Journal of Cleaner Production 216 (2019) 311–322

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Water crisis, environmental regulations and location dynamics of pollution-intensive industries in China: A study of the Taihu Lake watershed

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A R T I C L E I N F O

Article history:
Received 4 May 2018
Received in revised form
14 December 2018
Accepted 16 January 2019
Available online 21 January 2019

Keywords:
Environmental regulations
Industrial location
Pollution-intensive industry
Water crisis
Taihu lake watershed
China

A B S T R A C T

Most existing studies on environmental regulations and the location dynamics of pollution-intensive industries regard new environmental procedures as an incremental development process, and neglect the influence of sudden changes in environmental regulations triggered by a pollution crisis. Using the drinking water crisis in the Taihu Lake Watershed (TLW) in 2007 as an example, this paper examines the spatial behavior of pollution-intensive firms across the TLW, and pays special attention to the regional differences in the effectiveness of enforcing environmental regulations. We find that the pollution haven hypothesis works efficiently in the short term after an unexpected pollution crisis because of the immediate strengthening of environmental regulations by local governments under pressure from the central government and the public. However, the effect of strict environmental policies was compromised by differences in the effectiveness of policy enforcement across the watershed. Specifically, when other regions (for example, Huzhou) were compared with Wuxi (the site of the crisis in the present study), these regions were found to be relatively insensitive to the effects of the pollution incidents and the environmental regulations that were triggered.

1. Introduction

Since the beginning of the reform process in the late 1970s, China has achieved remarkable economic growth by participating in global production networks and by promoting export-oriented industrialization (Yeung and Lin, 2003; He et al., 2008; Wei et al., 2009; Yang, 2014). This economic growth is widely recognized as the 'Chinese miracle' (Bramall, 2008). However, environmental pollution and ecological degradation resulting from this economic growth pose growing threats to sustainable development (Brunnermeier and Levinson, 2004; Wei, 2016). Lax environmental regulations have provided China with comparative advantages in attracting pollution-intensive (PI) industries from the Global North (Bu et al., 2013). This has led to serious environmental problems associated with the rapid growth of international trade (Jalil and Mahmud, 2009; Yan and Yang, 2010; Ren et al., 2014). However, China's central government has recently begun to introduce stringent regulations to prevent pollution and to protect the environment (Jahiel, 1997; Wang and Lin, 2010), as its developed counterparts have done earlier (Lucas et al., 1992; Plummer et al., 2010).

In recent years, there has been an increasing number of studies on the effects of environmental regulations on industrial (re)location in China (Yang, 2012; Yang and He, 2015; Zhu and Lan, 2016; Shen et al., 2017; Zheng and Shi, 2017). These studies were mainly based on the pollution haven hypothesis (PHH), which posits that differences in the stringency of environmental regulations between developed and developing regions could provide developing regions with a comparative advantage in pollution-intensive (PI) production (Walter and Ugelow, 1979; Baumol and Oates, 1988; Copeland and Taylor, 1994; Cole, 2004). Although these studies have broadened our knowledge of environment-economy relationships (Bridge, 2008; Hayter, 2008), the location

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https://doi.org/10.1016/j.jclepro.2019.01.177
0959-6526/

dynamics of PI industries in response to changes in various environmental regulations have not been fully examined.

The specific knowledge gaps and study limitations are now presented. First, much of the literature has viewed the development of environmental regulations as an incremental process, and de-emphasized the influence of new environmental regulations triggered by pollution incidents (Schwartz and McConnell, 2009; Plummer et al., 2010). In response to a crisis, governments tend not to follow an incremental process, but immediately impose compulsory policies to prevent point source pollution, which does not allow PI firms to incrementally upgrade their technological capabilities for clean development or to shift to new non-polluting products (Kettl, 2002; Plummer et al., 2010). Second, the influence of an environmental crisis varies across regions, and local governments may adopt different strategies in the formulation and enforcement of environmental policies to deal with the pollution (Jahiel, 1997; Wang and Lin, 2010). Although the existing literature has carefully examined the influence of regional differences in environmental policies, such as pollution emission standards on the location dynamics of industries, it has paid relatively little attention to the effectiveness of the enforcement of environmental regulations (Tang et al., 2003). Finally, there are limitations in terms of study-area scale: most of the existing research has been conducted at the national or provincial scales (Chung, 2014; Yang and He, 2015), although studies at a finer geographical scale have been advocated (Wei, 2015; Shen et al., 2017).

To address the research issues described above, the present study attempts to broaden the knowledge of the relationship between environmental regulations and industrial dynamics by investigating the regional difference in policy enforcement effectiveness at the watershed scale. In particular the imposing of strict environmental regulations subsequent to water pollution incidents is investigated. Specifically, we focus on the heterogeneous response of PI industries and firms to the drinking water crisis in the Taihu Lake Watershed (TLW) in 2007, and track the differences between the regulatory actions in different sub-regions. The study addresses two questions: 1) What were the characteristics of the spatial-temporal dynamics of PI firms in response to the changing environmental regulations within the TLW before and after the crisis? 2) How, and to what extent, did differences in the enforcement of the environmental regulations in response to the crisis, as well as industry and firm heterogeneity affect the exit or survival of PI firms?

2. Literature review and conceptual framework

2.1. Environmental regulations, enforcement effectiveness, and industrial location dynamics

Although the debate on environmental regulations and industrial location dynamics is not new, it has regained attention in recent years because of severe environmental pollution and degradation in developing countries. Many empirical studies have attempted to verify the PHH and to test whether stringent environmental regulations in developed economies have pushed PI industries to (re)locate to regions with relatively lax regulations (e.g., Cole, 2004; Copeland and Taylor, 1994; Levinson, 1996; Jaffe et al., 1995; Zhu et al., 2014). However, the empirical evidence for the PHH is mixed and can be controversial (Jeppesen and Folmer, 2001). Some studies have found robust evidence to support the assumption that lax environmental regulation policies attract an increasing inflow of PI industries (Mulatu et al., 2010; Bagayev and Lochard, 2017; Zheng and Shi, 2017), while other studies have come to the conclusion that PI industries are insensitive to interjurisdictional differences in environment regulations (Jaffe et al., 1995; Levinson, 1996).

There are a number of reasons why the influence of environmental regulations on industrial dynamics may be statistically insignificant or difficult to detect. One reason is that compliance costs for environmental regulations are too small to have a significant influence on firms' location decisions; this was a common explanation in the early studies (Levinson, 1996). Moreover, many researchers have reached a consensus that the effects of uneven environmental regulations on the dynamics of PI industries are related to firm heterogeneities, such as firm size, technological competence, and business strategy. The firm heterogeneities make it difficult to use aggregated industry-level data to estimate the effects of environmental regulations on firm dynamics (Zhu et al., 2014; Zhou et al., 2017; Wu et al., 2019). In addition, the effects of environmental regulations on industrial dynamics are also sensitive to regional differences in the enforcement effectiveness of environmental regulations. The enforcement effectiveness is also related to regulation type and government intervention (Tang et al., 2003; Zhou et al., 2017).

