APHTOT	boosters/ Mains	wedensity water
APHTOT	1		
boosters/Mains	0.22	1	
wedensitywater	-0.25	-0.55	1

Our Below Models have therefore been developed with the conceptually more appropriated Average Pumping Head (APHTOT) Variable

5. Cost Interactions between Water Resource Plus and Distribution Network Costs are Fundamental and are best Modelled by Allowing for them in the Model

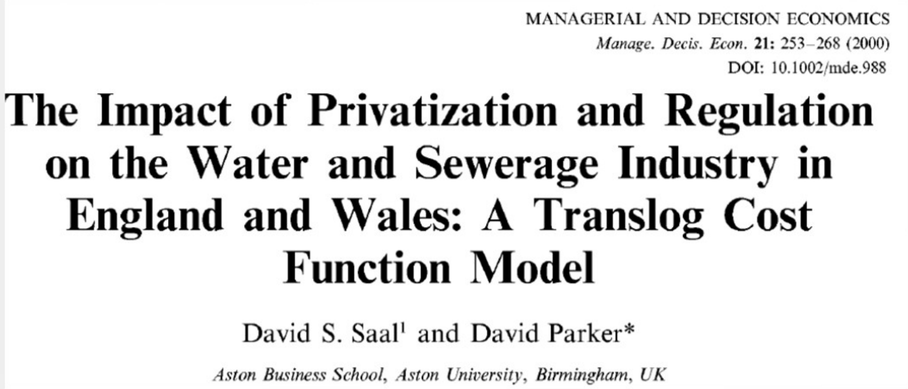
Do Models that Take this Approach provide a viable and appropriate alternatives to models which make the *a priori* assumption that density controls alone are sufficient?

Multiple Output Modelling of Network Industries Allowing for Cost Interactions as an Appropriate and Parsimonious Alternative

- **Regulatory modelling needs to carefully consider how complex cost interactions and operating characteristics influence water system costs**

- **A vast academic literature on multiple output network infrastructure** industries has found considerable evidence of important **cost interactions** between the upstream and downstream components that Ofwat seeks to separately assess costs for
- This includes my own research and consulting work for both Ofwat and companies (Anglian Water, Severn Trent Water, and Untied Utilities)

My own work began with a paper that opened the path to becoming an “expert” in water and wastewater cost modelling



MANAGERIAL AND DECISION ECONOMICS
Manage. Decis. Econ. **21:** 253–268 (2000)
DOI: 10.1002/mde.988

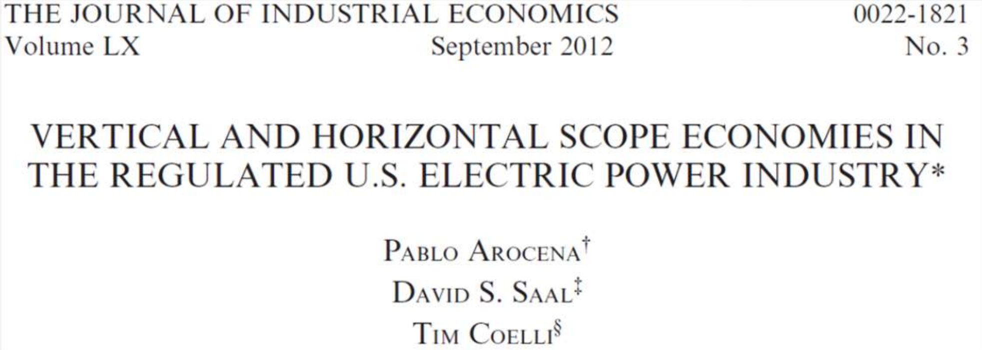
The Impact of Privatization and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Model

David S. Saal[1] and David Parker*

Aston Business School, Aston University, Birmingham, UK

- Translog Model -
- “Separability of inputs and outputs is rejected, thereby demonstrating that it is inappropriate to evaluate WASC costs without using a multiple-output cost function.”
- “These results demonstrate that the costs of water and sewerage services are intricately linked, suggesting that Ofwat’s preference to model WASC water and sewerage costs separately may be inappropriate”

