ESSAYS ON THE ECONOMICS OF THE ENVIRONMENT IN KOREA

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ABSTRACT OF THE DISSERTATION

Essays on the Economics of the Environment in Korea

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This dissertation aims to improve the understanding of environmental policy mechanisms and provide estimates of the costs of toxic pollution (in the air and water) and ambient particulate matter air pollution in Korea. The results will be useful for future evaluations and formulations of Korean environmental policies and regulations.

In Chapter 2, businesses' incentives to participate in voluntary environmental programs are explored through the 30/50 program conducted from 2004 to 2013 in Korea. The industrial facilities that joined the 30/50 program promised to reduce their toxic emissions by 30% within 3 years and 50% within 5 years. Unlike mandatory regulations, the voluntary 30/50 program did not include sanctions for noncompliance. However, most of participating facilities achieved the emission reduction goals (although any implication regarding the causal impact of the program cannot be made without formal study), and the linear probability model estimation results indicate that public recognition and strong regulatory background threats (or the prospect of relaxed regulatory oversight) are important predictors of businesses' participation in the program. A notable finding is that facilities owned by chaebols, i.e., family-owned conglomerates, showed a considerably higher probability of participation. Chaebols with great economic and political power in

Korea might have wished to participate in order to take advantage of any opportunities to influence future environmental regulations and relax the greater regulatory pressures usually placed upon them. Chaebols' higher participation rates reveal the importance of studying VEPs within a country's specific political, economic, and social structures.

In Chapters 3 and 4, estimates of the costs of toxic air and water pollution as well as ambient particulate matter air pollution are provided. Chapter 3 estimates the effects of pregnant mothers' exposures to toxic emissions on newborns' health. Using 2004-2007 birth data merged with data on toxic emissions in the mothers' counties of residence, linear probability models for the probabilities of babies being born with low birth weight (<2.5kg) and very low birth weight (<1.5kg) are estimated. The estimation results indicate that toxic and carcinogenic water emissions increase the probability of low birth weight and toxic water emissions increase the probability of low birth weight more than non-toxic water emissions do. It is also found that heavy metal air emissions have the most harmful effects on the probability of low birth weight and are the only type (and medium) of chemical emissions found to increase the probability of very low birth weight. Chapter 4 examines Korean households' willingness to pay to avoid ambient PM_{10} (particulate matter 10 micrometers or less in diameter) air pollution using a hedonic approach. Here, the transaction records for all apartments sold during 2006-2016 in Korea are used. The OLS estimation, even when including apartment-complex fixed effects, yields statistically significant and positive point estimates of the effects of local ambient PM_{10} concentrations on apartment prices. This suggests that there must be bias coming from an omitted time-varying factor(s). An IV approach using Asian dust events as an instrumental variable for the annual average PM_{10} concentrations was also utilized. Although a naturally occurring

Asian dust storm is likely to satisfy the exclusion restriction, it forms a weak instrument, and the weak-instrument robust Anderson-Rubin test cannot identify the parameter estimate of the effect of local ambient PM_{10} concentration on apartment prices. No conclusive evidence regarding Korean households' willingness to pay to avoid ambient PM_{10} air pollution can be found using these approaches.

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Chapter 1. Introduction

Pollution has become a serious public concern and made its way to the top of the policy agenda in South Korea, as South Korea ranks among the countries with the highest particulate matter air pollution levels. In addition to particulate matter air pollution, South Koreans have also become concerned about toxic pollution due to frequent news coverage of consumer products containing unsafe levels of toxic chemicals and the health risks associated with these toxic substances. In order to protect the environment and address public concerns, the Korea government has implemented an array of regulations and policies to control air and toxic pollution. For the sound evaluation and construction of effective regulations and policies, it is crucial to understand polluters' incentives in order to improve their environmental behavior and provide reliable estimates of the costs of pollution. This dissertation contributes to policy-making by exploring the mechanisms of the voluntary environmental programs which have been implemented widely in Korea and providing estimates of the costs of toxic pollution and ambient particulate matter air pollution.

Along with mandatory regulations, the Korean Ministry of Environment (MOE) relies on many voluntary environmental programs (VEPs) for pollution control. Unlike mandatory regulations, VEPs do not involve sanctions for noncompliance. Therefore, it may be challenging to induce businesses to participate in VEPs, and the success of VEPs depends, at least in part, on recruiting a large enough number of participants or heavy polluters via providing the right incentives. Studies on the US and EU countries that have adopted VEPs reveal that businesses participate in VEPs to reduce market and regulatory pressures. That is, through VEP participation, they aim to appeal to green consumers, preempt stricter regulations, and enjoy relaxed regulatory oversight. In Chapter 2, tests are done to see whether these motivations apply to businesses in Korea, which has different political, institutional, and socioeconomic conditions than the US and EU countries, and the VEP participation behavior of *Chaebols*, family-run conglomerates with great economic and political power in Korea, is examined. In particular, the businesses' motivations for joining the voluntary 30/50 program are examined. Running from 2004 to 2013, the goal of the 30/50 program was to reduce toxic releases by industrial facilities by 30% within 3 years and 50% within 5 years. Using data on eligible facilities belonging to publicly-traded firms in manufacturing industries, the linear probability models of facility-level participation in the program are estimated. The estimation results indicate that firms sought relief from market and regulatory pressures through participation in the 30/50 program, as has been the case in other developed countries, implying that public recognition and credible regulatory threats are important features of successful VEPs. A notable finding emerging from Korea's 30/50 program is that facilities owned by chaebols showed a considerably higher probability of participation. Chaebols with great economic and political power in Korea might have had greater interest in taking advantage of any opportunities to influence future environmental regulations and relax the greater regulatory pressures usually placed upon them. Chaebols' higher participation rates reveal the importance of studying VEPs within a country's specific political, economic, and social structures. In addition, the chaebols and large firms' higher likelihoods of participation imply that VEPs may put non-chaebol and smaller firms at disadvantages in the market and the importance of providing technical or financial assistance to non-chaebol and smaller firms to encourage their VEP participation.

