Income inequality and environmental quality in China: A semi-parametric analysis applied to provincial panel data

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Abstract: This article contributes to the literature on the inequality-environment nexus in China by filling three major gaps. First, we enlarge the scope of environmental variables so as to include several air and water pollutants. Second, we combine different data sources to construct several measures of income inequality at provincial level to reflect its social and spatial dimensions. Third, we propose to use flexible semi-parametric methods in order to analyze the potential nonlinearities in the inequality-environment relationship. Our investigations emphasize that this relationship is more complex than previously evidenced, because the association is non-linear and depends on the pollution and inequality variables taken into account. Three conclusions can be drawn from this empirical study. (i) Provincial inequality has a decreasing effect on air and water pollution. (ii) This negative association is primarily explained by inequality between urban and rural areas, which also has a negative impact on environment quality. This result is of particular interest since it reveals that the effects of pollution-reducing policies will probably be altered by policies aiming at reducing regional income disparities through industrialization. (iii) Urban income inequality contributes to increasing soot emissions and water pollution, which confirms the deleterious impact of inequality for localized pollutions.

Key words: inequality, air pollution, water pollution, environmental Kuznets curve, semi-parametric analysis

1. Introduction

China's rapid economic development has raised great environmental concerns that are extensively addressed in the academic literature. In line with Liu and Diamond (2005) and World Bank (2007), many studies have analyzed the multiple environmental costs associated with air pollution, water pollution, soil erosion or waste generation in China. Social and spatial inequalities in the exposure to pollution and to subsequent environment-related problems are an important issue addressed in the recent literature (Sun et al., 2017). But it is now recognized that inequality may also have an upstream impact on pollution.

There is a significant body of empirical literature analyzing the determinants of environmental degradations in China but, while many studies address the impact of economic growth and development on environment quality in an environmental Kuznets curve (EKC) framework (e.g. Song et al., 2008; Liu, 2012; Luo et al., 2014),[1] little attention has been paid to the influence of inequality. However, the rapid economic growth of China over the last three decades has been accompanied by an explosion of social and spatial inequalities (Bonnefond and Clément, 2012; Knight, 2014). Following the pioneering works of Boyce (1994) and Torras and Boyce (1998), we argue that such inequalities can potentially impact environmental performances.

From a theoretical perspective, two main channels through which inequality may affect environment have been identified (Berthe and Elie, 2015): consumption and political channels. The first channel focuses on the impact of households' consumption behaviors on environmental pressure. The key issue is to determine which income groups have the highest marginal propensity to cause environmental degradation. Two opposite hypotheses can be found in the literature. Scruggs (1998) and Heerink et al. (2001) suggest that more affluent households are associated with lower levels of environmental pressure, because the environment is assumed to be a superior good. In this case, greater income inequality would be associated with lower environmental pressure. Conversely, other studies empirically show that wealthy households generate higher environmental deterioration (Cox et al., 2012; Liu et al., 2013), supporting the idea of a harmful impact of inequality on environment quality. The second channel addresses the formation of environmental demands and the design of environmental policies. According to Boyce (1994), in most cases, those who benefit from environmental deteriorations are the wealthiest people because they are at the root of a wide range of polluting activities (through production or consumption). Moreover, they are more able to protect themselves against these environmental costs. As a result, the most affluent people would express a low interest in the preservation of the environment. Conversely, the losers in a deteriorated environment are the poorest people because they depend more on natural resources and suffer more from pollution. In a context of high income inequality, it could be argued that poor people do not have enough political influence to assert their interest in the implementation of pro-environmental policies, which could explain higher levels of environmental deterioration. This political channel is still debated in the literature because external factors could potentially modify the mechanism described above (Berthe and Elie, 2015).[2]

In addition to being discussed from a theoretical perspective, the inequality-environment relationship is not well-established empirically. The empirical literature provides mixed

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[1] The EKC hypothesis argues that the relationship between income and environment quality is non-linear, and that pollution rather follows an inverted U-shaped pattern relative to the country's income level.

evidence, with studies identifying positive, negative or non-significant associations. As shown by the survey of Berthe and Elie (2015), results are clearly context-dependent and pollution-specific. In the case of China, the empirical literature addressing the inequality-environment nexus is still emerging. In this respect, the main objective of our study is to provide an in-depth examination of the causal effect of income inequality on environment quality at the provincial level for the 2000-2012 period. Compared to the existing literature, this study expands the scope of environmental variables taken into account to include air pollution variables (CO_2, SO_2, and soot emissions) and water pollution variables (chemical oxygen demand, ammonia nitrogen and wastewater discharged). We also consider several inequality measures to account for the social and spatial dimensions of income inequality. Lastly, a key contribution of this article is its analysis of the potential nonlinearities in the inequality-environment relationship using flexible semi-parametric methods.

Our empirical investigations underline that the relationship between income inequality and environmental performances in Chinese provinces is more complex than previously evidenced. Indeed, our results show that the association is non-linear and depends on the pollution and inequality variables taken into account. Three main conclusions can be drawn from the empirical study conducted as part of this article. First, provincial inequality has a decreasing effect on air and water pollution. Second, this negative association is primarily explained by the inter-urban-rural component of provincial inequality, whose impact on environment quality is also negative. Third, urban income inequality contributes to increasing soot emissions and water pollution variables, confirming the harmful impact of inequality in terms of localized pollution.

The article is structured as follows. Section 2 reviews the empirical studies examining the impact of social and spatial inequalities on pollution in China. Data and the econometric framework are respectively presented in Sections 3 and 4. Section 5 presents the results while Section 6 concludes and provides suggestions for further research.

2. Inequality and environment quality in China: A survey

In the Chinese context, there is a substantial literature analyzing the socioeconomic determinants of environmental quality. Broadly speaking, such studies fall within the scope of the empirical literature on environmental justice and primarily rely on household micro-data. In particular, some studies examine the influence of household income, living conditions and wealth on CO_2 emissions and tend to show that emissions are higher among the richest households (Golley and Meng, 2012; Liu et al., 2013; Yang et al., 2017). Other studies have addressed the role of rural-urban migration and show that rural-urban migrants suffer more than urban citizens from a deteriorated environment (Schoolman and Ma, 2012; Ma, 2010).

Another body of empirical research focuses on the influence of regional inequality on the environment. Using time-series data, Guo (2014) analyzes the impact of regional income disparity on per capita CO_2 emissions. He shows that regional inequality has a negative impact on CO_2 emissions and explains this result by the fact that the development of the industrial sector in low-income Chinese provinces simultaneously reduces regional inequality and increases energy consumption and pollution. Moreover, the transfer of industry from high-income regions to low-income regions could also contribute to narrowing the regional income gap and increasing emissions given the lower energy efficiency in low-income regions (Lu and Lo, 2007). As underlined by Hou et al. (2013) and in line with the literature on pollution havens, a lower degree of environmental regulation in less developed provinces is crucial to explain these transfers. This kind of thinking can be applied to urban-rural transfers of industrial pollution (Wang and Zhou, 2012; Zhao et al., 2014). Such transfers, linked to urban-rural disparities in terms of economic development, can be viewed as a major source of environmental inequality in China (Zhao et al., 2014). In a similar vein, Duvivier and Xiong (2013) analyze the phenomenon of transboundary pollution. The main underlying idea is that the decentralized environmental policy in China can lead to polluting havens and free-riding effects, resulting in an excess of pollution at regional borders. All in all, we suggest that taking into account regional and/or urban-rural inequality is crucial to understand the inequality-environment relationship.

Although these studies are informative on how socioeconomic factors and spatial inequality affect the environment, they do not specifically address the impact of income inequality. The main reason is the absence of adequate measures of income inequality at provincial level for a large time span. However, we do find some evidence in the recent empirical literature.

