Environmental Protection for Bureaucratic Promotion: Water Quality Performance Review of Provincial Governors in China

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Abstract

We show that including explicit water quality targets in the otherwise GDP centered performance review of provincial officials in China has improved water quality and reduced digestive cancer mortality, but at significant economic costs. We take advantage of the gradual expansion of the water quality performance review (WQPR) over time and space, and use the difference-in-difference approach to evaluate WQPR's effects. We find that WQPR significantly reduced the ambient concentrations of criteria pollutants but not other pollutants excluded from the review. It reduced the annual digestive cancer death rate by 7% and the county-level GDP growth rate by 6.7% proportionally. We find strong evidence that government officials responded to bureaucratic promotion incentives: WQPR's effects are more pronounced along provincial borders, which are targeted specifically by WQPR, and when the provincial officials have more promotion opportunities.

Keywords: water quality performance review, imperfect enforcement, digestive cancer
JEL: Q58, Q56, O13

1. Introduction

Many developing countries are experiencing severe environmental degradation, partly due to inadequate enforcement of their environmental laws and regulations (Montero 2002, van Rooij 2006). These countries often have sophisticated regulations on books, but insufficient enforcement leads many to question whether environmental policies in developing nations actually work at all (Blackman 2010; Blackman, Li and Liu 2018). Economists have studied a variety of factors contributing to imperfect enforcement of environmental regulations, including asymmetric information (Somanathan 2010), inadequate capacity for monitoring and enforcement (O'Connor 1998, Macho-Stadler and Perez-Castrillo, 2006), corruption, rent-seeking and patronage (Damania, Fredriksson and Mani 2004, Wang 2002, Dean, Lovely and Wang 2009, Varkkey 2013), and the government's primary concern for economic growth (Liu 2013). One reason that has not attracted much attention in the literature, which is the focus of this paper, is that regulators may lack incentives within the bureaucratic promotion system to enforce environmental regulations in the first place.

In this paper, we empirically demonstrate that, by including water quality improvement targets in the performance review of provincial governors, the Chinese government has effectively reduced ambient water pollution and the associated digestive cancer death rate, albeit at the cost of reduced economic growth. By matching water quality with death by cause and GDP data, and taking advantage of the gradual expansion of water quality performance review (WQPR) over time and space, we employ the difference-in-difference method to estimate the effects of the policy change on ambient water quality, digestive cancer mortality and GDP growth. The core contribution of the paper is to show that providing bureaucratic promotion incentives can help enforce environmental regulations and lead to significant environment improvement, but does not ensure cost effective implementation. Specifically, we show that (i) WQPR reduced ambient concentrations of criteria pollutants, ones that are included in the performance review, but not water pollutants excluded from the review; (ii) water quality improvements manifest not only at monitoring stations operated by the local government agencies but also at real-time stations operated by the central government, ameliorating concerns for data manipulation; (iii) water quality and digestive cancer mortality improvements are higher at provincial boundaries, which are specifically targeted by WQPR; (iv) these improvements are higher when the provincial governors have higher promotion potential, further highlighting the importance of incentivizing the regulators within bureaucratic systems for environmental protection; and (v) WQPR reduced GDP growth significantly, with the associated cost per life saved far exceeding value of statistical life estimates. Our results are consistent with but offer an encouraging contrast to Jia (2017), which shows that the incentives of Chinese government officials in a GDP-centered bureaucratic system raised pollution.

China has faced daunting challenges of water pollution. An early study by the World Bank estimates that "between 2001 and 2005, on average about 54% of the seven main rivers in China contained water deemed unsafe for human consumption" (World Bank 2006). Almost a quarter of major lakes and reservoirs suffer from eutrophication. Partly due to water pollution, China has experienced high mortality rates from digestive cancer, which is the second leading cause of cancer related deaths.[2] The World Bank (2007) estimates that water pollution resulted in over 60,000 deaths annually in rural areas alone. A number of studies investigate the causal linkages between water pollution and digestive cancer in China (Ren et al. 2015). In an important study, Ebenstein (2010) shows that one grade degradation of water quality (on a six grade scale) raises the digestive cancer death rate by almost 10%.

The Chinese government developed a set of increasingly stringent and comprehensive water quality control measures, aimed at both reducing emissions and improving ambient water quality. Surface water qualities in lakes and rivers are tracked by almost 500 water pollution monitoring stations; a pollution levy system against industry polluters was launched in 1982 with subsequent more stringent stipulations; permits systems were imposed on polluters limiting their total emissions; and wastewater treatment in urban areas was mandatory and highly promoted. However, these policies have failed to improve water quality on the national scale, with the primary reason being that the policies are poorly enforced, especially for water bodies spanning different jurisdictions (World Bank 2006, 2009). In response, WQPR was introduced to promote enforcement by providing direct incentives to provincial governors. Under WQPR, the annual performance review of provincial governors by the central government, perhaps the most critical element for promotion in a highly competitive bureaucratic system, would include not only the traditional metrics such as GDP growth and social stability, but also quantified targets on ambient water quality and pollution reduction. The coverage of WQPR expanded from one key watershed during 2005-2007 to 9 key watersheds during 2008-2010, and all key watersheds since 2011, providing us with sufficient variations to estimate the effects of WQPR.

Each phase of WQPR specifies the river cross-sections to be assessed within each watershed, with each assessed cross-section (ACS) located at a RMS (so that water quality data at the ACS are available for assessment).[3] The 2005 – 2007 phase of WQPR includes 25 ACS's and the 2008 – 2010 phase includes additional 47 ACS's. We match water quality data from 492 river monitoring stations (RMS's) during 2004 – 2010, annual death by cause data from 161 nationwide Disease Surveillance Points (DSPs) during 2004 – 2012, as well as county level GDP data during 2004-2012, with the ACSs during the two phases of WQPR. An assessed RMS, DSP, and county is one that is matched with an ACS.

[2] The leading cause of cancer related death is lung cancer due to air pollution.
[3] All phases of WQPR also include assessed lake cross-sections. We exclude lakes from our study due to lack of water quality data.

We employ DID to estimate the effects of WQPR by comparing the water quality changes of the assessed RMS's before and after the implementation with those not covered by WQPR. We use a similar approach to estimate the effects of WQPR on the digestive cancer mortality rate, and to estimate the effects of WQPR on GDP growth.

WQPR includes quantified targets for water quality improvements, and as such, might provide incentives for local governments to misreport the water quality data, especially since the RMS's are infrequently sampled (once a month), and are operated by local government agencies. To control for possible misreporting, we re-estimate the water quality effects using data from 132 "automatic monitoring stations" (AMS's), which are sampled more frequently (6 times a day), with water quality data automatically released to the public. We show that the estimates based on the RMS and AMS data are similar in magnitude, alleviating concerns for data manipulation.

A main goal of WQPR is to improve water quality at provincial boundaries, which have much higher levels of water pollution than those in the interior of provinces (Kahn et al. 2015). We identify assessed RMS's, DPS's, and counties that are at or close to provincial boundaries, and show that the impacts of WQPR in improving water quality, reducing digestive cancer mortality, and reducing GDP growth are more pronounced at the boundaries. Kahn et al. (2015) find that the 2005 WQPR reduced water pollution along provincial boundaries by a large amount when the upstream provincial party secretaries are younger than 65 years old because they can still be promoted due to a mandatory retirement age of 65. We adopt a similar approach, using the cutoff age of 65 as a proxy for the promotion potential. However, since provincial governors are directly responsible for water quality performance, we use the age of the governors rather than party secretaries. We show that the effects of WQPR are larger in improving water quality and reducing digestive cancer mortality and GDP growth when the governor is younger than 65. These results provide strong evidence that government officials respond to bureaucratic incentives when deciding on the enforcement of environmental regulations.

Our paper contributes to the empirical literature on the environmental, health and economic effects of environmental regulation. While much of the literature studies developed nations,[4] a growing body of literature focuses on developing countries such as China, India, Brazil and Mexico, as part of the emerging field of envirodevonomics (Greenstone and Jack 2015).[5] Blackman et al. (2018) provides a comprehensive review of this literature, showing that environmental regulations lead to positive

[4] Examples include Greenstone (2004), which shows that the nonattainment designation under the US Clean Air Act played a minor role in the reduction of SO_2 pollution, .Auffhammer and Kellogg (2011), which studies the air quality effects of the gasoline content regulation in the US and in California, and Kaiser and Shapiro (2018), which demonstrates the moderate water quality effects of the US Clean Water Act.

[5] Our paper addresses one of the research agendas highlighted by Greenstone and Jack (2015): "what factors determine whether environmental regulations are effective in developing countries?"

environmental and sometimes health benefits in about three quarters of 40 published empirical studies. For example, Greenstone and Hanna (2014) uses the DID approach to evaluate the environmental and health effects of two pieces of air and water regulation in India, and finds that while the air quality regulation improved air quality and reduced infant mortality, the water quality regulation did not show statistically significant impacts. A number of papers focus on an important component of monitoring and enforcement, namely inspections and audits. In general, they find that more effective inspections can reduce pollution (Dasgupta et al. 2000, Escobar and Chavez 2013). For example, Duflo et al. (2013) conducts a randomized control trial (RCT) in India to evaluate the effects of providing incentives for environmental auditors to report more truthfully, and finds that the changed behavior of the auditors lead to reduced pollution. However, Lin (2013) finds that inspections conducted by environmental authorities in China where emission levies (taxation) are imposed are effective for verifying firms' self-reported emissions but not for reducing their emissions. While the literature studies either new regulations or specific implementation strategies such as audits, our paper evaluates the effects of a holistic change in the bureaucratic promotion system that brings increased incentives for implementation, noting the heterogeneity in specific implementation strategies across jurisdictions.

There is a small but growing body of literature that studies the environmental and health effects of environmental regulation in China. Most of this literature investigates air pollution policies (e.g., Wang and Wheeler 2996, 2005; Dasgupta et al. 2001; Jiang and McKibbin 2002; Tanaka 2015; and Chen at al. 2011), with a few incorporating water pollution (e.g., Jin and Lin 2014; Liang and Langbein 2015; Kahn et al. 2015). Jin and Lin (2014) estimate the effects of province level pollution targets and show that they reduced both air and water pollution intensity. Liang and Langbein (2015) investigates the broader version of the policy change studied in our paper, which includes targets in both air and water qualities. They use a panel data of both air and water pollution in China during 2000 – 2010, and show that the policy change in 2007 reduced air pollution but not water pollution. One potential drawback of this study is that it does not control for potential endogeneity of the policy treatment - as we show in this paper, provinces “treated” with the policy change tend to have higher pollution levels than the control group.

Our paper is most closely related to Kahn et al. (2015), which uses a DID approach and a panel data set of water quality from 499 RMS’s during 2004 – 2010 to estimate the effects of WQPR on water quality along provincial borders. They proximate WQPR by a post-2005 dummy, effectively estimating the difference in the average water quality changes before and after 2005 of RMS’s close to provincial borders versus the changes of RMS’s in provincial interiors. They find that WQPR improved water quality along provincial borders (as compared with provincial interiors), and more so when the provincial governor is younger (i.e., with more promotion potential). Our paper extends Kahn et al. (2015) in several aspects. First, rather than using the year 2005 as a proxy for a blanket policy change, we identify which

RMS is covered by WQPR and which is not for ever year during 2004-2010. Doing so allows us to use DID to estimate the effects of WQPR on water quality for *all* RMS's, instead of only for those close to provincial borders as supposed to provincial interiors. It also enables us to take advantage of the gradual expansion (instead of one-shot implementation) of WQPR, with the first phase occurring in 2005 with both COD and NH targets and covering 25 RMS's, and the second phase in 2008 with COD targets only and covering additional 47 RMS's. Second, to ameliorate concerns for potential mis-reporting of water quality data of RMS's, we re-estimate our model using data from AMS's, showing that estimates from the two data sets are similar in magnitude. Third, by showing that WQPR reduced digestive cancer mortality and the GDP growth rate, we are able to conduct a preliminary cost benefit analysis of the program. These results, in addition to being interesting and important in their own right, offer corroborating evidence that government officials did respond to the bureaucratic incentives in WQPR, but the command-and-control style implementation might have significantly reduced the net social benefits of the program.

