Water Pollution and Digestive Cancers in China

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Abstract

Following China's economic reforms of the late 1970s, rapid industrialization has led to a deterioration of water quality in the country's lakes and rivers. China's cancer rate has also increased in recent years, and digestive cancers (i.e. stomach, liver, esophageal) now account for 11 percent of fatalities (WHO 2002) and nearly one million deaths annually. This paper examines a potential causal link between surface water quality and digestive cancers by exploiting variation in water quality across China's river basins. Using a sample of 145 mortality registration points in China, I find using OLS that a deterioration of the water quality by a single grade (on a six-grade scale) is associated with a 9.3 percent increase in the death rate due to digestive cancer, controlling for observable characteristics of the Disease Surveillance Points (DSP). The analysis rules out other potential explanations for the observed correlation, such as smoking rates, dietary patterns, and air pollution. This link is also robust to estimation using 2SLS with rainfall and upstream manufacturing as instruments. As a consequence of the large observed relationship between digestive cancer rates and water pollution, I examine the benefits and costs of increasing China's levy rates for firm dumping of untreated wastewater. My estimates indicate that doubling China's current levies would save roughly 29,000 lives per year, but require an additional 500 million dollars in annual spending on wastewater treatment by firms, implying a cost of roughly 18,000 dollars per averted death.

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1 Introduction

During the 1980s and 1990s, China's rapid economic growth transformed the country and lifted millions of its citizens out of poverty. The economic boom, however, has been accompanied by environmental side effects, including a severe deterioration in the water quality of the country's rivers and lakes. Extensive use of fertilizers by farmers and industrial wastewater dumping by manufacturing firms have rendered the water in many lakes and rivers unfit for human consumption. China's water monitoring system indicates that roughly 70% of the river water is unsafe for human consumption, although many farmers in rural areas still rely on these sources for drinking water (World Bank 2006).

Concurrent with the decline in water quality in China's lakes and rivers, the country has witnessed an increase in rural cancer rates during the 1990s (see Figure 1). Stomach cancer and liver cancer now represent China's 4th and 6th leading causes of death, and in combination with other digestive tract cancers (e.g. esophageal) account for 11% of all fatalities and nearly one million deaths annually (World Health Organization 2002). Several media outlets have reported incidents of contaminated river water from industrial activity leading to outbreaks of cancer in rural villages in China (New York Times 2007, British Broadcasting Corporation 2007), but systematic analysis of these trends is lacking.

Researchers have found connections between water quality and acute water-borne diseases such as typhoid (Cutler and Miller 2005) and diarrhea (Jalan and Ravalion 2003), and access to cleaner water may lower infant mortality (Galiani et al. 2005). The connection between water quality and cancer, however, has not been fully explored. A limited literature has linked water pollution to particular cancer types such as liver cancer (Lin et al. 2000, Davis and Masten 2004) or gastric cancer (Morales-Suarez-Varela et al. 1995). However, as described by Cantor (1997), the literature is incomplete regarding the causal link between water contaminants and cancer: "The epidemiologic data are not yet sufficient to draw a conclusion."

China however represents an almost ideal context to investigate a causal association between contaminated water and digestive cancers. First, in most developing countries reliable data on pollution and mortality are unavailable. However, China's efforts in the late 1980s to begin carefully monitoring both mortality and water pollution provides reliable data on these patterns in areas where millions of inhabitants still rely on well water and lake water as their primary drinking sources. Second, since water quality is not randomly assigned to individuals, researchers must also pay attention to why a particular set of inhabitants live in an area of polluted water, and the time-frame that survey respondents were exposed. In China, however, for most of the exposure window mobility was extremely limited by government regulations. Therefore, the location of residents at the time of observation in the data will likely reflect their true lifetime surface water pollution exposure. Third, China's high rates of cancer, high rates of pollution, and dramatic regional variation in water quality – driven in part by plausibly exogenous rainfall patterns – allow for more precise measurement of the causal effect of contaminated water on digestive cancer incidence.[1]

In this paper, I exploit rich data on water quality, air quality and cause-specific death rates to estimate the causal association between exposure to polluted water and cancer rates. Using a sample of 145 Disease Surveillance Points (DSP) in China and water quality measures from China's nationwide monitoring system, I examine the relationship between water quality and cancer incidence. At each DSP point I observe cause-specific death rates, and the average water grade among monitoring stations in the same river basin.[2] Using Geographic Information System (GIS) software, I am able to examine several other environmental features of the river basins, such as the average air quality observed from satellite imagery and long-term averages of monthly precipitation.[3] I am also able to observe manufacturing output in each basin, including the basins upstream any particular DSP point, which affects the water grade in the basin but should otherwise be exogenous to the digestive cancer rate at the site.

By comparing DSP sites in basins with better and worse water quality, I estimate using OLS

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[1] Northern China has a shorter rainy season than southern China, and as a consequence exhibits higher levels of pollutants in its surface water. This is discussed further in the next section.

[2] The river basins are identified by the United States Geological Survey project which uses satellite imagery to divide China into basins, or watersheds, which can be presumed to have similar water quality levels near the DSP point. This is described in greater detail in the data section.

[3] Air quality is proxied by average optical depth observed from NASA satellite imagery for 2002-2007. Precipitation is measured for 1961-1990 by the Global Precipitation Climatology Center (2008).

that a deterioration of water quality by a single grade (on a six-grade scale[4]) increases the incidence of digestive cancers by 9.3 percent in my preferred specification, which includes control variables for air quality and other potential confounding factors also associated with industrialization, such as whether the site is urban, the share employed in farming, and region.[5] By exploiting plausibly exogenous variation in rainfall within each river basin, as well as the presence of manufacturing in the river basin upstream, I estimate 2SLS models of the relationship between digestive cancer rates and water quality, which provide further support for a causal link between digestive cancer and surface water quality. I also rule out other factors that might confound the effect of water quality on cancer, such as smoking or diet, by demonstrating that there is no strong relationship in China between regional variation in smoking rates or dietary patterns and water quality.

In light of the potentially large health consequences of China's water pollution, I present an analysis of the benefits and costs of wastewater treatment in China. Industrial firms in China are subject to a system of levies for wastewater that fails to meet discharge standards, and I exploit regional variation in the policy's effective levy rate (yuan collected per ton discharged) to estimate the potential impact of revisions to China's current rates. Using provincial data from China's environmental yearbooks (1992-2002), I estimate that industrial cleanup (in tons) rises by 0.82 percent and spending on wastewater treatment (in yuan) rises by 0.14 percent with respect to a 1 percent increase in the effective levy rate. These estimates imply that a doubling of China's levy rates would avert roughly 29,000 deaths per year, but require firms to spend roughly $500 million[6] more per year on treatment, yielding a cost per averted death of roughly $18,000. In addition, since these estimates do not include the potential benefits of cleaner water in reducing

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[4] The water grade is measured on a 6 point scale: drinkable water (grade I or grade II), undrinkable but suitable for human contact (grade III), appropriate for general industrial water supply and recreational waters in which there is not direct human contact with the water (grade IV), appropriate only for agricultural water supply and general landscape requirements (grade V), and water that is essentially useless (grade V+).

[5] In an alternative specification, I estimate using OLS that a deterioration of water quality from drinkable quality to unfit for direct human contact is associated with a 43% increase in the incidence of digestive cancers, and the effect is somewhat smaller (32 percent) when control variables are added for air quality and other potential confounding factors. See Appendix Table 3.

[6] I estimate that China's firms would need to increase spending on wastewater treatment by 14% from the level reported in 2001 of roughly $3.7 billion, or an extra $500 million in compliance costs.

the incidence of other causes of disease and death, they potentially understate the full benefits of tighter environmental regulations. Policymakers should recognize that cleanup efforts could yield large improvements in public health in a relatively cost-effective manner.

The next section provides background information on China's waterways and regional variation in industrial dumping and water quality. Section 3 describes the data in more detail, and summarizes the patterns observed in the data in water quality, industrial dumping, and cause-specific mortality. Section 4 reports the empirical results of the analysis. Section 5 concludes.

2 Background

The pollution levels in China's water bodies are almost without historical precedent, and in spite of recent efforts to reduce water dumping by manufacturing firms, roughly 70% of China's surface water was found unfit for human use (World Bank 2006). In this section, I provide background information on environmental factors that affect water quality, geographic variation in these factors, and the variation in water quality that the analysis exploits to estimate its effect on digestive cancer rates.

Water pollution is classified as either point source or non-point source pollution. Point source pollution is wastewater from domestic sewage and industrial wastes that is discharged from a single point. Nonpoint source pollution, such as urban and agricultural runoff, enters rivers and lakes at multiple points. China's experience following industrialization has led to the increase in both: farmers have attempted to increase yields through widespread fertilizer use (non-point source), and manufacturing firms have dumped inorganic compounds into water as part of their production processes. When these chemicals drain into waterways, they stimulate a river's algal growth beyond its natural speed in a process known as eutrophication. The water becomes populated by cyanobacteria (blue-green algae) which leads to the formation of microcystins (Davis and Masten 2004). These compounds in particular are thought to be carcinogenic, and have been linked directly to liver cancer (Codd 2000).

The deterioration of China's rivers and lakes over the past decades has been regionally bound, with water quality in northern regions declining more severely due to lower levels of precipitation. The rainy season may last as long as six to seven months in some southern areas and be as short as two or three months in more arid northern regions (World Bank 2006). As such, northern river systems have a lower capacity to absorb contaminants. In a thorough review of monitoring data for 1991-2005, the World Bank (2006) reported that 40 to 60 percent of the northern region's water is continuously in the non-functional water classification categories (grade V and VI), and therefore unfit even for agricultural use. The Hai river basin, located in northern China, is the most polluted basin in the country with 57% of monitored sections failing to meet Grade V, and therefore far below drinkable standards. The Yangtze river basin, however, has exhibited a far smaller deterioration in water quality, in spite of industrialization. Regional differences in water quality induced by rainfall patterns provide for observation of areas of China with similar levels of industrialization, but different levels of pollution.

In China, the degradation of waterways has also led areas without industrial activity to experience a decline in water quality. Within a watershed, downstream river segments are contaminated by upstream sources of wastewater and this was the case in a famous episode in Anhui, which has very low industrial activity of its own but is downstream of a major industrial zone located in the Huai river basin. According to Elizabeth Economy in her book *The River Runs Black* (2004), "Heavy rain flooded the [Huai] river's tributaries, flushing more than 38 billion gallons of highly polluted water into the Huai. Downstream, in Anhui Province, the river water was thick with garbage, yellow foam, and dead fish." In this way, regions downstream of industrial firms suffer from the same, or more serious, water pollution as those directly engaged in wastewater discharge and in these rural areas the inhabitants have experienced the environmental costs of industrialization without realizing the economic benefits.[7] In the next section, I describe how I will attempt to exploit both regional variation in water quality and the flow dynamics of water to estimate the causal link between water quality and cancer incidence.

