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# Economy-pollution nexus model of cities at river basin scale based on multi-agent simulation: A conceptual framework

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ABSTRACT

Rapid urbanization greatly accelerated economic and social development in key river basins of China, but also created numerous environmental problems, from the local to the global scale, including increased air and water pollution and decreased water supply, local climate alteration and increased energy demands, as well as a major reduction in natural vegetation production and carbon storage/sequestration. The correlation analysis between urban economy and pollution transfer among cities in river basins has become one of highlights in current researches. Based on the Netlogo software platform, this paper establishes a correlation model among cities in the same river basin from the point of view of multi-agent simulation. Moreover, it assesses the relationship between urban economic development and pollution transfer from three aspects: network concentration; network size; link intensity. The influence of network concentration and link intensity on the total economic size and pollution transfer of the entire river basin is similar. In parallel, the influence of network size on the two modelled variables shows an opposite trend, demonstrating that network size has a greater impact on the city. By comparing the trend of economic size and pollution transfer with the change of network concentration in the context of different economic transfer thresholds, results demonstrate that, with the increase of network concentration, the influence becomes more pronounced. Appropriate error analysis was used to validate the simulation results. In particular, according to it, the error between 10-time and 20-time steps simulation is less than 10%. Consequently, the simulation results are valid. This paper, deepening the research on the correlation among river basin cities, lays the foundation for further research on the directional transmission of the economy and pollution.

## 1. Introduction

Since its reform and opening up, China has witnessed a great breakthrough in its economy. However, this was followed by a variety of environmental pollution problems, which have become the toughest and the most concerning issues in the context of Chinese urbanization. Urbanization is causing serious disturbances and destruction of the ecological environment in river basins (Xu, 2011). Both environmental and resources-related problems in river basins, which were caused by urbanization, are mainly reflected into water and air pollution, water shortages, over-exploitation of groundwater, as well as local health problems caused by polluted air.

The adverse effects of urbanization on basins water quality has recently become a hot issue. The widely-reported cases of "cancer villages" in the Huaihe River Basin (China), whose distribution declines from East to West, reflecting also economic development and environmental pollution between Eastern and Western China, is one among the possible examples. The Atlas of the Water Environment and Digestive Tumor Cancer Mortality in the Huaihe River Basin, published in year 2013, first confirmed the direct relationship between the high incidence of cancer and water pollution in the Huaihe River Basin. Approximately 60% of cancer villages are found within 3 km from rivers, while 81% are within 5 km from rivers. This demonstrates that rivers' water quality is an important factor on cancer villages (Gong and Zhang, 2013).

The urbanization spatial and socio-economical dynamics are closely related to the emergence of these environmental hotpots. On one hand, as a consequence of the further urban economic development, cities

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cannot meet the needs of their inhabitants via their own development. Thus, cities need to enhance their economic interactions (or trade) with surrounding cities. On the other hand, urban economic activities produce pollution of all types, thus affecting the environment quality and the population health through a variety of media. With the increase of population density and the expansion of space, multiple and transboundary pollution effects occur (this phenomenon called "pollution transfer"), as are already reported in the scientific literature (e.g.: Casazza et al., 2017; Li et al., 2017a; Liu et al., 2017). In particular, many scholars studied pollution transfer caused by economic trade. Several studies focused on the environmental pollution caused by interregional trade. For example, Okadera et al. (2006) calculated the overall virtual water and pollution discharges in the Yangtze River Basin based on a regional input-output model, discussing about the influence of the final consumption by other regions on Yangtze River basin. Li et al. (2013) analyzed the embodied pollution inter-regional transfer in China. In particular, they constructed an evaluation model of the embodied pollution inter-regional transfer and calculated the pollution amount from four typical industrial pollutants on the basis of an input-output table. Their results demonstrated that embodied pollution transfer in China is mainly directed from central and western China (less developed) to the more-developed eastern coastal areas. In fact, the eastern areas shift their burden of pollution discharge to the central and western areas by inter-regional trade. Tan and Chen (2015) calculated the implicit carbon trade between China and the EU, based on the multi-regional input-output model. Their work showed that the total amount of carbon embodied in trade between China and EU is increasing. Gao and Liu (2016) calculated China's carbon emissions with respect to import and export from 38 countries. Moreover, they compared the difference of virtual import emissions and actual import emissions between China and European countries. Meanwhile, Zhang (2016a) targeted the embodied carbon emissions in export trade in Sichuan Province and measured the amount of the embodied carbon emissions by systematic analysis of the export data. He, then, performed a comparative analysis between the results and the amount of national export-embodied carbon emissions. John (2014) analyzed the boundary conditions leading to positive welfare effects. In particular, in the case of trade with an embodied pollution transfer, his results showed that countries' welfare doesn't necessarily increase proportionally with distance from the pollution source location. Instead, it grows in proportion both with the marginal disposition to consume the good and with its characteristics and substitutability, as well as with the pollutant spatial separability. Lee and Roland-Holst (2002) analyzed the trade-induced pollution transfer, studying its implications for Japan's investment and assistance. Dong and Bai (2015) evaluated the influence of environmental regulation on the industrial location choice, as well as the effect of "pollution heaven" in China. Their results showed that this kind of effect is significant. In particular, pollution intensive industries tend to move toward the central and western regions, where the environmental regulations are weaker. Weng et al. (2017) analyzed the driving factors of pollutants emission, based on the data of 285 cities in China from 2004 to 2013. Part of results showed that, with the increase of population density and the expansion of space, a "pollution transfer" occurred among different scales and degrees of economic development. The above-mentioned studies mainly focused on static data and relationship studies. However, the environmental impacts of inter-city economic trade still need to be discussed.

