THE ROLE OF REGIONAL COLLABORATIONS WITHIN CHINA'S URBAN AGGLOMERATIONS IN HAZE POLLUTION ABATEMENT

A SPATIAL-TEMPORAL DECOMPOSITION OF CENTRAL AND PERIPHERAL CITIES

Banban Wang, Huazhong University of Science and Technology, +86 13971210462, wangbanban@hust.edu.cn
Xiaojie Liao, Huazhong University of Science and Technology, +86 136 3138 4859, liaoxiaojie@hust.edu.cn

Overview

In recent years, a great number of people in developing countries are suffering serious damage to health from haze pollution. China, as the largest developing country, has made remarkable achievements fighting against urban haze pollution since 2013, with nationwide $PM_{2.5}$ concentration significantly dropping by 39% on average from 2013 to 2018, which contributes nearly three quarters of the decrease of worldwide haze pollution (Greenstone & Fan, 2020). Exploring the key role of China's air pollution abatement policy in combating haze pollution coming along with urbanization process is of great significance to other developing countries.

Haze pollution is mainly from urban residents' activities, industrial production emissions, construction sites and transportation (Huang et al., 2015; Y. Zhang et al., 2016), and it is closely connected to population agglomeration, economic growth, structural change, and crowded transportation during urbanization process (Han et al., 2018; Liang et al., 2019; Lin and Zhu, 2018; Luo et al., 2018). Besides, a city's air quality can be also affected by its neighboring cities because of the spatial spillover effect of haze pollution (Cheng et al., 2017a; Du et al., 2018). However, the form of urban agglomerations, which are planned to be the primary form of China's urbanization process according to the 11th Five-Year Plan (2006-2010), may make it easier to form regional haze pollution, because the compact distribution of cities and close economic ties among cities within urban agglomerations can enlarge the mutual transmission of haze pollution among cities. Central cities are the main vittims of regional haze pollution. For instance, regional transmission accounts for 20%-40% of the haze pollution in Beijing and Shanghai, while in some peripheral cities with the secondary industries as the economic pillars, industrial emissions account for over 30%. The special characters of urbanization in China, together with the differences in main sources of haze pollution between central cites and peripheral cities, stands out the importance of regional cooperation to fight against haze pollution.

In September 2013, the State Council of China issued the Air Pollution Prevention and Control Action Plan (APPCAP), marking the beginning of nationwide action to combat haze pollution. The policy put forwards some key actions and measures targeted at various main sources of haze pollution closely related to urbanization, such as strengthen the haze control in densely populated areas and large cities, promote energy structure, industrial structure, and traffic structure. Aiming to control regional haze pollution, the policy specially introduced to establish regional joint prevention and control mechanism, underlining the importance of regional collaboration in haze pollution abatement. The mechanism required to set an overall regional reduction target, carry out unified standard policies and supervision, work together through providing economic assistances and sharing environmental information. From 2013 to 2018, China has achieved a sustained and significant reduction in air pollutants with the average concentration of PM2.5 in 74 key cities decreasing by 42%, while maintaining a high-speed economic growth with GDP increasing by 39% (Ministry of ecology and environment of China, 2019).

APPCAP, especially the regional collaboration mechanism, played an important role in urban haze pollution abatement. Based on the background mentioned above, this paper raised three questions and try to answer them: (1) Does APPCAP alleviate the haze pollution during urbanization processes and promote the effect of haze pollution abatement action? (2) Are there any differences in policy effects between central cities and peripheral cities? (3) Does the regional collaboration mechanism coordinate the haze pollution control within urban agglomerations? To answer the questions above, we leverage the data of the top nine Chinese urban agglomerations comprised 15 central cities and 132 peripheral cities as our sample. We used haze exposure to measure haze pollution to reflect the damage of haze pollution to citizens' health better. Haze exposure is one of the main indicators of air quality used by the World Bank, calculated as the PM2.5 concentration weighted by the propotion of the city's population to the total population. By applying the spatial-temporal LMDI (ST-LMDI) method developed by Ang et al. (2016), we decomposed the change of haze exposure into contributions of factors reflecting various aspects of urbanization processes and haze pollution control. This updated method facilitates us to conduct multi-dimensional comparison of decomposition results across urban agglomerations, over time periods and within urban agglomerations.

