Florida Tax Review

Volume 23 Article 25

2023

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FLORIDA TAX REVIEW

Volume 23 *2020* *Number 2*

IMPLICATIONS OF DENMARK'S WATER PRICE REFORM FOR RIVERINE AND COASTAL SURFACE WATER QUALITY

by

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Article 9 of the EU's Water Framework Directive suggests that Member States should provide "adequate incentives" for efficient use of water resources. Although the Directive is mainly about protecting the ecological quality of water bodies, control of quantity serves as an "ancillary element" in delivering on the objectives. Despite their financial difficulties, Member States have been slow to bring their policies on

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This article is based on results from the EPI-WATER project "Evaluating Economic Policy Instruments for Sustainable Water Management in Europe" funded under the seventh Framework Program for Research by the European Commission (Grant 255213). Full documentation of the study is available from the report Mikael Skou Andersen et al., *Macroeconomic Perspective on Water Quality and Quantity Issues of Relevance to the System of Environmental-Economic Accounting for Water (SEEAW)* (2013), http://vbn.aau.dk/ws/files/157592095/Macroeconomic_perspective_on_water_quality_and_quantity_issues_of_relevance_to_the_system_of_environmental_economic_accounting_for_water.pdf. The Article has been previously published with minor modifications in ECONOMIC INSTRUMENTS FOR A LOW-CARBON FUTURE 204 (Theodoros Zachariadis et al. eds., Edward Elgar Press 2020). The original manuscript is published here in full with kind permission from the publisher.

water pricing up to the wording and 2010 deadline of the Directive's article 9.

This Article explores the significance of water pricing reform for the ecological quality objectives for surface waters and, as a stepping stone in this analysis, for water resource efficiency. It does so with a catchment-based analysis of implications from water pricing reform introduced in the early 1990s in Denmark. Household water use is found to have been 50% higher per capita before the reform, which introduced full-cost pricing and a water supply tax.

Good data availability for the catchment allows the analysis to demonstrate estimates for the improvements in water flows as well as for a specific water quality parameter. Despite the significant reduction in water demand, the main river is affected only at the margin. For smaller streams and brooks, however, there are more notable impacts for water quality and with potential benefits for rare species dependent on clean waters. A small reduction in emission loadings to coastal waters has comparatively high economic value. The Article finds that water pricing has an important role to play for future management.

Introduction

Article 9 of the EU's Water Framework Directive (WFD) establishes "that water-pricing policies [should] provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this Directive."[1]

1. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action

The requirement for "adequate incentives" can be derived from the preamble of the Directive, which states that "[f]or purposes of environmental protection there is a need for a greater integration of qualitative and quantitative aspects of both surface waters and ground waters."[2] Although the WFD is primarily concerned with surface water quality, control of quantity is seen as an "ancillary element" in securing good water quality.[3] The WFD defines the "available groundwater resource" for potable water in view of the need to respect the "long-term annual rate of flow required to achieve the ecological quality objectives for associated surface waters."[4] This definition is effectively linking water abstraction to ecological water quality, which helps explain why the WFD mandates the curbing of water demand with water pricing.

This Article explores relationships between water pricing policies, water resource efficiency, and attainment of water quality objectives (in this case, nitrogen levels). The literature suggests how water pricing affects water demand, pending on price elasticity, but few if any studies have ventured to explore the wider implications of adequate incentives for attainment of specific riverine and coastal water quality targets.[5] This is unfortunate as water pricing policies could help improve cost-effectiveness if they played a more significant role in water quality planning. We might expect policy instruments of economic nature to be generally more efficient than the command-and-control type of policy instruments commonly applied by water quality managers.[6]

Numerous studies have explored how water demand is affected by price incentives,[7] although this literature is rather short of research addressing the long-term impacts of water pricing policies. Our dataset

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in the Field of Water Policy, art. 9 ¶ 1, 2000 O.J. (L 327) 1, 12–13 [hereinafter Directive 2000/60/EC].

2. *Id.* pmbl. ¶ 34.

3. *Id.* pmbl. ¶ 19.

4. *Id.* art. 2 ¶ 27.

5. *See generally* Sheila M. Olmstead, *The Economics of Managing Scarce Water Resources*, 4 Rev. Envtl. Econ. & Pol'y 179 (2010).

