Linking risk contribution and risk bearing: an input-output and big-data assessment of air pollution health-risk inequity in China

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Author: Ruoqi Li
Co-Authors: Miaomiao Liu, Yuli Shan, Jun Bi, Klaus Hubacek

Promoting equity in air pollution health risks is critical not only for advancing environmental health governance in China, but also for designing pollution-control policies that are socially accepted, effective, and resilient. Residents play a dual role in the formation of air pollution health risks: they are contributors to pollution through consumption and bearers of the resulting health burden. This dual role makes the equity of air pollution health risks far more complex than simply asking which groups are more exposed. From an income perspective, differences in consumption capacity, consumption patterns, and living environments often create a mismatch between the health burden borne by different groups and the pollution responsibility associated with their consumption.

Existing studies have approached this issue from the perspectives of pollution contribution, risk bearing, and equity assessment, but three major limitations remain. First, conventional expenditure surveys do not adequately capture households at both ends of the income distribution, especially the richest and poorest groups, creating substantial uncertainty in consumption-based pollution accounting. Second, the lack of high-resolution socioeconomic data leads to serious ecological fallacy in identifying differences in risk bearing across income groups. Third, existing assessments of air-pollution health-risk equity in China still largely rest on an â€œequal risk-bearingâ€• notion of fairness, assuming that all individuals should bear the same level of air-pollution-related health risk, without considering whether risk bearing is commensurate with risk contribution. The core question is therefore whether air pollution health risks are equitably distributed across income groups in China when both risk contribution and risk bearing are considered.

To answer this question, we combine an environmentally extended input-output framework with high-resolution exposure and health-risk assessment, supported by large-scale transaction and social big data. Using automatically recorded China UnionPay transaction data, we construct a refined consumption matrix covering 3,670 population groups and 270 consumption categories across mainland China in 2019. This enables, for the first time, city-level accounting of air pollutant emissions induced by the consumption of different income groups. To identify differences in risk bearing, we integrate 3.01 million housing-price records from Lianjia and 14.94 million restaurant review records from Dianping, and use machine-learning methods to infer the spatial distribution of income groups at 1-km grid resolution. This produces, for the first time, a gridded wealth-distribution dataset covering 367 Chinese cities and 10 income groups, allowing group-specific exposure and health-burden assessment with unprecedented socioeconomic and spatial detail.

Our results reveal pronounced inequalities in both risk contribution and risk bearing across income groups in China. In terms of contribution, emissions are highly concentrated among high-income groups. For SOâ‚‚ and NOx, the top income decile is associated with about 50% of total household-induced emissions, whereas the bottom 50% contributes less than 10%. For PMâ‚‚.â‚… and PMâ‚•â‚€, the top decile still accounts for 27-28% of total emissions. These inequalities are substantially stronger than suggested by previous survey-based studies, which underestimate the contribution of the richest decile by as much as 30%. In terms of risk bearing, the absolute PMâ‚‚.â‚… exposure gap across income deciles reaches 2.3 Î¼g mâ•»Â³. Unlike the pattern commonly observed in Western countries, where lower-income groups tend to experience higher exposure, the highest income decile in China experiences about 6% higher PMâ‚‚.â‚… exposure than the lowest decile.

Considering risk contribution and risk bearing together reveals a pervasive mismatch between who drives pollution and who bears its health burden. In 2019, Chinaâ€™s overall inequity index for air pollution health risks, constructed using a Theil-index-based approach, reached 0.69, around 14 times higher than the estimate derived from the conventional risk-bearing-only perspective. About 65% of total inequity arose from disparities between income groups. The lowest income decile contributed only 3% of household air-pollution-equivalent emissions but bore 10% of the associated health burden, whereas the highest income decile contributed 44% while also bearing only 10% of the health burden. City-level heterogeneity further shows that inequity generally increases with socioeconomic development. These findings suggest that more rational urban planning and risk regulation will be crucial for alleviating air-pollution health-risk inequity and for building pollution-control policies that are not only efficient, but also fairer and more resilient.