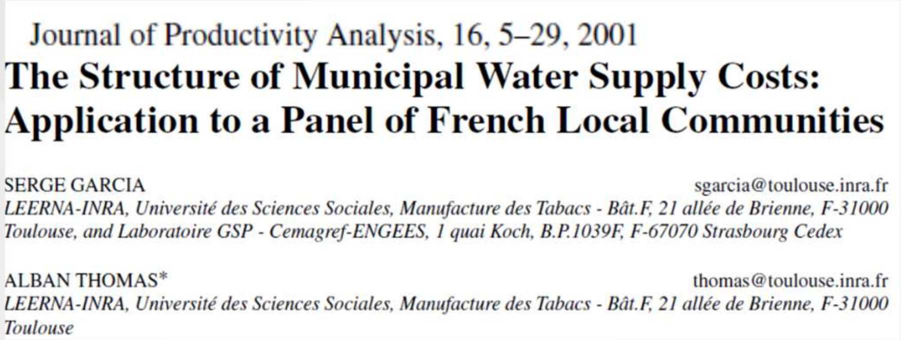
A Few More Relevant Examples from that Vast Academic Literature Considering Cost Interactions in Multiple Output Network Infrastructure Industries



THE JOURNAL OF INDUSTRIAL ECONOMICS 0022-1821
Volume LX September 2012 No. 3

VERTICAL AND HORIZONTAL SCOPE ECONOMIES IN THE REGULATED U.S. ELECTRIC POWER INDUSTRY*

Pablo Arocena[†]
David S. Saal[‡]
Tim Coelli[§]



Journal of Productivity Analysis, 16, 5–29, 2001

The Structure of Municipal Water Supply Costs: Application to a Panel of French Local Communities

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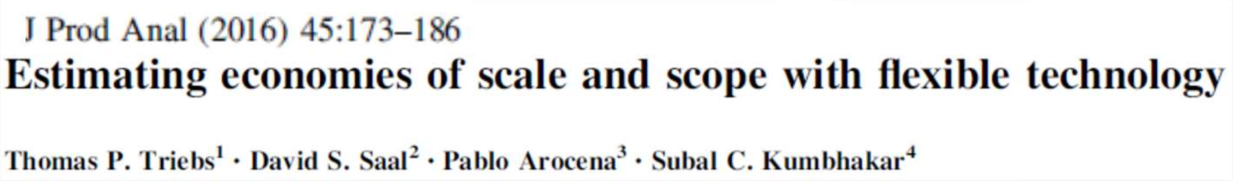
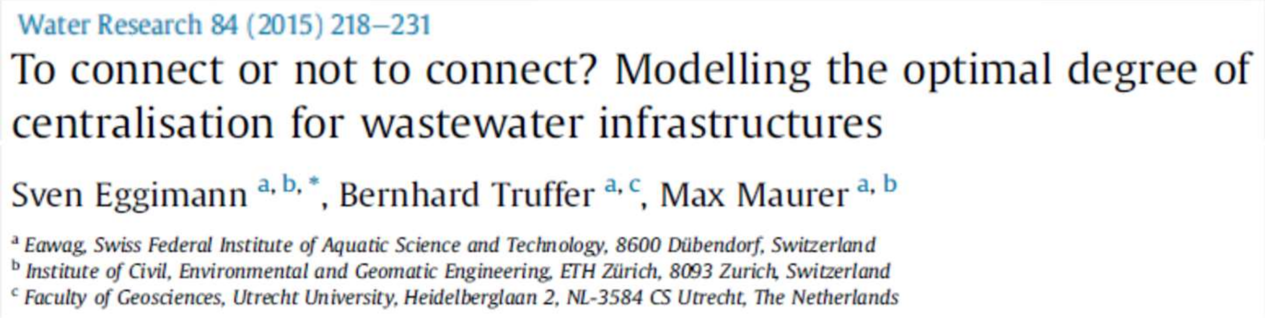