6. Allen V. Kneese & Blair T. Bower, Managing Water Quality: Economics, Technology, Institutions (1968).

7. *See, e.g.*, Fernando Arbués et al., *Estimation of Residential Water Demand: A State-of-the-Art Review*, 32 J. Socio-Econ. (2003); Jaroslav Mysiak et al., *Evaluating Economic Policy Instruments for Sustainable Water Management in Europe: Synthesis Report* (EPI-WATER deliverable no. D 5.1, 2014), http://www.feem-project.net/epiwater/docs/epi-water_DL_5-1.pdf; OECD,

spans three decades and is suitable for ex-post and ex-ante assessment of water pricing policies as it reflects incentive approaches that come close to WFD ambitions for Europe—that is, water pricing with recovery of utility costs as well as application of the polluter-pays principle for wastewater discharges and resource costs. In addition to cost-recovering user charges for water services, our study base features a water related tax, implying that the wider resource costs are priced. The fiscal water supply tax (WST)[8] is in place at the national level[9] and has been introduced in exchange for a lowering of other taxes. The rate of WST has been agreed on by policymakers and, unlike a volumetric user charge, the tax rate is not directly or indirectly affected by water demand, whereby endogenous price impacts from water savings do not arise. WST has been expected to contribute to protecting water resources and surface water quality.

We explore a scenario for future economic growth and the WST adjustments required to maintain water demand in balance so as "to avoid any significant diminution in the ecological status of such waters" for the future.[10] This type of analysis is suggestive as to the potential significance of water pricing policies for sustainable water management.

I. Material and Methods

A. Data

The study site is a major river basin in Odense, Denmark covering some 1,061 km^2.[11] The water utility of Odense has applied volumetric water

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Pricing Water Resources and Water and Sanitation Services (2010), https://doi.org/10.1787/9789264083608-en.

8. Eurostat refers to the tax under the name 'Duty on piped water.'

9. Fiscal water taxes are in place in several EU Member States including Belgium, Czech Republic, Germany, Hungary, Italy, Netherlands, and Poland. For the OECD database on instruments used for environmental policy, see *Database on Policy Instruments for the Environment*, OECD, http://www2.oecd.org/ecoinst/queries/ (last visited Aug. 7, 2020). Some tax rates are a great deal lower, although the Netherlands recently increased its rate to a level comparable to that of Denmark.

10. Directive 2000/60/EC, *supra* note 1, pmbl. ¶ 27.

11. *See Odense*, Freshwater Info. Sys., http://fis.freshwatertools.eu/index.php/odense.html (last visited Aug. 7, 2020). The birthplace of

pricing, so that a variable charge is dominating the water bill with only a small fixed metering charge, and with an absence of block charging that can complicate analysis.[12] Primary data on abstractions, consumption (155,000 inhabitants), and prices refer to the timespan from 1983–2010.

Cost recovery on the basis of user charging became a legal obligation to water utilities when the Danish government approved plans to clean up surface waters and make advanced sewage treatment mandatory. The costs of this scheme were reflected in wastewater charges and are the most important element of the observed increase in volumetric water charges, which have more than doubled since 1990. In 1993 the government introduced the household-WST, phasing it in gradually with 1 DKK per year to a final rate of 5 DKK (€0.67) per m^3. Thanks to the WST, the dataset allows for separating out households' share of water supply. The average household consumption, which has been declining ever since water pricing reform, amounted to 40.3 m^3 per capita (110 litres per day) in 2010. It was 50% higher before reforms. "Jupiter"[13] holds data for water abstractions per well, while water quality has been monitored systematically since 1989 under the national water quality surveillance scheme, Nationwide Monitoring and Assessment Programme for the Aquatic and Terrestrial Environments (NOVANA).[14]

B. Models

Although it has been demonstrated in previous econometric studies how household water demand varies with water pricing, it is also influenced by household income and property size (including water-using

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Danish poet, Hans Christian Andersen, who found inspiration in the river's ecology for his fairy tale *The Little Mermaid*. *See Hans Christian Andersen*, WIKIPEDIA, https://en.wikipedia.org/wiki/Hans_Christian_Andersen (last visited Aug. 7, 2020).

12. Frank A. Ward & Manuel Pulido-Velazquez, *Incentive Pricing and Cost Recovery at the Basin Scale*, 90 J. ENVTL. MGMT. 293 (2009).

13. The Jupiter National Well Database is a project of the Geological Survey of Denmark (GEUS). *See National Well Database (Jupiter)*, GEUS, https://eng.geus.dk/products-services-facilities/data-and-maps/national-well-database-jupiter/ (last visited Aug. 7, 2020).

