Indepen

Volterra

Risk, regulation and behavioural modelling of water company performance

Anglian Water, Severn Trent Water and Wessex Water

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Indepen Limited 50 Broadway, Westminster, London SW1H 0RG
T +44 (0)20 3283 8991 E info@indepen.uk.com
www.indepen.uk.com

Table of Contents

Summary 1

1 - Background 3

Behavioural modelling 3

Agent based modelling 3

This project 3

Report 4

2 - Main elements of the model 4

3 - Results of the simulations 6

4 – Conclusions 7

5 - Areas for further consideration 8

Appendix – Model specification and results 1

Summary

This project

Indepen and Volterra have worked together on this project, funded by three water and sewerage companies, Anglian, Severn Trent and Wessex. Representatives of the companies formed a steering group for the work of which a director of Ofwat was also a member. The project uses a technique known as 'Agent Based Modelling' to explore the feasibility of using behavioural modelling to inform the design of water regulation.

The project ended with a seminar involving the sponsors and a number of Ofwat staff members. The seminar discussed the model and ideas for how it might inform the development of the regulatory regime.

Why it is relevant

The framework within which regulation happens is of paramount importance and, for both regulators and firms, understanding the possible ramifications of different approaches will be valuable.

In practice, companies and customers may have constraints and motivations that are not altogether in line with the assumptions of standard economics, to which regulators and companies tend to have regard. The way in which a regulatory decision on outcomes or incentives plays out will interact with these constraints and motivations. The purpose of the model it see whether it can help to develop a shared understanding of the possibilities that will inform the thinking of both sides.

The Budget announcement of support to certain groups of water customers in the South West demonstrates the diversity of the circumstances in which the different water companies operate, as do the contrasting levels of rainfall in the east and west of the country. The companies involved in providing water services differ substantially in their scale and scope and also in terms of their financial structures as well as in other dimensions. These and other differences may be more pronounced in future. The localism agenda and Ofwat's proposed changes to regulation both admit of more diverse and tailored company and regulatory approaches and outcomes. Given these developments, the potential benefits of this sort of modelling are likely to increase.

What the model does

Agent based modelling uses a set of relationships to map out how decision makers and their behaviour interacts to achieve certain outcomes.

Our model has as 'agents' the regulator, water companies and customers. There are different company types defined by their attitudes to risk and quality. The regulator sets the output target for each company. In this paper, we have characterised the output as quality improvement but it the target could relate to any other output or to several. The different company types will make different decisions on how much they spend to try to meet this. Given spending decisions and consequent quality improvements, the regulator assigns a penalty or reward for each company. Customer utility is dependent upon the quality that the supply company achieves and the price. Companies' profits are determined

by their revenue (a function of price) and their costs (a function of capex, opex, maintenance spend and any reward or penalty).

A key feature of the model is the inclusion of uncertainty. We have said that the quality improvement delivered by a given amount of capex is uncertain and we have modelled the starting points of the individual companies, in terms of initial quality level and relative efficiency, are drawn randomly from a fixed range. Simulation works by running the model many times with the random elements varying. Running the model enough times results in a frequency distribution of outcomes. This is a standard approach to assessing the results of modelling the random factors and rules of behaviour.

Conclusions and areas for further consideration

The report represents work-in-progress but the results so far suggest we can simplify the regulatory relationships and structures in a way that advances our understanding.

We believe that the process of developing and working with the model has provided insights into how the regulatory regime works in water. Two examples are as follows.

- Feasible differences in company and customer preferences and behaviour, combined with a one size fits all approach to regulation can potentially discourage positive outcomes, an example of an unintended consequence.
- Variables such as customer priorities, uncertainty around capex spending and quality outcomes, and the relative scale of financial rewards and penalties are important in affecting outcomes. This is not new. The insight is to know in more quantified terms the size of these effects and the significance of the definition and scale of the variables.

Under areas for further consideration, we have looked at how we might refine the model. We received valuable input on this from a seminar at Ofwat on July 12th, when we presented and debated a summary of the approach and the model.

The possibilities include changes in the assumptions and relationships within the existing model and more fundamental changes to the structure of the model. Inevitably, some of these will make the model more complex and in deciding which to adopt we will have regard to the trade off between complexity and realism on the one hand and simplicity and our ability to understand the results on the other. We have also considered how the model might be used.

1 - Background

The aim of this project was to explore the use of behavioural modelling in the context of the regulated water industry. It sought to establish the feasibility of using an approach known as agent based modelling (ABM) to simulate the effect of regulatory incentives on the performance of water companies that display different types of behaviour.

Behavioural modelling

Behavioural modelling seeks to simulate the outputs from a system of rules and relationships between agents with a view to use the model to predict the effects of changes in the rules and relationships. In the context of this model, these would include the effect on company performance of changes in the drivers of company behaviour or in the incentives established by the regulator. The reason why such an approach might be of value is that even simple relationships between a small number of agents can generate complex outcomes and the effects of such a system of relationships cannot be easily understood by conventional analysis.

Agent based modelling

We have used the technique known as agent based modelling, which is a form of behavioural modelling that includes

- Defined agents
- Decision rules and interactions between agents based on characterisations of behaviour
- A representation of key factors that are outside the model
- Specification of aspects of uncertainty in the relationships

The challenge is to simplify the situation sufficiently to analyse it and at the same time for the definitions and assumptions to be recognisably related to the real world.