J Prod Anal (2016) 45:173–186

Estimating economies of scale and scope with flexible technology

Thomas P. Triebs[1] · David S. Saal[2] · Pablo Arocena[3] · Subal C. Kumbhakar[4]



Water Research 84 (2015) 218–231

To connect or not to connect? Modelling the optimal degree of centralisation for wastewater infrastructures

Sven Eggimann[a, b, *], Bernhard Truffer[a, c], Max Maurer[a, b]

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Modelling Approach

Translog Models with Testing Down from General to Specific Model

- Allows Modelling of the Complex Cost Interactions that Must be Controlled for in Water Systems, that are precluded in Ofwat's approach to modelling
- Allows for Restriction to Both a Multiple Output "Cobb-Douglas Specification", more consistent with Ofwat's modelling framework , and rejection of these models as underspecified and therefore resulting in omitted variables bias due to omitting Interacted Water System Network Characteristic Variables

Requires Normalisation of Data Around Sample Means

- Ofwat's criticism that translog models lead to models that are difficult to interpret is disingenuous – This standard technique can be applied and is almost always applied in academic literature
- Direct parameter estimates reflect the elasticities with regard to logged variables for a typical sample average firm
- Interacted variable coefficients indicate how elasticity of costs are influenced by differences across firms

Variables

Interacted Basic Outputs

- **Effective Water(EffWD) = Ditribution Input – Leakage**
- **Network Transportation – Mains Length (Mains) -** best available proxy for the amount of network transportation required, and tradeoffs with location and amount of required upstream water production and defined to include raw water mains in addition to distribution mains to be consistent with whole system modelling

Non-Interacted System Characteristics

- **Share of Properties Metered (Pmetshr) -** Indicative of Effort in Water Demand Management and Impct on Whole System Costs
- **Share of Water by Type (Ground v. Surface) and Treatment Level (0 to 3 versus 4 to 6) -** To better capture how treatment complexity as well as type of water sources influences costs
- **Ofwat's density (density) and density squared (density) variables** - to test if Ofwat's density variables remain statistically significant when a whole system specification is employed, but squared term dived by 2 as is standard practice in translog modelling to aid interpretation
- **Average Pumping Head (APHTOT) -** To further capture how managers consider pumping costs in whole water system design, and the resulting trade-offs faced by water company managers in system design

Estimation Approach – Random Effects – As Ofwat Does, but

1. **We estimate the models with statistically significant time dummies**

as given strong time trends in the underlying data this is necessary to avoid bias in both backward looking cost assessment and forward looking cost projection (as we have demonstrated elsewhere)

2. **We prefer estimating the models using 2014 -18 as required for consistent cost-efficiency estimation for 2014-18 with random effects**

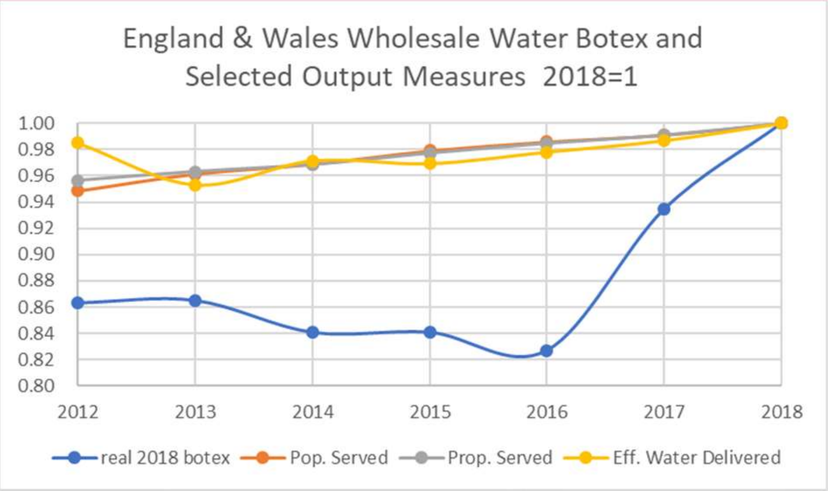
We have argued elsewhere that cost efficiency estimation for the 2014-18 period with random effects is not consistent with a random effects model using data for 2012-18 as done by Ofwat, as this effectively assumes a single random effect for each company for the entire 2012-18 period, thereby conflating and biasing the cost-efficiency estimate for the 2014-18 period with cost-efficiency conditions for 2012-13.