Finally, our paper contributes to the growing body of literature on how political leaders are incentivized to carry out policy objectives in centralized political systems such as China. Li and Zhou (2005), using turnover data of China's top provincial leaders during 1979 – 1995, shows a tournament style promotion scheme where (relative) economic performance was the major criterion in affecting the promotion and termination of provincial leaders. Shih et al (2012) argues that the tournament is based on provincial revenue collection. The tournament scheme arises from a regionally decentralized system in China: while the central government controls personnel including the promotion and termination of provincial government leaders, local government officials make implementation decisions, including "resist(ing) reforms, policies, rules, and laws" (Xu 2011). In this system, including environmental performance in promotion evaluation of regional officials has been shown to lead to environmental improvements: Zheng et al. (2014) and Chen et al. (2018) show evidence of this at the city level, and our paper, similar to Liang and Langbein (2015) and Kahn et al. (2015) provides evidences at the province level. Our paper further shows that the tournament system might have contributed to the adoption of command-and-control measures that can ensure achieving environmental assessment goals, even though doing so is not cost effective.

The paper is organized as follows. We discuss the institutional background and data sources in Section 2 and present the regression models in Section 3. We present the main estimation results in Section 4 and discuss their implications in Section 5. We conclude the paper in Section 6.

2. Institutional Background and Data

In this section, we describe the institutional background of our study as well as the data sources. This study involves several datasets, including water quality and location data of river water monitoring stations, data of the temporal and spatial expansion of WQPR, mortality data from disease surveillance points, the biographical data of provincial governors, meteorological data from weather stations, and county-level economic development indicators. We will also describe how the data are matched.

Water quality monitoring

China started to establish a national surface water quality monitoring network in 1988. By 2003, a total of 759 water quality monitoring stations have been set up in key river/lake basins, covering 318 rivers and 26 lakes (including reservoirs). The network was further expanded to 972 stations by 2013, with 492 stations being river monitoring stations (RMS), the locations of which are shown in Figure 1. The operation of these monitoring stations is delegated to local environmental protection bureaus, and monitoring activities are manually conducted once per month involving sampling water, and analyzing and reporting pollutant concentrations. Our water quality data include annual average values of water quality indictors (i.e. concentrations of COD, NH and DO) of the 492 RMS during 2004-2010, obtained from China Environmental Yearbook.[6]

With the emergence of advanced automatic monitoring technologies, China started to build a network of automatic real-time water quality monitoring stations since 2000 to complement the traditional manually operated (and locally controlled) monitoring stations. For each automatic station, water quality information is automatically gathered by instruments once every four hours, instantly reported and released to the public. By 2013, a total of 132 AMS's are in operation, distributed in all key river and lake basins (Figure 2). Our data contain the annual average values of water quality indicators (i.e., concentrations of COD, NH, and DO) from these automatic stations during 2004 – 2012, calculated based on their weekly average values obtained from the Ministry of Ecology and Environment.

Data from the manual and automatic monitoring stations complement each other. While there is a larger network of manual stations, they are potentially susceptible to manipulation by local governments. For instance, there are reported cases where upstream reservoirs release water right before a month's sampling day in order to dilute downstream pollutant concentrations, thereby beefing up the water quality data.[7] The network of automatic stations is smaller, but they are not vulnerable to manipulation since they are automatically and more frequently sampled (6 times a day), and the water quality data are released to the public in real time. We rely on the manual station data for our main regression results, but use the automatic station data to check the reliability of our results.

[6] China stopped publishing water quality data from these stations after 2010.
[7] http://zjnews.zjol.com.cn/system/2014/01/17/019815895.shtml

Water quality performance review

Water quality performance review in China began as a pilot program in the Huai River Basin during the 10th Five-Year Plan period of 2001-2005 (Table 1). The policy document specifies the specific "assessed cross-sections" (ACS's) on a river, and at each ACS, there is always an existing RMS to provide water quality data. The pilot program covered four provinces and 25 ACS's, with targets in concentrations of Chemical Oxygen Demand (COD) and ammonia (NH, measured in ammoniacal nitrogen NH3-N).[8] The formal policy documents were signed towards the end of 2004 between the State Environmental Protection Bureau (SEPB, now renamed the Ministry of Ecology and Environment) acting on behalf of the State Council, and the four provincial governments. For three consecutive years since 2006, SEPB organized teams to review the performance of the provinces, with review results included in the annual evaluation of provincial governors.

After three pilot years, WQPR was expanded during the 11th Five-Year Plan period of 2006-2010 to include 9 key river and lake basins, covering 22 provinces, autonomous regions, and municipalities. A total of 157 ACS's are covered by the new program, with 72 of which being river cross-sections. The criterion pollutants differ across water basins, with COD and NH in the Huai River basin, and COD only in other key river basins. The formal policy document was announced by the Ministry of Environmental Protection (now renamed the Ministry of Ecology and Environment) towards the end of 2008, and the formal review started in 2009. This and the pilot phases of WQPR form the main policy variations used in our DID analysis, for the sample period of 2004 – 2010.

The program was expanded again during the 12th Five-Year Plan period of 2011-2015. It now covers 10 key river and lake basins, 428 river/lake cross-sections, and 22 comprehensive water quality indicators such as dissolved oxygen, biochemical oxygen demand, cyanide and a variety of chemicals and metals. We will utilize this phase of the program in some of our analysis that relies on the AMS data for the sample period of 2004 – 2012.

It is worth noting that the locations of the water quality monitoring stations are predetermined long before WQPR was implemented. The locations are thus treated as exogenous in evaluating the water quality effects of WQPR.

Bureaucratic promotion of provincial governors

A provincial governor is the "number two boss" of a province, after the provincial party secretary. The governor is evaluated each year by the central government, with termination and promotion decisions made based partly on the performance evaluation. The next step along the bureaucratic ladder is

[8] Water quality performance is based mainly on the RMS data. AMS data can be "consulted" but no formal targets are established based on those stations.

provincial party secretary, i.e., the “number one boss” of a province or a ministry. Promotion processes are often opaque, but in many cases promotion decisions are based on a tournament system, with multiple officials at the governor level competing for a single position of a party secretary.

China has a mandatory retirement age system, with higher retirement ages set for officials at higher levels of the government. Since 1982, the retirement age for provincial governors and party secretaries has been set at 65 years old. A 2006 regulation stipulated that provincial governors are appointed for a term of 5 years and they should serve the full term under normal circumstances. Hence, the precondition for promotion (e.g., to provincial level party secretary or to governorship at a larger province) is whether a governor is younger than 65 year old at the completion of his or her current term. We collect the birth year and the inauguration year of each provincial governor from Xinhua News Agency, China’s central news service, and calculate the age when the governor finishes his or her current term as a proxy for the promotion potential. Our measure of the promotion potential integrates age and term-in-office information, and is slightly different from Kahn et al. (2015), which uses the current age of a provincial party secretary as the proxy for the promotion potential.

Disease monitoring

China started to pilot the Disease Surveillance Point (DSP) system in 1978, and the system experienced several phases of expansion ever since. It is currently a mortality-monitoring system comprised of reporting points (i.e. counties or urban districts) selected by stratified cluster random sampling. During our study period of 2004 – 2012, it has 161 surveillance points, covering 31 provinces, autonomous regions and municipalities and 73 million people, about 6% of China's population. Using the death by cause data from the DSP system, we calculate the age-adjusted mortality rates from three main digestive cancers, namely esophagus, stomach and liver cancers.[9] For the purpose of placebo tests, other major non-digestive disease (age-adjusted) mortality data, such as lung cancer and respiratory infections, are also collected from the DSP dataset.

Weather and economic development data

Precipitation affects water quality. We collect annual average precipitation data at 840 nationwide meteorological observation stations, and match them with water quality data by linking each RMS with its nearest meteorological station. The local socio-economic development data include county-level per capita GDP (adjusted by local CPI), prefecture/city-level proportion of households having access to tap

[9] These three kinds of digestive cancers account for approximately 84% of total digestive cancer death cases recorded by the DSP system during 1991-2000. Other digestive cancers include colon cancer, intestinal cancer and pancreatic cancer.

water, and city-level number of hospital beds per thousand residents collected from Region/Province/City Statistical Yearbooks.

Data matching

Official WQPR documents list the assessed cross-sections in the covered watersheds, which are matched with RMS's by comparing their names and locations. For AMS's, we consider am AMS to be assessed if and only if it is close to the assessed cross sections– we will vary the threshold distances for matching and show that our results are robust to the variations. All other RMS or AMS are considered not assessed by WQPR. Figures 1 and 2 show the stations assessed by each of the different phases of WQPR, as well as those that are not assessed by WQPR at all. Table 1 shows the number of RMS's and AMS's that are assessed by WQPR during each of the phases.

To evaluate the health effects of WQPR via water quality, we match the 161 DSPs with ACS's, and consider a DSP to be assessed or covered by WQPR if and only if it can be matched with an ACS. Specifically, using ArcGIS, for each DSP, which is a county or city district, we identify the major river that runs through the DSP. We then identify whether there is an ACS along the river that is within 100km of the DSP.[10] If multiple rivers run through the DSP, then it is assessed if there is any ACS along any of the rivers within 100km. Figure 3 shows an example of Gansu province: there are two DSPs, each with one ACS within its boundary; one DSP with two ACS's within its boundary; and two DSPs for which no ACS exists. Figure 4 shows the locations of the DSPs for each of the assessment category.

3. Estimation Models

We adopt the DID approach to estimate the effects of WQPR on water quality, digestive cancer mortality, and GDP growth respectively. Our main estimation model assessing the effects of WQPR on water quality is given by

$$\ln(P_{it}) = \alpha_0 + \alpha_1 PR_{it} + \boldsymbol{\alpha}_3 \mathbf{X}_{it} + Year_t + \mu_i + \varepsilon_{it} \,. \tag{1}$$

Variable $P_{it} \in \{COD_{it}, NH_{it}\}$ measures the annual average value of a particular attribute of water quality P for RMS i in year t. Dummy variable $PR_{it} = 1$ when the particular attribute P of water quality at RMS i is included in WQPR in year t, and 0 otherwise. Thus, for COD, which are included in both phases of WQPR, $PR_{it} = 1$ for 25 stations for periods $t \geq 2005$, and for additional 47 stations for $t \geq 2008$. For NH, which are assessed only for the stations in the Huai River Basin during our sample period of 2004 – 2010, $PR_{it} = 1$ for 25 stations for periods $t \geq 2005$. We control for economic activities and weather

[10] We choose 100km as the threshold distance because of the guiding principle in setting up the RMS's, which stipulates that that there should be a RMS every 100km along a major river.

conditions important for water quality in $\boldsymbol{X}_{it}$. Specifically, we include per capita GDP (adjusted by the provincial CPI) as well as the annual rainfall of the county or district that RMS i is located in. The year fixed effect controls for common time patterns across all RMS's, and the station fixed effect μ_i captures unobserved station specific heterogeneity. Finally, ϵ_{it} is the i.i.d. error term. Our main interest is in coefficient α_1, which measures the effects of WQPR on the (log) water quality attributes.

A major target of WQPR is to improve the water qualities at rivers across provincial boundaries as water pollution tends to be much higher at boundary waters than provincial interiors; Kahn et al. (2015) showed that the 2005 WQPR successfully reduced COD levels in boundary rivers relative to interior rivers. To estimate the additional effects of WQPR on water quality at provincial boundaries, we estimate an augmented version of (1):

$$\ln(P_{it}) = \alpha_0 + \alpha_1 PR_{it} + \alpha_2 PR_{it} \times Boundary_i + \boldsymbol{\alpha_3}\mathbf{X}_{it} + Year_t + \mu_i + \varepsilon_{it}, \tag{2}$$

where $boundary_i = 1$ if RMS i is a provincial boundary station and equals zero otherwise. Coefficient α_2 captures the additional effects of WQPR on boundary water quality, compared with interior RMS's covered by WQPR.

To evaluate whether WQPR's effects are influenced by the promotion potential of the provincial governors, we estimate another augmented version of (1):

$$\ln(P_{it}) = \alpha_0 + \alpha_1 PR_{it} + \alpha_2 PR_{it} \times Younger65_{it} + \boldsymbol{\alpha_3}\mathbf{X}_{it} + Year_t + \mu_i + \varepsilon_{it}, \tag{3}$$

where $Younger65_{it}$ is a dummy variable taking the value of 1 if the governor of the province where RMS i is located is younger than 65 at the end of his or her term, based on information in year t, and equals 0 otherwise.[11] It is possible that during our sample period, different governors with different ages have served in the same province. Thus, α_4 captures the effects of both cross-sectional and temporal variations in the governor's age.

