WATER RESOURCES RESEARCH, VOL. 46, W11543, doi:10.1029/2009WR009065, 2010

Environmental, political, and economic determinants of water quality monitoring in Europe

Lucas Beck,[1] Thomas Bernauer,[1] and Anna Kalbhenn[1]

Received 31 December 2009; revised 26 August 2010; accepted 8 September 2010; published 23 November 2010.

[1] Effective monitoring is essential for effective pollution control in national and international water systems. To what extent are countries' monitoring choices driven by environmental criteria, as they should be? And to what extent are they also influenced by other factors, such as political and economic conditions? To address these questions, we describe and explain the evolution of one of the most important international environmental monitoring networks in Europe, the one for water quality, in the time period 1965–2004. We develop a geographic information system that contains information on the location of several thousand active monitoring stations in Europe. Using multivariate statistics, we then examine whether and to what extent the spatial and temporal clustering of monitoring intensity is driven by environmental, political, and economic factors. The results show that monitoring intensity is higher in river basins exposed to greater environmental pressure. However, political and economic factors also play a strong role in monitoring decisions: democracy, income, and peer pressure are conducive to monitoring intensity, and monitoring intensity generally increases over time. Moreover, even though monitoring is more intense in international upstream-downstream settings, we observe only a weak bias toward more monitoring downstream of international borders. In contrast, negative effects of European Union (EU) membership and runup to the EU's Water Framework Directive are potential reasons for concern. Our results strongly suggest that international coordination and standardization of water quality monitoring should be intensified. It will be interesting to apply our analytical approach also to other national and international monitoring networks, for instance, the U.S. National Water-Quality Assessment Program or the European Monitoring and Evaluation Program for air pollution.

Citation: Beck, L., T. Bernauer, and A. Kalbhenn (2010), Environmental, political, and economic determinants of water quality monitoring in Europe, *Water Resour. Res.*, *46*, W11543, doi:10.1029/2009WR009065.

1. Introduction

[2] International environmental data sets are widely used by policy makers and their scientific advisors for "diagnostic" and "therapeutic" purposes, that is, for identifying environmental problems, designing new policies, and implementing them [*Kim and Platt*, 2008]. Many users of such data tend to assume that environmental conditions, whenever measured, are measured with the best scientific methods and tools available and that existing data for any given location and environmental parameter at a specific point in time are of reasonably good quality and are reported accurately to international agencies. However, a cursory look at various sources of environmental information reveals that data coverage for most environmental indicators varies very strongly across countries and time. The main reason is that international data sets rely primarily on information that governments and their agents decide to collect and make available. The willingness and/or ability of governments to do so clearly differ across environmental issues, countries, and time. While this may appear obvious, we do not know of any systematic quantitative study that has examined this issue in detail.

[3] In this paper we are interested in whether the intensity of water quality monitoring (measured in our study in terms of density of active monitoring stations) is driven solely by environmental factors, as it should be, or whether political and economic factors also play a role. While this question is interesting from an academic viewpoint because it illuminates the science-society linkage in water management, it is also important from a policy perspective. Water pollution data are very important in influencing international policy making and investment with respect to water resources. To the extent monitoring intensity is influenced by political and economic factors, water quality data are likely to be biased. If so, there is a need for effective policies designed to correct for such biases because accurate and representative water quality data are essential for effective international water management.

[4] We focus on international water quality monitoring in Europe during 1965–2004. We chose Europe for two reasons. First, sufficient data on the spatial and temporal

[1]Center for Comparative and International Studies and Institute for Environmental Decisions, ETH Zurich, Zurich, Switzerland.