The marginal contributions of this paper to the current literature are as follows. First, we inspected the vital catalytic role of APPCAP in haze pollution control; We especially evaluate the significant effects of the regional collaboration mechanism by comparing the decomposition results between central and peripheral cities. Second, by applying the spatial-temporal LMDI approach (Ang et al., 2016), we decomposed the haze exposure into factors relating to urbanization and urban haze pollution control, and compare decomposition results before and after the policy, across urban agglomerations and within urban agglomerations, recovering the effects of APPCAP from different perspectives. Third, by utilizing the updated $PM_{2.5}$ concentration data released by the Dalhousie University, we expanded the research period to 2001-2018, which facilitates us to realized better inter-temporal comparison since the uniform data set covers the period before and after APPCAP.

Methods

The spatial-temporal LMDI decomposition proposed by Ang et al. (2016).

The change of city-level haze pollution exposure are decomposed into contributions of five factors related to urbanization and haze pollution control: population agglomeration, population density, city expansion, economic growth and emissions intensity.

$$\bar{P} = \sum_{i=1}^{N} \bar{P}_i = \sum_{i=1}^{N} \frac{L_i}{L} P_i = \sum_{i=1}^{N} \frac{L_i}{L} \cdot \frac{L_i}{A_i} \cdot \frac{Y_i}{L_i} \cdot A_i \cdot \frac{P_i}{Y_i} = \sum_{i=1}^{N} PA_i \cdot PD_i \cdot PY_i \cdot CE_i \cdot EI_i \qquad (1)$$

The footmark i represents the city; N=147, is the total number of cities in the sample; $\bar{P}_i$ and P_i are the haze exposure and PM2.5 concentration, respectively; L_i and L represent the population of city i and the total population of all cities, respectively; A_i denotes the urban built-up area; Y_i is is the city's gross product. The above formula decomposes haze exposure into five factors (1) two population urbanization variables: urban population agglomeration (PA_i), the proportion of the population of city i to the total population of all cities, reflecting the relative agglomeration and polarization level of urban population; urban population density (PD_i), the population per unit area of a city, reflecting the degree of crowding; (2) one economic urbanization variable: urban per capita GDP (PY_i), reflecting the economic growth of city i in urbanization process, and also meaning the changes of production and living standards. (3) one land urbanization variable: city expansion (CE_i), the urban built-up area, reflecting not only the spontaneous expansion of urban area, but also the process of administrative urban area expansion in China, such as "withdrawing county into city", "withdrawing county into district" and building industrial parks; (4) one urban pollution control variable, PM2.5 emission intensity, calculated as the $PM_{2.5}$ concentration per unit GDP, reflecting the correlation between urban economic growth and pollution emissions. The reduction of emission density may reflects stronger pollution control policies or improvements of pollution control technology.

We sum up the decomposition results at the level of urban agglomerations after using ST-LMDI approach on the full sample to get the decomposition result of each urban agglomeration:

$$\bar{\boldsymbol{P}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{N}} \bar{\boldsymbol{P}}_{\boldsymbol{i}} = \sum_{\boldsymbol{j=1}}^{\boldsymbol{K}} \boldsymbol{k_j} \bar{\boldsymbol{P}}_{\boldsymbol{j}} \qquad (2)$$

j represents urban agglomerations; K=9, is the total number of urban agglomerations in the sample; urban agglomeration j includes k_j cities.

The advantages of ST-LMDI approach enable us to compare the decomposition results in a larger spatial-temporal range across urban agglomerations and over time periods. Ang et al. (2016) proposed that the average value of the full sample can be used to construct a benchmark city, which can be compared with all cities in all years, so the comparison between all cities and years is based on the same benchmark, breaking through the limit of pairwise comparison.

We use the arithmetic mean values of all cities in all years in the sample to construct a benchmark city u with haze exposure denoted as $\bar{P}_u$.

