China-Based Air Pollution and Epistemic Community Building in the Northeast Asian Region

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Introduction

There is a ‘common pool’ resources problem in Northeast Asia with regard to air pollution, and potentially hundreds of millions of people in Northeast Asia are affected. This air pollution represents a violation of the 1979 UN Convention on Long-range Transboundary Air Pollution, as it originates primarily in Mongolia and northern China as yellow dust but “has adverse effects in the area under the jurisdiction of another State at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources” (Article 1(b)). Both natural and anthropogenic processes are at work, though, making it difficult to create practical policy prescriptions. Specifically, air pollution from Chinese industry, manufacturing, and transportation attaches to the yellow desert sand/dust that blows eastward out of northern China and Mongolia (presented in panel (b) of Figure 1), settling eventually in the eastern region of China but also in Korea, Japan, and beyond.

[Figure 1 here]

Industrial practices in eastern China are responsible for up to 70 percent of the acid rain present in the Yangtze River Delta (Ge *et al*. 2015). Furthermore, pollution emanating from China in the form of particulate matter ten micrometres or less in size (PM_{10}) amounts to 13-26 percent of contributing sources in Korea and Japan (Li *et al*. 2014) and 30 percent of contributing sources in Taiwan (Tsai *et al*. 2014), shown graphically in Figure 2. Naturally occurring dust aerosols contribute 46.5 percent, 11.7 percent, and 11.0 percent of the PM_{10} concentrations in China, Korea, and Japan, respectively (Li *et al*. 2014). As of 2010, the highest concentrations of pollution 2.5 micrometres or less in size ($PM_{2.5}$) were in China (73 micrograms); in Korea, $PM_{2.5}$ concentrations were more than double those of countries in the European region (38 micrograms) (World Bank 2015). $PM_{2.5}$ pollution emanating from China has impacts on downwind areas (Han *et al*. 2015), and the health effects are extreme (see also Li *et al*. 2014 and Sun *et al*. 2010). The construction sector in China is a particularly significant contributor to increases in $PM_{2.5}$ (Meng *et al*. 2015), with impacts measured as far away as the Pacific Northwest of the USA. (Fischer *et al*. 2009).[1] For Korea alone, the costs in 2002 were estimated to range from $3.9 to $7.3 million (Jeong 2008). Yet differences between immediate and delayed effects of yellow dust make it difficult to measure these costs, as shown in Ai and Polenske (2008).

[Figure 2 here]

The common pool resources problem under study here also reflects regional politics, which has been known to trump the ecological interdependence of Northeast Asia (Nam 2002). A prevailing view is that economic costs, a lack of regional agreement, and an absence of researchers to address the problem perpetuate the absence of coordination in Northeast Asia (I.

Kim 2007). It is argued here that this position must be revised: environmental regionalism thrives, and the naturally and anthropogenically occurring air pollution arising from northern China is being addressed incrementally through increased urban-based and science policy-related efforts. The roots of Northeast Asian environmental regionalism go back thirty years, beginning with the efforts of the Asia Development Bank, the UN Environment Program, the state of environment reports prepared by the UN Environment and Social Commission for Asia and the Pacific (UNESCAP), the Northeast Asian Conference on Environmental Cooperation (NEAC) and the Environment Congress for Asia and the Pacific (ECO ASIA) (Shapiro 2012). Transboundary air pollution has been specifically addressed through the Tripartite Environment Ministries Meeting (TEMM), the Northeast Asia Sub-regional Program on Environmental Cooperation (NEASPEC), the Northeast Asian Training Center for Pollution Reduction in Coal-fired Power Plants and North East Asian Center of Environmental Data Training (NEACEDT) and the Acid Deposition Monitoring Network in East Asia (EANET).

There are two shared themes among regional organisations such as TEMM, NEASPEC, NEACEDT and EANET. First, they all focus on data collection and dissemination. Second, they all prioritise education and information provision to policymakers and the general public. Rather than engage in a comparative analysis of these different organisations (cf. Tsunekawa 2005), the focus here is on EANET, which fosters the sharing of knowledge and experience regarding air pollution-related data collection. More importantly, EANET is seemingly apolitical. Its members, despite being affiliated with their countries' respective environmental bureaucracies and science communities, are expressly focused on how to improve, standardise, and disseminate information to others about the accurate collection of data related to air pollution.[2]

The success of EANET and other similar organisations can be attributed to their focus on science, data accuracy, and data dissemination, all of which produce informal institutions such as intra-regional research collaborations. We must thus examine opportunities for these collaborations in the context of EANET and possibly other region-fostering institutions in Northeast Asia. Despite the political costs at the individual country level and the ecological costs at the regional level, science and technology have continued to thrive across the region (Shapiro 2014a, 2014b). More importantly, when researchers establish cross-national ties, the resulting environmental regime is at least partly determined by what Haas (1990) calls an 'epistemic community'—that is, a group of individuals who are politically empowered, knowledgeable, and motivated around a shared cause. The crucial aspect of this community is that its impacts are a function of its expertise. Its conclusions are thus rooted in scientific norms. Of course, this does not preclude scientists and researchers from being affected by domestic policies.

To better understand the nexus of EANET and the epistemic community of researchers in Northeast Asia, this paper attempts to answer the following questions: What is the nature of environmental coordination in Northeast Asia? Is there a role for polluted urban centres in affecting national priorities to address cross-border air pollution? What are some of the relevant developments thus far to address cross-national air pollution in Northeast Asia, including specific inventions/innovations developed to limit yellow dust-related effects? Finally, what future steps should be taken to ensure that any identified progress continues?