In Chapter 3, the cost of toxic pollution in terms of infant health is estimated. Using 2004-2007 birth data merged with data on toxic emissions in mothers' counties of residence, I examine the effects of pregnant mothers' exposures to toxic chemical substances (of different types and media) on the probabilities of babies being born with low birth weight (<2.5kg) and with very low birth weight (<1.5kg). Looking at infant health rather than adult health outcomes allows the effects of pollution on human health to be identified more accurately. Since an infant's health is affected by his/her brief period in utero, it is possible to measure the infant's lifetime exposure to pollutants when assuming that a pregnant mother's mobility is low. This study contributes to policy-making in Korea by providing estimates of the effects of toxic emissions on infant health at the 2004-2007 levels of emissions. This study finds statistically significant adverse effects of heavy metal air emissions on both probabilities of low birth weight and very low birth weight. An interquartile increase in heavy metal air emissions increases the probability of low birth weight by 0.3% and the probability of very low birth weight by 1%. In addition, interquartile increases in toxic water emission densities and carcinogenic water densities are found to increase the probability of low birth weight by 0.3% and 0.1%, respectively. Toxic water emissions have greater detrimental effects on infant health than non-toxic water emissions. Almost all drinking water in Korea comes from surface water, which is contaminated more easily than ground water. Although Korea has a high rate of access to filtered water, on average, mothers in rural areas may be exposed to toxins in their drinking water, and, even with filters, some toxins may slip through. The greater effects of heavy metal emissions on birth weight outcomes indicate that heavy metals are more hazardous to infant health than other types of chemicals.

In Chapter 4, a hedonic approach is used to estimating Korean households' marginal willingness to pay to avoid ambient particulate matter air pollution in their residential locations through the Korean housing market. Rather than relying on survey data on housing prices and characteristics, this study uses the Ministry of Land, Infrastructure, and Transport's transaction records for all apartments sold during the period 2006-2016 in Korea. Doing so allows apartment-complex fixed effects to be accounted for. However, the OLS estimation with apartment-complex fixed effects yields a statistically significant and positive point estimate for the effect of PM_{10} on apartment price, suggesting that there is bias coming from an omitted time-varying factor(s). As an alternative, the annual total number of days with Asian dust events is used as an instrumental variable for the average annual PM_{10} concentration at the county level. Although naturally occurring Asian dust is likely to satisfy the exclusion restriction, it is found to form a weak instrument, and the weak-instrument robust Anderson-Rubin test cannot identify the parameter estimate of the effect of local ambient PM_{10} concentrations on apartment prices. Therefore, the instrumental variable estimation results cannot provide conclusive evidence that Korean households are willing to pay for PM_{10} concentration reductions in their neighborhoods.

Chapter 2. Why do Firms Participate in Voluntary Environmental Programs? Evidence from the 30/50 Program in Korea

2.1. Introduction

The Korean government made great strides in environmental policy in the 1990s amid democratization and growing public concerns about the environment. During the early 1990s, a number of major pieces of environmental legislation were passed, and a cabinet-level Ministry of Environment (MOE), responsible for implementing the environmental laws, was established. Seven regional offices were charged with granting permits, monitoring, and enforcement of environmental regulations (Aden et al., 1999). Korean environmental regulations throughout most of the 1990s relied on command-and-control policies which specified the legal rules and standards and penalized those who violated them. However, since joining the Organisation for Economic Cooperation and Development (OECD) in 1996, and following the examples of the United States and European Union, Korea began employing voluntary approaches, with the aim of inducing firms to make pollution abatement efforts voluntarily, without imposing legal obligations on the polluters. With voluntary environmental policies, the Korean government expected to save the costs associated with the enactment, monitoring, and enforcement necessary under the command-and-control policies, and to reduce abatement costs by allowing polluters flexibility in their abatement strategies (OECD, 2003; Segerson and Miceli, 1998; Arora and Cason, 1996).

