Journal of Economic Perspectives—Volume 31, Number 1—Winter 2017—Pages 71–92

A New Era of Pollution Progress in Urban China?

Siqi Zheng and Matthew E. Kahn

China's rapid and sustained growth since the start of its economic reforms in the late 1970s is an economic miracle, but it has also brought environmental costs in the form of air and water pollution. For example, air pollution from particulates is conventionally measured as PM_{10} or $PM_{2.5}$, which refers to particles with an aerodynamic diameter less than either 10 or 2.5 microns (commonly abbreviated as μm). In 2013, 99.6 percent of China's population was exposed to $PM_{2.5}$ air pollution levels exceeding the guidelines of the World Health Organization (Brauer et al. 2015). The Asian Development Bank reports that fewer than 1 percent of the 500 cities in China meet the air quality standards recommended by the World Health Organization, while seven of China's cities are ranked among the top ten most polluted cities in the world (Zhang and Crooks 2012).

Even at the beginning of China's economic reform in the 1980s, Chinese cities already suffered from black smoke from heavy industry and high levels of coal-burning by power plants and winter heating units. This activity created extremely high levels of acid rain pollution in southern cities (He, Huo, and Zhang 2002). But the pollution challenge grew worse after the 1980s as Premier Deng Xiaoping launched a new economic development strategy. China's air pollution problems

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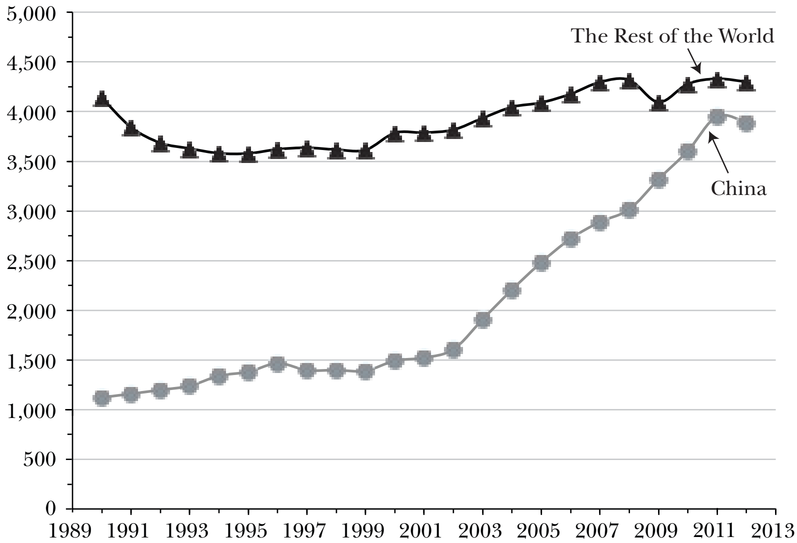
† For supplementary materials such as appendices, datasets, and author disclosure statements, see the article page at
https://doi.org/10.1257/jep.31.1.71 doi=10.1257/jep.31.1.71

Figure 1
Coal Consumption in China and the Rest of the World
(million short tons)



Source: US Energy Information Administration, https://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=1&pid=1&aid=2.

had become acute by the 21st century, when consumption of coal took off. As one vivid example of the linkage from economic growth to air pollution, China's annual consumption of coal increased from less than 700 million to almost 4 billion tons between 1980 and 2012. Figure 1 shows that in the late 1990s, China consumed about one-third as much coal as the rest of the world combined. By 2012, China was consuming almost as much coal as the rest of the world combined. Such coal burning has caused China's aggregate carbon dioxide emissions to soar. China's share of global carbon dioxide emissions has increased from 12.8 percent in 2000 to 23.6 percent in 2012.

China's combination of coal-burning and rapid industrialization has increased a number of pollutants, including sulfur dioxide and nitrogen oxides, but for simplicity we will focus much of our discussion on particulate matter (Guan et. al. 2014; Chen, Ebenstein, Greenstone, and Li 2013). In 2016, 56 percent of China's population lives in cities, and this percentage will grow over time. China's hundreds of cities differ with respect to their environmental quality. For example, Xiamen is a coastal city with relatively clean air, while Beijing has severe fog and haze: the average $PM_{2.5}$ concentrations in these two cities in the 2013–2014 winter were 45 and 108 μg/m^3, respectively. For an international historical perspective, Beijing's ambient total suspended particulates was 118 μg/m^3 in 2011, while Pittsburgh's 1960 concentration for total suspended particulates was 160 μg/m^3 (Davidson 1979).

In this essay, we begin with an overview of the broad institutional background and drivers that led to China's pattern of urban development. We look at the rise in air pollution over recent decades, and the perhaps surprising finding that in many of China's urban areas, PM_{10} levels have been decreasing during the last 10–15 years. We then turn to the costs and tradeoffs of air pollution, including costs to human health, reductions in worker productivity, and how people are seeking to reduce their exposure to pollution as shown by compensating differentials in real estate prices and purchases of masks and air filters. We discuss how rising incomes tend to raise the demand for environmental amenities, and thus increase political pressure for environmental protection, and then we turn to the policy tools that China has used to reduce pollution. We conclude by arguing that as China's government is preparing for an additional 300 million people to move to urban areas over the next 30 years, it will have a number of opportunities for China to reduce pollution through a shift from manufacturing to services, along with various steps to improve energy efficiency and resource conservation. Overall, we will argue that China is on track to improve its environmental performance in the years ahead.

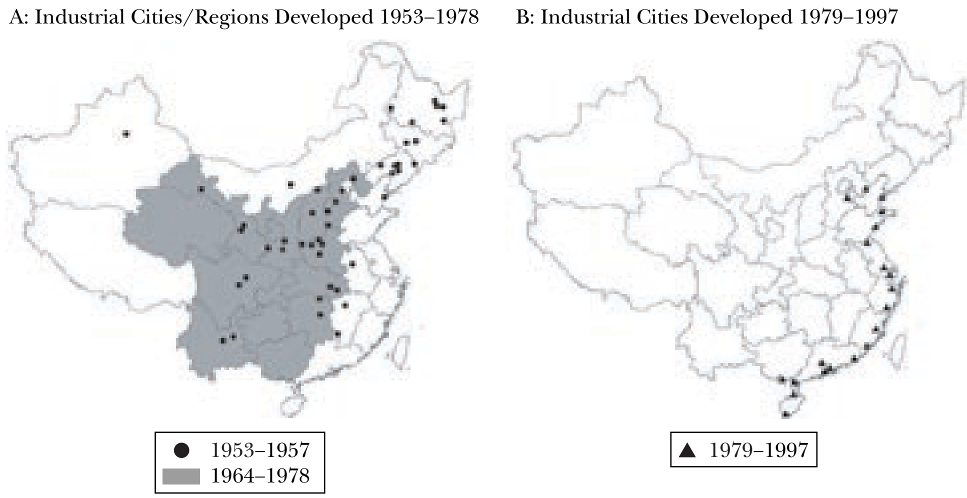
The Rise of China's Highly Polluted Industrial Cities