Understanding environmental coordination at the regional level

With or without the yellow dust-related pollution, there are two principal ways that one can describe prospects for environmental regionalism in Northeast Asia: politics predicts environmental regionalism, or environmental regionalism predicts politics (Lee 2001, 2002). The reality in Northeast Asia is that both situations are present, albeit to varying degrees. Regional environmental governance has been weak because non-state actors have been relegated to roles of less influence, there has been poor coordination around environmental initiatives, and there have been few clear outcomes from reducing environmental harms (Komori 2010). At the same time, seasonal fluctuations of the pollution arising from China has created a groundswell of public support for policy change, focused the attention of the scientific community on the problem, and focused the government's R&D budget on solutions for yellow dust-related pollution.

The creation of a regional environmental regime is extremely complex (Keohane & Victor 2011), and the Northeast Asian case in particular has been plagued with a number of confounding factors. For example, in China, top-down environmental mandates alone do not effect real reductions in environmental pollution (Kostka 2015; Lo 2015). Thus, increased decentralisation and the inclusion of non-state actors into the process must continue if the environmental components of the recent Five-Year Plan (No. 12, 2011-2015) are to be met (Kostka & Mol 2013; Mol 2009). The vehicle for such changes is the urban geography, as cities are typically the most environmentally challenged, politically motivated and technologically innovative, providing an ideal context through which improved sustainability efforts can be identified and employed

(McHale *et al*. 2015). Public dissatisfaction has been documented particularly in Guangzhou (Zi *et al*. 2012), evidenced by the recent violent protests against the creation of an incinerator plant in Luoding (BBC News 2015).[3] Chinese citizens are even willing to offset economic gains with greater levels of environmental protection in urban areas ranging from Lanzhou (Zhao & Yang 2007) to Hangzhou (Chen & Shao 2007). Indeed, increased levels of air pollution over time have led to a relative shift in emphasis of China's urban centres away from economic growth and toward, among other things, environmental issues (Huang, Yan & Wu 2016). With 50 percent of the population in China living in urban centres (719.4 million people) (World Bank 2015),[4] these concentrated concerns and demands for improvements in quality of life can no longer be ignored by the government (Zheng & Kahn 2013).

Other confounding factors in the development of a Northeast Asian environmental regime, such as improving the existing pollution measurement methods across the region and thus providing data upon which regional discussions can be based, are addressed directly through programs such as EANET. Other confounding factors, however, are exacerbated given historical tensions and concerns about hegemony. China, for example, has claimed that EANET challenges its national sovereignty (Tsunekawa 2005), and that its locally accumulated pollution and environment-related data does not have to be shared (Brettell 2007). Underlying these claims is the argument that dust storms carrying pollutants are natural despite evidence that desertification, the cause of the dust storms, is anthropogenic. Before 1992, China had even denied any effects of transboundary acid rain on its neighbors (Brettell & Kawashima 1998). Korea was also initially opposed to the institutional setup of EANET, protesting against the Japan-based headquarters of EANET's network centre. EANET has avoided these hazards primarily because it acknowledges at an institutional level both local and international interests, and its organisational structure reflects both domestic and regional concerns about the collection and dissemination of pollution data.

Regionally, we can expect that the decrease in the number of international players increases opportunities to address the common-pool resources problem. This is illustrated in the 'club' model, evident in East Asia (Kelley 2013), that describes how collective action problems such as climate change can be addressed with greater efficacy when international negotiations are limited to those countries that matter the most (Victor 2011). Ultimately, the club approach, through the outreach efforts of scientists and researchers, bolsters the effects of EANET and other similar institutions. This claim is rooted in existing research on international environmental regimes, such as Young's (1990) study of cross-national efforts to mitigate suboptimal outcomes with respect to environmental change, specifically ozone layer depletion, global warming and biodiversity loss. In light of the club approach, Young's (1990) focus on non-state actors is invoked, 'epistemic communities' in particular: 'transnational networks of knowledge based communities that are both politically empowered through their claims to exercise authoritative knowledge and motivated by shared causal and principled beliefs' (Haas 1990, p. 349). The epistemic community that is particularly emphasised here is comprised of scientists and researchers that are able to resist political concerns while simultaneously informing policymakers. These scientists and researchers are not independent of the policymaking process, but can affect international cooperation at times.[5]

The transboundary air pollution and the relatively apolitical nature of EANET is assumed to result in scientists and engineers having a clear influence on overall regional attention to the problem of transboundary air pollution. What continues to confound the development of environmental regionalism in Northeast Asia is variance in how each state addresses the problem of yellow dust, particularly the extent to which China accepts its responsibility for the air pollution in its neighboring countries. There are a number of cross-state policies designed to address pollution in Northeast Asia (Shapiro 2012, 2014b), and perhaps EANET addresses this directly with its major goal of improving data collection and dissemination. We can attempt to measure at least the sharing of scientific information—inventions and innovations related to air pollution monitoring in particular—by identifying instances of international R&D collaboration within Northeast Asia. By doing so, though, we relegate well-established research that acknowledges the role of trade (Haggard 2013, Yoo & Kim 2015), finance (Sohn 2012), and public and private organisations (Abbott 2012; Abbott *et al*. 2013; Bulkeley *et al*. 2012).

International R&D collaboration actively contributes to a country's economic growth (Frantzen 2002; L. Kim 1999; J. Park 2004; Shapiro & Nugent 2012). Building on R&D-based endogenous growth theory (Aghion & Howitt 1992; Helpman 1993; Romer 1990), it has been shown that 'green' innovation benefits both the producing sectors' comparative advantage and their current output (Fankhauser *et al*. 2013). Yet there is also a disincentive for knowledge to be shared across countries if it results in economic losses. We know that China now plays a dominant role in global research output and networking (Wagner, Park & Leydesdorff 2015), and, with respect to yellow dust-related policies and programs, we also know that the economic benefits are likely to be greater overall than the environmental benefits, at least over time (Guo *et al*. 2008). This is likely because countries are conflicted about investing public R&D funds in pollution-reducing technologies, particularly air pollution, that have differing impacts between the origin and where it is deposited. How benefits are distributed across countries is also important. Greater benefits for more powerful countries that are disproportionately benefiting from green technology incentivise R&D investment, while concerns about non-reciprocity disincentivise investment (Urpelainen 2011). We must thus assess whether research on yellow dust-related technology is occurring in Northeast Asia and whether it is being done collaboratively.

