Groundwater Valuation & Pricing

Roy Brouwer

The Water Institute / Department of Economics
University of Waterloo, Canada

The value of the world's ecosystem services and natural capital

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The services of ecological systems and the natural capital stocks that produce them are critical to the functioning of the Earth's life-support system. They contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet. We have estimated the current economic value of 17 ecosystem services for 16 biomes, based on published studies and a few original calculations. For the entire biosphere, the value (most of which is outside the market) is estimated to be in the range of US$16–54 trillion ($10^{12}$) per year, with an average of US$33 trillion per year. Because of the nature of the uncertainties, this must be considered a minimum estimate. Global gross national product total is around US$18 trillion per year.

Because ecosystem services are not fully 'captured' in commercial markets or adequately quantified in terms comparable with economic services and manufactured capital, they are often given too little weight in policy decisions. This neglect may ultimately compromise the sustainability of humans in the biosphere. The economies of the Earth would grind to a halt without the services of ecological life-support systems, so in one sense their total value to the economy is infinite. However, it can be instructive to estimate the 'incremental' or 'marginal' value of ecosystem services (the estimated rate of change of value compared with changes in ecosystem services from their current levels). There have been many studies in the past few decades aimed at estimating the value of a wide variety of ecosystem services. We have gathered together this large (but scattered) amount of information and present it here in a form useful for ecologists, economists, policy makers and the general public. From this synthesis, we have estimated values for ecosystem services per unit area by biome, and then multiplied by the total area of each biome and summed over all services and biomes.

Although we acknowledge that there are many conceptual and empirical problems inherent in producing such an estimate, we think this exercise is essential in order to: (1) make the range of potential values of the services of ecosystems more apparent; (2) establish at least a first approximation of the relative magnitude of global ecosystem services; (3) set up a framework for their further analysis; (4) point out those areas most in need of additional research; and (5) stimulate additional research and debate. Most of the problems and uncertainties we encountered indicate that our estimate represents a minimum value, which would probably increase: (1) with additional effort in studying and valuing a broader range of ecosystem services; (2) with the incorporation of more realistic representations of ecosystem dynamics and interdependence; and (3) as ecosystem services become more stressed and 'scarce' in the future.

Ecosystem functions and ecosystem services

Ecosystem functions refer variously to the habitat, biological or system properties or processes of ecosystems. Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions. For simplicity, we will refer to ecosystem goods and services together as ecosystem services. A large number of functions and services can be identified[1–4]. Reference 5 provides a recent, detailed compendium on describing, measuring and valuing ecosystem services. For the purposes of this analysis we grouped ecosystem services into 17 major categories. These groups are listed in Table 1. We included only renewable ecosystem services, excluding non-renewable fuels and minerals and the atmosphere. Note that ecosystem services and functions do not necessarily show a one-to-one correspondence. In some cases a single ecosystem service is the product of two or more ecosystem functions whereas in other cases a single ecosystem function contributes to two or more ecosystem services. It is also important to emphasize the interdependent nature of many ecosystem functions. For example, some of the net primary production in an ecosystem ends up as food, the consumption of which generates respiratory products necessary for primary production. Even though these functions and services are interdependent, in many cases they can be added because they represent 'joint products' of the ecosystem, which support human

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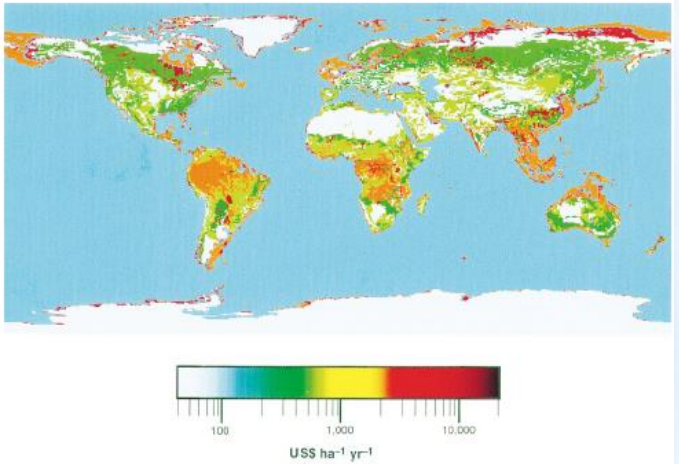
Figure 2 Global map of the value of ecosystem services. See Supplementary Information and Table 2 for details.



Wetlands	$14,785 $ha^{-1}yr^{-1}$
Lakes/rivers	$ 8,498
Tropical forests	$ 2,007
Coral reefs	$ 675
Open ocean	$ 252
Grasslands	$ 232

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Why price water?

- Application market based instruments limited (e.g. Ireland)
- Water policy traditionally dominated by technical standards & engineering solutions
- Water pricing controversial

ENTREVISTA - Roy Brouwer - «Os agricultores pagam muito pouco que água que utilizam»

2010-10-01

O especialista holandês em economia de água, Roy Brouwer, não põe de lado a subida dos preços de água para irrigação, mas sugere outras medidas de compensação para o sector agrícola não perder competitividade.

