



# TRANSBOUNDARY AIR POLLUTION IN NORTHEAST ASIA: THE POLITICAL ECONOMY OF YELLOW DUST, PARTICULATE MATTER, AND PM<sub>2.5</sub>

By Matthew Shapiro

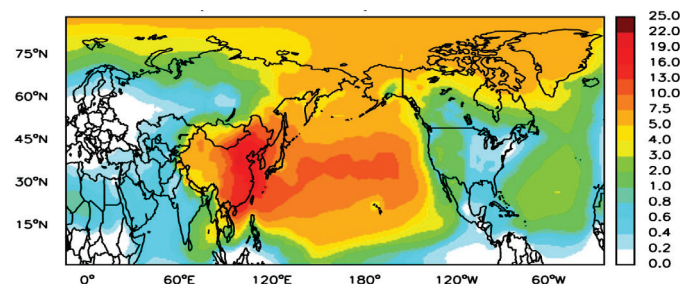
## Abstract

This paper details the nature of transboundary air pollution in Northeast Asia, employing an analytical approach rooted in the political economy of the region. To measure public perceptions of the air pollution problem, it is shown that the Korean media largely frame transboundary air pollution in the region as a problem emanating from China. While it is true that the pollution originates in China and is carried eastward on the trade winds, China is not the sole contributor to this problem. Rather, Korean investments in China and the subsequent exports of goods from firms in China all play a role. The impacts can be quite severe and long lasting for individuals prone to respiratory problems. The economic costs are thus framed largely in terms of health costs in Korea, providing strong incentives for policy makers to effect change. Using correlation analysis, it is shown that China's pollution levels are positively associated with both Korean FDI flows to China and Korean respiratory deaths. The path forward must of course account for continued FDI flows from Korea to China, but it must also include greater levels of coordination between Korea and China on the issue of transboundary air pollution. Several existing institutions provide a solid foundation, but the curation and sharing of China-based emissions data with the Korean government will facilitate the tracking of high-polluting Korea-invested enterprises in China. In terms of preventative measures, Korea and China must coordinate on the development of technologies related to the reduction of air pollution.

## Introduction

Korea is faced with periodic environmental disasters in the form of pollution blowing from China.<sup>1</sup> In the winter, excessive burning of coal for heating has effects as far away as the U.S., shown in Figure 1, where cities like Los Angeles receive the equivalent of one extra day of pollution per year from China's production of goods for export.<sup>2</sup> In the fall and spring, western trade winds sweep up yellow dust from the deserts of northern China and Mongolia, to which soot and carcinogens from China-based industrial processes attach,<sup>3,4</sup> shown in Figure 2 (<http://www.eanet.asia/product/RSAP/RSAP.pdf>). The health-related consequences are more deleterious than those produced from traditional air pollution. Indeed, the long-term health consequences of particulate matter 2.5 micrometers or less in size (PM<sub>2.5</sub>) is particularly concerning, as PM<sub>2.5</sub> is so small that it can directly enter the bloodstream after being inhaled. Such dust is laden with pathogens,<sup>5</sup> lead, cadmium, and arsenic,<sup>6</sup> and East Asia's concentrations of PM<sub>2.5</sub> pollution are the highest worldwide.

**Figure 1. Percentage and distribution of black carbon in 2006 from Chinese export industries**

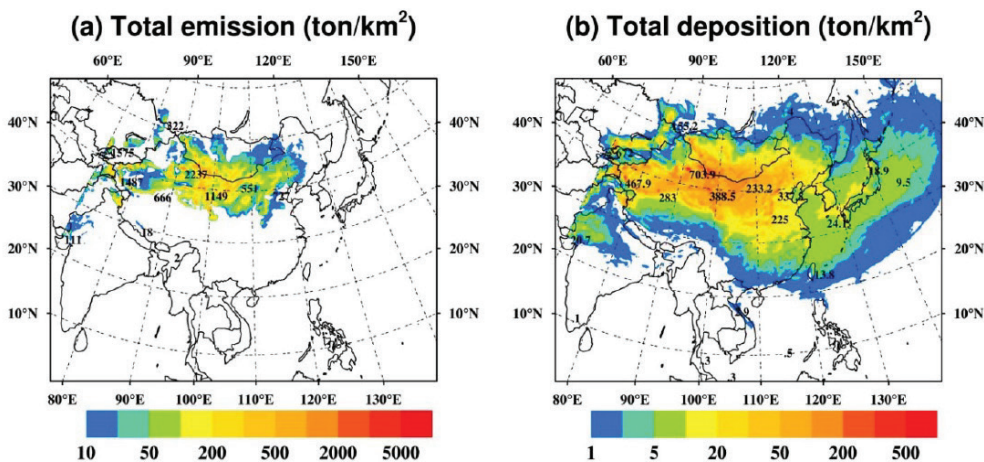


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Figure 2. Spatial distributions of annual emissions and deposition of yellow dust in 2010



Source: Acid Deposition Monitoring Network in East Asia (<http://www.eanet.asia/product/RSAP/RSAP.pdf>)