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[7] Lipscomb and Mobarak (2007) deals with a set of related political economy issues and finds that pollution is higher near county boundary points, where neighboring counties will incur a larger share of the pollution's cost.

China's environmental conditions have continued to worsen in spite of long-running regulatory efforts to punish firms for dumping untreated wastewater. In 1982, China established a nationwide system of fine levies assessed on the tonnage of untreated wastewater emitted by factories. By 1998, Chinese regulators had collected about 40 billion RMB yuan ($4.9 billion) in levies, with both private and state-owned enterprises being subject to the policy (Wang and Wheeler 2005). Though China's environmental regulatory agencies have gained increasing clout in administrative decisions nationally, incentive conflicts with local administrators who rely primarily on local industries for tax revenue have limited the effectiveness of the program (Ma and Ortolano 2000). However, when enforced, the levies have been found to induce reductions in chemical dumping by firms and higher spending on wastewater treatment facilities (Wang and Wheeler 1996, Wang 2002).[8] In my empirical analysis, using more recent data, I find that the levy system continues to be an effective policy measure at inducing firms to modify their behavior and limit the discharge of untreated wastewater.

3 Data

The analysis of mortality patterns in China is based on China's Disease Surveillance Point system (DSP). The DSP is a set of 145 sites chosen to form a nationally representative sample of China's population, and selects sites across different levels of wealth and urbanization (see Appendix Table 1). The coverage population was also chosen to reproduce geographic dispersion in China's population, relative to patterns in China's 1990 census. The DSP records all deaths among the coverage population of 10 million residents at the points, and due to careful sample selection of the DSP sites, yields an annual sample of deaths that mirror patterns in the country nationwide (Yang 2005). This paper relies on the data taken from roughly 500,000 deaths recorded at DSP sites between 1991 and 2000, and population counts by age and sex that are used to convert the

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[8] Wang and Wheeler (1996), in an analysis on provincial data from 1987-1989 and 1992-1993, estimate an elasticity of roughly minus 1 for the dischard of chemical oxygen demand (COD) pollution intensity (discharge/output) with respect to the effective levy rate. Wang (2002), using plant level level data, estimates an elasticity of .65 for firm spending on operating expenses and .27 for firm investment in waste-water treatment facilities.

recorded deaths into death rates. A summary of cause-specific death rates during the sample period are shown in Table 1.

China's severe problems with water pollution began in the 1980s, following economic reforms in the late 1970s that led to an industrial boom. The national water monitoring system was established during the late 1980s and collects annual readings of chemical content at a set of sites across China. The World Bank produced a comprehensive assessment of water quality patterns in China from 1991-2005 using data collected by the monitoring system. The analysis presented here relies on the 2004 readings, which report water quality readings for 484 geographic points across China's nine river systems (see Appendix Table 2). The DSP and water quality data are geographically overlaid by using data on China's river basins created by the Hydro1k project, conducted by the United States Geological Survey center (see Figure 2). The projects provides a suite of geo-referenced data sets that are created using a Digital Elevation Model (DEM) in which China can be separated into a set of 989 basins, and a smaller set of larger basins. Satellite imagery is also exploited to assess regional variations in air quality that might also affect cancer rates.

Using NASA estimates of optical depth from aerosol imagery, I proxy for the impact of air quality on digestive cancer rates. The measure is taken between zero and 1, with higher numbers representing higher optical depth and implying the presence of more particulates and worse air quality (see Figure 3). I assign to each river basin a measure of the average particulates over the basin's region between 2002 and 2007 to reduce annual fluctuations in the data.[9] In order to examine how precipitation may affect water quality, I include measures of monthly rainfall collected by the Global Precipitation Climatology Center for 1961-1990. These measures are calculated by river basin in a manner similar to how I calculate average air quality, where I use GIS software and average the rainfall measure across the area in the same basin as the DSP point (see Figure 4). Summary statistics are shown for the water quality measures assigned to each DSP point and other characteristics of the decedents at the points in Table 2.

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[9] The NASA data on optical aerosol levels are only available beginning in 2002. However, China's industrialization exhibits a high degree of spatial concentration that suggests that the air quality during the available window is a reasonable proxy for air quality at the DSP points following China's large boom in manufacturing (Ebenstein and Hanink 2008).

The river basin data from the Hydro1k project are coded using a consistent numerical scheme that allows for inference regarding water flows within the network of basins (see Figure 5). The Pfafstetter coding system, designed in 1989 by Otto Pfafstetter, assigns watershed identification numbers based on the topology of the land surface. Since it is hierarchical, it is possible to identify the watershed immediately downstream of each watershed by its numbering (see Figure 6). This property is exploited to consider the impact of industrial activity upriver on cancer rates at DSP points in basins subordinate to the basin where the emissions are observed. The data on emissions are proxied by total value of manufacturing output, which is observed for each of China's counties (2,800+) at a particular latitude and longitude, and can therefore be placed in a river basin. The measure of upstream manufacturing is the total value of output in the level 4 basins that are upstream of the basin containing the DSP site.

China's Environmental Yearbooks are produced by the State Environmental Protection Agency (SEPA) and provide the necessary data to examine the responsiveness of both water quality to industrial dumping, and the responsiveness of dumping to regulatory incentives. China's environmental regulations require manufacturing firms to register all emissions, and each Yearbook contains province-level totals for the tonnage of discharge of wastewater that fails to meet standards, and the total levies collected as a result of these infractions in a consistent format for 1992 to 2002. The data also contain information on the tonnage of dumping and treatment by chemical, allowing for more detailed analysis of the statistical relationships between firm behavior and water pollution graded by chemical. Lastly, the Yearbooks contain reported spending by firms in wastewater treatment in each year, both in terms of equipment investments and operating expenses. During the 1990s, many provinces began to ratchet up enforcement of water discharge standards, leading to an increase in the fine levy collections as well as a decline in industrial dumping of untreated wastewater relative to output (see Figure 7). Using variation across provinces in the timing of these increases, I am able to assess how firm spending on cleanup responds to the environmental regulations, which reflects the marginal cost to firms of compliance with respect to levy rate increases.

4 Empirical Results

4.1 Main Results

In Table 3, I report the baseline results of the paper, where I examine OLS models of water quality and digestive cancer rates, measured in logs. Note that water quality is graded on a 6 point scale, where I (1) is the best water and VI (6) indicates that the water is unfit even for agricultural use. In the first regression, I examine the partial correlation of digestive cancer with the overall water quality grade, and find that an increase in the water grade by 1 level (e.g. IV to V) increases the digestive cancer rate by 14 percent. The coefficients are 35 percent, 14 percent, and 9 percent for the impact of water quality on esophageal, stomach, and liver cancer respectively, with the coefficients statistically significant at the 5% level for all but liver cancer, which is significant at the 10% level.

In a second set of specifications, I assess the impact of water quality on the same set of dependent variables, but with a rich set of controls for factors that might also affect digestive cancer rates. Controls are included for whether the DSP point is urban, the average education of decedents at the site above the age of 20, the share who were employed in farming and manufacturing, an imputed measure of ambient air quality (where a higher number reflects more particulates), and region fixed-effects. The results are somewhat lower, with the estimates implying that water quality eroding by one grade induces a 9.3 percentage point increase in the digestive cancer rate. The estimates for the aforementioned types of digestive cancer are 22, 7, and 8 percentage points respectively. It may be unsurprising that the coefficients are not dramatically changed by including controls, since Table 2 reflects that much of the water quality variation is regional, and the regions do not exhibit large differences in urbanization or air quality, and most of the change in estimate is due to the inclusion of region fixed-effects.[10] The results also indicate that urban sites have 30% lower digestive cancer rates, net of all the included controls. This is consistent with an interpre-

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[10] The preferred estimate with full controls and region fixed-effects in column 4 is also attributing the North-South difference in digestive cancer rates partially to region. Insofar as the relevant difference between the North and South is in rainfall patterns, and consequently water quality, the estimated coefficient in column 4 is overly conservative relative to the specification without regional controls.

tation that digestive cancer is linked to exposure to polluted water, since rural inhabitants are less likely to have access to a safe drinking supply (World Bank 2006). In addition, Table 3 indicates that air quality also has a positive relationship with digestive cancer rates, with an increase in the particulate index variable (that varies from 0-1) by 0.1 inducing a 2.5% increase in the digestive cancer rate.[11] This may reflect a causal link between contaminants in the air and the likelihood of tumors forming in digestive organs (Jerret et al. 2005), or may reflect a correlation between air quality and other carcinogenic environmental factors, such as water dumping or exposed carcinogenic chemicals.

In Table 4, I present an additional set of OLS regressions in which I examine whether the relationship between water quality and digestive cancers is observed differently by gender or by particular pollutant. All regressions include the full set of controls used in the regressions in Table 3. The results in Table 4 reflect a consistency between the estimated impact for men and women. For example, an increase in the water grade by 1 unit is associated with a 22 percentage point increase in the esophageal cancer rate for men, and a 18 percentage point increase for women. The impact of overall water quality on stomach cancer is also positive and similar by gender (8 percentage points for men, 6 percentage points for women) and this holds for liver cancer as well (8 percentage points for men, 9 percentage points for women). These findings are compelling evidence that environmental factors are responsible for the correlation between water quality and digestive cancer rates. In particular, if water quality did not directly affect digestive cancer rates but was instead reflecting an unobserved correlation between water quality and omitted factors, such as occupational exposure to carcinogens, one would expect to find larger elasticities for men, who are more likely to work in mines and other hazardous occupations. However, the similarity by gender is suggestive instead that factors shared by men and women are responsible for the correlation, such as water quality. The second result of interest in Table 4 is the statistically significant relationship between different measures of water pollution and digestive cancers, such as ammonia nitrogen and oils. While these measures of water pollution are correlated ($\rho = .70$) due to overlap in factors

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[11] The air quality measure has a mean of .48 and a standard deviation of .19 in the sample of DSP sites.

that affect water quality (e.g. rainfall), the robust statistical relationship between various measures of water pollution and digestive cancer support the paper's main hypothesis that poor water quality increases the incidence of digestive cancers.