Wolde-Rufael and Idowu (2017) carry out a comparative time-series analysis for China and India. Broadly speaking, their results indicate that there is no significant relationship between income inequality and per capita CO_2 emissions. They also show that income inequality is the least important variable explaining emissions. While this study is based on national-level data, other studies rely on provincial panel data to examine the inequality-environment relationship. For instance, Zhang and Zhao (2014) analyze the impact of inequality on CO_2 emissions (not expressed in per capita terms) by adding a measure of intra-provincial income inequality in an EKC equation. They emphasize a positive impact of income inequality on emissions and show that this deleterious impact is greater in the Eastern region than in the Western region. Hao et al. (2016) do the same kind of empirical analysis for per capita CO_2 emissions. Their results confirm the previous ones with a significant and positive association between income inequality and air pollution that is greater in Eastern provinces than in non-Eastern provinces. Using the same kind of provincial panel data, Jun et al. (2011) study the influence of intra-provincial income inequality on two dependent variables describing environment quality: industry wastewater and industry waste gas. A significant negative impact of income inequality on environment quality (observed for the two environmental variables) is found. The major contribution of the study by Guo (2018) is to test the existence of an indirect effect of income inequality on per capita CO_2 emissions that would transit through the consumption channel. The empirical analysis confirms the existence of a significant and positive indirect effect.

Although these macro-provincial empirical studies offer evidence of a positive effect of inequality on pollution, they have at least three limitations. First, they could be viewed as CO_2-biased since they neglect other important variables accounting for environmental quality. Second, the existence of potential non-linear relationships between environmental quality and inequality is not addressed. Third, they do not analyze the effect of urban-rural inequality on environment quality, which is a crucial dimension of income inequality in China. The main purpose of our study is to fill these gaps.

3. Data

Empirical investigations conducted as part of this research are based on provincial panel data covering the 2000-2012 period. Three categories of variables are used, namely environmental variables, inequality variables and control variables.

3.1. Environmental variables

Compared to previous studies, we enlarge the scope of environmental dimensions and select six environmental variables. Carbon dioxide emissions (CO_2), sulfur dioxide emissions (SO_2) and soot emissions are used as air pollution indicators, while Chemical Oxygen Demand (COD), Ammonia Nitrogen (AN) and wastewater discharged are used as water pollution indicators. These six pollutants are widely accepted indicators to measure environmental pollution in previous empirical studies. Our six environmental variables are observed at the provincial level and are expressed in per capita terms.

The provincial data on SO_2, soot, COD, AN and wastewater are collected from *China Environment Yearbooks*. It is worth noting that the Ministry of Environmental Protection modified its survey methods and related technologies in 2011 for SO_2 and soot emissions and COD and AN discharged. This is why we restrict the observation period to 2000-2010 for these four pollutants. Official data on province-level CO_2 emissions are not available. We therefore calculate the provincial CO_2 emissions (measured by 10,000 tons of standard coal equivalent) from fossil fuel consumption, heating consumption and electricity consumption for which data are available in *China Energy Statistical Yearbooks*. For fossil fuel consumption, raw coal, cleaned coal, other washed coal, briquettes, coke, coke oven gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas (LPG), refinery gas and natural gas are considered. CO_2 emissions from each type of fossil energy are estimated by multiplying the final energy consumption by its carbon emission factor. The different emissions factors used can be found in Liu et al. (2011) and Clarke-Sather et al. (2011). Note that we assume that all carbons in the fuel are completely combusted and transferred into the carbon dioxide form. As for CO_2 emissions from heating consumption and electricity consumption, we use the method proposed by Qin and Wu (2015) to estimate them.

(Insert Figure 1)

These pollutants display different trends over time. For instance, as indicated in Figure 1, CO_2 emissions per capita revealed an increasing trend. Per capita wastewater discharged also increased gradually before 2004, and accelerated thereafter. For other pollutants, trends are more favorable. Per capita SO_2 emissions had an upward trend over the period 2002-2006 but began to decline after 2006. We also observe a decrease in soot emissions and COD and AN discharged from the mid-2000s. These observed reductions are in line with the literature (Xu et al., 2014; Liu and Wang, 2017). For instance, Liu and Wang (2017) show that the SO_2 and COD reduction targets (-10% over the 2005-2010 period) included in the 11th five-year plan (2006-2010) have been met and even exceeded.[3] They also document the decline of AN discharged (which was added as a controlled pollutant in the 12th five-year plan) and soot emissions.

3.2.Income inequality variables

One main issue related to the measurement of inequality in China is the absence of adequate income inequality indices at the provincial level for a large time-span. Household surveys traditionally used for the measurement of inequality only cover selected years (e.g. *China*

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[3] These targets were decentralized and assigned to provinces, cities and counties. To reach these objectives, several measures were implemented such as the shutdown of small polluting factories and power plants, the installation of desulfurization equipment in existing coal-fired power plants and the strengthening of environmental supervision (Xu et al., 2014; Liu and Wang, 2017).

Household Income Project or *China Family Panel Survey*) and/or selected provinces (e.g. *China Health and Nutrition Survey*). Consequently, we adopt an alternative strategy. Given the lack of an annual index of income inequality at the provincial level, we use information on the mean incomes of income quintiles included in the *Provincial Statistical Yearbooks*, respectively for urban and rural areas, to calculate Gini indices for both areas. More specifically, quintile data are used to estimate general quadratic Lorenz curve equations at the provincial level, separately for urban and rural areas, by means of the *PovcalNet* software of the World Bank. The estimated equations are then used to estimate an urban Gini index and a rural Gini index, at the provincial level. While the urban Gini is well documented (360 observations covering 30 provinces), there are many missing values for the rural Gini (134 observations covering only 14 provinces) since only patchy quintile data are available in *Provincial Statistical Yearbooks*.

At all events, information on urban and rural Gini can be combined to construct a provincial Gini index following the methodology adopted by Sundrum (1990):

$$GINI = p_U \frac{\mu_U}{\mu} GINI_U + p_R \frac{\mu_R}{\mu} GINI_R + p_U p_R \left| \frac{\mu_U - \mu_R}{\mu} \right| \qquad (1)$$

Where $GINI$ is the provincial Gini index, $GINI_U$ and $GINI_R$ are the Gini indices for urban and rural areas respectively. p_U and p_R are the proportion of urban and rural populations and μ, μ_U and μ_R are the mean incomes, respectively for the whole province and urban and rural areas (data on these variables are available in *China Statistical Yearbooks*). This provincial Gini index is the best approximation of intra-provincial inequality. However, given the constraints of the number of observations for the rural Gini, only 134 observations are available. It should be noted that the third term in equation (1) is a measure of urban-rural inequality that accounts for mean income disparities between urban and rural areas (390 observations). From this methodology, we select three measures of inequality, namely the provincial Gini ($GINI$) and the urban Gini ($GINI_u$) that account for social inequalities, and the inequality between urban and rural areas (i.e. the third component of equation (1)) that accounts for spatial inequality. Due to the weak number of observations, we do not consider the rural Gini.

(Insert Figure 2)

The evolution of our four measures of income inequality in Chinese provinces between 2000 and 2012 is depicted in Figure 2. Overall, the observation of the provincial Gini shows a slow declining trend in income inequality from the mid-2000s. This trend is in line with previous estimates based on household survey data and showing that, after having strongly increased from the 1980s to the early 2000s, the decrease in income inequality in China began from the mid-2000s (e.g. Li, 2016). Figure 2 shows that this decreasing trend in income inequality at the provincial level is primarily due to the reduction of inequality between urban and rural areas. The urban Gini displays an increasing trend until 2009, and then started to slowly decrease.

3.3. Control variables

The purpose of our econometric analysis is to identify the effect of income inequality on different measures of environment quality in China. Such an analysis necessitates additional control variables that are seen as important determinants of environment quality.