Versão integral na edição papel do jornal «água&ambiente» de Outubro 2010

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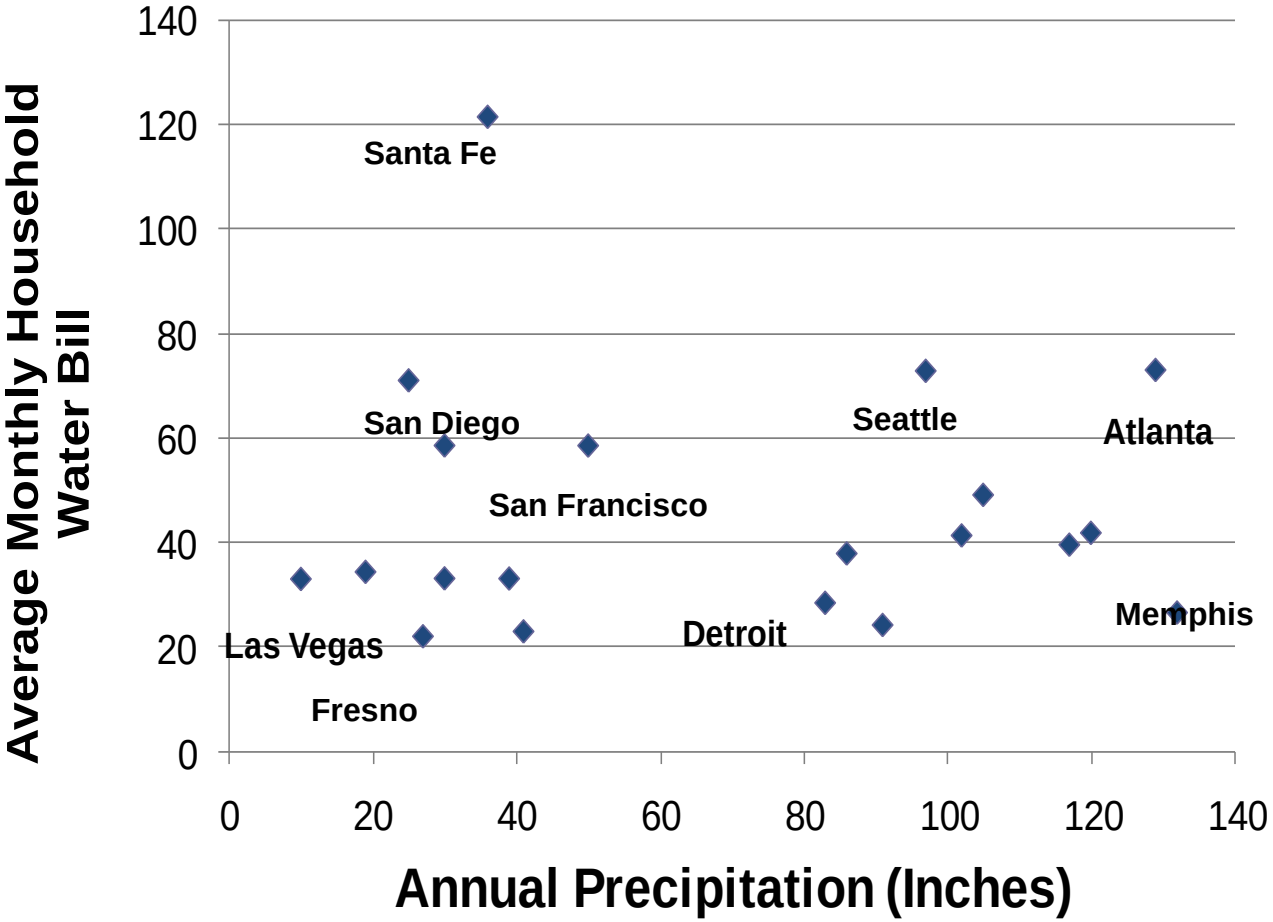
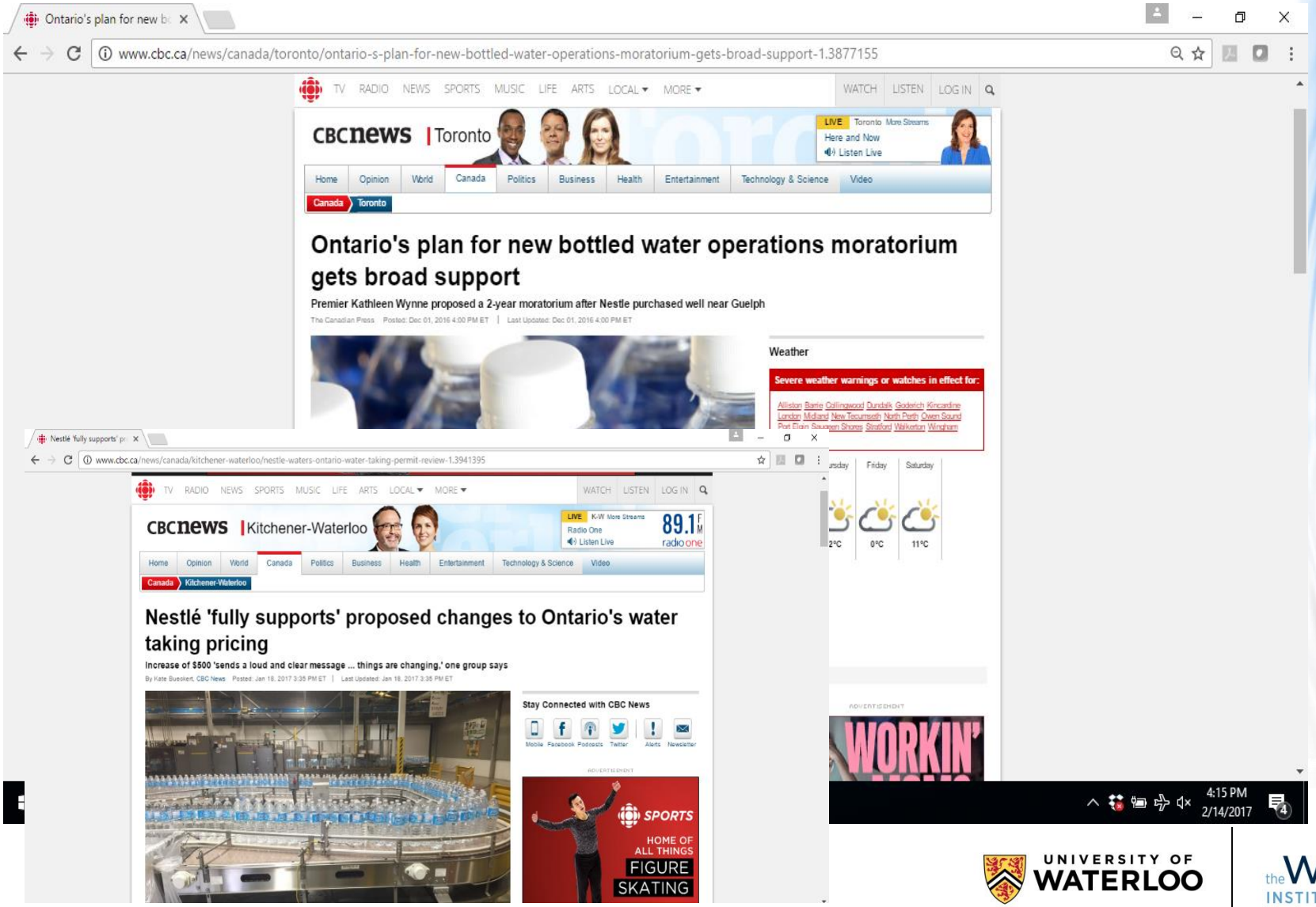
Monthly water bill vs. precipitation in US cities