In Table 5, I consider whether the OLS results could be explained by unobserved correlation between water quality and other potential risk factors for digestive cancer, such as smoking rates and dietary patterns. Using province-level information on smoking rates and dietary practices from household survey data (China Household Income Survey 1995, China Health and Nutrition Survey 1989-2006), I examine whether either smoking or diet patterns covary with water quality. The results indicate that smoking rates are similar across the water quality readings, suggesting that the estimated impact of water quality is not being confounded by smoking patterns.[12] Likewise, no large difference in diet is observed across sites with better and worse quality, suggesting that regional differences in diet are not responsible for the correlation between water quality and digestive cancer. So, although diet is a known risk factor for digestive cancers, it is uncorrelated with water quality and is therefore unlikely to be biasing the estimated effect of water quality on cancer.

Although dietary patterns in China are known to vary by region, it is unlikely to explain the patterns in cancer mortality I observe in the data, which reflect high digestive cancer rates among northern areas with lower rainfall (and consequently worse surface water quality). First, while salty and pickled foods are thought to be associated with higher digestive cancer rates (Kono and Hirohata 1996), southern China is not very different than northern China in this dietary dimension. In fact, the principal difference between northern and southern China in terms of diet is the South's "rice culture" versus the northern "wheat culture". Carbohydrates are thought to be a risk factor for Asian men with high rates of this disease (Ji et al. 1998) but inhabitants of both regions consume large amounts of carbohydrates. Since regional differences in diet are not thought to be risk factors for digestive cancer, it is unlikely that unobserved differences in diet are confounding the regression

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[12] National surveys reflect that smoking rates for men are in excess of 75%, but fewer than 8% of women smoke (Yang 1997). The age profile of smoking rates was very similar in both the national smoking survey of 1984 and in a follow-up survey in 1996, suggesting that smoking patterns are unlikely to be responsible for the recent increase in China's digestive cancer rate.

analysis.

4.2 Robustness Checks

In Table 6, I present a set of 2SLS estimates of water quality's relationship with digestive cancer rates, exploiting plausible exogenous variation in water quality due to differences in precipitation across the DSP sites, and variation in upstream manufacturing output. In the first column, I examine the first-stage relationship between monthly rainfall in milliliters, upstream manufacturing output, and the observed water grade within the river basin. The coefficient implies that an increase by 100 milliliters lowers the water grade by 1.2 levels, significant at the 1% level, which suggests that large variation in surface water quality is induced by variation in rainfall patterns. The impact of an additional million yuan of manufacturing output in the river basins directly upstream is associated with an increase in the water grade by 0.001 units, and the relationship is statistically significant at the 5% level. An F test of the joint significance of the two instruments is 11.73, which is highly significant as well.

In column 2, I exploit this variation and regress the log of the death rate from digestive cancer on the predicted water quality reading from the first-stage, and the covariates included from Table 3 (e.g. urban, years of education, etc.). The 2SLS estimates are larger than the OLS estimates, and imply that increasing the water quality grade by 1 level increases the digestive cancer rate by 30%. The estimates for esophageal cancer and stomach cancer imply that increasing the water quality grade by 1 level increases the incidence of these diseases by 104% and 48% respectively, and both are statistically significant at the 5% level. The 2SLS estimate for liver cancer is 2% and not statistically significant. Overall, the 2SLS results support the claim that there is a causal link between water quality and digestive cancers, though the point estimates are somewhat larger than what I find using OLS in Table 3. The per-grade estimate from 2SLS of 30% is similar to the OLS result using broader categorical measures (see Appendix Table 3), where I find that digestive cancer rates are 25% higher in areas with medium water quality (grade III) and 32% higher in areas with very poor water (grade IV+) relative to areas with potable surface drinking water (grade I and grade II). The preferred estimate from Table 3 of 9.3 percent per grade of water decline, however, is the most conservative specification and so it is used in the subsequent policy analysis.

In Table 7, I perform a falsification exercise where I attempt to assess whether water quality's correlation with cancer is an artifact of a correlation between water quality and higher death rates in general. As shown in the table, water quality appears largely unrelated to other causes of death, but is strongly correlated with cancer rates. A deterioration of water quality by a single grade induces an 8.7 percentage point increase in the cancer rate (significant at 5%), but has a small and statistically insignificant relationship to the death rate from other leading causes of death such as heart disease or stroke. Interestingly, the fact that the overall death rate is only weakly correlated (.021) with water quality in spite of water quality's impact on cancer rates suggests that other compensating effects of industrialization may mitigate the increase in cancer rates, such as greater wealth and better access to health care. The results also indicate that the correlation between water quality and cancers of all type is 8.7%, similar to what is found between digestive cancers alone. Since digestive cancers represent nearly two-thirds of all cancers, this is perhaps unsurprising, but reflects that non-digestive cancers, such as lung cancer and throat cancer, are also positively correlated with water pollution and may be causally linked to water pollution as well. Water pollution has been blamed by local residents for the outbreak of throat and lung cancer in some of China's "cancer villages" (Voss 2008), and has been linked to the incidence of certain respiratory tract cancers in China (Yu 2007).[13] While the analysis here focuses on digestive cancers, the link between water quality and cancer incidence may exist across a broader class of cancer types, and represents an area for further research.[14]

Digestive cancers are responsible for nearly one million deaths annually (WHO 2002) and policy efforts to lower the incidence of these diseases can have large benefits in terms of population

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[13] Voss (2008) documents high rates of cancer and poor water quality in Shenqiu County (Henan Province). Accessible online at http://www.stephenvoss.com/stories/ChinaWaterPollution/

[14] A comparison of cancer rates in China relative to the United States reveals that in spite of China's high male smoking rate, which is roughly 3 times the American, lung cancer is less common in China and represents a smaller share of total cancer deaths (see appendix Table 5). The table suggests that the causal links between behavior, environment, and cancer incidence may operate differently in China and the United States.

health and life expectancy. Digestive cancers represent 20% of deaths among those age 40 to 60 and are more common at these ages than other leading causes of death, such as stroke (see Figure 8). The conservative estimate of the impact of improving China's water grade is that almost 93,000 deaths could be averted annually, since nearly 1 million people (980,000) die each year of these diseases, and each water grade improvement is associated with 9.3% fewer digestive cancer deaths. As such, it is of great policy interest to know the cost of improving China's waterways by a single grade. In combination with my estimates of the potential benefit in averted cases of digestive cancer, it provides information regarding the tradeoffs associated with tighter wastewater regulations in China.

4.3 Estimating the Costs of Cleanup

In order to assess the cost of improving China's water, in this section I examine the relationship between China's surface water quality and industrial dumping, and the relationship between industrial dumping and the levy rates for wastewater discharge.[15] In combination with estimates of the cost of complying with higher levy rates, this provides the necessary parameters to estimate the cost of averting a death through an increase in the levy rates.[16]

In Table 8, I examine the relationship between industrial dumping and water grade, using provincial measures of dumping by chemical and the average monthly rainfall in the province. For each measure of water pollution reported by China's National Monitoring Center (2004), I examine its relationship with provincial measures of industrial wastewater dumping that are available by chemical. The water quality measures are averaged by province across the monitoring points and merged with industrial wastewater dumping data from the China Environmental Yearbook (2005). Dumping by chemical is available for nearly 500,000 manufacturing firms, which covers the vast majority of industrial production in China.

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[15] Summary statistics of the industries with the largest share of industrial pollution are presented in Appendix Table 5. Firms classified as producing chemicals or chemical products were responsible for 19% of the dumping of untreated wastewater, the largest share among the 21 industrial categories.

[16] See the appendix for further details regarding this calculation.

In column 1, I report the relationship between the overall water grade and the total dumping of untreated wastewater, which indicates that an increase in dumping by 10% would induce a .039 unit increase in water grade, and the result is statistically significant at the 1% level. Each additional millimeter of monthly rainfall is associated with a water grade that is -.021 lower, consistent with a prior that rainfall mitigates the impact of industrial dumping on surface water quality. In columns 2 through 7, I examine how water quality responds to the amount of dumping of a particular chemical. Note that measures of water quality can be linked to particular forms of pollution. For example, in column 2 I report that the ammonia nitrogen content in the surface water is .015 units higher for each 10% increase in the reported tonnage of dumping. Similar results are presented linking the other chemical dumping measures with the most closely linked measure of observed toxins in the water (grade). Though these estimates are based on limited data, they provide a benchmark for examining the potential benefit of reducing the dumping of untreated wastewater, and the importance of increasing enforcement in China's industrial zones in the northern arid parts of the country, which are also densely populated.

In Table 9, I examine how China's levy rates affected firm dumping behavior for 1992-2002, the window for which China's environmental yearbooks contain the necessary data on industrial wastewater treatment (in tons) and total spending by firms in wastewater treatment. Raising fines by 1 percent increases the tonnage of cleanup by 0.82 percent (significant at the 1% level) and spending on cleanup by 0.14 percent (significant at the 10% level). This is estimated with province and year fixed effects that absorb province- or year-specific variation in levies, and the standard errors are clustered at the province level. Since China's levy rates have been rising generally, this strategy essentially exploits the timing of levy increases across China, and is robust to either time-invariant or province-invariant factors driving levy rates and dumping behavior. These coefficients indicate that the marginal cost of abatement in China is much lower than the average cost, since anticipated wastewater treatment is anticipated to increase by almost 6 times as much as the total spending on cleanup, implying that during the 1990s many provinces could have induced large increases in cleanup by raising levy rates.[17]

In Table 10, I synthesize the preceding analysis to calculate the anticipated savings (in lives) of raising China's levy rate, and the compliance costs required of firms in wastewater treatment spending. A full 100% increase in China's levy rate is predicted to reduce untreated dumping by 82%, which in turn improves the water grade by 39% (from Table 8) of 82%, yielding a predicted improvement in water quality of .29 units (.82*.39). In the preferred OLS specification in Table 3, each unit decrease in water grade is associated with roughly 9.3% fewer deaths due to digestive cancer, or roughly 93,000 deaths due to digestive cancer. Since water quality is expected to improve by .29 units, the proposed levy increase would avert roughly 29,000 deaths. In terms of the anticipated compliance costs, I estimate that China's firms would need to increase spending on wastewater treatment by 14% from the level reported in 2001 of 29 billion yuan, or roughly $3.7 billion on wastewater treatment, which implies an anticipated extra $500 million in compliance costs.[18] This implies a cost per death averted of roughly $18,000 ($500 million/29,000 deaths averted). Since each digestive cancer death imposes a cost of slightly more than 20 years in life expectancy (20.12), this amounts to a cost of roughly $900 per year.[19]

This estimate is low relative to conventional valuation placed on a human life, even in low-income countries. According to surveys conducted in China by the World Bank in 2005, estimates based on the contingent valuation method indicate a mean value of a statistical life among the participants of 1.4 million yuan, or $175,000 (World Bank 2007).[20] While it is difficult to

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[17] An alternate interpretation is that the province and year fixed-effects are over-controlling for the relevant incentives. The simple correlation between the levy rate and spending on cleanup is roughly 0.43, which would imply marginal costs roughly three times larger than the preferred estimate of 0.14, but much of this variation is absorbed by the province and year fixed-effects. In terms of the cost to avert a death by increasing the levy rates, this would yield an estimate three times larger than what I present in Table 10.