Water pollution not only raises the incidence of digestive cancer but can negatively affect digestive cancer treatment, leading to higher mortality rates among cancer patients. If WQPR indeed improves water quality, one would expect to observe reductions in digestive cancer mortality, even in the short run. Further, since WQPR targets only water pollution indicators, there is no incentive for local governments to manipulate the mortality data. To estimate the effects of WQPR on mortality of digestive cancers, we run a set of regressions similar to (1) - (3), but with the outcome variables being the different forms of digestive cancer death rates, with the DSPs as the sampling units and with a longer sampling period (2004-2012):

[11] In contrast to Kahn et al. (2015), which uses the actual age of the party secretary to represent the potential for promotion, we use the dummy variable to directly measure whether a governor is eligible for promotion or not.

$$\begin{cases} M_{it} = \beta_0 + \beta_1 R_{it} + \boldsymbol{\beta}_3 \mathbf{X}_{it}^M + Year_t + \mu_i^M + \varepsilon_{it}^M \\ M_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 PR_{it} \times Boundary_i + \boldsymbol{\beta}_3 \mathbf{X}_{it}^M + Year_t + \mu_i^M + \varepsilon_{it}^M \\ M_{it} = \beta_0 + \beta_1 R_{it} + \beta_2 PR_{it} \times Younger65_i + \boldsymbol{\beta}_3 \mathbf{X}_{it}^M + Year_t + \mu_i^M + \varepsilon_{it}^M \end{cases} . \quad (4)$$

Outcome variable M_{it} is the age-adjusted digestive cancer (overall as well as specific digestive cancers including liver, stomach, and esophageal cancers) death rate at DSP *i* in year *t*. Age-adjusted death rate is calculated as the weighted average of age-specific death rates, with the weights being the population percentages of each age group using China's 2010 Census data. The dummy variable $R_{it} = 1$ if DSP i is assessed (i.e., matched with an ACS) and equals 0 otherwise. Control variables $\boldsymbol{X}_{it}^M$ include log per capita GDP and hospital beds per 1,000 residents. Dummy variable $Boudary_i = 1$ if DSP i is matched with an ACS at a provincial boundary, and $= 0$ otherwise, and $Younger65_i = 1$ if DSP i is matched with an RMS that is located in a province whose governor is younger than 65 at his or her end of term.

Enforcing environmental protection laws and regulations usually comes at a cost. The costs tend to be higher when governments adopt command-and-control approaches instead of cost-effective approaches, as is the case in many developing countries (Blackman et al. 2018). There are widespread repoAMS of rather chaotic enforcement of environmental laws in China, including water pollution related enforcement, and the approaches taken are mostly far from being cost effective. Local governments would shut down polluting firms, especially small scale industry firms, often temporarily at the last minute, in order to meet mandated pollution targets. Lack of long-term planning means no intertemporal smoothing, and efforts are lacking in smoothing abatement burdens among heterogeneous firms. One thus would expect that WQPR might come at a high cost, especially if ambitious goals are to be met in relatively short time periods. For example, He et al. (2018) finds that WQPR reduced the TFP of firms upstream of ACSs by about 27% (compared with downstream firms) in pollution intensive industries. To estimate the effects of WQPR on GDP growth, we run another set of regressions similar to (1) - (3), with the outcome variable being the county level GDP growth rate, with the sampling units being 1884 counties drawn from all provinces and autonomous regions (excluding the four municipalities of Beijing, Shanghai, Tianjin and Chongqing), and with a sampling period of 2003 – 2012:

$$\begin{cases} G_{it} = \gamma_0 + \gamma_1 R_{it} + Year_t + \mu_i^G + \varepsilon_{it}^G \\ G_{it} = \gamma_0 + \gamma_1 R_{it} + \gamma_2 PR_{it} \times Boundary_i + Year_t + \mu_i^G + \varepsilon_{it}^G \\ G_{it} = \gamma_0 + \gamma_1 R_{it} + \gamma_2 PR_{it} \times Younger65_i + Year_t + \mu_i^G + \varepsilon_{it}^G \end{cases} . \quad (5)$$

Outcome variable G_{it} is the GDP growth rate of county i during year t, and dummy variable $R_{it} = 1$ if there is an ACS within the county, and equals 0 otherwise.

4. Estimation Results

We next present the estimation results for each outcome of interest. We also formally test the main identification assumption in the DID approach, including the common-trend assumption, and conduct a series of supplementary analyses to help further establish the credibility of our results. Table 2 presents the summary statistics for each of the models outlined in Section 3.

4.1. Effects of WQPR on water quality

As discussed earlier, WQPR was introduced in two phases, the pilot phase in the Huai River Basin in 2005 covering both COD and NH, and the more comprehensive phase in 9 major river basins in 2008 covering only COD. Figure 5 graphs the levels of Log(COD) and Log(NH) over time. Panel (a) shows the average Log(COD) levels for three groups of RMS's: the 2005-assessed group consists of 25 RMS's covered by the first phase of WQPR, the 2008-assessed group includes the additional 47 RMS's covered by the second phase of WQPR, amounting to a total of 72 RMS's, and the never-assessed group includes the 420 RMS's that were not covered by WQPR. Panel (b) shows the average Log(NH) levels for two groups, the 2005-assessed group consisting of the 25 RMS's, and the never-assessed group including the rest 467 RMS's.

The figures indicate overall decreasing trends of COD and NH pollution across all RMS's on average, but COD decreased faster after WQPR among the 2008-assessed group, while NH decreased faster after WQPR for the 2005-assessed group. The treated and control groups seem to demonstrate similar trends before WQPR was implemented, and overall the unconditional means offer some evidence that WQPR lead to lower pollution levels.

<u>Main estimation results</u>

Table 3 shows the main estimation results of (1) - (3) in Panels A – C respectively, with standard errors clustered at the river system level. Columns (I) – (IV) report the results for pollutant COD and NH, which are assessed during various phases of WQPR, and as a placebo test, columns (V) – (VI) report the results for DO, which is never included in WQPR during our sample period of 2004 – 2010. For each pollutant, we report the estimates with and without the control variables $\boldsymbol{X}_{it}$, and the estimated coefficients of PR remain largely the same across the two specifications.

Panel A shows that, compared with RMS's that are not assessed, WQPR on average reduced the COD concentration by about 7.5% and the NH concentration by about 6.5%. Panel B shows the additional effects of WQPR on boundary water quality: for COD, for which WQPR covers RMS's both at provincial boundaries and interiors, WQPR reduced the pollution level by over 12%. In fact, WQPR by itself (COD-Assess) is not statistically significant, indicating that the significant negative effects of

WQPR in Panel A are likely due to the large negative effects at provincial boundaries. For NH, it is only assessed during the pilot program in the Huai River basin, which included only RMS's at provincial boundaries. Panel C demonstrates the role of bureaucratic promotion in responding to WQPR: the reduction of both COD and NH pollution is more significant when the provincial governor's age at termination of his or her term is lower than 65 years old. In all panels, WQPR is not significant for DO, which is never included as a criteria pollutant in the assessment.

To evaluate the scope of the WQPR's effects on water quality, we expand the selection of RMS's that are considered assessed or covered by WQPR. Specifically, we run a series of regressions of (1) with an RMS being considered assessed if it is within 10 – 50km of an ACS. The results, reported in Table 4, show that WQPR's effects are stable as more RMS's are included. There could be two reasons for this pattern. First, efforts to reduce water pollution are regional, so that water pollution is reduced at multiple points along a river. Second, if pollution data are manipulated, e.g., upstream reservoir releases water to dilute the pollution intensity at the assessed RMS, then all stations close to the assessed station will experience the dilution and report lower pollution intensity. We will come back to this issue later using the AMS data.

<u>Identification tests</u>

Identification in the DID approach can be achieved either when the treatment and control groups are randomly assigned, or, without random treatment, the following three assumptions are satisfied: (i) water quality in the control and treatment groups follows parallel trends before the implementation of WQPR; (ii) WQPR did not affect water quality in the treatment group, and (iii) no events other than WQPR affected the control and treatment groups differently after the implementation of WQPR. We formally test the common trend assumption (i) through an event study analysis, replacing PR_{it} in (1) by a series of before and after treatment variables $Year_{i\tau} * WQPR_i$, where $WQPR_i = 1$ if RMS i is assessed during the sample period, and =0 otherwise, and $Year_{i\tau}$ is a dummy for τ years before or after the implementation of WQPR at station i.

Table 5 shows the event study estimation results for COD and NH, and Figure 6 graphs the point estimates with 95% confidence intervals. Since WQPR for NH started in 2005 (in Huai River basin only) but our water pollution data only go back to 2004, the event study cannot be used to test the common trend assumption for NH. We report the even study results to show the dynamic effects on NH pollution after the implementation of WQPR: as time progresses, WQPR reduces NH pollution by larger amounts. For COD, the event analysis indicates that there is no clear difference between the pollution trends of the treated and control RMS's. WQPR reduces COD pollution after its implementation, but the effects are relatively stable over time.

Since for NH, we cannot test the common trend assumption, we run an augmented version of (1) by adding $PR_{it} \times t$ as an explanatory variable, allowing different time trends between the treated and control groups of RMS's. The estimation results, shown in Table 6, demonstrate that assessing NH in WQPR leads to a statistically significant downward trend of NH pollution, consistent with the pattern shown in Table 5 and Figure 6.

<u>Possibility of data manipulation: automatic monitoring station data</u>

Since RMS's are operated by local government agencies, a natural concern is whether the RMS data are manipulated in order to meet the WQPR requirements. AMS's, being automatically and more frequently sampled (6 times a day) with the results immediately released to the public, are less susceptible to local manipulation. We next use the AMS data to re-run models (1) - (3) as well as model (1) controlling for different time trends between treated and control groups, and report the estimation results in Table 7.

Comparing Tables 3, 6, and 7 shows little effects of data manipulation for the overall sample: the estimation results using AMS match the pattern of results from RMS data. The effects of WQPR in the main model tend to be higher from AMS data than RMS data, but the levels of statistical significance are lower due to fewer sample points. The effects of WQPR for COD are statistically significant, and are larger when a provincial governor's end-of-term age is lower than 65 years old. The effects of WQPR for NH are mostly statistically insignificant, except for a negative trend for assessed stations. A distinctive result using the AMS data is that the additional effects of WQPR along provincial boundaries are of lower magnitudes and statistically insignificant. This might offer some evidence of data manipulation for manual stations along provincial borders, which are the focus of WQPR and tend to have tougher pollution reduction goals (thereby creating more incentive for data manipulation).

Similar to the case of AMS's, we re-estimate (1) - (3) using AMS data but with different matching distances. Specifically, we re-define an AMS as assessed or covered by WQPR if it has an ACS within 10 – 50km of distance along a river. The estimation results, summarized in Table 8, demonstrate a slightly different pattern from Table 4 of the RMS's. Specifically, the effects of WQPR measured using AMS data decrease as the threshold distance rises from 10 to 50km, while the effects of WQPR measured using RMS data are stable across the threshold distances. The pattern of AMS data is intuitive: it shows that local efforts of reducing water pollution targeted the ACS's, so that one observes less effects of WQPR on water quality as the observation point is further away from ACS's. This observation is also consistent with the main results of Table 3: assessed stations experienced less pollution than non-assessed stations. The difference between the patterns of AMS and RMS data offers some tangential evidence of data manipulation. For example, the timed release of upstream reservoirs influences the RMS data but not the AMS data. These results still hold when we expand the data range to 2012, which includes the additional set of WQPR programs implemented in 2011 (Tables A1 and A2 in Appendix A).

Overall, the results so far provide strong evidence that local government officials responded to the incentives of WQPR. They successfully reduced levels of criteria pollutants at assessed stations, but the effects are less pronounced at other stations, and they only targeted criteria pollutants. To further evaluate the effects of WQPR, we next turn to its effects on local digestive cancer mortality and GDP growth rates.

4.2. Effects of WQPR on digestive cancer mortality

Figure 7 shows the average digestive cancer death rates during 2004 – 2012 for various treatment and control groups of DSPs. Although the groups have different levels of average mortalities, they demonstrate similar trends, for periods before the implementation of WQPR. They also show slight overall faster decreases in mortality after the 2005 and 2008 WQPR.