In the early years of the Chinese Communist Party (CCP), its leaders sought to minimize transportation costs by locating factories for heavy manufacturing industries close to the Soviet Union, China's main trading partner at that time. Environmental protection goals were not prioritized. During the First Five-Year Plan, between 1953 and 1957, 156 national industrial projects were built with the help of the Soviet Union. Those projects were mainly located in the cities in the Northeast Region and the Central Region, shown by black dots in Figure 2A. The Central Region has a large endowment of coal. The Northeast Region had a better pre-existing industrial base, along with infrastructure left over from the Japanese occupation during World War II.

As foreign relations soured between China and the Soviet Union during the late 1950s and into the 1960s, China became concerned about bolstering national defense. Mao initiated the "Third Front" construction movement which included investing in 13 provinces within its core area in the Northwest and Southwest, shown as the shaded area in Figure 2A. More than 1,100 large and medium-sized projects, such as Panzhihua Iron and Steel, and Second Auto Works, were established during the Third Front period (1964–1978). Dozens of cities, such as Mianyang, Deyang, and Panzhihua in Sichuan, Guiyang in Guizhou, and Shiyan in Hubei, emerged as major industrial cities. By deciding to specialize in heavy industry while using coal as the major energy source, China's central planners chose a pollution-intensive growth policy. These initial conditions persist and influence the economic geography of China's pollution today.

Starting in the early 1980s, China transitioned from a centrally planned economy to a market economy. Transportation costs relative to global markets came

Figure 2
The Geography of Industrial Production in China after 1949



Source: Authors using information from Wikipedia.

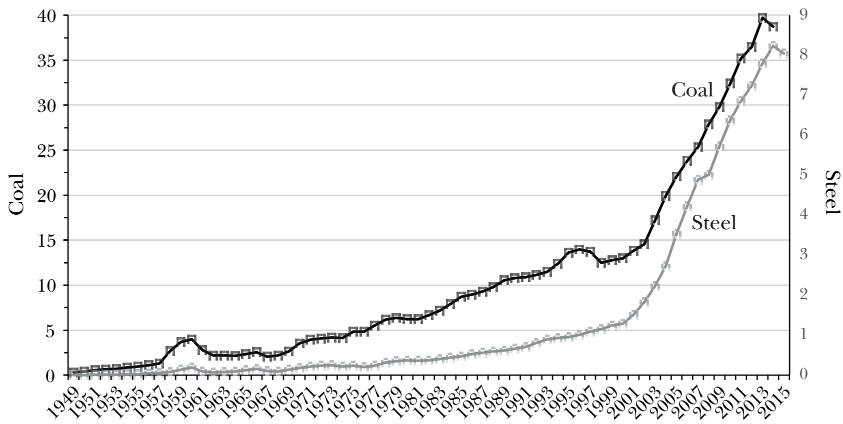
to play an increasingly important role in determining the locational choice for a profit-maximizing firm. China's coastal cities in the Eastern Region feature access to global markets and thus became the most attractive locations for private manufacturing firms (Zheng, Sun, Qi, and Kahn 2014c). The black triangles in Figure 2B represent the "coastal open cities" and "special economic zones" specified by Deng Xiaoping. In the mid-2000s, more than 65 percent of manufacturing employment in above-scale industrial firms (with annual sales above 5 million RMB) was located in the coastal region, as compared to 42 percent in 1980. The geographic concentration of this production has meant that certain industrial cities are the epicenters of pollution hot spots.

Figure 3 presents a time series of coal and steel production since the establishment of the People's Republic of China (1949–2015). Both production indicators climb steadily after the early 1980s when the economic reform was initiated and then exhibit very rapid growth after China joined the World Trade Organization in 2001. In recent years, such production has declined.

Air Pollution

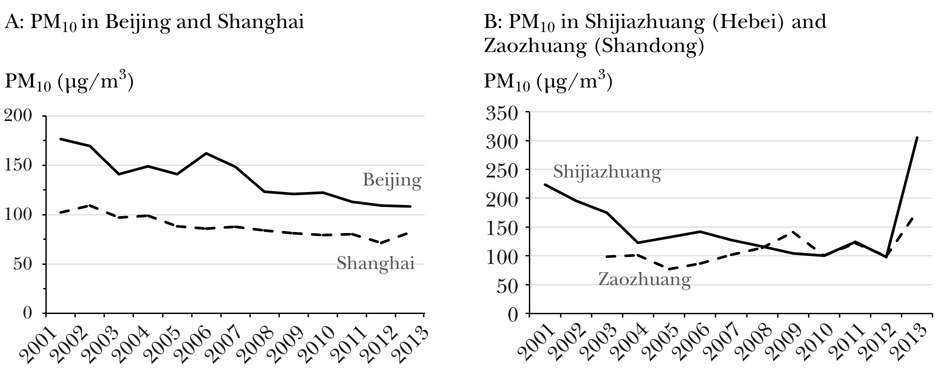
During the last decade or so, China's major cities—such as Beijing and Shanghai—have experienced improvements in urban air pollution. Figure 4A shows the average particulate matter level as measured by PM_{10} in these cities between 2001 and 2013. During these years—when both cities experienced population growth and significant per-capita income growth—Beijing's PM_{10} levels have declined by 39 percent and Shanghai's by 20 percent. On the other hand, some

Figure 3
Coal and Steel Production in China (1949–2015)
(100 million tons)



Source: China *Automotive Industry Yearbook*, China *Energy Statistical Yearbook,* and China's *Economic Statistics Bulletin*.