When t = 0, the difference of haze exposure between city i and city u can be decomposed into the differences of the above five contribution factors:

$$\bar{P}_{i0} - \bar{P}_u = \Delta\bar{P}_{i0-u}^{PA} + \Delta\bar{P}_{i0-u}^{PD} + \Delta\bar{P}_{i0-u}^{CE} + \Delta\bar{P}_{i0-u}^{PY} + \Delta\bar{P}_{i0-u}^{EI} \qquad (3)$$

When t = T, the difference of haze exposure between city i and city u can be also decomposed as the following formula:

$$\bar{P}_{iT} - \bar{P}_u = \Delta\bar{P}_{iT-u}^{PA} + \Delta\bar{P}_{iT-u}^{PD} + \Delta\bar{P}_{iT-u}^{CE} + \Delta\bar{P}_{iT-u}^{PY} + \Delta\bar{P}_{iT-u}^{EI} \tag{4}$$

Then the change of haze exposure from 0 to T in city i can be decomposed as:

$$\begin{aligned}\Delta\bar{P}_{iT-i0} &= \bar{P}_{iT} - \bar{P}_{i0} = (\bar{P}_{iT} - \bar{P}_u) - (\bar{P}_{i0} - \bar{P}_u) = \sum(\Delta\bar{P}_{iT-u}^{e} - \Delta\bar{P}_{i0-u}^{e}), e = \{PA, PD, CE, PY, EI\} \\ &= \Delta\bar{P}_{iT-i0}^{PA} + \Delta\bar{P}_{iT-i0}^{PD} + \Delta\bar{P}_{iT-i0}^{CE} + \Delta\bar{P}_{iT-i0}^{PY} + \Delta\bar{P}_{iT-i0}^{EI}\end{aligned} \tag{5}$$

In the above formula, the contribution of each influencing factor to the change of haze exposure of city i during the period of 0-T can be expressed as follows:

$$\Delta\bar{P}_{iT-i0}^{e} = \Delta\bar{P}_{iT-u}^{e} - \Delta\bar{P}_{i0-u}^{e} = w_{iT-u}\ln\frac{e_{iT}}{e_u} - w_{i0-u}\ln\frac{e_{i0}}{e_u}, \quad e = \{PA, PD, CE, PY, EI\} \tag{6}$$

where e denotes the five impact factors; w is the logarithmic mean value of haze exposure between city i and city u:

$$w_{iT-u} = L(\bar{P}_{iT}, \ \bar{P}_u) = \frac{\bar{P}_{iT} - \bar{P}_u}{\ln\bar{P}_{iT} - \ln\bar{P}_u} \tag{7}$$

According to Ang et al. (2016), the decomposition process satisfies all the good properties of LMDI method, which enables us to easily conduct cross cities and over period comparison, and to aggregate the results whitin any urban agglomeration or time period to make spatial-temporal comparison more convenient at the level of urban agglomeration.

The change of haze exposure from 0 to T in urban agglomeration j can be decomposed as:

$$\bar{P}_{jT} - \bar{P}_{j0} = \sum_{i=1}^{k_j}(\bar{P}_{iT} - \bar{P}_{i0}) = \sum_{i=1}^{k_j}\Delta\bar{P}_{iT-i0}^{PA} + \sum_{i=1}^{k_j}\Delta\bar{P}_{iT-i0}^{PD} + \sum_{i=1}^{k_j}\Delta\bar{P}_{iT-i0}^{CE} + \sum_{i=1}^{k_j}\Delta\bar{P}_{iT-i0}^{PY} + \sum_{i=1}^{k_j}\Delta\bar{P}_{iT-i0}^{EI} \tag{8}$$

When comparing the contribution of each factor to haze exposure among urban agglomerations, we need to take the mean value of the decomposition results of urban agglomerations, that is, dividing by the number of cities contained in urban agglomerations k_j. The contribution of each factor (ug/m^3) from 0 to T in urban agglomeration j is as follow:

