Development of a Parsimonious Set of City-level Environmental Performance Metrics for Jiyuan, Henan, China

by

Dong Guo & Satyajit Bose

The Earth Institute, Columbia University

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All errors are our own.

Contacts: guodong@columbia.edu (corresponding) and sgb2@columbia.edu

Abstract

The potential tradeoff between the twin goals of reducing environmental impact while maintaining growth will require China's cities to evaluate the economic impact of urban pollution at the local level. Using economic input-output analysis, city level indicators of economic activity and environmental impact and available estimates of the benchmark relationships between output and pollution by sector, we outline a method to quantify in monetary terms the marginal damages of air pollution by sector at the city level. By applying the framework of environmental accounting to the pilot case of Jiyuan, a small city in Henan province, we demonstrate a method for local public agencies to facilitate administrative tracking of monetized air pollution based on underlying economic activity, and outline a minimum set of metrics which a small city in China must track in order to estimate the monetized damage of air pollution by sector. Our methodology leverages economy-wide aggregate models (Ho and Nielsen 2007, The World Bank 2007) to significantly reduce the metrics required for a simple approximation of the relative value added per unit of emission by sector for medium-sized cities in China.

I. Introduction

While the goal of reducing environmental impact has become a high priority objective for China's cities, the central question and potentially competing objective for policymakers and city planners remains economic growth and job creation. For example, the government's 12th Five Year Guideline (2011-2015) aims for hitherto unattained reductions in emissions and resource use per unit of output while attaining GDP growth rate of 7% and increasing urban employment by 45 million.

This potential tradeoff between environmental and growth objectives requires a monetary accounting of the impact of urban pollution at the local level. Pollution should be valued by the economic damage caused, not merely measured in physical units. A monetary accounting facilitates an identification of the highest value-added[1] sectors per unit of pollution or resource use so that planning agencies can target industry-level directives and incentives at a local scale.

Local municipal governments have emerged recently as both laboratories for sustainability policies and as leaders in creating and implementing sustainability action plans. This trend is significant for a variety of reasons, most notably that the global population is increasingly urban and that cities uniquely control important policy levers that many national governments do not. The world's cities consume between 60-80%

[1] The value added of an industry is the market value of output minus the market value of inputs, not including the factors of production—labor, land, and capital.

of energy production worldwide and account for roughly two-thirds of global carbon dioxide emissions (Kamal-Chaoui and Robert 2009). More efficient water and energy use, more cost effective waste management, lower traffic congestion and cleaner air are all needed to make cities more sustainable over the long run.

As providers of many important local services and operators of facilities, cities have a unique ability to take specific measurable action to reduce the use of fossil fuels and to develop more ecologically sound emissions plans, water supply, sewage and solid waste management systems. They have direct control over critical systems like water and wastewater, waste and recycling, public transit, sustainability of service delivery, and building and zoning codes, among others; and cities are able to create localized solutions.

While environmental performance and economic development have been measured at the country-level for decades, cities are beginning to measure their own impacts. Cities are aggregating sustainability metrics at the micro-level, from households to local businesses to municipal operations, and incorporating those measures into strategic policymaking at local levels. Adopting sustainability practices is central to urban vitality and to making cities desirable places both for businesses and residents. Cities are turning to sustainable solutions that will attract residents, stimulate economic growth, and encourage more lifestyles based on renewable resources. Cities throughout China have begun to integrate environmental protection and economic development in order to build urban sustainability.

Therefore, our research objective is to apply the framework of environmental accounting for pollution to a pilot case, that of Jiyuan, a small Chinese city, by quantifying the marginal damages of air pollution emissions by industry and to compute gross damages by multiplying marginal damages by emissions data. We use the marginal damage framework within an economic input-output analysis to attempt to answer the following question: what sectors in Jiyuan have the highest ratio of Yuan-denominated air pollution damages to value added? Our research will allow us to identify the minimum set of metrics that a small city in China must track in order to estimate the monetized damage of air pollution by sector. This research will eventually allow city-level environmental agencies to develop simplified local environmental accounting systems which facilitate economic cost-benefit analyses and scenario analyses of changes in economic activity, industry structure and local pollution.