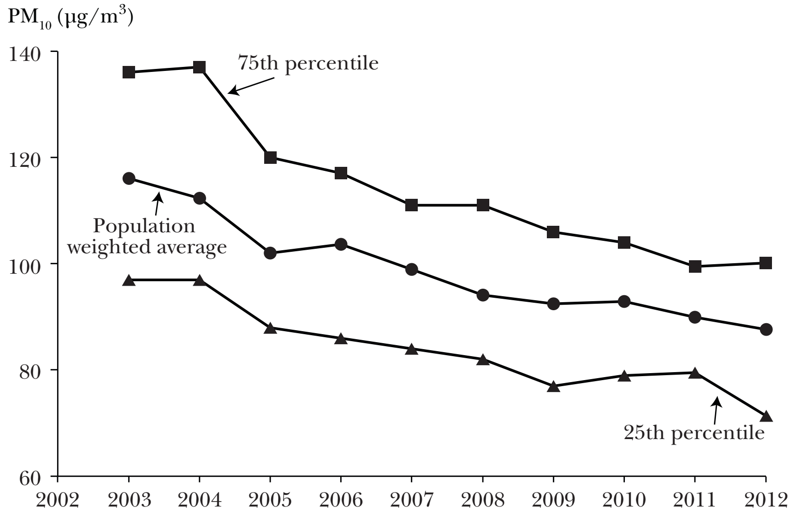
Figure 4
Air Pollution in Selected Chinese Cities, 2001–2013



Source: The PM_{10} concentration data are calculated from the official Air Pollution Index (API) use the API calculation formula. Both API and its formula are obtained from the Data Center of the China's Ministry of Environmental Protection (http://datacenter.mep.gov.cn/).

heavy industrial cities such as Shijiazhuang in Hebei Province and Zaozhuang in Shandong Province, shown in Figure 4B, saw a rise in PM_{10}. But overall, Figure 5 presents the population-weighted average PM_{10} concentration for 85 Chinese cities, and also this measure for the two cities ranked at the 25th and 75th percentiles of the PM_{10} distribution across those cities. These three numbers have all declined during this period.

Figure 5
Chinese Urban Population PM_{10} Exposure for 85 Cities

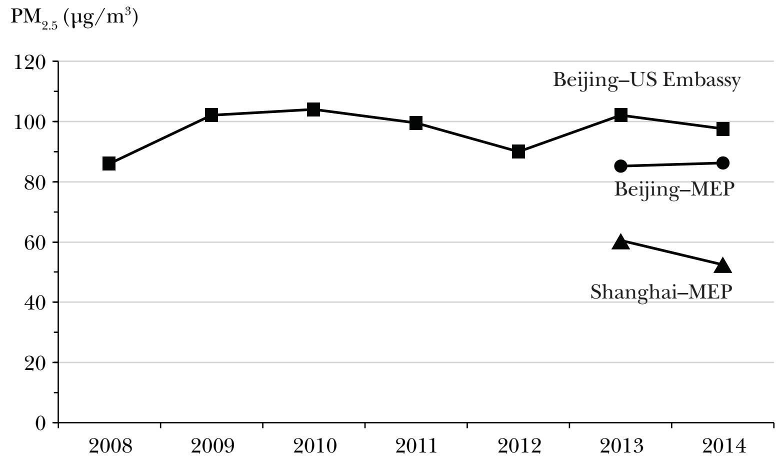


Source: Same as Figure 4.
Note: Figure 5 presents the population-weighted average PM_{10} concentration for 85 Chinese cities, and also this measure for the two cities ranked at the 25th and 75th percentile of the PM_{10} distribution across those cities.

In recent years, $PM_{2.5}$ has become the primary air pollutant of concern in many large Chinese cities. China's Ministry of Environmental Protection (MEP) started to report $PM_{2.5}$ readings in major Chinese cities in 2013. The US Embassy in Beijing has been releasing $PM_{2.5}$ data around its location (in downtown Beijing) since 2008. Figure 6 presents three time series—the long time series from the US Embassy in downtown Beijing, and two short time series for the average $PM_{2.5}$ readings in Beijing and Shanghai from MEP. The two time series for Beijing have similar trends in the short time period (the downtown US Embassy's reading is slightly higher than the Beijing average). Shanghai's pollution level is much lower than Beijing's. Beijing's $PM_{2.5}$ level reached its lowest level in 2008, when the Olympic Games were held in Beijing and the government implemented many short-run regulations to control the pollution. After that, the $PM_{2.5}$ concentration has averaged around 100μg/m^3, and it is worse in the winter due to coal-based heating.

Air pollution can drift across regions, just as industrial water pollution can flow downstream. In major urban cities such as Beijing and Hong Kong, much of the air pollution is caused by emissions from nearby regions. This cross-boundary spill-over problem is most severe when a city is adjacent to a very dirty neighbor, such as the Hebei Province near Beijing and the Guangdong Province near Hong Kong. According to the latest report on $PM_{2.5}$ sources conducted by a research group within the Ministry of Environmental Protection, Hebei Province, which produces a significant chunk of the entire world's steel, contributed to 18 percent of the $PM_{2.5}$

Figure 6
$PM_{2.5}$ in Beijing and Shanghai



Source: The $PM_{2.5}$ concentration data are obtained from the Data Center of the China's Ministry of Environmental Protection (MEP) (http://datacenter.mep.gov.cn/) and US Embassy.

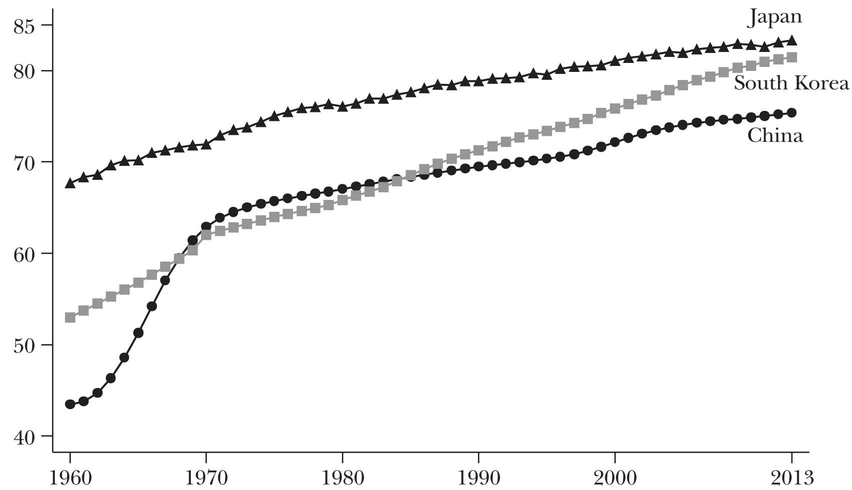
in Beijing and 20 percent in Tianjin (Ecns.cn 2016). Hong Kong has also suffered from nearby industrial emissions drifting into its airspace. In the Pearl River Delta, about two-thirds of air pollutant emissions are from industrial cities in Guangdong Province such as Dongguan and Foshan. Indeed, since 2008, Hong Kong has paid manufacturers in Guangdong Province about $150 million every year to install pollution-reducing equipment (Hong Kong Environment Bureau 2013).