In line with the EKC hypothesis, we first include the per capita GDP and the squared per capita GDP of each province. Moreover, it is widely acknowledged that technological progress in industry results in more efficient use of inputs and hence in less pollution. This is why, in line with Du et al. (2012) and Zhang and Zhao (2014), we include energy intensity to capture the heterogeneity of, and variation in, technology progress across provinces. This energy intensity variable is defined as energy consumption divided by GDP and is measured as tons coal equivalent per 10,000 Yuan of GDP.

We also take into account additional control variables that are identified as potential important determinants of pollution in the empirical literature: the share of industry in GDP (Du et al. 2012; Zhang and Zhao, 2014), urbanization rate (Du et al., 2012), trade openness measured by the sum of exports and imports as a share of GDP (Managi et al. 2009), financial development measured by loans from financial institutions as a percentage of GDP (Jalil and Feridun, 2011) and fiscal decentralization measured by the ratio of fiscal revenues to fiscal expenditures, identified in existing studies as an indicator of fiscal autonomy (Zhang et al., 2017). Data sources and descriptive statistics for the different variables included in the empirical analysis are summarized in the Appendix (Table A1).

4. Econometric strategy

As for our econometric strategy, we adopt an EKC framework and add provincial income inequality as a potential determinant of environment quality. We propose to investigate the potential non-linearity of the relationship between inequality and environment quality. To do this, we rely on semi-parametric methods that enable us to leave the nature of the relationship between inequality and environment unspecified in the regression analysis. More precisely, following Baltagi and Li (2002), we adopt a partially linear model with fixed effects in which a specific environmental variable env_{it}, observed for province i at year t, depends linearly on control variables x_{it} while its relationship to inequality $ineq_{it}$ is characterized by a flexible non-parametric function $g(.)$:

$$env_{it} = x_{it}\beta + g(ineq_{it}) + \delta_i + \varepsilon_{it} \qquad (2)$$

The estimation procedure proposed by Baltagi and Li (2002) consists in expressing the model in first-difference to eliminate the fixed effects:

$$\Delta env_{it} = (\Delta x_{it})\beta + \left[g(ineq_{it}) - g(ineq_{it-1})\right] + \Delta\varepsilon_{it} \qquad (3)$$

To approximate the unknown component $\left[g(ineq_{it}) - g(ineq_{it-1})\right]$ of this first-differentiated model, Baltagi and Li (2002) propose to use a series of K basic functions $\left[p^K(ineq_{it}) - p^K(ineq_{it-1})\right]$. Equation (3) can be rewritten as follows:

$$\Delta env_{it} = (\Delta x_{it})\beta + \left[p^K(ineq_{it}) - p^K(ineq_{it-1})\right]\gamma + \Delta\varepsilon_{it} \qquad (4)$$

A typical example of these series terms is splines that are piecewise polynomials defined for a sequence of knots, where they join smoothly. As recommended by Libois and Verardi (2013), we use B-splines that are a linear combination of basic splines (Newson, 2000), with knots determined optimally. The parameters β and γ can then be estimated with least squares from equation (4) and can be used to fit the fixed-effects. Finally, the non-parametric component is easily fitted following equation (5) and using a standard non-parametric regression estimator (i.e. kernel-weighted local polynomial smoothing):

$$env_{it} - x_{it}\hat{\beta} - \hat{\delta}_i = g(ineq_{it}) + \varepsilon_{it} \qquad (5)$$

One important issue lies in the potential endogeneity of inequality variables. Although we control for many potential determinants of environmental quality and include provincial fixed-effects in the regression analysis, endogeneity may still persist due to reverse causality. It may be argued that environmental quality socially determines the place of residence and thus inequality at provincial level. For instance, rich people probably have the financial resources to move to cleaner areas in case of strong pollution. Conversely, poor people have a greater probability of remaining exposed to a deteriorated environment due to their financial constraints. To control for the potential endogeneity of the inequality variable, we use the augmented regression technique proposed by Blundell et al. (1998). The main idea of this procedure is to estimate a first-stage regression in which the inequality variables are regressed on a set of instruments *z*. Given the panel structure of the dataset, this first-stage regression is expressed as a fixed-effects model:

$$ineq_{it} = z_{it}\pi + \gamma_i + v_{it} \qquad (6)$$

Residuals predicted from this first-stage regression are then included as a control variable in our structural model:

$$env_{it} = x_{it}\beta + g(ineq_{it}) + \rho\,\hat{v}_{it} + \delta_i + u_{it} \qquad (7)$$

Identifying a relevant instrumental variable is a great challenge. We make the choice of using gender differences in labor market participation to predict income inequality. More precisely, our instrument is the ratio of male to female employment in State-owned units, calculated at the provincial level using data from *China Statistical Yearbooks*. We can reasonably argue that this instrument is a good predictor of income inequality and has no direct impact on environmental variables.

5. Results

Tables 1 to 3 report estimates for control variables. Figures 3 to 6 present the non-parametric fits of the relationship between the three inequality measures and environmental variables derived from the semi-parametric estimates. Our instrumental variable, i.e. the ratio of male to female employment in State-owned units, is significant and has the expected positive influence in the first-stage regressions (not reported) for two of the three inequality variables (provincial Gini and inter-urban-rural inequality). Predicted residuals from these first-stage regressions are significant in several semi-parametric regressions indicating the importance of dealing with this endogeneity issue.

5.1. The influence of control variables

Although it is not the primary focus of the paper, the EKC hypothesis seems to be validated for two pollutants, namely CO_2 emissions and wastewater discharged. It is also confirmed for SO_2 emissions when provincial Gini is used as an inequality measure. For the three other pollution variables (soot emissions, COD and AN discharged), our results fail to establish U-inverted associations with per capita GDP. Energy intensity is another important explanatory factor. With the exception of several regressions including the provincial Gini, it is systematically significant (at 1% level) and has a positive influence on pollution. In the same vein, industrialization is globally associated with a higher level of several pollutants (except for the provincial Gini), confirming that heavy industries are more energy intensive and therefore emit more pollution. Conversely, when significant, the coefficient of trade openness exhibits a negative sign indicating that greater openness is associated with lower pollution.[4]

(Insert Tables 1 to 3)

For other control variables, our results provide mixed evidence. The influence of urbanization, financial development and fiscal decentralization depends on the pollutant and the inequality variable that are considered, with positive, negative and non-significant impacts. This mixed evidence is in line with existing studies. For instance, the effect of the urbanization level on environment quality is uncertain, with negative associations observed when provincial Gini is considered but positive associations with other inequality variables included. Such mixed evidence has already been discussed by Du et al. (2012). Urban areas usually have better infrastructures than rural areas (and this is particularly true for China), which may increase the use of energy and therefore generate more pollution. But urbanization might also be assumed to be negatively associated with pollution for two main reasons. The distribution of the urban population is often more concentrated than in rural areas. As a consequence, cities are more likely to reap the benefits of increasing returns to scale in energy use. Moreover, urban households are provided with easier access to cleaner fuels such as natural gas.

5.2. The impact of inequality variables

First, let us examine the results for provincial Gini (Figure 3). Our results fail to establish a positive relationship between provincial inequality and environmental quality. Rather, the non-parametric fits tend to emphasize negative associations between provincial inequality and pollutions. This decreasing relationship is evident for the three water pollution variables, namely wastewater, COD and AN discharged, but also for CO_2 and SO_2 emissions. For soot emissions we observe a slightly decreasing relation for low levels of inequality but the relationship becomes increasing for high levels of inequality, indicating a U-shaped nonlinear association. In a nutshell, our results underline that higher degrees of inequality at the provincial level are associated with lower degrees of air and water pollution. This result is clearly in contradiction with the few previous studies that analyze the impact of inequality on pollution. As mentioned previously, the empirical literature addressing this issue at the provincial level in China, primarily focused on CO_2 emissions, concludes on the deleterious impact of inequality on environmental performances. Obviously, we cannot confirm this conclusion with semi-parametric estimates, either for CO_2 or for other pollution variables. On the contrary, we find a favorable effect of provincial inequality on environment quality. However, further examination is required. Let us recall that the provincial Gini results from the combination of the urban Gini, the rural Gini and the urban-rural inequality component. This means that understanding the underlying dynamics behind the negative association requires investigating the nature of the relationship between these different components and pollution.