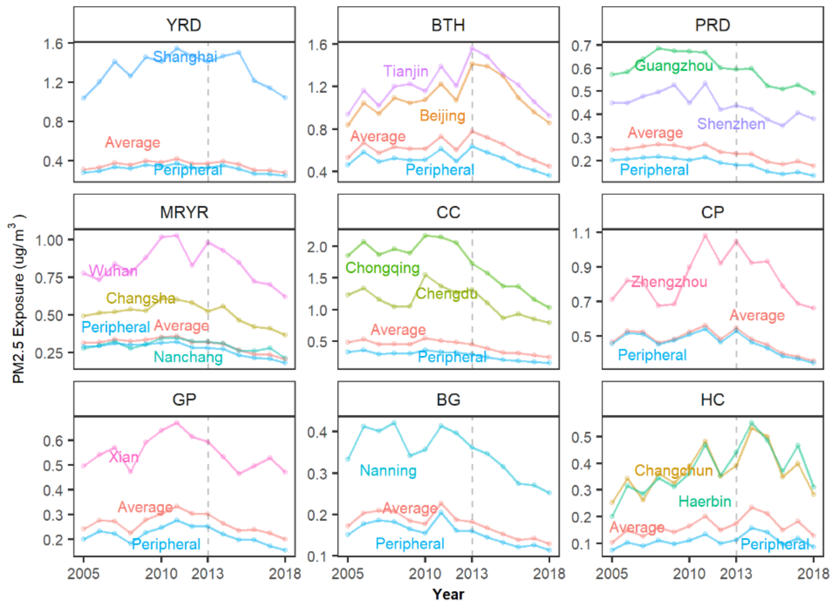
$$C^e = \frac{1}{k_j}\Delta\bar{P}_{jT-j0}^{e} = \frac{1}{k_j}\sum_{i=1}^{k_j}\Delta\bar{P}_{iT-i0}^{e} = \frac{1}{k_j}\left(\sum_{i=1}^{k_j}\Delta\bar{P}_{iT-u}^{e} - \sum_{i=1}^{k_j}\Delta\bar{P}_{iT-u}^{e}\right) \ e = \{PA, PD, CE, PY, EI\} \tag{9}$$

The spatial-temporal LMDI allows flexible and direct comparison among cities, urban agglomerations and time periods.

Results

Figure 1 shows the trends of haze exposure of the nine urban agglomerations and the central the peripheral cities on average. It is obvious that no matter in UA, central cities or peripheral cities, the haze exposure went up over the first several years, and then dropped significantly, with inflection point around 2013. Specifically, the averaged haze exposure of the nine UA increased by 17% during 2005 and 2013, and then drop by 35% in the following five years.

Besides, central cities have a higher level of haze exposure than peripheral cities thoughout the sample period. The average haze exposure in central cities increased by 26% from 2005 to 2013, while that in peripheral cities only increased by 11%. However, it decreased by more than 30% in both kinds of cities from 2013 to 2018, implying that they both made great efforts to lower the haze pollution.



Names of China's City Clusters:

YRD: Yangtze River Delta
BTH: Beijing-Tianjin-Hebei
PRD: Pearl River Delta
MRYD: Middle Reaches of the Yangtze River
CC: Chengdu-Chongqing
CP: Central Plains
BP: Guanzhong plain
BG: Beibu Gulf
HC: Harbin-Changchun

Figure 1 The Trends of Haze Exposure in China's Urban agglomerations

Figure 2 shows the contribution of factors releated to urbanization and haze pollution control on haze exposure in the nine urban agglomerations. Before 2013, the contributions of emission intensity are positive in some urban agglomerations but negative in the rest, and the negative contributions are smaller than that of population density. However, after 2013, emission intensity became the primary negative contributor in the top eight urban agglomerations, suggesting that the haze pollution control policy was carried out well in most urban agglomerations, and help a lot to decrease haze exposure.

The contributions of population agglomeration are the smallest but noteworthy. Before 2013, they are only positive in the top three UAs, and negative in the rest. But after 2013, they became negative in YRD and BTH while positive in some other UAs. It means that the population urbanization is becoming greener in YRD and BTH, while in some other UAs, population inflow may brought some pressure to the air quality.