The 30/50 program, which ran from 2004–2013, is one of the earliest voluntary environmental programs (VEPs) implemented in Korea. Similar to the US 33/50 program conducted during 1991–1995, the Korean 30/50 program aimed to reduce releases of toxic substances listed under the MOE's public disclosure program, called the Pollutant Release and Transfer Register (PRTR). Under the oversight of local government, regional MOE offices, and environmental nongovernmental organizations (NGOs), program participants were expected to achieve a 30% reduction in their releases of targeted chemicals within 3 years and a 50% reduction within 5 years through preventive strategies rather than end-of-pipe cleanup. All participants enjoyed exemption from annual inspections during the program, and those that achieved their target reductions received certificates and awards, which could be publicized, and extra points towards green firm designation. Those that failed to meet their targets, however, did not face any legal penalty. An MOE report found that most of the program participants achieved the emissions-reduction targets (though the report is limited to abatement outcomes that were evaluated as of 2010, and does not extend to outcomes in 2011 to 2013, when the program concluded). Kim et al. (2013) find that, between 2004 and 2010, the emissions of targeted PRTR chemicals declined more for participants than for non-participants, controlling for year effects and chemical fixed effects.

The success of VEPs such as the 30/50 program depend on creating incentives that will induce polluters to participate in the program and commit to making abatement efforts even in the absence of legal obligations. US studies identify the following factors that firms consider when making the decision of whether or not to participate in the US's 33/50 program: firms' capabilities to adopt costly and innovative pollution abatement methods measured by their size, profitability, financial health, and R&D expenditures; and external pressures from consumers, environmental authorities, local communities, and environmental groups (Arora and Cason, 1995, 1996; Khanna and Damon, 1999; Videras and Alberini, 2000; Gamper-Rabindran, 2006; Vidovic and Khanna, 2007; Innes and Sam, 2008). By earning goodwill from these pressure groups, participating firms expect benefits in terms of increased sales, regulatory relief, and prevention of local residents' and environment groups' complaints, legal actions, and lobbying attempts in pursuit of tighter regulations. However, firms' multinational ownership may additionally be an important predictor of VEP participation in developing countries with weak environmental regulations, low demand for green products, and politically weak communities and NGOs. Multiple studies postulate that multinational firms operating in developing countries may be more likely to participate in VEPs than domestic firms because they adopt higher environmental standards from their home countries to exploit economies of scale and cater to green consumers, investors, and NGOs in their markets in developed countries (Christmann and Taylor, 2001; Earnhart et al., 2014, Prakash and Potosky, 2007; Kumar and Shetty, 2018).

This study is the first formal analysis of firms' incentives to join the 30/50 program in Korea. Each country has its own political and socioeconomic conditions that determine consumer characteristics, the stringency of environmental regulations and enforcement, corporate environments and attitudes towards environmental management, and the collective power of local communities and NGOs. Therefore, successful VEP participation incentives in one country may not be applicable in other countries with different institutional, social, and cultural backgrounds. In particular, the Korean economy has an unusual structure due to the role of the *chaebols*, which are the family-run conglomerates with monopoly powers in multiple industries (Kim and Cho, 2017). By exploring why

Korean firms participate in the 30/50 program in their specific environment, this study aims to provide insight into what incentives the MOE needs to offer the polluters to implement a successful VEP in Korea.

This study estimates a linear probability model for the 30/50 program participation decision of a sample of PRTR facilities belonging to publicly traded firms in the 20 manufacturing industries which are the most heavily represented in the PRTR system. The outcome variable is a dummy that takes the value of 1 if a PRTR facility joined the program during the recruitment period of 2004–2009 and zero if it never participated. Explanatory variables are from 2004, which is the most recent year available before participation status has any influence on the facility, firm, industry, and regional characteristics.

The estimation results indicate that facilities belonging to chaebols were much more likely to participate in the 30/50 program than those belonging to non-chaebols. By participating in the 30/50 program, chaebols, which control the majority of the Korean economy and have substantial political influence, may have sought to steer future environmental regulations in their favor or/and avoid strict regulatory oversight. Higher participation probabilities in industries that are in greater contact with consumers, as measured by advertising intensity, further suggests that firms' participation in the 30/50 program was a way of conducting green marketing. The program was successful in recruiting facilities with high levels of toxic emissions, although they were from less pollution-intensive industries. This suggests that while the MOE may have been very effective in its persuasion, heavy polluters may also have been inclined to participate in the program in anticipation of stricter environmental regulations. Regardless of chaebol status, market and regulatory pressures appear to be the critical incentives for Korean firms' participation in the 30/50 program. The results of this study imply that successful VEPs in Korea should leverage the firms' desires to alleviate pressures from consumers and regulators, as has been found in other developed countries.

The rest of the paper is structured as follows. Section 2 describes the 30/50 program in detail. Section 3 provides the theoretical framework for discussing the program participation incentives. Data sources, variables, and descriptive statistics are presented in Section 4. The econometric model is explained in Section 5. The results are discussed in Section 6, and Section 7 concludes.

2.2. 30/50 program in Korea

The 30/50 program was initiated by the MOE in 2004 and was one of the first voluntary initiatives adopted after Korea became an OECD member country. Seven regional MOE offices recruited the program participants during 2004–2009, with the declared goal that participating facilities reduce their toxic releases by 30% within 3 years and 50% within 5 years from their initial participation year.[1] The toxic pollutants facilities needed to target for reduction were drawn from the set of pollutants they were required to report to the MOE under the PRTR system.[2] All facilities that reported their toxic emissions

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[1] As shown in Table 2.1, for the facilities participating in 2004 and 2005, the 2001 release was used as a baseline level against which to measure their abatement outcome in the evaluation years. The 2002 release was used as a baseline for 2006–2007 participants, and the 2003 release for 2008–2009 participants.

