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DECISION SUPPORT SYSTEM FOR WATER ADAPTING PRICING POLICY

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In the paper, the conception of Enterprise Information Portal (EIP) as an end-user interface of Simulation and Modeling System for Business (SMS-B) is presented. The system is a proposition of Business Intelligence education platform. EIP portals are also a base for Enterprise Integration Platform (EIP II) introduction in information and communication system in an institution.

Keywords: dynamic pricing system, water prices, efficiency of water consumption, demand management

1. Introduction

Nowadays, Integrated Support System for Efficient Water Usage and resources management (ISS-EWATUS) [1] is the outcome of the international research project entitled “Integrated Support System for Efficient Water Usage and resources management.” The ISS-EWATUS consist of four subsystems:

1. decision support system (DSS) for the efficient water usage at households,
2. DSS for efficient water management at municipal water company,
3. social-media platform: enabling and promoting water-saving behaviour, development and simulation of adaptive water price systems,

4. the adaptive water pricing system developed to assess the implications of current and optimal water pricing policies.

The ISS EWATUS adaptive pricing module is centred on research that consists of residential water consumption. The purpose of the module is to evaluate different pricing schemes to assess the viability of such schemes. In the paper, we provide an overview of the functionality of the dynamic pricing module. Moreover, we explain the different features of the module to correctly assess pricing schemes.

2. Validity of the adaptive pricing DSS

The dynamic pricing tool has been developed based on many steps that have been researched. First, water consumption data of both Poland and Greece has been analyzed to discover the impact of the tool. The unit water demand in Poland has been decreasing over the last 10-15 years as far as households connected to water supply systems are concerned. Analysis of municipal companies shows that current unit water demand in households fluctuates between 90 and 110 liters per inhabitant per day. Further decrease in households seems to be unfeasible because of the minimum water demand necessary to meet human needs. The influence of water prices, although difficult to be precisely assessed, does not seem to be significant. This renders the applicability and the arguments for applying adaptive water pricing void for Poland. For Greece, there is added value in the use of the tool. According to current practices, the water price is simply added up by the components of water supply cost, sewerage and waste treatment cost as well as infrastructure-improvement cost. Up to date, water policy pricing in almost all water utilities in Greece is not designed with any estimation, or prediction of the consumers' reaction to a change imposed in the water price. So, demand elasticity is ignored completely!

Based on the findings of the research, an adaptive pricing model has been developed with its corresponding computing infrastructure. The parameters of the model are based on data analysis and the literature. Research conducted for the estimation of the drop in water demand caused by changes in water tariffs and especially demand price elasticity for water in Greece is indicated only in a few projects [2–5]. The research differs by size of the agglomeration, sample of the investigated inhabitants and the research period. The review was made with the differentiation of the calculation starting from average prices and marginal prices (the average price is defined as the water bill paid by the consumer divided by the amount of water consumed. The marginal price is the price that a consumer should pay, according to the water price structure, for the next m^3 of water).

The impact of changes in the pricing policy by implementation in practice is a sensitive and delicate task that is influenced by many economic and social factors.

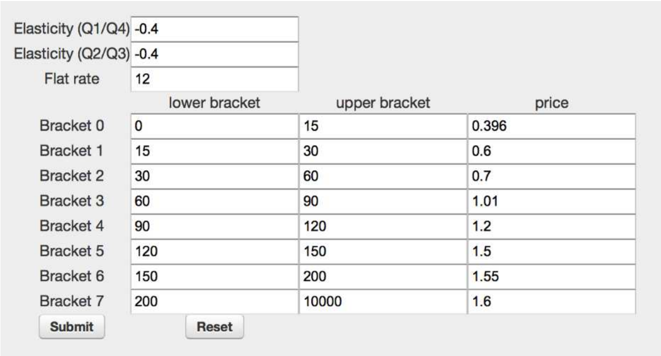
In practice, one tries to integrate on the one hand principles of free economy and on the other hand social justice. In both Poland and Greece, one implements a low-cost pricing policy while aiming at full cost recovery. In Poland, however, the water demand level is very low, leaving little room for water reduction through adaptive pricing. Adaptive pricing in Greece has more added value, but due to the economic crisis, there is a tension in affordability of pricing when full cost recovery needs to be achieved. These reasons prohibit the adoption of adaptive pricing in practice, limiting the validation of adaptive pricing to simulation studies (see also recent research on this topic with the same conclusions [6]).