Methods

To understand the nature of the yellow dust-oriented epistemic community across Northeast Asia, descriptive and interview-based analyses are the primary vehicles. The analysis below begins with an examination of EANET itself, as there may have been changes in the orientation of this regional organisation that reflect both the increased threat of the yellow dust-related disaster as well as shifts in EANET's research focus. Given that EANET provides the air and water pollution data for scientists to analyse and model in order to make informed prescriptions to policymakers, the connection between EANET's efforts can be correlated with the relevant scientific and technological output of these countries. To this end, the catalog of EANET's activities shall be triangulated with the patenting and publications record for air pollution-related work. These are compiled from several sources, primarily the US Patent and Trademark Office's (USPTO) database (USPTO 2015) and the Web of Science publications database (Thomson-Reuters 2015).

The following analysis is designed along the lines of a large body of research that uses patents as a proxy for innovation (see, for example, Griliches *et al*. 1990; Hall *et al*. 2002; Schmookler 1966). Air pollution-related patents specific to either 'yellow dust' or 'yellow sand' or that reference $PM_{2.5}$ may fall within the classification of the USPTO Environmentally Sound Technologies (EST) Concordance (USPTO 2009), specifically patents addressing 'environmental purification, protection, or remediation – disaster in atmosphere.'[6] When these particular patents are not sufficient in number, data have been collected for "air pollution" patents as determined by a keyword search of patent descriptions. This also applies to USPTO patent data sourced from other entities, such as the OECD. With sufficient data—and if there are cross-patenting efforts within Northeast Asia—we can infer that an epistemic community is present that addresses the yellow dust issue (or at least air pollution). We know that China is now one of the world's leaders in terms of the generation of green R&D patents, where 'green' is based on patents falling under the EST Concordance. As well, China allocates a large amount of its public R&D budget to encourage collaboration across borders (Cainelli *et al*. 2012; Perkins & Neumayer 2008). Within Northeast Asia, however, Japan remains the overall greatest producer of green patents (Shapiro 2014a).

Complementary to yellow dust-related patents is publication output. Research on publications has shown, for example, that China's greatest overall international collaborator in terms of publication output is the USA (Wagner *et al*. 2014). If this is also confirmed with regard to yellow dust-related research, the epistemic community focusing on transboundary air pollution would have expanded all the way to the USA.[7] There are a number of ways in which one can tabulate a country's publication output on a particular subject: by journal or journal cluster or by topic/keyword. I have opted for a rather conservative measure of publication output by basing the keyword search of article abstracts on whether the term '$PM_{2.5}$' is included. As before, frequency of collaborations across the Northeast Asian region will be examined.

Where relevant, interview-based data will also be analysed. Interviews were conducted solely with stakeholders and experts in Korea; however, while the omission of Chinese, Japanese and Taiwanese experts is significant, the value of the Korean-based interviews should not be discounted. As shown in Shapiro and Gottschall (2011) and Shapiro (2012, 2014a), Korea has played a crucial role in engaging countries within the region as a 'middle power' (S. Kim 2014) and a regionally centred nation. Key actors in Korea were identified through the probing of members of the Presidential Commission on Sustainable Development,, now called the Presidential Committee on Green Growth (see GNNCSDS n.d.). This commission arose from the Framework Act on Low Carbon, Green Growth, effective on April 14, 2010, to address climate change and energy issues and to target the growth of green industries. Employing a snowball sampling strategy, a sample of nineteen individuals—eight affiliated with the commission and eleven recommended by members of the commission—was established, and interviews were conducted in the summer of 2014.[8] The survey instrument focused on the following topics: leadership roles within Northeast Asia, pollution's effects on environmental coordination efforts, political and economic forces affecting coordination, technology-oriented goals affecting coordination, and prospects for shared norms across the Northeast Asian countries in dealing with climate change via technology.

Results

A cataloging of all of EANET's activities over time, or at least since formalising its mission in January 2001, reveals a number of changes since it began its 'regular phase activities' (EANET 2010). Presented longitudinally in Figure 3 and reflecting changes in the number of meetings/fellowships/etc. held, EANET administrators have shifted the organisation's focus in several ways. The steady increase in research fellowships since 2006, the integration of workshops designed for policymakers, and the continued focus on public awareness is emblematic of its new approach to transboundary pollution. The committee meetings that address the state of air pollution in East Asia since 2012 also indicate that EANET is making a clear and deliberate connection between national reporting efforts and the region's overall environment.

[Figure 3 here]

Two measures of patents are presented here. The first, reflected in Figure 4, is a hand-collected dataset based on a keyword search of 'air pollution' in issued patents.[9] Also included in these findings are data for the USA, a country that represents a benchmark for maximum patenting output. Figure 4 shows that Japan's focus on air pollution patents has waned slightly since the turn of the century; however, Korea's has been on the rise in the last five years and especially from 2013 to 2014.[10] Overall patenting efforts, reflected by the number of patent applications related to air pollution technologies as shown in Figure 5, indicate that the global focus on air pollution abatement is really still in its infancy, beginning in the late 1990s, and that Japan and the USA have been much more active than the other countries.[11] However, to compare the findings in Figure 4 with those in Figure 5, Korea's efforts have been the most effective, as the number of its issued air pollution-related patents now exceeds that of Japan. Despite these findings, few if any of these patents have occurred through Northeast Asian collaborations. With regard to air pollution-related innovations, the few collaborations that have occurred were primarily between Japan and the USA.