This project

Indepen and Volterra have led this project with funding from three water and sewerage companies, Anglian, Severn Trent and Wessex. Representatives of the companies formed a steering group for the work of which a director of Ofwat was also a member.

The purpose was to explore the feasibility of behavioural modelling in the context of water regulation. Given that the modelling technique is a simulation, the test will be a judgment as to how well the model represents reality. Subject to feasibility, it would then be possible to consider how to use the model to inform questions such as the following.

- How big is the effect of variation in company behaviour on customer utility?
- What is the effect of regulator decisions on company profitability?
- What is the effect of regulator rules and changes therein on customer utility?

Report

This report summarises the project and its results under the following headings.

- Section 2 - description of the model
- Section 3 - the results of the simulations
- Section 4 - interpretation and possible applications
- Section 5 – areas for consideration and analysis

The appendix contains more on the model's specification and illustrative results.

2 - Main elements of the model

The elements of the model we have developed are set out in Table 1. A description of the model and the relationships is in the Appendix.

The results are from the simulation of a range of cases with sampling from the frequency distributions that represent the uncertain nature of some of the relationships. In some areas, the model allows for uncertainty or draws inputs randomly from a frequency distribution. For example, the initial output (quality of service) that each company has is drawn at random, the quality improvement achieved for a given amount of capex is subject to uncertainty, and the extent of a company's type of behaviour varies – for example, they could be very risk averse or only slightly risk averse. This generates a frequency distribution of the outcomes.

The focus of the model is the effect on customer utility of different sorts of company behaviour, given the rules established by the regulator. The change in customers' utility is a function of two variables: the change in quality of service over the price review period; and the change in the water bill that customers pay. The quality change depends on a company's decision on how much capital expenditure (capex) it should incur to improve the quality of the service. The price change depends on the extent to which the regulator decides to pass on the cost of any "discretionary" capex to customers.

With respect to the latter, we have looked at various cases. For simplicity of presentation in this report, and given the purpose of the project, the results we present reflect one case on price, namely that in which the regulator applies an efficiency deduction of 30% to any additional capex[1], passing on 70% to customers in the form of higher prices.

[1] 30% is based on the central value of the incentive under the CIS at PR09.

Table 1 – elements of the agent based model

Elements		***Adopted in the model***
Scope	Water supply service for one price review period for 12 companies, each with 100 customers	
Agents	12 companies, each with 100 customers, one regulator	The numbers do not affect the results of the modelling
Outputs	The outputs of the model are • Water charges • An index reflecting the quality of water services • The change in customer utility • Company profits	We have assumed • diminishing marginal returns to increased capex • that the companies are uncertain about the amount of quality improvement that they will gain from a given amount of capital expenditure
Types of customer	The model assesses the change in customers' utility between the position at the beginning of the first period and the position at the beginning of the second period.	The change in customer utility is a function of the change in quality (+) and in price (-). There are three types of customer. • Price focused • Equally interested in price and quality • Quality focused
Regulatory decisions and Incentives	The regulator determines • the allowed revenue and opex for each company • a quality improvement target (QIT) for each company • financial penalty for those not meeting the QIT • financial reward for those exceeding the QIT • the cost of capital for the sector	The QIT is related to the initial quality ranking of the companies (random). The financial penalty (reward) is related to the quality shortfall (excess) relative to the QIT.
Types of company behaviour	A company's behaviour depends on its approach to quality and its risk appetite ***Quality*** • Quality satisficers – try to meet the QIT • Quality emphasisers – try to exceed the QIT ***Risk*** • Risk neutral - spend just the capex they think is required, based on an assumed relationship • Risk averse - spend additional capex to reduce the likelihood that they will fail to meet the QIT	This means there are four types of company • Risk neutral emphasisers • Risk averse emphasisers • Risk neutral satisficers • Risk averse satisficers Taken together the type of company and its initial quality level drive decisions on the amount of capex.

For the ABM technique to be effective, as with any modelling approach, it is necessary to simplify. In developing the model, we considered a number of variations but decided to park them for the time being. Salient among these were the following.

- Services and outcomes
  - The model relates to a single generalised service with one price cap. We have referred to it as a water model but it would apply equally to wastewater or any other service.
  - We have used a single measure of company output, which takes the form of a composite quality index. Similarly, we have used a single capex number rather than explicitly including different aspects of quality and types of capex.
  - We have provided for a random distribution of initial endowments (initial service quality, maintenance cost, relative efficiency) and behavioural characteristics among the companies. We have not modelled variations in companies' circumstances, such as geographical, demographic hydrological factors.
- Company behaviour
  - The company decision is about how much capex to incur to achieve quality improvement: we have not modelled capex aimed at improving efficiency.
  - We have considered the effect on company behaviour of two drivers - attitude to quality and appetite for risk. We have treated these as independent and exogenously determined. We did not explore any linkage between financial structure and risk appetite.
- Customer utility
  - We have used a linear utility function, whereas company research suggests the presence of non-linearity in some cases or for some customers. This is discussed below and is an area for further exploration.
- Incentives
  - The incentive element of the model is around capex and quality. We have not considered other incentives, such as those relating to the SIM or to leakage.
  - At this stage, we have not incorporated any element of comparative competition, where the outcome for any company depends, in part, on what the others do.
  - There are multi-period aspects to water regulation including retrospective incentives. The model relates to one five-year control period, assuming that decisions by the regulator and the companies are taken at the beginning of the period with the results materialising at the end of the period, or more strictly in the case of the bill increase at the beginning of the next period. This form of analysis means the model can be extended to cover more than one period.

