Concentration of Industrial Pollution in China

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Abstract

We pioneer the application of the Theil index, a statistic primarily used to measure economic inequality or racial segregation, to studying the concentration of local pollutants. While most discussions are on reducing the level of pollution, our goal is to investigate the effect of China’s development strategies on the distribution of pollution. Decomposition of the index into the between-region and within-region concentrations provides a unique policy evaluation for China. We find that while the within-region and between-region imbalances of industrial output have both been reduced, the speed of diversion of pollution does not follow. There is not much between-region movement of pollution over time. Most changes are within-region.

Keywords: Theil index; Industrial pollution; Inequality; Chinese Development
1. Introduction

This study uses the Theil index to measure the concentration of pollution in China during 2003-2015. This index measures the disproportionality of a population distribution relative to a predetermined reference distribution. It is primarily used to measure the regional imbalance in income, employment, or industry; or the racial segregation. Applying it to measure the concentration of pollution has not drawn much attention.

While most discussions are on reducing the level of pollution, lowering the concentration of pollution is equally important. Millimet and Slottje (2002) argue that if pollution is highly concentrated, the citizens would suffer adverse health effects by exposing to a threshold level of toxins and face disproportionately increasing health risk. From an economic perspective, if income is 'good' and pollution is 'bad', society may wish to distribute the cost of pollution evenly across regions just as it may wish to distribute the benefit of income equally. As suggested by Wu and Heberling (2013), the level of pollution has become a less critical environmental issue and environmental justice for a less concentrated pollution is the next goal to achieve.

The case of China is of particular interest. Initiated in the 10th Five-Year Plan (2001-2005), the “Great Western Development” and the “Northeast China Revitalization” strategies provoke moving the center of the economy to the inland from the advanced east-coast region. The plan is believed to be on the right track in reducing the concentration of industries (Lemoine et al. 2015; Long and Zhang 2012). While most discussions are on the redistribution of income and industries, our purpose is to assess the effectiveness of this initiative on the redistribution of pollution.

We take advantages of two methodological features of the Theil index to investigate the over-time changes of pollution concentration. The first is the relative measure. The relative concentration of pollution with respect to the concentration of industrial output allows us to assess the impact of
diversions of industries on the concentration of pollution. The second is the decomposition of the index into the between-region concentration and the within-region concentration, which distinguishes itself from the popular Gini coefficient as a measure of regional inequality as it suggests the relative importance of spatial dimension of inequality. This decomposition is of particular interest in that the between-region concentration reveals whether the decline in the regional imbalance of industries since the mid-2000s has changed the regional distribution of pollution as well.

2. Methodology

Consider the following Theil index:

\[
\text{Theil} = \frac{1}{n} \sum_{i=1}^{n} \frac{E_i}{\Pi_i} \ln \left( \frac{E_i}{\Pi_i} \right) \left( \frac{E_i}{\Pi_i} \right)
\]

(1)

where \( E_i \) is the measure of pollution, \( i \) represents cities and \( n \) the number of cities, and \( \Pi_i \) is the reference distribution. The existence of concentration is indicated by a deviation of \( E \) from \( \Pi \). The absolute measure assumes that the reference distribution is uniform. For the relative measure it is the distribution of industrial output. A zero measure means the pollutant is distributed the same way as the industry across cities.

To decompose the Theil index, let \( E_{r,i} \) be the pollution in City \( i \) of Region \( r \) and \( n_r \) be the number of cities in Region \( r \). The Theil index of an individual region is 

\[
\text{Theil}_r = \frac{1}{n_r} \sum_{i=1}^{n_r} \frac{E_{r,i}}{\bar{E}_r} \ln \left( \frac{E_{r,i}}{\bar{E}_r} \right),
\]