On the one hand, multiple environmental regulations have different impacts on firm-specific behaviors such as (re)location choice, exit decision, and technological upgrading strategies. Generally, environmental policies can be divided into three categories: command and control, economic instruments, and public participation (World Bank, 1997; Turner, 2000). Environmental regulation, especially in developing and transition economies, is usually dominated by direct regulatory instruments that impose constraints or obligations on the actions of firms in order to protect the environment (Jahiel, 1997; Turner, 2000). There is evidence that economic instruments, such as taxes and auctioned permits, provide more incentives to upgrade technological capability, while direct command and control instruments are dominated by administrative actions and usually provide the lowest relative incentives for technological changes (Milliman and Prince, 1989). The implementation of command and control policies encourages PI firms to exit from the original location and migrate to regions with lax environmental regulation, as predicted by the PHH. Public protests against industrial pollution have exerted an increasingly significant impact on industry (re)location in recent years (Van Rooij, 2010; Deng and Yang, 2013; Gao and Yuan, 2017).

On the other hand, firm-specific behaviors in response to environmental regulations are also related to the enforcement effectiveness of policies, particularly government intervention at a local level (Tang et al., 2003; Bair and Palpacuer, 2015). Economic transition in China can be attributed to the influences of marketization, globalization, and decentralization. Economic transition has had a mixed effect on environmental regulations and the spatial dynamics of PI firms (Wei, 1999; Wei, 2001; He et al., 2011; Shen et al., 2017). In particular, the process of decentralization has granted more responsibilities and greater autonomy to local governments for economic development and environmental protection (He et al., 2011). However, the enforcement of environmental policies in China has been compromised because of the decentralized governance structure and because of regional disparities (Zhu et al., 2014). Although environmental protection has been recently added to the cadre evaluation system, economic development remains the focus of local governments, and environmental protection is often given a lower priority and suffers from insufficient authority and lack of coordination (He et al., 2011). Previous studies have found that local governments consistently undermine the enforcement of environmental regulations to protect local economic interests (Tang et al., 2003), especially in inland China and rural regions where public awareness is lacking. For governments in coastal China, which have relatively well developed economies but poor environmental conditions, the main concern is that excessively stringent environmental regulations may drive firms away from the coast; mass relocation to other regions would weaken their own plans for further industrial and economic development (Zhu et al., 2014). Hence, local governments, whether in coastal or inland China, have a high tolerance for pollution if their territories do not experience severe pollution incidents. Recent research has revealed that, given the flawed legal system, local officials play the most important role in implementing regulations (Yee et al., 2016), and that this determines the enforcement effectiveness of environmental regulations at a local level.

2.2. Research framework and questions

Environmental incidents or crises can act as trigger events (Cobb, 1983), external perturbations (Jenkins-Smith and Sabatier, 1993), stressors (Wilson, 2000) or focusing events (Birkland, 1997) to punctuate the normal rhythms of policy-making and environmental administrative procedure. These incidents open up new 'windows of opportunity' for policy change (Kingdon, 1984) and also influence policy enforcement, especially in transitional China. With the emergence of a growing body of scientific evidence documenting significant environmental risks from current patterns of economic activity, governmental and public concern about environmental issues has grown rapidly in contemporary China. Unexpected pollution incidents, such as the Taihu Lake drinking water crisis in 2007, not only caused economic losses, social instability, and significant environmental damage, but also triggered a wave of intensified environmental regulations to prevent pollution generated by economic activities (Fig. 1).

In periods of environmental crisis, such as the 2007 Taihu Lake crisis, new structures for environmental regulations emerge, some of which may form the basis of a new period of stability and hence a new mode of regulation (Gibbs, 2006). The central government may introduce more stringent environmental policies to control and prevent pollution, and require local governments to issue a series of detailed policies and measures. However, the decentralization of economic development and environmental protection creates a dilemma for local governments, which tend to adopt different approaches to environmental regulation and enforcement after a pollution incident. On the one hand, local governments will issue more stringent policies under pressure from the central government and the public. For example, the Jiangsu provincial government revised the *Taihu Water Pollution Prevention and Control Regulations* after the crisis, and introduced more stringent environmental regulations. On the other hand, local governments may discriminate by implementing stringent enforcement in regions where the incidents occurred and lax enforcement in those regions with the least public awareness. However, the detailed effects of changes in regulations on the (re)location of industries triggered by a pollution incident, such as the Taihu crisis, have not been investigated.

To address these knowledge gaps, the first research question that we pursued was the extent to which a pollution incident and corresponding regulation changes influenced the spatial-temporal dynamics of industry location. The Taihu Lake drinking water crisis in 2007 was clearly mainly caused by water pollution, especially from the chemical industry; the environmental policies issued by central and provincial governments were therefore specifically aimed at this type of pollution. The chemical industry is regarded as a water-polluting industry and one of the primary sources of water pollution (Qin et al., 2007). However, in the process of implementing environmental regulations, it is very hard to distinguish the firms guilty of water pollution from those that are not. In addition, authorities tend to take a one-size-fits-all approach to preventing pollution. For instance, the Jiangsu government required the municipal- and county-level governments around Taihu Lake to close and eliminate almost all PI industries. However, the impact of this approach may vary across specific industrial sectors because of variable environmental enforcement by local governments. Most studies use lumped data from various PI industries because of data constraints, and the estimated regulatory effect is an average that is an under-estimate for the chemical industry (Jeppesen et al., 2002). To better understand the impact of the pollution incidents, this paper estimated the effects of environmental regulations on PI industries in general, and compared the effects on the non-chemical PI versus the chemical PI industries.

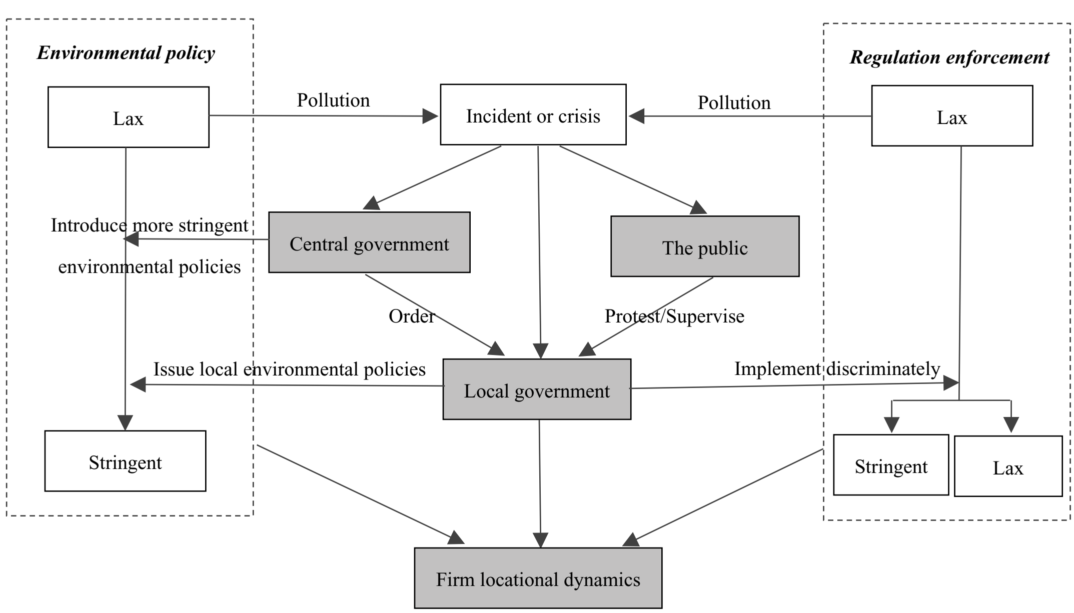


Fig. 1. A conceptual framework of effects of pollution incident and resultant environmental regulation on firm locational dynamics.