The movement of toxic  $\text{PM}_{2.5}$  beyond China's borders is technically in violation of the United Nations Convention on Long-Range Transboundary Air Pollution, but the fact that both natural and anthropogenic processes are at work makes it difficult to establish practical policy prescriptions. This dilemma of shared resources represents a classic commons problem, meaning that individual countries in Northeast Asia are reluctant to pay for the costs of abatement and clean-up because the benefits will be shared. This is confounded by regional politics, which has been known to trump the ecological interdependence of Northeast Asia, although the Chinese Academy of Sciences has now definitively acknowledged that China-based sulfur dioxide and nitrogen oxides must be effectively controlled.<sup>7</sup>

The problem is also confounded by Korea's trade and investments with China. Like much of the world, Korea imports heavily from China. At the same time, outflows of foreign direct investment (FDI) from Korea to China are massive, representing an average of 6-10 percent of China's FDI inflows. In short, Korean investors – both SMEs and large multinational firms – are quite possibly exporting a portion of their pollution-producing entities to mainland China where weaker environmental standards and lax enforcement (not to mention lower labor costs) provide a more advantageous profit margin. This process is consistent with what is known as the "pollution haven" hypothesis, i.e. the claim that businesses target locations for their manufacturing operations in order to, among other reasons, avoid higher environmental enforcement costs at home. Higher transportation costs, human capital concerns, green field investment costs, etc. are all offset

by the opportunity to produce without internalizing the firms' domestic environmental costs.

Nothing is unequivocal about the international political economy of North-east Asian transboundary pollution. Evidence confirms the pollution haven status of China,<sup>8,9,10</sup> but it is conditioned by the type of regulated pollutant and the specific province under analysis.<sup>11,12</sup> These varied findings are also a function of different assumptions about the nature of FDI and ultimately the need to address the underlying political economy of transboundary air pollution.<sup>13,14</sup> For example, some argue that multinational firms play a role in improving the Chinese environmental regime, and

there is evidence that Chinese firms with international ties are more compliant with environmental regulations than those lacking such ties.<sup>15</sup> Could the answer be simply to make an appeal to foreign firms in China to be environmental standards setters and transfer pollution-reducing technology to local Chinese firms?<sup>16</sup> Unfortunately, that is not possible, particularly when considering the poor record of corporate social responsibility worldwide.<sup>17,18</sup> Yet, as I will ultimately prescribe, it is precisely through such technology transfers that China's air pollution can be most directly addressed.<sup>19,20</sup>

There are several factors that must be understood before prescribing policy alternatives that address transboundary air pollution in Northeast Asia. First, and maintaining the Korean focus, we must examine the role of the media in affecting Korean public opinion on the subject of transboundary air pollution from China. *Are Koreans aware of their contribution to China-based air pollution?* Differences in the discourse and imagery used by those communicating information can be deliberately employed to promote a particular interpretation of events that ultimately impact policy decisions. Second, we must consider FDI and trade data while acknowledging the role of regional environmental institutions. *How do these institutions lay a foundation for further coordination between Korea and China?* Third, we must analyze Korea's internalized health costs associated with transboundary air pollution from China. *Are these costs increasing over time, and how are they associated with FDI flows from Korea to China and with exports from China?* The mechanisms are not entirely understood between air pollution and health-related effects,<sup>21</sup> but epidemiological research has identified a relationship



between particulate matter concentrations and increased human mortality and morbidity.

Though the Korean media tends to lay the blame for the costs of transboundary air pollution on China, Korean firms operating in China in fact play a role in contributing to the problem. Indirectly, thus, Korea's investments in China are negatively impacting health outcomes at home and increasing health costs overall. This is an urgent problem, requiring the cooperation of both countries to manage what is ultimately a regional pollution issue.

### Media Framing and Public Opinion

The framing of yellow dust and particulate matter by both traditional and new media provides the basis for understanding how transboundary air pollution can be interpreted by the public.<sup>22</sup> Framing, however, is not merely a function of media reporting but also involves the public's attention to air pollution. I invoke Downs' "issue-attention cycle" to explain the overall attention received by the media and the public, which states that fluctuations in public and press attention are a function of the cycles that narratives take as issues of public concern evolve in media coverage over time. In stage one of Downs' cycle, people are unaware of the problem; in stage two, dramatic events focus people's attention on the problem; in stage three, the costs of solving the problem become clear; in stage four, there is a steady decline of public interest; and, in stage five, the issue is no longer central to the public's concern.<sup>23</sup>

What is remarkable about particulate matter/yellow dust is the seasonal and thus periodic nature of the problem. This represents an exceptional characteristic in the context of the Downsian cycle in that news about this problem cycles with the natural blowing of the dust and other seasonal phenomena such as the excessive burning of coal in China for the heating of homes during the winter. Whether information about China in the Korean media is similarly cyclical will diminish the importance of the problem, perhaps preventing the issue from advancing to stage three of Downs' cycle.