The remainder of this paper is organized as follows: Section II outlines the reasons for choosing Jiyuan as our target city, and its economic and sustainability background. Section III briefly reviews the literature relating to environmental accounting and its progress made in China. Section IV outlines the calibration methodology adopted to estimate marginal damages of pollution emissions at the city level, while Section V illustrates the computation of a damage estimate for the emission of PM10 and SO_2 by all sectors recorded in Jiyuan. Finally, Section VI summarizes the main findings from this research, and discusses its applicability to other cities in China.

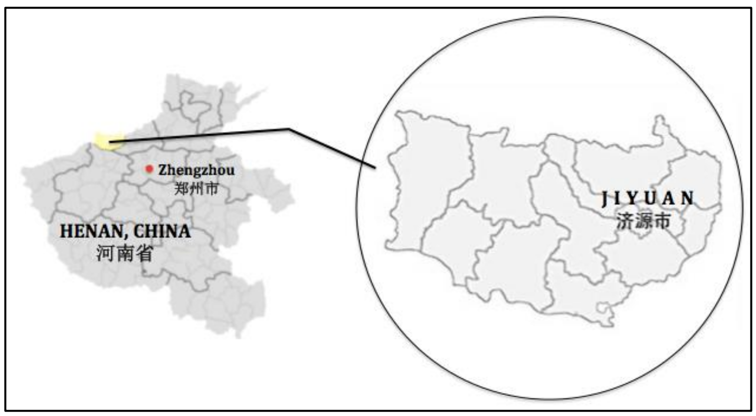
II. Background on Jiyuan

We selected Jiyuan for its dependence on primary and secondary industries, its location in a populous and underdeveloped province, its designation as a Sustainable Development Experimental Zone, the manageable size of the city and due to the willingness of city officials to provide data and cooperation.

Jiyuan is a prefecture level city with a population of approximately 700,000, and an urbanization rate of 51.44% in 2011 (China National Bereau of Statistics 2010). Jiyuan is a resource-based city, with a GDP of 43 billion Yuan, and an annual growth rate of 13% in 2012. (Jiyuan Bureau of Science and Technology 2013) Jiyuan will be a large mid-sized city by 2020. Jiyuan produces more than 20% of China's lead, and is a major source for zinc and other minerals; with zinc, lead and steel industries generating annual revenue in excess of 10 billion Yuan (Jiyuan Municipal Government 2013).

According to a recent study conducted by Accenture and the Chinese Academy of Sciences (Lacy, Ding et al. 2013), the most economically developed cities show more serious imbalances between economic growth, available resources and the state of the environment. In addition, Chinese cities classified as "resource-based cities"[2] show the most unbalanced development. The study argues that China's mid-sized cities, those with 1 to 3 million people should be the primary sites for future urbanization and represent the potential to achieve a balance between GDP growth and environmental quality.