Main estimation results

Table 9 presents the main estimation results of the three models in (4). Panel A shows that, compared with the control group of DSPs, the average death rate from digestive cancers is lower at the assessed DSPs. The average reduction due to WQPR is about 0.4 death per 10,000 people, or by about 7% annually. The reduction is averaged over all the years after the implementation of WQPR – as we show later, the rate of reduction increases as WQPR is in place for longer time periods. Panels B and C show that the reduction in digestive cancer mortality is more pronounced if the DSPs are matched with ACS's located at provincial boundaries, and if the matched ACS's are located in provinces with governors younger than 65 at end of term. These patterns are consistent with those of WQPR's effects on water quality, and corroborates the conclusion that WQPR has been successful in reducing water pollution around ACS's.

In Table 10, we break down the effects of WQPR to three kinds of digestive cancers: liver, stomach and esophageal cancers. The effects are all negative, but statistically less significant than the effects on overall digestive cancer mortality. Specifically, WQPR is most effective in reducing the death rates from liver cancer and stomach cancer, but its effect on esophageal cancer is not statistically significant.

As placebo tests, we estimate the effects of WQPR on all cause death rate other than digestive cancer, as well as lung cancer death rate. Table 11 shows that the policy does not have statistically significant effects on these mortalities.

Common trend and dynamic effects of WQPR

We again conduct an event study to assess whether the digestive cancer mortality rates of the treated and control groups of DSPs follow common trends before the implementation of WQPR, as well as to evaluate the time pattern of WQPR's effects after its implementation. Table 12 shows the estimation results, reporting the effects on mortality of being an assessed DSP (relative to other DSPs) in all years before and after WQPR's implementation, relative to 7 years before the implementation. These effects are graphed in Figure 8, together with their 95% confidence intervals.

We fail to reject the null hypothesis of common trend: the coefficients of the assessed DSP in each of the years prior to WQPR implementation are statistically insignificant. Further, the reduction in digestive cancer death rates becomes more significant as time progresses after WQPR implementation: while the annual death rate is reduced by about 1.1% one year after implementation, it is reduced by 2.7% seven years after implementation. This is intuitive because the health damage is higher from continuous exposure to water pollutants, and the longer-term effect likely also captures reductions in the incidence of digestive cancers.

4.3. Effects of WQPR on GDP growth

Figure 9 presents the county level GDP growth rates for the treated and control groups during 2004 – 2012, which includes the implementation of WQPR in 2011 in more watersheds. Table 13 presents the estimation results of the three models in (5). Columns (I) and (II) show the overall effects of WQPR on GDP growth, when WQPR is represented by either a dummy variable "Assess" or the number of ACS's in a county. Columns (III) and (IV) present the additional effects of provincial boundary and governor's age. Column (V) allows the time trend of GDP growth to differ between the treated and control counties. For robustness, we exclude the 2005-assessed counties in column (VI), showing that the results are similar to the results in (I).

On average, WQPR reduced the GDP growth rate by about 1%, relative to the average growth rate of 15%, amounting to a proportional reduction of 6.7%. Having more ACS's is even more damaging to economic growth, further showing the economic costs of reducing water pollution. The effect of provincial boundaries is not statistically significant, although it has the expected sign. The negative effects on GDP are more pronounced if the provincial governor's end of term age is lower than 65, demonstrating that officials with promotion potential are more willing to trade off economic growth for reduced water pollution.

We conduct an event study to assess the common trend assumption and the time pattern of WQPR's effects after its implementation. Table 14 shows the estimated effects of being an assessed county relative to control counties in all years before and after WQPR's implementation, relative to 7 years before the implementation. These effects are graphed in Figure 10, together with the 95% confidence intervals.

On average, across all WQPR programs, we cannot reject the common trend assumption: the coefficients for all years prior to the start of the WQPR programs are statistically not different from zero. The negative effects after the implementation of WQPR are stable for the first few years but are much larger after year 5. This is likely driven by the significant drop in GDP growth among the 2005-assessed counties – they are the only counties which have more than 4 years of experience after WQPR started. As shown in Figure 9, these counties experienced significant drops in their GDP growth after year 2009.

5. Discussion and Conclusion

This paper presents evidence that local government officials responded to bureaucratic incentives in enforcing environmental laws ands regulations. The inclusion of water quality attributes in annual performance reviews of provincial governors led to lower ambient levels of criteria pollutants, even when doing so comes at the cost of reduced economic growth. Promotion in the bureaucratic system is a driver of such responses, as jurisdictions under officials with a bigger promotion potential achieved lower levels of criteria pollutants, although at the cost of even lower economic growth. Further showcasing officials responding to the bureaucratic incentives rather than intrinsic concerns about the environment, the greatest reductions in pollution levels occurred along provincial borders, which are the main targets in performance review, and ambient concentration of water pollutants not included in performance reviews did not decrease at all.

Our analysis shows that, on average, WQPR reduced COD concentration by about 7.5% and NH concentration by about 6.5%. It reduced the annual digestive cancer death rate by 7%, equivalent to about 0.4 death per 10,000 people. The annual life-saving benefits increase over time, as WQPR leads to sustained improvements in water quality. The environment and health benefits come at a cost of 1% reduction in GDP growth rate. Back-of-envelope calculation shows that the cost of saving one life per year amounts to about 11m RMB, which is way higher than the value of statistical life measures from other studies (usually less than 1m RMB).[12] Given that the reduction in short-term digestive cancer death rates is only one of the many benefits of improved water quality, the benefit cost analysis of WQPR should be much more favorable than that reflected by the cost of lives saved. Nevertheless, our finding questions the cost effectiveness of WQPR. As shown in Blackman et al (2018), command-and-control

[12] For our study region of the 9 key watershed regions during 2004-2010, the life-saving benefits translate into XXX lives saved, while the reduction in GDP growth rate amount to $YYY of lost GDP. The equivalent value of statistical life, XXX/YYY, provides a back-of-envelope measure of the net social benefits of WQPR.

policies in developing countries tend to be more effective than market based policies in terms of bringing forth observable environmental benefits. Such policies, however, are not cost effective. Our findings provides evidence consistent with this observation. Bureaucratic incentives can be effective in achieving observable environmental benefits, but without proper design of implementation mechanisms, the associated economic cost can be significant, and can even be higher than the social benefits.

The reduced form study in this paper cannot tell how WQPR worked its way to improved water quality and in what aspects it has been inefficient. There are anecdotal evidence of chaotic implementation such as last minute efforts in shutting down polluting firms, but more systematic analysis is needed to identify measures to complement WQPR, to enable cost effective environmental policies.

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Figures

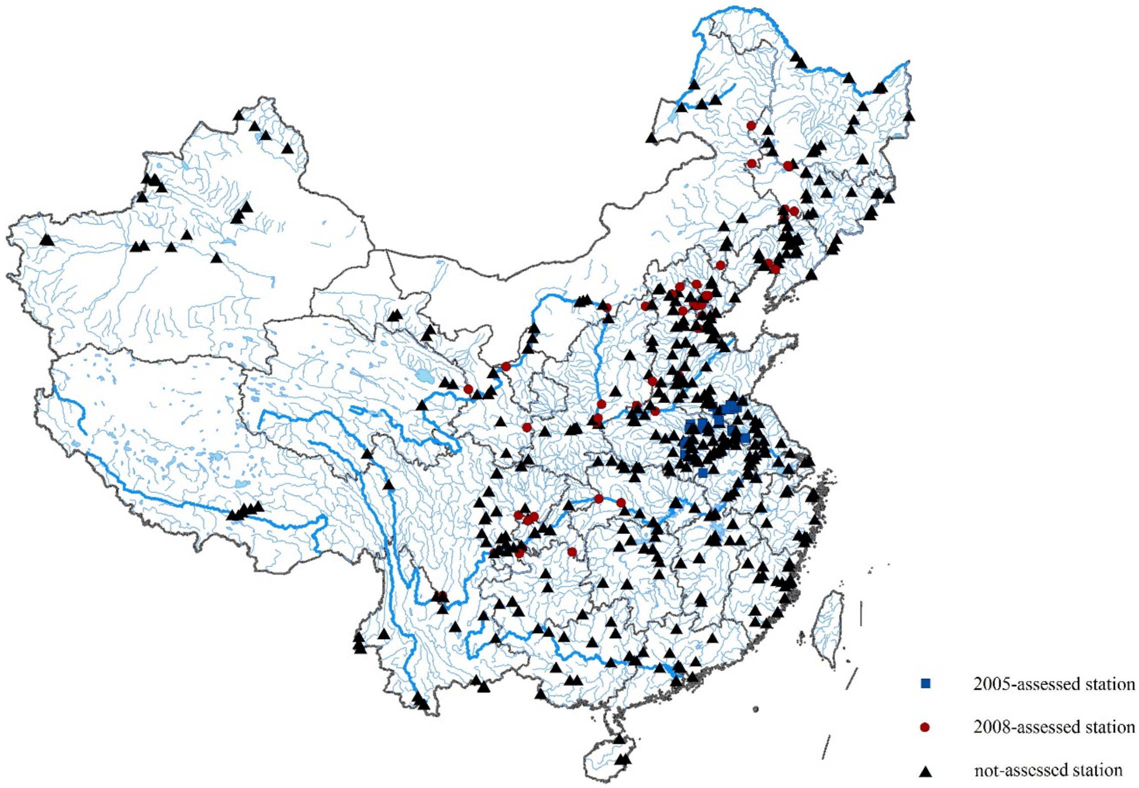


Figure 1. Locations of River Monitoring Stations (RMS's) of Water Quality

Note: "2008-assessed stations" indicate the RMS's that are *newly* added in 2008. "2005-assessed stations" continue to be assessed by WQPR during the 2008 phase.

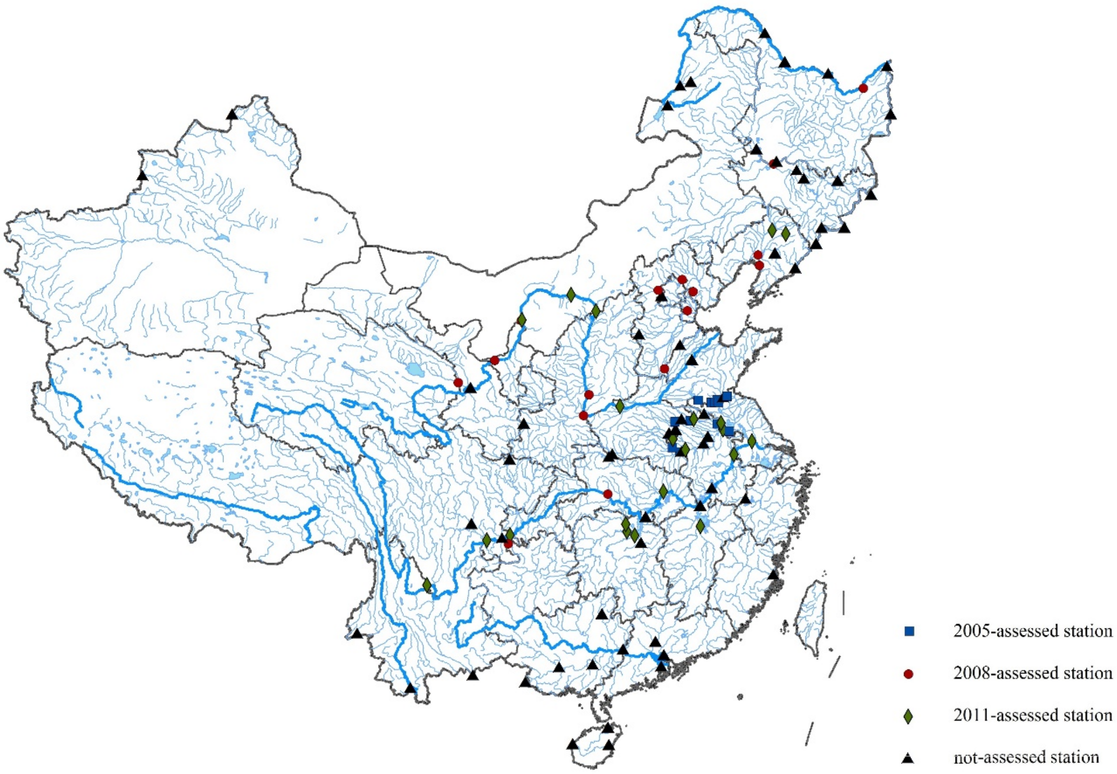


Figure 2. Locations of Automatic Monitoring Stations (AMS's) of Water Quality

Note: "2005-assessed stations" continue to be assessed during the phases of 2008 and 2011, and "2008-assessed stations" continue to be assessed by WQPR during the phase of 2011.