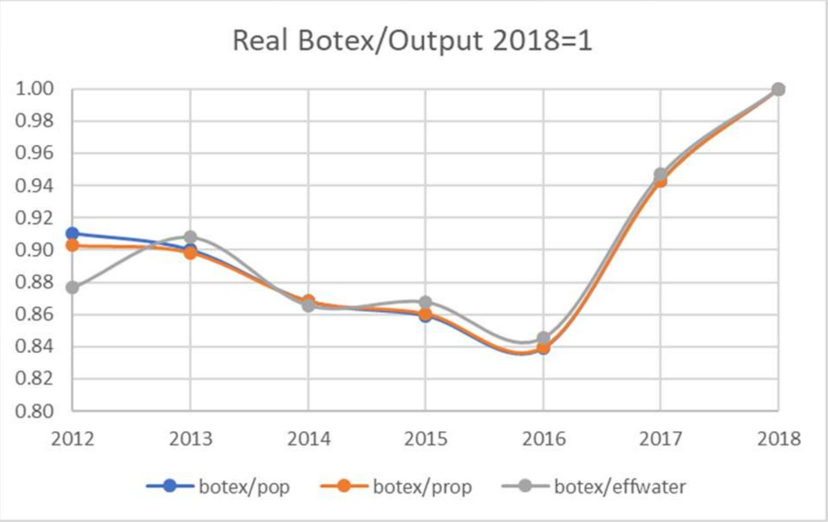
3. Reported Models, Including Ofwat's Models, are estimated with a definition of cost consistent with Ofwat's Botex definition in its January 2019 Initial Assessment of Plans and not the expanded cost definition it used in July 2019 Draft Determinations

We have demonstrated elsewhere that there are Important Implications with Regard to the Appropriateness of Ofwat’s backward looking cost assessment and its forward looking assessment of company business plans, given that it simply ignores these differences across time in its cost assessment