Soil and Water Pollution

Although our discussion will focus mostly on air pollution, as has much of the research in this area, soil and water pollution deserve some mention. During China's rapid urbanization process, many old, dirty firms moved away from the central areas of large cities; as a result, land contamination has emerged as a new and serious issue in recent years. A World Bank study estimated that there are over 300,000 total brownfield parcels in China (Xie and Li 2010). At the same time, high levels of heavy metal pollution can be found throughout China's farmlands. It is estimated that the country loses US$3 billion per year to soil pollution, and that between 40 to 70 percent of China's soil is already contaminated with heavy metals and toxic fertilizers (as discussed in Guilford 2013). These facts highlight that a "web of nature" connects the urban economy to its natural surroundings. If polluting factories leave the city and relocate in the countryside, urbanites enjoy a reduced direct exposure to industrial pollution, but they still face the challenge of brownfield remediation and increased risk of food contamination as dirty industry moves near farmland.

Some recent research has studied water pollution along China's major rivers. Kahn, Li, and Zhao (2015) document evidence of higher pollution levels at provincial

Figure 7
Life Expectancy Trends in Three Asian Nations



Source: The World Bank Data, http://data.worldbank.org.

borders. Polluting industries such as pulp and paper mills cluster in these areas such that the social costs of this type of activity flow downstream. The central government recognizes the challenge of free riding at political borders (Sigman 2002) and has introduced regulations to reduce transboundary water pollution levels. Such regulations have helped to reduce pollution for targeted criteria but did not reduce such spillovers for nontargeted pollutants, like heavy metals (Kahn, Li, and Zhao 2015).

Costs and Consequences of High Pollution Levels

Elevated pollution levels have a variety of costs. Perhaps most obvious and severe are the immediate costs to human health. But in addition, pollution reduces worker productivity, alters real estate values, and affects the local quality of life, and it has contributed to global environmental concerns like climate change.

The Health Costs of China's Pollution

Life expectancy trends for China, Japan, and South Korea from 1960 to 2013 are reported in Figure 7. During the 1960s, China's life expectancy converged with South Korea's. At that time, many "barefoot doctors," trained with basic medical knowledge, were sent to work in rural areas. That program effectively reduced the high mortality of newborn infants and the morbidity of contagious diseases. But then, starting in the late 1980s, the two nation's life expectancies diverged, and in recent years South Korea's life expectancy has converged with Japan's.

The relatively flat profile for China's life expectancy during a time of sharp growth after the 1980s hints that some factor, like rising pollution levels, may be hindering life expectancy. Ebenstein et al. (2015) use several datasets to document that China's growth in life expectancy is less than what would be predicted given the nation's per capita income growth. They study the relationship between income, pollution, and mortality in China from 1991–2012. They document a positive association between city-level GDP and life expectancy. They also find a negative association between city-level particulate air pollution exposure and life expectancy that is driven by elevated cardiorespiratory mortality rates: for example, a 100 $\mu g/m^3$ increase in PM_{10} exposure is associated with a decline in life expectancy of 1.5 years at birth and 2.3 years at age five. Hanlon and Tian (2015) use cross-city data in modern China and in late 19th-century England to study the relationship between polluting industry agglomeration and mortality. In both settings, there is a positive correlation between heavy industry and death risk, although modern China's gradient is less steep than the relationship found in historical England.

There are other studies on the relationship between air pollution and life expectancy in China. Chen et al. (2013) find that China's Huai River policy, which provides free winter heating via the provision of coal for boilers in cities north of the Huai River but denies heat to the south, results in about 184 $\mu g/m^3$ higher ambient concentrations of total suspended particulates in the north. This pollution exposure is associated with a reduction in average life expectancy of 5.5 years in the North, due to an increased incidence of cardiorespiratory mortality.

The health costs of air pollution is also directly reflected in mortality and morbidity. Aunan and Pan (2004) find that an increase of one $\mu g/m^3$ in PM_{10} and sulfur dioxide will result in a 0.03 and 0.04 percent increase in all-cause mortality, respectively, along with a 0.07 and 0.19 percent increase in hospital admissions due to cardiovascular diseases, respectively, while the coefficients for hospital admissions due to respiratory diseases are 0.12 and 0.15 percent, respectively. The impact of long-term PM_{10} levels on the prevalence of chronic respiratory symptoms and diseases per $\mu g/m^3$ are a 0.31 percent increase in adults and 0.44 percent in children.

Such health damages caused by pollution in China have created a substantial burden for its economy. According to Matus et.al. (2012), the ozone and particulate matter concentrations beyond background levels have led to a loss of US$16 billion to US$69 billion in consumption (or 7 to 23 percent) in 2005. In another study, Kan and Chen (2004) find that the total economic cost of health impacts due to particulate air pollution in Shanghai in 2001 was approximately $625 million in US dollars, accounting for 1 percent of the gross domestic product of the city. Wang and Mauzerall (2006) estimate that the health costs due to year 2000 anthropogenic emissions in Zaozhuang, a city in eastern China heavily dependent on coal, are 10 percent of that city's GDP.

The costs imposed by ambient air pollution can be reduced by investing in self-protection. Chinese urbanites can choose where to live in a city and what private self-precautions to take, such as purchasing masks or air filters, and how much time to spend outside.

These adaptation strategies have increased in importance over time in China. In the past, China's domestic passport or *hukou* system limited the ability of individuals to vote with their feet and move across cities or from rural to urban areas. Within a city, firms provided cheap housing close to the workplace to minimize commutes. Moreover, there was not a strong understanding of how pollution affects health and productivity, and there were few self-protection products that a concerned susceptible person could purchase. But in modern urban China, urbanites have at least some control over their air pollution exposure through location decisions and self-protection measures, and the urban wealthy in particular may be able to reduce their exposure substantially (Kahn and Zheng 2016).

Effects of Pollution on Worker Productivity and Local Growth

In an open system of cities that compete for workers and firms, geographic pollution hot spots can influence the spatial distribution of firms, workers, real estate prices, and wages. Hanlon (2016) develops a spatial equilibrium theory incorporating local pollution effects that can explain how the evolution of city pollution levels, driven by local industrial growth, can affect overall local economic development. He applies the theory to study the cities of 19th century Britain, where some cities specialized in heavy coal-using industries such as iron and steel production, resulting in very high levels of local pollution. As these industries grew (because of world demand), the cities that specialized in such dirty industries experienced a rise in local coal use and hence in local air pollution. Hanlon shows that the increase in local pollution acted as a substantial drag on local employment growth. Industries in more polluted cities had to pay higher "combat pay" to attract workers at the same time that the elevated pollution reduced worker and firm productivity. A study in China also shows that higher levels of air pollution decrease worker productivity by reducing the number of calls that workers complete each day at call centers (Chang, Zivin, Gross, and Neidell 2016).