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[4] In the literature, there is no consensus on the sign of the trade-environment relationship (Managi et al. 2009; Du et al. 2012). On the one hand, trade openness might result in more pollution if the country chooses to export products that are energy intensive. On the other hand, international trade facilitates technology diffusion, including that of green technologies.

(Insert Figures 3 to 5)

Figure 4 presents the results for inequality between urban and rural areas. Broadly speaking, the non-parametric fits exhibit negative relationships between urban-rural inequality and the six pollution variables. However, it should be noted that obvious non-linear relationships are emphasized for most pollutants. More precisely, for all the environmental variables except CO_2 emissions, the decreasing associations are primarily observed for low and very high levels of urban-rural inequality. For intermediate levels, the associations flatten out (or even become increasing for SO_2 emissions). Despite these non-linearities, our estimates give clear evidence of negative associations between urban-rural inequality and pollution. This result calls for two comments. First, the negative associations between provincial inequality and pollution evidenced in Figure 3 are very likely linked to the negative associations observed with urban-rural inequality. Second, the diminishing impact of urban-rural inequality on pollution chimes with the literature analyzing the effect of the industrialization of Chinese rural areas on environment quality. Location and geography undoubtedly matter in understanding the influence of income inequality on polluting activities at the provincial level. The development of the industrial sector in less urbanized areas reduces the urban-rural income gap through accelerated rural income growth and simultaneously increases energy consumption and pollution (Guo, 2014). Wang et al. (2008) have extensively analyzed the impact of rural industries such as Township and Village Enterprises (TVEs) on water pollution. They show how the small scale of TVEs, their poor management, their technological deficit, their spatial dispersion but also existing connections between environmental regulators and rural entrepreneurs can explain bad practices in terms of water quality management. As already explained, the development of industry in rural areas often operates through the transfer of industrial polluting activities to less urbanized areas, due to lower environmental policy constraints (Duviver and Xiong, 2013; Hou et al., 2013).

Results on the impact of urban inequality on environment quality, reported in Figure 5, are of particular interest. Broadly speaking, the conclusions clearly depend on the pollutant that is analyzed. For CO_2, SO_2 and wastewater, non-linear relationships are emphasized. Indeed, for these three pollutants, Figure 5 seems to highlight U-shape relationships mainly driven by the associations observed for extreme values of urban Gini. If we exclude the two tails of the urban Gini distribution, the associations are quite flat, indicating the absence of clear effects. For COD discharged, AN discharged and soot emissions, our results tell a different story. Despite some non-linearities (particular for soot and AN), there is evidence of a positive association with urban inequality for these three pollutants. Regarding air pollution, our results are interesting insofar as they highlight the existence of a positive link with urban inequality only for soot emissions, which are a local and city-specific pollutant. For CO_2 and SO_2, which could be viewed as more global pollution, we cannot conclude on a positive relationship. For water pollution, which is localized by definition, the same kind of conclusion could be established considering the positive association of urban inequality with COD and AN discharged. However, the evidence is less conclusive for wastewater discharged.[5] At all events, our results indicate that the spatial scale of environmental costs is crucial to understand the nature of the relationship with (urban) inequality. As suggested by Boyce (2008) and Clément and Meunié (2010), this supports the idea that the harmful impact of urban inequality is mainly observed for local pollutants.

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[5] It is worth noting that we also test the relationship between urban inequality and pollution using the share of the top quintile in total income instead of the Gini index (results not reported but available on request). With this alternative measure, we emphasize a positive impact of urban inequality on wastewater discharged.

6. Discussion and conclusion

This article aimed to provide an in-depth analysis of the causal effect of inequality on environment quality in Chinese provinces for the 2000-2012 period. Compared to the existing empirical literature, we have enlarged the scope of the pollution and inequality variables taken into account. Moreover, semi-parametric estimates allow us to explore possible non-linearities in the inequality-pollution relationship.

A very general conclusion drawn from this study is that the relationship between income inequality and environmental performances in Chinese provinces is more complex than prior evidence suggested, for two main reasons. Associations between the different variables of income inequality and pollution are primarily non-linear, as shown by semi-parametric estimates. These non-linearities are particularly evident in the case of the urban-rural inequality. Next, the kind of associations depends on the pollution and inequality variables taken into account. Despite these two sources of complexity, our study has identified three stylized facts. First, provincial inequality seems to have a decreasing effect on air and water pollution. This result contradicts some of the existing evidence. Nonetheless, it should be noted that existing studies mainly focus on CO_2 emissions and do not address the potential non-linearities of their association with inequality. Second, this decreasing relationship is primarily explained by the inequality between urban and rural areas. As shown by the semi-parametric estimates, this inequality component has a harmful impact on environment quality for the six environmental variables taken into account. Furthermore, given the non-linear shapes highlighted, these negative effects are mainly observed for low and very high levels of rural-urban inequality. This result confirms that the development of the industrial sector in Chinese rural areas produces antagonist effects by reducing the rural-urban income gap and increasing the pollution level at the provincial scale. These two sides of Chinese rural development are described as the “bitter and sweet fruits” of rural industrialization by Liu et al. (2016). This result has important policy implications since the effects of pollution-reducing policies will probably be altered by policies aiming at reducing urban-rural income gaps through industrialization. Third, the analysis of the influence of urban inequality on environment quality tells a different story. Our results suggest that urban income inequality has a positive impact on soot emissions and two water pollution variables (COD and AN discharged). This confirms that the deleterious effect of inequality is primarily observable for localized pollution, as already suggested by Boyce (2008) and Clément and Meunié (2010).

In a nutshell, this study expands the empirical literature on the inequality-environment nexus in China. However, we suggest that microeconomic evidence has to be strengthened to understand the underlying mechanisms behind the positive impact of income inequality on urban localized pollution. More specifically, further research is needed to address the relevance of the two transmission channels discussed in the introduction of the article, i.e. the consumption channel and the political channel. Regarding the first channel, existing microeconomic evidence shows that the most affluent households have a greater propensity to create environmental pressure in Chinese cities (Golley and Meng, 2012; Yang et al., 2017), which could justify the deleterious impact of inequality on urban environment quality. However, little is known about the political channel. In line with Boyce (1994), it may be argued that, in a context of high income inequality, the poorest households express a strong interest in the preservation of the environment but do not have enough political power to influence the design of environmental policies in this respect. To test the relevance of Boyce’s hypothesis, further investigation is required to assess the interests of pro-environmental policies of different social groups and to determine how the emanating environmental demands are taken into account by the decentralized political authorities in the formulation of environmental policies.