[18] The environmental yearbook estimate for 2000 (in the 2001 yearbook) is the most recent year in which China's environmental yearbook reported both operating expenses and equipment value. This calculation also assumes an exchange rate of 8 yuan per dollar.

[19] This is calculated as the weighted average of remaining life expectancy, where the weights are defined by the share of digestive cancer deaths that occur at that age in the DSP. Alternatively, I have calculated that life expectancy at birth would be increased by 1.5 years through the elimination of this cause from a standard life table. The life expectancy at birth in the DSP sample (1991–2000) is 73.9 years, and is 75.4 years when the death rate from digestive cancer is set to zero, and the death rates from other causes are assumed to equal their distribution in the DSP. Results available upon request.

[20] The World Bank (2007) reports that the survey was administered in Chongqing and Shanghai (twice) and the survey questionnaire, with minor changes, was identical to those administered in the U.S., Canada, U.K., France, Italy,

measure the full cost in quality and length of life of contracting digestive cancer, the simple back-of-the-envelope calculation here suggests that the cost of compliance with higher pollution levies is justified by their benefit. My estimates suggest that even if the cost per averted death was much higher than the estimated $18,000, the cost to saving a life through cleanup would still be justified by the benefit in improved health outcomes.

In addition, my estimate of the potential health benefit of raising levies may be very conservative. First, the preferred OLS estimate of 9.3 percent is smaller than point estimates without regional control variables (12 percent) or estimates from 2SLS (30 percent), which serves to understate the impact of improving water quality. Second, I am focusing on a narrow measure of the health benefits of cleanup, the estimate presented here can be thought a lower bound of the full impact on mortality. Third, these calculations only count the cost of a death, when in fact digestive cancer is also associated with years of poor health and distress preceding death. Lastly, China's rapid income increases have led to large reductions in infant mortality and the incidence of infectious diseases. As the population ages, reducing the prevalence of digestive cancer will avert an increasing number of deaths, since the disease's share of deaths is higher among those in middle and old age (see Figure 8).

5 Conclusion

Despite an increase in clean-up efforts in recent years, the overall degradation of China's waterways continues. While the capacity of wastewater treatment facilities has grown, it has not kept pace with the growth of industrial output. The pollution intensity of China's industrial firms has declined (discharge per yuan of output), but the tonnage of water dumping has continued to increase (World Bank 2007).

Although China's economy has grown rapidly, the adverse health effects of pollution threaten to mitigate the health benefits of the country's newfound wealth. While China's industrial

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and Japan. See Krupnick et al. (2006) for more information regarding the surveys in China.

firms have contributed greatly to economic growth, the results presented here highlight one channel by which they have led to deterioration in health outcomes. The dumping of untreated wastewater in densely populated areas has contributed to China's increasing cancer rate, and cancer is now the country's leading cause of death (Chinese Ministry of Health 2008). The cost of industrial pollution is also disproportionately borne by the millions of Chinese farmers are unable to access safe drinking water, and who are least able to share in the benefits of China's urban manufacturing boom. Recent estimates by the World Bank (2006) indicate that as many as half of China's inhabitants still lack access to safe drinking water. In 2005, China's Ministry of Water Resources announced ambitious plans to reduce the number of residents without access to clean drinking water by a third by 2010 and to provide safe access to drinking water to all rural residents by 2030. Even if these goals are met, however, in the near future the need to curb industrial dumping of untreated wastewater is clear and pressing.

The analysis reveals a relatively low cost to averting deaths via water cleanup of roughly \$18,000, suggesting that dumping regulations need to be more aggressively enforced. The gaps in enforcement of China's regulations reveal inappropriately "cheap" opportunities to avert deaths relative to the value of life that Chinese citizens report in contingent valuation surveys. These surveys indicate average valuations of roughly \$175,000 for the value of a statistical life (Krupnick et al. 2006). In addition, the physical harm caused by water pollution is incurred by many of China's poorest citizens. Protests by villagers who are justifiably angered by the contamination of the water supply also suggest that the current Chinese policy may represent an ongoing threat to political stability in China. The government reported 50,000 environmental protests in 2005 alone (Los Angeles Times 2006), providing further motivation for tightening environmental standards on China's industrial firms. Wastewater dumping is in part responsible for China's emerging cancer epidemic, and addressing this problem through stricter levy enforcement may yield large improvements in public health and life expectancy at a reasonable cost. Failure to act could prove costly for the millions of rural Chinese farmers who continue to rely on surface water for their drinking supply.

6 Appendix Materials

6.1 Estimating the Cost of Averting a Death through Water Cleanup

In Section 4.3, I examine the potential policy impact of raising China's fine levies as a mechanism for inducing improvement in China's water quality and consequently reducing mortality. These calculations assume that the only benefit of water clean-up on health is through a decline in digestive cancer rates. The death rate from digestive cancer at site i is given by $DeathRate_i$, the water quality and dumping at site i be given by $WaterQuality_i$ and $Dumping_i$, and the effective tax applied to dumping is given by $TaxRate_i$. By definition, the total deaths from digestive cancer is related to the death rate (measured as deaths per 100,000) by the following equation, where N is the total population.

$$TotalDeaths = DeathRate \cdot (\frac{N}{100,000}) \tag{1}$$

The anticipated change in total deaths from a change in the tax rate can be re-written in terms of elasticities as follows.

$$\begin{aligned} \frac{\partial TotalDeaths_i}{\partial TaxRate_i} &= \frac{\partial \ln TotalDeaths_i}{\partial \ln TaxRate_i} \cdot \frac{TotalDeaths_i}{TaxRate_i} \\ &= \frac{\partial \ln DeathRate_i}{\partial \ln TaxRate_i} \cdot \frac{TotalDeaths_i}{TaxRate_i} \end{aligned} \tag{2}$$

where the second line follows from the definition of $TotalDeaths$ in (1). By the chain rule, we can express the relationship between the death rate and the tax rate as the product of several partial derivatives that are observed in the data.[21]

$$\frac{\partial TotalDeaths_i}{\partial TaxRate_i} = \frac{\partial \ln DeathRate_i}{\partial WaterQuality_i} \cdot \frac{\partial WaterQuality_i}{\partial \ln Dumping_i} \cdot \frac{\partial \ln Dumping_i}{\partial \ln TaxRate_i} \cdot \frac{TotalDeaths_i}{TaxRate_i}$$

The first term can be estimated by regressing the log of the death rate from digestive cancer on the water quality (i.e. grade) and demographic features of the site X_i.

$$\ln(DeathRate_i) = \beta_0 + \beta_1 WaterQuality_i + \beta_2 X_i \tag{3}$$

The second term can be estimated by regressing the water quality on the log of dumping of untreated waste $Dumping_i$ and millimeters of monthly rainfall R_i.

$$WaterQuality_i = \gamma_0 + \gamma_1 \ln(Dumping_i) + R_i \tag{4}$$

Firms will optimize by adjusting three dimensions of behavior: they can change the amount of pollution per unit of production at existing plants, they can alter output, or they can choose to

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[21] Since no data set has reliable information on the direct relationship between the death rate and the tax rate, I estimate the parameters in separate data sets with different sample sizes. The relationship between death rates and water quality is observed at the 145 DSP sites (See Table 3). The relationship between water quality and firm dumping is observed at the province level in 2004 (See Table 8). The relationship between water dumping, cleanup spending, and the tax rate is observed by province and year for 1992-2002 (See Table 9). For expository purposes, in this appendix I refer to the data as being observed at site i.

relocate to a location with less regulation. These three factors will yield a reduced form pattern in the data in which water dumping and the tax on dumping are negatively correlated. The elasticity of dumping to the tax rate is estimated as follows.

$$\ln(Dumping_i) = \lambda_0 + \lambda_1 \ln(TaxRate_i) \tag{5}$$

The increase in the tax rate also requires firms to spend more on wastewater treatment. Suppose the total cost of spending by firms at site i is given by $TotalCost_i$ and there are T firms.

$$TotalCosts = \sum_{i}^{T} TotalCost_i \tag{6}$$

The anticipated change in total costs from a change in the tax rate can be re-written in terms of elasticities as follows.

$$\frac{\partial TotalCost_i}{\partial TaxRate_i} = \frac{\partial \ln TotalCost_i}{\partial \ln TaxRate_i} \cdot \frac{TotalCost_i}{TaxRate_i} \tag{7}$$

The first term can be estimated by regressing the log of the total cost of cleanup on the log of the tax rate on dumping.

$$\ln(TotalCost_i) = \delta_0 + \delta_1 \ln(TaxRate_i) \tag{8}$$

The statistic of interest is the cost of saving a life through water cleanup. Using (2), we can predict the number of averted deaths due to an increase in the tax rate by applying the elasticity to the base-period level of deaths from digestive cancer, roughly 980,000 (World Health Organization 2002). Using (7), we can predict the amount of increased costs to firms in cleanup spending induced by an increase in the tax rate by applying the elasticity to the base-period level of spending on cleanup, roughly \$3.7 billion (China Environmental Yearbook 2001). The estimated cost to avert a death from wastewater cleanup implied by an increase in the tax rate can be expressed in terms of the reduced-form coefficients that define the elasticities, the base-period level of cleanup costs, and the base-period level of deaths from digestive cancer.

$$\frac{\partial TotalCosts / \partial TaxRate}{\partial TotalDeaths / \partial TaxRate} = \frac{\delta_1 \cdot TotalCosts}{\beta_1 \cdot \gamma_1 \cdot \lambda_1 \cdot TotalDeaths} \tag{9}$$

6.2 Supplementary Material

In Appendix Table 6 and Appendix Table 7, I examine further the claim that water quality and digestive cancer are causally linked. In Appendix Table 6, I present evidence that digestive cancer rates are especially high in rural sites in northern China. This paper's main hypothesis is that populations exposed to worse water quality will have higher digestive cancer rates, and the risks are greatest for those who rely directly on surface water for their drinking supply. Since surface water quality is worse in northern China, and rural inhabitants are more likely to rely on surface water for drinking than urban inhabitants, the results in Appendix Table 6 are consistent with the paper's main hypothesis. While this evidence does not rule out all alternative explanations for my result, it does weaken a set of rival hypotheses. For example, it is unlikely that regional dietary differences between northern and southern China would produce the results in Table 7, which indicate similar digestive cancer rates in urban sites in northern and southern China.