0043-1397/10/2009WR009065

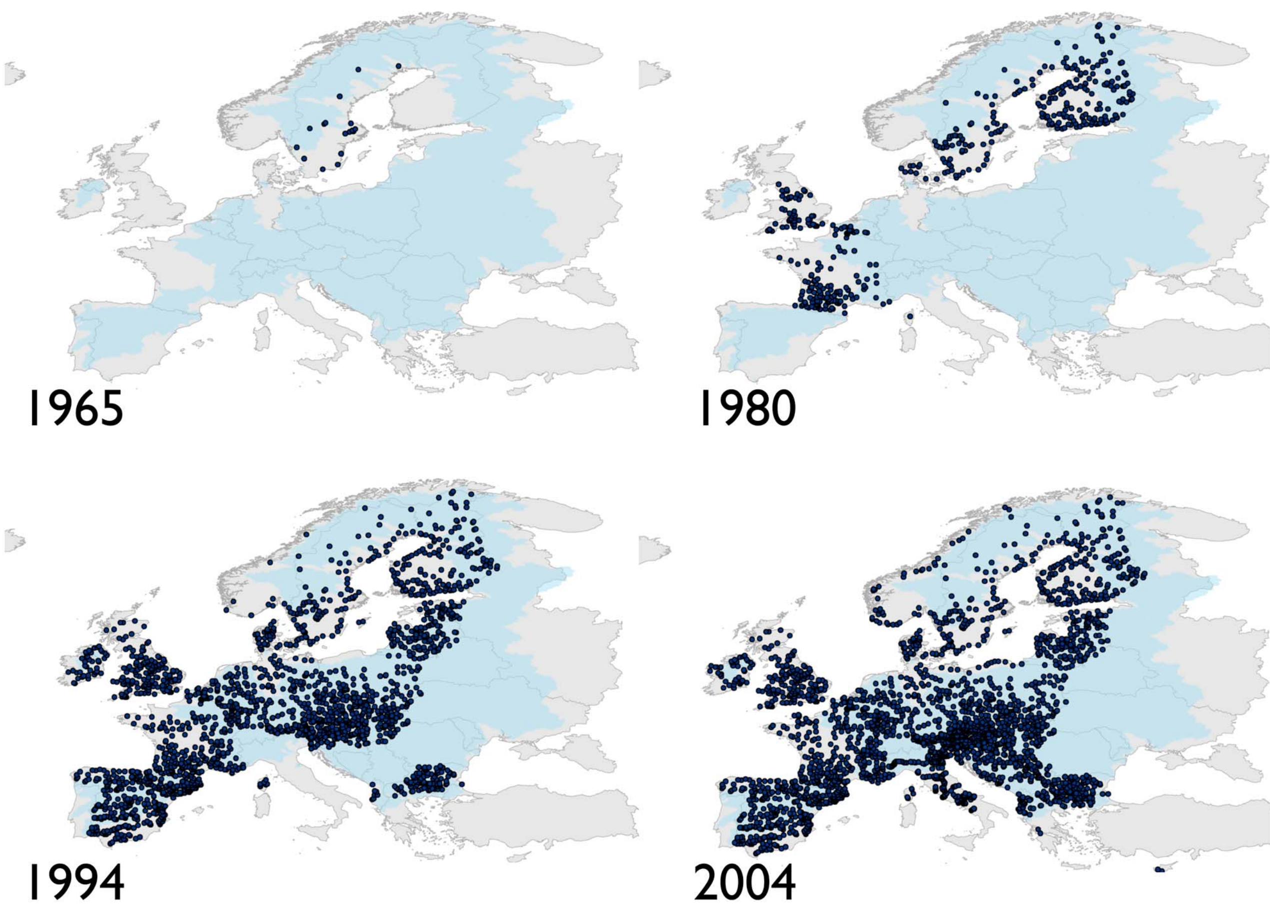

Figure 1. Evolution of the European water quality monitoring network (based on information from http://www.eea.europa.eu/themes/water/). Snapshots for 4 years in the time period 1965–2005. The statistical analysis in section 4.4 uses annual data. National boundaries are marked in gray, and international river basins are marked in blue. Data for Portugal and Switzerland are not available. See also Table 2 and Figure 4 for data definitions. An animation showing the density of monitoring locations over time (yearly) is included in the auxiliary material.

distribution of water quality monitoring activity in a rather large number of countries and years are available for this continent. Second, the European Union has made concerted efforts to standardize water quality monitoring. In the European Environment Agency's (EPA) own words: "Through Eionet [the EEA's reporting system], the EEA brings together environmental data from individual countries concentrating on the delivery of timely, nationally validated, high-quality data…. This information serves to support environmental management processes, environmental policy-making and assessment, and public participation at national, European and global levels" (European Environment Agency (EEA), The Water Information System for Europe (WISE), 2007, http://water.europa.eu/en/welcome). This implies that we should observe weaker effects of nonenvironmental factors on monitoring activity. In other words, if nonenvironmental factors play a significant role in monitoring activity in Europe, they are likely to play an even stronger role in poorer and internationally less coordinated settings.

[5] Though our empirical focus is on Europe, our analytical approach could also be used to examine the evolution of other international environmental monitoring networks, for instance, the one established in the context of the international Convention on Long-Range Transboundary Air Pollution (European Monitoring and Evaluation Programme (EMEP), http://www.emep.int/), which involves countries in Europe and North America, or national environmental monitoring programs, such as the U.S. National Water-Quality Assessment Program (U.S. Geological Survey, http://water.usgs.gov/nawqa/).

2. Spatial and Temporal Clustering of Monitoring Activity

[6] According to data provided by the European Environmental Agency, the international organization responsible for collecting and analyzing such data in Europe, water quality monitoring varies both spatially and over time (Figure 1). Some patterns, such as the increasing density of monitoring activity in most countries over time and its expansion to eastern Europe after the end of the Cold War, are obvious. More subtle patterns and their driving forces are identified by means of a statistical analysis in section 4.4.

[7] Considering the development of monitoring intensity in Europe over time, measured by the average number of active monitoring stations per year in all river systems as well as in domestic and international river systems (see Table 2 and Figure 4 for data definitions), international

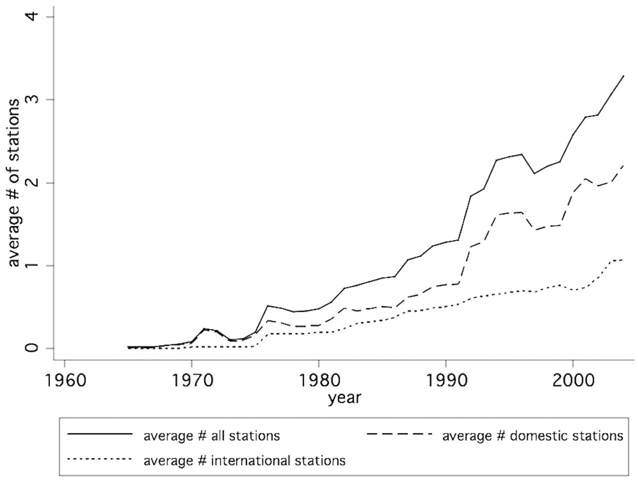

Figure 2. Monitoring intensity in domestic and international river basins. Average number of active monitoring stations per year for three categories of stations: all, domestic, and international. International monitoring stations are defined as stations located in an international river system within a distance of 10 km from an international border. All other stations are defined as domestic monitoring stations (see Table 2 and Figure 4 for data definitions).

monitoring, i.e., monitoring activity close to international borders, has increased over time, albeit at a somewhat slower rate than monitoring in domestic river systems (Figure 2).

3. Environmental, Political, and Economic Determinants of Monitoring Intensity

[8] On the basis of a large body of literature in political science and economics that compares environmental policies across countries and seeks to explain variation in this respect [cf. *Sprinz and Vaahoranta*, 1994; *Grossman and Krueger*, 1995; *Jahn*, 1998; *Neumayer*, 2002a, 2002b; *Neumayer and De Soya*, 2005; *Ward*, 2006; *Li and Reuveny*, 2006], we expect three types of factors to influence the intensity of monitoring activity in our case: (1) environmental or geographical, (2) political, and (3) economic factors (Table 1).