[Figure 4 here]

[Figure 5 here]

A search of articles indexed in the Web of Science (Thomson-Reuters 2015) for the keyword '$PM_{2.5}$' in the abstract reveals increased focus both overall and with specific regard to Northeast Asia. Shown in Figure 6, publications focusing on $PM_{2.5}$ increased steadily from the late 1990s, dipped slightly in 2009 and 2010, and then have increased since then. Highlighted among these are publications that also have topics mentioning any of the Northeast Asian states, i.e. China, Korea, Japan, and Taiwan. Publications focusing specifically on the Northeast Asian region in whole or part have been increasing exponentially since 2010. Shown in Figure 7, those articles covering the issue of $PM_{2.5}$ with regard to Northeast Asia are primarily produced in the Northeast Asian states, although researchers in the USA are the second-most frequent producers of research on this subject. China's efforts to address $PM_{2.5}$ have nearly paralleled the amount of published research produced by the USA.

[Figure 6 here]

[Figure 7 here]

Unlike the pattern for air pollution-related patents, researchers in the states under examination here are likely to collaborate with each other to generate air pollution-related publications. Shown graphically in Figure 8, among the 1,668 publications on this topic published by Chinese researchers, 4.9 percent are with Japanese researchers, 2.6 are with Taiwanese researchers and 1.6 percent are with Korean researchers. Of Korea's 318 publications, 8.2 percent are with Chinese researchers and 6.6 percent are with Japanese researchers. Among Japan's 271 publications, 30.3 percent are with Chinese researchers, 7.7 percent are with Korean researchers and 2.6 percent are with Taiwanese researchers. And, among Taiwan's 408 publications, 10.5 percent are with Chinese researchers and 1.7 percent are with Japanese researchers. The function of China in fostering an epistemic community of researchers in Northeast Asia on the subject of $PM_{2.5}$ is phenomenal, particularly in light of Japan's dominance in green-related research overall (Shapiro 2014a). While the USA is the prevalent partner for each of these countries save Japan, we do not know the extent to which USA-based publication partnerships are a function of USA-based foreigners collaborating with researchers back home. However, this should become less a concern given research identifying China as the dominant producer in global research output and networking (Wagner *et al*. 2015).

This publication-based data is corroborated with interview analysis, which revealed a common theme among most interviewees: specifically, that the Northeast Asian states are collectively focused not only on the yellow-dust problem but on prospects for increased nuclear power plants in China. Talks at the regional level tend to focus on the fact that the prevailing winds blow west-to-east and, thus, airborne pollution generated in China extends far beyond the country's political borders. Given these winds, nuclear disasters are a point of concern for China's neighbors, as any failure in nuclear plants sited on China's coast will have impacts similar to those of transboundary yellow dust. Interviewees highlighted that the hazards from a power plant failure will be even more devastating than the impact of transboundary pollution in the form of $PM_{2.5}$.

[Figure 8 here]

Conclusion

Transboundary air pollution from China represents an environmental disaster in the clearest sense. When the facts of the pollution are debated, challenged, or disputed, EANET and other regional organisations like it provide an avenue out of the quagmire in which regional discussions may be trapped. EANET does not merely assign blame for transboundary pollution but highlights data collection and dissemination. Separating the politics and historical animosity from the environmental disaster is an ideal option to address the transboundary air pollution originating in China. Further, many of the changes that have occurred in patent and publication output overlap with the institutional changes at EANET. One cannot yet claim causality, but there are clear correlations between EANET's second-generation approach to transboundary pollution and the increase in attention to the issue by the research community. This is evidence of an epistemic community of researchers, and it is growing larger with each passing year.

The different outcomes between the patents and publications analysed above are a function of the science infrastructure. Publication-based research is generated for the purpose of expanding the larger body of scientific research, while patents are designed to limit the sharing of intellectual property and provide a temporary monopoly to the patent owner. The temporary monopoly is needed to provide the incentive to engage in the pursuit of new innovations. Publications, on the other hand, serve to present, test, and revise theory in order to improve our overall understanding of specific phenomena. If we separate the scientific community from the innovation community, the latter of which engages in patenting activities, the findings presented earlier confirm what was proposed in Urpelainen (2011): differences in the benefits from green technology among countries decrease investment in the generation of such technologies. It should not necessarily be a surprise, thus, that there are great differences between the amount of air pollution-related patents and publications but also between the amount of cross-national collaborations via patents and publications.

Future research would do well to track the effects of these epistemic communities on improvements in cross-border pollution management and mitigation. The findings presented here represent solely an alignment between research output and existing efforts such as EANET, but it will eventually be possible to identify the causal connections between the two if research efforts continue unabated. Future research must also account for parallel organisations' efforts to create an epistemic community around the issue of transboundary air pollution. It is worth noting that

NEASPEC's meetings in 2013, 2014 and 2015 seemed to subsume the goals of EANET. Indeed, EANET's data were used as part of NEASPEC's modeling of the source-receptor relationship with regard to transboundary air pollution. NEASPEC also attempts to integrate EANET, the Scientific Research Institute for Atmospheric Air Protection (SRI Atmosphere), the Joint Research Project on Long-Range Transboundary Air Pollutants in Northeast Asia, and a host of universities and (domestic) government research institutes. Further examination of these cross-organisation dynamics will provide an even better understanding of how transboundary air pollution is being addressed.

Future research should also focus attention on the general public. EANET focuses on acid deposition monitoring, data curation and analysis, quality control of monitoring methods across countries, training of monitoring methods, and research on acid deposition and air pollution. There is also a clear focus now on disseminating these findings to the layman (EANET 2011), a practice which will ultimately challenge claims that EANET is apolitical. Thus far, the general public has been largely ignored, but it is nonetheless critical that we understand precisely how EANET's activities are connected to public perceptions of transboundary pollution. These perceptions can translate into policy action if there is a groundswell of support, and this in fact seemed to happen after the US Embassy in Beijing installed an air quality monitor on its roof. The accompanying Twitter updates of air quality based on EPA standards have led some to speculate that, since Twitter posts from this monitoring station became the preferred information source for many Beijing residents, it provided the impetus for Beijing to ultimately update its $PM_{2.5}$ monitoring infrastructure (Roberts 2015).[12] Whatever the case, a complete assessment of public opinion will provide the necessary bridge between EANET's recently revised orientation and policy outcomes.