[2] In 1999, Korea enacted and implemented a public disclosure policy called the Pollutant Release and Transfer Register (PRTR) system. Under the PRTR system, facilities are required to report the amounts of the specified toxic pollutants they release to the environment and transfer to other sites for treatment and disposal if the amounts exceed specified threshold levels. The information reported by the facilities was made available to public from 2000 on; however, the information was available only at the district level. Facility-level toxic information was disclosed starting in 2008. The MOE reported that between the implementation of PRTR and the 30/50 program, PRTR facilities' toxic emission intensities (which is the amount of toxic pollutants released divided by the amount of toxic pollutants handled) decreased by only 2.7% from 2001 to 2002. This suggests that firms might not have had the incentive to engage in voluntary pollution abatement while the public disclosure of toxic emissions under PRTR was limited to the district level.

to PRTR as of the recruiting year were eligible to participate in the 30/50 program. The regional MOE officials sent out invitation letters to all eligible facilities but made extra efforts to persuade large facilities with high aggregate or carcinogenic emissions to join the program. Firms that decided to have their facilities participate in the 30/50 program signed a contract with their local government, regional MOE offices, and the environmental NGOs that also oversaw the evaluation of the participating facilities' abatement outcomes.

The program participants were required to submit detailed plans for their toxic emissions abatement programs, including the types of chemicals they planned to target and their proposed abatement methods. They were required to choose three or four of the most harmful PRTR chemicals that they released in the greatest amounts. A total of 71 pollutants listed under PRTR were chosen for reduction by the participating facilities. Participants were given the freedom to choose their own abatement methods, but were required to use methods that prevented emissions at the sources rather than those that involved end-of-pipe cleanup. While no penalties were imposed for failing to meet the reduction targets, participants were promised the benefits of exemption from annual inspections during the program period, extra points towards green company designation, certificates of program participation, and awards for outstanding abatement outcomes in terms of the amount of emissions reductions and innovativeness of abatement methods. In the course of the program, the environmental officials promoted the participants' sharing of their pollution abatement technologies with each other through several workshops, which non-participating firms could attend, as well.

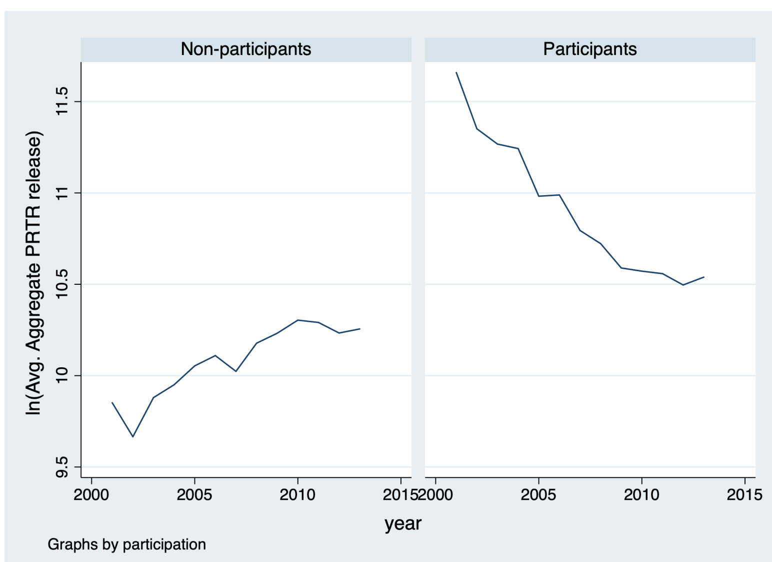
During the entire recruitment period of 2004–2009, a total of 219 facilities belonging to 158 firms joined the 30/50 program. The program began in 2004 with 17

Table 2. 1. The 30/50 participants' abatement outcomes

Participation year	2004/2005	2006	2007	2008	2009
Number of participants	17/148	5	39	4	6
Number of participants that achieved targets	124	4	30	3	-
Midterm Δemissions of targeted chemicals	-14,493	-22 tons	-1,470 tons	-324 tons	-
	(-72%)	(-40%)	(-67%)	(-77%)	
Final Δemissions of targeted chemicals	-15,999	-31 tons	-	-	-
	(-80%)	(-55%)			
Midterm Δemission intensity	-0.042	-3.17	-0.011	-0.057	-
	(-78%)	(-66%)	(-65%)	(-89%)	
Final Δemission intensity	-0.046	-3.52	-	-	-
	(-85%)	(-74%)			
Base year	2001	2002	2002	2003	2003
Midterm evaluation year	2007	2008	2009	2010	2011
Final evaluation year	2009	2010	2011	2012	2013

Note: The changes in emissions and emissions intensity are only for the 30/50 program participants that achieved their targets. The base year against which participants' abatement performance is evaluated is different across participants based on their participation year. MOE did not publish the results after 2010, which is why the figures for 2011–2013 are missing in the table. One-hundred twenty-four out of 148 facilities that joined the program in 2004 and 2005 and submitted their abatement reports met the reduction targets. Fourteen facilities opted out of the program because they shut down or/and their firms went out of business. Three facilities were dropped from evaluation because the amount of the chemicals they manufactured or used fell below the threshold levels of the PRTR reporting requirement.