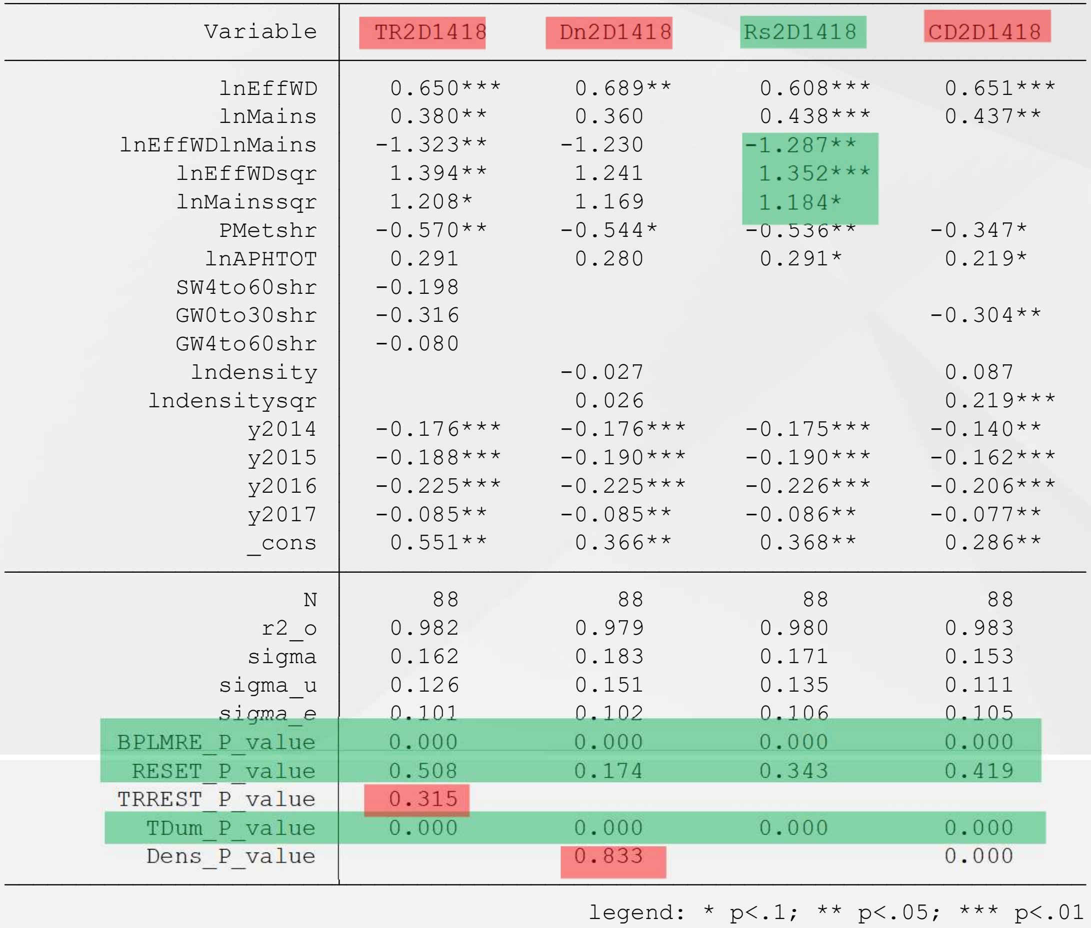
Aggregate Wholesale Water Botex and Selected Output Measures

year	real 2018 botex (000,000)	Pop. Served (000)	Prop. Served (000)	Eff. Water Delivered (Ml/day?)
2012	3,054.3	55,798.8	24,845.2	11,257.4
2013	3,060.8	56,555.9	25,023.7	10,894.1
2014	2,974.9	56,991.8	25,162.2	11,103.8
2015	2,975.2	57,590.6	25,391.6	11,079.2
2016	2,926.2	57,990.2	25,586.2	11,179.7
2017	3,306.1	58,297.1	25,750.2	11,279.2
2018	3,537.2	58,822.3	25,979.9	11,429.2





Effective Water 2014-2018 Translog Restriction Tests



Variable	TR2D1418	Dn2D1418	Rs2D1418	CD2D1418
lnEffWD	0.650***	0.689**	0.608***	0.651***
lnMains	0.380**	0.360	0.438***	0.437**
lnEffWDlnMains	-1.323**	-1.230	-1.287**	
lnEffWDsqr	1.394**	1.241	1.352***	
lnMainssqr	1.208*	1.169	1.184*	
PMetshr	-0.570**	-0.544*	-0.536**	-0.347*
lnAPHTOT	0.291	0.280	0.291*	0.219*
SW4to60shr	-0.198			
GW0to30shr	-0.316			-0.304**
GW4to60shr	-0.080			
lndensity		-0.027		0.087
lndensitysqr		0.026		0.219***
y2014	-0.176***	-0.176***	-0.175***	-0.140**
y2015	-0.188***	-0.190***	-0.190***	-0.162***
y2016	-0.225***	-0.225***	-0.226***	-0.206***
y2017	-0.085**	-0.085**	-0.086**	-0.077**
_cons	0.551**	0.366**	0.368**	0.286**
N	88	88	88	88
r2_o	0.982	0.979	0.980	0.983
sigma	0.162	0.183	0.171	0.153
sigma_u	0.126	0.151	0.135	0.111
sigma_e	0.101	0.102	0.106	0.105
BPLMRE_P_value	0.000	0.000	0.000	0.000
RESET_P_value	0.508	0.174	0.343	0.419
TRREST_P_value	0.315			
TDum_P_value	0.000	0.000	0.000	0.000
Dens_P_value		0.833		0.000

legend: * p<.1; ** p<.05; *** p<.01

Cobb Douglas Model (CD2D1418) demonstrates a feasible noninteractive modelling approach to Ofwat's modelling which allows for statistically significant water scarcity, demand management, density, and pumping controls