Source: Walton, 2010.

Water as a scarce resource



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Shifts in water governance

Lower and higher jurisdictional levels (decentralization, devolution, Europeanization, globalization)

Independent bodies (agentification) and courts (judicialization)

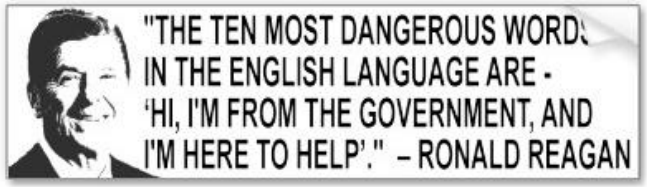
↑

← **From nation state to** →

↓

Markets (privatization, markets, contracting out, public private partnerships)

Civil society (networks, self governance, participation)



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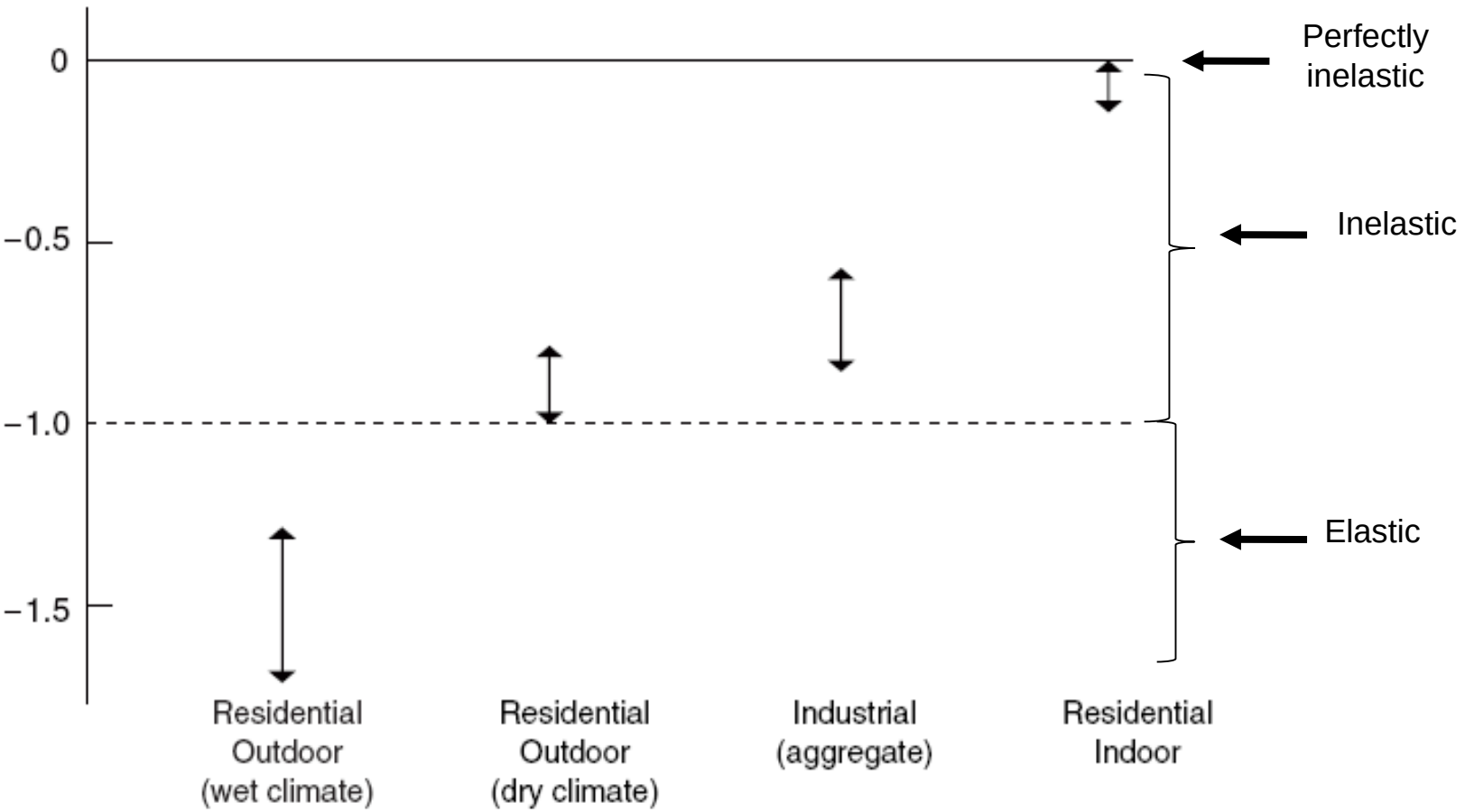
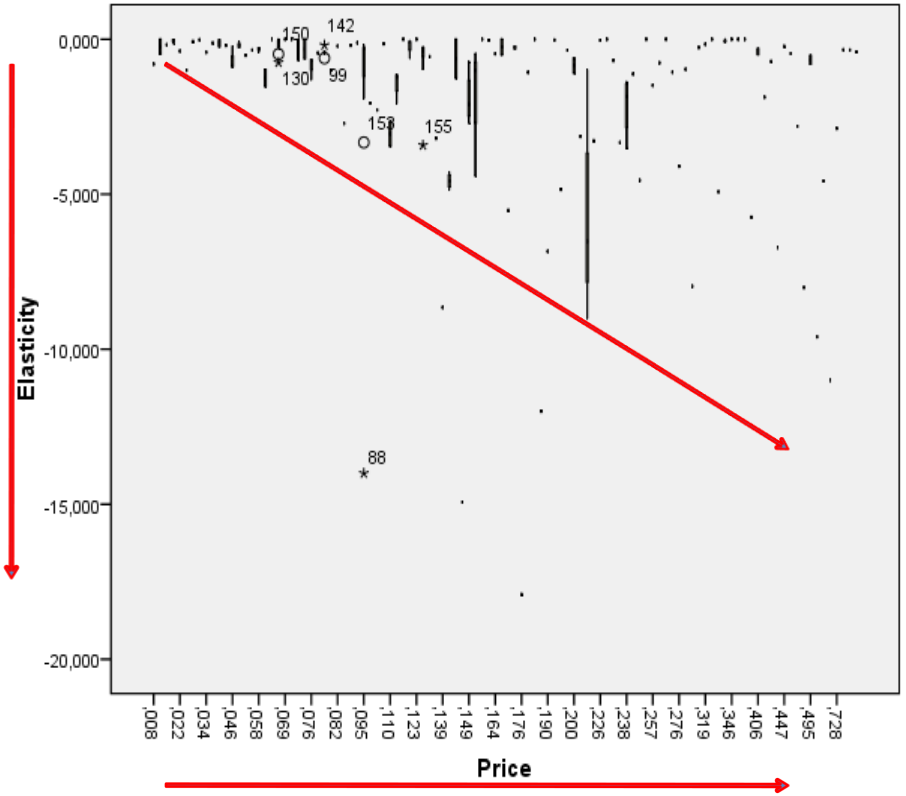
Price elasticity of water demand