In Appendix Table 7, I attempt to measure whether water quality and digestive cancer rates were correlated prior to China's industrialization. Using the 1973-1975 China Cancer Survey, I am able to estimate the correlation between digestive cancer rates and water quality when the association should have been weaker, since few areas had experienced industrialization prior to China's economic liberalization of the late 1970's. In columns 1-3, I report the correlation between water quality and the digestive cancer rate in 1973-1975. The results reflect that water quality in 2004 and digestive cancer rates in the survey were only weakly correlated. In contrast, in columns 4-6 I regress the digestive cancer rate on water quality in 2004 using the DSP data from 1991-2000, and the results are statistically significant and positive. The null result in the"pre" period and significant result in the "post" period is suggestive of a causal link between industrial water pollution and digestive cancer. The standard errors in the 1973-1975 Cancer Survey are large relative to the magnitude of the coefficients, however, which indicates that this test may not have sufficient statistical power to draw firm conclusions.

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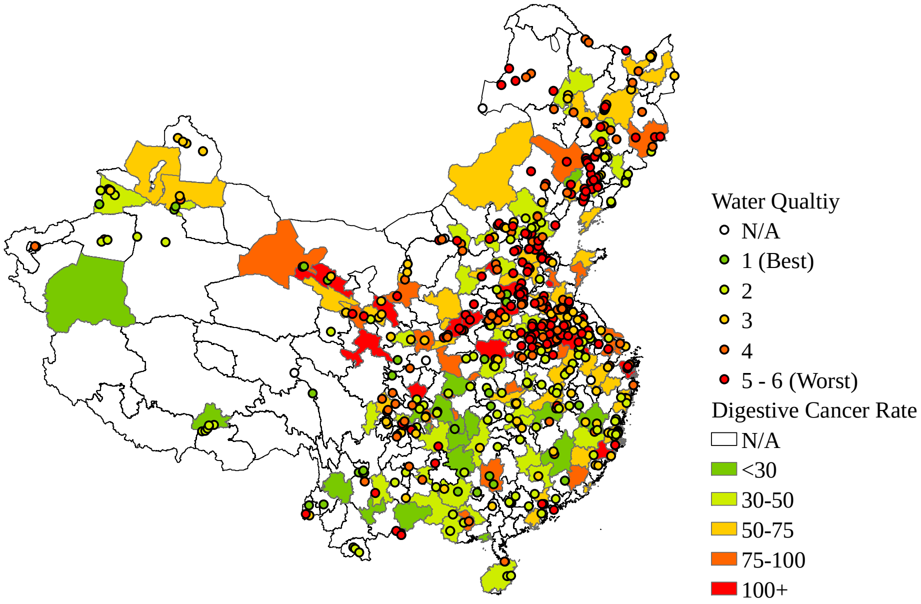
7 Figures and Tables`

Figure 1: Trends in Cancer Death Rates in Rural China

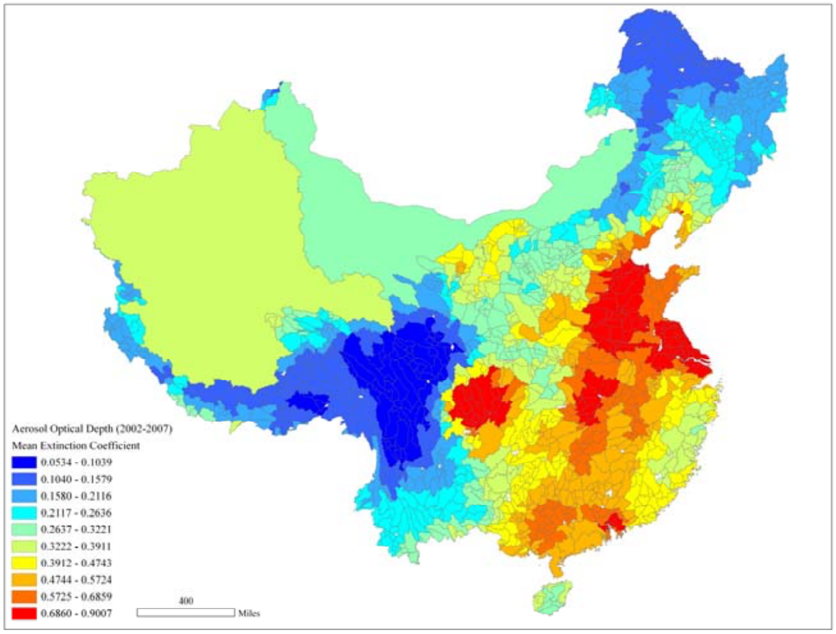
Source: China DSP. Graph displayed is created using STATA lowess smoother.
Death rates are per 100,000 persons.

Figure 2: Water Quality and Digestive Cancer Rates in Select Locations, 1991-2000



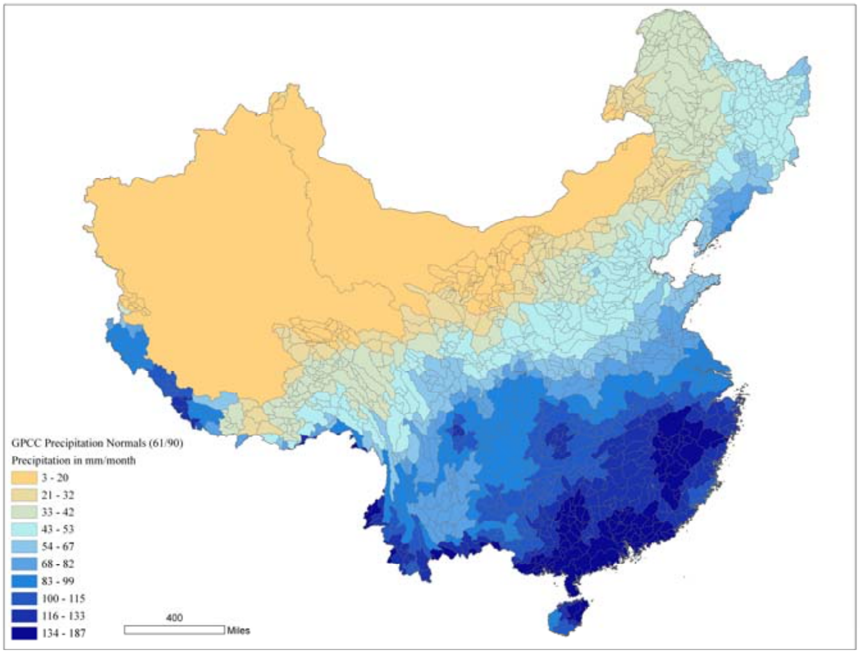
Source: China Center for Disease Control. Disease Surveillance Points (DSP) comprise a nationally representative sample of mortality for China. Rates reported per 100,000 and are age and sex adjusted using the 2000 census population structure.

Figure 3: Air quality patterns in China



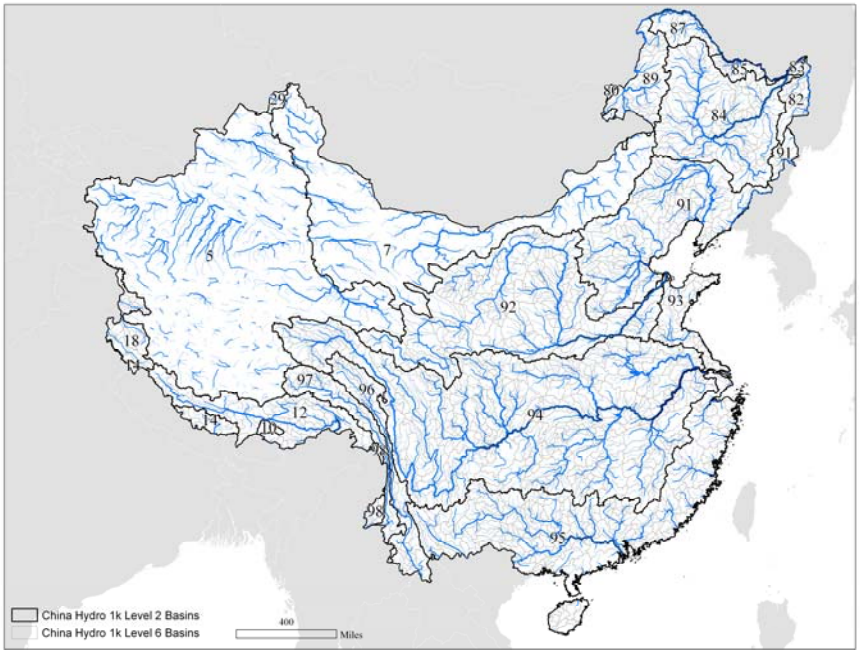
Source: NASA satellite imagery.

Figure 4: Monthly Precipitation Patterns in China, 1961-1990



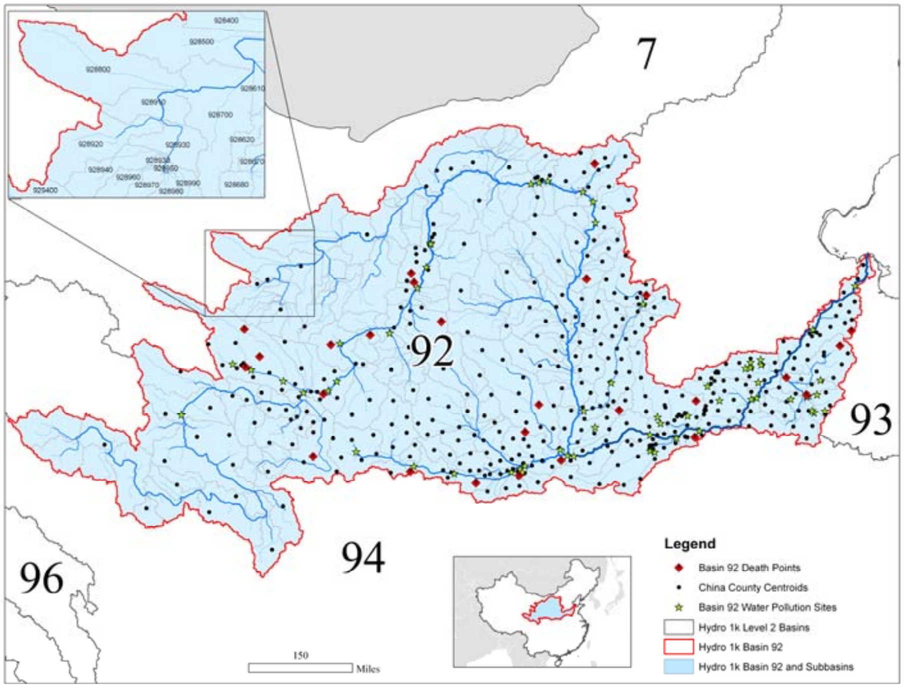
Source: Global Precipitation Climatology Center.