Epistemic communities are key to solving common pool issues. Their foundation in scientific pursuits and their overarching expertise about a shared cause enables them to stand slightly above the political fray, as analyses of long-term international R&D networks reveal that they are not analogous to political networks (Wagner *et al*. 2015). On this point, Northeast Asia shows considerable promise in dealing with transboundary air pollution, as Chinese urban planners readily adopt best practices from abroad (Wu, Xiang & Zhao 2014). This will be crucial, as air pollution levels are dropping in the coastal urban centres while increasing inland (Zheng *et al*. 2014). In this way, the current environmental challenges and responses in China—and thus the rest of the region—provide the foundation for sustainable development of inland/westward urban areas.

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[1] The effects of China-originating yellow dust and soot are felt even in the USA, where cities like Los Angeles receive one extra day of pollution per year from China's production of goods for export (Lin *et al.* 2014).

[2] Even under these strict targets, EANET has not been free of politicisation. China was reluctant to join EANET initially, as its leaders correctly assumed that the group would exert pressure on China to cooperate with its neighbors to reduce pollution (Tsunekawa 2005). And Korea, in order to counter the hegemony of Japan in fostering EANET, founded the Joint Research Project on Long-rang Transboundary Air Pollutants in Northeast Asia (Yoshimatsu 2014).

[3] Chinese citizens also use social media to share images about air pollution in Beijing, including posts from celebrities (Gardiner 2014), prompting acknowledgement of the problem by public officials.

[4] In Korea, the urban population is even more concentrated: 82 percent of the Korean population is urban-based, amounting to 41.2 million people (World Bank 2015).

[5] A classic example of how this has occurred is the 1987 Montreal Protocol. Studies conducted in the pre-Montreal Protocol period showed that international controls on chlorofluorocarbons would help protect the ozone layer. This argument founded the efforts of a transnational epistemic community of atmospheric scientists to influence the positions of the UNEP and the USA (Haas 1990).

[6] Included here are those patents dealing with electric or electrostatic field (e.g., electrostatic precipitation, etc. [class/subclass: 95/57+]) and liquid contacting (e.g., sorption, scrubbing, etc. [class/subclass: 95/149+]).

[7] This may not be inappropriate given the impact of yellow dust-related pollution on the west coast of the USA (Fischer *et al.* 2009).

[8] From the first group, specialists were interviewed from KEEI, the University of Science and Technology, Yonsei University, Seoul National University (2), Sejong University, Chung-Ang University and the KDI Graduate School. From those recommended by commission members, those interviewed are from the KDI Graduate School, STEPI (2) , KISTEP, KETEP, GTCK, KEMCO, Jeju Technopark, KRIED and KEITI (interviewed together), Seoul National University and Dongguk University.

[9] Note that ‘air pollution’ was the most appropriate proxy for yellow dust-related patenting output; the search for ‘yellow dust’ or ‘transboundary pollution’ yielded virtually no results in the USPTO’s patent search engine.

[10] For ease of exposition, the focus of an individual country is representative of the focus of that country’s research community.

[11] Declines in the most recent years are not evidence of declining patenting activity but, rather, represent the lag time required for patents to move from ‘application’ to ‘issued’ status.

[12] Air pollution-related information has in fact been distorted by the Chinese government (Ravetti *et al.* 2014), although such practices seem to have ended (at least in Beijing) in 2012 (Stoerk 2015).

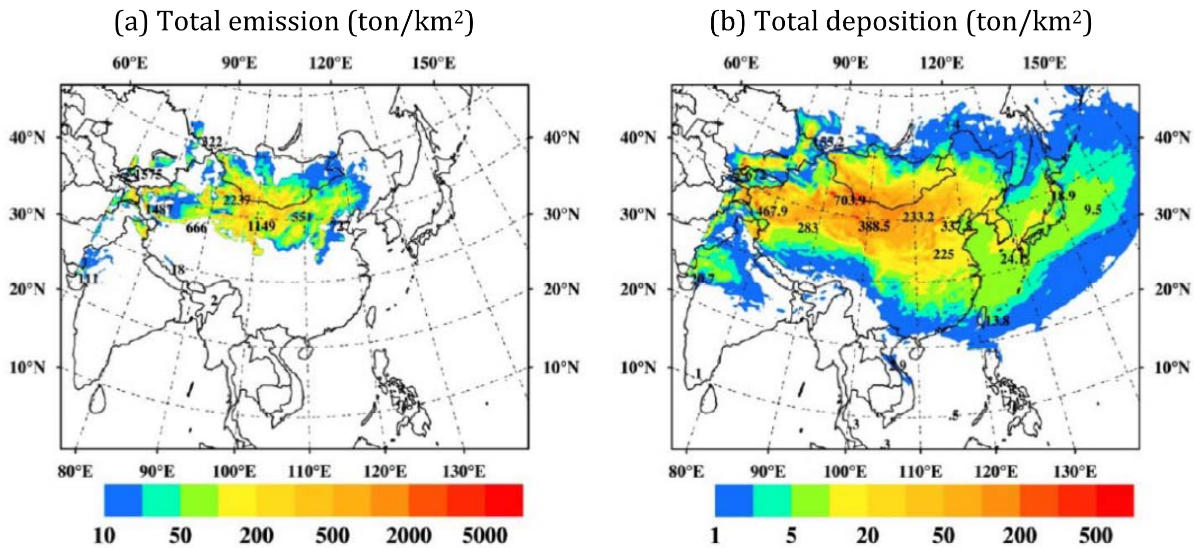


Figure 1. Spatial distributions of annual emissions and deposition of yellow dust in 2010
Note: Based on the ADAM2 model presented in Park et al. (2010).
Source: EANET (2015) [copyright permissions pending].