where \( \bar{E}_r = \frac{1}{n_r} \sum_{i=1}^{n_r} E_{r,i} \) is the mean pollution in Region \( r \) across cities. Assume \( R \) disjoint regions and \( N = R \times n_r \) cities. Let \( \bar{E} \) be the overall mean pollution across all cities. The entire concentration explained by the Theil index can be decomposed as:
The first term on the right-hand side is the within-region concentration, measuring the concentration as a result of the differences concerning the city-level pollution concentration in these $R$ regions. It is the weighted arithmetic mean of the regional Theil indices, with the weight being the share of each region's pollution in total pollution. The second term is the measure of between-region concentration, which quantifies the part of pollution concentration due to the differences of concentration that exist between these $R$ regions. It is a Theil index for the average pollution at the regional level.

For inference, since the index is a non-linear function of a random variable, Mills and Zandvakili (1997) suggest using bootstraps. To test the statistical significance of the changes of an index over time, we follow their methodology, which is analogous to comparing means from two samples.

### 3. Empirical Results

Data for industrial output, wastewater, and soot-dust emissions are from the *China City Statistical Yearbook*, including 287 cities from 2003 to 2015. Wastewater is the amount of water discharged by factories at the end of the pipes, and soot-dust emission is the mass of suspended particulate emitted into air. The industrial output is deflated by the GDP deflator. Table 1 reports the summary statistics. While industrial outputs continue to grow, the levels of wastewater and soot-dust emissions behave differently over time. Wastewater pollution remains stable, possibly due to the utilization of sewage treatment technology. On the other hand, soot-dust emissions shoot up after 2010, indicating a disproportional acceleration of air pollution compared to economic growth.
Figures 1a-1c plot the absolute measures along with their 90% confidence intervals. The concentration of industrial output starts at a very high level, arguably caused by the “open door” strategy in the early 1980s that drives a fast development in the east coast. It continuously declines up to 2011 and remains stable afterwards, reflecting that the strategic plan successfully narrows the disparities between the east coast and the inland. Panel (A) of Table 2 reports that the decreasing concentration of industry is statistically significant for both 5-year sub-periods (2005-2010, 2010-2015) and the whole sample period. The concentration of wastewater also has a significant declining trend. The concentration of soot-dust emissions slightly decreases up to 2010, but jumps to a higher level afterwards, although the changes over time are statistically insignificant.

[Figure 1]

[Table 2]

To what extent has the decline in concentration of industry changed the distribution of pollution? We resort to the relative measures, plotted in Figures 2a-2b, for the answers. Panel (B) of Table 2 reports the changes of the index. If the spreading of industrial output also spreads out pollution, the relative measure would be stable over time. This is apparently not the case. Although both wastewater and industrial output show a downward trend of concentration, the concentration of wastewater relative to industry increases in the early sample, especially from 2006 to 2008. This implies that when the overall industry experiences a decreasing concentration, the concentration of wastewater-generating firms does not change as much. This is because water-polluting industries are subject to geographical constraint (water source) and do not relocate as quickly as other industries. After the water source is found and the constraint is unchained, these industries begin to spread more widely and the relative concentration falls back to the original level.

[Figure 2]
The relative measure for soot-dust emissions shows an opposite pattern to that of wastewater. It declines from 2006 to 2010, then rises back to the original level afterwards. Soot-dust emissions are not perceived as a critical issue until substantial jumps in the latter period. The plan does have impact on spreading soot-dust emissions more widely in earlier years when the issue is not severe. After 2010 the air pollution shoots up along with the expansion of industrial outputs, but at the same time the concentration of industry stops to decline. While relocating of air polluting industries is completed in early period, restructuring the facilities fails to control the increase in soot-dust emissions.

The decomposition analysis is based four regions characterized by the National Bureau of Statistics of China: East, Central, West and Northeast. Figures 3a-3c plot the decompositions. For industrial output, the within-region and the between-region concentrations share a similar downward trend and are almost parallel. Therefore, the development strategy successfully diverts the industries not only to other cities within individual regions but also across the regions.