Before discussing how the issue is framed by the Korean media and thus the Korean public's opinion about transboundary air pollution, we should engage in a corresponding examination of the Chinese case. Implied by the Downsian cycle, if there is no media-based discussion or if there is no interest in FDI flows in relation to pollution, the Chinese government will be less incentivized to respond. However, our analysis of the Chinese media is limited by the government's excessive media censorship.<sup>24</sup> Reporters without Borders (<https://rsf.org/en/ranking>) ranks the

Chinese media as 176<sup>th</sup> out of 180 countries in terms of media transparency and freedom of the press. This was certainly apparent when China's central propaganda department suddenly blocked online viewing of the documentary covering China's air pollution crisis, "Under the Dome," after hundreds of millions of people viewed it in the few days that it was first publicly available.<sup>25</sup> If air pollution-related content is discussed in the media, it should be expected that it would take on attributes similar to health-related content,<sup>26</sup> focusing on the individual rather than institutions. This would manifest in media reports calling for increased bicycling, better insulation of homes, and maintenance of automobiles in order to limit carbon monoxide emissions. We should thus not expect there to be explicit discussion about environmental regulations.

In terms of public opinion, surveys of the Chinese public in spring 2015 found that air pollution and water pollution are the public's second- and third-most important problems. Seventy-six and 75 percent of respondents, respectively, felt that air and water pollution were either a very big problem or a moderately big problem. Approximately one third of respondents expect air pollution (and water pollution) to get even worse in the next five years. This expectation is even more pronounced in Beijing and Shanghai, where 53 percent of the public expects air pollution to get worse over the next five years.<sup>27</sup> These opinions may have been affected by the viral viewing of "Under the Dome," which Environmental Minister Chen Jining stated was China's "Silent Spring-moment."<sup>28</sup>

Turning now to Korea, my analysis of the media is based on data curated from the National Information Agency's (NIA) media search tool. NIA's search tool summarizes all news articles, social media, and online blog posts from approximately 300 Korean news companies.<sup>29</sup> While new/social media afford increased opportunities for the public to contribute to the corpus of news through reposts on Facebook, YouTube, Twitter, etc.,<sup>30</sup> I limit the sample to all Korean-based traditional media and online blog posts. A longitudinal analysis of media content patterns is employed, consistent with existing analytical approaches.<sup>31, 32</sup>

Korean media content is examined in terms of whether yellow dust, particulate matter, the combination of yellow dust and particulate matter, or PM<sub>2.5</sub> are discussed concurrently with China. If China is mentioned in the context of one of these three (or more) topics, I assume that it is being attributed as the source of the pollution.<sup>33</sup> Figure 3 presents an overview of Korean media content from November 2015 through March 2016 on the topics of yellow dust and particulate matter. As we can see, yellow dust



is presented in the media to a significant degree only when the actual dust is blowing, specifically from February and into March (and likely increasing in April). There are no clear differences between those reports mentioning yellow dust or yellow dust/particulate matter with and without China. Media reports covering particulate matter are present throughout the news cycle, indicating that the topic is important and not yet passing into stage four of Downs' issue attention cycle. We should also note the December increase in content mentioning China in combination with particulate matter/PM<sub>2.5</sub> is a likely function of China's increased use of coal for heating.

the transboundary air pollution problem. The campaign for the hearts and minds of the Korean public – if one exists – is dominated by the Korean medical and epidemiological community.

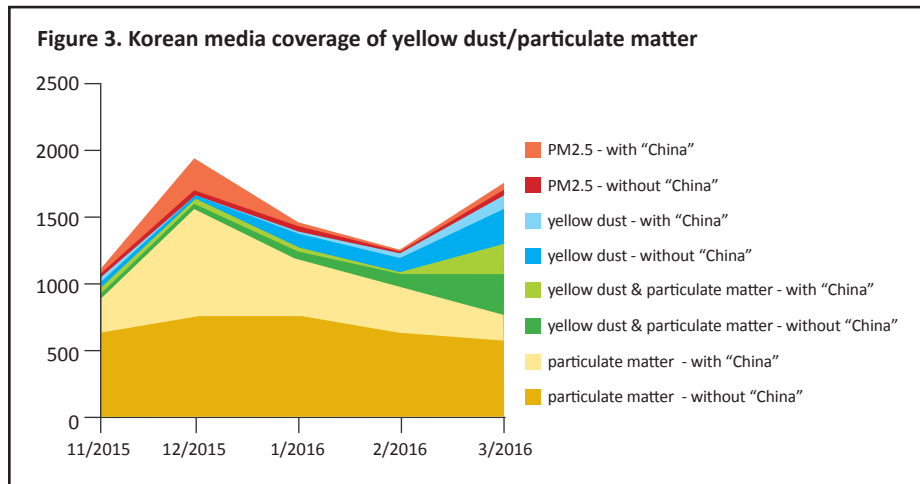
**Transboundary Air Pollution and the Role of Institutions**

The solution for commons problems such as transboundary air pollution is negotiation and problem-solving among a handful of invested and capable individuals. In Northeast Asia, this occurs through formal negotiations and discussions, such as meetings of the annual Tripartite Environmental Ministers Meeting (TEMM), one of many attempts to deal with environmental concerns across the region, as shown in Figure 4. Indeed, at the 2001

TEMM, environmental ministers of China, Korea, and Japan stated explicitly that action needed to be taken regarding the yellow dust problem; yet, there has been no binding commitment to action, and the participating countries make reference to TEMM's infringement of national sovereignty. Another option, also presented in Figure 4, is the Acid Deposition Monitoring Network in East Asia (EANET), which is a regional initiative to install air pollution-related monitors across the region to improve data quality and analysis. Like TEMM, however, China has voiced concerns about EANET's challenge to its national sovereignty. In past years, this has resulted in its refusal to share large portions of its pollution and environment-related data.<sup>37</sup>