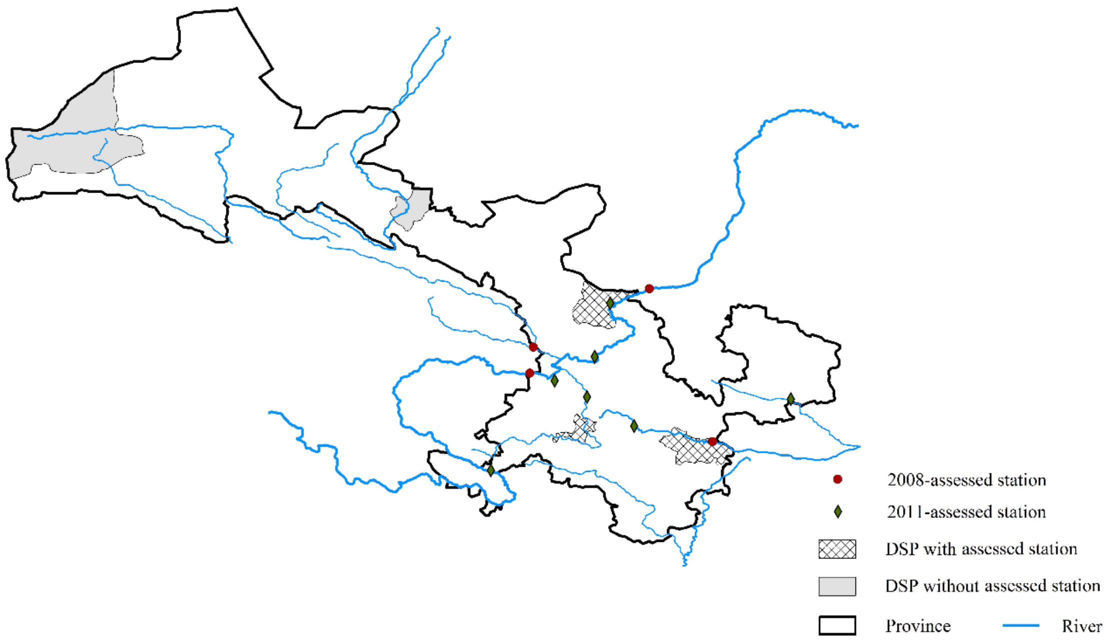


Figure 3. Matching DSPs with RMS’s, Gansu Province

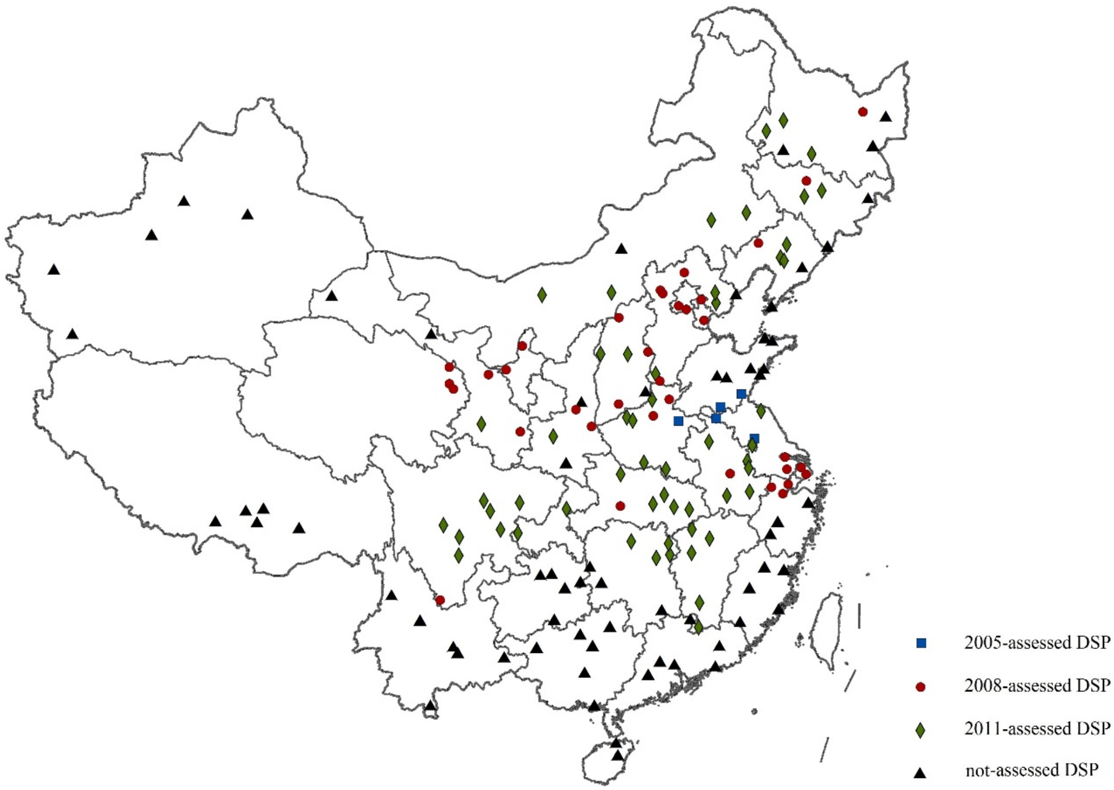
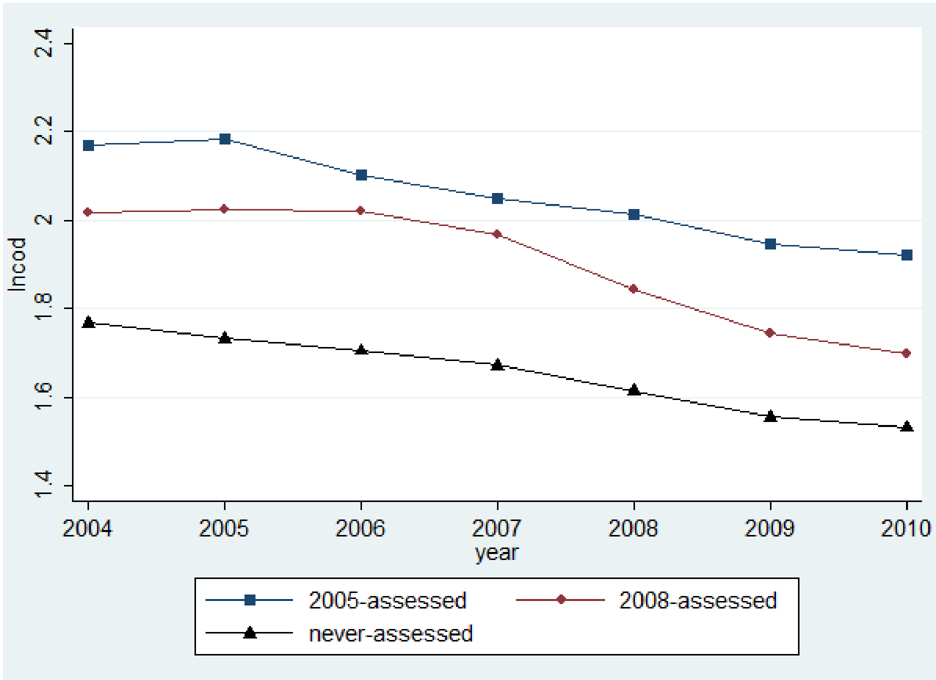
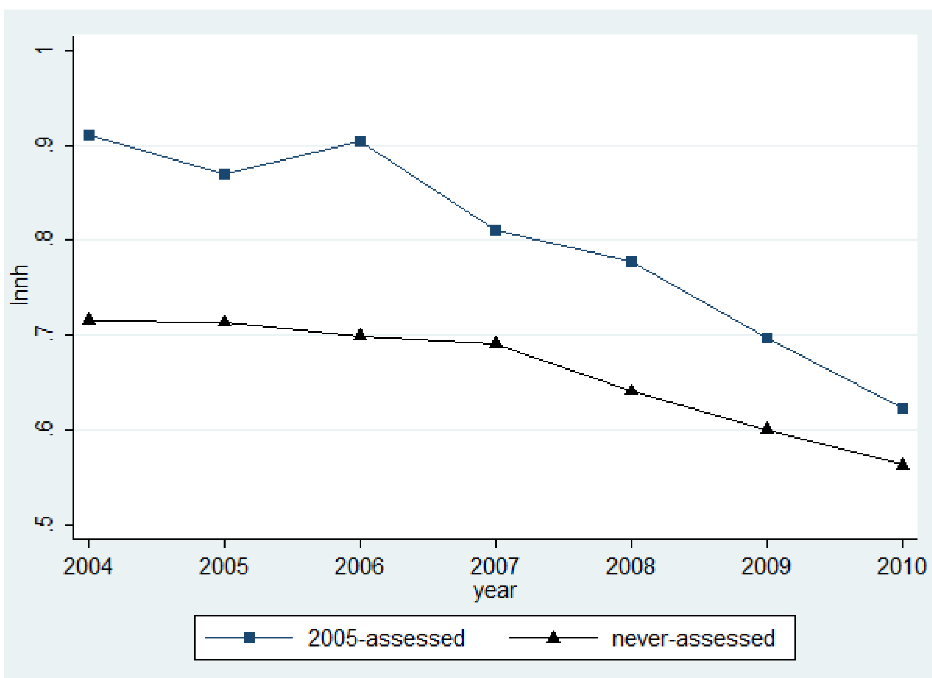


Figure 4. Locations of Disease Surveillance Points

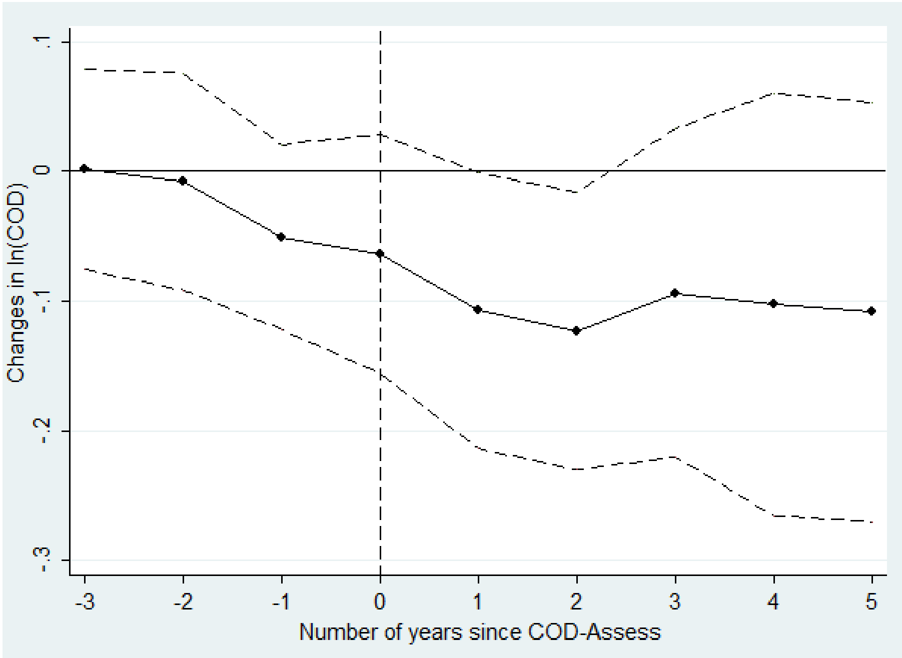


(a) Average Log(COD) levels over time

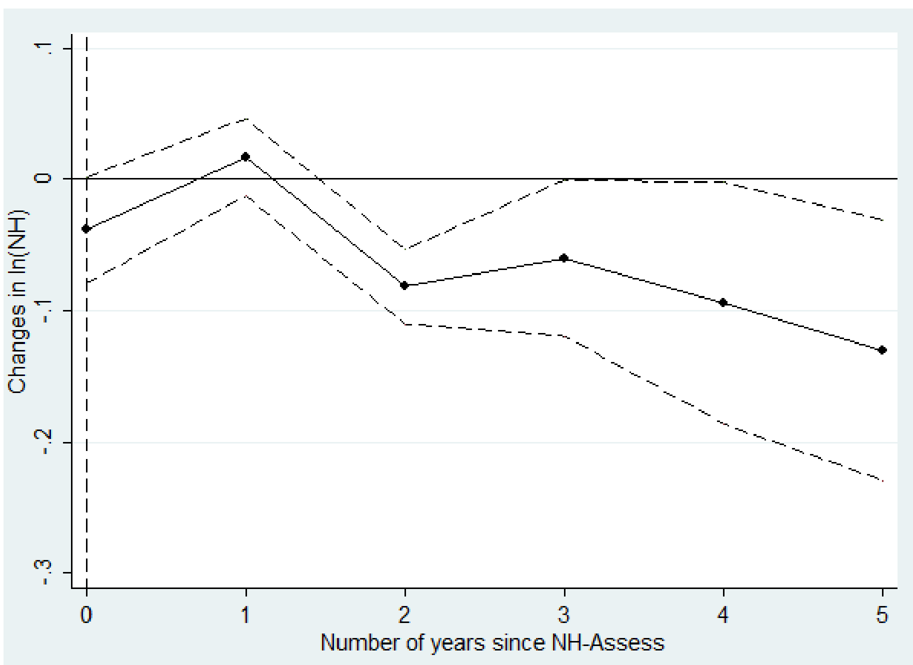


(b) Average Log(NH) levels over time

Figure 5. Average water pollution levels for treatment and control groups of RMS's