Figure 1 Map of Jiyuan City, China

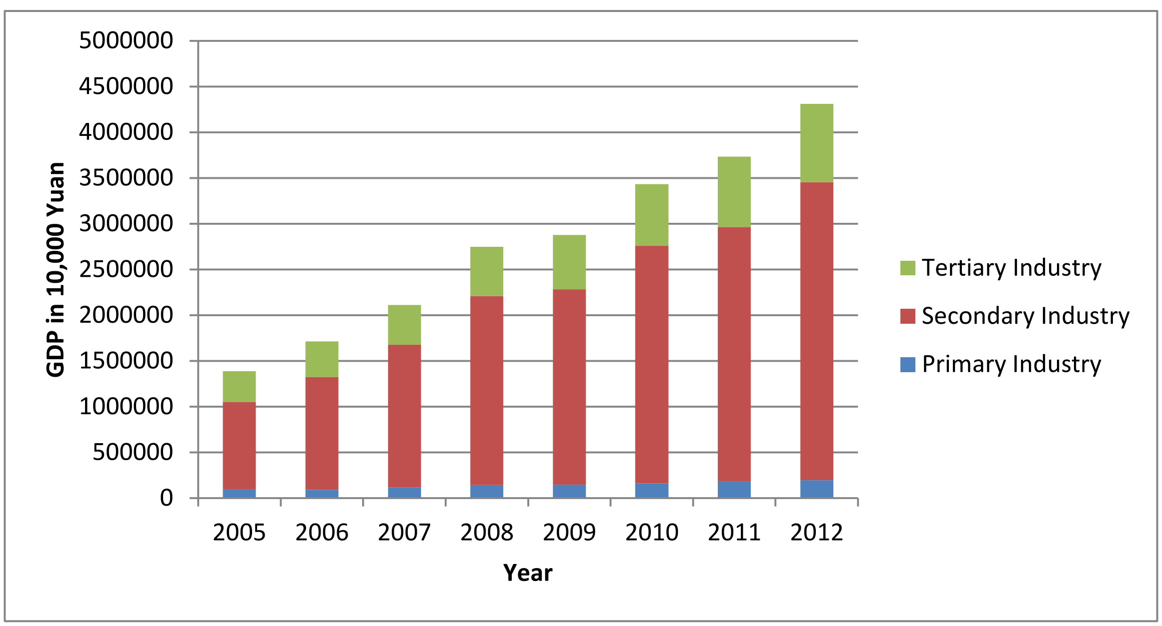


Jiyuan is located in Henan Province, China's 2nd most populous province, which ranks at the bottom among 30 provinces in a green development index system prepared by researchers at Beijing Normal University and the National Bureau of Statistics of China[3]. Although Jiyuan has a per-capita GDP of 64,811 Yuan that ranks first in Henan province (Jiyuan Municipal Government 2013), it still suffers from

[2] "Resource-based cities" are defined as those that depend on non-renewable resources for economic growth.
[3] See page 18 in Li, X. and J. Pan, Eds. (2013). China Green Development Index Report 2011. Current Chinese Economic Report Series. New York and Heidelberg, Springer.

challenges of sustainable development comparable to other small and medium sized cities in north and central China. Such challenges include unbalanced urban development with numerous rural villages in the middle of urban centers that lag in housing quality and living standards and an unsustainable industry structure, where extractive and manufacturing industries comprise approximately 70% of economic output.[4] Figure 2 below demonstrates that the secondary industry has been growing and is by far the most dominant industry in Jiyuan. In addition, simple calculation shows that the secondary industry as a proportion of the total economy is also increasing, while the share of the tertiary industry is declining, which further illustrates an unbalanced growth path for Jiyuan.

Figure 2 GDP by Industry Sector in Jiyuan City, China (2005-2012)



Source: Jiyuan Bureau of Statistics (2013)

[4] See Hao, H. (2011). "Jiyuan Urban Sustainable Development SWOT Analysis." Science, Technology and Industry (in Chinese) **11**(4).

In addition to the rapid economic growth Jiyuan has experienced, the city has been designated as a Sustainable Development Experimental Zone in Henan in 2008, a province first at the prefecture level.[5] In 2011, Jiyuan was upgraded to a National Sustainable Development Experimental Zone. National Sustainable Development Experimental Zones were established in 1986, and aimed at promoting local sustainable development through demonstration and piloting. This initiative was intended to build local sustainability capacity and explore different mechanisms and models for sustainable development, adapted to the varied socioeconomic contexts and resource levels of the regions. By March 2014, there were 160 National Sustainable Development Experimental Zones established at the city, district, county, and village level, with considerable variation in theme and approach to sustainable development.

For example, Jiyuan, a small-to-medium city aims to champion rural-urban integration policies to achieve sustainable development, and set an example for cities in central China. As outlined in the Jiyuan National Sustainable Development Experimental Zone Master Plan (2010-2015)[6], the city plans to promote sustainable integration of urban rural areas within the city, structural adjustment and industrial restructuring, urbanization, eco-construction projects, and environmental protection to

[5] In April 2013, the City of Hebi is approved as the second prefecture-level National Sustainable Development Experimental Zone in Henan.
[6] See Sustainable Development Experimental Zone Working Committee Jiyuan. (2010). Jiyuan National Sustainable Development Experimental Zone Master Plan 2010-2015 (in Chinese).

achieve balanced growth based on a range of economic, social, political, cultural, and ecological considerations.[7]

The National Sustainable Development Experimental Zone recommends a list of more than 60 metrics encompassing all areas of sustainability that the approved government must track and report. The city of Jiyuan consequently has been compiling an interagency portfolio of 30 recommended metrics, as well as other indicators specific to Jiyuan's development. These encompass population growth, ecology, natural resource consumption, emissions and waste, the economy, society, and science and education.[8] Many of these indicators are collected and published by the statistics bureau of all Chinese cities. Although they can help track the sustainability progress of the city, they are not sufficient for the development of an environmental accounting framework as outlined here.