3 - Results of the simulations

In this stage, we were seeking to test the feasibility of the modelling approach and to consider ways in which to apply it. We validated the assumptions underlying the model in discussion with the steering group and in building the model, adjusted the definitions and assumptions.

The most accessible form for the results consists of frequency distributions of the various modelled outcomes, namely company profits, rewards and penalties, and customer utility. These are illustrated in the Appendix.

In summary, the findings are as follows.

- Satisficers get higher penalties, as do risk neutral companies.
- Emphasisers on average get rewards for over-achieving on quality, more so if they are risk averse.
- Occasionally, satisficers can get rewards and emphasisers can get penalties.
- Penalties and rewards are low as a proportion of overall company costs.
- Despite the higher penalties, satisficers typically make significantly bigger profits than do emphasisers.
- The penalties and rewards as currently modelled do not incentivise companies to spend more than required on improving quality.
- Price sensitive customers are better off with satisficing and risk neutral companies, who spend less on capex and therefore the price they charge increases less.
- Quality sensitive customers are better off with emphasisers than satisficers, and slightly better off with risk averse rather than with risk neutral companies, because they spend more to achieve quality improvements.
- Equal interest customers are better off with satisficing companies. The adverse effect of price increases incurred by customers of emphasising companies outweighs the beneficial effect of quality improvements. This is due to the relative scales of prices and quality in the model.

4 – Conclusions

The report represents work-in-progress but the results so far suggest we can simplify the regulatory relationships and structures to build a model that advances our understanding.

Price sensitive customers are better off with companies that spend less and deliver less (risk-neutral satisficers) and quality sensitive customers are better off with companies than spend more and deliver more (risk-averse emphasisers). Under current assumptions, "equal interest" customers align with "price sensitive" customers and are better off with companies that spend less and deliver less.

Customer research suggests that customers are more concerned about price, with quality being a secondary consideration, so that in our representation most customers will be "price sensitive" or possibly "equal interest". Given that customers have no choice of who supplies them, this suggests that to serve customers interests, the regulator should provide incentives that reward risk-neutral satisficers. This is in the context of a scenario under which a proportion of additional capex is reflected in price limits.

In a scenario where the regulator does not acknowledge increased capex in the form of increase bills, it would seem to be in customers' interests for the regulator to encourage risk-averse emphasisers as they will deliver the highest quality and there would be no increase in price. If the regulator, however, did not allow discretionary capex in price limits, any under-spend would result over time in lower prices for the customers of risk-neutral satisficers who would still be better off than the customers of the risk-averse emphasisers.

The type of customer matters and targeting behaviour that improves utility will be beneficial. The model results suggest that while, other things being equal, company behaviour that prioritises quality improvements has a positive effect on customer utility, utility is nonetheless maximised by companies that spend less and deliver less. This is consistent with a regime that encourages companies to be risk-averse by making the penalties stronger than the rewards. In such a world, a regulator might seek to encourage risk neutral behaviour by altering the balance of rewards and penalties.

We believe that the process of developing and working with the model has provided improved insights into how the regulatory regime works in water. Two examples are as follows.

- Feasible differences in company and customer preferences and behaviour, combined with a one size fits all approach to regulation can potentially discourage positive outcomes, an example of an unintended consequence.
- Variables such as customer priorities, uncertainty around capex spending and quality outcomes, and the relative scale of financial rewards and penalties are important in affecting outcomes. This is not new. The insight is to know in more quantified terms the size of these effects and the significance of the definition and scale of the variables.

5 - Areas for further consideration

We have considered how we might refine the model and how it might be used. We received valuable input on these topics from a seminar at Ofwat on July 12th, when we presented and debated a summary of the approach and the model.

The following is a summary of the possibilities, including

- changes in the assumptions and relationships
- more fundamental changes to the structure of the model
- possible uses of the model.

Inevitable, some of these ideas will make the model more complex and in deciding which to adopt we will have regard to the trade off between complexity and realism on the one hand and simplicity and our ability to understand the results on the other.

Assumptions
Variants on the assumptions include the following.

- **Different form of utility function**. The linear utility function may oversimplify the position. Results from customer research suggest that the form of the utility function might depend on the following.

  – Service levels. When service is good, customers may be in price-sensitive mode and would be happier with companies that spend less and deliver less, but if service is at risk, customers become more quality-sensitive and benefit if their supplier were a risk-averse emphasiser.

  - Customer experience. A variant on the above might apply to customers who have experienced service failures or live in areas that are prone to such failures.
  - The nature of the service. Customers may have different utility functions for different aspects of the service they receive. Customer research suggests, unsurprisingly, that customers are particularly sensitive to the prospect of disruption of their supply of drinking water, where some conclude that the prospect of a reduction in water quality might be unacceptable at any feasible price.

  This might suggest non-linear utility functions generally, possibly with different parameters for different customer segments or different services.