Figure 2. 1. Trends in log of average aggregate PRTR releases



facilities, expanded to 148 additional participants by 2005, and had 54 more facilities join from 2006 to 2009. According to the MOE's report (Pollution Release and Transfer Register, n.d.), 74% of the 2004–2008 participants achieved their targets through 2010. The MOE's report also indicates that the participants reduced not only the total release of their targeted chemicals, but also their emission intensities (calculated as the total release divided by the total amount of the chemicals manufactured or used). By 2010, the total amount invested by 2004–2008 participants in pollution abatement was 803 billion won. From the most to least costly abatement methods, 52% of the 2004–2005 participants installed pollution-abatement technologies, 32% changed their production methods, and 16% substituted less harmful substances. Table 2.1 summarizes the MOE's report on the total amount of emissions reductions and changes in emission intensities that participants achieved within 3 and 5 years of their initial participation.[3] In addition, as shown in Figure 2.1, average aggregate PRTR releases for the participants exhibit an overall downward trend during 2001–2013, while those for nonparticipants show an overall upward trend during the same period.

2.3. Theoretical framework

Korea's 30/50 program was preceded by the US's 33/50 program, which was conducted from 1991–1995. The 33/50 program was the US Environmental Protection Agency (EPA)'s first, and one of the most notable VEPs. Similar to the 30/50 program, the US's 33/50 program challenged the participating facilities to reduce their emissions of 17 specified chemicals by 33% by 1992 and 50% by 1995 using any abatement method

[3] The MOE has not published the detailed results of the 30/50 program since 2010.

available except end-of-pipe cleanup. It provided the participants with a set of benefits, including publicity as a program participant, technical assistance, and awards for outstanding abatement performance. The EPA and many independent researchers found varying degrees of program success,[4] and many studies examined the determinants of participation in the program. However, to this point, there have been only a few studies examining the effectiveness of Korea's 30/50 program in terms of program participation and abatement outcomes. Song (2016) examines the associations between the 30/50 program participating firms' abatement outcomes and their characteristics but do not examine the causal effect of the program. Kim et al. (2013), with access to the private data on facilities' targeted chemicals, find that through 2010 (the last year of their study), program participants made greater reductions in their targeted chemicals than nonparticipants that used the same chemicals. However, they do not account for possible confounding factors including facility, firm, and regional characteristics, spillover effects, and the self-selection of program participants. This study contributes to the existing literature by providing a formal econometric analysis of firms' motivations for participating in the 30/50 program.[5]

Firms will participate in the 30/50 program if the expected benefit exceeds the expected cost of participation. Firms' costs of participation in the program will vary depending on their size, financial status, and information on pollution abatement technology. Large firms with higher profits and sound financial health will have more

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[4] See Videras and Alberini, 2000; Khanna and Damon, 1999; Vidovic and Khanna, 2007, 2012; Carrion-Flores, Innes, and Sam, 2013; Bui and Kapon, 2012; Bi and Khanna, 2012, 2017; Sam, Khanna, and Innes, 2009.

[5] Although it is known that participating facilities were encouraged to choose three or four of the most harmful chemicals they released in the largest amounts as targets, data on each facility's targeted chemicals is not publicly available. Therefore, I cannot improve on Kim et al. (2013)'s analysis of the program's effect on toxic abatement outcomes.

resources to allocate to program participation and environmental improvement (Arora and Cason, 1996; Videras and Alberini, 2000). Therefore, firms that are large in terms of sales and numbers of employees and firms with higher profits and lower debt-to-asset ratios may be more likely to participate in the program. The relationship between firms' information on abatement technologies and participation is more ambiguous. Some studies find a higher likelihood of participation in the 33/50 program among the US firms that incurred higher R&D expenditures and therefore were more likely to have a lower cost of allocating additional resources to innovation in terms of pollution reduction methods (Arora and Cason, 1995, 1996; Khanna and Damon, 1999; Vidovic and Khanna, 2007). Other studies find that firms with limited R&D propensities were more likely to participate in the 33/50 program to learn about pollution abatement technologies through the program (Videras and Alberini, 2000; Khanna and Damon, 1999). This study tests whether likelihood of participation in the 30/50 program is lower or higher in industries with higher R&D intensities.

One benefit that firms may gain from participating in the 30/50 program is a potential increase in sales. The value of the green market in Korea increased from 2.5 trillion won in 2001 to 4.8 trillion won in 2004, then to 14.5 trillion won in 2006, which was 1.8% of Korea's GDP in 2006 (Ha, 2008). With growing public awareness of environmental risks and increasing green consumption behavior in Korea during the early 2000s, Korean firms might have been motivated to participate in the program to appeal to green consumers. In this case, firms in industries that have a higher advertising intensity and are therefore thought to be in greater contact with consumers may be more likely to participate in the 30/50 program. US empirical studies find a greater likelihood of participation in the 33/50 program among the firms that are closer to consumers, as proxied by their advertising expenditures and whether selling finished products or not (Arora and Cason, 1996; Khanna and Damon, 1999; Vidovic and Khanna, 2007). These results confirm that firms with more interactions with consumers can expect greater sales benefits from green marketing.