14. *Monitoring*, DANISH CTR. ENV'T & ENERGY, https://dce.au.dk/en/monitoring/ (last visited Aug. 10, 2020).

appliances), as well as by climatic factors such as precipitation and temperature; the characteristics of our case study suggest these variables are less important here.[15] While average incomes have generally increased, the property stock has been fairly constant and climatic factors are not considered to affect household water use in Odense.

We use ordinary least squares (OLS) regression analysis to determine the basic relationship between water pricing and water consumption, as it allows for quantification of the price elasticity of water demand. Moreover, models have been controlled for endogeneity by solving them with an Instrumental Variable and by performing the Hausman test. Focusing on households, the effect of water pricing can then be estimated in terms of reduced per capita water use and the associated relief on water abstractions, whereby the reduced pressure on the natural reservoirs in the basin is identified.

Table 1: Variables (V) Considered in the Analysis

Variable (V)	Details and unit	Source
ehWS	Estimated water sold to households [m3]	VCS[16]
POP	Users [person]	VCS
ehPC	Estimated per-capita household water cons. [m3/person]	=ehWS/POP
dVP	Deflated variable price [DKK/m3]	VCS
dFP	Deflated per capita fixed price [DKK]	VCS
dINC	Deflated income [DKK/person]	DK-stat

The linear regression model takes the form of:

$$ehPC = \beta_1 * dVP + \beta_2 * dFP + \beta_3 * dINC + \beta_4 * T + \ldots + \varepsilon$$

15. *See* Arbués et al., *supra* note 7; *see also* Sheila M. Olmstead et al., *Water Demand Under Alternative Price Structures*, 54 J. Envtl. Econ. & Mgmt. 181 (2007); A. Ruijs et al., *Demand and Distributional Effects of Water Pricing Policies*, 66 Ecological Econ. 506 (2008).

16 Data provided by VCS Denmark, http://www.vcsdenmark.com/ (last visited Aug. 10, 2020).

where: $\beta_1, \beta_2 \ldots \beta_k$ are known as regression coefficients. The interpretation of β_k is the expected change in the dependent variable for a one-unit change in the related variable V_k (or equivalently, 1% change if variable V_k is expressed in logarithms) when the other dependent variables are held fixed. Moreover, ε is the error term capturing all factors that influence the dependent variable, other than the explanatory variables. Several assumptions have to be verified, such as independence of errors, homoscedasticity, lack of multi-collinearity among the dependent variables, exogeneity, linearity, and endogeneity. We apply both linear and log-log regression models.

Once the elasticity of water demand is determined, the value can be used to separate out the impact of water pricing on demand. For the scenarios, it is used to predict the changes in per-capita household water consumption resulting from WST-adjustments compared to a business-as-usual scenario.

This information feeds the lumped hydrological rainfall-runoff model, Nedbor Afstromnings Model (NAM),[17] which can convert climate data into daily river runoff estimations. The model has specifications for the source split of the river discharge and feeds water into the river from three different sources: ground water, inter flow, and surface water.

River water originates from different sources; in this case we consider groundwater and surface water as well as the interflow through upper soil layers. Groundwater has a longer travel time from precipitation till entering the river than surface water. During this longer travel time a large part of the nitrogen (N) that was originally in the water when leaving the upper soil (root zone) is removed (retention)—it is primarily turned into nitrogen gas through denitrification (both chemical and biologically). Therefore groundwater entering the river has a lower N concentration than surface water.[18]

The catchment water abstraction is entirely from groundwater aquifers, whereby the flow from aquifers to the river is affected by the abstracted amount. As a result of abstractions, the share of river

17. *See* Danish Institute of Applied Hydraulics (DHI), MIKE 11 User Guide (2017), https://manuals.mikepoweredbydhi.help/2017/Water_Resources/MIKE11_UserManual.pdf.

18. Jørgen Windolf et al., *A Distributed Modelling System for Simulation of Monthly Runoff and Nitrogen Sources, Loads and Sinks for Ungauged Catchments in Denmark*, 13 J. Envtl. Monitoring 2645 (2011).

water originating from groundwater is reduced, relative to the share of surface water. Because surface waters feature a higher N concentration than groundwater, the river's N concentration is elevated with added groundwater abstraction. Conversely, by incentivizing a curbing of groundwater abstraction, the share of groundwater relative to surface water in the river increases, causing riverine N-concentrations to drop.