4. Data and Methods

[9] We first built a geographic information system (GIS) that includes information on the locations of several thousand monitoring stations in Europe. We then constructed an indicator for monitoring intensity (the outcome to be explained), merged these data to data for the explanatory variables shown in Table 1, and used statistical methods to test the empirical relevance of expected effects.

4.1. GIS Data

[10] We relied on EEA data for the locations of monitoring stations as well as data from other sources to set up a GIS. First, we defined and distinguished between national and international watersheds and rivers by overlaying hydrological maps and political (country) boundaries. International watersheds and rivers are defined as aquatic systems that have a common terminus, in most cases an outlet to the ocean, and are shared by two or more countries. National watersheds and rivers also have a common terminus but are located entirely within a single country. Second, we identified the positions of the monitoring stations with reference to rivers, watersheds, and political boundaries. This includes the riparian position, distance to international boundaries, and also the positioning in the same basin relative to other stations. In particular, we distinguished national and international monitoring stations and monitoring stations in international upstream-downstream settings from stations in other geographic settings. International monitoring stations are defined as stations located in an international river basin within a distance of up to 10 km from an international border. Monitoring stations in international upstream-downstream

Table 1. Environmental, Economic, and Political Determinants of Monitoring Intensity

Explanatory Factor	Expected Effect on Monitoring	Argument[a]
Environmental and geographical factors	Environmental pressure: positive	Environmental pressure leads to more public demand for stricter environmental policies; such policies require more information on pollution
	International upstream-downstream setting: positive	Greater attention to water pollution because of greater international conflict potential
Political factors	Democracy: positive	Greater demand for and governmental supply of environmental policies; better ability of population to acquire information about environmental risks, organize politically, and express demands for environmental protection
	EU membership: positive	EU environmental regulation, control capacity of EU institutions, pressure by greener EU countries on other member states
	Runup to EU Water Framework Directive (WFD): positive	WFD includes provisions on monitoring and pollution control
	Monitoring behavior of peer group: positive	Countries pay attention to what other countries do and behave in similar ways
	Membership in international institutions: positive	Facilitates learning from other countries; increases reputational costs of being a laggard
Economic factors	Income level: positive	Demand for green policies and technical and financial capacity to implement such policies are higher in rich countries
	Trade openness: ambiguous	Positive: trade tends to foster income growth and thus creates positive income related effects on monitoring; it also exposes countries to green demands by international trade partners. Negative: concerns over economic competitiveness reduce investment in environmental policies

[a]Noted here, in very brief form, are the underlying causal arguments. These arguments are discussed in greater detail in the auxiliary material.

Figure 3. International river basins in Europe, shown in blue, for which monitoring activity is examined. The countries that are riparian in these basins are listed in the auxiliary material. Domestic river basins, which are also covered by the analysis, are, by implication, located outside the area covered by international basins.

settings are a subset of international monitoring stations. They are located on an international river that crosses from one country (upstream) into another country (downstream) within 10 km of the international border.

[11] We constructed GIS layers for water catchments and international boundaries, using information from the EEA European river catchments database (L. Bredahl and A. Sousa, European river catchments, version 1.01, European Environment Agency, Copenhagen, 2006, http://www.eea.europa.eu/data-and-maps/data/european-river-catchments) and other sources. The resulting GIS covers national and international watersheds; basins with an area of less than 1 km^2 were excluded. For GIS layers showing country borders and major rivers, we used standard data sets provided by the Environmental Systems Research Institute (ESRI Geoinformatik AG, http://esri-suisse.ch/index.html) and data from a GIS by the European Commission (GISCO). We adjusted these data for changes over time in the delineation of country boundaries, e.g., the unification of the two Germanies (Figure 3), and we added information on monitoring stations and their location. Information on locations and station properties was taken from the EEA databases operating in the context of the Eionet-Waterprocess (European Environment Agency, Waterbase-rivers, 2007, http://www.eea.europa.eu/data-and-maps/data/waterbase-rivers-5). We only included "active" monitoring stations, that is, monitoring stations from which water quality data are in fact reported to the EEA (the EEA data sets also include stations for which no pollution data are available). The EEA data do not describe the position of a station in relation to international boundaries or river geography (notably, upstream-downstream or other setting). Moreover, some station location data from the original data set (version 7) had to be adjusted manually because some reported locations did not correspond with reality or other data sets we used to cross-check the EEA data. We also found some stations that could not be attributed to any water system; we assigned these stations to a specific river basin if plausible or possible and removed the other nonattributable stations from our GIS. Some of these (and other) challenges in constructing the GIS are illustrated in the auxiliary material.[1]

[12] Information from the CCM River and Catchment Database version 1.0 (J. Vogt et al., DEG Joint Research Centre, European Commission, 2003, http://agrienv.jrc.ec.europa.eu/publications-ECpubs.htm, and Developing a pan-European database of drainage networks and catchment boundaries from a 100 metre DEM, DEG Joint Research Centre, European Commission, 2007, http://agrienv.jrc.ec.europa.eu/publications-ECpubs.htm) was used to identify the location of monitoring stations within catchments as well as partial river length and catchments. This database

[1] Auxiliary materials are available in the HTML. doi:10.1029/2009WR009065.