Source: Brouwer and Pearce (2005)

Meta-analysis of irrigation water pricing

(Brouwer and Georgiadou, 2010)



- 39 studies worldwide
- 1963-2008
- 396 observations
- US, Canada, Australia
- Spain, Italy, Greece, Portugal
- Morocco, Israel, Jordan

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Conclusions

- Price elasticity of water is negative

>> Users do react to price increases

- The higher the price, the greater the elasticity

>> important reason for low response irrigation water

Groundwater Values

- Groundwater resources exposed to pollution, degrading their quality for uses now and in the future

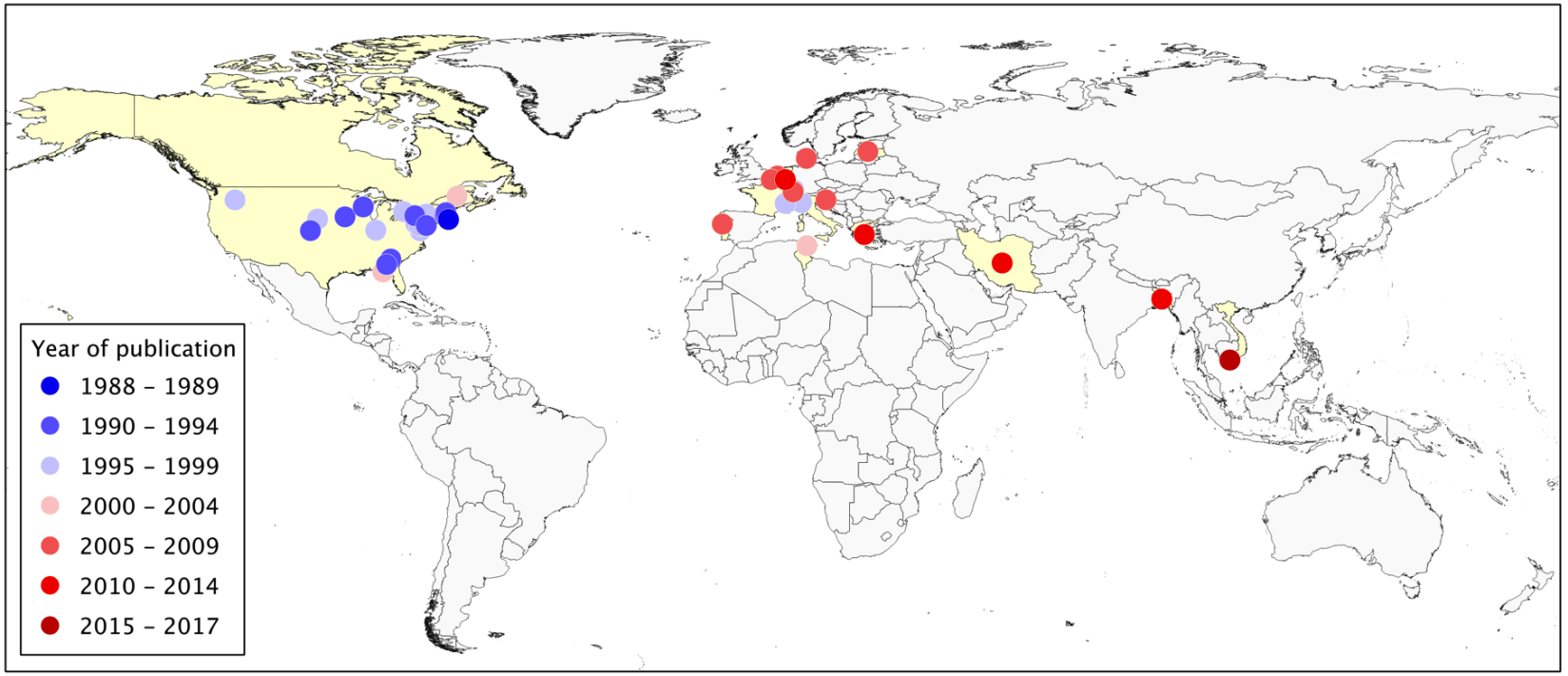
- To inform sustainable policy and decision-making (GW protection, pollution remediation): nonmarket values attached to GW resources