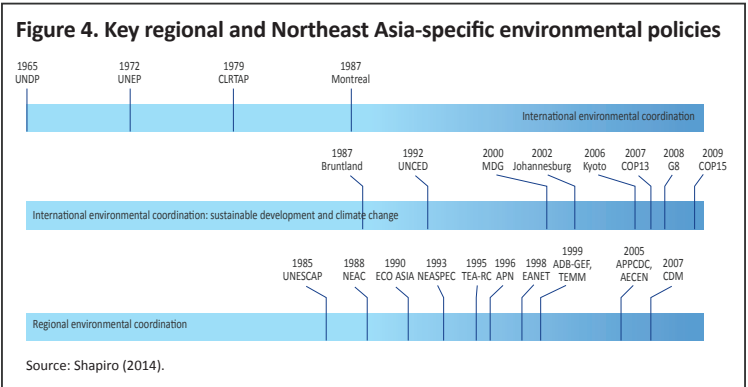
Similarly, Korea has attempted to limit Japan's dominance of EANET by opposing the placement of EANET's network center in Japan. Despite these challenges, the region has effected coordinated management as well as a host of multilateral organizations.<sup>38,39</sup>

Within China, the most readily available tool for addressing transboundary pollution is regulatory enforcement.



A keyword analysis of these 7,000 articles and blogs reveals a number of differences in how the media covers air pollution.<sup>34</sup> It was found that yellow dust-related media content is primarily focused on health-related information and preventative measures. These include topics such as dust masks, air purifiers, humidifiers, advisories, and respirators. This is consistent with efforts by the Korean Medical Association to understand preventative measures for pulmonary diseases through the use of masks with filters, promoting the restriction of outdoor activities, and communicating the risks of exposure to the dust to the public.<sup>35,36</sup>

Media reports covering particulate matter and PM<sub>2.5</sub>, however, highlight the Chinese influence. Virtually all articles on these topics were international in nature. The media thus present the yellow dust problem from an epidemiological perspective while particulate matter/PM<sub>2.5</sub> is framed as a China-based problem. More importantly, there is virtually no discussion in the media about the holistic nature of the yellow dust/particulate matter problem; i.e. that FDI from Korea and Korea-China trade may exacerbate





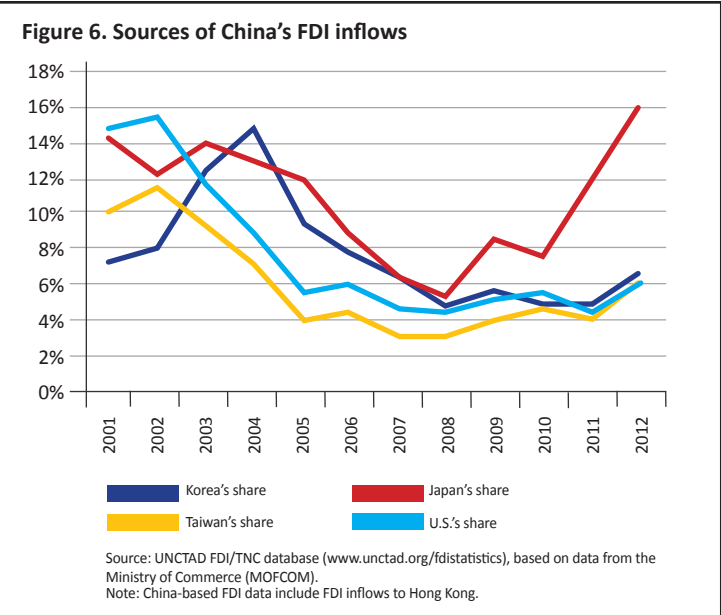
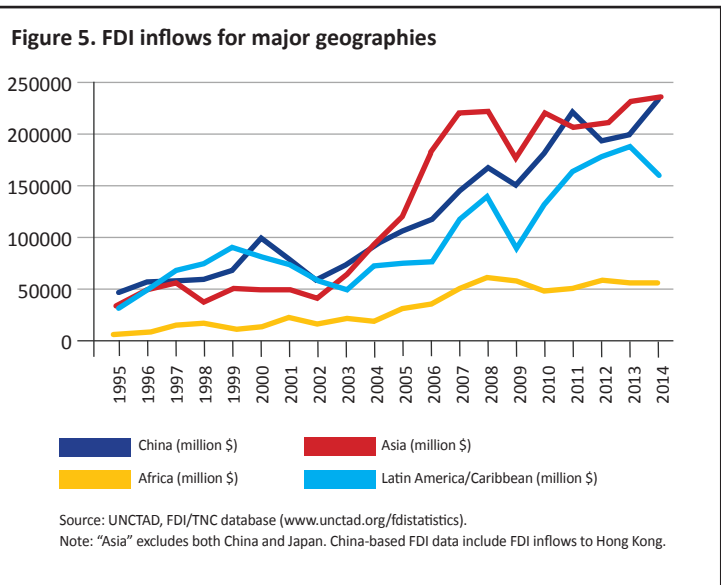
Enforcement has been, however, a chronic problem for the severely understaffed environmental and energy ministries in China.<sup>40</sup> There are several notable updates. First, in early 2016, one-quarter of the 191,000 firms violating environmental regulations in 2015 were either shut down or forced to suspend operations. Environmental Minister Chen Jining stated that “many companies [are] still behaving illegally and local governments [are] still hampering enforcement efforts” of the central government.<sup>41</sup> This represented a continuation of the Supreme People’s Procuratorate’s 18-month investigation and prosecution of more than 2,100 corrupt government officials from January 2014.<sup>42</sup> As well, Minister Chen oversaw the closure of 3,400 companies, 3,700 construction sites, and 3,100 workshops in 2015. This was preceded in 2014 with the allocation of \$1.6 billion for air pollution prevention and control. Coal mining facilities were also to be shut down in order to improve the quality of coal, natural gas supplies were to be made more stable, and clean energy and energy efficient buildings were to be promoted. As a result, nitrogen oxides are expected to be reduced by 5 percent.<sup>43</sup>