Table 2. Three Samples Used for the Statistical Analysis[a]

	Unit of Analysis	Dependent Variable	Population
Sample 1: all monitoring stations	River basin per country and per year	Number of monitoring stations per river basin in a given country per year	Up to 44 countries, 325 river basins, and 40 years (1965–2004)
Sample 2: domestic monitoring stations	Domestic river basin per country and per year	Number of monitoring stations located in a domestic river basin or an international river basin beyond 10 km away from the international border in a given country per year	Up to 44 countries, 323 river basins, and 40 years (1965–2004)
Sample 3: international monitoring stations	International river basin per country and per year	Number of monitoring stations located in an international river basin within a distance of 10 km from an international border in a given country per year	Up to 27 countries, 316 river basins, and 40 years (1965–2004)

[a]See also Figure 4 for illustrations of how the types of monitoring stations are defined. For the sample and time period analyzed, the number of countries varies over time (e.g., because of the unification of Germany or the disintegration of former Yugoslavia). Changes in the number of countries also have effects on the distinction of domestic and international river basins.

offers a hierarchical set of river segments and catchments, structured by hydrological feature codes based on the Pfafstetter system, which forms a basis for queries on topological relationships within the database (http://agrienv.jrc.ec.europa.eu/publications-ECpubs.htm). The CCM2 database offers additional possibilities for characterizing the relative position of monitoring stations.

4.2. Location of Monitoring Stations: Three Samples

[13] Finally, we extracted data on the location of monitoring stations from the GIS just described. Our outcome (dependent) variable captures monitoring intensity as it appears in reporting to the EEA monitoring network (more details in the auxiliary material). Monitoring intensity is measured in terms of monitoring station density in a particular geographic space per year. The resulting indicator is a count variable (0, 1, 2, 3, …) that measures, for instance, the number of monitoring stations in a given (domestic or international) catchment in a given country (e.g., Netherlands) in a given year. Note that in our context the term station density differs somewhat from conventional notions, since we do not normalize the number of stations by geographic area. However, we use river basin area as an explanatory variable in the statistical analysis because the number of stations in larger river basins is likely to be higher.

[14] Additional geographic criteria are used to measure station density in what we define as domestic and international locations. This results in three samples (Table 2 and Figure 4) of monitoring stations on which we test the expected effects of the three groups of explanatory variables. The first sample measures station density in each river basin of a country per year. The unit of observation in the resulting (tabular) data set for this sample is the number of monitoring stations located in a specific river basin (e.g., the river Douro) on a country's territory (e.g., Spain) in a spe-

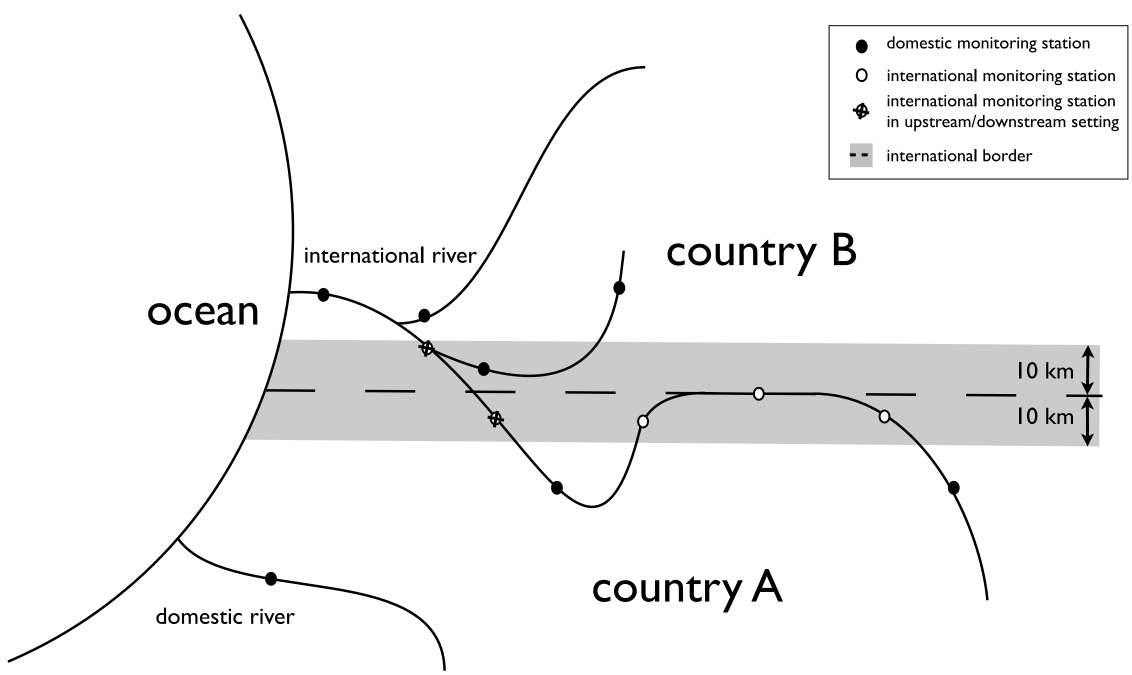

Figure 4. Identification of domestic, international, and international upstream-downstream monitoring stations.

Table 3. Explanatory Variables and Data Used for the Statistical Analysis, Grouped by Environmental and Geographical Factors, Political Factors, and Economic Factors[a]