The total contributions of economic growth and city expansion has decreased in some UAs, especially in YRD, PRD and BG, which means that economic urbanization and land urbanization have been getting less dirty for sky in these urban agglomerations.

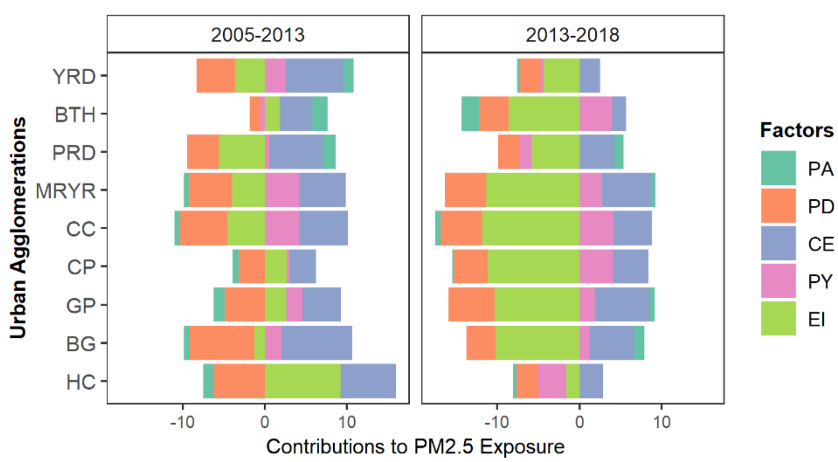


Figure 2 Contribution of factors on haze exposure in China's Urban agglomerations

Figure 3 compares the contribution of factors on haze exposure between central cities and peripheral cities. Before 2013, in plot (a), population agglomeration increases in central cities and bring an increase in haze exposure, but after 2013, the red dots move down to x-axis, showing that the increase in population agglomeration no longer increases haze exposure, and even helps to decrease haze exposure in some cities such as Tianjin, Chongqing, Wuhan and Chengdu, which implies the green population urbanization in central cities, and reflects the scale effect and agglomeration effect. While in YRD, MRYR & CC, and Regional urban agglomerations, some blue dots move up to y-axis, showing that the population agglomeration in some peripheral cities greatly increases the haze exposure, which means that in this cities, population inflow brought pressure to the air quality and increased the risk of haze exposure.

Before 2013, in plot (c) and (d), most cities are above the x-axis, showing that economic and land urbanization brought haze pollution in both central cities and peripheral cities. While after 2013, the red dots move down to x-axis in both plots, showing that the contributions of economic growth and city expansion are around zero. In other words, the economic and land urbanization in central cities no longer pollutes the sky. But the positive relations between haze exposure as well as city expansion are still hold in peripheral cities, showing that economic and land urbanization still bring haze pollution.