- **Include an efficiency target set by the regulator.** This would allow specific modelling of company efficiency and a form of efficiency incentive. It would entail companies having another purpose for incurring capex. In the present model, we could analyse this issue by treating efficiency or productivity as the output. This would require us to define a measure of efficiency and to re-consider the nature of the existing quality incentive mechanism.

- **Include the level of opex or totex as a company decision.**

- **More complex outcome specification.** As noted above, we have characterised the outcome of regulation as the quality improvement. It might be helpful to include a more complex output specification.

Structure

The most obvious structural change would be to extend the model to include more than one period. As noted above the regulatory regime has multi-period effects and reflecting these is not possible in a single period model.

Nor is it possible in a single period model to reflect changes that might occur in the behaviour of the companies and this suggests a second significant change, namely to model company behaviour as an endogenous factor that can change from period to period. At present, the structure of the model has companies making decisions, dependent on their type. It might be possible to adopt a different approach, which would introduce learning by the companies. We could then be able to allow more specifically for the efficiency incentive inherent in the price cap.

Such an approach would require us to introduce an explicit company objective. This could be profit maximization or something to do with quality improvement, or more realistically both. As discussed in the steering group and at the Ofwat seminar, there is considerable interest in the issue of whether and if so how, companies make trade offs between short-term profit and reputation and whether reputation is some sort of indicator of future profits.

Uses of the model

The model as currently specified can be used in two main ways.

- Sensitivity analysis. We can explore the sensitivity of the outcome, in terms of customer utility, to variations in any of the assumptions and parameters in the relationships. Some obvious items to begin with would be to look at the effect on the outcome of
  - the strength and form (symmetry or functional form) of the quality incentive
  - the form and parameters of the utility function
  - the extent of uncertainty around the quality: capex relationship.
- Reverse engineering. The model can identify the extent of any change in a "policy" variable that is needed to generate a change in the outcome, for example how strong does the quality incentive need to be to change the preferred company type for a customer with a mixed utility function?

There are numerous possibilities under each of these headings.

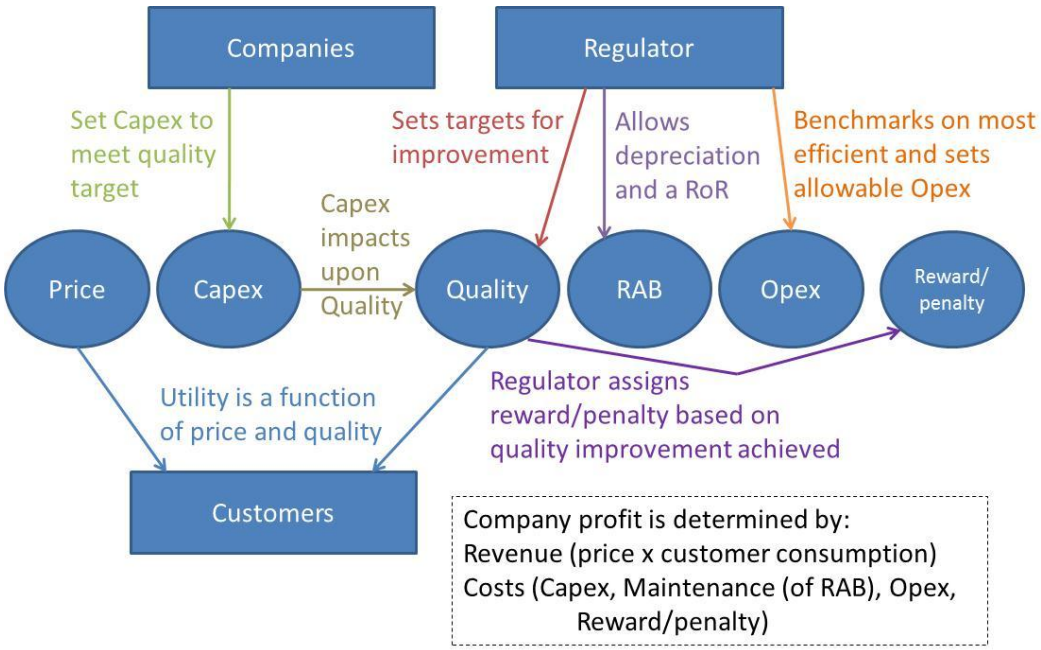
Appendix – Model specification and results

This appendix describes the specification of each of the main elements of the model. It is derived from a working document used for discussion at meetings of the steering group and we have not sought to edit the presentation.

Model specification

Overview

The diagram shows the elements of the model.



The regulator sets quality improvement targets for each individual company, based upon their initial quality ranking relative to other companies. These targets determine the relative amounts of capex that each company decides to spend. There are different company types, which determine how much capex they actually spend to meet their quality objectives.

The regulator allows depreciation and a rate of return on RAB and it allows a proportion of the desired opex for each company. Capex spending results in a level of quality improvement, which is subject to some uncertainty. The regulator assigns a penalty or a reward to each company, dependent upon whether it has achieved its quality target or not. Customers' utilities are dependent upon the quality that their supply company achieves and the resulting price. Companies' profits are determined by their revenue (a function of price) and their costs (a function of capex, opex, maintenance spend and any reward/penalty).