- Summarize estimations of groundwater quality values

➢ Meta-analysis: 3 decades of studies in 15 countries, broad range of values and factors

Pool of studies

- 16 studies from the USA (108 estimates)
- 14 from European countries (83 estimates)
- 5 from the rest of the world (10 estimates)



- All values converted to PPP adjusted 2015 $

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Explanatory variables

- 3 groups of variables

Meta regression:

$$Y_{i,j} = a + b_1 X_{1,i,j} + b_2 X_{2,i,j} + b_3 + X_{3,i,j}$$

Y = average WTP/household/year
X_1 = resource, pollution and policy characteristics
X_2 = characteristics of the population of beneficiaries
X_3 = survey design and methodology characteristics
i: observation, j: study

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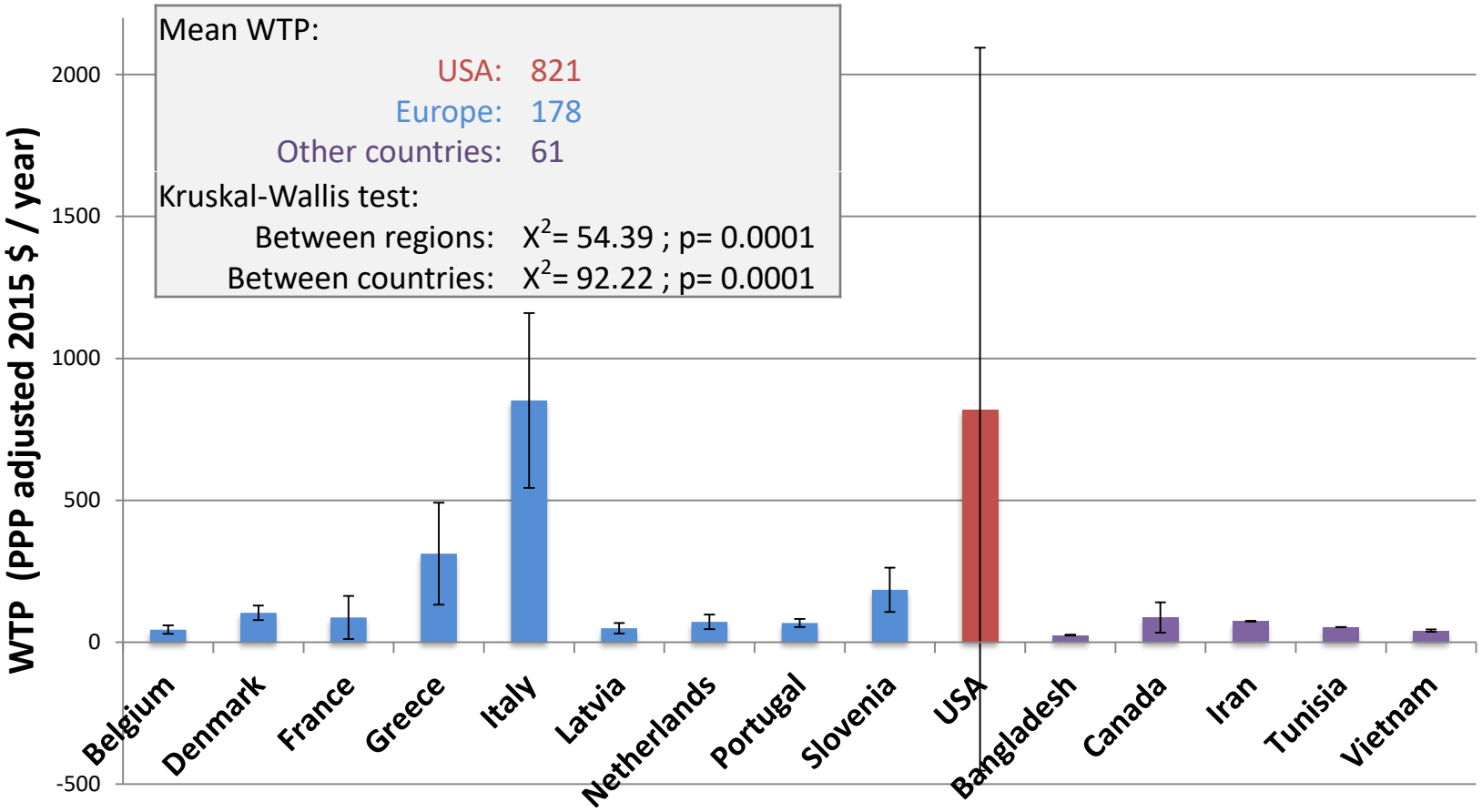
A first look at groundwater quality values

- Average WTP in the different countries



N obs	4	4	41	14	6	4	5	3	2	108	2	4	1	1	2

Table 4. Distribution of PPP-adjusted WTP (2015 $/household/year) across groundwater, population and methodological characteristics