(a) Spring

(b) Fall

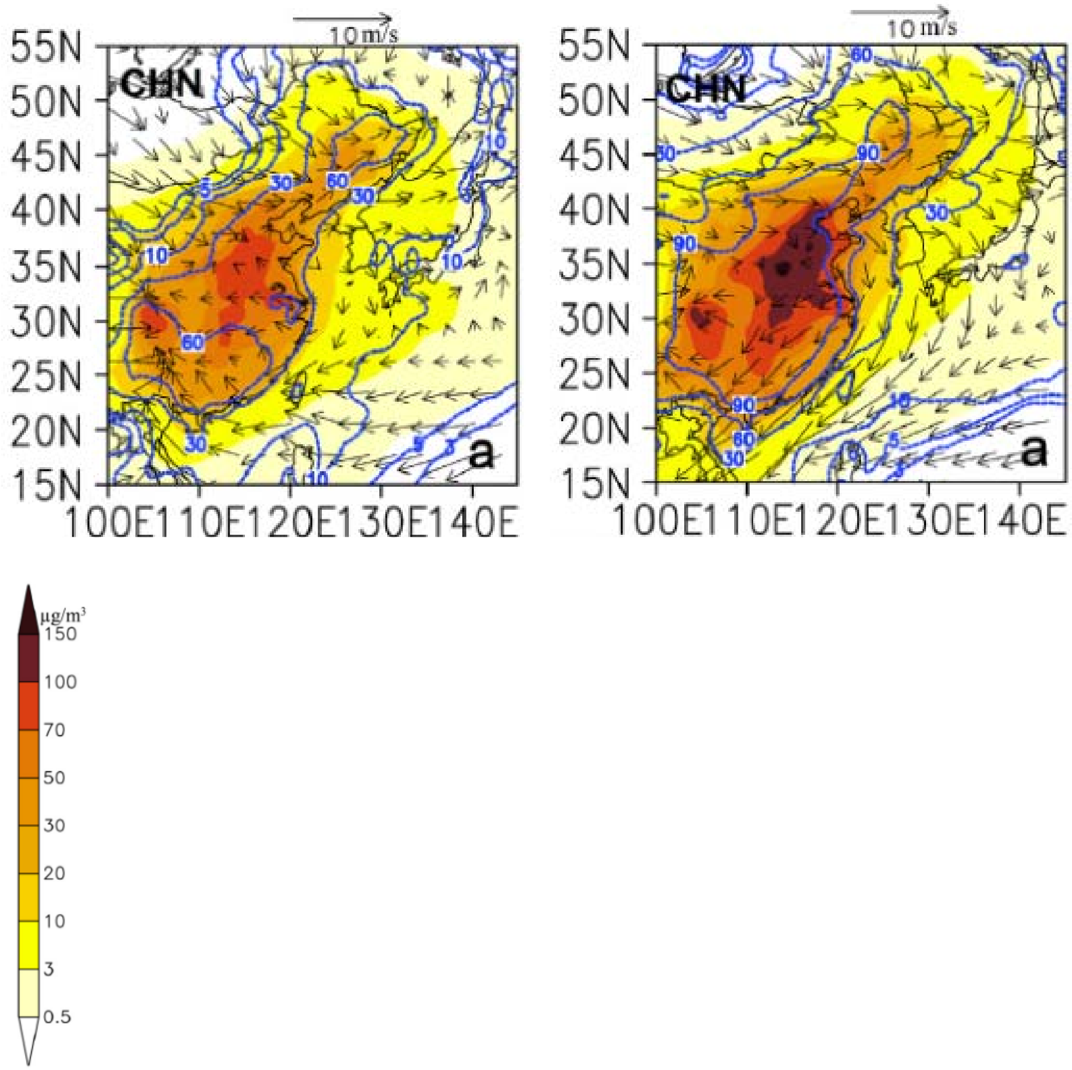


Figure 2. Simulated contributions of anthropogenic aerosols from China to surface PM_{10} concentrations in 2010

Note: Included are seasonal average wind vectors.

Source: (Li et al. (2014) [copyright permissions pending].

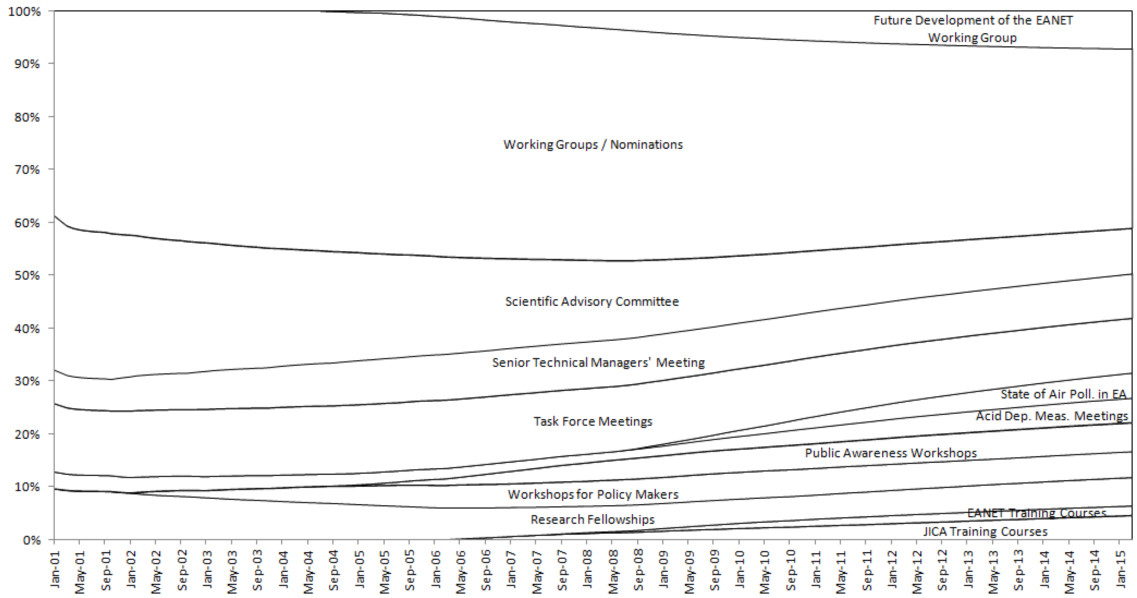


Figure 3. Distribution of EANET's activities over time Source: http://www.eanet.asia/schedule/index.html.