In addition to indicators of production and employment published at the sector level by the statistics bureaus in the statistical yearbooks, local statistics bureaus in coordination with energy administrations and environmental protection bureaus regularly publish energy use statistics, and emission and waste data by industry sector

[7] See Sustainable Development Experimental Zone Working Committee Jiyuan. Constructing National Sustainable Development Zone: Establish Prosperous and Harmonized New Jiyuan (in Chinese).
[8] See Jiyuan Bureau of Science and Technology (2013). Jiyuan--National Sustainable Development Experimental Zone 32 Metrics Performance Review (2010-2013) (in Chinese).

in the Statistical Yearbook on the Environment and the Statistical Yearbook on Energy.[9] The environmental accounting system proposed in this study can leverage these interagency data sets available for Jiyuan to facilitate construction of a balance sheet and integrated flows statement which tracks resource use and environmental impact.

The accounting system has the potential to describe the pollution impact of land use changes, fuel use and greenhouse gas emissions generated by existing and proposed residential, commercial and industrial zones or forms of transportation. The accounting framework has the capacity to clarify and specify the interactions among the numerous sustainability and economic development metrics which are being gathered.

By incorporating marginal damage estimates, the accounting system incorporates full cost accounting, that is, the monetization of pollution impacts. The framework would allow estimation of the impacts that changes in policies ranging from land use change, green building directives and transportation choices would have on urban sustainability. Our admittedly ambitious research agenda is to construct a balance sheet and flows statement and related marginal damage estimates for Jiyuan that tracks energy conservation, waste management, carbon footprint, water neutrality, landscaping and biodiversity among others. We expect that our methodology can be

[9] Data on CO_2 emission is not published, and is usually calculated based on available data on energy use in China.

easily replicated to other medium sized cities and special economic development zones which track economic and environmental data at the sectoral level.

III. Literature Review

A longstanding issue in environmental economics has been the development of integrated accounting systems for resource use and pollution externalities. As with other forms of capital, natural resource assets are limited and require measurement, budgeting and efficient allocation so as to maximize the economic growth generated per unit of resource use. There exists a large body of literature on environmental accounting at the national level[10], which can be broadly organized into four components: accounting for the monetary or physical flows of material related to the environment, accounting for environmental protection expenditures; accounting for natural resource assets; and construction of environmental-adjusted macro-level indicators.[11]

Early work on environmental accounting in the 1970s has focused on building accounts to account for the use of environmental resources, such as forests, fisheries, energy, and land. This work is dominated by materials flow analysis to calculate the

[10] There are other types of environmental accounting, for example environmental financial accounting and environmental management accounting at the company level, which are not focuses of this paper.
[11] Some studies classify environmental protection and pollution abatement expenditures as part of monetary and physical flow of material. See Hecht, J. E. (2007). "National Environmental Accounting: A Practical Introduction." International Review of Environmental and Resource Economics **1**(1): 3-66.

physical flows of resources and pollution per unit of output without attempting to price related externalities (Ayres and Kneese 1969). European countries that were the first adopters of environmental accounts then started to devise accounts for air pollutant emissions, which are closely tied to energy accounts in the 1980s.

The interconnections between sectors within an economy imply that the full repercussions of industry level changes in emissions must be computed taking into account the input-output structure of the economy (Leontief 1970). Therefore in the 1990s, the United Nations Environment Program (UNEP) and the World Bank tried to integrate environmental accounts into the System of National Accounts (SNA), which culminated in the System of Economic-Environmental Accounting (SEEA) that embodied the four major components of environmental accounting. This dominant standard in environmental accounting was then revised and updated in 2003. (United Nations 2003) In order to gain international agreement, in 2013, the Statistical Commission of the United Nations adopted a "central framework" of SEEA as an international standard, which includes only the least controversial elements of the framework.[12]

[12] For a detailed evolution of SEEA and comparison of its different versions, see Bartelmus, P. (2013). "Environmental–Economic Accounting: Progress and Digression in the SEEA Revisions." Review of Income and Wealth.

There are three ways in which SEEA values the depletion and degradation of natural resources: market price, maintenance costs[13], and contingent (damage) valuation. (United Nations 1993) Depletion and degradation of "marketed" resources is captured by SEEA and can be converted by the market price approach, while non-marketed natural assets, such as air is not included in the SEEA. (Hecht 2007)

Maintenance costs or costs of abatement can be used as an effective way to value pollution, especially when we assume regulations are efficient (Muller, Mendelsohn et al. 2011). Some countries such as Korea tried to implement much of "SEEA 1993" and estimate abatement costs for several emissions (Kim 1998). However, maintenance costs in the 1993 framework were hypothetical, calculated after the deterioration had occurred, and did not account for the structural adjustment in the market that would ineluctably follow had the maintenance cost been incurred. Furthermore, the assumption that all regulations are efficient is open to broad critique. Perhaps consequently, maintenance costs valuation was dropped in subsequent SEEA revisions.