The spatial equilibrium dynamics described in Hanlon (2016) did not play out in Mao's era because of the binding *hukou* system in China, in which citizens were designated as living in a certain area and not allowed to move without official permission. With the de facto relaxation of the *hukou* system and the liberalization of the labor and land markets starting in the 1980s, Chinese urbanites have more choice over where to work and live, both within and across cities. Given that Beijing is the nation's capital city, it continues to attract highly skilled workers and floating workers because its overall bundle of opportunities and benefits exceeds the disamenity costs of its relatively high local pollution. Now that China's cities form an open system, Hanlon's (2016) model offers relevant predictions. The major heavy industrial cities Mao established in the Northeast Region and the "Third Front Region" are now lagging behind because they feature dirty and declining industries and cannot attract high-skilled clean industries.

How Households Seek to Reduce their Pollution Exposure

With the relaxation of the *hukou* system and the liberalization of the labor and land markets, people are also able to "vote with their feet." The theory of compensating differentials yields insights about the pricing of real estate across cities and the resulting spatial allocation of different households and firms across China's cities (Rosen 1979; Roback 1982). Using standard revealed preference methods, several studies have documented the rising demand for environmental quality in China's cities.

In a compensating differentials study (Zheng and Kahn 2008), we find that all else equal, a 10 microgram per cubic meter increase in PM_{10} particulate pollution reduces home prices by 4.1 percent in Beijing. In an intercity study of 35 Chinese large cities (Zheng, Kahn, and Liu 2010), we find that home prices are lower in cities with higher ambient pollution levels, and the marginal valuation for green amenities is rising over time. In Zheng, Cao, Kahn, and Sun (2014a), we exploit the fact that the particulate matters that are imported into a city depend on the dominant wind direction and emissions from nearby cities, and the sandstorms from Inner Mongolia. Using wind and sandstorms as instrumental variables, we find that on average, a 10 percent decrease in imported neighbor pollution is associated with a 0.76 percent increase in local home prices. For such cross-city variation in disamenities to be capitalized into real estate prices requires that migrants both are aware of the differences in local public good quality and that such differentials influence their locational decisions.

Another method that households can use to reduce air pollution exposure is to purchase masks and air pollution filters. Using a dataset of Internet purchases in 35 Chinese cities, in Sun, Kahn, and Zheng (forthcoming), we document that Chinese households invest more in masks and air filter products when ambient pollution levels exceed key alert thresholds. Those with higher incomes are more likely to invest in air filters, which are much more expensive than masks but also more effective. This finding suggests that richer people are exposed to less air pollution than poorer people. When the outdoor air is polluted, people will prefer to drive private cars (rather than walk on the street), and they will also decrease their time spent outdoors (Neidell 2009). Based on the estimate in Chen and Zhao (2011), the indoor concentration of particulate matter is on average about 80 percent of the outdoor concentration in Chinese cities, so people can breathe less-polluted air when they are indoors on polluted days. More-educated workers are more likely to work in such indoor jobs.

Global Environmental Costs

Although our primary focus here is on costs experienced by Chinese from China's pollution, we should mention that China's contribution to greenhouse gas emissions is now the largest of any country. We are not aware of a study that puts the China-specific costs in context. China is now the world's leading greenhouse gas producer. However, Muller, Mendelsohn, and Nordhaus (2011) estimate that the global external damage for US petroleum and coal product manufacturing is 35 percent of the industry's value added. Also, China's pollution has imposed costs on nearby nations such as South Korea (Baek, Altindag, and Mocan 2015; Jia and Ku 2016).

Higher Incomes, Greater Awareness, and Pressures to Reduce Pollution

A number of economic arguments suggest that as incomes rise, demand for environmental protection also rises. As an example of US-based evidence on this subject, Costa and Kahn (2004) use data on wages and risks of fatalities on a range of jobs, using Census data from 1940 to 1980. They estimate the "value of a statistical life"—in this case, the amount that workers needed to be compensated for taking on riskier jobs. They estimate value of life with respect to per capita GNP in the range of 1.5 to 1.7; that is, the value of a statistical life rises faster than national per-capita income.

An array of evidence suggests that this pattern is occurring in China, as well. As one example, the evidence in the previous section about household spending to mitigate exposure to pollution, as shown by compensating differentials in real estate prices and by spending on masks and filters, clearly shows that as incomes rise, people are seeking a lower level of pollution.

Perhaps the best-known relationship between income and pollution is the "environmental Kuznets curve," which represents a reduced form relationship between a geographic location's pollution and per-capita income (Grossman and Krueger 1995; Harbaugh, Levinson, and Wilson 2002). In its simplest form, this curve posits that a location's pollution level is an increasing but concave function of local per-capita income: that is, as income rises, pollution first rises, but then falls. The earlier evidence that particulate matter concentrations have been falling in China's urban areas, even as economic growth has continued and coal consumption has risen dramatically, also offers a prima facie case that higher incomes are accompanied by pressure for lower pollution levels.

We investigated the environmental Kuznets curve in China more systematically using data for 83 cities for the years 2003 to 2012. For our dependent variable, we used the city's air pollution level as measured by the PM_{10} concentration in that year. For explanatory variables we used the log of per capita income, as well as the log of per capita income squared and cubed to allow curvature in the result. As other control variables, we also used population for the urban area, share of manufacturing in total output, average years of schooling, rainfall and a temperature index, longitude and latitude, and then in different specifications either a time trend or dummy variables for years.[1]

Table 1 reports our regression results. The first and second columns are the same except that one uses time trend and the other uses dummy variables for years. The results are quite similar. Chinese cities featuring a larger population and a

[1] City-level variables are obtained from the China *Statistic Yearbooks* and the China *City Statistical Yearbooks*. The variables include; GDP (adjusted by inflation), city population (nonagricultural population size), the employment share of manufacturing industry, average years of schooling in 2000, annual rainfall in 2007, and the temperature discomfort index in 2007. See Zheng, Kahn, and Liu (2010) for the definitions and descriptive statistics of these variables.