The second research question was whether there were differences in response to the crisis across regions. The TLW is a vast region and the sub-regions and municipalities within it experienced different impacts from the water crisis. For example, Taihu Lake has a complicated river and channel network, and water pollution incidents are more likely to occur in the north than in the south because of water retention and weather conditions (Qin et al., 2007). Different local governments may take a different approach to environmental regulations in response to pollution. To address this, we estimated the differences in the effects of environmental regulations among different municipalities along Taihu Lake, specifically for the Wuxi, Suzhou, and Huzhou municipalities. Differential environmental regulation is a promising approach that may optimize the reduction of the environmental impacts of pollution with the lowest possible costs for economic growth.

For the third research question, we investigated how PI firm behavior is influenced by the joint effect of environmental regulations and enforcement effectiveness of local governments. Local industries are usually made up of numerous individual firms with different ownership, size, products, technologies, business models, and resources (Martin, 2010). These differences may influence the relationship between environmental regulations and industrial dynamics in different settings (Bridge, 2008). Studies have shown that the relationship between the tendency of a firm to relocate and firm size (or capability) forms a roughly inverted U-shape. This relationship arises because of the complex interactions between the political environment, the regional hub effect, and environmental regulations (Zhu et al., 2014). To further investigate this relationship, we estimated how PI firms responded to environmental regulations and enforcement in various sub-regions in the TLW, and paid special attention to the exit of firms from their original locations.

3. Research setting and methodology

3.1. Study area

Taihu Lake is the third-largest freshwater lake in China. It has an area of 2338 km^2 and is located in the Yangtze River Delta. The TLW contains Shanghai and seven other municipal cities (Suzhou, Wuxi, Changzhou, Zhenjiang, Jiaxing, Huzhou, and parts of Hangzhou), and is located in the provinces of Jiangsu and Zhejiang (Fig. 2). The TLW has been a leading area in China's urbanization and industrialization, and is one of the most developed agriculture, manufacturing, and commerce regions (Su et al., 2010). Before the water pollution crisis, Taihu Lake provided domestic drinking water for approximately 10 million people (Qin et al., 2010). PI industries, such as the chemical industry, have prospered in the TLW because of the lack of concern with environmental norms and values, a lack of enforcement of environmental policies, and inadequate institutional capacity in the Yangzte River Delta (Zhu et al., 2014). Large volumes of untreated industrial, agricultural, and domestic wastewater were previously discharged directly into the lake and surrounding rivers, which resulted in large amounts of organic pollutants in the water (Qin et al., 2007; Yang and Liu, 2010). At the same time, urbanization was directly associated with the transformation of rural to urban land uses, which has led to the degradation of soil and vegetation, and decreases in the water's self-purification ability (Wu and Yuan, 2011; Xie et al., 2007). The deterioration in water quality is associated with eutrophication, and algal blooms have extended their coverage and persist throughout the summer. In May 2007, the lake was contaminated by a major algae bloom and pollution from cyanobacteria. This was triggered by industrial pollution, agricultural non-point source pollution, and urban domestic pollution (Qin et al., 2010). The crisis affected the drinking water supply of two million people, mainly in Wuxi, and attracted much attention from both the central and local governments, which consequently opened a window of opportunity for policy change (Kingdon, 1984).

To address the pollution issues in the TLW, the central, provincial, and local governments have, since 2007, implemented a package of measures, including by-laws, regulations, and rules, and have directly shut down some PI firms. For example, the Jiangsu provincial government revised the *Taihu Water Pollution Prevention and Control Regulations* in September 2007. The revisions required the municipal- and county-level governments around Taihu Lake to close and eliminate PI industries (such as chemical, pharmaceutical, metallurgy, printing, dyeing, and papermaking) that were located within 5 km of Taihu Lake and 1 km from the rivers flowing into Taihu Lake. The regulatory response to the Taihu Lake drinking water crisis was unexpected and illustrates how environmental regulations can influence the (re)location and distribution of PI firms across the watershed.

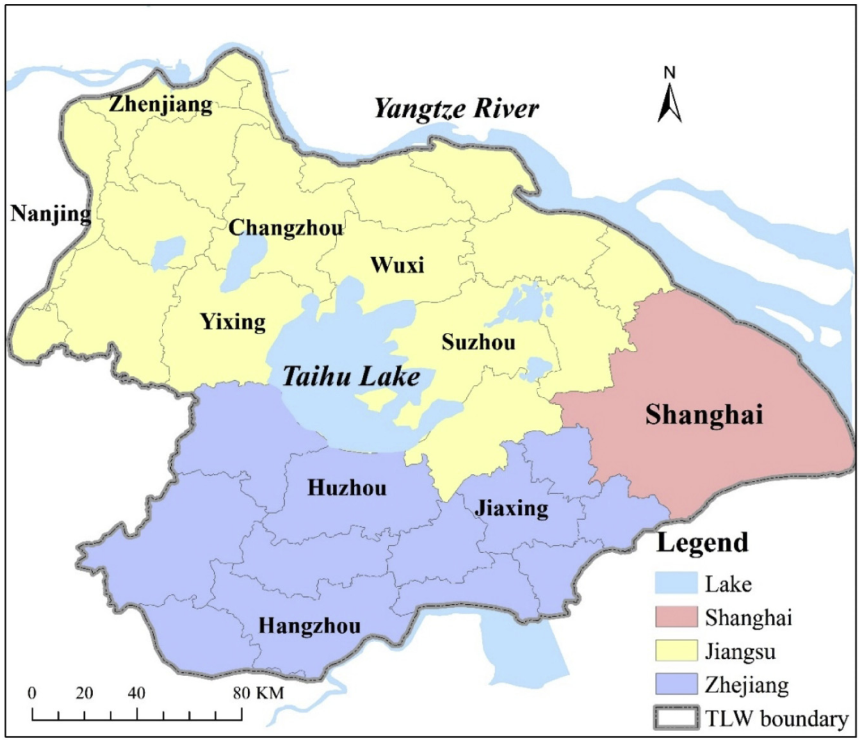
3.2. Data

The present study used firm-level data from China's first and second economic census, conducted at the ends of 2004 and 2008 by the National Bureau of Statistics of China. The database provides detailed information (including name, address, year of establishment, industry code, ownership, operating income, total assets, and number of employees) regarding all firms in the TLW. Using China's 2006 pollution industry classification, we classified the scale of pollution-intensity based on the firms' industry code, which included food processing, textiles, the chemical industry, smelting and pressing of non-ferrous metals, paper making, and non-metal mineral processing. The chemical industry was much more vulnerable to the regulatory response to the drinking water crisis than the other PI industries because it was regarded as the primary pollution source of the crisis, and because many government interventions targeted the chemical firms (Qin et al., 2007). For instance, approximately 500 chemical firms were closed by local governments in the months following the crisis. To clarify the impacts on the chemical industry, we classified the PI industries into either chemical or non-chemical industries, and compared their industrial location dynamics before and after the crisis.