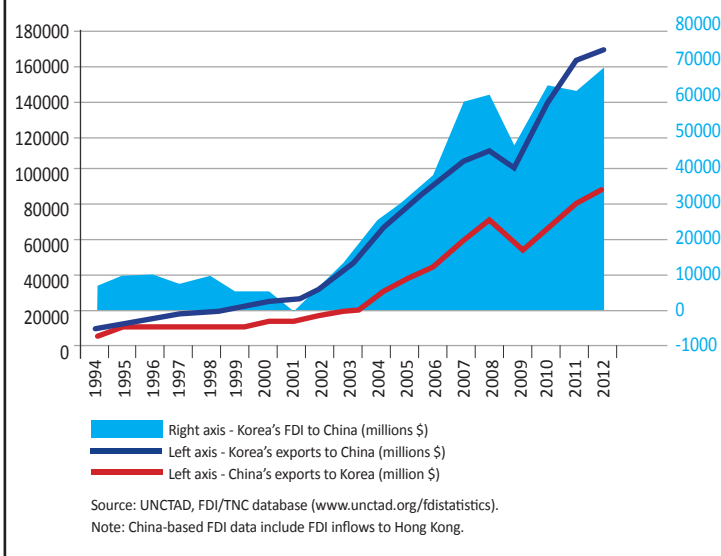
These changes in China’s regulatory landscape, if prolonged, will likely impact foreigners’ decisions to invest there. The exact effects are not necessarily clear, as stronger regulations can lead to increases in FDI,<sup>44</sup> or FDI can yield stronger regulations overall.<sup>45</sup> These results represent the challenges of establishing causality between FDI and regulations and, overall, the complex relationship between FDI and trade relations, a topic to which we now turn.

**China’s Inward FDI & Bilateral Trade with Korea**

The pollution haven hypothesis can be verified in a number of ways. The crucial piece of evidence is that pollution levels increase after multinationals or other international actors invest in the purportedly environmental institution-lacking country. Connecting FDI to pollution haven activities is plagued with obstacles, but updates now confirm that such a connection is both present and clear.<sup>46,47</sup> It is also worth examining the relative levels of pollutants produced in the manufacturing of goods for export, as emissions arising from foreign-invested enterprise exports are higher than those arising from Chinese-owned enterprise exports.<sup>48</sup> In 2006, approximately one-third of sulfur dioxide, one-quarter of nitrogen oxides, one-quarter of carbon monoxide, and exactly 17 percent of black carbon were the result of China’s export-related manufacturing. One-fifth of each of these can be attributed to exports destined for the U.S.<sup>49</sup> This is a story that has slowly played out in China since the 1997 economic stimulus plan stimulated the widespread use of fossil fuels.

In terms of FDI levels, shown in Figure 5, China is the single largest recipient of FDI in the world.<sup>50</sup> Figure 6 describes the source countries, led as of 2012 by Japan’s 16 percent, followed by Korea, the U.S., and Taiwan, each representing approximately 6 percent of China’s overall FDI inflows. To put it another way, one-third of all FDI flows to China originate in the areas that are most likely to be affected by China’s transboundary air pollution. (The most recent activity shows that Japan’s 2013 FDI to China decreased while Korea’s increased, coinciding with strengthened diplomatic ties between Beijing and Seoul.) Samsung Electronics and Kia Motors Corporation are the primary contributors from Korea in the most recent years.<sup>51</sup> There are no guarantees that



**Figure 7. Korea's FDI to China and Korea-China bilateral trade**


larger firms will introduce the more expensive and less polluting production process when setting up operations in China, as shown in a 2005 assessment of Fortune 500 companies operating in China.<sup>52</sup>

There is much at stake for Korea if FDI to China drops. Given the significant relationship between Korea's FDI to China and Korea-China bilateral trade, shown in Figure 7, changes in FDI flows will likely impact Korea's trade balance with China. It should be noted that Korea is unique among all of China's trading partners in that Korea operates on a trade surplus, and the surplus appears to be increasing over time. Yet, if FDI and thus bilateral trade drops, so too would a portion of China's pollution generation. The implication is that trade-related losses could be measured against the frequently undercounted and less understood health consequences of transboundary air pollution.