Quality

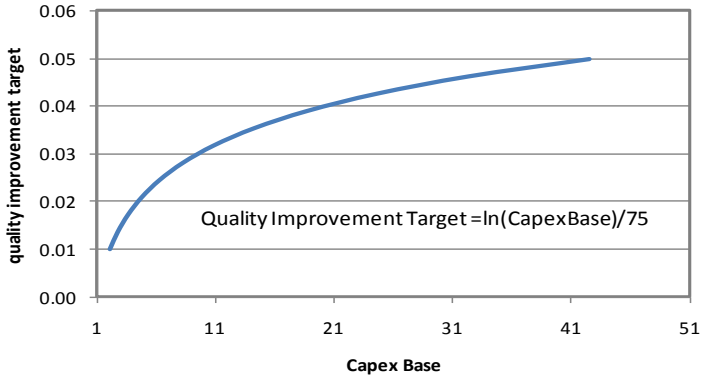
Initial quality for companies is randomly drawn from a range and the regulator sets the QIT between 1% and 5% based on the initial quality rankings of the companies.

Capex

The actual Capex spent by each company depends on company type:

- Company types 1 & 2 are *Emphasisers* – they try to exceed the quality improvement target set by the regulator. This is the Emphasis factor.
- Company types 3 & 4 are *Satisficers* – they just try to meet the quality improvement target set by the regulator.
- Company types 1 & 3 are *risk neutral*, 2 & 4 are *risk averse*.
- *Risk Neutral* companies just spend the amount of Capex required to hit their quality improvement target, based on the assumed relationship between Quality Improvement and Capex.
- *Risk Averse* companies spend extra Capex to try to increase the chances of achieving their quality target. This is the Risk Aversion factor.

There is a diminishing returns relationship between quality and capex.



Opex and maintenance

The regulator allows each company a certain proportion of the Opex it requests. The model allocates, for each company, an Opex Multiplier, which is drawn uniformly from (-5% to +5%).

Quality

The actual quality achieved by each company reflects the uncertainty around the quality~capex relationship. The model uses a multiplicative error factor to represent this.

Penalties and rewards

Companies that do not achieve the quality target set by the regulator get a financial penalty – this is a proportion of Capex determined by how far off they are. If they are 5% below their quality target, they get a penalty of 5% of Capex.

- Companies who exceed the quality target set by the regulator get a financial reward, but this is smaller than the potential penalty.

Price

A simple financial model of the building block approach to setting underlies the approach.

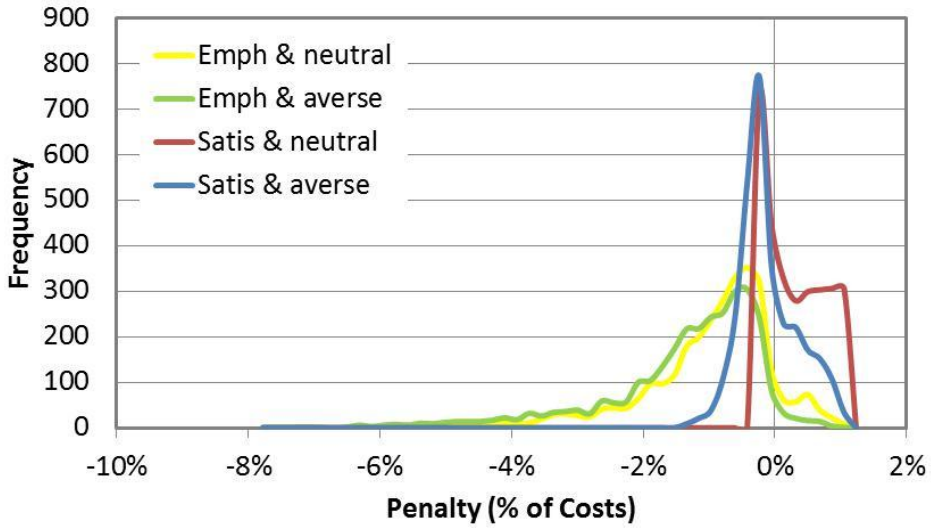
In a strictly one period model the company's decision on capex has no effect on price in that period. This would be overly simple and we have assumed instead that 70% of capex variation is passed on to customers in the form of price increases.

Customer utility

Customer utility is based on the quality and price offered by the supply company. We define three types of customer – quality focused, price focused and equal interest.

Model results

Penalties and rewards



Note: in this graph, a negative penalty is a reward.

Findings

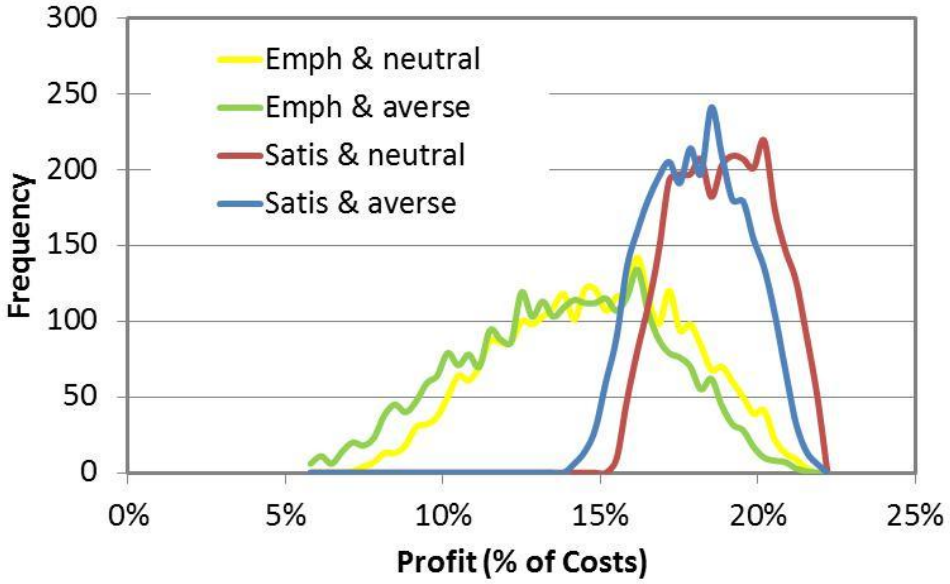
- Satisficers get higher penalties, as do risk neutral companies
- Emphasisers get rewards on average, more so if risk averse
- Satisficers can get rewards and Emphasisers can occasionally get penalties
- Penalties and rewards are however low as a proportion of overall company costs (on average 0-1%)