The degree of competition that firms face in their markets may also affect their decisions to participate in the 30/50 program. Arora and Cason (1995) find that US firms in less concentrated industries are more likely to participate in the 33/50 program, in accordance with their hypothesis that firms may try to differentiate their products in terms of environmental quality. However, counter to Arora and Cason's argument, firms in competitive industries may be more likely to engage in price competition rather than in product differentiation. Firms in less concentrated industries may also be less able to pass the pollution abatement cost onto consumers (Arora and Cason, 1995). Therefore, the direction of the effect of market concentration on participation is an empirical question, which this study will also attempt to answer in this analysis.

Firms may also participate in the 30/50 program to reduce future compliance costs with mandatory environmental regulations ahead of their competitors or/and seek relief from regulatory scrutiny. In the US, where there are relatively strict mandatory environmental regulations, regulatory pressures were found to be important factors driving participation in the 33/50 program. Khanna and Damon (1999) find that firms with more Superfund sites[6] and large firms with deeper pockets were both more likely to participate

[6] Superfund sites are hazardous-waste sites for which the responsible firms are held liable for cleanup by the US federal government under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980.

in the 33/50 program to avoid future liability costs. They also find that firms releasing a greater volume of pollutants that are regulated under the 1990 Clean Air Act Amendments were more likely to participate in the program to reduce compliance costs ahead of time and secure a competitive edge in the market. A number of studies which have found a higher likelihood of participation among firms with greater numbers of Superfund sites, records of more inspections and enforcement actions, and higher toxic emissions argue that firms with poor prior environmental performances, which are subject to greater regulatory scrutiny, sought regulators' goodwill through participation in the 33/50 program (Videras and Alberini, 2000; Innes and Sam, 2008; Vidovic and Khanna, 2007). These results suggest that when the penalties for violating the mandatory regulations are credible and strict, firms have a greater incentive to participate in VEPs. Although Korea had relatively weak environmental regulations during the early 2000s, firms may have anticipated the tightening of environmental regulations from observing the government's implementation of the 30/50 program and an array of other environmental initiatives. High-toxic emissions facilities, in particular, may have felt greater pressure from regulators because the regional MOEs pushed harder for them to participate in the 30/50 program. Therefore, facilities with high toxic emissions may be more likely to participate in the 30/50 program to seek regulatory relief or/and reduce future compliance costs.

Firms' participation decisions may also be influenced by pressure from environmental groups and local communities that may mobilize against them. Since local environmental NGOs served as witness to the 30/50 program, firms located in areas where the political and collective powers of such groups are stronger and there are more potential litigants to compensate for environmental damages might have had a stronger participation incentive (Hamilton 1993). Through participation in the 30/50 program, firms may be able to deter environmental groups' and local residents' complaints, boycotts, lawsuits, and attempts to lobby for stricter environmental regulations. US empirical studies produced mixed results on this effect. Innes and Sam (2008) find that firms under greater pressure from environmental groups, as measured by the number of per capita Sierra Club memberships in their home state, were more likely to participate in the 33/50 program. However, both Gamper-Rabindran (2006) and Vidovic and Khanna (2012) do not find compelling evidence of the effects of community characteristics (e.g., per capita Sierra Club memberships, voter participation rate in a presidential election and shares of minority, less than high-school educated, and poor households in the population) on the local facilities' participation in the 33/50 program.

In the countries that receive foreign direct investment (FDI) from developed countries, a firm's environmental performance may depend on whether or not it is under multinational ownership. The pollution halos hypothesis postulates that multinational firms transfer their superior pollution abatement technology to host countries in which they operate. Despite the less stringent environmental regulations in the host county, multinational firms implement cleaner environmental practices than domestic firms, as they tend to standardize their environmental practices across global markets for economies of scale and to keep up with higher standards held by the consumers, investors, and NGOs in their home countries and the large export markets in the developed countries that they serve (Eskeland and Harrison, 2003; Christmann and Taylor, 2001; Earnhart et al., 2014; Zugravu-Soilita, 2017). Empirical studies produced mixed results regarding the effects of multinational ownership or FDI on pollution. Some studies do not find that multinational firms use cleaner practices than domestic firms (Dasgupta et al., 2000; Pargal and Wheeler, 1996; Hartman et al., 1997; Hettige et al., 1996), while other studies find evidence to support the halo hypothesis. Christmann and Taylor (2001) find that multinational ownership increased the environmental performance and likelihood of ISO 14001 adoption in China.[7] Eskeland and Harrison (2003) find that in Cote de Ivoire, Mexico, and Venezuela, foreign firms were more efficient and cleaner in their energy use than domestic firms. With a panel of 98 countries from 1996–2002, Prakash and Potoski (2007) find that inward FDI from countries with high levels of ISO 14001 adoption increases the level of ISO 14001 adoption in host countries. This study tests whether multinational (foreign-owned) firms in Korea are more likely to participate in the 30/50 program.