The implications for water quality are likely to be more significant in upstream river segments, rather than downstream in river and fjord. The abstracted water is transported downstream for water use in the town of Odense, from where wastewater is discharged into an estuary. Incentives to reduce abstraction will mainly allow improved water flows in the upper segments of the catchment, thus improving the water quality of smaller water courses and brooks. Improvements in upstream river segments may improve river quality classifications and will support biodiversity. Time-series data for water quality at point-monitoring stations provide the basis for modelling incremental changes as output for the purpose of our assessment.

II. Calculation

A. Implications for Water Quantity

Based on the hypothesis that consumers respond to changes in water pricing, we included both of the variables price and fixed price in the model. Several simulations were performed by considering different groups of independent variables (variable price only; variable with fixed price), different demand functions (linear; log-linear), and by including/excluding specific independent variables (e.g., price + climate variables, price + income, etc.). The following models were found where *dfVP*, *dfFP* variables are significant, whereas *dfINC, T*, *C*, *S*, and *P* are not. The Hausman test shows that there are no endogeneity problems. Results of the OLS model are thus reported for two different regression models M1 and M2.

M1 − Solve by OLS:

$$hPC = 71.160 - 0.464\ dfVP - 0.017\ dfFP$$

$R^2 = 0{,}952$ Significance: constant: 0.000; *dfFP*: 0.006; *dfVP*: 0.000

M2 – Solve by OLS:

$\ln ehPC = 6.047 - 0.287 \ln dfFP - 0.118 \ln dfVP$

$R^2 = 0{,}928$ Significance: constant: 0.000; ln*dfFP*: 0.000; ln*dfVP*: 0.003

Once the formula for the demand function $Q_d = F(P_d)$ (where Q_d is quantity of water demanded and P_d is its price) is known, the price elasticity E_d of water demand (intended as the responsiveness of the quantity demanded of water to a change in its price) can be calculated as:

$$E_d = P/Q_d * (dQ_d/dP_d)$$

For the case of M1, the point price elasticity (i.e., the elasticity calculated for each year according to the equation above) E_d is negative and its absolute value is increasing in time: E_d ranges from the value of $E_{d\_1995} = -0.07$ (year 1983)[19] to the value of $E_{d\_2010} = -0.48$ (year 2010), whereas the average elasticity calculated for all 15 years is of $E_{d\_mean} = -0.36$. Not surprisingly, water demand is relatively inelastic. Similar considerations are valid for M2; since the function is of log-log type, the price elasticity calculated with this model is the coefficient $E_d = \beta_1 = -0.11$.

It is not entirely persuasive with the prominent role attributed to the fixed price component in our M2 model, as the fixed charge accounts for less than 10% of the total water bill. The fixed charge was almost doubled during that period of time in the late 1990s when water demand declined most rapidly, and partly in response to that decline so as to maintain revenues for the water utility. Although log-log models are sometimes preferred, we have more faith in the outcome of our M1 model, which is a more conventional OLS analysis. Still, for completeness we include the results of both models in our analysis of implications for water quality below.

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19. This corresponds well with elasticity for the 1980s, reported in Lars Gårn Hansen, *Water and Energy Price Impacts on Residential Water Demand in Copenhagen*, 72 Land Econ. 66 (1996).

B. Implications for Water Quality

Historical data for water demand have been used as input to the water modeling in order to establish the spin-off effect for river water quality of WST. The water abstraction data[20] refers to a groundwater aquifer in each sub-basin, and we maintain this spatial distribution in our scenarios. We focus on one important chemical parameter, the N concentration. As N-concentrations to some extent echo ammonium, reductions can be expected to support fish-life and habitat species. The reason for our approach is the poor quality of many water courses, which water planners have linked to reduced water flows. Our purposes are partly illustrative because water planners have so far disregarded the potential role of water pricing.

We explore two sub-catchments: (1) River Odense at Kratholm station (ID450003), with a catchment area of 487 km^2; and (2) the smaller Holmehave stream (ID450080), with a catchment area of 36 km^2. The latter is currently subject to excess water abstraction and typical of smaller water courses with poor water quality due to reduced water flows.