In economic analysis, pollution is valued either by marginal abatement costs or marginal damages (Nordhaus and Tobin 1972), where the two would be identical if regulation were perfectly efficient in the absence of information asymmetries. As

[13] Maintenance cost is defined as "costs that are required to prevent or mitigate a deterioration of the natural environment". See United Nations (1993). Handbook of National Accounting: Integrated Environmental and Economic Accounting. Studies in Methods. New York, United Nations.

pointed out by Muller et al. (2011), damage valuation of environmental impacts on health and human well-being is necessary to implement efficient, welfare-based based pollution control policies. Damage valuation is based on measuring the willingness-to-pay for damage reductions or willingness-to-accept compensation for increases in damage, which may vary significantly across location, income-level and underlying preference. Since the willingness-to-pay measure is generally not consistent with SNA's measurement based on price due to the ubiquity of externalities and other market imperfections, damage valuation is effectively omitted from SEEA as a result. Hence, the SEEA captures only a small fraction of the full costs of damage of environmental depletion and degradation imposed by economic activities. (Hecht 2007)

In China, systematic studies on environmental accounting started in the 1990s (Ding et al. 2014), and culminated in the publication of Green GDP in 2006[14]. Apart from the extensive research on environmental accounting in China, there is a large body of literature that specifically investigates the monetization of environmental damages in different regions in China, such as Wang and Mullahy (2006), Huang et al. (2012), Matus et al. (2012), and Zhang et al. (2010).

The standard approach to valuing mortality risks in the US and Europe employs the concept of "value of a statistical life", which is defined as the implied measure of the

[14] See Ministry of Environmental Protection of China and National Bureau of Statistics of China (2006). China Green National Accounting Study Report 2004.

value of a life computed from an individual's willingness to pay to reduce the risk of premature death. The majority of the earlier Chinese studies, such as Yu, Guo et al. (2007) adopted the adjusted human capital method as an alternative to the "value of a statistical life" approach[15]. Estimates with the adjusted human capital method, which is the official and the most widely used approach in China in valuing the cost of pollution, is often used to place a lower bound on value of a statistical life. (The World Bank 2007) Other studies, especially more recent ones starting with (Wang and Mullahy 2006)[16] utilized value of a statistical life based on mean estimates of willingness-to-pay in certain Chinese regions to value mortality risks due to environmental pollution.

IV. Calibration Methodology

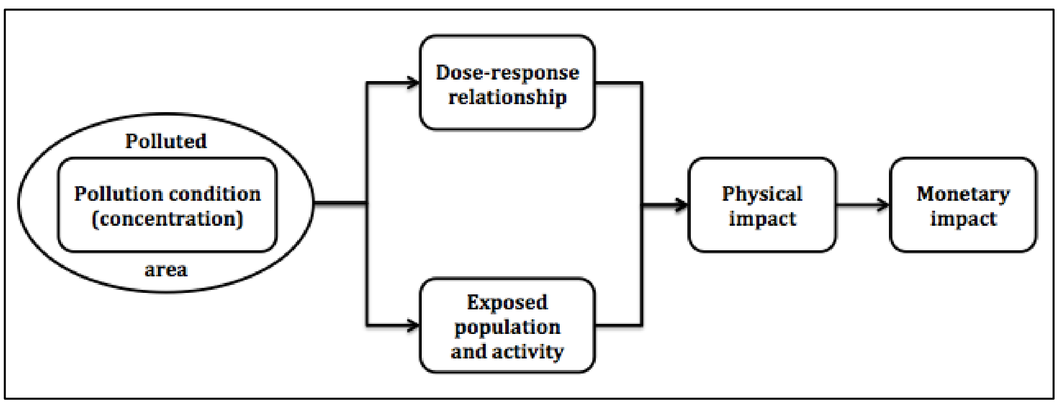
An integrated assessment model of the economic costs and benefits of pollution control at the national level has been developed by a joint Harvard-Tsinghua research team (Ho and Nielsen 2007, Jing, Ho et al. 2009). This model provides national level benchmarks for energy and emissions intensity and damage estimates by industry for human health impacts. Additional estimates of the monetary damage of pollution for health and non-health impacts (crop loss, material damage and fisheries

[15] The adjusted human capital method measures the productivity loss or foregone earnings associated with premature mortality.