(a) COD: relative to four years before WQPR



(b) NH: relative to one year before WQPR

Figure 6. Event study: pollution levels before and after WQPR

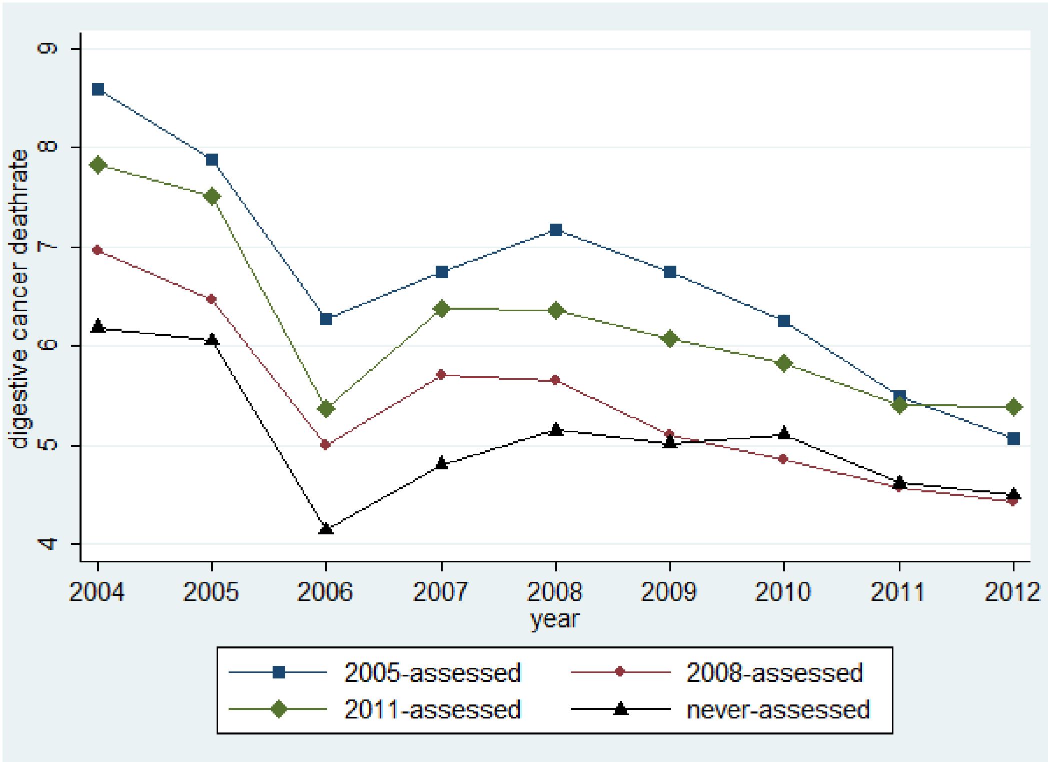


Figure 7. Average digestive cancer death rates for treatment and control groups of DSPs

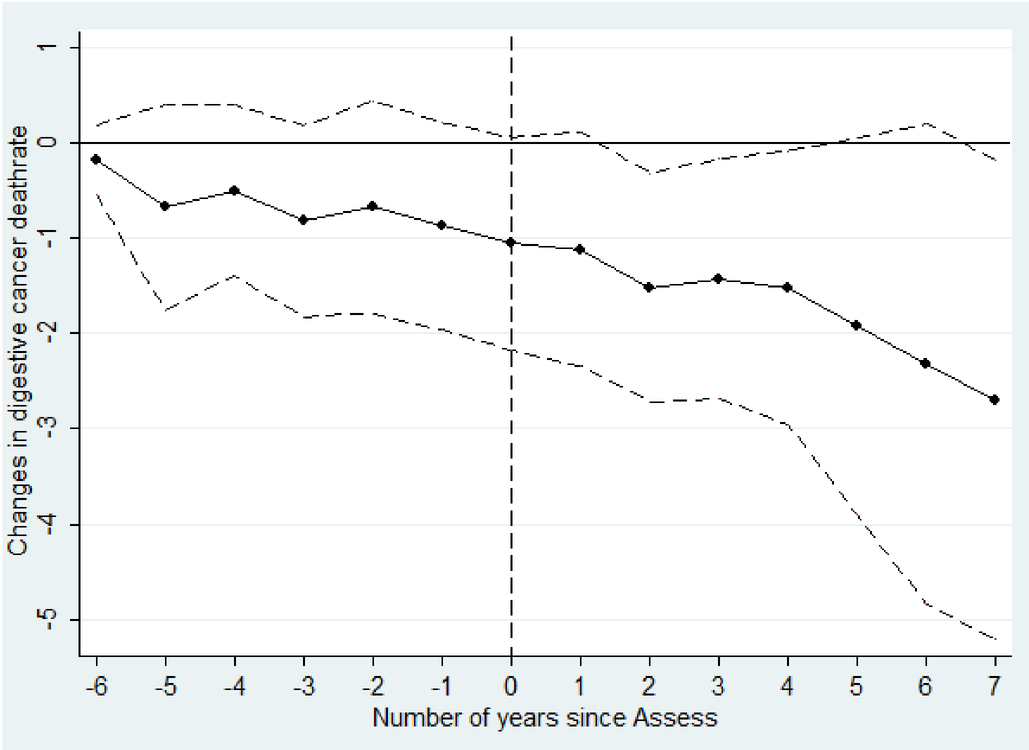


Figure 8. Event study: digestive cancer mortality before and after WQPR

Notes: the horizontal axis measures the number of years before and after "Assess" or the first implementation year of WQPR. The solid line represents point estimates of the digestive cancer death rate compared to the period 7 years before Assess conditional on year fixed effects, DSP fixed effects, ln(GDP per capita) and hospital beds per 1000 residents. The dotted lines indicate the 95% confidence intervals where standard errors are clustered at the province level.

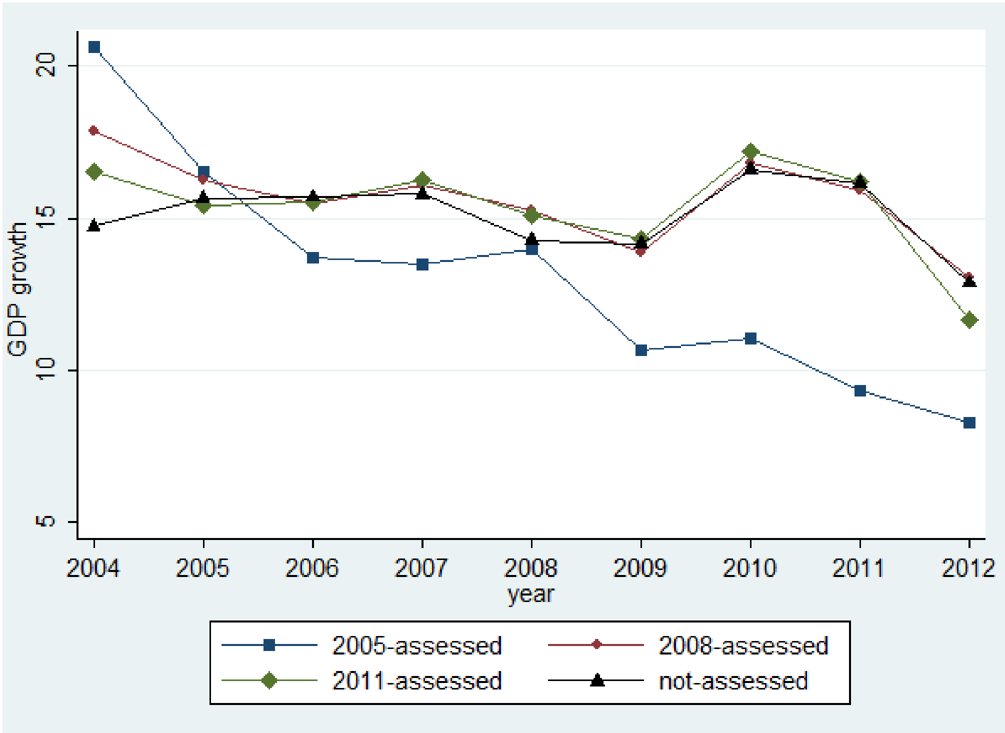


Figure 9. County level GDP growth rates for treatment and control groups

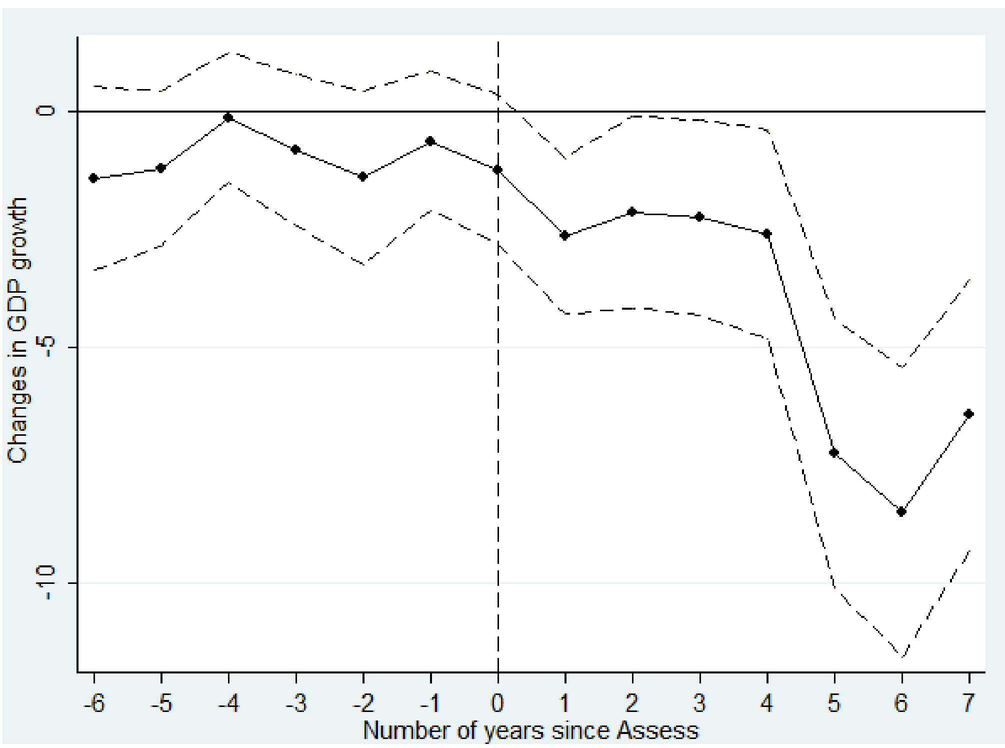


Figure 10. Event study: GDP growth rates before and after WQPR

Tables

Table 1. The development of the water quality performance review programs in China

Planning Phase	10th 5-year Plan	11th 5-year Plan	12th 5-year Plan
Implementation years	2005-2007	2008-2010	2011-2015
Water Basins Covered	Huai River basin	Huai river, Hai river, Liao river, Songhua river, upstream and midstream of yellow river, Tai lake, Chao lake, Dian lake and Three Gorges Reservoir basins (**9 total river/lake basins**)	Huai river, Hai river, Liao river, Songhua river, upstream and midstream of yellow river, Tai lake, Chao lake, Dian lake, Three Gorges Reservoir and midstream and downstream of Yangtze river basins (**10 total river/lake basins**)
Water quality indicators	COD and NH	COD, NH, total nitrogen and phosphorus	COD, NH, total nitrogen, total phosphorus, DO and others 22 items
River and Lake Manual Monitoring Stations assessed	25 monitoring stations (all river stations)	132 monitoring stations (47 river stations)	296 monitoring stations (XX river stations)
Automatic Real-Time River Stations assessed	13	16	22
Disease Surveillance Points assessed	5	35	54
Counties assessed (out of 1884 counties)	52	242	783

Note: the monitoring stations, DSPs and counties covered represent the newly added units that are covered during a certain phase of WQPR.