The simulation study was carried out by assessing multiple scenarios and their impact. We conducted two major analysis. The first analysis was focused on using the tariffs as a tool for demand management. This instrument, however, has quite limited applicability and the associated consequences seem to be not affordable due to political and social reasons. The reduction of water demand by 20% requires an increase in the average price by 87% in the best scenario, and by 190% in more realistic scenarios. The second analysis was geared towards an increase in the net income of the water operator. An increase of 10% in the income, would require an increase by 16% in the average price of water. This will typically hurt the most sensitive of all clients.

3. The adaptive pricing module

The adaptive pricing module consists of four tabs with various statistics on pricing schemes. The main page has a focus on global characteristics of pricing policies. The input to the module consists of the price demand elasticity for a normal season (Q1/Q4) and the tourist season (Q2/Q3) (i.e., how does water consumption by consumers change as the price changes), and the pricing policy (which consists of the flat rate and the prices as a function of different water consumption brackets). The user can input these quantities in the grey area on the main page of the module, see Fig. 1 below. The prices are specified in euros per m^3, and the brackets indicate the region in m^3/calculation period (quarter) in which the price is in effect.

Once the parameters have been given by the user, the parameters can be submitted to the module by the submit button. The tool will then display the new pricing policy together with the benchmark policy. The benchmark policy is the policy that was in use a specific year to create a benchmark with the new pricing policy. One can see an example of this graph in Fig. 2.



Elasticity (Q1/Q4)	-0.4		
Elasticity (Q2/Q3)	-0.4		
Flat rate	12		
	lower bracket	upper bracket	price
Bracket 0	0	15	0.396
Bracket 1	15	30	0.6
Bracket 2	30	60	0.7
Bracket 3	60	90	1.01
Bracket 4	90	120	1.2
Bracket 5	120	150	1.5
Bracket 6	150	200	1.55
Bracket 7	200	10000	1.6
Submit	Reset		

Figure 1. Input parameters of the module

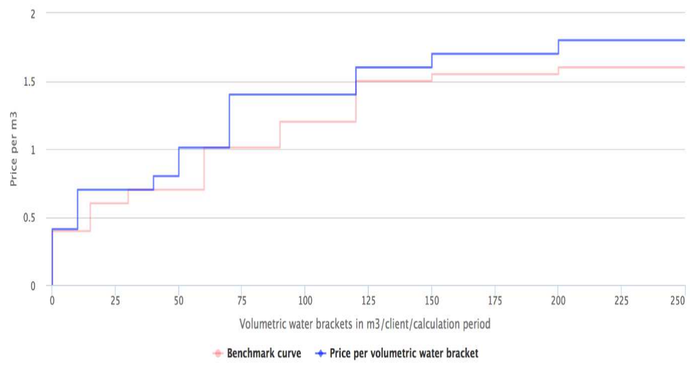


Figure 2. Example of pricing scheme

4. Statistics

Statistics of the new pricing policy are calculated automatically and are depicted in a table on the main page. The table includes the total water consumption in m^3 over a year, as well as the breakdown into the different quarters of the year. It also lists the total revenue based on the water consumption not considering any effect of demand elasticity of consumers. This gives an intuitive idea of how much one would receive in revenues by changing the pricing schemes while everything else remains constant (this quantity is also specified per quarter). However, a change in the pricing schemes comes with changes in water consumption. Hence, the total revenue that one really collects is different. This is listed in the total revenue after the change in the water consumption, which has also a breakdown in quarters.

In the following example (see Fig. 3) one can see that a new pricing scheme is in effect. The scheme is such that if the water consumption would remain the same (at the level of 51,949 m3 per year) for this population, then the total revenue would increase by 11.46% (from 68,216.10 euro to 76,034.28 euro). However, due to the fact that the water consumption decreases with 9.22% the total increase in revenues is actually less than 11.46%. It turns out that the revenues increase only by 0.27%. This example directly illustrates the difficulty in assessing pricing schemes. In cases where one expects that the revenues go up while at the same time water usage is reduced, it turns out that in practice different numbers correspond to reality. This warrants the development of a dynamic pricing tool.