Table 1
Correlates of Urban Air Pollution in China

	Dependent Variable: log(PM_{10})					
Sample	*All*	*All*	*Above-median-educated cities*	*Below-median-educated cities*	*2003–2007*	*2008–2012*
Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
log(*GDP per capita*)	−0.434***	−0.424***	−0.161	−0.616***	−0.524***	0.0505
	(−3.37)	(−3.32)	(−0.31)	(−3.30)	(−3.03)	(0.23)
(log(*GDP per capita*))^2	0.300***	0.296***	0.137	0.392***	0.316***	0.0944
	(4.02)	(4.00)	(0.57)	(2.69)	(2.99)	(0.81)
(log(*GDP per capita*))^3	−0.0596***	−0.0592***	−0.0355	−0.0641*	−0.0586***	−0.0331*
	(−4.42)	(−4.42)	(−0.98)	(−1.89)	(−2.97)	(−1.68)
log(*population*)	0.164***	0.164***	0.248***	0.0812***	0.169***	0.161***
	(11.95)	(12.01)	(13.62)	(3.64)	(7.77)	(10.09)
log(*manufacturing share*)	0.0498	0.0450	0.0387	0.0410	0.115*	−0.00172
	(1.25)	(1.14)	(0.71)	(0.65)	(1.71)	(−0.04)
log(*average years of schooling*)	−0.918***	−0.926***	−1.883***	−0.606**	−0.876***	−0.937***
	(−6.43)	(−6.53)	(−7.18)	(−2.11)	(−3.86)	(−5.64)
log(*rainfall*)	−0.0987***	−0.0977***	0.0554	−0.113*	−0.187***	−0.000664
	(−2.84)	(−2.83)	(1.20)	(−1.93)	(−3.40)	(−0.02)
log(*temperature index*)	0.391***	0.394***	0.672***	0.208**	0.431***	0.330***
	(5.29)	(5.37)	(5.25)	(2.16)	(3.62)	(3.87)
T	−0.0316***					
	(−10.11)					
Year dummies	No	Yes	Yes	Yes	Yes	Yes
Constant	−1.095**	−1.252***	−0.353	−1.020	−0.929	−2.011***
	(−2.47)	(−2.86)	(−0.44)	(−1.22)	(−1.31)	(−3.85)
Turning point (thousand RMB in 2012)	100	99	53	204	100	85
Observations	846	846	428	418	421	425
F-statistic for joint significance of income polynomial	7.25***	7.35***	6.47***	9.17***	3.52**	8.72***
R^2	0.432	0.444	0.568	0.428	0.440	0.443

Note: The latitude and longitude of each city are controlled for in all columns.

higher manufacturing share of total employment are more polluted. The negative time trend during the years 2003–2012 from column 1 highlights the potential for technological change to reduce pollution. Based on our regression estimates, we find that wealthier cities are reaching the turning point at about 100,000 yuan (about US$15,000) in terms of GDP per capita (2012 constant RMB).

We partition the observations into higher-educated cities and lower-educated ones (based on the average years of schooling) in columns 3 and 4, and then into the early period (2003–2007) and late period (2008–2012) in columns 5 and 6. The higher-educated cities have earlier turning points than the set of cities whose education is below the cross-city median, which is consistent with the hypothesis that citizens with a higher education level will tend to be more concerned about environmental costs and will tend to strategically locate, or exert political pressure, to experience lower environmental costs. Comparing the results in columns 5 and 6, we find that cities are reaching the environmental Kuznets curve turning point at a lower level of per-capita income in the later period, which is consistent with a hypothesis that concern over environmental issues is rising over time.

This latter finding is consistent with the claim of Dasgupta, Laplante, Wang, and Wheeler (2002, in this journal) that the environmental Kuznets curve shifts down and in over time. This claim means that, over time, geographic areas suffer less environmental damage as they develop and that they reach the per-capita turning point earlier. Endogenous technological change and the diffusion of cleaner technology provides one micro-foundation for this observed pattern (Acemoglu, Aghion, Bursztyn, and Hemous 2012; Acemoglu, Akcigit, Hanley, and Kerr 2016).

An advantage of the kind of approach shown in Table 1 is that it emphasizes within-China variation in ambient air pollution production and exposure. The cross-national research on an environmental Kuznets curve implicitly averages the cities within a country. This removes the within-nation urban variation that arises due to the sorting of heterogeneous industries and workers and the policies implemented by local leaders.[2]

A Suite of Environmental Protection Policies

Starting in the early 2000s, the Chinese central government has increasingly emphasized pollution reduction, including climate change mitigation. China's five-year plans provide blueprints that foreshadow the medium-term goals of the Chinese Communist Party. We counted the words related to environment, energy, and ecology in each of the 13 five-year plans the central government made after 1949. The content of the five-year plans sends clear signals to local officials about what goals they should prioritize. The first three five-year plans had almost no mention of environmentally oriented terms; indeed, the 3rd Five-Year Plans had literally no mention of these terms. From the 5th to the 9th Five-Year Plan, from 1.8–2.5 percent of the words were related to environmental issues. In the 11th through 13th Five-Year Plans—the most recent ones—about 5 percent of the language is devoted to environmental issues. We view this simple word count as a starting point. Future work could use more machine-trained semantic analysis algorithms from computational linguistics to quantify the details and trends of those "green" words in the five-year plans and other Chinese government documents. According to the

[2] We recognize that our within-China evidence shown in Table 1 concerning a cross-city environmental Kuznets curve does not test the claim that China is on a more benign curve than the rest of Asia. To test this claim, one would have to use cross-national panel data for each Asian nation j at time t and run a regression of the form

$$Pollution_{jt} = B_j + D_t + f(income_{jt}) + B \times China_j \times time\ trend_t + U_{jt}$$

One test of whether China is on a different pollution/income path than the rest of Asia would be if, controlling for nation fixed effects, year fixed effects, and a per-capita income polynomial, B is less than zero where B is the coefficient on the China specific time trend. Given data limitations, we cannot estimate this regression.

statistics released by Chinese government, the 11th FYP met or exceeded all of the stated goals, including an energy intensity reduction target (Price et al. 2011; see also Casey and Koleski 2011). By 2014, the energy intensity reduction number set in the 12th FYP (2011–15) had been 82.5 percent fulfilled. At the political level, one motivation for the Chinese Communist Party to emphasize "green progress" is that the Party seeks to build legitimacy by signaling to both domestic constituents and international actors that it cares about the quality of life for everyone (Wang 2013).

China's government has a suite of policy tools that it has been using to improve environmental quality: command and control, incentives for local officials, reducing subsidies for energy and water, and direct investments in pollution mitigation.

Command and Control Regulations

The Chinese Communist Party has often relied on command-and-control regulation to achieve its urban externality mitigation goals. Examples include shutting down firms, imposing driving restrictions, and mandating car registration lotteries. Based on daily data from multiple monitoring stations, Viard and Fu (2015) find that, air pollution falls 19 percent during an every-other-day driving restriction (during the 2008 Beijing Olympics) and 8 percent during one-day-per-week restriction (October 2008 to December 2009).