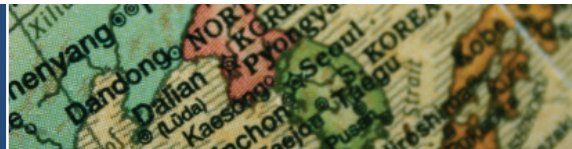
### Cost Assessment

One can assess the economic costs of transboundary air pollution in East Asia in terms of GDP or any of GDP's constituents. For example, pathogens hitching rides on Saharan dust impact agricultural crop yields in the Caribbean and the Americas.<sup>53</sup> As well, transboundary acid rain deteriorates metal machinery and structures. Less well known but nonetheless important for the national income accounts are health effects and its attendant costs. These costs are quite high, equivalent to 80 percent of the total air pollution costs.<sup>54</sup> They also contribute to the creation of the compelling media frame identified earlier that, in turn, has influenced public opinion about the health effects of transboundary pollution.

The health effects associated with specific air pollutants vary according to temporal variance and pollutant type. Short-term effects of the combination of particulate matter and nitrous oxide include an increase in mortality, hospital admissions, and asthma symptoms. For particulate matter alone, there are also cardiovascular effects as well as lung inflammation; for nitrous oxide alone, there is an increase in allergic inflammation. Long-term effects for the combination of both pollutants include a reduction in lung function and an increase in respiratory symptoms. For particulate matter alone, long-term effects also include an increase in chronic obstructive pulmonary disease, lung cancer, diabetes-related effects, and a risk of myocardial infarction.<sup>55</sup> The mechanisms are not fully understood between outdoor air pollution and morbidity and mortality linked with respiratory and cardiovascular diseases,<sup>56</sup> but existing evidence identifies the relationship between dust and human health and, specifically, particulate matter concentrations and increased human mortality and morbidity.<sup>57,58</sup>

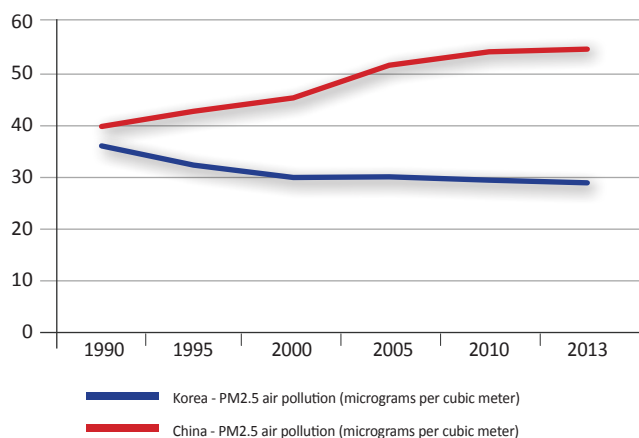
Based on data drawn from the Asian Regional Emission Inventory, premature mortality from PM<sub>2.5</sub> for all of East Asia in 2005 was 520,000 and will range from 450,000 to over 1 million cases in 2020 depending on policy scenario.<sup>59</sup> In Japan specifically, the health effects of yellow dust have been found to increase the potential of heart disease and pneumonia mortality.<sup>60</sup> In Korea, PM<sub>2.5</sub> due to high levels of yellow dust is associated with cardiovascular mortalities.<sup>61</sup> This is consistent with an internal report from 2003 by the Chinese Academy of Environmental Planning estimating that 300,000 people die each year from ambient air pollution as well as a 2005 report by Chinese environmental experts estimating that annual premature deaths from air pollution would reach 380,000 in 2010 and 550,000 in 2020.<sup>62</sup> In sum, and based on a World Bank- and Chinese State Environmental Protection Administration-authored report, the economic costs of air pollution in China are as high as or more than 3.8 percent of China's GDP.<sup>63</sup>

In East Asia, we are discovering both temporal and constitutive differences between the effects of PM<sub>2.5</sub> and larger forms of particulate matter.<sup>64</sup> For example, PM<sub>2.5</sub> has been found to lead to more chronic diseases of the lung and heart than PM<sub>10</sub>.<sup>65</sup> Mean annual exposure to PM<sub>2.5</sub> for Korea and China is presented in Figure 8, showing 25 percent growth in China from 1990 to 2013.<sup>66</sup> Given that fossil fuel use plays a big part in of particulate matter concentrations and that China-based nitrogen oxides are especially prone to travel across borders,<sup>67,68</sup> Figure 9 presents data on China's and Korea's fossil fuel energy consumption (as a



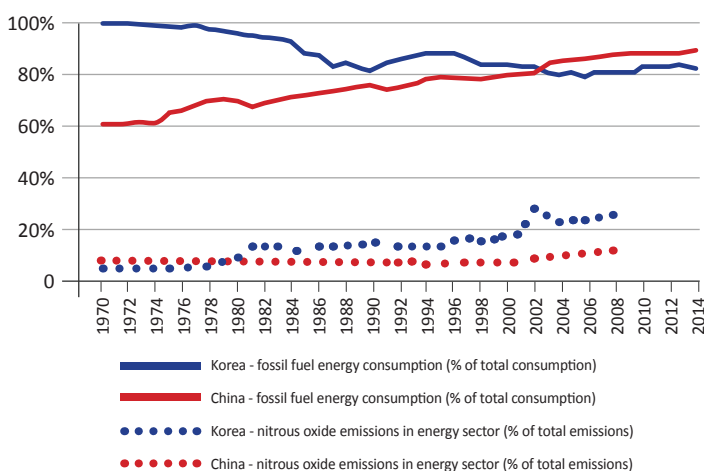
percentage of total energy consumption) and nitrous oxide emissions in the energy sector (as a percentage of total emissions). While nitrous oxide emissions as a percentage of total energy sector emissions have increased more rapidly in Korea vis-à-vis China, fossil fuel energy consumption as a percentage of total consumption has increased in China while it has decreased in Korea. Finally, in Figure 10, I present longitudinally the number of respiratory deaths in Korea and the per capita consumption of tobacco in Korea, the latter acting as a control for respiratory conditions in general. There has been a decline in tobacco use