Penalty (as % of costs)

Company type	Emph & Neutral	Emph & Averse	Satis & Neutral	Satis & Averse
Minimum	-6.0%	-7.8%	-0.2%	-1.3%
1st Quartile	-1.3%	-1.7%	-0.0%	-0.3%
Mean	-0.9%	-1.3%	0.4%	0.0%
3rd Quartile	-0.3%	-0.4%	0.8%	0.3%
Maximum	1.2%	1.1%	1.2%	1.2%

Profits

Despite the higher penalties, Satisficers on average make significantly better profits than Emphasisers. The difference between risk averse and risk neutral companies is statistically significant but much smaller.



Emphasisers make profits of 14-15% in comparison to Satisficers making profits of 18-19%. The scale of these effects is a function of the assumptions within the model, although the relative sizes are interesting. Emphasisers can occasionally make large profits however, and the maximum profits which can be achieved by different company types are similar.

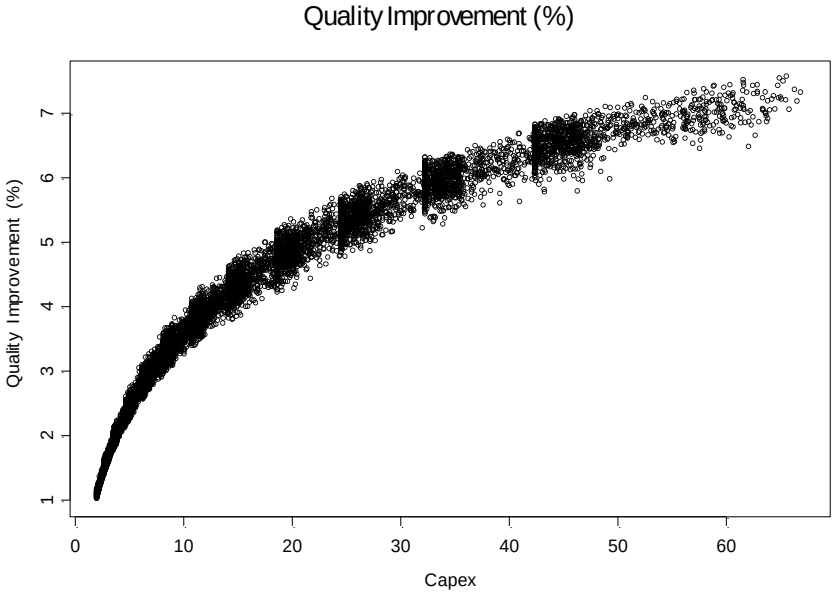
The penalties and rewards as currently modelled do not incentivise companies to spend more than required on improving quality.

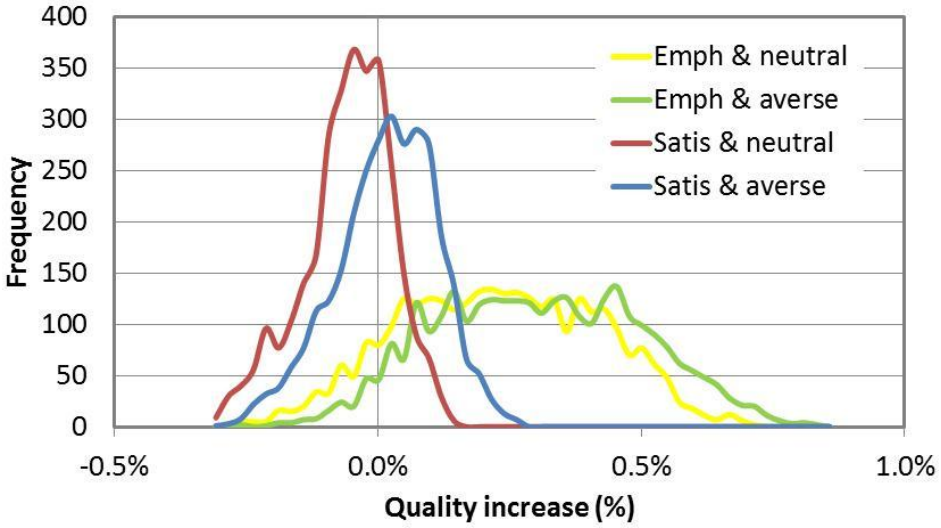
Profit (% of costs)

Company type	Emph & Neutral	Emph & Averse	Satis & Neutral	Satis & Averse
Min	7.5%	5.8%	15.6%	14.2%
1st Q	12.8%	11.7%	17.8%	17.0%
Mean	15.0%	14.0%	19.0%	18.2%
3rd Q	17.2%	16.4%	20.3%	19.4%
Max	21.7%	21.8%	22.2%	22.2%

Capex and quality

Emphasisers and Risk Averse companies spend more on Capex and achieve higher quality improvements. In the model, Emphasisers spend over 20% more on Capex. Risk averse companies spend on average 5% more. This is in comparison to rewards for exceeding targets of only around 1%.