In contrast, a study by Sun, Zheng, and Wang (2014) finds that Beijing's driving restriction has some effect on mitigating road congestion but an insignificant effect on reducing air pollution. Li (2015) compares the two types of car license allocation mechanisms in China's major cities. To combat worsening traffic congestion and urban pollution, Beijing requires that potential car buyers participate in a random lottery, while Shanghai auctions vehicle registration licenses. In both cities, the licenses obtained are nontransferable. Li (2015) finds that the nontransferable lottery is inefficient compared to an auction mechanism. This within-nation variation in policy raises the possibility of social learning as local experimentation offers new insights about the effectiveness of different policies. As other cities learn, they have an option to adopt policies that have achieved environmental improvements in other Chinese cities.

Incentives for Local Officials

China has a strong one-party central government, but hundreds of local governments act as competing enterprises. Upper-level governments promote or demote local leaders based on performance evaluation. Such a political tournament raises the possibility that the central government can provide strong incentives for local officials, and indeed, this has been a tool for encouraging local officials to promote economic growth in the past. However, the central government has been changing the performance evaluation and promotion criteria for local officials, moving beyond purely output-based criteria to include more environmental goals in the performance metrics (Zheng, Khan, Sun, and Luo 2014b; Kahn, Li, and Zhao 2015).

We have studied the promotion propensities for mayors in 83 Chinese cities during the years 2004 to 2010. We find that local GDP growth continues to be the most important factor in determining promotion rates, but that declines in local air pollution and reductions in local industry energy intensity are also statistically significant correlates of promotion chances, especially in relatively richer cities on the east coast (Zheng et al. 2014b).

Chen, Li, and Lu (2016) evaluate the effectiveness of China's "Two Control Zones" (TCZ) policy. This policy intends to reduce sulfur dioxide levels in targeted cities. They employ a difference-in-differences econometric approach and find that, compared to the control group (non-TCZ cities), local bureaucrats in TCZ cities exerted more effort to reduce sulfur dioxide emissions after the emissions quota was built into their performance evaluation in 2006. Local officials appear to devote more effort to reducing pollution when their performance evaluation is partially based on environmental performance.

Local mayors, especially those in richer cities with a more educated populace, face pressure from both the central government and the public who are increasingly expressing their pollution concerns (Kahn and Zheng 2016). Mayors of poorer cities are aware of their city's industrial structure and the need for sheer economic growth. In our interviews with these mayors, some of them admit that they are implementing policies targeted to increase industrial production, and they recognize that this will increase local pollution levels.

The two cities of Dalian and Tangshan offer an example of how these dynamics can unfold. Both cities are on the coastal line of the Bohai Sea and have similar climate conditions, but they implemented quite different development strategies. Tangshan is rich in iron and close to coal mines, so it chose to develop energy-intensive industries such as steel, construction materials, and chemicals. In 1984, Dalian was selected to be one of the 14 coastal "open cities" by Deng Xiaoping and thus attracted many high-tech firms. Dalian also regards itself as a tourist city, so a clean environment is viewed as offering direct economic benefits.

As China invests in bullet trains, the Chinese people now have the opportunity to decentralize and live in nearby second-tier cities if the megacities of Beijing and Shanghai suffer from low quality of life. For example, the construction of China's high-speed rail system means that nearby second-tier cities such as Tianjin (40 miles from Beijing) offer a type of safety valve if quality of life declines in China's megacities. Transport innovation has been associated with rising real estate prices in secondary cities near first-tier cities such as Shanghai and Beijing (Zheng and Kahn 2013).

Reducing Price Distortions

China has removed the most egregious distortions and subsidies in its energy sector: for example, prices for electricity, gasoline, and natural gas generally reflect costs over the long run, and some are at or even above international market levels (World Bank and DRC 2014).

For gasoline, oil prices were under tight state control and were set very low before 1998. With rising dependence on oil imports, China had to adjust its domestic oil prices. In June 1998, China reformed the oil pricing system to set domestic oil price in accordance with the global oil price (Hang and Tu 2007). Since then, China's National Development and Reform Commission (NDRC), which regulates petroleum prices, has used international oil prices as the benchmark for domestic prices. Price subsidies offered during the early years contributed to sharp increases in energy consumption in the 1990s before falling for the first time in 1998 when energy reforms began to take effect (Poon, Casas, and He 2006). The pricing system has adjusted several times since 1998, and the current policy was implemented since 2009. Gas prices in China are no longer low. In April 2016, the price of gasoline in China was roughly 50 percent higher than in the United States.

However, "economic and social stability" is also considered by the NDRC when it adjusts gas prices. If the international benchmark price exceeds $130 a barrel, diesel and gasoline prices are not raised or are raised only by a small margin (World Bank and DRC 2014). When the central government raises gasoline prices, it faces tradeoffs between interest groups. The fossil fuel market is dominated by three major state-owned enterprises—PetroChina, SINOPEC, and CNOOC—that would benefit from gasoline price increases. But the public will be angry and may protest against such price increases, which is a potential threat to social stability. Studying the consequences of this tension between interest groups in determining the enforcement of Chinese environmental regulations remains an open research topic.

For electricity, industrial users pay around RMB 0.70 ($0.10) per kilowatt-hour on average ($0.17 per kilowatt-hour on a purchasing power parity basis), while the average rate in the OECD countries is $0.11 per kilowatt-hour in 2010 (IEA 2012). However, residential electricity prices in China are quite low compared with many developed countries. For example, in Beijing the rate was $0.08 in 2011, which was about one-third of that in New York ($0.20) and even lower in comparison to Berlin or Copenhagen ($0.40) (World Bank and DRC 2014). The cross-subsidy from industrial to residential electricity use in China has been widely criticized.

Residential water prices in Chinese cities are quite low by international standards: in Beijing the residential tariffs ($0.54 in US dollars per cubic meter) are less than one-tenth of those in Berlin or Copenhagen. However, the current industrial water tariff in Beijing (6.21 RMB) and Tianjin (7.85 RMB) are higher than those in Canada, the United States, and other developed countries (World Bank and DRC, 2014).