Statistic	Benchmark	Current	Rel. difference (in %)
Total water consumption (in m3)	51949.00	47158.20	-9.22
Total water consumption Q1 (in m3)	10543.00	9474.56	-10.13
Total water consumption Q2 (in m3)	13855.00	12551.09	-9.41
Total water consumption Q3 (in m3)	17395.00	15939.41	-8.37
Total water consumption Q4 (in m3)	10156.00	9193.14	-9.48
Total revenue before change in water consumption (in euros)	68216.10	76034.28	11.46
Total revenue Q1 (in euros)	13113.26	14418.27	9.95
Total revenue Q2 (in euros)	17175.33	19289.76	12.31
Total revenue Q3 (in euros)	25052.34	28387.21	13.31
Total revenue Q4 (in euros)	12875.16	13939.04	8.26
Total revenue after change in water consumption (in euros)	68216.10	68402.02	0.27
Total revenue Q1 (in euros)	13113.26	13045.30	-0.52
Total revenue Q2 (in euros)	17175.33	17101.11	-0.43
Total revenue Q3 (in euros)	25052.34	25447.62	1.58
Total revenue Q4 (in euros)	12875.16	12807.96	-0.52

Figure 3. Statistics of a new pricing scheme

The tab with the details gives insight into the underlying data that the dynamic pricing tool works with. It is based on consumer data on water usage over a specific period. The table shows the customer code, the number of people in the household of the consumer, the water usage over the different quarters, the water bill in each quarter, the new price for the consumer of the new policy per quarter, and the water usage based on the new price per quarter. The columns BM Cons 1 to BM Cons 4 denote the water consumption in m^3/household for that quarter in the baseline scenario. The columns BM WB Q1 to BM WB Q4 depict the expenditures in the baseline scenario in euros for that quarter. The columns WB Q1 to WB Q4 are the expenditures in the new scenario in euros for that quarter. Finally, Cons Q1 to Cons Q4 denote the water consumption in the new scenario in m^3 per household. The data on this page essentially aggregates to the statistics on the main tab. The dynamic pricing tool internally calculates for each household the effect of price changes using the price demand elasticity and then aggregates this data on the statistics tab. Figure 4 gives an impression of part of the data on the detailed level.

Customer Code		Household	BM Cons Q1	BM Cons Q2	BM Cons Q3	BM Cons Q4	BM WB Q1	BM WB Q2	BM WB Q3	BM WB Q4	WB Q1	WB Q2	WB Q3	WB Q4	Cons Q1	Cons Q2	Cons Q3	Cons Q4
0049300000	3	16.00	11.00	1.00	14.00	20.21	17.83	13.51	19.12	21.32	18.05	13.51	20.01	13.00	10.50	1.00	12.14
0049400000	2	151.00	62.00	44.00	68.00	316.20	65.79	49.20	76.98	314.04	63.63	47.70	74.82	151.27	63.31	45.22	69.12
0054500000	4	23.00	58.00	106.00	77.00	24.79	60.54	156.52	93.75	25.90	58.38	154.37	91.59	21.21	59.43	106.55	77.92
0056500000	4	47.00	58.00	101.00	37.00	52.15	60.54	144.48	39.28	49.99	58.38	142.32	40.40	48.66	59.43	101.60	35.87
0057000000	3	24.00	54.00	161.00	27.00	25.44	57.49	362.52	27.40	26.55	55.33	360.36	23.51	22.25	55.50	161.24	25.38
0057500000	4	1.00	20.00	35.00	2.00	13.51	22.82	36.45	13.94	13.51	23.94	37.56	13.94	1.00	18.05	33.78	2.00
0060500000	2	32.00	62.00	90.00	18.00	32.20	65.79	117.98	21.52	33.31	63.63	115.82	22.63	30.62	63.31	90.73	15.93
0064000000	2	20.00	83.00	124.00	25.00	22.82	104.93	206.42	26.09	23.94	102.78	204.27	27.21	18.05	83.82	124.42	23.30
0064100000	5	21.00	32.00	32.00	25.00	23.48	32.20	32.20	26.09	24.59	33.31	33.31	27.21	19.11	30.62	30.62	23.30
0069500000	3	26.00	36.00	41.00	30.00	26.09	37.87	44.96	29.36	27.21	38.98	45.41	30.48	23.30	34.83	40.69	28.49

Figure 4. Detailed information on the household level

When a pricing scheme has been set the main page calculates several statistics, of which the most important ones are the effect on water consumption and total revenues. However, for a complete picture, it is necessary also to evaluate how this impacts the household on an individual level.

The details already give some insight into individual behaviour, however, the influence allows for further analysis. The table provides a sorted overview of the top 10 households that are affected most in several ways. One can select the top 10 households that have the highest expenditure, but also the top 10 households that have the highest reduction in water consumption. The table lists the costumer code, the number of people in its household, the total water consumption and water bill under the benchmark policy, and the total water consumption and water bill under the new pricing policy. The last two columns display the difference in the expenditure of the consumer (in %) and the difference in water consumption (in %). Both of these columns can be sorted on to generate different top 10 listings. Fig. 5 depicts a screenshot of the table. One can see that the household set by this policy are affected such that there is an increase in expenditures of at most 5.59%. At the same time, this household, as a result of price changes, will use 14.44% less water.