[Figure 3]

Figures 3b-3c, on the other hand, tell a different story about the effects of the development plan on pollution. The between-region pollution concentrations over time are very low and stable. It is understandable that there is no significant movement of water-polluting industries across regions over time. Water-polluting industries are more likely to site within watershed. For example, many factories in these industries are located in the Yangtze Delta. This geographical constraint makes most of the decline of the wastewater concentration over time to be within-region.

On the other hand, soot-dust emissions have been evenly distributed across regions because the between-region concentration is very low. The improvement and deterioration of the concentration of soot-dust emissions all happen within each region. Compared to wastewater, soot-dust emissions are
more common to all industries. While the relocation of air polluting firms within region may follow the overall trend, restructuring their facilities is not very successful.

4. Discussion

We pioneer the application of the Theil index to pollutants and take advantages of its two special features. It is definitely not the only statistical tool available for this type of research. Comparisons of the Theil index and other inequality measures is out of the scope of this paper and we leave it for future research. Another extension is to identify the industries that generate specific pollutants, providing a more direct link between pollution and industrial output to assess the effectiveness of policies aiming at relocating and restructuring these industries. Finally, there is no decisive scientific measure of the threshold level and accelerating speed of the harmful effect of pollution. If the within-region reduction and diversion of pollution have lowered the level below the threshold, it may not be necessary to spread the inferior goods to other regions. We need more advanced studies in other fields for this research to be feasible.

Acknowledgement

Wu acknowledges supports from the Liberal Arts and Social Sciences Foundation of the Ministry of Education in China under Grant number 17YJC790166. Hueng acknowledges supports from the 2016-17 U.S. Scholar Fulbright Program.
References


<table>
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<tr>
<th>Year</th>
<th>Industry outputs (100 million RMB)</th>
<th>Wastewater (10000 tons)</th>
<th>Soot-dust (10000 tons)</th>
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<tr>
<td>2003</td>
<td>807</td>
<td>1566</td>
<td>14</td>
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<tr>
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<td>1004</td>
<td>1896</td>
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<td>1269</td>
<td>2364</td>
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<td>2006</td>
<td>1543</td>
<td>2790</td>
<td>26</td>
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<td>2007</td>
<td>1825</td>
<td>3160</td>
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<tr>
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<td>2114</td>
<td>3440</td>
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<td>2308</td>
<td>3551</td>
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<td>3098</td>
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<tr>
<td>2015</td>
<td>3826</td>
<td>4867</td>
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Table 2: Concentration of Pollution and Industry

(A) Absolute Theil Index

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<td>Industry</td>
<td>0.690</td>
<td>-0.325***</td>
<td>-0.217***</td>
<td>-0.081*</td>
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<td>Wastewater</td>
<td>0.498</td>
<td>-0.156***</td>
<td>-0.086**</td>
<td>-0.080*</td>
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<td>Soot-dust</td>
<td>0.403</td>
<td>-0.018</td>
<td>-0.100</td>
<td>0.082</td>
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(B) Relative Theil Index

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<tbody>
<tr>
<td>Wastewater</td>
<td>0.499</td>
<td>-0.020</td>
<td>0.076</td>
<td>-0.128</td>
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<tr>
<td>Soot-dust</td>
<td>0.575</td>
<td>0.021</td>
<td>-0.087</td>
<td>0.130**</td>
</tr>
</tbody>
</table>

***/**/* denotes rejection of H0: ΔTheil index = 0, based on the bootstrapping 99%/95%/90% confidence intervals (1000 replications).
Figure 1: Absolute Theil Index

1a. Industry

1b. Wastewater

1c. Soot-Dust Emissions
Figure 2: Relative Theil Index

2a. Wastewater

2b. Soot-Dust Emissions
Figure 3: Decomposed Absolute Theil Index

3a. Industry

3b. Wastewater

3c. Soot-Dust Emissions