Variable	Description	Source
Environmental and geographical factors	Population density: we use population data from the Landscan Global Population Data set. Time series from 1965 to 2005 are estimated using UN and Eurostat national population estimates that are based on national census statistics. The resulting data set includes spatially disaggregated population estimates since 1965 with a spatial resolution of 30″ × 30″.	Landscan (http://www.ornl.gov/sci/landscan/index.shtml), United Nations Statistics Division (Statistical yearbooks, 2008, http://unstats.un.org/unsd/demographic/products/dyb/dyb2.htm), Eurostat (Statistical database of the European Commission, 2009, http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/)
	Agricultural land use: land principally occupied by agriculture, with significant areas of natural vegetation	European Environment Agency (Corine Land Cover 2000 (CLC2000) seamless vector database, 2007, http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-1)
	Basin area in country	Vogt et al. (http://agrienv.jrc.ec.europa.eu/publications-ECpubs.htm)
	River type: international upstream-downstream setting, other geographic setting (dummy variable). These are settings in which a river crosses from one country into another rather than flowing along an international border or corresponding to some other geographic pattern (e.g., shared lakes). See illustration in Figure 4.	Own data
Political factors	Democracy: revised combined Polity IV score. The Polity IV project codes states' institutional characteristics. The Polity IV score is an indicator ranging from −10 to 10, where −10 denotes most autocratic and 10 most democratic countries.	J. Pevehouse et al. (Intergovernmental organizations 1815–2000: A new correlates of war data set, 2004, http://www.correlatesofwar.org/Datasets.htm) and K. S. Gleditsch (Modified Polity P4 and P4D data, version 3.0, 2008, http://privatewww.essex.ac.uk/~ksg/polity.html)
	EU membership	http://europa.eu/abc/europen_countries/index_en.htm
	Runup to EU WFD (in force since the year 2000): dummy variables for the years 1998, 1999, 2000	Own coding
	Peer pressure: average number of active monitoring stations in countries in the same income group; income groups are defined as low, middle, high, according to the empirical sample distribution	Own coding; income data from A. Heston et al. (Penn World Table version 6.2, Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, 2006, http://pwt.econ.upenn.edu/php_site/pwt_index.php)
	Membership in intergovernmental organizations (IGO)	Pevehouse et al. data set
	Global environmental policy involvement: cumulative number of ratifications of global environmental treaties	Own data generated from data provided by Ronald Mitchell and Center for International Earth Science Information Network (http://www.ciesin.org/)
Economic factors	Income: GDP per capita	Heston et al. income data and *Gleditsch* [2002]
	Trade openness: Ratio of the sum of exports and imports divided by GDP	

[a]Descriptive statistics for all variables and a list of countries included in the samples can be found in the auxiliary material.

cific year (e.g., 1988). The second sample measures station density in each domestic river basin of a country per year. Our definition of domestic covers all areas of a river basin except those areas in an international river basin that are located within a distance of 10 km from an international border (see third sample). The unit of observation in the resulting (tabular) data set for this sample is the number of monitoring stations located in a specific river basin (e.g., Danube) on a country's territory (e.g., Romania, more than 10 km away from an international border) in a specific year (e.g., 1988). The third sample measures station density in each international water catchment of a country per year. Our definition of international includes all stations located in an international river system within a distance of 10 km from an international border [*Ganser*, 2007]. An international river system is a catchment area that extends beyond national borders and involves two or more countries. That is, our geographic notion of international, in this context, includes only a particular part of any given international river basin, namely, the part close to an international border. The logic behind this particular definition is that most pollutants do not travel very far; hence, monitoring stations within 10 km of an international border capture pollution flows that may travel from one country to another [*Bernauer and Kuhn*, 2010]. These criteria imply that the unit of observation in the resulting (tabular) data set for this sample is the number of monitoring stations located in a specific international river basin (e.g., the Rhine) on a country's territory (e.g., France) within 10 km of an international border (e.g., the border between France and Germany) in a specific year (e.g., 1988). With these three samples we are able to examine whether there are geographical effects in the data. Yet another potential geographic effect, namely, location of monitoring stations in an international upstream-downstream setting (see Table 3 and Figure 4), is examined not through sample construction and comparison of statistical effects across models for different samples but by direct inclusion of an explanatory variable in the multivariate models.

4.3. Data for Explanatory Variables

[15] Data for the explanatory variables are taken from various sources (Table 3).

Table 4. Main Results of Multivariate Negative Binomial Regressions With Country Fixed Effects[a]

	Model 1 All Stations		Model 2 Domestic		Model 3 International	
	β	$E(y\|x)$	β	$E(y\|x)$	β	$E(y\|x)$
Environmental and Geographic Factors						
Population density	0.171 (0.013)***	1.187 (0.015)***	0.150 (0.016)***	1.162 (0.018)***	0.084 (0.028)***	1.087 (0.030)***
Agricultural land use	−0.000 (0.000)***	1.000 (0.000)***	−0.000 (0.000)***	1.000 (0.000)***		
Basin area	0.000 (0.000)***	1.000 (0.000)***	0.000 (0.000)***	1.000 (0.000)***	0.000 (0.000)***	1.000 (0.000)***
River type	0.881 (0.068)***	2.414 (0.165)***	0.089 (0.106)	1.093 (0.116)	2.668 (0.126)***	14.407 (1.813)***
Political Factors						
Democracy	0.158 (0.011)***	1.171 (0.013)***	0.189 (0.014)***	1.208 (0.017)***	0.093 (0.021)***	1.098 (0.023)***
EU member	−0.789 (0.078)***	0.454 (0.035)***	−0.678 (0.091)***	0.508 (0.046)***	−0.530 (0.193)***	0.588 (0.113)***
1998	−0.297 (0.092)***	0.743 (0.068)***	−0.145 (0.110)	0.865 (0.095)	−0.510 (0.226)**	0.601 (0.136)**
1999	−0.370 (0.092)***	0.691 (0.064)***	−0.266 (0.114)**	0.766 (0.087)**	−0.392 (0.212)*	0.675 (0.143)*
2000	−0.292 (0.089)***	0.747 (0.066)***	−0.254 (0.106)**	0.776 (0.082)**	−0.210 (0.203)	0.811 (0.164)
Income group	0.009 (0.002)***	1.009 (0.002)***	0.024 (0.004)***	1.025 (0.004)***	0.024 (0.008)***	1.025 (0.008)***
IGO membership	−0.008 (0.004)*	0.992 (0.004)*	−0.015 (0.005)***	0.985 (0.005)***	−0.005 (0.010)	0.995 (0.010)
MEA membership	0.003 (0.002)	1.003 (0.002)	0.004 (0.002)*	1.004 (0.002)*	−0.001 (0.005)	0.999 (0.005)
Economic Factors						
Income	1.513 (0.128)***	4.539 (0.579)***	1.592 (0.153)***	4.915 (0.750)***	1.678 (0.306)***	5.353 (1.640)***
Trade openness	−0.000 (0.000)***	1.000 (0.000)***	−0.000 (0.000)	1.000 (0.000)	0.000 (0.000)	1.000 (0.000)
Overall Statistical Results						
Year	0.078 (0.006)***	1.081 (0.007)***	0.068 (0.007)***	1.071 (0.008)***	0.073 (0.016)***	1.076 (0.017)***
Constant	−171.155 (12.282)***		−153.795 (14.235)***		−164.265 (31.225)***	
Observations	10332	10332	10260	10260	5526	5526
Number of groups	28	28	27	27	25	25
Log-likelihood	−8395.415		−6288.238		−1209.752	