[16] See also Hammitt, J. and Y. Zhou (2006). "The Economic Value of Air-Pollution-Related Health Risks in China: A Contingent Valuation Study." Environmental and Resource Economics **33**(3): 399-423., and Krupnick, A., S. Hoffmann, B. Larsen, X. Peng, R. Tao, C. Yan and M. McWilliams (2006). "The willingness to pay for mortality risk reductions in Shanghai and Chongqing, China." Resources for the Future, The World Bank: Washington, DC.

loss) are available from a joint World Bank and Ministry of Environmental Protection study (The World Bank 2007). We use the empirical estimates of marginal damage or shadow prices and the overall methodology employed by these studies wherever applicable. As outlined in Figure 3, the overall approach is to compute emissions as a function of economic activity, determine the impact of emissions on pollution concentrations in the affected area, compute the physical impact on the exposed population via estimated dose-response relationships, and convert the physical impact into monetary estimates by employing VSL or willingness-to-pay measures.

Figure 3 Pollution Impact Measurement Process



Source: The World Bank (2007)

We begin with the data expected to be available from Jiyuan. Jiyuan, as is the case for many Chinese cities, publishes output, employment and energy use data by sector. As part of its commitment as a Sustainable Development Experimental Zone, the city is also currently preparing a report for publication that is expected to include emissions of air pollutants by sector. Our aim is to develop an algorithm to estimate the marginal damages of sectoral economic activity using data available for all Chinese cities. In constructing our algorithm, we rely heavily on the steps outlined by Ho and Jorgenson (2007) for computing marginal damage estimates at the national level, while adjusting the algorithm to account for the very different data inputs available at the city scale as well as being cognizant of the analytical and modeling capacity available to the typical city level environmental agency.

For Jiyuan, a major industry and significant contributor to local pollution is the production of nonferrous metals (primarily lead and zinc) whose detailed characteristics are not studied by the Harvard-Tsinghua research team. Ho and Nielsen (2007) perform detailed estimation of the emission characteristics of five major polluting sectors: chemicals, nonmetal mineral products, metals smelting and pressing primarily of iron and steel, electricity generation and transportation. For the nonferrous metals mining and smelting sector, it will be important to use actual sector level emissions data which Jiyuan is expected to release in the future. In the meantime, we use the economy-wide average relationship between output and emissions (of TSP and SO_2) prepared by Ho and Nielsen (2007) from a simpler assessment procedure as a gross estimate.

To convert emissions data into damage estimates, we rely on the intake fraction methodology outlined by (Ho and Nielsen 2007). An intake fraction *(iF)* is a simplified estimate of the amount of a pollutant emitted by a particular source that is eventually inhaled by people before the pollutant is dissipated into the atmosphere. The measure encapsulates the impact of atmospheric transport of the pollutant and the population density and distribution within a given radius around the pollutant source. Formally, the intake fraction *iF* is expressed as

$$iF = \frac{\sum_{i=1}^{n} POP_i \times CONC_i \times BR}{EM}$$

where POP_i is the population at grid cell *i*, $CONC_i$ is the change in the ambient concentration at grid cell *i*, *BR* is an average breathing rate and *EM* is the total emission from the pollutant source.

Ho and Nielsen (2007) compute estimates of the intake fraction for PM10 for the iron and steel sector based on a sample of 187 plants. We use their mean, minimum and maximum estimates for the nonferrous metals sector in Jiyuan as there exists no specific study of intake fractions for this sector. However, as has been demonstrated in previous studies, relatively precise intake fractions can be estimated from *iF* regressions that incorporate the stack height of pollution sources and estimates of population residing within specific distances of the source (Levy and Greco 2007). Ideally we would calibrate the national level intake fractions prepared by Ho and Nielsen (2007) to the local scale by adjusting for actual stack height of key pollution sources as well as population density, proximity and income factors. We expect that this adjustment process will allow us to transform a national cost-benefit analysis of pollution control into a local assessment of marginal costs and benefits of abatement.