Available studies, coupling urban economy with pollution, mainly related to traditional panel data and Environmental Kuznets Curves (EKCs). More in detail, Tian and Xie (2017) studied the relationship between China's agricultural per capita carbon dioxide emissions per capita and gross national product per capita. This work demonstrated that the relationship between the two is consistent with Kuznets theory. Fan and Ma (2016) calculated the land, carbon and water footprints using an Input-output approach. Then, they integrated the footprints using the Vertical and Horizontal Deviation Maximization Method, analyzing the Environmental Kuznets Curve of the footprints synthesis index, as well as the indicators of footprints family. Wang and Chen (2016) applied a cluster analysis to statistical economic and pollution data for 20 major city clusters in China in 2013. The purpose was to fit the EKCs of all city clusters. They classified the 20 city clusters and quantitatively determined the relevant relationships between economic development and environmental pollution, as well as the turning point of development in each type of cluster. Lu et al. (2017) calculated the relationship among energy, economy and environment (3E) by constructing a coupled model, showing that the economic and environmental comprehensive index for several provinces continuously tended to rise, while, more specifically, energy index has a stable positive trend with little fluctuations. Wang, 2016) analyzed the relationship between the economic growth and pollution load for Beijing, based on the EKCs, from year 1990 to year 2014. Their results showed that the total amount for most of the emissions remains at a high level, while the intensity for most of the pollutants arrived at a turning point around 2006. Mazur et al. (2015) explored the relationship between carbon dioxide and economic growth for European Union countries from 1992 to 2010. Their research didn't confirm empirically the existence of any U-shaped EKC. Almeida et al. (2017) used the modified Composite Index of Environmental Performance (mCIEP) as a measure of environmental damage. GDP per capita was also considered to represent economic growth. Their results confirmed that, at present, the EKC hypothesis is not proved. Moreover, economic growth alone is not enough to improve environmental quality. (Liddle, 2015) tested an inverted-U relationship between GDP per capita and three urban transport-related emissions. In particular, they found that per capita emissions of CO, VHC, and $NO_x$ in relation to urban transport firstly increased and, then, declined, depending on the observed individual income levels. Biswas et al. (2012) based their work on a two-stage game theory model, using the panel data, referred to the years 1999–2005, of more than 100 countries. They studied, in this way, the influence of shadow economy on pollution, as well as the impacts of corruption on such dynamics. Results showed that the relationship between the shadow economy and the levels of pollution are dependent on the levels of corruption. Liu et al. (2015) applied a system dynamics method and built a Beijing urban passenger transport carbon model, this model included different subsystems (economy, population, transport, energy consumption and $CO_2$ emission subsystems) and set different scenarios. A special reason for interest is the use of flow diagrams, which are able to unveil the causal flow connections along processes. Results showed that Administrative rules and regulations management (ARM) had the best overall effect of the individual policies on both energy savings and emission reductions. Similarly, the work by Liu et al. (2017), focused on the quantification of Traffic Atmospheric Environmental Capacity (TAEC) and Total Atmospheric Environmental Carrying Capacity (TAECC), demonstrated the ability of capturing within a model both complexity and interactions within the same mode. Their results, applying this approach, showed that $NO_X$ carrying capacity is a key restraining factor of TAEC. Moreover, the change of TAECC and TAECC's service life under the circumstance of clean vehicle strategy and mobility management strategy was analyzed. Brouwer et al. (2018) introduced the concept of "Nexus", pointing out that, ignoring synergies and trade-offs between energy and natural flows, misleading modeling outcomes can be obtained. Most of current studies mainly focus on the static data and static analysis on the relationship between the economy and pollution. Thus, we are still at the initial period of studying the coupling relationship between urban economy and pollution by constructing a network model being able to provide new perspectives in this field.

Despite the large number of available studies, the use of network models for highlighting the coupling between urban economy and pollution is still limited. In fact, present studies mostly focus on static indicators related to environmental and economic variables, almost ignoring the dynamics behind urban economy and pollution