[a]Here β is the regression coefficient. Standard errors are shown in parentheses (one asterisk, significant at 10%; two asterisks, significant at 5%; three asterisks, significant at 1%). $E(y|x)$ is the expected value of the dependent variable given our set of independent variables, in this context often called the incident rate ratio. It allows for an interpretation of substantive statistical effects. For example, the coefficient on democracy is $\beta = 0.158$ (***), with $E(y|x) = 1.171$. This means that each unit increase on the democracy indicator (i.e., an increase by 5% on the sample range for the democracy scale) is predicted to increase monitoring station density by around 17% (i.e., percent change = $E(y|x) - 1 = \exp(\beta) - 1$), while all other explanatory variables are held at their respective mean value. For explanatory variables that are not dummy variables and whose units are not intuitive (such as the democracy scale), we estimate the effect of a 10% increase within the empirical sample range of the respective explanatory variable on station density (also in percentages). To simplify the discussion, we present substantive effects only for the sample including all monitoring stations.

4.4. Statistical Method

[16] The dependent (outcome) variable measures variation in the number of monitoring stations across river basins and countries over time (per year). The most appropriate statistical technique for analyzing such data are multivariate event count models [cf. *Long*, 1997, pp. 230ff.]. Because of overdispersion we opt for negative binomial rather than Poisson regressions. Results from robustness checks using the quasi maximum likelihood approach suggested by *Wooldridge* [2009] are shown in the auxiliary material. Our main results survive.

[17] Defining the dependent variable in terms of the number of monitoring stations per country-river basin-year raises questions of proportionality and context. For example, some countries' water systems are largely confined to the respective national territory; other countries are located in international river basins; and countries differ very much in geographical size. Rather than controlling for many such effects (in which we have little direct interest) by defining monitoring activity proportional to country size, we include country fixed effects. The fixed effects procedure controls for unobserved, time-invariant unit heterogeneity. In addition, we add a year counter to control for general time trends in monitoring activity.

5. Results

[18] As to the environmental and geographical factors, the results indicate that environmental pressure plays a significant role in monitoring decisions (Table 4). Population density has a positive and statistically significant effect on monitoring in all three samples. An increase by 10% of population density (within the empirical sample range) is associated with a 23% increase in monitoring station density. This indicates that countries are more likely to monitor in basins that experience greater environmental pressure. The same holds for larger river basins, even though the substantive effect is very small: a 10% increase in river basin size is associated with a station density increase that is positive but very close to zero. Monitoring is less intense when the share of agricultural land use is higher, even though agriculture is usually a major source of water pollution by nutrients. A 10% increase in agricultural land use is associated with a 7% decrease in station density. However, the positive effect of population density is statistically more robust (and also larger in substantive terms) than the negative effect of agricultural land use. By and large, therefore, it appears that environmental pressure is associated with increasing intensity of monitoring.

[19] We observe more monitoring in international upstream-downstream locations than in other international locations (the coefficient on this variable in Table 4 is positive and statistically significant for models 1 and 3). In substantive terms, station density is 141% higher in international upstream-downstream settings. The positive effect of international upstream-downstream settings is likely to reflect the fact that such settings are usually more prone to international conflict because they lend themselves to "exporting" pollution from one country to another (beggar-thy-neighbor behavior [e.g., *Bernauer and Kuhn*, 2010]). Hence, they attract greater attention from policy makers and their agents, who decide on the location of monitoring

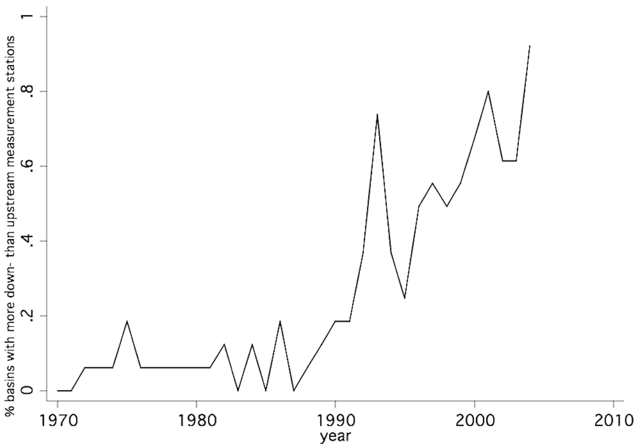

Figure 5. Monitoring activity downstream and upstream of international borders. The monitoring stations taken into account here include those located in international boundary crossing (upstream-downstream) water systems. The vertical axis shows the percentage of international upstream-downstream basins in which there are more monitoring stations located downstream than upstream within 10 km of the international border.

activity. This implies that once we consider the upstream or downstream location of monitoring stations within a given international border situation explicitly, such beggar-thy-neighbor behavior is rather weak (Figure 5). We had suspected that we would, in international upstream-downstream settings, find more monitoring downstream of the international border, the assumption being that downstream countries have an incentive to demonstrate their victim status, whereas upstream countries have an incentive to ignore their pollution transfers to other countries. The percentage share of international upstream-downstream river basins where more monitoring takes place in the downstream rather than the upstream country exhibits a sharp increase over time but is small in absolute terms (less than 1%).