We expect to construct a scaled down economic input-output model for Jiyuan that utilizes city-level sectoral emissions data, grafted onto the 33-sector input-output model constructed by Ho and Jorgenson (2007). We provide below an illustrative calculation of the monetary value of mortality damages resulting from estimated emissions of PM10 and SO_2 in Jiyuan using Ho and Jorgenson (2007)'s method. When, industry level emissions data for Jiyuan becomes available, our illustrative calculation can be constructed using actual emission coefficients for Jiyuan (with appropriate mapping or interpolation) to construct relatively accurate estimates of value-added per unit of emission.

V. Illustrative Result

Here we illustrate the computation of a damage estimate for the emission of PM10 and SO_2 by all sectors recorded in Jiyuan.

Jiyuan's 2012 GDP in the manufacturing sector is 30.7 billion yuan, comprising 71% of city GDP. This sector comprises coal mining and processing, metal ore mining and nonferrous mineral mining (including lead and zinc). We have assumed initially that emissions coefficients for the Jiyuan manufacturing sector is a simple average of these 3 sectors from among the 33 sectors in the Ho and Jorgenson (2007) study. Table 1 lists sectoral GDP, sector composition using Ho and Jorgenson (2007) sectors and emissions factors used.

Table 1
Jiyuan Sectoral GDP and Assumed Emission Factors

Jiyuan Sector	2012 GDP (10,000 Yuan)	Assumed Ho-Jorgenson Sector		Emissions Factors (kilotons per bn Yuan)	
				TSP	SO2
Primary Industry	195,477	1	Agriculture	0.0648	0.1487
Secondary Industry	3,258,449				
Manufacturing	3,079,285	2, 5, 6	Coal mining & processing, Metal Ore Mining & Nonferrous	0.6984	0.5195
Construction	179,164	25	Construction	0.0696	0.2381
Tertiary Industry	854,717				
Transportation, storage and communication	137,375	26, 27	Transport, warehousing & posts & telecommunications	0.5139	0.8754
Commerce and restaurants	301,132	28	Commerce and restaurants	0.0835	0.1933
Finance and Insurance	30,972	29	Finance and insurance	0.0362	0.0779
Real Estate	83,577	30	Real estate	0.3881	0.6685
Others	301,661	31, 32, 33	Social services, health, education, public	0.4501	0.8227
TOTAL	4,308,643				

These emission factors allow us to construct estimated emissions by sector for Jiyuan. We note that in practice, the actual emissions in Jiyuan are likely to differ quite significantly from these illustrative estimates for a number of reasons. In particular, the emissions factors from Ho and Jorgenson (2007) embed an inter-sectoral structure based on China's economy in 1997. Obviously, China's intersectoral variation in emission intensity of GDP has changed quite significantly in the last 16 years. Hence, current sector-level emission data is a *sine qua non* of any local environmental accounting system.

To illustrate the method we continue using estimated emissions from the Ho and Jorgenson (2007) emission factors. We note that as expected, the emission factors show that the manufacturing sector is significantly more emissions intensive than others, followed by transportation and real estate. Using the intake fractions prepared for the appropriate sectors by Ho and Jorgenson (2007), we are able to compute emission doses and associated health impacts. We replicate the method outlined in section 9.4 of Ho and Jorgenson (2007) to produce estimates of Jiyuan's contribution to nationwide excess mortality cases measured in the number of statistical lives.

Table 2
Illustrative Calculation of Estimated Contribution to Nationwide Excess Mortality Cases in Statistical Lives from Jiyuan Economic Activity

Sector	Intake Fractions (Ho-Jorgenson)			Estimated Contribution (number of statistical lives)		
	TSP	SO2	Secondary PM	PM10	SO2	Total
Primary Industry	1.54E-06	3.32E-07	4.40E-06	0	0	0
Secondary Industry						
Manufacturing	1.05E-05	1.66E-05	4.40E-06	19	26	45
Construction	5.79E-05	1.66E-05	4.40E-06	1	1	1
Tertiary Industry						
Transportation, storage and communication	5.74E-05	1.66E-05	4.40E-06	3	2	5
Commerce and restaurants	5.49E-05	1.66E-05	4.40E-06	1	1	2
Finance and Insurance	3.86E-05	1.66E-05	4.40E-06	0	0	0
Real Estate	3.86E-05	1.66E-05	4.40E-06	1	1	2
Others	3.86E-05	1.66E-05	4.40E-06	4	4	8
Total				28	34	62