We geocoded the firms' addresses with the help of the Baidu map (http://map.baidu.com/) and carried out spatial analysis and econometric regression. A total of 28,900 PI firms for 2004 and 30,199 PI firms for 2008 were georeferenced. There were 11,667 chemical firms and 17,233 non-chemical firms in 2004 and 11,841 chemical firms and 18,358 non-chemical firms in 2008, which accounts for more than 90% of the total number of PI and chemical firms in the TLW. City-level environmental data were compiled from the Statistical Yearbook of Wuxi, Suzhou, and Huzhou (2003–2011).

3.3. Methodology

To explore the effectiveness of environmental regulations in protecting Taihu Lake, we investigated the changes in industrial wastewater standards for the cities of Wuxi, Suzhou, and Huzhou. These cities, located along the Taihu Lake waterfront, are influenced directly by the policies to protect Taihu Lake. We used kernel density estimation and firm density plots to evaluate the spatial distribution of PI industries in general, and the spatial distribution of the chemical and non-chemical industries in particular, before and after the water crisis. First, we used kernel density estimation to investigate the spatial distribution of the PI firms. In comparison with a standard density map of firm locations, kernel density



Note: TLW=Taihu Lake Watershed

Fig. 2. The Taihu Lake Watershed.

estimation is useful for visualizing the intensity of events (locations of firms) by generating a smoothed estimation surface (Wei et al., 2013). Second, we plotted the firm densities (defined as the number of firms in a square kilometer) against the distances to Taihu Lake. We also compared the differences in firm density plots between Wuxi, Suzhou, and Huzhou.

In addition to the point pattern analysis, a regression model was employed to investigate the effects of environmental regulations on location-specific dynamics, and the exit of PI firms after the crisis, in particular. The Binary Probit model has been widely used in similar research (Cosh et al., 1999) and was selected because the exit of firms was a discrete event. We defined a firm's exit according to He and Yang (2016). If a firm is reported in the database in 2004 but is not reported in 2008, we assumed the firm exited during this period. In this study, the dependent variable (Y) was a dummy variable representing whether the firm exited (was either shut down or migrated) from the original location before the end of 2008. For firms that exited, we assigned the value 1, while for the remainder we assigned the value 0. Based on the study's theoretical propositions, we focused on two categories of explanatory variables to represent the impacts of environment regulations and firm/industry characteristics on the location dynamics of PI firms in the THW (Table 1).

For the firm/industrial characteristics, we chose relative variables of total assets (lnTA), number of employees (lnEMP), year of establishment (YEAR), ownership (SOF (state-owned firm), FIF (foreign investment firm), and PF (privately-owned firm)), and chemical firm (CF). There has been much research on firm-level factors, such as total assets, number of employees, year of establishment, and ownership (Mata and Portugal, 1994; Audretsch and Mahmood, 1995; Acs et al., 2007; He and Yang, 2016). However, little research has been carried out on the impact of these factors when strict environmental regulations are imposed. The chemical industry was regarded as one of the main pollution sources for the Taihu Lake water crisis; most of the environmental regulations targeted chemical firms after the crisis. If the chemical industry was indeed one of the main pollution sources, then chemical firms will have a positive association with firm exits.

For environmental regulations, four dummy variables were introduced to the analysis (YTZ (Yangtze River), COA (along the coast), BDR (borders of jurisdictions), and DT (downtown)) in addition to variables relative to environmental enforcement in regions surrounding the Taihu Lake (THL) and rivers flowing into Taihu Lake (RV). It was assumed that the PI firms located in the regions close to the YTZ or COA, where there is more environmental capacity and a greater self-purification ability, had a greater chance of survival. The dummy variables (YZR and COA) are equal to 1 if the PI firm is located within 5 km from the Yangtze River or from the coast. We chose this distance because there are a number of development zones located in this area. Decentralization in China has led to a "not-in-my-backyard" phenomenon, and thus PI firms that are located at the borders of jurisdictions (BDR) can escape strict environment regulations and public concern, and will have a better chance of surviving (Yang and He, 2015). In addition, China is undergoing a process of suburbanization of manufacturing, and thus the probability of PI firms exiting the DTs is higher than in the suburbs (Yuan et al., 2014; Yuan et al., 2017).

A simple, standard, least squares regression of y on x was not appropriate because, amongst other things, the implied model of the conditional mean places inappropriate restrictions on the residuals of the model. Furthermore, the fitted values from a simple linear regression are not restricted to between zero and one.

These limitations were addressed using the relationships described below. Suppose the dependent variable, y_i^*, can be characterized as a function of x_i.

Table 1
The definitions of dependent and independent variables.

Categories	Variable name	Description (unit)	Expected sign
Dependent variable	Y	Dummy variable equals 1 if the firm exited in 2008; 0 if the firm survived in 2008	
Firm/industry characteristics variables	lnEMP	The number of employees (log)	Negative
	lnTA	Total assets (log)	Negative
	YEAR	Year of establishment	Positive
	SOF	Dummy variable equals 1 if the firm was state-owned	Positive
	FIF	Dummy variable equals 1 if the firm was foreign investment	Negative
	PF	Dummy variable equals 1 if the firm was private-owned	Positive
	CF	Dummy variable equals 1 if the firm was a chemical firm	Positive
Environmental regulation variables	THL	Dummy variable equals 1 if the firm located within 5 km from the Taihu Lake	Positive
	RV	Dummy variable equals 1 if the firm located within 1 km from river the Taihu Lake	Positive
	DT	Dummy variable equals 1 if the firm located in the downtown	Positive
	YZR	Dummy variable equals 1 if the firm located within 5 km from the Yangzte River	Negative
	COA	Dummy variable equals 1 if the firm located within 5 km from the coast	Negative
	BDR	Dummy variable equals 1 if the firm located within 5 km from the municipal boundary	Negative

$$y_i{}^{*}=\beta'X+\varepsilon \tag{1}$$

where ε is a random variable, and β is the vector of the regression coefficients to be estimated. Although y_i^* is unobserved, the integer index y_i is observed and is related to y_i^* by the following relationship:

$$y_i=0, \text{ if } y_i^*\leq 0;\ y_i=1, \text{ if } 0< y_i^* \tag{2}$$

where γ is the unobserved threshold defining the boundaries between the different levels of y_i. Given the relationship between y_i and y_i^* and the distribution of the error term ε, the probability of observing an individual as having a zero value of the index y_i can be expressed as:

$$Pr(y_i=1|X_i,\beta')=Pr(y_i^*>0)=1-F(-\beta'X) \tag{3}$$

where F is the cumulative distribution function. Estimates are obtained by the maximum likelihood method:

$$L\left(\beta'\right)=\log L=\sum_{i=1}\sum_{i=1}\log\left(\Pr\left(y_i|X,\beta'\right)\right)\bullet 1(y_i=j) \tag{4}$$

where, $1(.)$ is the indicator function; when the variable is true, the value of the function is 1, otherwise the value is 0.