[20] As to the political factors, democracy has the expected positive effect on monitoring intensity. An increase in democracy of 2 points on the democracy indicator ranging from −9 to +10 is associated with a 33% increase in station density. Surprisingly, the effect of EU membership on monitoring intensity is statistically significant and negative. This effect shows up in all three models, and our robustness checks confirm that this effect is very unlikely to be a statistical artifact. EU membership is associated with a 55% decrease in station density for the sample including all stations. Similarly, the effects of the year dummies for 1998, 1999, and 2000 suggest that in the runup to the Water Framework Directive, which entered into force in the year 2000, monitoring intensity declined. We discuss potential causes of this finding in section 6. As to peer group pressure, we observe that if countries in a given income group engage in more intensive monitoring, other countries in that group tend to follow this trend. A 10% increase in this explanatory variable is associated with an 8% increase in station density. The effects of membership in international organizations and global environmental agreements are significant only in one of the three samples, and one of the significant effects cuts against the expected positive effect. In that case, an increase in membership by 10% is associated with a 10% decrease in station density. This inconclusive result for memberships in intergovernmental organizations (IGOs) and multilateral environment agreements (MEAs) is not surprising, however, given that these variables are multicollinear with GDP, democracy, trade openness, and membership in multilateral environmental agreements.

[21] With respect to the economic factors, income has the expected positive effect: richer countries engage in more monitoring. A 10% increase in income is associated with a 120% increase in station density. The effect of trade openness is statistically significant and negative for the sample including all stations (a 10% increase in trade openness is associated with a 6% decrease in station density) but insignificant for the other two samples. The time trend effect is significant and positive in all three models, reflecting more monitoring over time. Station density increases by around 8% per year.

[22] We have examined whether our main results are sensitive to changes in the statistical approach and whether the results differ when we use a different data structure (a dyadic data set; see auxiliary material). With two minor exceptions, which in fact turn out to offer more rather than less support for the effects we expected, the main results survive when employing a different statistical approach (the results are shown in the auxiliary material). First, when we use a quasi maximum likelihood approach, trade openness becomes statistically significant and positive in most of the samples. This result, in contrast to the results produced by our main models, supports our initial expectation (see Table 1). Second, the coefficient on agricultural land use is not robust across different statistical specifications.

[23] In an additional robustness check, we take into account bilateral relations between country pairs (i.e., dyads) to assess whether variables measuring joint riparian characteristics (i.e., joint membership in international organizations or bilateral trade interdependencies) have an effect on monitoring behavior (the results are shown in the auxiliary material). In contrast to the results for our main models, the effects of both joint IGO membership and agricultural land use become positive, which supports our initial expectations (Table 1). The effect of membership in global environmental regimes, in contrast, is statistically significant and negative. Again, these unstable effects might be due to the rather high correlation between memberships in international organizations and multilateral environmental agreements (see correlation tables in auxiliary material, Text S1). Other results from our main statistical models (Table 4, notably those that are consistent across samples and in accordance with our expectations) survive in the dyadic setup.

6. Discussion

[24] Describing and explaining the location and nature of water quality monitoring can offer important insights into environmental policies at national and international levels. Water quality data, on which this paper has focused, are important not only for diagnostic purposes when designing policies [*Kim and Platt*, 2008]. As demonstrated by the EEA network examined in this paper, the U.S. National Water-Quality Assessment Program (http://water.usgs.gov/nawqa/), and other monitoring programs around the world (e.g., EMEP, http://www.emep.int/), is also highly relevant for

implementing national and international water policies. Assuming that monitoring behavior is unlikely to follow a strictly environmental logic, we have tested several hypotheses that seek to account for temporal and spatial clustering of monitoring activity also in terms of political and economic factors.

[25] We observe that monitoring intensity is higher in locations exposed to greater environmental pressure. In addition, political and economic factors have an effect on monitoring. On a positive note (from an environmental viewpoint), democracy, income, and peer pressure are conducive to monitoring, and monitoring intensity generally increases over time. Moreover, even though monitoring is more intense in international upstream-downstream settings, we observe only a weak bias toward more monitoring downstream of international borders.

[26] In contrast, negative effects of EU membership and runup to the Water Framework Directive (WFD) are potentially reasons for concern. One interpretation for the unexpected EU effect is that, at the beginning of our period of analysis, most of the countries in our data set were not yet members of the EU but many were aspiring to become EU members. Countries seeking to join the EU may thus have engaged in greater efforts to "establish credit" with the EU by increasing their monitoring intensity [e.g., *Skjærseth and Wettestad*, 2006]. Once they have joined the EU, political pressure to engage in more monitoring may, paradoxically, be smaller.

[27] The EEA has no legal enforcement capacity that could be used to enhance monitoring and data reporting [*Hedemann-Robinson*, 2006]. For example, it cannot take EU member countries to court (in this case, the European Court of Justice) if they supply poor quality data or even no data to the EEA. From a strictly EU legal viewpoint, therefore, monitoring and reporting have, until the WFD entered into force in the year 2000, taken place on a voluntary basis (though they may have, and probably have, taken place in response to domestic legal requirements) [*Chave*, 2001]. Whereas reporting efforts might thus reflect countries' attempts to become "good European citizens," enforcement has to rely on naming and shaming of laggard countries. This is precisely the aim of (public) EEA reports that assign smileys and frowneys to each country.

[28] Our results strongly suggest that international coordination and standardization of water quality monitoring should be intensified, and those who aggregate locally produced environmental data into national averages or use such averages for scientific research or policy making should be alert to potential biases, such as the ones studied in this paper. International agencies, such as the EEA, should invest much more in standardizing and controlling data quality as well as naming and shaming, but also in helping countries that perform poorly in environmental monitoring. The EEA, for example, has taken some, albeit still very gentle, steps in this direction by publishing reports that rate the quality of countries' environmental monitoring (see auxiliary material; section S10 and Figure S5 in Text S1). Similar efforts are being undertaken by the EU Commission in the context of implementing Article 8 of the Water Framework Directive, which asks for improved monitoring.