	USA			Europe		
	Mean	Standard deviation	*N*	Mean	Standard deviation	*N*
Resource, pollution and policy characteristics						
Pollutant						
Chemicals only	101.1	50.3	3	64.4	27.6	22
Herbicides/pesticides only	4,717.3	3,931.0	4		n.a.	
Nitrate only	642.0	576.8	52	73.2	23.5	7
Mixed/other	1,758.4	972.5	18	180.3	164.4	39
Not specified	144.6	105.6	31	386.6	435.1	15
Kruskal–Wallis test:	$X^2 = 60.504$; $p = 0.0001$			$X^2 = 11.11$; $p = 0.0111$		
Use of the groundwater resource						
Drinking water supply only	658.1	791.1	102	221.0	313.3	36
Environmental uses only		n.a.		158.0	55.7	2
Drinking water and environmental uses	3,594.7	3,510.4	6	144.2	161.9	45
Kruskal–Wallis test:	$X^2 = 12.537$; $p = 0.0004$			$X^2 = 2.331$; $p = 0.3118$		
Quality level reached with the policy scenario						
Very good status	364.3	396.2	21	71.8	48.9	27
Good status	798.2	866.0	76	247.6	335.9	31
Irrigation water quality		n.a.		46.5	6.9	2
Not specified	1,852.8	3,133.4	11	219.7	182.9	23
Kruskal–Wallis test:	$X^2 = 5.816$; $p = 0.0546$			$X^2 = 15.294$; $p = 0.0016$		
Welfare impact of the policy scenario: secure welfare gain (CSWTP) vs. prevent welfare loss (ESWTP)						
CSWTP	326.2	343.6	53	118.6	138.2	62
ESWTP	1,298.2	1,621.9	55	352.6	366.6	21
Wilcoxon (Mann–Whitney) test:	$z = -4.840$; $p = 0.0000$			$z = -4.127$; $p = 0.0000$		

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Continued

Table 4. Distribution of PPP-adjusted WTP (2015 $/household/year) across groundwater, population and methodological characteristics

	USA			Europe		
	Mean	Standard deviation	*N*	Mean	Standard deviation	*N*
Uncertainty in the baseline and policy scenarios						
Base 0, Policy 0	228.5	0.0	1		n.a.	
Base 0, Policy 1	805.6	754.7	39	103.6	25.9	4
Base 1, Policy 0		n.a.		157.2	98.6	13
Base 1, Policy 1	838.9	1,504.6	68	186.4	264.8	66
Kruskal–Wallis test:	$X^2 = 2.102$; $p = 0.3495$			$X^2 = 3.552$; $p = 0.1693$		
Cancer mentioned as a possible pollution outcome						
No	774.9	1,424.5	64	181.6	245.1	79
Yes	888.5	1,028.7	44	103.6	25.9	4
Wilcoxon (Mann–Whitney) test:	$z = -0.413$; $p = 0.6798$			$z = -0.447$; $p = 0.6552$		
Population of beneficiaries characteristics						
Rural or urban households						
Rural	371.8	267.7	21	76.0	52.1	10
Urban	132.9	75.8	4	288.8	311.6	39
Mixed	778.3	868.8	79	80.5	52.7	34

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CONCLUSIONS

Key findings:

- Public WTP for groundwater quality sensitive to:
  - Specific benefits involved, Ability to pay, Elicitation technique
  - Sensitivity to scope (pollutant, quality level)
  - Reference dependence (prevent deterioration / improve)
  - More sensitive to uncertainty in the baseline scenario than in the policy scenario
  - Importance of the institutional context of WTP elicitation (mode and timing of payments)

CONCLUSIONS

- Significant unexplained difference remains between USA / Europe / other countries
- Extended database -> heterogeneity in the data
  - Differences in survey designs (accounted for)
  - Cultural differences (not accounted for)
- Guidelines for more standard study design and reporting procedures in nonmarket valuation studies

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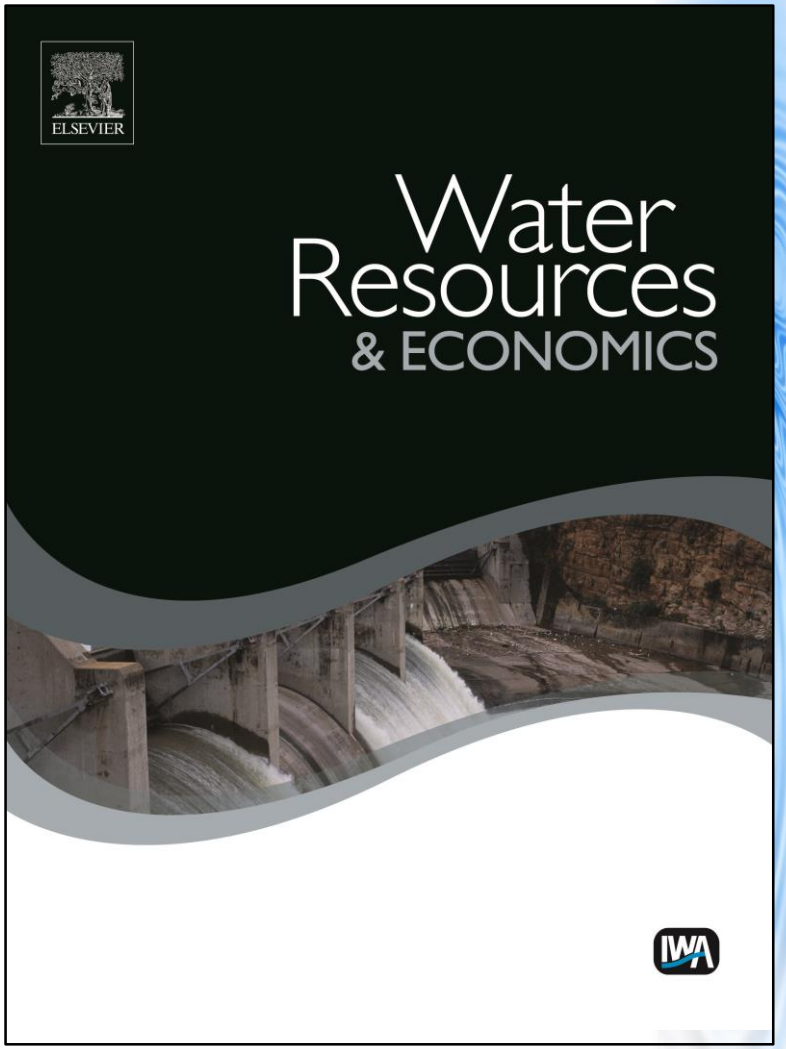