Figure 5: Main river basins in China



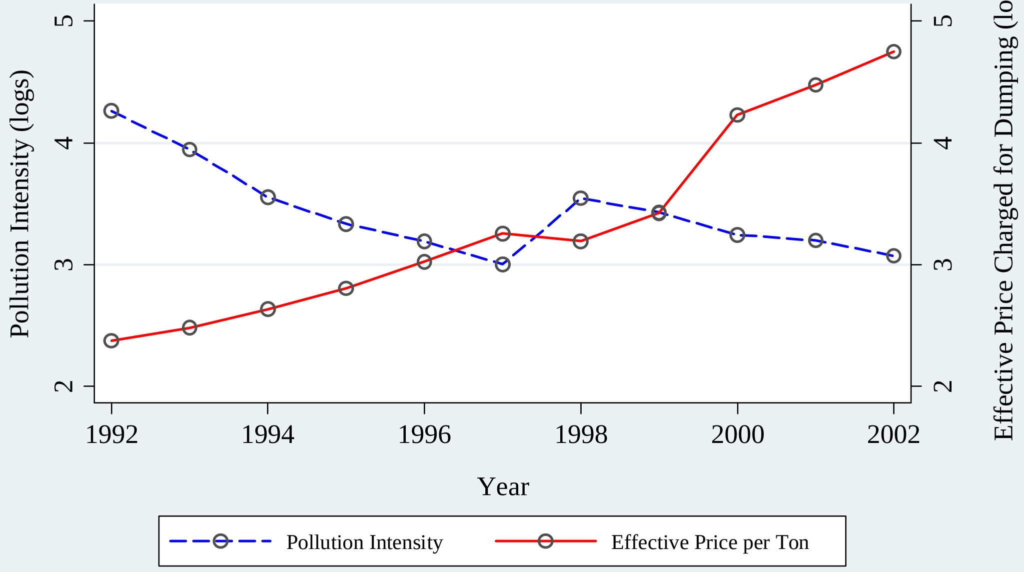
Source: Hydro 1k Project. The above figure reflects the principal 2-digit basins (or watersheds) that comprise the hydrological surface of China. The dark lines reflect the breakdown of the 2-digit basins, and the lighter outline is the breakdown of China into 989 lower-level basins.

Figure 6: Example of a River Basin



Source: China Hydro 1k Project.

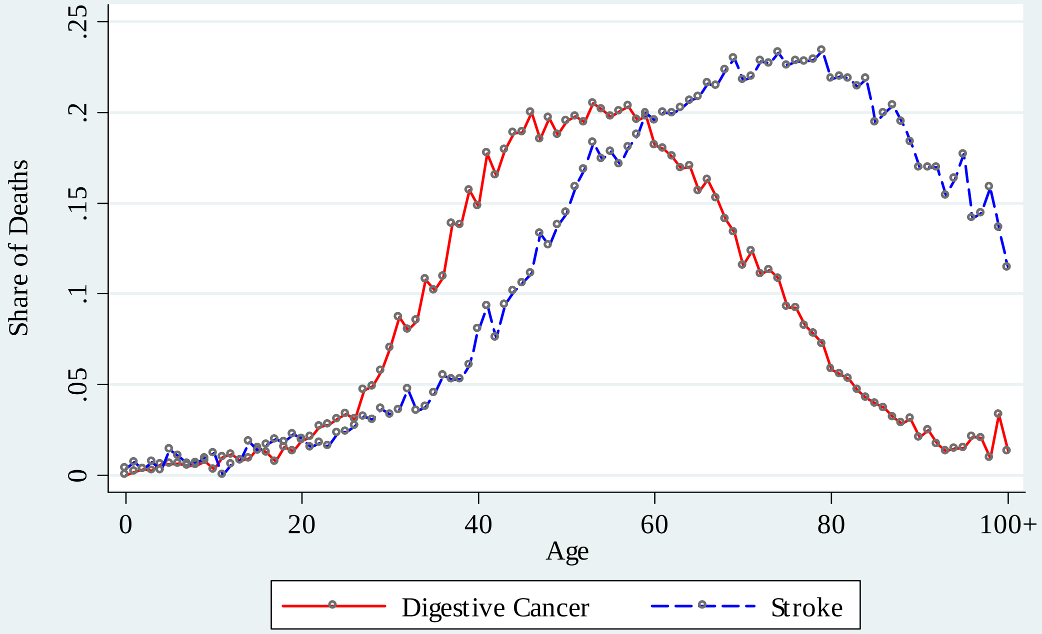
Figure 7: Pollution Intensity and the Effective Price Charged for Dumping



Soure: China Environmental Yearbook (1993-2003).

Note: Pollution intensity is the ratio of dumping in tons to 10,000 yuan of industrial output. The effective price is the value of collected yuan per hundred tons not meeting wastewater discharge standards

Figure 8: Age Distribution of Digestive Cancer and Stroke Deaths



Source: China DSP.

Table 1

Age-adjusted Death Rates (per 100,000) by Cause in China, 1991-2000

	Males		Females	
	Rural	Urban	Rural	Urban
	(1)	(2)	(3)	(4)
Panel 1: Death Rates by General Cause				
All Causes	726	599	600	463
Cancer	133	150	78	85
Digestive Cancers	94	79	49	38
Lung Cancers	26	50	12	21
Other Cancer	14	21	18	25
Heart	133	100	134	91
Stroke	125	125	107	100
Respiratory Illnesses	126	72	120	58
Accidents / Violence	91	49	59	31
Other	118	102	100	97
Panel 2: Death Rates for Types of Digestive Cancer				
Esophageal Cancer	21	11	11	4
Stomach Cancer	32	22	17	11
Liver Cancer	33	31	14	11
Other Digestive Cancers	9	15	7	12

Source : Chinese Disease Surveillance Points Mortality Registration System (DSP)

Note : N=145. Age adjustment is performed by calculating age-specific death rates and creating weighted averages using the population structure in China's 2000 census. Other digestive cancers includes colon cancer, intestinal cancer, and pancreatic cancer. The reported death rates are the average rates for the 145 sites, weighted by the population at each site. These calculations exclude roughly three thousand deaths (of the 500,000 deaths) in the sample where I am missing information on the age or sex of the decedent.

Table 2

Sample Means for Disease Surveillance Points by Region

Statistic	North	South	Overall
	(1)	(2)	(3)
Digestive Cancer Rate	78.8	63.2	68.7
Overall Water Grade	4.46	3.25	3.67
Ammonia Nitrogen	3.78	2.59	3.01
Biological Oxygen Demand	3.61	1.64	2.32
Oils	3.16	1.70	2.21
Permanganate	4.01	2.35	2.93
Volatile Phenol	2.26	1.30	1.64
Average Years of Education	3.92	4.33	4.19
Share in Farming	0.71	0.63	0.65
Urban site (1=yes)	0.24	0.23	0.23
Air Pollution Reading	0.53	0.49	0.51
Monthly Rainfall (mm)	50.7	99.6	82.5
Upstream Manufacturing (millions)	63.8	8.8	28.0
# of Sites	66	79	145

Source : Chinese Disease Surveillance Points Mortality Registration System (DSP), China National Monitoring Center (2004), Global Precipitation Climatology Center (2008)

Note : Higher grades reflect lower water quality (1=best, 6=worst) and a greater concentration of the listed pollutants. The water grade measure at each DSP site reflects the average water grade among monitoring sites in the same river basin. The air pollution reading is taken from satellite imagery and takes on values from 0-1, with higher values reflecting more particulates in the air, and is reported as the average reading in the river basin containing the DSP site. The rainfall measure is the average monthly rainfall in millileters in the river basin containing the DSP site from 1961-1990. Upstream manufacturing is based on the total value of output in yuan of firms with greater than 500,000 yuan in sales. The sample means are the average values (e.g. average education) among decedents at each site restricted to deaths among persons age 20 and older. Sample means are reported weighted by the population at each site.

Table 3

Ordinary Least Squares (OLS) Regressions of Log of Digestive Cancer Rates on Water Grade

	No Controls				With Controls			
Statistic	Digestive (all)	Esophageal	Stomach	Liver	Digestive (all)	Esophageal	Stomach	Liver
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water Grade (1=best, 6=worst)	0.135**	0.349***	0.141**	0.090*	0.093**	0.222**	0.074	0.079**
	(0.053)	(0.102)	(0.065)	(0.047)	(0.044)	(0.089)	(0.058)	(0.033)
Average Education					-0.014	0.005	-0.075	0.011
					(0.041)	(0.101)	(0.063)	(0.027)
Share in Farming					-0.304	0.078	-0.027	-0.595***
					(0.255)	(0.889)	(0.391)	(0.158)
Urban (1=yes)					-0.300*	-0.160	-0.034	-0.561***
					(0.176)	(0.656)	(0.256)	(0.126)
Air Pollution					0.249	0.580*	0.108	0.271*
					(0.147)	(0.302)	(0.176)	(0.151)
Region Controls	No	No	No	No	Yes	Yes	Yes	Yes
R Squared	0.097	0.140	0.064	0.054	0.198	0.251	0.170	0.239

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China Disease Surveillance Points Mortality Registration (DSP), China National Monitoring Center (2004)

Note : N=145. The first four columns represent OLS regressions of the logarithm of the death rate of a cause on the average water grade of the river basin in which the DSP site is located. I add covariates for columns (5)-(8), which are the average values (e.g. education) among decedents at each site restricted to deaths among persons age 20 and older. Standard errors are robust and clustered at the province level. The water grade measure at each DSP ite reflects the average water quality among monitoring sites in the same river basin. Regressions are weighted by the population at each DSP site.