4. Pre- and post-crisis environmental regulations and the spatial redistribution of PI firms

After the drinking water crisis, provincial and local governments in the TLW immediately adopted various command and control measures, including raising standards for pollution control and shutting down PI firms, to prevent water pollution. To investigate the influence of the water crisis and environmental regulations on the spatial dynamics of PI industries, we selected three cities along Taihu Lake for a comparative analysis. The cities were Wuxi and Suzhou in Jiangsu Province, and Huzhou in Zhejiang Province. Wuxi (located to the north of Taihu Lake) is more sensitive to water crises than Suzhou and Huzhou because of local hydrological and meteorological conditions.

We used changes in environmental standards, especially the rate of reaching industrial wastewater discharge standards, to evaluate the effectiveness of environmental policy enforcement in the different cities in response to the crisis. Fig. 3 shows the changes in the rate of reaching industrial waste water discharge standards in Wuxi, Suzhou, and Huzhou before and after the crisis. The rate changed little in Suzhou before and after the crisis because the city had employed stronger discharge standards for industrial waste

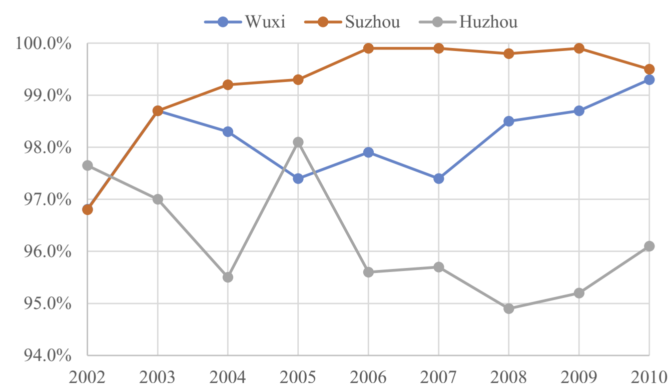
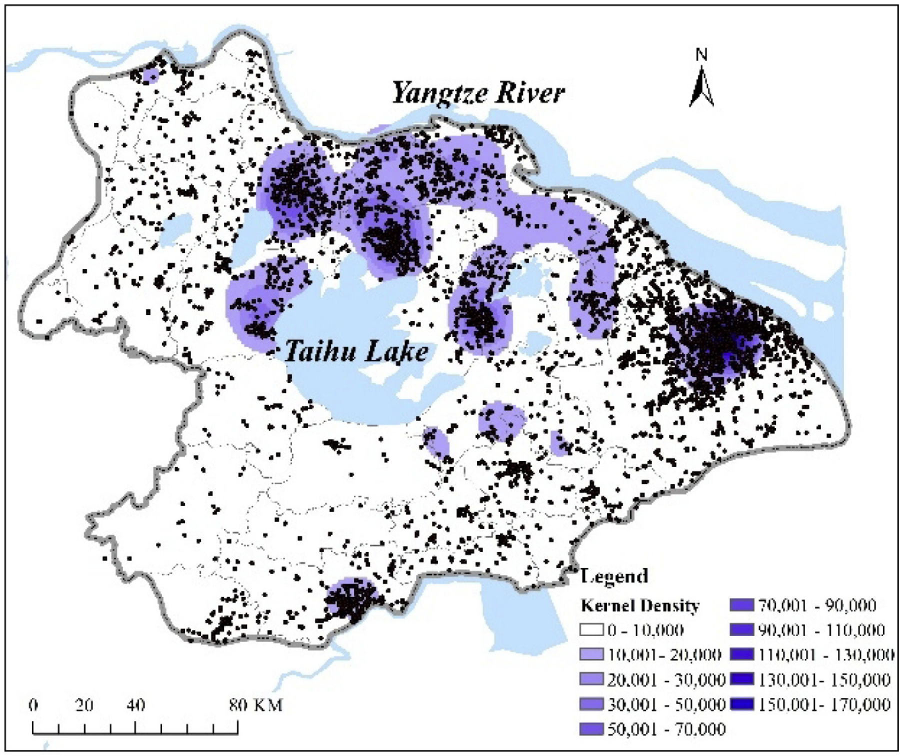


Fig. 3. Changing rates of reaching the industrial waste water discharge standard in Wuxi, Suzhou, and Huzhou, 2002–2010.

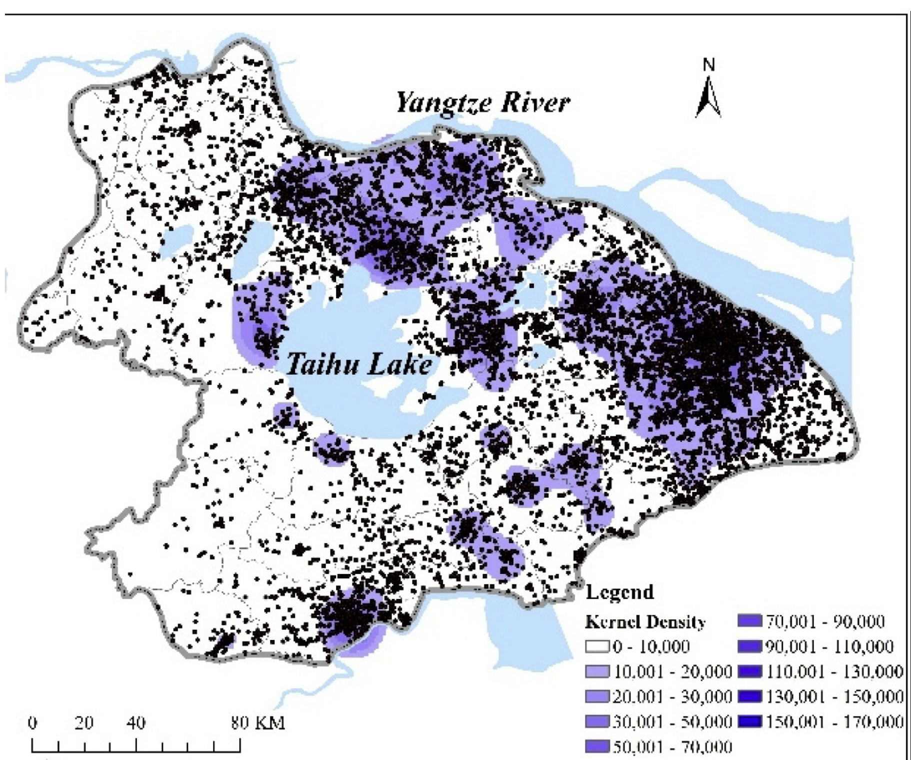
water since 2006. The rate for Wuxi increased from 97.4% in 2007 to 98.7%, while the rate for Huzhou decreased from 95.7% to 94.9%. This indicates that the enforcement of environmental regulations has been compromised in cities such as Huzhou, because of problems in the decentralized governance structure that created insensitivities to the crisis (Zhu et al., 2014).