A notable feature of the Korean economy is that a large share of it is controlled by chaebols, defined as family-controlled conglomerates with monopoly powers in multiple industries (Kim and Cho, 2017). Given that 43% of the 30/50 participating facilities belong to chaebol firms, it is important to discuss chaebols' roles in the Korean economy and the public perception of chaebols. Chaebol firms became the leaders of the Korean economy in the 1960s–1970s due to the Park Chung-hee administration's economic growth policy. Economic development, as led by the Park administration, relied intensively on heavy and chemical industries, which required large-scale production that would serve foreign export markets. Firms in those industries received massive financial advantages from the government in the form of tax reductions, loans, subsidies, and business opportunities, and grew large with many subsidiaries (Ko, 2008). In return, the Park administration could tout

[7] ISO 14001 is an international standard that organizations can follow to establish an effective environmental management system (International Organization for Standardization, 2018). ISO 14001 does not state legal requirements for environmental performance, and its adoption is on a voluntary basis.

its role in economic growth and use it to further its political power. With democratization in the 1980s, the chaebols' power expanded beyond the economy into politics, and politicians relied on chaebols' financial and political support to win elections. Under the protection of the government, chaebols continued to accumulate economic power, controlling two-thirds of Korean manufacturing by the end of the 1990s (Tejada, 2017).

Public perception of chaebols became increasingly negative after the 1997 financial crisis (Moskalev and Park, 2010). The 1997 financial crisis exposed chaebols' problematic practices in terms of keeping ownership and managerial power within their families and maximizing their personal profits at the expense of minority shareholders. The government's preferential treatment of chaebols and chaebols' poor governance structures were blamed for the structural weakness in the Korean economy which led ultimately to the crisis (Moskalev and Park, 2010; Kim and Kim, 2008; Ko, 2008). The massive layoffs at chaebols and the surrender of Korean economic independence to the IMF that followed the crisis angered the public, which then called for reforms in corporate governance (Moskalev and Park, 2010; Kim and Kim, 2008). Despite the new regulations targeting chaebols in the aftermath of the crisis, the chaebols' dominant share in the Korean economy has not decreased significantly since the reform (Lee, 2014), and chaebols' problems, such as economic concentration and the family owners' absolute power, continue today (Ko, 2008; Lee, 2014; Kim and Cho, 2017). Public concern over the chaebols' political power and corruption remains wide, especially as the news of chaebol owners' corrupt behavior often makes media headlines today.[8]

[8] In the most recent and notable scandal, the Vice Chairman of Samsung Electronics and the Samsung Group founder's son, Lee Jae-yong, was sentenced to five years in prison in 2017 for paying a bribe to ousted former Korean president Park Geun-hye in exchange for government support in securing his position as the heir of Samsung group. However, the appeals court suspended the sentence in 2018.

For several reasons, chaebol firms may have a greater inclination to participate in the 30/50 program than non-chaebol firms. Through participation in the 30/50 program, chaebols with political clout that may have been under great regulatory pressure may have tried to influence environmental regulations in their favor or/and raise rivals' costs (Salop and Scheffman, 1983; Innes and Bial, 2002). In the Stewardship-Based Management for Area-Specific Risk Reduction Target (SMART) program which followed the 30/50 program, the MOE recruited facilities that emitted specific chemicals that posed threats in specific areas and set the emissions-reductions targets based on the results of the 30/50 program. Indeed, the 30/50 program served as a process by which the regulators learned about what constituted reasonable environmental standards for polluters and how they could be met given the industries' and firms' circumstances, significant motivators for chaebol participation. In addition, chaebols may have intended to remedy their corrupt public images by showing that they were taking the initiative on environmental protection. Since they have many subsidiaries, chaebols may expect greater potential benefits from winning the goodwill of regulatory authorities and consumers.

2.4. Data and descriptive statistics

The list of facilities that participated in the 30/50 program is available from the MOE website. Information on the PRTR facilities that were eligible to participate in the 30/50 program comes from the PRTR website. The PRTR website also provides information on individual facility's toxic releases and transfers, number of employees, address, phone number, and industry. Firms' sales, debt-to-asset ratios, and profits come from the KISVALUE data provided by NICE Investors Service Co., Ltd., which provides firms' credit and financial information. PRTR facilities were matched to the KISVALUE firm data based on the facility address, CEO's name, industry, and phone number.[9] The list of chaebol firms comes from the OPNI website managed by the Fair Trade Commission.[10] Industry-level advertising expenditures have been aggregated from the firm-level data from the annual Survey of Mining and Manufacturing Firms conducted by Statistics Korea.[11] This survey data on all mining and manufacturing firms was also used to calculate the industry's Herfindahl-Hirschman Index (HHI). Voter turnout in the local elections that are held every four years in Korea is provided by the National Election Commission. County-level population density comes from the Korea Statistical Information Service, which maintains a composite database for numerous national and regional data sets in Korea.