Brouwer, R. and Neverre, N. (2018). A global meta-analysis of groundwater quality valuation studies. European Review of Agricultural Economics, doi:10.1093/erae/jby043.

http://www.sciencedirect.com/science/journal/aip/22124284

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Meta-regression model

	World	
	Coef.	Robust Std.Er.
D_supply	1.044***	-0.143
D_supply_envt	1.140***	-0.0464
D_protec	-0.952***	-0.225
D_eswtp	0.505***	-0.153
D_local	0.531**	-0.204
D_supplycut	-2.746***	-0.421
DELTA_SUPPLY	-0.0196***	-2.73E-14
D_sub	-0.829***	-0.149
D_subcost	0.25	-0.163
D_cancer	0.710***	-0.0993
D_bluebaby	0.0125	-0.081
D_nit	-0.656*	-0.364
D_pest	1.444***	-0.423
D_chem	-0.856***	-0.293
D_qual1	-0.284***	-0.0627
D_qual3	0.394***	-0.131
PROBA_BASE	1.140***	-0.355
D_cert_00	-0.917*	-0.483
D_cert_01	-1.000***	-0.198
D_cert_10	-0.582	-0.591
ln_INC	0.500*	-0.273
D_private	0.776***	-0.266
D_nonusers	-0.496	-0.416
D_urban	0.0901	-0.0828
D_rural	0.107	-0.207
D_Eur	-0.734***	-0.227
D_othercountry	-1.898***	-0.395
D_mail	-1.762***	-0.249
RR	-0.867*	-0.462
D_SBDC	0.439***	-0.133
D_DBDC	0.345**	-0.169
D_PC	0.486	-0.299
D_tax	0.105	-0.642
D_taxreall	0.979***	-0.249
D_rate	-0.198	-0.358
D_bond	0.737	-0.657
D_year	0.692*	-0.402
D_indef	0.581	-0.906
DURATION	0.0871	-0.114
D_zeros_excl	0.832***	-0.193
TIMETREND	-0.0402***	-0.0122
Constant	4.167*	-2.309
Random-effects		
σsurvey	$2.72\ 10^{-12}$***	($5.09\ 10^{-12}$)
σresidual	0.300***	-0.033
Observations	176	

	World	
	Coef.	Robust Std.Er.
D_supply	1.044***	-0.143
D_supply_envt	1.140***	-0.0464
D_protec	-0.952***	-0.225
D_eswtp	0.505***	-0.153
D_local	0.531**	-0.204
D_supplycut	-2.746***	-0.421
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D_subcost	0.25	-0.163
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D_bluebaby	0.0125	-0.081
D_nit	-0.656*	-0.364
D_pest	1.444***	-0.423
D_chem	-0.856***	-0.293
D_qual1	-0.284***	-0.0627
D_qual3	0.394***	-0.131
PROBA_BASE	1.140***	-0.355
D_cert_00	-0.917*	-0.483
D_cert_01	-1.000***	-0.198
D_cert_10	-0.382	-0.391
ln_INC	0.500*	-0.273
D_private	0.776***	-0.266
D_nonusers	-0.496	-0.416
D_urban	0.0901	-0.0828
D_rural	0.107	-0.207
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D_PC	0.486	-0.299
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Random-effects		
σsurvey	$2.72\ 10^{-12}$***	($5.09\ 10^{-12}$)
σresidual	0.300***	-0.033
Observations	176	

Resource, pollution and policy characteristics

Meta-regression

	World	
	Coef.	Robust Std.Er.
Type of good valued:		
D_watersupply	1.044***	-0.143
D_watersupply_environmt	1.140***	-0.0464
D_protection	-0.952***	-0.225
D_prevent_welfare_loss	0.505***	-0.153
D_local	0.531**	-0.204
Outcomes of the pollution:		
D_supply_cut	-2.746***	-0.421
DECREASE_SUPPLY	0.0196***	-2.73E-14
D_substitutes	-0.829***	-0.149
D_substitutes_cost	0.25	-0.163
D_cancer	0.710***	-0.0993
D_bluebaby	0.0125	-0.081

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Meta-regression

	World	
	Coef.	Robust Std.Er.
Pollutant:		
D_nitrate	-0.656*	-0.364
D_pesticides	1.444***	-0.423
Quality level:		
D_qual_irrigation	-0.284***	-0.0627
D_qual_very_good	0.394***	-0.131
Uncertainty:		
PROBA_BASELINE	1.140***	-0.355
D_base0_policy0	-0.917*	-0.483
D_base0_policy1	-1.000***	-0.198
D_base1_policy0	-0.582	-0.591

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	World	
	Coef.	Robust Std.Er.
D_supply	1.044***	-0.143
D_supply_envt	1.140***	-0.0464
D_protec	-0.952***	-0.225
D_eswtp	0.505***	-0.153
D_local	0.531**	-0.204
D_supplycut	-2.746***	-0.421
DELTA_SUPPLY	-0.0196***	-2.73E-14
D_sub	-0.829***	-0.149
D_subcost	0.25	-0.163
D_cancer	0.710***	-0.0993
D_bluebaby	0.0125	-0.081
D_nit	-0.656*	-0.364
D_pest	1.444***	-0.423
D_chem	-0.856***	-0.293
D_qual1	-0.284***	-0.0627
D_qual3	0.394***	-0.131
PROBA_BASE	1.140***	-0.355
D_cert_00	-0.917*	-0.483
D_cert_01	-1.000***	-0.198
D_cert_10	-0.382	-0.391
ln_INC	0.500*	-0.273
D_private	0.776***	-0.266
D_nonusers	-0.496	-0.416
D_urban	0.0901	-0.0828
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D_PC	0.486	-0.299
D_tax	0.105	-0.642
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σresidual	0.300***	-0.033
Observations	176	