A simple model identifying groundwater and surface water N concentrations, respectively, was developed. The model is based on N concentration measurements (n = 1399) from the period 1998–2000 (Baseline). For the River Odense, the mean N concentration of a 100% groundwater fed river water was calculated to be 3.2 mg/l at Kratholm monitoring station, see Table 2. Because there is a trend towards higher concentrations with higher base flow values, a regression model was calculated (EQ. 1).

$$\text{EQ. 1:} \qquad N_{conc} = 3.2573Q_{groundwater}^{0.109}$$

N_{conc} is the groundwater (base flow) N concentration in mg/l. $Q_{groundwater}$ is the base flow discharge (groundwater) in m^3/s.

The N concentration of river flows fed by surface water was calculated as a residual for all days with >0.5 m^3/s surface water discharge in the river. The mean surface water N concentration was calculated to be 11.1 mg/l, more than three times as high and reflecting presence of intensive farming in the catchment (see Table 2). For Holmehave stream, we use the mean N concentration of groundwater.

20. *See supra* note 13.

Table 2: Nitrogen Model Calibration Statistics

	N (mg/l) observations	N mg/l groundwater	N mg/l surface water	N mg/l River	r^2
Observations	1399	3.2	11.1	5.3	–
Simulated	–	3.4	11.1	5.6	0.69

The model is run on daily records of three climate parameters (precipitation, potential evaporation, and temperature) for a standardized period 1989–2001 including both dry and wet years.[21] The model is calibrated against observed daily values of overall river water balance and using a standard auto-calibration routine with a maximum of 100,000 model calibration runs (see Table 3).

Table 3: Catchment Information and Calibration Statistics (WBL%: Water Balance Error in % for the Calibration Period).

	Area km²	Runoff (mm/y)	WBL%	R^2
Odense R. Kratholm	487	290	0.7	0.95
Holmehave stream	36	262	1.4	0.87

Water abstraction in Holmehave sub-catchment is substantial with above 100 mm per year. The most important abstraction point is located close to the border of the neighboring sub-basin, and it is likely that part of the abstraction stems from the neighboring topographic sub-basin (meaning that some of the water fell as precipitation in the neighboring sub-basin and runs under ground into our sub-basin). We reduce the simulated groundwater abstraction values from our sub-basin by 30% to avoid overstating the significance of Holmehave abstractions to water flows, cf. Table 4.

21. Hans Thodsen, *The Influence of Climate Change on Stream Flow in Danish Rivers*, 333 J. Hydrology 226 (2007).

Table 4: Mean Monthly Ground Water Abstractions for Baseline and Scenarios in Catchment

	Units	Odense R. Kratholm DMU ID450003	Holmehave stream DMU ID450080	Holmehave stream 70%
Baseline	mm/month	1.58	11.0	7.7
Before taxation	mm/month	1.86	14.5	10.2
WS1	mm/month	1.46	11.3	7.9
WS2	mm/month	1.43	11.2	7.8
EcF	mm/month	2.82	21.9	15.3

C. Scenarios

For our analysis, the actual groundwater abstractions for 1998–2000 constitute the baseline period, as WST was phased in gradually, with the full tax rate in place from 1998.

For the ex-post analysis we can estimate what the abstractions would have been in the absence of WST, and how that in turn would have affected water flows and our water quality parameter, which is done in scenario 1 for the period 1983–1993.

Altogether these scenarios have been run:

- Before WST (average of abstractions 1983–1993)
- WS1 taxation scenario; mean abstractions 1994–2010, elasticity M1
- WS2 taxation scenario; mean abstractions 1994–2010, elasticity M2
- EcF future scenario; mean abstractions 2040–2050

The changes in groundwater abstraction resulting from the various scenarios are distributed proportionally (with same relative change) for each well. In reality, new abstraction sites might be developed, but as the overall water balance is fragile in the catchment, water quality targets would only be affected elsewhere. The standardized climate period (see above) is used to avoid climate signals interfering with the water abstraction signals, which ensures that all modeled differences originate from differences in water abstractions.

III. Results

Resulting changes for water quantity and water quality of river and stream for baseline and scenarios are provided in Tables 5 and 6.

For Odense River, the daily average water volume flows were 2% less in the decade 1983–1993 before water pricing reform, while for Holmehave stream flows were 12.6% less during this period with about 35% of the baseline flow being depleted. Implications for water quality differ markedly between our stream and river, with N concentrations in average 20% higher for our stream, while only about 0.5% more in the river. As certain rare species depend on the quality of fresh water in the smaller brooks and streams, there are wider implications for biodiversity that have not been addressed in full detail here and which might suggest that the quality improvement upstream is as important as any improvement in water quality of the main river.