Supports engineering and operational understanding that low treatment groundwater has lower costs, ceteris paribus than other types of water

- **Translog Model (RS2D1418)**

Demonstrates a parsimonious alternative to Ofwat's density specification, which demonstrates the relevance of cost interactions between water production and distribution activities

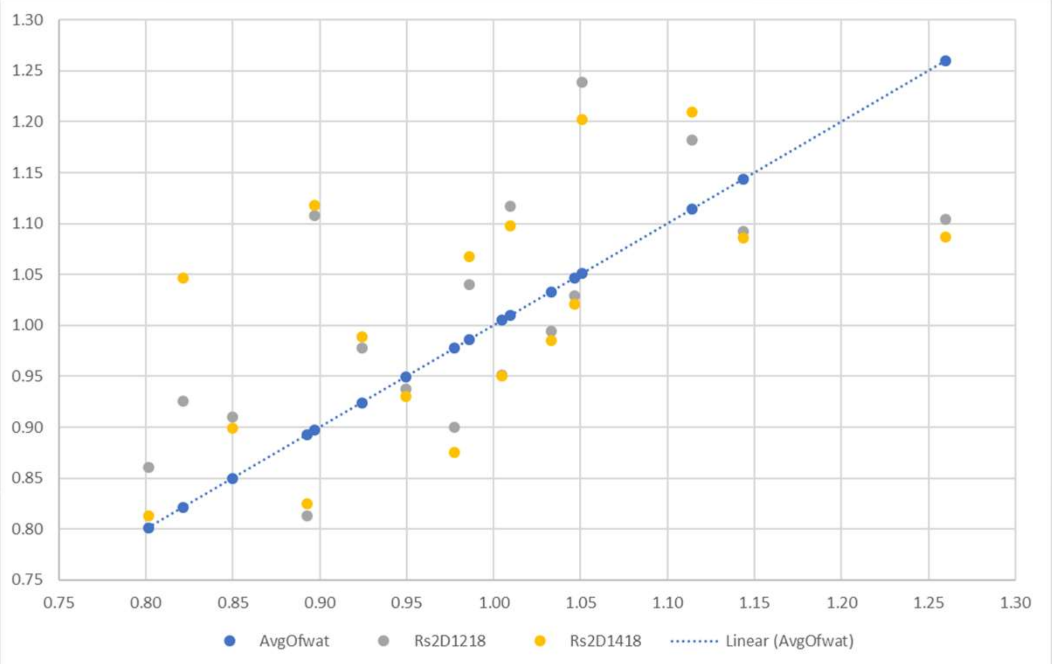
Suggests that once cost interactions between water production and distribution activities are allowed, water type and treatment controls are no longer required – e.g they are controlled for by the models allowed cost interactions

Comparison of 2012-2018 and 2014-18 Preferred Regressions demonstrates that estimation is robust in both databases and interaction parameters are jointly significant as required in translog modelling

```
-----------------------------------------------------
          Variable |   Rs2D1218        Rs2D1418      
-------------------+---------------------------------
           lnEffWD |    0.589***        0.608***     
           lnMains |    0.446***        0.438***     
   lnEffWDlnMains |   -1.013*         -1.287**      
       lnEffWDsqr |    1.203***        1.352***     
       lnMainssqr |    0.793           1.184*       
           PMetshr |   -0.541***       -0.536**      
          lnAPHTOT |    0.322***        0.291*       
             y2012 |   -0.176***                     
             y2013 |   -0.117**                      
             y2014 |   -0.170***       -0.175***     
             y2015 |   -0.186***       -0.190***     
             y2016 |   -0.222***       -0.226***     
             y2017 |   -0.085**        -0.086**      
             _cons |    0.371***        0.368**      
-------------------+---------------------------------
                 N |      124              88        
              r2_o |    0.978           0.980        
             sigma |    0.179           0.171        
           sigma_u |    0.133           0.135        
           sigma_e |    0.120           0.106        
   BPLMRE_P_value |    0.000           0.000        
    RESET_P_value |    0.494           0.343        
     TDum_P_value |    0.000           0.000        
-----------------------------------------------------
           legend: * p<.1; ** p<.05; *** p<.01
```