Table 2. Summary statistics

Variable	Observations	Mean	St. Dev.
Model: effects of WQPR on water quality (RMS)			
ln(COD) (mg/l)	3387	1.70	0.70
ln(NH) (mg/l)	3387	0.67	0.76
ln(DO) (mg/l)	3387	2.07	0.33
COD-Assess (1 = yes)	3387	0.09	0.28
NH-Assess (1 = yes)	3387	0.04	0.21
Assess (1 = yes)	3387	0.09	0.28
COD-Assess × Boundary (1 = yes)	3387	0.08	0.27
NH-Assess × Boundary (1 = yes)	3387	0.04	0.21
Assess × Boundary (1 = yes)	3387	0.08	0.27
COD-Assess × Governor age＜65 (1 = yes)	3387	0.08	0.26
NH-Assess × Governor age＜65 (1 = yes)	3387	0.04	0.19
Assess × Governor age＜65 (1 = yes)	3387	0.08	0.26
ln(GDP per capita) (yuan)	3387	9.61	0.77
ln(Annual rainfall) (mm)	3387	6.58	0.68
Model: effects of WQPR on water quality (AMS)			
ln(COD) (mg/l)	549	1.66	0.70
ln(NH) (mg/l)	549	0.57	0.64
ln(DO) (mg/l)	549	2.06	0.37
COD-Assess (1 = yes)	549	0.18	0.38
NH-Assess (1 = yes)	549	0.11	0.32
Assess(1 = yes)	549	0.18	0.38
COD-Assess × Boundary (1 = yes)	549	0.15	0.35
NH-Assess × Boundary (1 = yes)	549	0.11	0.32
Assess × Boundary (1 = yes)	549	0.15	0.35
COD-Assess × Governor age ⩾65 (1 = yes)	549	0.01	0.09
COD-Assess × Governor age＜65 (1 = yes)	549	0.17	0.38
NH-Assess × Governor age ⩾65 (1 = yes)	549	0.01	0.09
NH-Assess × Governor age＜65 (1 = yes)	549	0.11	0.31
Assess × Governor age ⩾65 (1 = yes)	549	0.01	0.09
Assess × Governor age＜65 (1 = yes)	549	0.17	0.38
ln(GDP per capita) (yuan)	549	9.75	0.72
ln(Annual rainfall) (mm)	549	6.67	0.57
Model: effects of WQPR on digestive cancer mortality			
Digestive cancer death rate (per 10,000 persons)	1425	5.56	3.12
Liver cancer death rate (per 10,000 persons)	1425	2.28	1.14
Stomach cancer death rate (per 10,000 persons)	1425	2.13	1.59
Esophageal cancer death rate (per 10,000 persons)	1425	1.15	1.38
Assess (1 = yes)	1425	0.23	0.42
Assess × Boundary (1 = yes)	1425	0.13	0.34
Assess × Governor age ⩾65 (1 = yes)	1425	0.02	0.15
Assess × Governor age＜65 (1 = yes)	1425	0.21	0.41
ln(GDP per capita) (yuan)	1425	9.80	0.88
Hospital beds per 1000 residents	1425	3.77	2.33
Model: effects of WQPR on GDP growth			
GDP growth rate (%)	16956	15.22	12.63
Assess (1 = yes)	16956	0.19	0.39
Assess × Boundary (1 = yes)	16956	0.10	0.29
Assess × Governor age＜65 (1 = yes)	16956	0.18	0.38

Table 3. The effects of WQPR on water quality

Dependent variable	ln(COD)		ln(NH)		ln(DO)	
	(I)	(II)	(III)	(IV)	(V)	(VI)
Panel A: Model (1)						
COD-Assess	-0.0759*	-0.0749*				
	(0.0389)	(0.0386)				
NH-Assess			-0.0600**	-0.0647**		
			(0.0222)	(0.0225)		
Assess					0.0274	0.0279
					(0.0396)	(0.0398)
ln(GDP per capita)		-0.0500		0.0474		-0.0494
		(0.0572)		(0.0442)		(0.0534)
ln(Annual rainfall)		-0.0095		0.0226		0.0148
		(0.0329)		(0.0420)		(0.0295)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3387	3387	3387	3387	3387	3387
R2	0.9078	0.9079	0.9164	0.9165	0.8115	0.8119
Panel B: Model (2)						
COD-Assess	0.0377	0.0393				
	(0.0785)	(0.0774)				
COD-Assess × Boundary	-0.1276*	-0.1281*				
	(0.0642)	(0.0658)				
NH-Assess			-0.0600**	-0.0647**		
			(0.0222)	(0.0225)		
Assess					-0.0176	-0.0181
					(0.0760)	(0.0792)
Assess × Boundary					0.0505	0.0516
					(0.0698)	(0.0735)
Control variables	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3387	3387	3387	3387	3387	3387
R2	0.9079	0.9080	0.9164	0.9165	0.8116	0.8120
Panel C: Model (3)						
COD-Assess × Governor age⩾65	0.0485*	0.0490*				
	(0.0258)	(0.0240)				
COD-Assess × Governor age＜65	-0.0921**	-0.0911**				
	(0.0393)	(0.0391)				
NH-Assess × Governor age⩾65			-0.0000	-0.0029		
			(0.0117)	(0.0120)		
NH-Assess × Governor age＜65			-0.0682**	-0.0732**		
			(0.0250)	(0.0253)		
Assess × Governor age⩾65					-0.0703	-0.0689
					(0.1054)	(0.1055)
Assess × Governor age ＜65					0.0401	0.0405
					(0.0328)	(0.0328)
Control variables	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3387	3387	3387	3387	3387	3387
R2	0.9081	0.9082	0.9164	0.9165	0.8121	0.8126

Notes: Standard errors clustered at the river system level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 4. The effects of WQPR on water quality: RMS's within 10 – 50km of assessment

Dependent variable	ln(COD)		ln(NH)	
	(I)	(II)	(III)	(IV)
Panel A				
COD-Assess within 10km	-0.0746**	-0.0731**		
	(0.0310)	(0.0302)		
NH-Assess within 10km			-0.0771***	-0.0810***
			(0.0214)	(0.0220)
Panel B				
COD-Assess within 20km	-0.0971***	-0.0957***		
	(0.0209)	(0.0203)		
NH-Assess within 20km			-0.0764***	-0.0803***
			(0.0211)	(0.0232)
Panel C				
COD-Assess within 30km	-0.0839***	-0.0825***		
	(0.0208)	(0.0201)		
NH-Assess within 30km			-0.0764***	-0.0803***
			(0.0211)	(0.0232)
Panel D				
COD-Assess within 40km	-0.0927***	-0.0914***		
	(0.0197)	(0.0191)		
NH-Assess within 40km			-0.0764***	-0.0803***
			(0.0211)	(0.0232)
Panel E				
COD-Assess within 50km	-0.0917***	-0.0905***		
	(0.0196)	(0.0190)		
NH-Assess within 50km			-0.0695***	-0.0729**
			(0.0213)	(0.0239)
Control variables	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes
Observations	3387	3387	3387	3387

Notes: Standard errors clustered at the river system level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and ln(Annual rainfall).

Table 5. Event analysis of WQPR's effects on water quality

Dependent variable	ln(COD)		ln(NH)	
	(I)	(II)	(III)	(IV)
3 years before COD-Assess	0.0017	0.0015		
	(0.0325)	(0.0342)		
2 years before COD-Assess	-0.0066	-0.0078		
	(0.0361)	(0.0370)		
1 year before COD-Assess	-0.0488	-0.0503		
	(0.0325)	(0.0315)		
Year of COD-Assess	-0.0636	-0.0635		
	(0.0400)	(0.0407)		
1 year after COD-Assess	-0.1065*	-0.1074**		
	(0.0488)	(0.0470)		
2 years after COD-Assess	-0.1249**	-0.1228**		
	(0.0505)	(0.0474)		
3 years after COD-Assess	-0.0957	-0.0936		
	(0.0589)	(0.0559)		
4 years after COD-Assess	-0.1023	-0.1025		
	(0.0769)	(0.0721)		
5 years after COD-Assess	-0.1065	-0.1082		
	(0.0797)	(0.0715)		
Year of NH-Assess			-0.0313**	-0.0384*
			(0.0113)	(0.0179)
1 year after NH-Assess			0.0183	0.0168
			(0.0128)	(0.0130)
2 years after NH-Assess			-0.0720***	-0.0817***
			(0.0115)	(0.0126)
3 years after NH-Assess			-0.0536*	-0.0599**
			(0.0268)	(0.0262)
4 years after NH-Assess			-0.0908*	-0.0941**
			(0.0421)	(0.0407)
5 years after NH-Assess			-0.1304**	-0.1302**
			(0.0484)	(0.0439)
Control variables	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes
Observations	3387	3387	3387	3387
R2	0.9080	0.9081	0.9166	0.9167

Notes: Standard errors clustered at the river system level are reported in parentheses.
***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.
The control variables include ln(GDP per capita) and ln(Annual rainfall).
In columns (I) – (II), the effects are relative to four years before COD-Assess. In columns (III) – (IV), the effects are relative to one year before NH-Assess.

Table 6. The effects of WQPR on NH pollution: control for time trend

Dependent variable	ln(NH)	
	(I)	(II)
NH-Assess	0.0204	0.0131
	(0.0175)	(0.0193)
NH-Assessed station × Time_Trend	-0.0230*	-0.0221**
	(0.0102)	(0.0093)
Control variables	No	Yes
Year fixed effects	Yes	Yes
Station fixed effects	Yes	Yes
Observations	3387	3387
R2	0.9165	0.9166

Notes: Standard errors clustered at the river system level are reported in parentheses.
***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.
The control variables include ln(GDP per capita) and ln(Annual rainfall).

Table 7. The effects of WQPR on water quality: automatic real time stations

Dependent variable	ln(COD)		ln(NH)	
	(I)	(II)	(III)	(IV)
Panel A: main model				
COD-Assess	-0.2328***	-0.2293***		
	(0.0411)	(0.0407)		
NH-Assess			0.0058	0.0047
			(0.0311)	(0.0341)
ln(GDP per capita)		-0.0246		-0.0119
		(0.1255)		(0.1064)
ln(Annual rainfall)		-0.0418		0.0084
		(0.0390)		(0.0499)
Observations	549	549	549	549
R2	0.9361	0.9363	0.9300	0.9300
Panel B: provincial boundaries				
COD-Assess	-0.1070	-0.0972		
	(0.1087)	(0.1012)		
COD-Assess × Boundary	-0.2165	-0.2280*		
	(0.1259)	(0.1118)		
NH-Assess			0.0058	0.0047
			(0.0311)	(0.0341)
Control variables	No	Yes	No	Yes
Observations	549	549	549	549
R2	0.9372	0.9374	0.9300	0.9300
Panel C: promotion potential				
COD-Assess × Governor age⩾65	-0.1402**	-0.1391**		
	(0.0481)	(0.0464)		
COD-Assess × Governor age＜65	-0.2367***	-0.2331***		
	(0.0420)	(0.0415)		
NH-Assess × Governor age ⩾65			0.2772***	0.2760***
			(0.0334)	(0.0343)
NH-Assess × Governor age＜65			-0.0360	-0.0372
			(0.0324)	(0.0358)
Control variables	No	Yes	No	Yes
Observations	549	549	549	549
R2	0.9362	0.9364	0.9312	0.9312
Panel D: control for time trend				
COD-Assess	-0.2158***	-0.2054***		
	(0.0437)	(0.0379)		
COD-Assessed station × Time_Trend	-0.0055	-0.0076		
	(0.0081)	(0.0069)		
NH-Assess			0.1709***	0.1770***
			(0.0424)	(0.0504)
NH-Assessed station × Time_Trend			-0.0472***	-0.0484***
			(0.0116)	(0.0123)
Control variables	No	Yes	No	Yes
Observations	549	549	549	549
R2	0.9361	0.9363	0.9312	0.9312

Notes: Standard errors clustered at the river system level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. All panels include year fixed effects and station fixed effects. Control variables include ln(GDP per capita) and ln(Annual rainfall).