Direct Government Investment

In 2016, the general public budget of China's Ministry of Environmental Protection (MEP) increased by 18 percent over the previous year, from 3.2 billion RMB in 2015 to 3.8 billion RMB in 2016.[3] The final budget in 2015 indicates that 63 percent of the general public expenditure was on "energy saving and environment protection," such as purchasing equipment to construct the national environmental monitoring web, hiring workers to supervise the enforcement of environmental laws, investigating and evaluating countrywide underground water environment conditions, developing educational activities on environment

[3] The source is in the Chinese language, at the Ministry of Environmental Protection webpage http://www.mep.gov.cn/xxgk/zwgk_1/czzj.

protection, and other activities. The other 32 percent of the expenditure was spent on "science and technology, including funding public scientific research and major science and technology projects on environment protection.

The central government provided a 10.6 RMB billion special fund to support air pollution control in key areas including the Beijing–Tianjin–Hebei area, Yangtze River Delta, and Pearl River Delta. With the funding, a number of new regulatory actions have been taken. For example, 1.26 million "yellow label cars"—the name given to heavy-polluting vehicles—were phased out. The funding was used to support strict inspection on road and gas quality, and subsidies to those car owners to upgrade to lower-polluting cars. Subsidies were also given in rural areas to encourage a switch from burning crop straw to using (cleaner) coal.

Future Environmental Progress

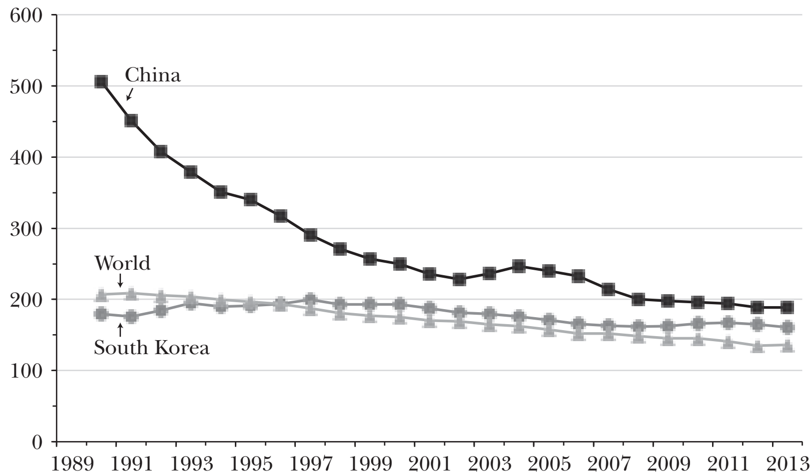
China's future environmental progress in reducing air pollution can be viewed as a race. On the one side, even if China's economy does not grow at the fast pace of the last couple of decades, it seems plausible that the economy could continue growing at 6 percent per year. On the other side, even with a growing economy, technological progress and industrial composition shifts could help to offset the amount of pollution emitted and its effects. Over the medium term, China should be able to reduce both its energy intensity (energy use/GDP) and its pollution intensity (emissions/GDP).

The ratio of energy use/GDP in China has declined dramatically over the last 25 years, as shown in Figure 8. During the last decade, it dropped by nearly 25 percent, reaching close to the level of the whole world and South Korea by the year of 2013.

The relative size of China's manufacturing and construction industries is shrinking—its share in GDP fell from 45.4 percent in 2000 to 40.5 percent in 2015, while the size of what is referred to as "tertiary industry" increased from 39.8 percent to 50.5 percent. China's share of power generated from coal decreased from 80.3 percent in 2000 to 73 percent as of 2015. Indeed, China's overall coal use declined 3.7 percent in 2015, which followed a decline of 2.9 percent in 2014 (as reported in Yeo 2016). This reduction took place during a time that China's economy grew by 6–7 percent annually. Green and Stern (2015) predict that China's coal use has peaked and is likely to plateau over the next five years and to continue to decline. As China's cities transition from industry to cleaner services, and as more power is produced from cleaner energy sources, ambient air and water pollution is likely to decline.

As hundreds of millions of Chinese move to new cities over the next decades, there is an opportunity to take advantage of cutting-edge technology in building energy-efficient real estate, transportation systems, and power generation infrastructure. Energy consumption in buildings accounts for about 30 percent of China's total energy use, but China has a program for green building certification since 2008, and the central government started to offer subsidies for green buildings in 2012. China became the largest producer of solar photovoltaic cells in the world in

Figure 8
Energy Use per Unit of GDP in China, South Korea, and World
(kg of oil equivalent per constant 2011 PPP $1000)



Source: The World Bank Data, http://data.worldbank.org.

2007 (as reported in PR Newswire 2015), and in 2015, China overtook Germany as the nation with the largest installed photovoltaic capacity (as reported in Hill 2016). China is aiming to increase its non-fossil-fuel energy capacity to 15 percent of total primary energy consumption.

In September 2016, China ratified the Paris Climate Change Agreement. It has promised that its greenhouse gas emissions will peak by the year 2030. It further has pledged to reduce its carbon emissions per unit of GDP by 60 percent from its 2005 level by 2030 and to increase its share of power generated by renewables to 20 percent. As the world's high-income nations invest in green technology, China will be able to import new technologies. The investments in basic research at China's universities suggest the possibility that China could become a producer and exporter of green technology innovation (Freeman and Huang 2015). Several promising trends, especially in China's rich coastal cities, are now unfolding that suggest significant environmental progress could take place. Manufacturing is land-intensive. As urban rents rise, such industrial activity is leaving the major cities. In addition, the inland cities have a cost advantage in electricity price. Given these push factors, the second-tier and third-tier inland cities have become increasingly attractive destinations for labor- and energy-intensive industries (Zheng, Sun, Qi, and Kahn 2014c). During a time of rapid urbanization, environmental progress can occur if a city's industrial composition shifts from heavy industries to cleaner services (Kahn 1999).

Taken together, these political and economic factors strongly suggest the possibility that China's pollution per unit of economic activity could sharply decline, but this dynamic may unfold unevenly across the country. China's leaders face the challenge that macroeconomic growth is slowing. The government has responded with strategic subsidies to foster profitability of heavy industries that employ many low-skill laborers. If the Chinese Communist Party faces a strict "jobs versus the environment" tradeoff, it is likely to choose protecting jobs. Poorer cities in China's western region, such as Baotou and Panzhihua, continue to rely on heavy industry as the area's major employer. In contrast, the rich coastal cities such as Shanghai feature a cleaner set of industries and high-human-capital workers who seek out clean air, both for the amenity value but also to raise their own and their children's productivity (Zivin and Neidell 2013). This "tale of two cities" could give rise to increasing environmental inequality across China's regions.

■ *Xiaonan Zhang provided excellent research assistance. This research is supported in part by the National Natural Science Foundation of China (No. 71625004, No. 71273154, No. 71322307, No. 71533004), the national key research & development (R&D) plan of China (2016YFC0502804).*

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