Table 4

OLS Regressions of Log of Digestive Cancer Rates on Water Grade by Chemical

	Men			Women		
	Esophageal	Stomach	Liver	Esophageal	Stomach	Liver
Chemical	(1)	(2)	(3)	(4)	(5)	(6)
Overall Grade	0.219**	0.084	0.077**	0.177	0.059	0.093**
	(0.10)	(0.06)	(0.03)	(0.11)	(0.06)	(0.04)
Ammonia Nitrogen	0.214**	0.077	0.067**	0.203**	0.058	0.078**
	(0.10)	(0.05)	(0.03)	(0.10)	(0.05)	(0.03)
Biological Oxygen Demand	0.229***	0.090*	0.064*	0.170*	0.088*	0.080**
	(0.07)	(0.05)	(0.03)	(0.10)	(0.05)	(0.03)
Oils	0.214**	0.114	0.021	0.127	0.090	0.027
	(0.09)	(0.07)	(0.04)	(0.11)	(0.07)	(0.04)
Permanganate	0.228***	0.064	0.079**	0.183*	0.045	0.107***
	(0.08)	(0.06)	(0.04)	(0.11)	(0.05)	(0.04)
Volatile Phenol	0.201**	0.137**	0.035	0.085	0.091	0.088*
	(0.09)	(0.06)	(0.05)	(0.13)	(0.07)	(0.05)

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China Disease Surveillance Points Mortality Registration (DSP), China National Monitoring Center (2004)

Note : N=145. Each reported coefficient represents a separate regression. The regressions are estimated using the column variable as the dependent variable and the water grade measure in the row as the independent variable. Overall grade and chemical pollution are graded on a 6-point scale, with 1 being the highest quality and 6 being the most polluted. The dependent variable is the logarithm of the age and sex adjusted death rate by cause. The independent variable is a measure of water pollution, which is the amount of the chemical found in readings among water surveillance points in the river basin. All specifications include the control variables shown in Table 2. Standard errors are robust and clustered at the province level. Regressions are weighted by the population at each DSP site.

Table 5

Smoking and Dietary Habits by Water Grade in China

	Smoking Rates		Dietary Patterns				
Water Grade	Males	Females	Caloric Intake	Carbo-hydrates	% Fat	% Protein	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Level 1 (Best)	0.732	0.034	2,172	15.21	2.89	2.86	79.04
Level 2	0.705	0.066	2,376	15.12	2.96	2.84	79.08
Level 3	0.697	0.025	2,303	14.75	3.06	2.92	79.28
Level 4	0.705	0.034	2,238	15.38	2.75	2.97	78.90
Level 5	0.704	0.059	2,311	16.13	2.41	2.99	78.47
Level 6 (Worst)	0.710	0.046	2,316	15.19	2.82	2.92	79.06

Source : Smoking rates are taken from the China Household Income Survey (CHIS, 1995). The diet information is taken from the China Health and Nutrition Survey (CHNS, 1989-2006).

Note: The smoking rates are shown for the DSP sites which were in the 19 provinces included in the CHIS (1995), which includes 102 of the 145 DSP sites. Information on diet is shown for DSP sites located in the 9 provinces included in the CHNS, which includes 56 of the 145 sites.

Table 6

Two-stage Least Squares (2SLS) Regressions of Log of Digestive Cancer Rates on Water Grade using Annual Rainfall and Upstream Output as Instruments

	First-Stage	Two-stage Least Squares			
Statistic	Water Grade	Digestive (all)	Esophageal	Stomach	Liver
	(1)	(2)	(3)	(4)	(5)
Monthly Rainfall	-0.013**				
	(0.005)				
Upstream Output	0.001**				
	(0.0005)				
Water Grade (1=best, 6=worst)		0.303**	1.025***	0.470**	0.042
		(0.131)	(0.291)	(0.175)	(0.122)
Average Education	0.008	-0.018	0.019	-0.080	0.004
	(0.111)	(0.044)	(0.097)	(0.074)	(0.027)
Share in Farming	-0.702	-0.277	0.776	0.151	-0.817***
	(1.04)	(0.31)	(0.85)	(0.59)	(0.17)
Urban (1=yes)	-0.654	-0.247	0.432	0.163	-0.724***
	(0.852)	(0.198)	(0.548)	(0.391)	(0.156)
Air Pollution	0.593*	0.256	0.375	0.083	0.358**
	(0.332)	(0.165)	(0.341)	(0.208)	(0.172)
F Test of Instruments	11.73***				

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China Disease Suveillance Points Mortality Registration (DSP), China National Monitoring Center (2004), Global Precipitation Climatology Center (2008)

Note : N=145. The first column is the first-stage relationship between water grade at the DSP site, the covariates (e.g. urban), and two instrumental variables: the average monthly rainfall in millileters in the basin and output upstream of the basin containing the DSP site. The F statistic for the joint significance of the two instruments is reported (11.73), and the instruments also pass a Sargan-Hansen over-identification test, failing to reject the null hypothesis of their validity. The regressions in columns (2) through (5) represent 2SLS regressions where the dependent variable is the logarithm of the death rate of a cause on the predicted average water grade from colum (1) and the other covariates. Standard errors are robust and clustered at the province level. Regressions are weighted by the population at each DSP site.

Table 7

Impact of Water Pollution on Log of Death Rates by Cause in China, 1991-2000

	All Causes	Cancer	Heart	Stroke	Respiratory	Violent/ Accidents	Other
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Overall Grade (1=best, 6=worst)	0.021	0.087**	-0.009	0.042	0.001	-0.009	-0.008
	(0.02)	(0.04)	(0.04)	(0.05)	(0.06)	(0.03)	(0.02)
Ammonia Nitrogen	0.010	0.072**	-0.022	0.027	0.013	-0.007	-0.028
	(0.02)	(0.03)	(0.04)	(0.05)	(0.05)	(0.02)	(0.02)
Biological Oxygen Demand	0.010	0.070**	-0.016	0.010	-0.014	-0.008	-0.024
	(0.02)	(0.03)	(0.04)	(0.04)	(0.06)	(0.02)	(0.02)
Oils	0.020	0.059	0.076	0.024	-0.056	-0.014	-0.027
	(0.03)	(0.04)	(0.05)	(0.05)	(0.05)	(0.02)	(0.03)
Permanganate	0.008	0.072**	-0.022	0.028	-0.006	-0.031	-0.032
	(0.02)	(0.03)	(0.05)	(0.05)	(0.07)	(0.02)	(0.02)
Volitile Phenol	0.035	0.074*	0.045	0.052	-0.024	-0.007	0.019
	(0.04)	(0.04)	(0.06)	(0.05)	(0.06)	(0.03)	(0.02)

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : Chinese Disease Surveillance Points Mortality Registration System, China National Monitoring Center (2004)

Note : N=145. Each reported coefficient represents a separate regression. The regressions are estimated using the column variable as the dependent variable and the water quality measure in the row as the independent variable. Each water reading is graded on a 6-point scale, with 1 being the highest quality and 6 being the most polluted. The dependent variable is the log of the death rate by cause for each DSP site (see Table 2). The independent variable is a measure of water pollution, which is calculated as the average chemical reading among the water surveillance points in 2004 for the watershed containing the DSP site. All specifications include the controls listed in Table 3 and are weighted by the population at each DSP site.

Table 8

OLS Regressions of Water Grade on Industrial Chemical Dumping and Rainfall

	Overall Quality	Ammonia Nitrogen	Biological Oxygen Demand	Oils	Permanganate	Volitile Phenol
Chemical	(1)	(2)	(3)	(4)	(5)	(6)
Log of Chemical Dumping (Tons)	0.387***	0.154**	0.262**	0.237***	0.347***	0.078
	(0.10)	(0.07)	(0.12)	(0.07)	(0.10)	(0.07)
Monthly Rainfall (mm)	-0.021***	-0.014***	-0.019***	-0.018***	-0.020***	-0.011***
	(0.005)	(0.005)	(0.006)	(0.004)	(0.005)	(0.004)
Chemical Dumping Measure	Total Dumping	Ammonia Nitrogen	Chemical Oxygen Demand	Petroleum	Suspended Solid Waste	Volitized Phenol
Number of Tons Per Site	71,900	13,979	168,645	767	105,032	52
Average Grade	3.54	2.89	2.31	2.21	2.83	1.70
R Squared	0.40	0.28	0.33	0.52	0.41	0.26
N	30	30	30	30	30	30

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China National Monitoring Center (2004), China Environmental Yearbook (2000, 2005)

Note: The dependent variable in each regression is the average water grade for the listed chemical within the province. Water quality is graded on a 6-point scale, with 1 being the highest quality and 6 being the most polluted. The independent variables are the log of chemical dumping reported at the province level in China's Environmental Yearbook (2005), except Suspended Solid Waste, which is taken from the 2000 Yearbook. Standard errors are robust.

Table 9

OLS Regressions of the Log of Firm Cleanup (tons) and Firm Spending on Cleanup (yuan) on the Log of the Water Pollution Levy Charge (yuan per ton)

	Total Industrial Cleanup (tons)	Spending on Cleanup (100 million yuan)
Chemical	(2)	(3)
Log of Effective Fine Levy	0.815***	0.137*
	(0.21)	(0.08)
Period Available	1992-2002	1992-2002
R Squared	0.706	0.902
N	319	319

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China Environmental Yearbooks (1993-2003)

Note : The effective fine levy is yuan collected per ton of wastewater discharge failing to meet regulatory standards. This is reported for all registered manufacturing firm by province and year. The sample sizes correspond to the 29 provinces in China for 1992-2002. All regressions include province and year fixed effects and the standard errors are robust and clustered at the province level. Industrial dumping and cleanup measures are taken from the Environmental Yearbooks and gross output is taken from the Statistical Yearbooks. The dependent variable in the first column is the log of total tons of reported water tonnage of cleanup across all chemicals. The dependent variable in the second column is the log of total spending on cleanup (in 100 million yuan). Chongqing is included in the totals for Sichuan, and Tibet is excluded from this analysis since data on levies are unavailable. I censor the bottom and top 1 percent of the observed provincial levy rates (6 observations). The results are very similar whether I include or exclude these values. Regressions are weighted by the population of each province.

Table 10

Estimated Benefits and Costs of Raising Fine Levies

	$\frac{\partial \ln DeathRate_i}{\partial WaterQuality_i}$	$\frac{\partial WaterQuality_i}{\partial \ln Dumping_i}$	$\frac{\partial \ln Dumping_i}{\partial \ln TaxRate_i}$	Benefits and Costs of Doubling Fine Rates: Deaths Averted Per Year	Extra Compliance Cost Per Year ($)	Cost per Averted Death	Cost Per Year of Life
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				(1)*(2)*(3)*(980,000[a])	(Costs[b])*(0.137)	(5)/(4)	(6)/20.12[c]
Overall Grade	0.093** (0.044)	0.387*** (0.096)	0.815*** (0.21)	28,746	$ 504,888,032	$ 17,564	$ 873

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China Disease Surveillance Points Mortality Registration (DSP), China National Monitoring Center (2004), China Environmental Yearbooks (1993-2003), World Health Organization (2002)

Note : In column 1, I report the relationship between the log of the digestive cancer rate on the overall water grade (See Table 3). In column 2, I report the relationship between the water grade and the log of total dumping (See Table 8). In column 3, I report the relationship between the log of total dumping and the log of the effective fine levy on water dumping (See Table 9). [a]In column 4, I predict the number of lives saved by raising the levy rate, using the fact that the total annual deaths due to digestive cancers is roughly 980,000 (World Health Organization 2002). [b]In column 5, I predict the cost of compliance of raising the levy rate, using the fact that total reported compliance costs in 2000 was roughly $3.7 billion dollars (China Environmental Yearbook 2001), and the estimated elasticity of spending on cleanup of .137 (see Table 9). In column 6, I present the cost to firms in addtional spending required to avert one additional death from digestive cancer. [c]In column 7, I report this cost in terms of extra years of life expectancy, using the fact that decedents have on average 20.12 years of remaining life expectancy.