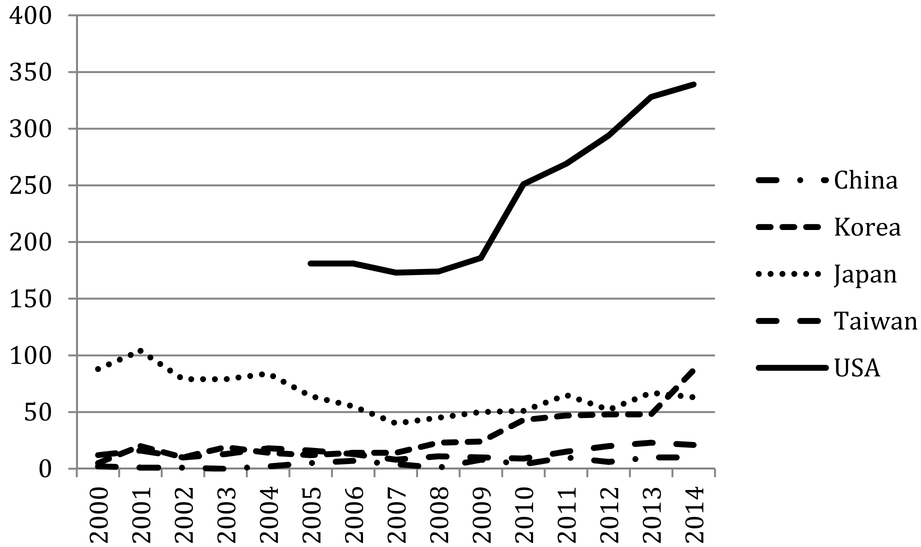


Figure 4. Longitudinal count of air pollution patents issued
Note: US patent data not available for “air pollution” search before 2005.
Source: USPTO (2015).

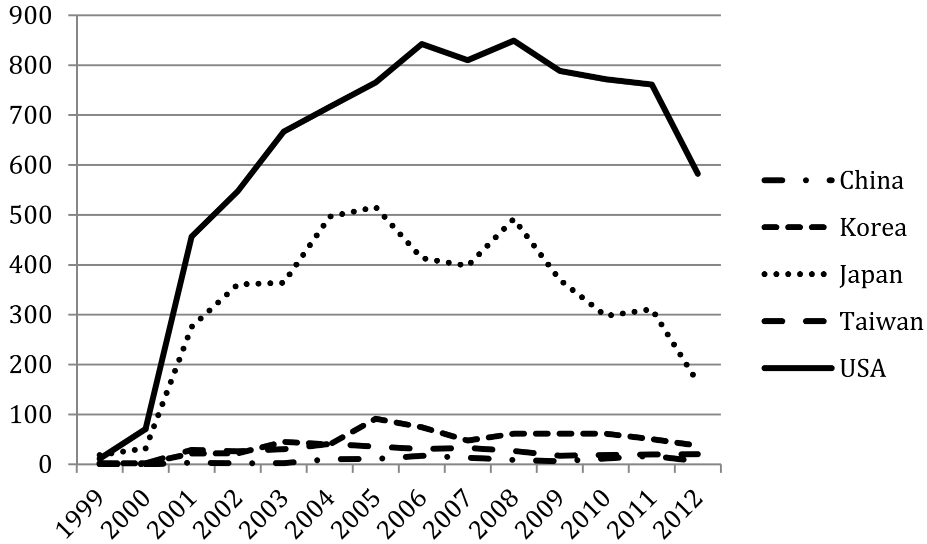


Figure 5. Longitudinal count of air pollution abatement patent applications
Note: Based on USPTO data sourced from OECD.stat.
Source: OECD.stat (http://stats.oecd.org/).

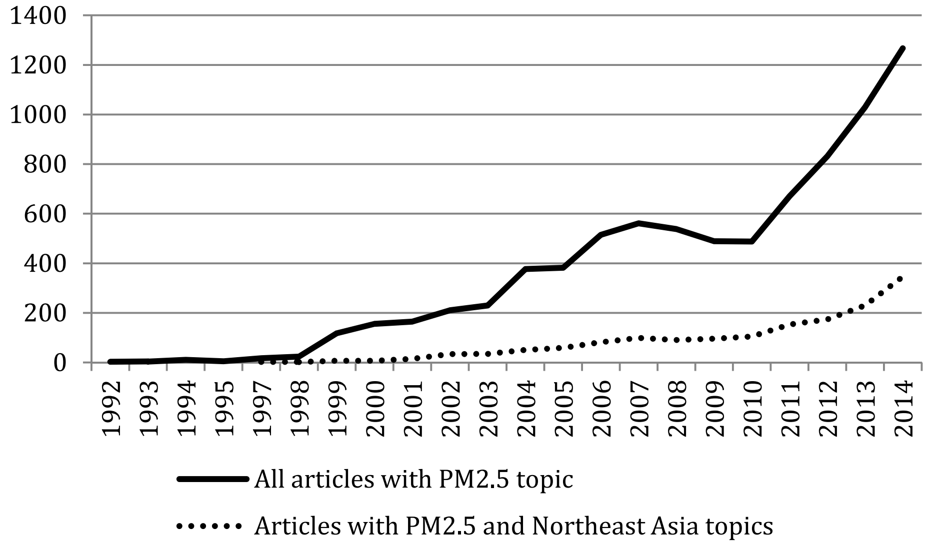


Figure 6. Longitudinal count of $PM_{2.5}$ articles, overall and with focus on Northeast Asia
Note: "All articles with $PM_{2.5}$ topic" subsumes "Articles with $PM_{2.5}$ and Northeast Asia topics"
Source: Thomson-Reuters (2015).