There are many different pricing schemes that can be devised and evaluated. The different combinations of the flat rate, the volumetric brackets and the respective prices therein are immense. Therefore, one needs to be assisted in the evaluation of different pricing schemes. The simulation tab provided help in this requirement.

Customer Code	Household	BM Consumption	BM Waterbill	Consumption	Waterbill	Rel. exp.diff. (in %)	Rel. cons.diff. (in %)
1337000000	2	62.00	79,53	53.05	83.97	5.59	-14.44
1288000000	2	65.00	81,49	56.25	85.94	5.46	-13.46
1103500000	2	69.00	84,10	60.53	88.55	5.29	-12.27
1116500000	2	72.00	86,07	63.70	90.51	5.17	-11.52
1356500000	3	75.00	88,03	66.81	92.48	5.05	-10.91
1090310000	2	75.00	88,03	66.81	92.48	5.05	-10.91
1166500000	2	75.00	88,03	66.88	92.48	5.05	-10.83
1120000000	1	77.00	89,34	68.93	93.78	4.98	-10.48
1104000000	2	64.00	81,28	56.17	85.28	4.92	-12.23
1365500000	1	58.00	77,58	50.24	81.36	4.87	-13.38

Figure 5. Influences on the household level. Source: own preparation

This module simulates a large number of randomly generated pricing policies for a given price demand elasticity and flat rate. It changes the volumetric brackets and the prices therein. For each simulation, the module records several statistics, in particular, the difference in water consumption (in %) and the difference in revenues (in %) simulated over a period of one year. The module displays the Pareto frontier of the different pricing schemes, i.e., all combinations of the two performance indicators. Fig. 6 displays the Pareto frontier for a specific setting (in this case, an elasticity of -0.4 and a flat rate of 12 euro). The results show that it is hard to obtain both an increase in revenues and reduction in water consumption at the same time.

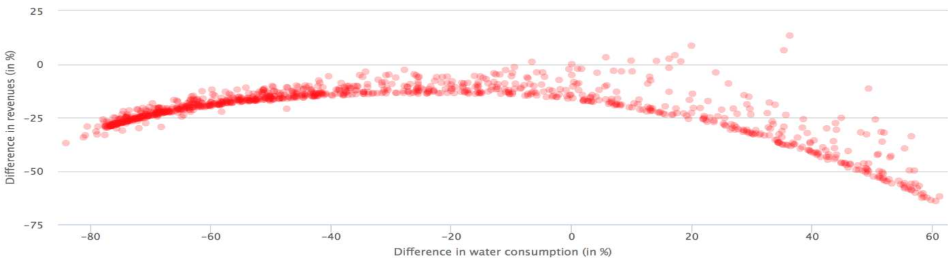


Figure 6. Pareto frontier of different pricing schemes

One the one hand, an increase in prices has such an impact on the reduction of water consumption that it will not generate additional revenues. On the other hand, lowering pricing is also a possibility. This will increase the water consumption, but will not generate sufficient demand that additional revenues are generated. Hence, the curvature of the graph. Note that there a few policies that do attain a higher revenue while at the same time also reduce water consumption (there is a point at -6.5% in water consumption and 1.09% in revenues), however, the final result depends on the value of demand price elasticity index. These are quite rare though and indicate that setting a good pricing scheme is a difficult problem that needs to be approached with considerable care

The price demand elasticity is a very important factor in this analysis. If the elasticity changes from the value –0.4 to –0.3, then there are more policies that attain better performance in water consumption and revenues simultaneously. In Fig. 7 we can see how the graph changes as the elasticity changes. It clearly shows that there are more points above the zero-line for the revenues. A similar analysis can be done with the flat rate.

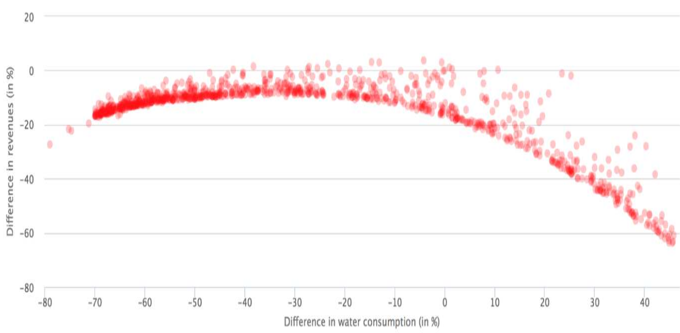


Figure 7. Pareto frontier of different pricing schemes with reduced price elasticity

The graph depicts the realm of possibilities of different pricing schemes. In order to get more insights into the type of policies that obtain these result, a table is presented with all simulated policies and their performance.