Appendix Table 1

Sample Means (and standard deviatons) for China Disease Surveilance Points by Urbanization, 1991-2000

Statistic	Poor Rural	Medium Rural	Rich Rural	Urban
	(1)	(2)	(3)	(4)
Share of Deaths Occuring in the Home	0.826	0.794	0.801	0.365
	(0.08)	(0.18)	(0.09)	(0.16)
Share of Deaths Occuring in the Hospital	0.073	0.109	0.104	0.490
	(0.05)	(0.17)	(0.09)	(0.15)
Share of Decedents Employed in Farming	0.919	0.837	0.788	0.013
	(0.09)	(0.20)	(0.23)	(0.04)
Average Education among Decedents	3.38	3.64	3.63	6.27
	(1.11)	(1.33)	(1.48)	(1.27)
Total Deaths Recorded	124,492	153,388	124,115	110,642
Total Person Years Covered	25,016,184	30,227,522	21,918,116	23,584,446
Crude Death Rate (Deaths/Persons)	0.0050	0.0051	0.0057	0.0047
Number of Sites	32	31	32	50

Source : China Disease Surveillance Points Mortality Registration (DSP)

Note : The table above summarizes differences across the 145 sites covered by the DSP. The sites form a nationally representative sample of deaths for China (see Yang et al. 2005). Employment and education for decedents restricted to deaths among persons age 20 and older. Total deaths recorded is for the entire sample frame from 1991-2000. The total person years covered refers to the total number of individuals covered by each DSP site summed over the entire sample frame from 1991-2000.

Appendix Table 2

Summary Statistics of Water Quality in China's Main River Systems

River System	Region	Overall	Ammonia Nitrogen	Biological Oxygen Demand	Oils	Perman-ganate	Volatile Phenol
Liao River	Northeast	4.94	3.90	4.07	2.93	4.31	3.11
Hai River	North	4.85	4.17	4.10	3.23	4.35	2.53
Huai River	North	4.63	3.94	3.54	2.71	4.00	1.75
Yellow River	North	4.23	3.57	2.68	2.98	3.34	2.21
Songhua River	Northeast	3.90	2.58	2.14	1.73	3.51	1.77
Fujian/Zhejiang	South	3.10	2.56	1.41	1.63	2.28	1.29
Yangtze River	South	2.85	2.38	1.36	1.65	1.93	1.17
Nu/Yarlung Zangbo	Southwest	2.71	1.62	1.40	1.86	2.10	1.00
Pearl River	South	2.50	1.88	1.35	1.33	1.62	1.09
Inward flowing systems	West	2.08	1.88	1.08	3.46	1.54	1.00

Source : China National Monitoring Center (2004)

Note : Higher numbers reflect lower water quality (1=best, 6=worst) and a greater concentration of the listed pollutants. These readings are taken from 484 water quality monitoring systems across China. The systems are displayed in descending order of overall water quality.

Appendix Table 3

Ordinary Least Squares (OLS) Regressions of Log of Digestive Cancer Rates on Water Grade by Category

	No Controls				With Controls			
Statistic	Digestive (all)	Esophageal	Stomach	Liver	Digestive (all)	Esophageal	Stomach	Liver
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Medium Quality Water (1=yes)	0.314	0.455	0.408*	0.255	0.247*	0.387	0.308	0.192
	(0.190)	(0.391)	(0.236)	(0.183)	(0.130)	(0.276)	(0.207)	(0.114)
Lowest Quality Water (1=yes)	0.429**	0.953***	0.554**	0.291*	0.323**	0.648**	0.348*	0.283**
	(0.170)	(0.344)	(0.226)	(0.152)	(0.146)	(0.289)	(0.200)	(0.109)
Average Education					-0.003	0.027	-0.064	0.021
					(0.042)	(0.104)	(0.062)	(0.027)
Share in Farming					-0.404	-0.117	-0.123	-0.671***
					(0.271)	(0.933)	(0.390)	(0.167)
Urban Site (1=yes)					-0.399*	-0.371	-0.125	-0.641***
					(0.197)	(0.699)	(0.261)	(0.143)
Air Pollution					0.282**	0.649**	0.141	0.299**
					(0.137)	(0.290)	(0.165)	(0.141)
Region Controls	No	No	No	No	Yes	Yes	Yes	Yes
R Squared	0.091	0.098	0.092	0.056	0.208	0.244	0.190	0.249

* significant at 10% ** significant at 5%. *** significant at 1%.

Source: China Disease Surveillance Points Mortality Registration (DSP), China National Monitoring Center (2004)

Note: N=145. See Table 3 for a description of the control variables included in columns 4-6. Standard errors are robust and clustered at the province level. Regressions are weighted by the population at each DSP site. The water grade is measured on a 6 point scale: the base category is drinkable water (grade I or grade II), the medium quality water category (grade III) is water that is not drinkable but suitable for human contact (grade III), and the lowest quality water category is water that is not suitable for human contact (grade IV+). The coefficient for medium quality and lowest quality water are reported relative to drinkable water.

Appendix Table 4

Comparison of Age-adjusted Death Rates (per 100,000) due to Cancer, China and the United States

	China		United States (Overall)		Asian Americans	
	Men	Women	Men	Women	Men	Women
All Cancers	137	80	228	157	137	92
Digestive	90	46	57	35	46	31
Lung	32	14	71	41	37	18
Other	15	20	101	82	54	43
% Digestive	66%	58%	25%	22%	34%	34%
% Lung	23%	17%	31%	26%	27%	20%
% Other	11%	25%	44%	52%	39%	47%

Source : China DSP 1991-2000, United States Cancer Statistics: 2004 Incidence and Mortality, Center for Disease Control (CDC)

Note : Statistics for the United States reported relative to US standard population in 2000, which is not directly comparable to the rates reported for China, which are adjusted using the age distribution of the 2000 China census, and would be slightly altered if evaluated using the US standard population. The US population is older than the Chinese population: the census for both countries in 2000 reflects that the US median age (41) is 4 years older than the Chinese median age (37).

Appendix Table 5

Industrial Wastewater Dumping and Manufacturing Output by Industry, China (1998-2000)

Industry	Dumping (10,000 tons)	Percent of Dumping	Output (million yuan)	Percent of Output	Pollution Intensity
	(1)	(2)	(3)	(4)	(2)/(4)
Chemicals and chemical products	1,081,982	18.9%	1,236,764	7.3%	2.6
Ferrous metal smelting and pressing	967,518	16.9%	318,901	1.8%	9.2
Paper and paper products	707,785	12.4%	814,550	4.7%	2.6
Electricity, gas, and water production	610,458	10.7%	471,520	2.7%	3.9
Food, beverages and tobacco	512,592	9.0%	1,512,839	8.7%	1.0
Mining	377,351	6.6%	523,205	3.0%	2.2
Textiles	357,017	6.2%	1,687,521	9.7%	0.6
Mechanical and electronic equipment	296,958	5.2%	4,645,496	26.8%	0.2
Construction materials	215,395	3.8%	757,880	4.4%	0.9
Other	597,352	10.4%	4,973,618	28.7%	0.4
Total	5,724,408	100.0%	16,942,295	100.0%	1.0

Source : Chinese Environmental Yearbooks (1998-2000), China Manufacturing Firm Database (1998-2000)

Note : Manufacturing output is based on the total value of output in yuan of firms with greater than 500,000 yuan in sales. Dumping by industry is reported for firms registered with China's State Environmental Protection Agency (SEPA).

Appendix Table 6

Digestive Cancer Rates and (standard errors) at DSP Sites by Region and Urbanization

Region	Rural	Urban	Difference
	(1)	(2)	(1)-(2)
Northern China	83.90	61.37	20.02**
	(6.24)	(3.80)	(7.82)
Southern China	61.10	61.37	0.109
	(5.20)	(4.11)	(6.79)

* significant at 10% ** significant at 5%. *** significant at 1%.

Source : China DSP, China National Monitoring Center (2004)

Note : Region is as defined in Table 2, with 66 sites classified as Northern and 79 sites classified as Southern. Statistics are reported weighted by the population at each DSP site.

Appendix Table 7

OLS Regressions of Digestive Cancer Rates on Water Grade by Period

	1973-75 Digestive Cancer Rates			1991-2000 Digestive Cancer Rates		
Statistic	Total (1)	Male (2)	Female (3)	Total (4)	Male (5)	Female (6)
Water Grade (1=best, 6=worst)	4.61	5.56	3.69	6.09**	7.41**	4.83**
	(3.1)	(4.3)	(2.2)	(2.8)	(3.5)	(2.1)
Average Education	-2.66	-4.00	-1.21	-2.92	-4.59	-1.25
	(2.5)	(3.6)	(1.8)	(2.8)	(3.6)	(2.1)
Share in Farming	-19.45	-35.05*	-8.30	-16.69	-21.05	-12.91
	(15.5)	(19.2)	(15.1)	(22.4)	(28.9)	(16.8)
Urban (1=yes)	-3.74	-13.43	1.38	-24.83	-27.33	-22.90*
	(14.3)	(18.1)	(13.2)	(16.2)	(21.4)	(11.9)
Air Pollution	7.31	11.22	4.94	16.59**	25.17**	7.63
	(10.2)	(14.5)	(6.7)	(8.0)	(10.3)	(5.9)
N	140	133	132	145	145	145

* significant at 10%. ** significant at 5%. *** significant at 1%.

Source : China Disease Suveillance Points Mortality Registration (DSP), China National Monitoring Center (2004), Global Precipitation Climatology Center (2008), China Cancer Database (2004)

Note : Columns 1-3 demonstrate the relationship between cancer rates and water quality in data from 1973-1975 overall (1) and by gender (2-3). Columns 4-6 demonstrate the relationship between cancer rates and water quality in data from 1991-2000 overall (4) and by gender (5-6). The number of observations varies by statistic due to incomplete data for the 1973-1975 period. Regressions are weighted by the population at each DSP site.