This illustrative calculation suggests that PM10 and SO_2 emissions from all of Jiyuan's economic activity contributes approximately 62 statistical lives to China's total tally of excess mortality cases computed by Ho and Jorgenson (2007) of approximately 94,000 cases. This represents an approximately 0.07% contribution. Applying Ho and Jorgenson (2007)'s VSL of 370,000 Yuan (in 1997 Yuan), the 62 statistical lives translate into approximately 23 million 1997 Yuan or approximately 37 million Yuan today, which amounts to 0.1% of Jiyuan's GDP. This calculation excludes all other damages from PM10 and SO_2 emissions such as restricted activity days, chronic bronchitis, emergency room visits and other impacts which can be valued using the Ho and Jorgenson (2007) framework as well as impacts on crops and related non-human impacts examined in the World Bank study. We expect that using actual emissions data by sector, we will be able to compute a full cost estimate of the impact of SO_2 and PM10 emissions.

This methodology can be improved significantly at relatively low cost by incorporating stack height and population density estimates for the largest pollution sources near the city. These additional variables have the potential to improve the accuracy of the intake fractions to within 15% of the estimates from detailed *in situ* measurements.

VI. Conclusion and Discussion

In their working report dated July 12th, 2013, the Jiyuan government outlines three key dilemmas relating to their work on environmental protection[17].

1. The contradiction between limited environmental (carrying) capacity and economic development. The city has very limited land mass but a large population, so the environmental damage due to continued economic growth that consumes the environment, per unit of land mass is comparably high.
2. The contradiction between old industry structure and energy-saving/emission reduction requirements. The city still relies heavily on resource-dependent heavy chemical industries for economic growth, a structure hard to change in the short term.
3. Despite marked improvement, the environmental quality is still not in line with people's expectation.

A local environmental accounting system has the potential to influence a shift in local land use and transportation policy by making both inputs and outputs more transparent. The system would elucidate the predicted impact of land use or infrastructural changes on monetary damage estimates. The integrated 'what if' scenario analysis facilitated by the accounting system allows policymakers to find ways

[17] See Department of Environmental Protection Jiyuan. Jiyuan Ecology and Environmental Protection Working Report (in Chinese).

to reduce city-level resource use and pollution while meeting economic growth and employment goals through changes in land use and targeted incentives to specific industries. The system would provide the potential to adapt Jiyuan's policy very precisely to the objective of reducing resource use per unit of growth.

Given data limitation, specifically the lack of emission data by sector, this study at the present stage is not able to calculate accurate damage levels for the full spectrum of 33 industrial sectors for Jiyuan. However when sectoral emission data becomes available, we expect to continue this analysis at the local level, and produce a more nuanced ranking of secondary industry sectors, which can be compared with like peer groups nearby. In addition, the lack of emission data prohibits estimates for damages other than to health, which could be significant contributors for full pollution impact. More importantly, this study utilizes emission factors from Ho and Jorgenson (2007) based on the structure of the national economy in 1997, which could differ significantly to Jiyuan's actual emission level. Hence, current sector-level emission data is absolutely necessary for any local environmental accounting system.

However, our outlined methodology has demonstrated its capacity in leveraging economy-wide aggregate models (Ho and Nielsen 2007, The World Bank 2007) to significantly reduce the metrics required for a simple approximation of the relative value added per unit of emission by sector for medium-sized cities or district in China.

The method relies on sector-level emissions of TSP and SO_2, data which is expected to be available for many Chinese cities in the near future.

In the United States, the least value-added industries have been identified to be solid waste combustion, sewage treatment, stone quarrying, marinas, and oil and coal-fired power plants. It is our preliminary expectation that with an environmental accounting method of sectors in Jiyuan or any other city and district in China will reveal the lowest value-added industries among both extractive and manufacturing sectors, given detailed emission data. It is also desirable for municipal governments to start collecting information on stack height of key pollution sources as well as population density at sub-municipal scales, proximity information in order to improve the accuracy of intake fraction calculations, which will lead to more precise estimates of emission damages.

It is therefore the hope of this research that the framework outlined in this paper will allow city-level environmental agencies to develop simplified local environmental accounting systems which facilitate economic cost-benefit analyses and scenario analyses of changes in economic activity, industry structure and local pollution. Such accounting systems are critical components of urban sustainability plans globally and in China.

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