Population of beneficiaries characteristics

Meta-regression

	World	
	Coef.	Robust Std.Er.
Income:		
ln_INCOME	0.500*	-0.273
Water supply:		
D_private_wells	0.776***	-0.266
D_non_users	-0.496	-0.416
Location:		
D_urban_only	0.0901	-0.0828
D_rural_only	0.107	-0.207
D_Europe	-0.734***	-0.227
D_other_country	-1.898***	-0.395

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	World	
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D_qual1	-0.284***	-0.0627
D_qual3	0.394***	-0.131
PROBA_BASE	1.140***	-0.355
D_cert_00	-0.917*	-0.483
D_cert_01	-1.000***	-0.198
D_cert_10	-0.582	-0.591
ln_INC	0.500*	-0.273
D_private	0.776***	-0.266
D_nonusers	-0.496	-0.416
D_urban	0.0901	-0.0828
D_rural	0.107	-0.207
D_Eur	-0.734***	-0.227
D_othercountry	-1.898***	-0.395
D_mail	-1.762***	-0.249
RR	-0.867*	-0.462
D_SBDC	0.439***	-0.133
D_DBDC	0.345**	-0.169
D_PC	0.486	-0.299
D_tax	0.105	-0.642
D_taxreall	0.979***	-0.249
D_rate	-0.198	-0.358
D_bond	0.737	-0.657
D_year	0.692*	-0.402
D_indef	0.581	-0.906
DURATION	0.0871	-0.114
D_zeros_excl	0.832***	-0.193
TIMETREND	-0.0402***	-0.0122
Constant	4.167*	-2.309
Random-effects		
σsurvey	$2.72\ 10^{-12}$***	($5.09\ 10^{-12}$)
σresidual	0.300***	-0.033
Observations	176	

Methodological characteristics

Meta-regression

	World	
	Coef.	Robust Std.Er.
Survey characteristics:		
D_mail_survey	-1.762***	-0.249
RESPONSE_RATE	-0.867*	-0.462
WTP elicitation format:		
D_SB_dichotomous	0.439***	-0.133
D_DB_dichotomous	0.345**	-0.169
D_payment_card	0.486	-0.299
Payment vehicle:		
D_tax	0.105	-0.642
D_tax_reallocation	0.979***	-0.249
D_water_rate	-0.198	-0.358
D_bond	0.737	-0.657
D_yearly	0.692*	-0.402
D_indef	0.581	-0.906
DURATION	0.0871	-0.114
Estimation procedure:		
D_zeros_excluded	0.832***	-0.193
TIMETREND	-0.0402***	-0.0122

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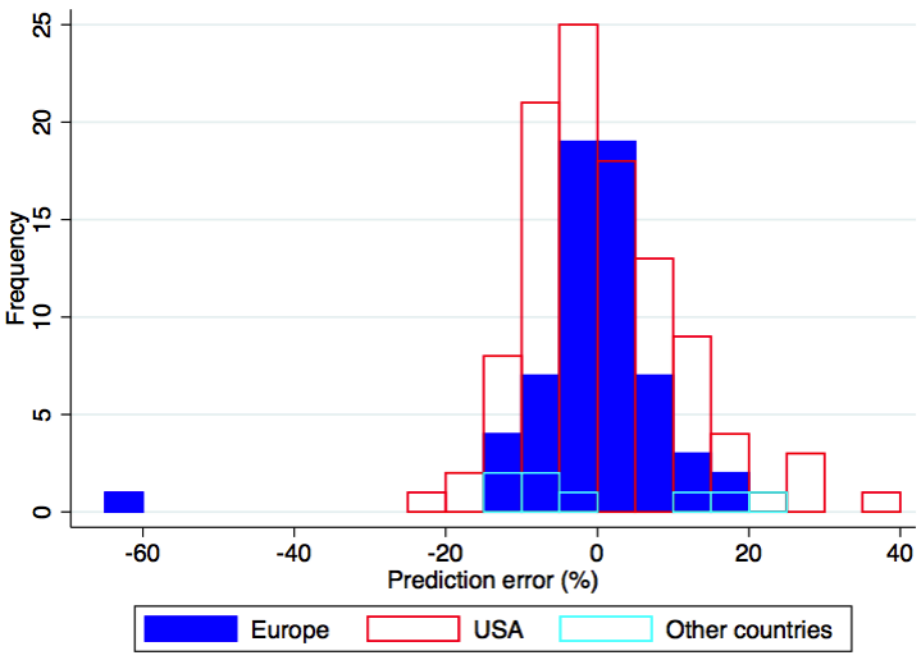
Leave one out cross validation

- Prediction error:
  - Leave one out model estimation: β_{N-i}
  - Predict: $\hat{y}_i = \beta_{N-i} x_i$; and compare with observation: y_i
  - ➢ Prediction error: $e_i = (\hat{y}_i - y_i)/y_i \times 100$



- Mean absolute prediction error:

7.3 %

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Relative contribution of the groups of variables

- OLS model with survey-clustered robust standard errors:

	(1)	(2)	(3)	(4)
Resource, pollution, policy variables	✓	✓	✓	✓
Uncertainty variables		✓	✓	✓
Population of beneficiaries variables			✓	✓
Methodological variables				✓
Timetrend	✓	✓	✓	✓
Observations	176	176	176	176
R^2	**0.62**	**0.68**	**0.85**	**0.94**
***F-test* for added variables**		F=2.86 $p<0.05$	F=41.38 $p<0.01$	F=21.32 $p<0.01$

+6% +17% +9%

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