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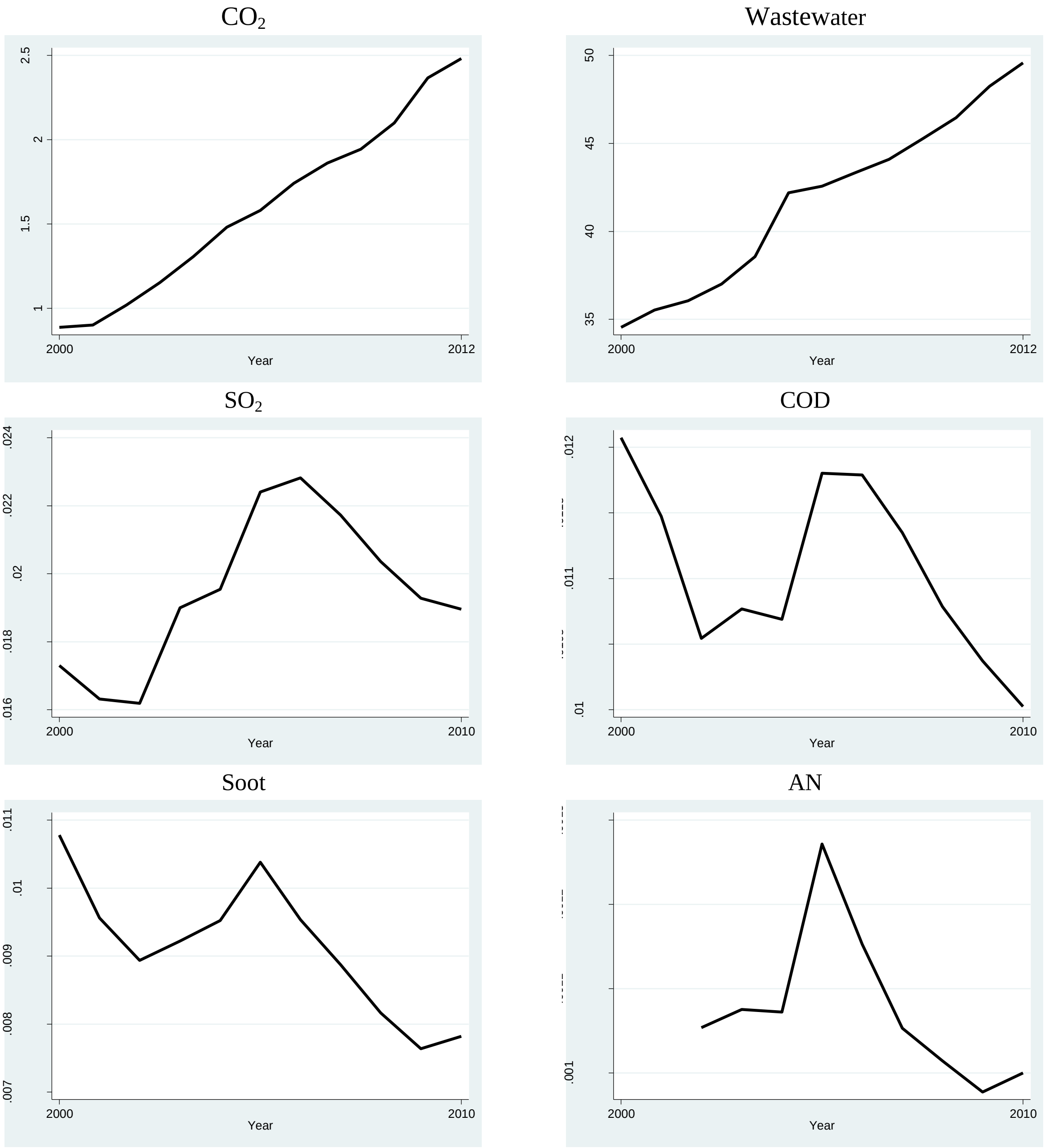
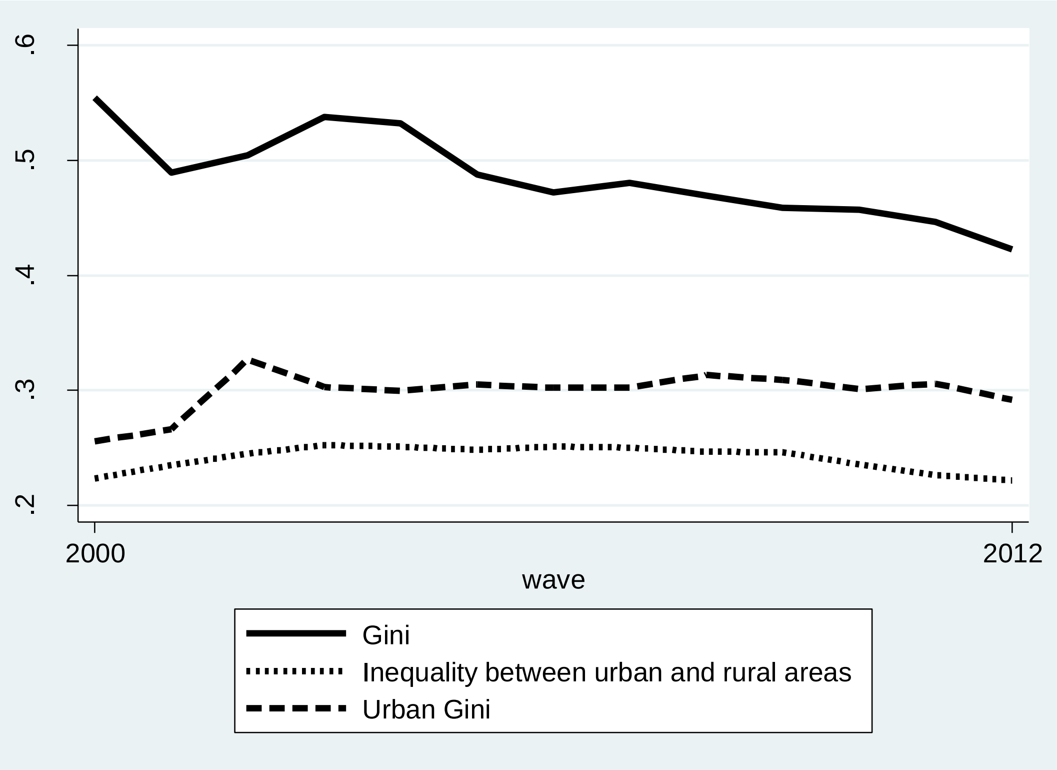
Figure 1: Evolution of pollution in China.



Source: Authors' calculation, based on *China Environment Yearbooks and China Energy Statistical Yearbooks* (2000-2012).

Figure 2: Evolution of income inequality.



Source: Authors' calculation, based on *China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).

Table 1: Semiparametric estimates (Gini).

Variables	CO_2	SO_2	Soot	Wastewater	COD	AN
GDP p.c.	0.7013***	0.0038*	0.0035**	26.7263***	0.0045	0.0002
	(6.24)	(1.78)	(2.08)	(2.77)	(1.55)	(0.54)
GDP p.c. ^{2}	-0.0618***	-0.0008***	-0.0002	-2.2801**	-0.0008***	-0.00004
	(-5.53)	(-4.48)	(-1.58)	(-2.37)	(-3.28)	(-1.43)
Energy intensity	0.5632***	0.0052**	0.0003	-14.4153	-0.0036	0.0003
	(4.55)	(2.40)	(0.18)	(-1.36)	(-1.20)	(0.92)
Industry	-0.0005	0.00008	-0.00003	-0.0070	0.00005	0.00005**
	(-0.06)	(0.61)	(-0.34)	(-0.01)	(0.28)	(2.13)
Urbanization	0.0005	-0.0002***	-0.00006	-2.0104***	-0.0004***	-0.00002
	(0.10)	(-2.79)	(-0.89)	(-4.01)	(-3.52)	(-1.31)
Trade	0.0003	-0.00002	-0.00004***	0.1226	-0.00002	-0.00000**
	(0.37)	(-1.55)	(-3.41)	(1.38)	(-1.06)	(-2.10)
Financial development	0.0002	-0.00001	-0.00004***	-0.0013	-0.00003**	-0.00000
	(0.44)	(-1.08)	(-5.45)	(-0.03)	(-2.30)	(-1.58)
Fiscal decentralization	-0.1365	0.0055	-0.0047	-9.2489	-0.0085	0.0011
	(-0.47)	(1.15)	(-1.22)	(-0.37)	(-1.26)	(1.24)
Predicted residuals	-0.7128*	-0.0065	-0.0008	-122.7909***	-0.0353***	-0.0024**
	(-1.97)	(-1.01)	(-0.16)	(-3.94)	(-3.94)	(-2.07)
Nb of obs.	134	108	108	134	108	97
Adjusted Within R-squared	0.976	0.941	0.912	0.917	0.902	0.722

Source: Authors' calculation, based on *China Environment Yearbooks*, *China Energy Statistical Yearbooks, China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).