**Figure 8. Mean annual exposure to PM2.5**



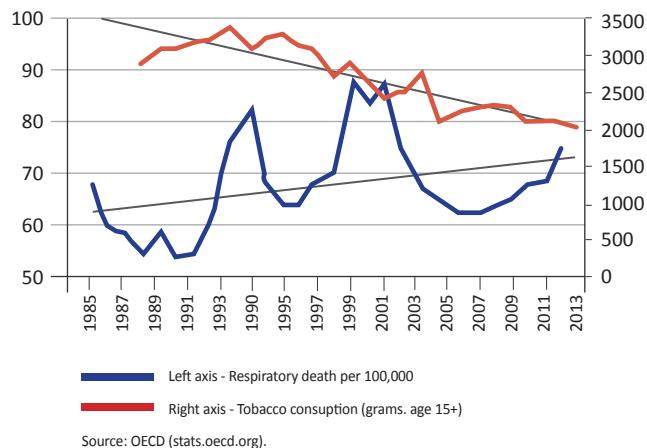
Source: World Bank World Development Indicators (<http://data.worldbank.org/data-catalog/world-development-indicators>)

**Figure 9. Fossil fuel consumption and nitrous oxide emission rates**



Source: World Bank World Development Indicators (<http://data.worldbank.org/data-catalog/world-development-indicators>).

**Figure 10. Korean respiratory-related indicators.**



Source: OECD (stats.oecd.org).

over time while the number of respiratory deaths has increased. For purely exploratory purposes and without claiming causality, I have also conducted a correlation analysis of the aforementioned measures as well as several others. Among those correlations that are significant, the number of respiratory deaths in Korea was found to be negatively associated with FDI flows to China. Respiratory deaths were also found to be negatively associated with trade between Korea and China. Respiratory-related deaths are, however, positively associated with increases in Korea's electrical production from oil, gas, and coal. They are also positively associated with China's fossil fuel energy consumption. Korea's, not China's, nitrous oxides emissions are strongly associated with Korean respiratory-related deaths. FDI flows from Korea to China are positively associated with decreases in Korea's fossil fuel energy consumption and positively associated with China's fossil fuel energy consumption. At the same time, Korea's fossil fuel energy consumption is negatively associated with China's electrical production from oil, gas, and coal, with China's fossil fuel energy consumption, and with China's nitrous oxide emissions.

On the basis of just these associations, one could argue – and with great trepidation given modeling deficiencies – that Korea's FDI flows to China are not on their own responsible for Korea's health costs as measured by the number of respiratory-related deaths. Yet, given the positive relationship between Korea's FDI flows to China and China's increased fossil fuel energy consumption – the latter of which is positively associated with respiratory deaths in Korea – one could tentatively claim that the pollution haven-related behavior of Korean investors is connected to



Koreans' overall health. We of course cannot ignore the fact that Korean respiratory deaths are also positively related to Korea's electrical production from oil, gas, and coal, but the presentation of these data establishes crucial connections among health effects, FDI flows, and transboundary air pollution.