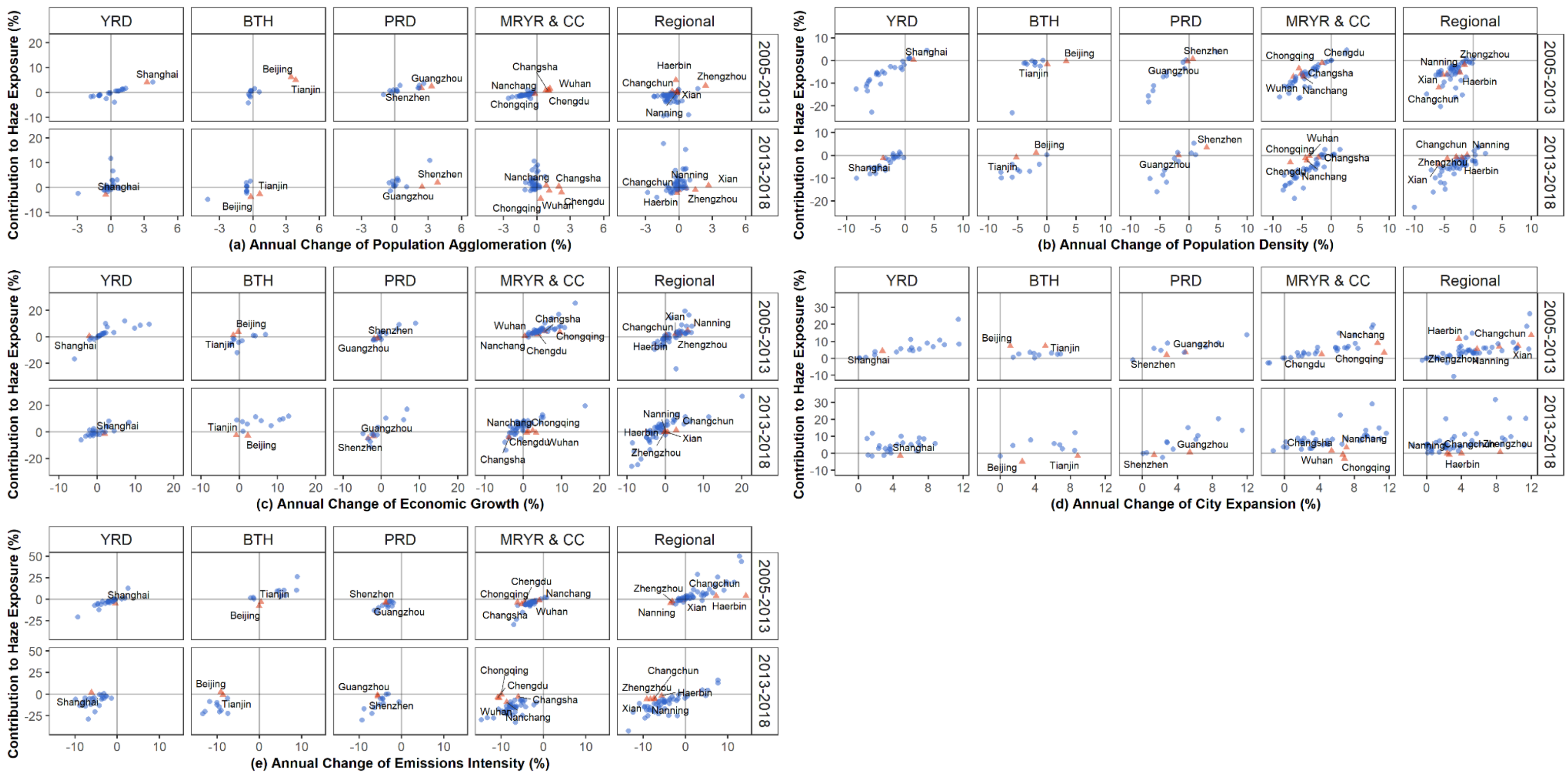


Figure 3 Contribution of factors on haze exposure in central cities and peripheral cities

In plot (e), it is obvious that after 2013, peripheral cities move down sharply, implying that emission intensity help a lot to reduce haze exposure, and showing the efficiency of haze pollution abatement in peripheral cities. While in central cities, although the emission intensity declined, its contribution are nearly zero, implying that haze pollution control in central cities is getting more difficult. This result shows that after the APPCAP policy, the haze pollution abatement in peripheral cities relieved the haze pollution control pressure of central cities, and effectively reduced the regional haze pollution. The regional collaboration mechanism can help to improve the air quality of urban agglomerations.

Conclusions

First, after the APPCAP, the haze exposures of urban agglomerations were lower than before, which justified the effectiveness of the policy. Emission intensity became the most important factor in alleviating the haze pollution, and the contributions of economic growth and city expansion to haze pollution were decreasing.

Second, population urbanization in central cities is becoming environmental-friendly, while population inflow brought some pressure to the air quility in peripheral cities; the adverse effects of economic growth and city expansion on air quality declined to nearly zero in central cities but still maintained in peripheral cities, implying that the economic and land urbanizations is getting cleaner in cenreal cities but still damage to air quility in peripheral cities.

Third, APPCAP encouraged the peripheral cities to strengthen haze pollution control enforcement, which relieved the pressure of central cities to control the haze pollution, and promoted the air quality of the whole urban agglomerations. It emphasize the important role of regional collaboration mechanism in achieving clean air goals of urban agglomerations.

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