Notes: Baltagi and Li (2002) semiparametric fixed-effects regression estimator; Robust t-statistics into brackets; Predicted residuals from a first-stage regression where the inequality measure is instrumented by the ratio of male to female employment in State-owned units. Level of statistical significance: 1 %***, 5 %**, and 10 %*.

Table 2: Semiparametric estimates (inequality between urban and rural areas).

Variables	CO_2	SO_2	Soot	Wastewater	COD	AN
GDP p.c.	1.1603***	0.0049	-0.0020	10.6288***	0.0028*	0.0001
	(10.97)	(1.44)	(-1.29)	(3.11)	(1.69)	(1.43)
GDP p.c. ^{2}	-0.0953***	-0.0010**	0.0001	-1.6949***	-0.00002	-0.00003**
	(-7.53)	(-2.19)	(0.54)	(-4.13)	(-0.10)	(-2.22)
Energy intensity	0.5669***	0.0118***	0.0038***	3.0465***	0.0014***	0.0002***
	(22.33)	(17.26)	(12.54)	(3.75)	(4.40)	(7.79)
Industry	0.0038	0.0002***	0.0002***	0.1835**	0.00006	0.00000
	(1.45)	(3.45)	(5.66)	(2.12)	(1.58)	(0.28)
Urbanization	0.0073**	0.0002***	0.0001***	0.251**	0.0001***	0.00001***
	(2.31)	(3.08)	(3.86)	(2.45)	(3.46)	(4.30)
Trade	-0.0043***	-0.00009***	-0.00005***	-0.0637**	-0.00006***	-0.00000***
	(-5.35)	(-4.43)	(-5.62)	(-2.43)	(-5.87)	(-5.78)
Financial development	-0.0011	-0.0001***	-0.00001	0.0877***	-0.00001	-0.00000***
	(-1.27)	(-5.82)	(-0.73)	(2.96)	(-1.18)	(-3.74)
Fiscal decentralization	-0.3692	0.0226***	0.0031	40.1082***	0.0110***	0.0005**
	(-1.52)	(3.15)	(0.96)	(5.12)	(3.20)	(1.97)
Predicted residuals	-1.4656	0.0042	-0.0126	-131.4793***	-0.0512***	-0.0002
	(-1.61)	(0.92)	(-1.17)	(-4.51)	(-4.45)	(-0.26)
Nb of obs.	386	330	330	390	330	270
Adjusted Within R-squared	0.765	0.590	0.552	0.752	0.258	0.411

Source: Authors' calculation, based on *China Environment Yearbooks*, *China Energy Statistical Yearbooks, China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).

Notes: Baltagi and Li (2002) semiparametric fixed-effects regression estimator; Robust t-statistics into brackets; Predicted residuals from a first-stage regression where the inequality measure is instrumented by the ratio of male to female employment in State-owned units. Level of statistical significance: 1 %***, 5 %**, and 10 %*.

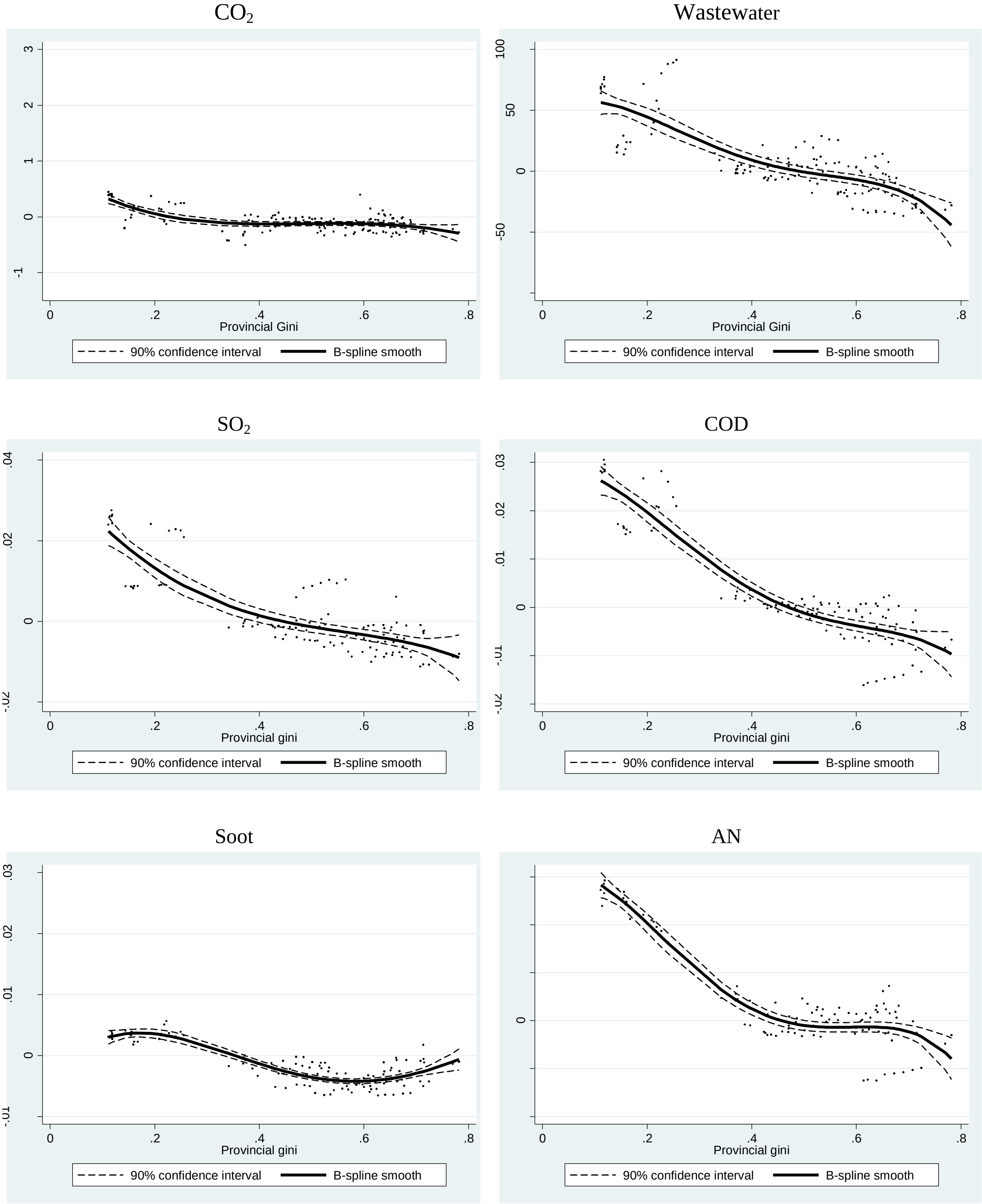
Table 3: Semiparametric estimates (urban Gini).