WS1 and WS2 are scenarios that allow us to inspect impacts of Denmark's WST for the period 1994–2010 and obviously depend on the chosen regression model. These scenarios simulate water flows and our quality parameter in the absence of WST. It can be recalled that we have the most faith in our M1 model, whereas the M2 model is included for completeness and presents a conservative estimate. Still, for both scenarios the impact appears to be relatively modest in the stream with water volumes improving by up to 2% and N concentrations with a mere 1.6%, while in the river impacts on water quality were apparently negligible.

Still, it must be recalled that we use WST as a basis for our modelling for methodological reasons (see above). The volumetric water charging for wastewater, along with some tariff increases for water supply, caused the total volumetric water price to increase from DKK 19 per m^3 in 1992 to DKK 42 per m^3 in 2010, which is an increase four-and-a-half times higher than WST itself. It is hence plausible to hypothesize that the greater part of the increased water flows relative to baseline can be inferred from provision of "adequate incentives" under water pricing reform. When considering stream water flow, it is likely that roughly 10% ($4.5 \times 2\%$) of the increase is due to water price reform, which is 3/4 of the 12.6% flow improvement. The relative significance is comparable for the river itself. Implications for water quality are also more substantial, though we cannot assume they are linear.

With less water being abstracted, the river and fjord receive higher quantities of groundwater fluxes, rather than of sewage waters with N concentrations up to the legally binding maximum of 8 mgN/l. Although insufficient to provide a cleansing "flush-effect" to the estuary, the scheme is reducing flows via sewage treatment plants with 1.5 million m^3, providing a small potential relief on final discharges to coastal surface waters of 11 tons N annually. Compared with an annual run-off of 1200–1500 tons N to the fjord, it may appear insignificant, but nevertheless provides value as the marginal land use measures providing a comparable relief on N removal would easily cost 50 euro per kgN annually.[22] Over a 20-year period, the avoided abatement costs suggest a potential shadow value of about €10 million for water pricing reform.

With regard to the scenario calculation for the future, the projections for population and water use have generically been derived from SCENES and IPCC SSP scenarios for Denmark,[23] although the specific 2020 population forecast is also in line with that of Statistics Denmark. The projected water withdrawals are driven by expected GDP increases (annually about 2% in the EcF "Economy First" scenario) and population growth of 30,000 inhabitants. Scenario results in Tables 5 and 6 indicate that implications for water volumes in both river and stream can become significant. For this scenario, the figures for Odense River reflect the overall catchment pressure and suggest a reduction of baseline flows with 13%, while the average water volume would be reduced with 6%. The flow reduction would result in N concentrations increasing with 1–2% in Odense River, whereas specific smaller streams could become more seriously affected. The increase in real N emissions via the sewage treatment plant would necessitate matching reductions in

22. Odense Pilot River Basin: Pilot Project for River Basin Management Planning: Water Framework Directive Article 13, at 70 (Harley Bundgaard Madsen et al. eds., 2007), http://naturstyrelsen.dk/media/nst/8817785/annex_2b_uk_main_report.pdf.

23. The scenarios of future socio-economic developments were drawn from the result of the EC project SCENES, *Fact Sheet*, Cordis (2011), https://cordis.europa.eu/project/id/36822. For SSP, see *Explainer: How 'Shared Socioeconomic Pathways' Explore Future Climate Change*, Carbon Brief (Apr. 19, 2018), https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change.

Table 5: Results for Odense River at Kratholm

	Description	Mean Q	Δ% Q	Mean BF m^3/s	Δ% BF	Mean N conc. mg/l	Δ% N conc.
Baseline	Mean 98–00	4.54	–	2.03	–	5.85	–
Scenario 1	Mean 83–93	4.45	–2.0	1.94	–4.5	5.88	0.5
Scenario 2	WS1	4.53	–0.3	2.02	–0.3	5.86	0.03
Scenario 3	WS2	4.53	–0.1	2.03	–0.1	5.85	0.01
Scenario 4	EcF	4.28	–5.8	1.77	–13.0	5.95	1.6

land-use-related runoff that, with present price relations, would not be insignificant.