**Prescriptions and Conclusions**

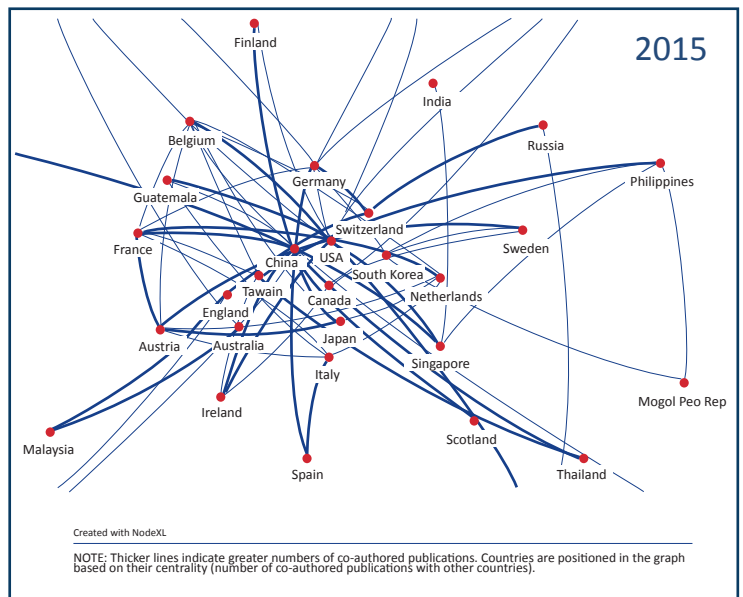
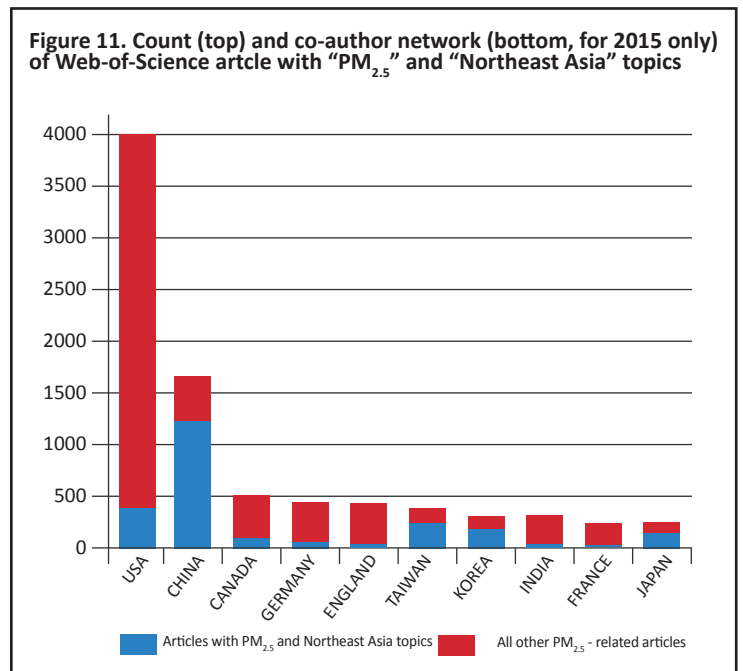
The pollution generated in China is not solely China's responsibility despite the fact that this frame dominates media-based reporting on the issue. I have shown that trade and FDI from Korea are connected to transboundary air pollution, and that there are likely health consequences for Koreans; i.e. exported pollution ultimately results in internalized health costs. Whether this is because Korean companies are investing in China chiefly for lower environmental regulations or to benefit from lower labor costs is of little consequence. It all points to a simple but untenable solution: Korea must decrease its FDI in China. The better, more practical solution is the further deepening of Korea-China cooperation, building upon TEMM and EANET while focusing expressly on opportunities for technology transfer and international R&D collaboration. Indeed, FDI can ultimately contribute to crucial technology transfers.

Korea must support China's efforts to rein in violators of Chinese environmental laws. This can occur through the release of official statements of support from the Korean Ministry of the Environment and the Korean Ministry of Trade, Industry & Energy whenever high-polluting China-based enterprises – particularly those in which Koreans are heavily invested/own – are identified and forced to close or improve their production processes. Indeed, this will greatly change the domestic media-based frame from one that highlights China as the source of pollution to one that details the complex connections between international economics and transboundary air pollution. Second, these same Korean ministries should more actively support the Chinese government's development and dissemination of a comprehensive emissions report that can be used to identify the sources at home, namely Korean investors in high-polluting enterprises in China. These polluters can subsequently be targeted in Korea as well as in China. This process would rely on a more elaborate version of EANET, as there will need to be many more air pollution monitoring stations across China, some situated very close to the Korean-invested enterprises.

China must continue to work internally as well as look abroad for technological solutions to the transboundary air pollution problem, as effective and sustained growth will ultimately be a function of continued manufacturing for exports while reducing

pollution emissions. This effort would thus build on the \$220 billion invested in China in wind, solar, hydropower, and clean-coal technologies during the 2008-09 recession.<sup>69</sup> From the Korean perspective, the technology sharing process can be incentivized for Korean investors in China-based enterprises, particularly those that are energy intensive in their production process. Such incentives may include subsidized intellectual property licensing payments or a health cost offset. These technological solutions are building on basic research efforts that identify specific innovation needs.

**Figure 11. Count (top) and co-author network (bottom, for 2015 only) of Web-of-Science article with "PM<sub>2.5</sub>" and "Northeast Asia" topics**







On that front, an analysis of the co-authorship network of scientists and researchers in the region reveals that there is a network within and extending beyond Northeast Asia that focuses on the region's PM<sub>2.5</sub> problem, shown in Figure 11. When research is oriented around air pollution, as is the case in cross-national research collaborations in Northeast Asia,<sup>70</sup> a foundation is laid for collaborative patenting efforts and the creation of a growth trajectory reliant upon green technologies.

Future research about transboundary air pollution must continue to be holistic in nature. With sufficient understanding, our knowledge of the Northeast Asian case will prove useful for

other transboundary air pollution geographies, such as the Saharan dust that disperses in much larger quantities and over much greater distances than Asian dust.<sup>71</sup> The lessons learned from Northeast Asia can become yet another model for economic and sustainable development in parts of the world faced with similar environmental conditions.

## Endnotes

- <sup>1</sup> "Korea," throughout this paper, represents South Korea.
- <sup>2</sup> Lin, J., Pan, D., Davis, S. J., Zhang, Q., He, K., Wang, C., ... Guan, D., "China's International Trade and Air Pollution in the United States," *Proceedings of the National Academy of Sciences of the United States of America*, 111(5) (2014): 1736-1741.
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