Variables	CO_2	SO_2	Soot	Wastewater	COD	AN
GDP p.c.	0.9821***	0.0066**	-0.0014	7.9125**	0.0002	0.0002*
	(9.66)	(2.08)	(-1.08)	(2.32)	(0.14)	(1.90)
GDP p.c. ^{2}	-0.0685***	-0.00008	0.0001	-0.4794	0.00004	-0.00001
	(-6.50)	(-0.22)	(1.27)	(-1.36)	(0.22)	(-0.63)
Energy intensity	0.5626***	0.0116***	0.0035***	2.5500***	0.0010***	0.0001***
	(19.34)	(15.12)	(11.21)	(2.63)	(2.67)	(5.12)
Industry	0.0069**	0.0001**	0.0001***	0.0910	0.00008**	0.00000*
	(2.47)	(2.15)	(4.83)	(0.96)	(2.09)	(1.65)
Urbanization	0.0107***	0.0002**	0.0001***	0.3783***	0.0001***	0.00001***
	(3.00)	(-2.57)	(3.25)	(3.17)	(3.01)	(4.62)
Trade	-0.0029***	-0.00006***	-0.00005***	0.0039	-0.00005***	-0.00000***
	(-3.33)	(-2.78)	(-5.37)	(0.13)	(-4.40)	(-4.45)
Financial development	-0.0012	-0.0001***	-0.00000	0.1438***	0.00001	-0.00000**
	(-1.32)	(-3.87)	(-0.27)	(4.55)	(0.67)	(-2.14)
Fiscal decentralization	-0.7725***	0.0044	0.0001	20.6324**	-0.0011	-0.0002
	(-3.21)	(0.64)	(0.06)	(2.56)	(-0.33)	(-0.91)
Predicted residuals	11.3817***	0.0084*	0.0801	498.6601***	0.1351**	-0.0043
	(2.65)	(1.91)	(1.60)	(3.48)	(2.19)	(-1.03)
Nb of obs.	356	306	306	360	306	249
Adjusted Within R-squared	0.744	0.554	0.558	0.732	0.160	0.391

Source: Authors' calculation, based on *China Environment Yearbooks*, *China Energy Statistical Yearbooks, China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).

Notes: Baltagi and Li (2002) semiparametric fixed-effects regression estimator; Robust t-statistics into brackets; Predicted residuals from a first-stage regression where the inequality measure is instrumented by the ratio of male to female employment in State-owned units. Level of statistical significance: 1 %***, 5 %**, and 10 %*.

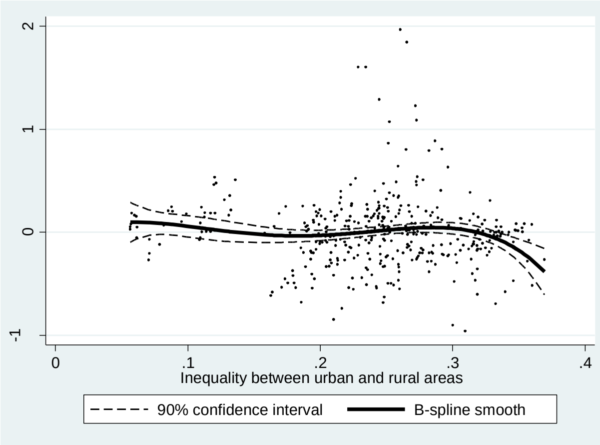
Figure 3: Non-parametric fits (Gini).



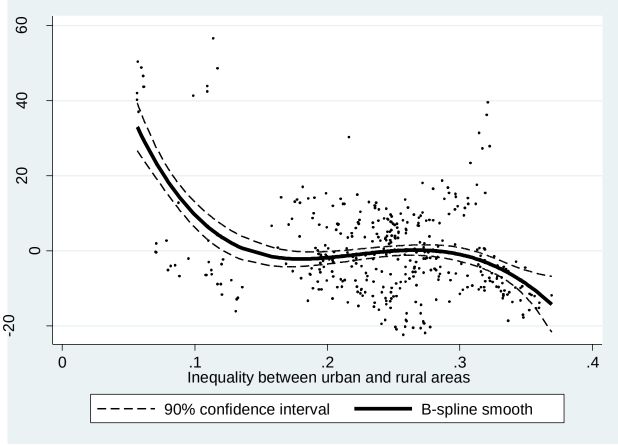
Source: Authors' calculation, based on *China Environment Yearbooks, China Energy Statistical Yearbooks, China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).
Note: The figures show non-parametric fitted value of function f which represents the relationship between residuals from the parametric part and the inequality variable (see Equation (5)).

Figure 4: Non-parametric fits (inequality between urban and rural areas).

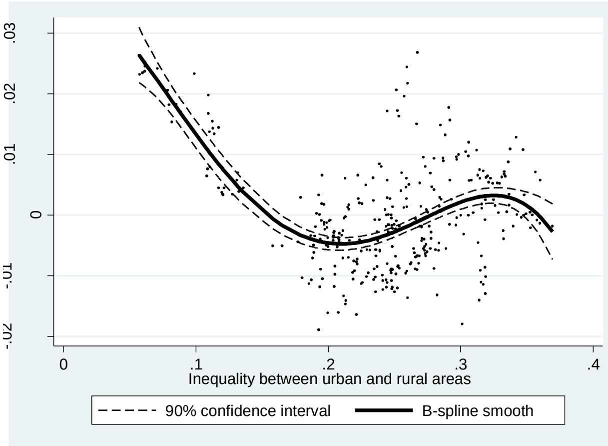
CO_2



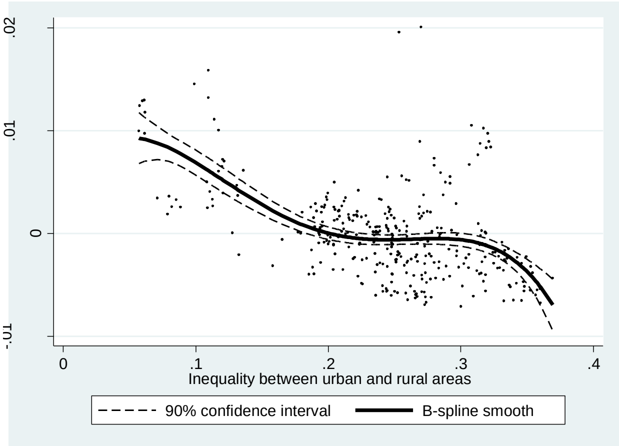
Wastewater



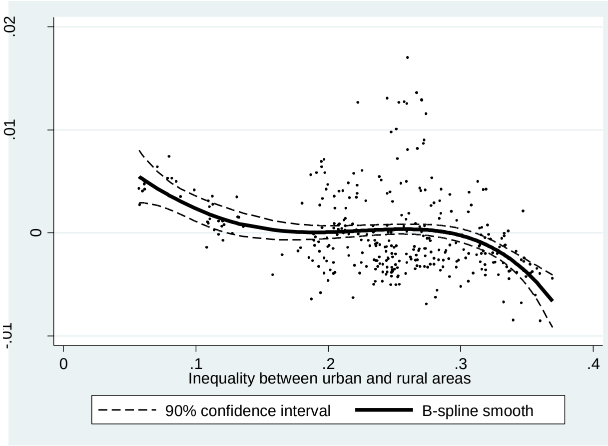
SO_2



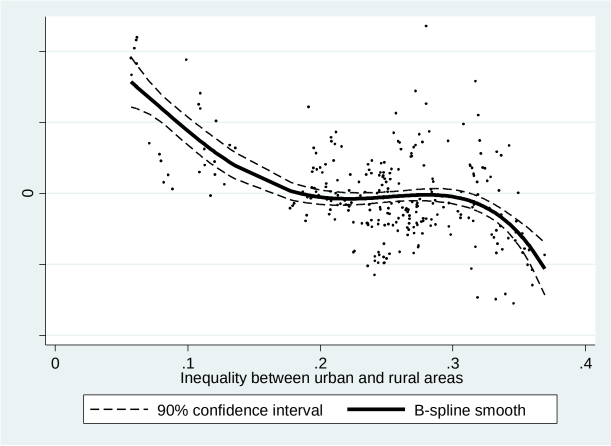
COD



Soot



AN

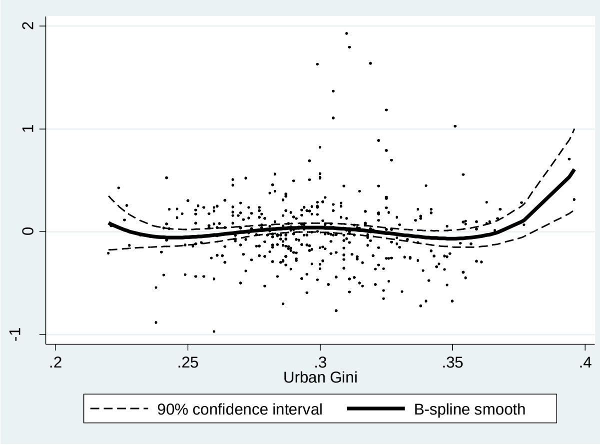


Source: Authors' calculation, based on *China Environment Yearbooks, China Energy Statistical Yearbooks, China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).