Policy (brackets, prices)	Diff. water.cons.	Diff. revenues	Diff. final revenues
(0,35,130,262,292,294,296,297), (0.075,1.812,1.946,1.989,1.992,1.997,2,2)	32.10	-17.72	7.81
(0,36,43,95,198,280,291,298), (0.197,1.501,1.835,1.852,1.971,1.974,1.996,1.998)	12.97	6.20	4.04
(0,30,45,117,148,248,277,294), (0.298,0.651,1.552,1.867,1.91,1.935,1.999,2)	14.61	-6.34	3.07
(0,48,105,146,175,190,213,248), (0.632,1.488,1.622,1.72,1.737,1.814,1.869,1.872)	-9.30	6.25	1.35
(0,57,91,130,295,296,296,299), (0.579,1.741,1.997,1.997,2,2,2,2)	-3.41	3.29	0.88
(0,19,229,256,290,300,300,300), (0.011,1.622,1.656,1.729,1.912,1.985,1.991,1.992)	2.73	4.33	0.86
(0,32,83,158,247,282,286,295), (0.433,1.983,1.985,2,2,2,2,2)	-7.63	16.51	0.77
(0,45,103,117,181,288,299,299), (0.477,1.226,1.727,1.847,1.961,1.986,1.996,1.997)	6.11	-5.89	-0.10
(0,32,36,107,209,246,262,271), (0.389,0.673,1.783,1.925,1.952,1.979,1.989,1.996)	-2.88	11.71	-0.12
(0,27,162,167,295,298,300,300), (0.389,1.584,1.982,1.984,1.99,1.996,1.996,1.999)	-3.70	5.97	-0.40

Figure 8. Details on the simulated policies

The table lists the policy, identified by a vector of the brackets and the price therein, the difference in water consumption (in %), the difference in revenues when no difference in consumption is taken into account (in %), and the expected revenues taking into account the changes in water consumption (in %).

Figure 8 shows a screenshot of the output table. There are filters for sorting the results on the different performance indicators. Currently, the table is sorted by the final revenues. The discrepancy between the different revenue values shows that the changing a pricing scheme while ignoring the elasticity in water consumption has potential threats. The ninth policy shows that in the pricing scheme one would expect an increase in revenues if one ignores consumer behavior, however, in practice one would observe a decrease in revenues. Note that the fourth policy achieves both a reduction in water consumption while at the same time the revenues are increased.

5. Technical validity of the adaptive pricing DSS

Taking into account the primary target of the project – the reduction of water consumption and balancing the demand with available resources - the methodology is focused on the assessment of the water savings using the economic instrument (water tariffs). The general approach can be described as:

$$dQ = f(dP), \tag{1}$$

where dQ represents changes in the quantity of a raw good or services (water supply in this case), and dP represents the change of the price for the good/service.

Of course, there are many other factors influencing changes in the quantity of consumed water, but this module is focused on economic instruments. In more details, but still focusing only on the economic aspects, the following formula describes the responsiveness of the quantity of a raw good or service demanded to changes in its price:

$$dQ = e_p * \frac{dp}{p} * Q, \tag{2}$$

where e_p is the coefficient of price elasticity of demand, P the initial price, and Q the quantity demanded before the changes of the price, in the calculation period.

In case of water demand, the term "price" is more complicated, especially, for mixed tariffs that consist of a flat rate and a volumetric charge. Therefore, the real price of water is derived using the formula below:

$$P = \frac{E_x}{Q}, \tag{3}$$

where E_x is the total expenditure per client in the calculation period, $E_x = Fl_r + Vch$ with FL_r the flat rate in the calculation period, and Vch the volumetric charge (quantity or quantities -multiplied by price or prices). The desk review gives us the estimation of the e_p in local conditions, the other data was derived from water operators.

Such methodology creates the possibility of predicting water saving by introducing changes in water tariffs. Such effects are related to an increase of water tariffs, however, the constructed model allows to review and check the affordability aspect.

6. Conclusion

The dynamic pricing tools allow simulating different pricing schemes under different assumptions. It shows that the dynamic pricing problem is a hard problem in which a lot of care needs to be taken. The policies that are simulated need to be judged together with the information on the influences. One need to find a balance between water reduction, increase in revenues, and feasibility of the policy in terms of influences and fairness. The dynamic pricing tool assists in finding this balance and has the potential to be integrated into important pricing policy decisions at a strategic level. It is important to remain in contact with stakeholders to show the benefit of adaptive pricing so as to implement it in practice and improve the validation

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