Table 8. The effects of WQPR on water quality: AMS's with 10 – 50km of ACS

Dependent variable	ln(COD)		ln(NH)	
	(I)	(II)	(III)	(IV)
Panel A				
COD-Assess within 10km	-0.2303***	-0.2270***		
	(0.0393)	(0.0394)		
NH-Assess within 10km			-0.0252	-0.0271
			(0.0317)	(0.0350)
Panel B				
COD-Assess within 20km	-0.2167***	-0.2135***		
	(0.0363)	(0.0367)		
NH-Assess within 20km			-0.0111	-0.0126
			(0.0334)	(0.0355)
Panel C				
COD-Assess within 30km	-0.1830***	-0.1795***		
	(0.0423)	(0.0413)		
NH-Assess within 30km			-0.0304	-0.0318
			(0.0344)	(0.0367)
Panel D				
COD-Assess within 40km	-0.1830***	-0.1795***		
	(0.0423)	(0.0413)		
NH-Assess within 40km			-0.0304	-0.0318
			(0.0344)	(0.0367)
Panel E				
COD-Assess within 50km	-0.1747***	-0.1714***		
	(0.0384)	(0.0374)		
NH-Assess within 50km			-0.0304	-0.0318
			(0.0344)	(0.0367)
Control variables	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes
Observations	549	549	549	549

Notes: Standard errors clustered at the river system level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and ln(Annual rainfall).

Table 9. The effects of WQPR on digestive cancer mortality

Dependent variable	Digestive cancer deathrate	
	(I)	(II)
Panel A: main effects		
Assess	-0.4053**	-0.4004**
	(0.1789)	(0.1792)
ln(GDP per capita)		-0.1330
		(0.3642)
Hospital beds per 1000 residents		0.0799
		(0.0617)
Year fixed effects	Yes	Yes
DSP fixed effects	Yes	Yes
Observations	1425	1425
R2	0.8532	0.8534
Panel B: boundary effects		
Assess	-0.0852	-0.0852
	(0.1886)	(0.1824)
Assess × Boundary	-0.6972***	-0.6933***
	(0.2350)	(0.2355)
Control variables	No	Yes
Year fixed effects	Yes	Yes
DSP fixed effects	Yes	Yes
Observations	1425	1425
R2	0.8545	0.8547
Panel C: promotion potential		
Assess × Governor age⩾65	-0.3334	-0.3413
	(0.2910)	(0.3076)
Assess × Governor age＜65	-0.4103**	-0.4044**
	(0.1824)	(0.1817)
Control variables	No	Yes
Year fixed effects	Yes	Yes
DSP fixed effects	Yes	Yes
Observations	1425	1425
R2	0.8532	0.8534

Notes: Standard errors clustered at the province level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and hospital beds per 1000 residents.

Table 10. The effects of WQPR on death rates of specific digestive cancers

Dependent variable	Liver cancer deathrate		Stomach cancer deathrate		Esophageal cancer deathrate	
	(I)	(II)	(III)	(IV)	(V)	(VI)
Assess	-0.1590**	-0.1551*	-0.1563*	-0.1576*	-0.0899	-0.0877
	(0.0769)	(0.0788)	(0.0918)	(0.0921)	(0.0608)	(0.0590)
Control variables	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
DSP fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1425	1425	1425	1425	1425	1425
R2	0.7838	0.7844	0.8318	0.8322	0.9149	0.9153

Notes: Standard errors clustered at the province level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and hospital beds per 1000 residents.

Table 11. Placebo test: effects of WQPR on other death rates

Dependent variable	All causes (excluding digestive cancer) death rate		Lung cancer death rate	
	(I)	(II)	(III)	(IV)
Assess	-0.3654	-0.3229	-0.0730	-0.0727
	(0.9199)	(0.9228)	(0.0815)	(0.0848)
Control variables	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes
DSP fixed effects	Yes	Yes	Yes	Yes
Observations	1425	1425	1425	1425
R2	0.8063	0.8068	0.8264	0.8278

Notes: Standard errors clustered at the province level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and hospital beds per 1000 residents.

Table 12. The effects of WQPR on digestive cancer death rates: event study

Dependent variable	Digestive cancer death rate	
	(I)	(II)
6 years before Assess	-0.1641	-0.1771
	(0.1779)	(0.1761)
5 years before Assess	-0.6633	-0.6766
	(0.5277)	(0.5274)
4 years before Assess	-0.4966	-0.5010
	(0.4413)	(0.4391)
3 years before Assess	-0.8129	-0.8213
	(0.4937)	(0.4914)
2 years before Assess	-0.6603	-0.6729
	(0.5513)	(0.5459)
1 year before Assess	-0.8665	-0.8769
	(0.5344)	(0.5320)
Assess: first year of WQPR implementation	-1.0514*	-1.0554*
	(0.5515)	(0.5473)
1 year after Assess	-1.1078*	-1.1175*
	(0.6074)	(0.6025)
2 years after Assess	-1.5215**	-1.5210**
	(0.5905)	(0.5886)
3 years after Assess	-1.4209**	-1.4255**
	(0.6136)	(0.6151)
4 years after Assess	-1.5151**	-1.5210**
	(0.7041)	(0.7045)
5 years after Assess	-1.9667*	-1.9276*
	(0.9766)	(0.9667)
6 years after Assess	-2.3543*	-2.3228*
	(1.2463)	(1.2323)
7 years after Assess	-2.7323**	-2.6955**
	(1.2360)	(1.2305)
Control variables	No	Yes
Year fixed effects	Yes	Yes
DSP fixed effects	Yes	Yes
Observations	1425	1425
R2	0.8558	0.8560

Notes: Standard errors clustered at the province level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and hospital beds per 1000 residents. The variable "7 years before Assess" is left out so that the effects are relative to seven years before Assess.

Table 13. The effects of WQPR on GDP growth rates

Dependent variable	GDP growth rates					
	(I)	(II)	(III)	(IV)	(V)	(VI)
Assess	-1.0343***		-0.6312		-0.4324	-0.9396**
	(0.3965)		(0.4466)		(0.4742)	(0.4128)
Number of assessed cross sections		-0.8878***				
		(0.2738)				
Assess × Boundary			-0.9791			
			(0.6604)			
Assess × Governor age⩾65				-0.1139		
				(0.6412)		
Assess × Governor age＜65				-1.1176***		
				(0.4115)		
Assessed county × Time_Trend					-0.1784	
					(0.1142)	
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	16956	16956	16956	16956	16956	16488
R2	0.1907	0.1909	0.1909	0.1908	0.1909	0.1906

Notes: Standard errors clustered at the county level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 14. The effects of WQPR on GDP growth rates: event study

Dependent variable	GDP growth rate
6 years before Assess	-1.4070
	(0.9982)
5 years before Assess	-1.1964
	(0.8406)
4 years before Assess	-0.1132
	(0.7061)
3 years before Assess	-0.7999
	(0.8185)
2 years before Assess	-1.3935
	(0.9407)
1 year before Assess	-0.6110
	(0.7539)
Year of Assess	-1.2210
	(0.8129)
1 year after Assess	-2.6343***
	(0.8453)
2 years after Assess	-2.1162**
	(1.0387)
3 years after Assess	-2.2370**
	(1.0539)
4 years after Assess	-2.5931**
	(1.1353)
5 years after Assess	-7.2532***
	(1.4576)
6 years after Assess	-8.5028***
	(1.5642)
7 years after Assess	-6.4400***
	(1.4621)
Year fixed effects	Yes
County fixed effects	Yes
Observations	16956
R2	0.1924

Notes: Standard errors clustered at the county level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The variable “7 years before Assess” is excluded so that the effects are relative to 7 years before Assess.

Appendix A: Additional Results

A.1 Effects of WQPR on water quality, automatic stations, 2004-2012

Table A1. The effects of WQPR on water quality: automatic real time stations, 2004-2012

Dependent variable	ln(COD)		ln(NH)	
	(I)	(II)	(III)	(IV)
Panel A: main model				
COD-Assess	-0.1470**	-0.1444**		
	(0.0603)	(0.0585)		
NH-Assess			-0.0746	-0.0770
			(0.0718)	(0.0705)
ln(GDP per capita)		-0.0405		-0.0174
		(0.1435)		(0.0910)
ln(Annual rainfall)		-0.0436		0.0437
		(0.0323)		(0.0490)
Observations	759	759	759	759
R2	0.9168	0.9171	0.9044	0.9047
Panel B: provincial boundaries				
COD-Assess	-0.1023	-0.0943		
	(0.1099)	(0.0975)		
COD-Assess × Boundary	-0.0786	-0.0877		
	(0.1285)	(0.1112)		
NH-Assess			-0.1279	-0.1312
			(0.1013)	(0.0993)
NH-Assess× Boundary			0.0901	0.0913
			(0.0979)	(0.0972)
Control variables	No	Yes	No	Yes
Observations	759	759	759	759
R2	0.9171	0.9174	0.9048	0.9051
Panel C: promotion potential				
COD-Assess × Governor age⩾65	-0.0917	-0.0878		
	(0.0822)	(0.0811)		
COD-Assess × Governor age＜65	-0.1493**	-0.1468**		
	(0.0593)	(0.0576)		
NH-Assess × Governor age ⩾65			0.1125	0.1105
			(0.0645)	(0.0637)
NH-Assess × Governor age＜65			-0.0819	-0.0843
			(0.0707)	(0.0693)
Control variables	No	Yes	No	Yes
Observations	759	759	759	759
R2	0.9169	0.9171	0.9053	0.9055
Panel D: control for time trend				
COD-Assess	-0.1108**	-0.1067**		
	(0.0493)	(0.0461)		
COD-Assessed station × Time_Trend	-0.0116	-0.0121		
	(0.0162)	(0.0153)		
NH-Assess			0.0029	-0.0013
			(0.0443)	(0.0435)
NH-Assessed station × Time_Trend			-0.0229**	-0.0222*
			(0.0097)	(0.0104)
Control variables	No	Yes	No	Yes
Observations	759	759	759	759
R2	0.9171	0.9174	0.9058	0.9059

Notes: Standard errors clustered at the river system level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. All panels include year fixed effects and station fixed effects. Control variables include ln(GDP per capita) and ln(Annual rainfall).

Table A2. The effects of WQPR on water quality: AMS's with 10 – 50km of ACS, 2004-2012

Dependent variable	ln(COD)		ln(NH)	
	(I)	(II)	(III)	(IV)
Panel A				
COD-Assess within 10km	-0.1411*	-0.1381*		
	(0.0640)	(0.0622)		
NH-Assess within 10km			-0.0615	-0.0648
			(0.0762)	(0.0743)
Panel B				
COD-Assess within 20km	-0.1307*	-0.1275**		
	(0.0596)	(0.0568)		
NH-Assess within 20km			-0.0394	-0.0436
			(0.0840)	(0.0814)
Panel C				
COD-Assess within 30km	-0.1122*	-0.1084*		
	(0.0533)	(0.0507)		
NH-Assess within 30km			-0.0236	-0.0264
			(0.0734)	(0.0716)
Panel D				
COD-Assess within 40km	-0.1072*	-0.1031*		
	(0.0554)	(0.0529)		
NH-Assess within 40km			-0.0156	-0.0184
			(0.0742)	(0.0727)
Panel E				
COD-Assess within 50km	-0.1005*	-0.0965*		
	(0.0484)	(0.0462)		
NH-Assess within 50km			-0.0151	-0.0181
			(0.0690)	(0.0681)
Control variables	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Station fixed effects	Yes	Yes	Yes	Yes
Observations	759	759	759	759

Notes: Standard errors clustered at the river system level are reported in parentheses. ***Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. The control variables include ln(GDP per capita) and ln(Annual rainfall).