[29] The negative effect of EU membership and the negative time effect in the runup to the WFD require further study. In-depth case studies on national water management and environmental authorities and their activity will be required to establish whether this effect is due to negligence once countries have made it into the EU, whether the WFD exerts a crowding out effect on the EEA's monitoring network, or whether other causes are responsible for the observed effect.

[30] Further research could also look not only at the location of monitoring activity but also at what types of pollutants are measured, where, and how frequently. It will be very interesting to examine whether the findings reported in this paper are similar when studying the specific contents of data reporting. Such research could also help in establishing what data from what location and at what time intervals would, from a strictly ecological and public health perspective, have to be collected and reported in order to generate a truly representative or accurate picture of national or aquatic system-specific environmental performance and how far, and where, current monitoring practices deviate from ideal practices. Interestingly, both the *European Environment Agency* [1996] and the U.S. Geological Survey (USGS) (http://water.usgs.gov/nawqa/) offer guidelines [see also *Kim and Platt*, 2008] on how water quality should be measured and how spatial and temporal monitoring coverage should look. We do not know of any systematic analysis that has juxtaposed such guidelines on de facto monitoring activity and has tried to explain gaps and differences between the two. When and where monitoring takes place and what is measured do at least to some degree also seem to depend on the preferences and influence of water professionals in a country rather than policy makers' decisions per se. Future research should take such determinants into account as well.

[31] Finally, it will be very interesting to use our approach to examine other international environmental monitoring networks, for example, the network established under the Convention on Long-Range Transboundary Air Pollution (EMEP, http://www.emep.int/), or national environmental monitoring programs, for example, the USGS-led National Water-Quality Assessment (http://water.usgs.gov/nawqa/). We do not know of any studies that have tried to account, with quantitative analytical methods, for the spatial and temporal development of these monitoring networks as a function of environmental, political, and economic factors.

[32] **Acknowledgments.** Tony Allan, Marit Brochmann, Ariel Dinar, Eran Feitelson, Nils Petter Gleditsch, Itay Fishhaendler, Simon Hug, Wolfgang Kinzelbach, Matias Margulis, Helen Milner, Naho Mirumachi, David Senn, Tobias Siegfried, Randall Stone, Janine Sutter, Tancrède Voituriez, Hugh Ward, Marc Zeitoun, the editor and associate editor of *Water Resources Research*, and the anonymous reviewers have provided most valuable comments on earlier versions of this paper.

References

Bernauer, T., and P. Kuhn (2010), Is there an environmental version of the Kantian peace? Insights from water pollution in Europe, *Eur. J. Int. Relat.*, *16*, 77–102.

Chave, P. A. (2001), *The EU Water Framework Directive: An Introduction*, IWA Publ., London.

European Environment Agency (1996), Requirements for water monitoring, *Topic Rep. 1/1996*, Copenhagen. (Available at http://www.eea.europa.eu/data-and-maps/data/waterbase-rivers-5)

Ganser, A. (2007), Grenzüberschreitende Wasserverschmutzung in Europa: Lagebeurteilung von grenznahen Messstationen, Cent. for Comp. and Int. Stud., ETH Zurich, Zurich, Switzerland.

Gleditsch, K. S. (2002), Expanded trade and GDP data, *J. Conflict Resolut.*, *46*, 712–724.

Grossman, G. M., and A. B. Krueger (1995), Economic growth and the environment, *Q. J. Econ.*, *110*, 353–377, doi:10.2307/2118443.

Hedemann-Robinson, M. (2006), *Enforcement of European Union Environmental Law: Legal Issues and Challenges*, Routledge-Cavendish, Milton Park, U. K.

Jahn, D. (1998), Environmental performance and policy regimes: Explaining variations in 18 OECD-countries, *Policy Sci.*, *31*, 107–131, doi:10.1023/A:1004385005999.

Kim, Y. J., and U. Platt (Eds.) (2008), *Advanced Environmental Monitoring*, Springer, Heidelberg, Germany, doi:10.1007/978-1-4020-6364-0.

Li, Q., and R. Reuveny (2006), Democracy and environmental degradation, *Int. Stud. Q.*, *50*, 935–956, doi:10.1111/j.1468-2478.2006.00432.x.

Long, J. S. (1997), *Regression Models for Categorical and Limited Dependent Variables*, Sage, Thousand Oaks, Calif.

Neumayer, E. (2002a), Do democracies exhibit stronger international environmental commitment? A cross-country analysis, *J. Peace Res.*, *39*(2), 139–164, doi:10.1177/0022343302039002001.

Neumayer, E. (2002b), Does trade openness promote multilateral environmental cooperation?, *World Econ.*, *25*, 815–832, doi:10.1111/1467-9701.00464.

Neumayer, E., and I. De Soya (2005), False prophet, or genuine savior? Assessing the effects of economic openness on sustainable development, 1980–1999, *Int. Organ.*, *59*, 731–772.

Skjærseth, J. B., and J. Wettestad (2006), EU enlargement and environmental policy: The bright side, *FNI Rep. 14/2006*, Fridtjof Nansen Inst., Lysaker, Norway.

Sprinz, D., and T. Vaahoranta (1994), The interest-based explanation of international environmental policy, *Int. Organ.*, *48*, 77–106, doi:10.1017/S0020818300000825.

Ward, H. (2006), International linkages and environmental sustainability: The effectiveness of the regime network, *J. Peace Res.*, *43*, 149–166, doi:10.1177/0022343306061545.

Wooldridge, J. M. (2009), *Introductory Econometrics*, 4th ed., Thomson, Mason, Ohio.

L. Beck, T. Bernauer, and A. Kalbhenn, Center for Comparative and International Studies, ETH Zurich, Haldeneggsteig 4, CH-8092 Zürich, Switzerland. (lucas.beck@ir.gess.ethz.ch; thbe0520@ethz.ch; annaka@ir.gess.ethz.ch)