Use of a parsimonious multiple output model allowing for cost interactions and specified with effective water as an incentive compatible output controlling for water scarcity, as well as metering and pumping head controls, **yields a model that should be considered robust for regulatory application, when compared to Ofwat's own models.**

These Alternative Models Also Suggest Substantially Different Estimates of 2014-18 Costs Relative to Ofwat's Models



	2014-2018 Actual/Pred. Cost			Dif. from Ofwat	
	Avg. of Ofwat M1 & M2	Rs2D1218	Rs2D1418	Rs2D1218	Rs2D1418
AFW	1.01	1.12	1.10	0.11	0.09
ANH	0.98	0.90	0.88	-0.08	-0.10
BRL	1.11	1.18	1.21	0.07	0.10
DVW	0.82	0.93	1.05	0.10	0.22
NES	0.95	0.94	0.93	-0.01	-0.02
NWT	1.05	1.24	1.20	0.19	0.15
PRT	0.80	0.86	0.81	0.06	0.01
SES	1.14	1.09	1.09	-0.05	-0.06
SEW	0.92	0.98	0.99	0.05	0.06
SRN	0.90	1.11	1.12	0.21	0.22
SSC	0.89	0.81	0.82	-0.08	-0.07
SVT	1.05	1.03	1.02	-0.02	-0.03
SWB	1.00	0.95	0.95	-0.05	-0.05
TMS	1.03	0.99	0.99	-0.04	-0.05
WSH	1.26	1.10	1.09	-0.16	-0.17
WSX	0.99	1.04	1.07	0.05	0.08
YKY	0.85	0.91	0.90	0.06	0.05
Min	0.80	0.81	0.81	-0.16	-0.17
Avg.	0.99	1.01	1.01	0.02	0.03
Median	0.99	0.99	1.02	0.05	0.01
Max	1.26	1.24	1.21	0.21	0.22
Range	0.46	0.43	0.40		
Correlations					
With Ofwat Model		0.66	0.57		
Between Models			0.95		

Conclusions on Ofwat's PR2019 Modelling Approach

- Ofwat's Integrated and Disaggregated Modelling Ignore Cost Interactions Between Upstream and Downstream Activities which are fundamental to understanding water system costs
- Ofwat's integrated (as well as its distribution only) models employ a specification that can be demonstrated to impose cost relationships that are not consistent with managerial, economic, and engineering understanding of cost relationships in the water industry.
- Ofwat's reliance on a limited number of models complying with its rigid modelling approach implies that it does not provide a set of "uniquely appropriate" regulatory cost assessment models for PR2019.
- This failure to appropriately "triangulate" its modelling suggests that Ofwat should urgently reconsider the robustness of its cost assessment modelling before its Final Determinations due on Dec 16th, and should develop more appropriate modelling for PR2024.

Conclusions on the Multiple Output Modelling Approach

- It is more than feasible to develop suitably parsimonious and robust regulatory cost assessment models while also respecting the academic literature, which supports the modelling of network infrastructure industry costs with multiple output cost models that allow for cost interactions between outputs.
- We have also demonstrated how defining an incentive compatible measure of "effective water demand" and allowing for water demand management provides a model where water, and managerial response to relative water scarcity are fundamental to water cost modelling.
- We have also demonstrated that the definition, appropriateness and statistical significance of control variables such as population density, pumping controls , water source type and treatment levels are dependent on the underlying model specification, thereby further reinforcing that Ofwat's rigid modelling approach does not provide "uniquely appropriate" regulatory cost assessment models.