Increasing the effectiveness of environmental regulations and policy enforcement can impact the (re)location and plant closure decisions of firms, and thus leads the spatial redistribution of PI firms. Fig. 4 maps the kernel density of the total assets of all PI firms in 2004 and 2008. In general, the crisis did not fundamentally alter the distribution of PI industries. Lakeside, riverside, and coastal zones were the main distribution areas for PI firms, especially in Shanghai, Suzhou, Wuxi, and Changzhou in Jiangsu Province. However, the following changes were observed: Firstly, there was a more obvious decentralization trend for PI firms in 2008 than in 2004, with the locations of firms spreading from the inner cities of Shanghai, Suzhou, Wuxi, and Changzhou to suburban areas, coastal areas, and areas along the Yangtze River in Jiangsu. Secondly, there was, with the exception of Wuxi, no obvious general decrease in density of PI firms in the areas surrounding Taihu Lake. In contrast, a new agglomeration of PI firms emerged in the area surrounding Taihu Lake in Huzhou. This indicates a different regulatory approach to the water crisis across the sub-regions.

Fig. 5 contains plots of the logarithm of firm density for the chemical industry and non-chemical industry against the distance to the lake waterfront. It can be seen that the distribution of firm densities has changed in the crisis, although there is only a slight increase in firm quantity. This indicates that the Taihu Lake crisis has had a major effect on PI firm dynamics. The densities of



All Pollution Firms, 2004



All Pollution Firms, 2008

Fig. 4. Kernel density estimation of pollution-intensive firms in the Taihu Lake Watershed, 2004 and 2008.

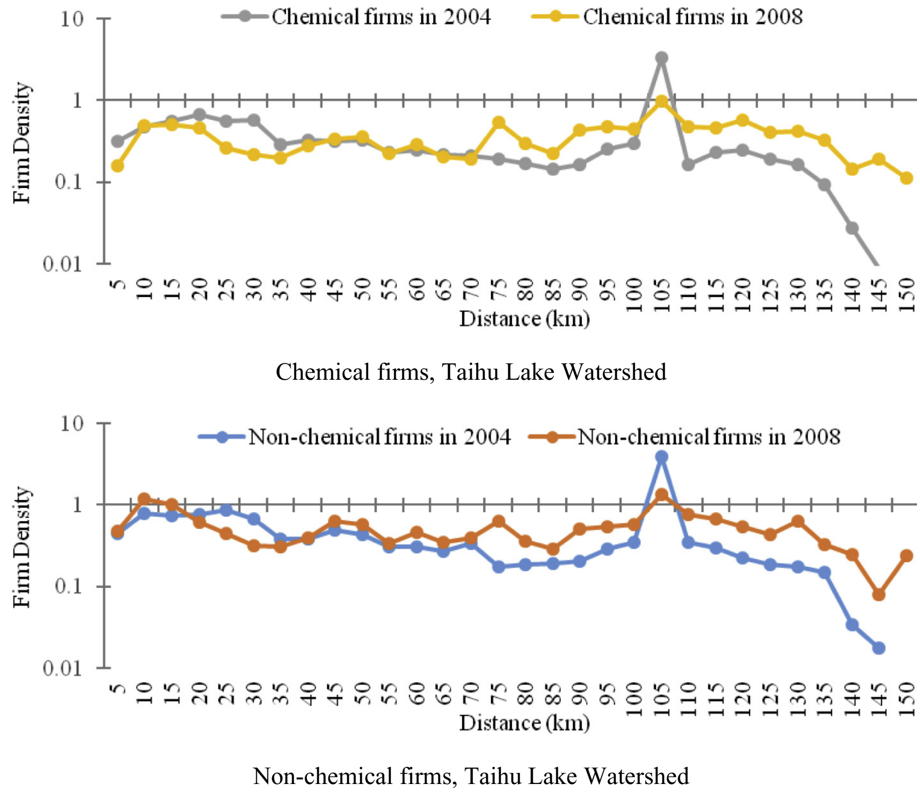


Fig. 5. Density of firms and distance to the Taihu Lake in the Taihu Lake Watershed, 2004 and 2008.

chemical and non-chemical firms are much higher in the areas near Taihu Lake and along the Yangtze River (about 100–110 km from Taihu Lake). This shows that proximity to a water source is a key locational factor for PI industries (Sigman, 2002). The influences of environmental regulations on the chemical industry and the non-chemical industry are quite different, indicating that the environmental regulations were orientated towards the chemical industry.

On the one hand, non-chemical firm density in 2008 was barely changed within 5 km of the lake in comparison to the density in 2004, but was higher in the 5–15 km range. Thus, it appears that the impact of environmental regulations on non-chemical firms for the protection of Taihu Lake was not significant near the lake. In addition, firm density grew rapidly in 2008 and exceeded the 2004 densities in the remote areas 75 km from the lake. This density increase reflects a decentralization and re-agglomeration of PI firms since the water crisis. National and provincial development zones along the Yangtze River (with its self-purification capacity) also became new destinations for non-chemical firms.

On the other hand, environmental regulations had a relatively significant impact on the distribution of chemical firms in comparison to the non-chemical ones near Taihu Lake. In 2008, although the firm density of the chemical industry increased slightly within 0–5 km of Taihu Lake, it decreased sharply in the 10–40 km range. Moreover, the chemical industry firm density grew rapidly in 2008 and showed a similar trend to the non-chemical industry. In summary, environmental regulations triggered by the crisis had an immediate impact, while the impact may have been limited to target industries to protect local economic interests and local government revenue (Tang et al., 2003).

A comparison of three selected cities located on the shore of Taihu Lake (Wuxi, Suzhou, and Huzhou), showed that the changing distribution of PI firms varied across cities between the pre- and post-crisis periods (Fig. 6). Generally, densities of non-chemical firms in Wuxi declined sharply after the crisis, with the biggest drops occurring at a distance of 20–30 km from the lake. Compared with the densities of non-chemical firms, the densities of chemical firms within 0–5 km of Taihu Lake showed an even more dramatic decline, indicating that the crisis-triggered regulatory measures mainly targeted the chemical industry near the lake. In fact, the government of Wuxi, which was responsible for the area most affected by the crisis, was under intense pressure to deal with the water pollution in Taihu Lake. The Wuxi government therefore responded by relocating or shutting down the chemical firms near Taihu Lake as an emergency measure to control water pollution in the short run. In Suzhou, however, many plants were still being established near Taihu Lake after the onset of the water crisis, especially within 0–15 km of the lake, as reflected by the rapidly growing densities of both PI and chemical firms. Similarly, the densities of chemical and non-chemical firms in Huzhou also increased rapidly in the 5–15 km range while the densities of chemical firms within 0–5 km of Taihu Lake dropped rapidly. We therefore argue that the implementation of the pollution control policies issued by the provincial government was less strict in the cities of Suzhou and Huzhou than in Wuxi. This occurred because of the relatively small impact, and lower risk, of the water crisis in Suzhou and Huzhou, which has advantageous hydrological and meteorological conditions.