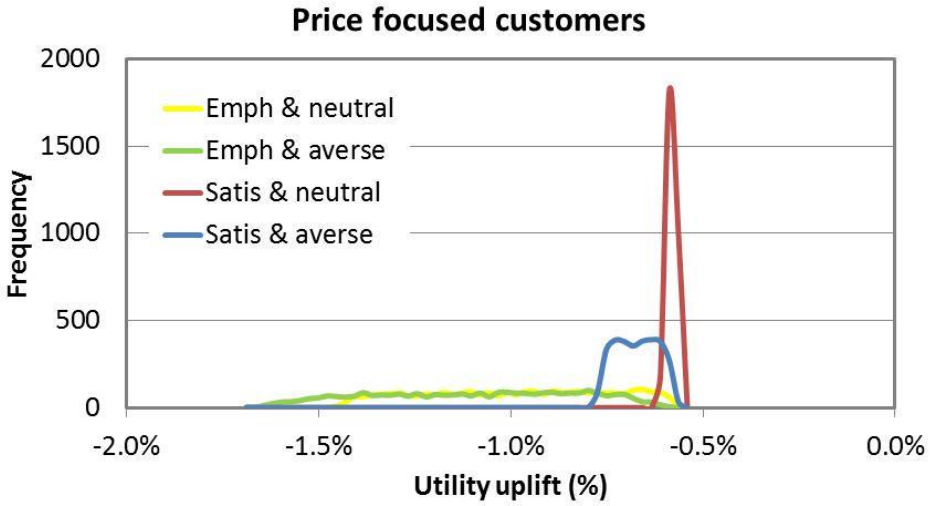




Utility

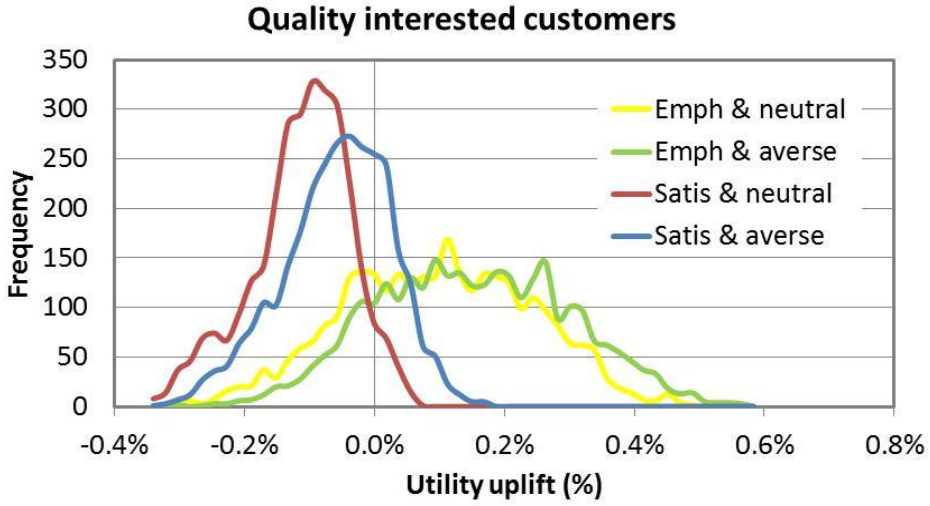
Price focused customers

- Price sensitive customers are better off with satisficing and risk neutral companies, who spend less on capex and therefore the price they charge increases less
- The price increase can be significantly higher with emphasising companies than with satisficing companies