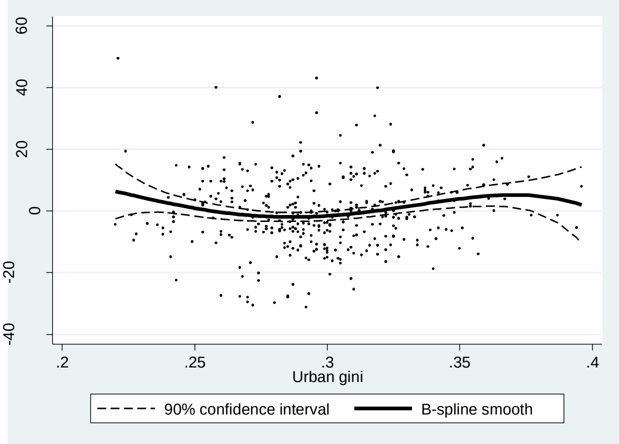
Note: The figures show non-parametric fitted value of function f which represents the relationship between residuals from the parametric part and the inequality variable (see Equation (5)).

Figure 5: Non-parametric fits (urban Gini).

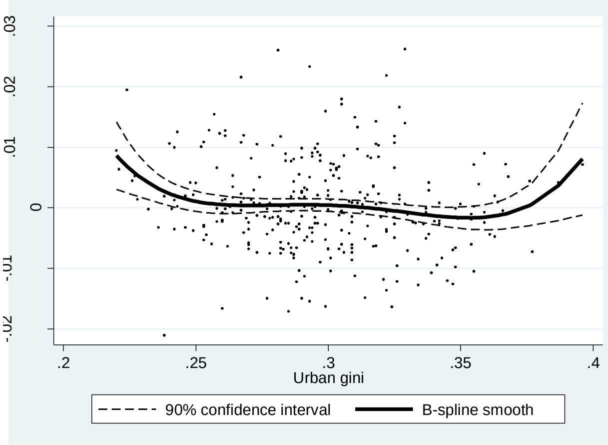
CO_2



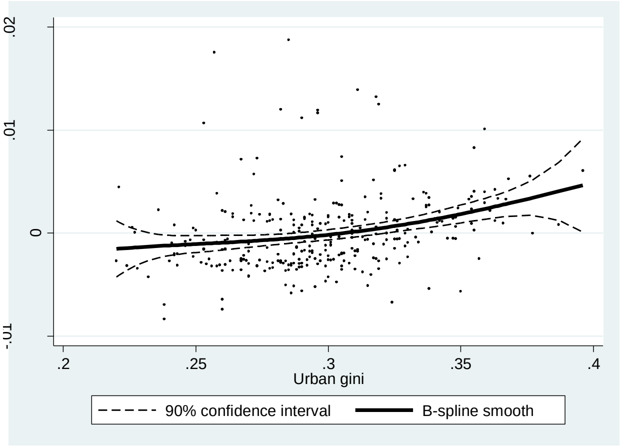
Wastewater



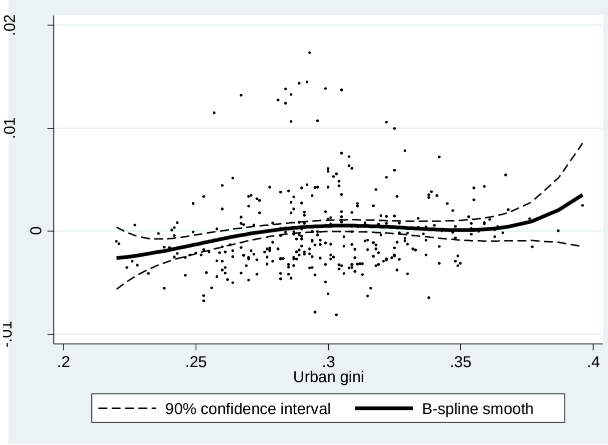
SO_2



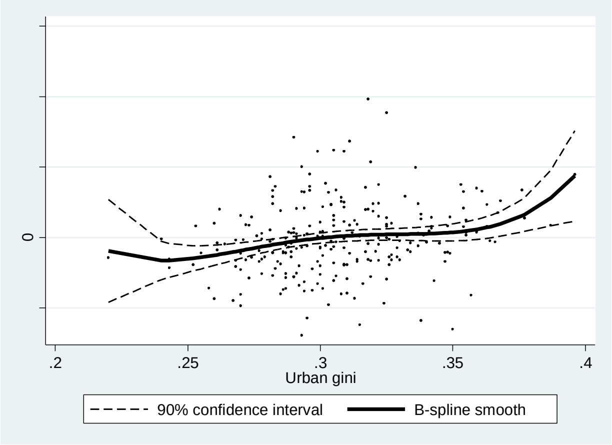
COD



Soot



AN



Source: Authors' calculation, based on *China Environment Yearbooks*, *China Energy Statistical Yearbooks, China Statistical Yearbooks* and *Provincial Statistical Yearbooks* (2000-2012).

Note: The figures show non-parametric fitted value of function f which represents the relationship between residuals from the parametric part and the inequality variable (see Equation (5)).

Table A1: Descriptive statistics.

Variable	Unit	Mean	Standard deviation	Min	Max	Nb of obs.	Data source
Environmental variables							
CO_2 per capita	10,000 t of standard coal equivalent	1.6078	0.9110	0.18	5.40	386	*CESY*
SO_2 per capita	10,000 t	0.0194	0.0119	0.003	0.064	330	*CEY*
Soot per capita	10,000 t	0.0091	0.0065	0.001	0.033	330	*CEY*
Wastewater per capita	10,000 t	41.8065	19.8228	13.81	120.39	390	*CEY*
COD per capita	10,000 t	0.0110	0.0040	0.005	0.033	330	*CEY*
AN per capita	10,000 t	0.0010	0.0004	0.000	0.003	270	*CEY*
Inequality Variables							
Gini		0.4784	0.1813	0.111	0.782	134	*PSY*
Urban gini		0.2983	0.0324	0.220	0.396	360	*PSY*
Between-urban-rural inequality		0.2410	0.0663	0.057	0.369	390	*PSY, CSY*
Control variables							
GDP per capita	10,000 Yuan (2000 prices)	1.7259	1.2608	0.27	7.01	390	*CSY*
GDP per capita squared		4.5641	7.2927	0.07	49.15	390	*CSY*
Energy intensity	tons coal equivalent per 10,000 Yuan GDP	1.7307	0.9354	0.64	6.58	390	*CESY,CSY*
Industry	% of GDP	39.645	8.1236	13.37	54.83	390	*CSY*
Urbanization	% of pop.	49.1871	15.3503	18.61	89.30	390	*CSY*
Trade	% of GDP	32.95	41.4253	3.57	172.15	390	*CSY*
Financial development	% of GDP	106.590	35.7606	54.55	258.47	390	*CSY*
Fiscal decentralization		0.5177	0.1897	0.148	0.951	390	*CSY*

Source: Authors' calculation, based on *China Environment Yearbooks (CEY), China Energy Statistical Yearbooks (CESY), China Statistical Yearbooks (CSY)* and *Provincial Statistical Yearbooks (PSY)* (2000-2012).