We further analyzed the spatial dynamics of PI firms by combining the firm density plots and kernel density analysis. The combined analysis showed that within 5 km of Taihu Lake, the expansion of PI firms has been controlled to some extent, and that there has been a clear decline in PI firms in general. In Wuxi, within 5–15 km of Taihu Lake, the number of non-chemical firms has been well controlled. This could be due to the prohibition of building, rebuilding, or expanding PI firms in accordance with the *Taihu Water Pollution Prevention and Control Regulations.* Nevertheless,

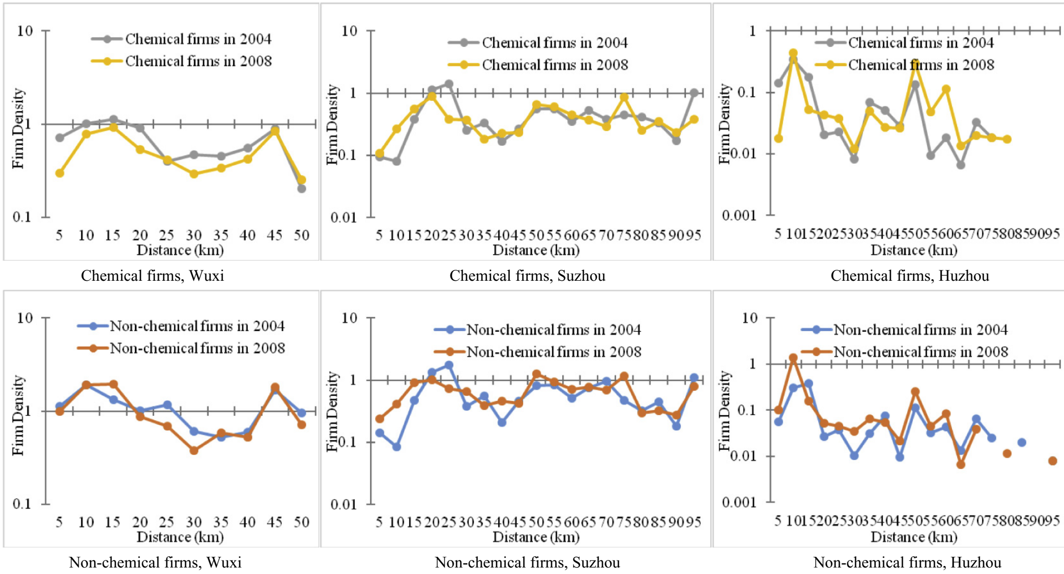


Fig. 6. Density of firms and distance to the Taihu Lake in Wuxi, Suzhou, and Huzhou, 2004 and 2008.

the number of chemical and non-chemical firms in other cities increased; it is also possible that these PI firms were spreading to villages and towns, remote from public and government awareness (Yuan et al., 2014).

5. Binary Probit model and firm exit determinants

In this section, the Binary Probit model was used to extend the preceding analysis of the effects of the Taihu Lake crisis by exploring the exit determinants for PI firms from 2004 to 2008. We deleted records with incomplete information. The variables SOE, FIF, and PF were substituted into the regression model because of co-linearity issues in the estimations. The results of the Binary Probit regression analyses are shown in Table 2.

By examining the factors influencing the exit of all PI firms in the TLW derived from Models 1 and 2 in the Table 2, it appears that both the characteristics of the firms, and the environmental regulations, had significant impacts on firms' exits from their original locations. Four main factors were found as follows: First, it was found that the coefficients of lnEMP and lnTA were negative and significant, indicating that smaller firms (based on the number of employees and the total assets) were more likely to fail or exit from the original location. This probably occurred because small firms, with limited financial and technological capacity, tended to shut down or relocate to regions where environmental standards were relatively low (Zhou et al., 2017). Second, the impacts of the YEAR variable were also negative and significant, indicating that as firms matured, they became more competitive and would be less likely to fail (He and Yang, 2016). Third, FIFs had a higher survival rate, while PFs were more likely to fail. This might be attributed to the fact that FIFs were larger and more competitive than PFs (Wei et al., 2013). SOFs were more sensitive to exiting because of their low efficiency and innovation capacity in general (Girma and Gong, 2008). Last, the efficiency of CF is positive and significant, indicating that the chemical firms were vulnerable to the implementation of environmental regulations.

Table 2
Estimation of industrial locations of pollution-intensive firms in Taihu Lake Watershed, 2004 and 2008.

Dependent variable	Y	
Independent variables	Model 1	Model 2
Constant coefficient	16.35***	16.74***
lnEMP	−0.12***	−0.12***
lnTA	−0.06***	−0.06***
YEAR	−0.01***	−0.01***
SOF	−0.05	
FIF	−0.08***	
PF		0.10***
CF	0.13***	0.12***
THL	0.22***	0.22***
RV	0.07**	0.07**
DT	0.13***	0.13***
YZR	0.23***	0.23***
COA	−0.11**	−0.11**
BDR	−0.07***	−0.07***
Number of obs	25,819	25,819
LR statistics	1004.99	1005.94
Probability (LR stat)	0.0000	0.0000
AIC	1.11	1.11

Note: LR = likelihood ratio, and AIC = Akaike information criterion.
*Significant at 0.1, **Significant at 0.05, and ***Significant at 0.01.

The THL and RV coefficients were positive and significant, indicating that PI firms located near Taihu Lake, and along rivers flowing into Taihu Lake, were more likely to exit from the original location after the water crisis. This finding is similar to the results from the firm density plot and kernel density analysis. The firms located in DTs were also more likely to fail because these cities' economies were transforming into service economies and manufacturing was being shut down or migrating to the suburbs (Yuan et al., 2017). The YTZ coefficient was positive and significant, which indicates that firms located near the Yangtze River were more likely to exit, as opposed to indicating that PI firms were more likely to survive because of the river's higher environmental capacity. This tendency probably arose because local governments attempted to attract larger firms to replace medium-sized and small firms. Thus, there was a high ratio of firm failure in this region. The COA and BDR coefficients were negative and significant, indicating that firms located along the coast, or along the borders of jurisdictions, have enhanced survival chances because of greater environmental capacity and less public scrutiny, respectively.

We also compared the exit determinants of PI firms among Wuxi, Suzhou, and Huzhou. The exit determinants varied across the

Table 3
Estimation of industrial locations of pollution-intensive firms in Wuxi, Suzhou and Huzhou, 2008.