We have explored what adjustments in our WST might imply for water demand to learn what tax rate adjustment would be required to maintain the catchment's water balance. The results are sensitive to assumptions about the specific price elasticity. When using our M1 model from above, we find that a gradual WST adjustment to a level of €1.32–1.48 per m^3 by 2030 is likely to be required to maintain abstraction at a stable level. This result does not take into account increases in precipitation driven by climate change, however, and might also be too draconian in view of the higher point price elasticity identified for the most recent years. Nevertheless, it is clear that WST could play a useful role in providing an "adequate incentive" for future water savings.[24]

Our simulations are suggestive as to the implications, while they demonstrate how it is possible to link quality parameters directly to the quantity assessment. The disentangling of the WST's impact illustrates how the water quality change can be linked to a sector in the economy (household consumption). The recent United Nations water accounting guidance document states that "it is difficult to attribute changes in stocks of quality to the direct causes,"[25] but the present analysis indicates how it might be feasible with appropriate models.

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24. Frank J. Convery, *Reflections—Shaping Water Policy: What Does Economics Have to Offer?*, 7 Rev. Envtl. Econ. & Pol'y 156 (2013).

25. U.N. Dep't of Econ. & Soc. Affairs, System of Environmental-Economic Accounting for Water, at 110, U.N. Sales No. E.11.XVII.12 (2012), https://seea.un.org/sites/seea.un.org/files/seeawaterwebversion_final_en.pdf.

Table 6: Results for Holmehave Stream

	Description	Mean Q	Δ% Q	Mean BF m³/s	Δ% BF	Mean N conc. mg/l	Δ% N conc.
Baseline	Mean 98–00	0.263	–	0.095	–	5.70	–
Scenario 1	Mean 83–93	0.230	–12.6	0.062	–35	6.82	20
Scenario 2	WS1	0.260	–1.1	0.092	–3.1	5.75	0.8
Scenario 3	WS2	0.258	–2.0	0.090	–5.5	5.79	1.6
Scenario 4	EcF	0.177	–33	0.009	–91	10.42	83

Table 7 shows water quality classes of standard river units (SRUs) for our catchment. To the extent that the activity-driven changes in quality parameters result in changed classifications, this would be captured in a water accounting system. For instance, if increased water flows change quality parameters, a distance of SRU's would achieve improved classification.

Table 7: Water Quality in SRUs (Kilometers of Standard River Units), Excl. Not Classified or Piped Water Courses

Odense river basin	High	Good	Moderate	Poor	Bad	Sum
Main rivers	9	18	11			38
Main tributaries	39	89	85	28		241
Small rivers	15	81	170	50	40	356

IV. Conclusions

Contributions from economic policy instruments have been largely ignored during the recent river basin management planning process that has focused on land use specific measures, many of which rely heavily on taxpayer financed subsidy schemes. In this study, we have explored what water pricing might contribute at the margin towards planning targets for our catchment, in particular with regard to water quality. Our methodology is based on availability of catchment specific data and analysis of behavioral responses to regulatory efforts and measures of pricing. Following water pricing reform, per capita water use has dropped 34% over the past 20 years, which has helped slightly increase water flows of the Odense River and of the smaller adjoining water courses too. Due to higher groundwater fluxes, this implies lower nitrogen concentrations, mainly upstream in smaller streams and brooks, and to a lesser extent in the main river itself. Our analysis indicates that river water flows were 2% less before water pricing reform, and more than 10% less for a specific smaller stream, while water quality for our nitrogen parameter improved by 20% in the small stream. The latter must be regarded to be a change with potential benefits for biodiversity in particular.[26]

Water pricing reform appears to explain the greater part of the change. Our analysis focuses on the WST, which accounts for about 1/5 of the volumetric water price increase. It can explain 1/6 of the observed change in water flow and about 1/12 of the water quality change. The outcome of the analysis depends on the specific price elasticity applied, and we have used an average for the period, whereas use of point price elasticities for the latter part of the period would lead to effects approximately 1/3 higher than reported. Future scenarios have been modeled to take into account projections for population growth and increases in economic activities and suggest how the WST could be increased to keep water demand in balance.

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26. 150 km of water courses are classified under the Habitats Directive. The draft water plan mentions ecological impacts on local species, for instance, a rare and threatened freshwater mussel (unio crassus) that requires clean water. It does not appear to be able to reproduce under present circumstances. MILJØMINISTERIET, BY- OG LANDSKABSSTYRELSEN FORSLAG TIL VANDPLAN. HOVEDVANDOPLAND 1.13 ODENSE FJORD (2010), https://mst.dk/media/122257/odensefjord_fyn.pdf.