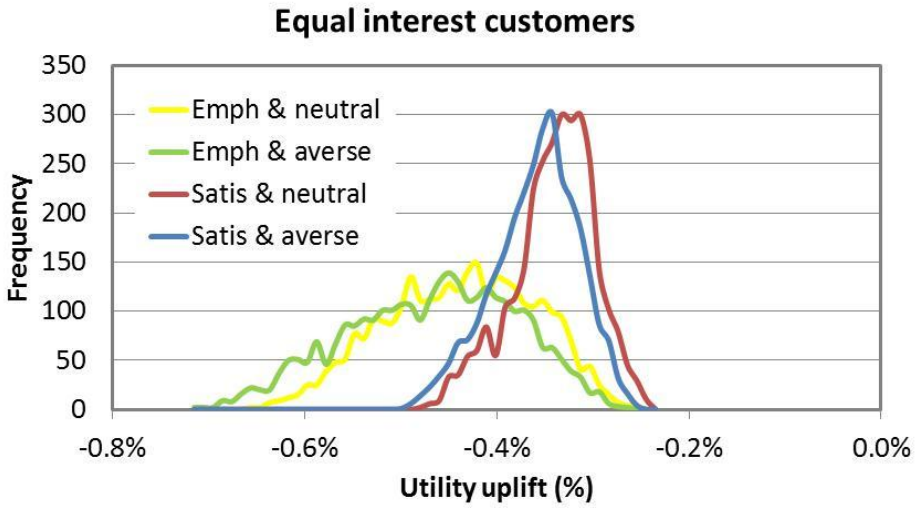
Quality focused customers

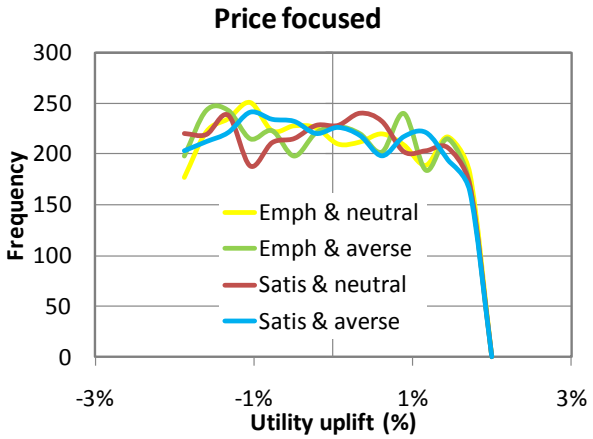
- Quality sensitive customers are considerably better off with emphasisers than satisficers, and slightly better off with risk averse rather than risk neutral companies, because they all spend more to achieve quality improvements

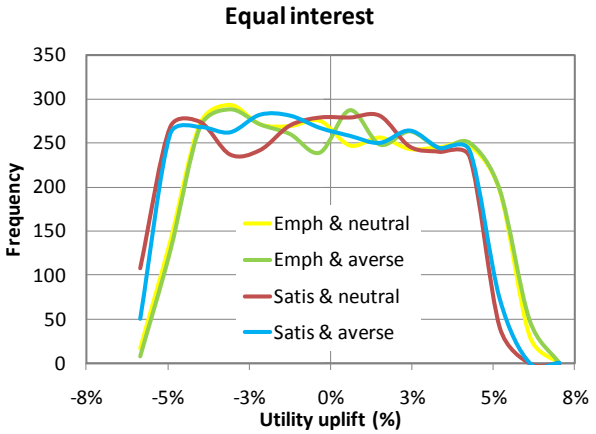


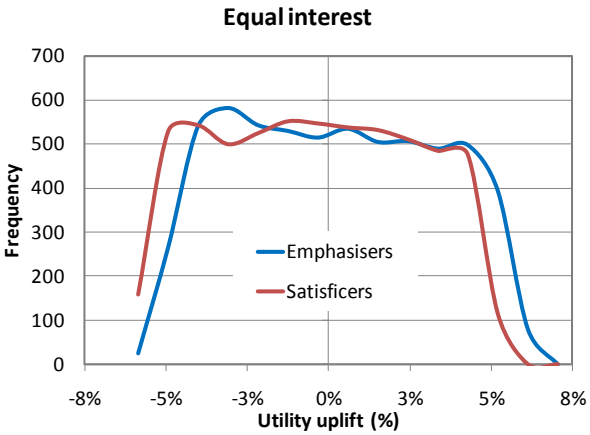
Equal interest customers

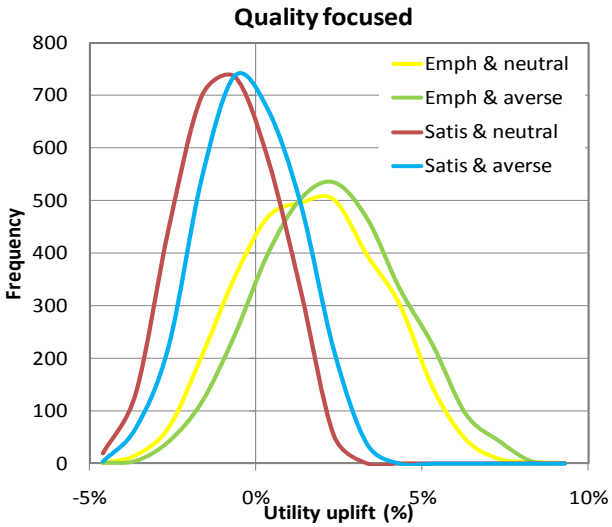
- In our scenario, equal interest customers are better off with satisficing companies. The adverse effect of price increases incurred by customers of emphasising companies outweighs the beneficial effect of quality improvements. This is due to the relative scales of prices and quality in the model.




Price focused
300
250
200
150
100
50
0
Frequency
Emph & neutral
Emph & averse
Satis & neutral
Satis & averse
-3%
-1%
1%
3%
Utility uplift (%)


Equal interest
350
300
250
200
150
100
50
0
Frequency
Emph & neutral
Emph & averse
Satis & neutral
Satis & averse
-8%
-5%
-3%
0%
3%
5%
8%
Utility uplift (%)


Equal interest
700
600
500
400
300
200
100
0
Frequency
Emphasisers
Satisficers
-8%
-5%
-3%
0%
3%
5%
8%
Utility uplift (%)


Quality focused
800
700
600
500
400
300
200
100
0
Frequency
Emph & neutral
Emph & averse
Satis & neutral
Satis & averse
-5%
0%
5%
10%
Utility uplift (%)