Dependent variable	Wuxi		Suzhou		Huzhou	
Independent variables	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Constant coefficient	28.18***	28.15***	10.56***	10.56***	3.69	2.37
lnEMP	−0.20***	−0.21***	−0.13***	−0.13***	−0.08	−0.08
lnTA	0.02	0.02	−0.06***	−0.07***	−0.12**	−0.13***
YEAR	−0.01***	−0.01***	0.01*	0.01*	−0.002	−0.002
SOF	−0.06		0.05		−0.002	−0.002
FIF	−0.06		0.08		0.25	0.25
PF		0.07		0.07		−0.22
CF	0.28***	0.28***	0.19***	0.19***	0.01	0.01*
THL	0.30***	0.29***	0.23***	0.23***	−0.08	−0.07
RV	−0.01	−0.01	0.12**	0.12**	0.89***	0.89***
DT	0.08	0.08	0.16**	0.15**	−0.35**	−0.37**
YZR	0.27***	0.27***	0.20***	0.20***		
BDR	−0.05	−0.05	−0.10**	−0.10**	−0.29**	−0.28**
Number of obs	5988	5988	5846	5846	771	771
LR statistics	259.70	259.73	256.76	255.01	59.60	59.03
Probability (LR stat)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
AIC	1.10	1.10	1.09	1.09	1.19	1.19

Note: LR = likelihood ratio, and AIC = Akaike information criterion.
*Significant at 0.1, **Significant at 0.05, and ***Significant at 0.01.

cities (Table 3). The comparison allowed four main patterns to be identified. First, it can be seen that firm size had different impacts on PI firm exits in these three cities. Both employment and total assets had a positive and significant influence on the exit of PI firms in Suzhou, while only employment and total assets had a significant effect in Wuxi and Huzhou. Second, the YEAR coefficient was negative and significant in Wuxi, while it was insignificant in Suzhou and Huzhou. This indicates that, after the water crisis in Taihu Lake, the experience of firms improved their chances of survival as in Wuxi. Third, the ownership factor was insignificant in all cities. This could be because the environmental regulations to reduce water pollution formed a one-size-fits-all policy and affected all types of firms. Last, CF factors had a significant effect in Wuxi and Suzhou (Jiangsu Province), and an insignificant effect in Huzhou (Zhejiang Province). This may be because the water crisis occurred in the city of Wuxi, which is in the Jiangsu Province, and because the subsequent environmental policies and enforcement aimed at the chemical firms were more stringent in Jiangsu than in Zhejiang.

The impact of THL is significant in Wuxi and Suzhou and insignificant in Huzhou, indicating there was a more stringent enforcement of environmental regulations in Jiangsu Province than in Zhejiang Province. In contrast, the coefficient of RV is significant in Suzhou and Huzhou and insignificant in Wuxi, which indicates that a lot of PI firms surrounding the rivers flowing into Taihu Lake had been shut down before the crisis in Wuxi. The DT coefficient was significant in Suzhou and insignificant in Wuxi, which may indicate that the Wuxi government more actively shut down or relocated the PI firms near Taihu Lake, and paid little attention to firms in the downtown area. The YTZ coefficient was positive and significant in Wuxi and Suzhou, which is a similar pattern to that in the results of Models 1 and 2. The BDT coefficient had an insignificant impact in Wuxi and had a significant impact in Suzhou and Huzhou, which may have been caused by the one-size-fits-all policy enforced in all regions in Wuxi, while the enforcement of environmental policies in Suzhou and Huzhou were selective and mainly concentrated near Taihu Lake and the rivers flowing into it.

6. Discussion and conclusions

China has been undergoing an unprecedented industrialization process, which has resulted in an increasing number of environment pollution incidents. These incidents are gaining increased academic and political attention. This study analyzed the location dynamics of PI firms in the TLW before and after the Taihu Lake drinking water crisis. The study focused on the enforcement effectiveness of heterogeneous regional policies. The main findings of the study are now summarized.

First, the study provides some evidence that the Taihu Lake pollution crisis opened new windows of opportunity for environmental policy change; in the short-term, the resulting tightened environmental regulations forced PI firms to shut down or relocate. This response was different to the usual response triggered by standard environmental policy-making and administrative procedures. Rural areas, which are away from the public eye, together with areas along the Yangtze River and coastal areas, have become transfer destinations for PI industries. These findings are similar to the findings of Zhu et al. (2014). However, the border areas between urban jurisdictions and rural areas are sensitive to industrial pollution because of a lack of environmental protection treatment facilities. This may lead to serious pollution incidents and ecological damage in the long run.

Second, this study has shown that enforcement effectiveness of environmental policies is an important factor underlying firm migration in China (Tang et al., 2003). However, there were obvious differences in response to the crisis across the region. Development in Asian countries is more state-oriented than in Western countries (Walder, 1995), which consequently leads to a greater government effect on the enforcement effectiveness of environmental policies and on the (re)location of industry (Lai and Tang, 2016). It is clear that the effect of environmental regulations was felt only in the area surrounding Taihu Lake, which encouraged the relocation of PI firms to regions with greater environmental capacity or far from public and government scrutiny. In addition, we estimated the effects of environmental regulations on the distribution of PI firms in the municipalities of Wuxi, Suzhou, and Huzhou. Differential environmental regulation is a promising approach that may optimize the reduction of the environmental impacts of pollution with the lowest possible costs for economic growth. Industry relocation involved negotiations between government and firms and also interactions among different levels of government (Gao et al., 2014).

Last, the effects of environmental policies and enforcement effectiveness are related to the characteristics of firms and industries. We found that environmental regulations triggered by a crisis can have an immediate impact but this tends to be limited to target industries—the chemical industry in particular—in order to protect local economic interests and local government revenue (Tang et al., 2003). Even in Wuxi, where more frequent firm migration was observed, the local government still took measures to increase revenue and develop the economy. For example, Wuxi Taihu New Town was planned with the aim of developing the urban land market and alleviating the pressure of population growth (Tian et al., 2017). However, the land left by relocated firms has been mostly used for real estate and service industry development in Wuxi (Yuan et al., 2014). Furthermore, both firm heterogeneity and government intervention have the potential to influence the relationship between environmental regulations and industrial dynamics (Zhou et al., 2017). However, in the long-run, more stringent environmental regulations will force low-cost, low-end small firms to close first.

In summary, these findings on spatial restructuring and locational determinants of PI firms, pre- and post-crisis, show that the effects of environmental regulations cannot be investigated without taking into account regional policy enforcement and specific firm/industry characteristics. These characteristics have, thus far, drawn little attention. This paper provides only a first explorative step; our findings raise a number of issues that call for further investigation: First, systematic theories are needed to explain how environmental regulations, including both environmental policies and policy enforcement, influence the heterogeneous distribution of various industries in the short and long term. These theories and explanations would clearly increase the understanding of environment-economy research (Levinson, 1996; Bridge, 2008; Hayter, 2008; Ben Kheder and Zugravu, 2012). Second, more empirical studies are needed of economic activities and environmental regulations triggered by other types of pollution incidents, such as air and soil pollution. These studies would systematically test the role of economic activities and environmental regulations, and would increase the understanding of the issues involved.

Acknowledgments

We would like to acknowledge the funding of the National Natural Science Foundation of China (41671133, 41701193 and 71573250), Strategic Priority Research Program of the Chinese Academy of Sciences (XDA230201), and "One-Three-Five" Strategic Planning of Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences (NIGLAS2018GH01).

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