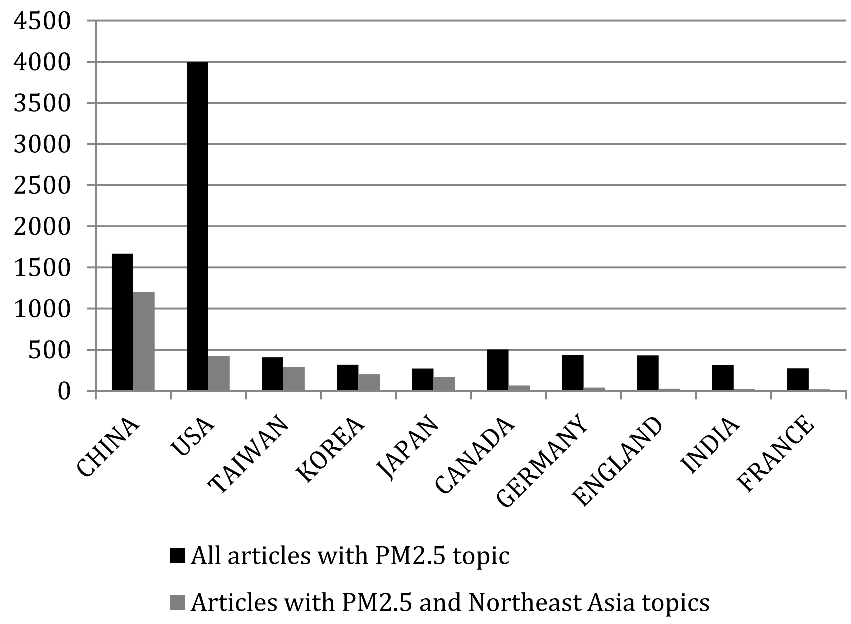
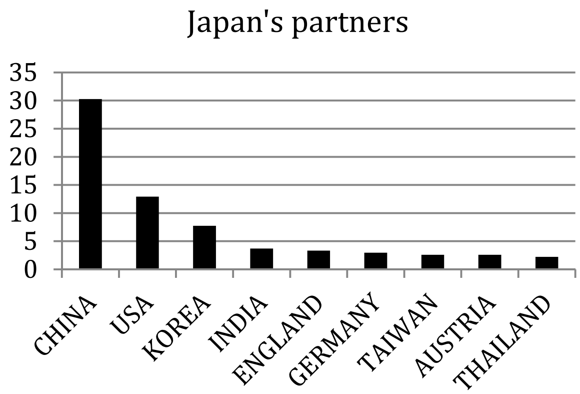


Figure 7. All-time count of $PM_{2.5}$ articles, overall and with focus on Northeast Asia
Note: “All articles with $PM_{2.5}$ topic” subsumes “Articles with $PM_{2.5}$ and Northeast Asia topics”
Source: Thomson-Reuters (2015).


Japan's partners
35
30
25
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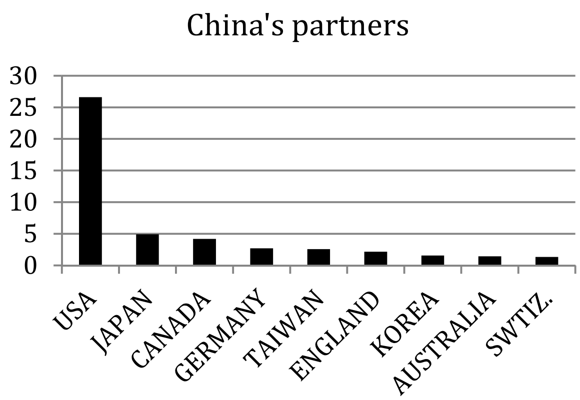
CHINA
USA
KOREA
INDIA
ENGLAND
GERMANY
TAIWAN
AUSTRIA
THAILAND


China's partners
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ENGLAND
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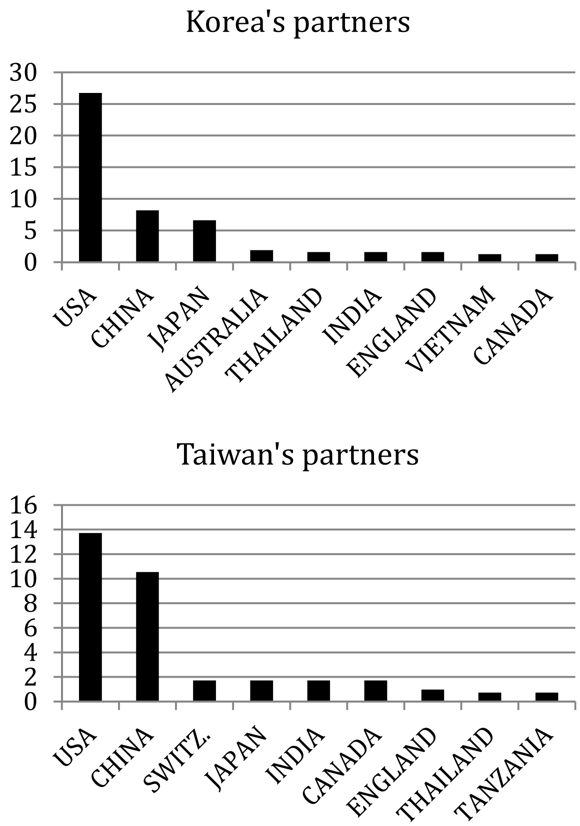

Figure 8. Top partnering countries, percentage of collaborative publications with $PM_{2.5}$ topic
Source: Thomson-Reuters (2015).