During 2001–2009, 3,965 facilities from publicly traded companies in 24 manufacturing industries reported to PRTR, and 215 of these facilities participated in the 30/50 program. Since this study uses explanatory variables from 2004 (the most recent year before program participation status could have had any effect on facility, firm, industry, and regional characteristics), the sample is restricted to the facilities that reported to PRTR between 2001 and 2003. Doing so results in a sample of 1,339 facilities from 1,040 firms, out of which 189 facilities belonging to 139 firms joined the 30/50 program. After dropping facilities missing data on the number of employees, the number of observations falls to

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[9] PRTR does not provide firm identifiers for the reporting facilities. Using the facility address and phone number, CEO's name, and industry, I matched each PRTR facility to its firm identifier from Data Analysis, Retrieval, and Transfer System, which provides an inventory of all publicly traded firms in Korea. Then, using the firm identifiers for the firms, I merged the facilities with firms' sales, profits, and debt-to-asset ratios from KISVALUE.

[10] The OPNI website publishes financial and management data for large conglomerates in Korea.

[11] Since the Survey of Mining and Manufacturing Firms does not reveal firms' identities, I could not match the survey data to PRTR firms. Therefore, I could only aggregate the firms' advertising expenditures from the survey to the industry level.

1,162. Removing firms missing information on sales, profit, and debt-to-asset ratio (all of which come from KISVALUE) results in the greatest reduction in the sample size, dropping it down to 789 facilities. The final sample with complete data includes 788 facilities from 600 firms in 20 manufacturing industry groups, of which 144 facilities from 101 firms joined the 30/50 program.

Among the 1,040 publicly traded firms (with 1,339 PRTR facilities) that reported to PRTR during 2001–2003, 176 (17%) firms had more than one PRTR facility, and 65 out of these 176 multi-facility firms participated in the 30/50 program. Out of the 65 multi-facility firms that joined the 30/50 program, only 12 firms had all of their facilities participate. The 65 firms had a total of 211 eligible facilities and enrolled 115 facilities in the program. On average, multi-facility participating firms had 4.6 eligible PRTR facilities and 2.3 participating facilities.

Table 2.2 shows the summary statistics for the variables for the entire sample and separately for participants and non-participants. Participating firms have higher shares of chaebol ownership, multi-facility firms, and higher average sales and profits than nonparticipating firms. Participating facilities have a greater number of employees and higher aggregate and carcinogenic PRTR releases prior to the program, on average, than non-participating facilities. Participating facilities are also located in areas with higher voter turnout in the 2002 local elections and lower population density. Additionally, participating facilities are in industries with higher R&D intensity. As shown in Table 2.3, the largest percentage of eligible facilities come from the chemical industry (26%), followed by the primary metal (11%) and textile (10%) industries. A higher percentage of participants than non-participants come from the chemical industry and the cork, coal, and

Table 2. 2. Descriptive statistics

	All facilities	Participants	Non-participants	Difference of means (t-statistics)
Chaebol	0.198	0.455	0.149	0.306***
	(0.399)	(0.499)	(0.356)	(10.01)
Foreign-owned	0.139	0.182	0.131	0.0505
	(0.347)	(0.387)	(0.338)	(1.83)
Multi-facility	0.367	0.610	0.321	0.289***
	(0.482)	(0.489)	(0.467)	(7.68)
Sales (one trillion won)	1.508	4.254	0.910	3.344***
	(5.659)	(9.573)	(4.140)	(6.69)
Debt-to-asset ratio	0.509	0.492	0.513	-0.0212
	(0.361)	(0.316)	(0.371)	(-0.65)
Profit (one trillion won)	0.150	0.495	0.0753	0.419***
	(0.888)	(1.599)	(0.612)	(5.29)
Number of facility employees (1,000people)	0.494	1.177	0.363	0.814***
	(1.730)	(3.102)	(1.274)	(5.98)
Prior aggregate PRTR releases (1,000kg)	29.36	78.24	19.53	58.71***
	(191.1)	(392.1)	(111.9)	(3.83)
Prior carcinogenic PRTR releases (1,000kg)	3.955	15.40	1.654	13.75***
	(24.96)	(54.42)	(11.13)	(6.96)
Voter turnout	0.465	0.492	0.460	0.0317***
	(0.0936)	(0.0831)	(0.0946)	(4.27)
Population density (1,000 people/km^2)	3.382	2.550	3.542	-0.992**
	(4.431)	(3.290)	(4.601)	(-2.81)
Advertising intensity	0.00200	0.00221	0.00196	0.000247
	(0.00208)	(0.000973)	(0.00223)	(1.49)
HHI	216.8	273.6	205.9	67.72
	(436.4)	(701.6)	(363.6)	(1.95)
R&D intensity	0.0101	0.0126	0.00965	0.00295**
	(0.0139)	(0.0129)	(0.0140)	(2.67)
Industry's mean prior PRTR releases (1,000kg)	28.95	26.29	29.46	-3.174
	(54.98)	(40.01)	(57.40)	(-0.72)
Observations	1,162	187	975	

Note: Standard deviations for the means are in parentheses. For the difference of means column, *t* statistics are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

refined oil products industry, and a lower percentage of participants than non-participants come from the primary metal industry, textile industry, and pulp and paper products industry. More than half of all eligible facilities come from regional offices along the Nakdong and Han Rivers. Compared to non-participants, a higher percentage of participants come from regional offices along the Nakdong and Youngsan Rivers, a region which contains the largest industrial complexes in Korea, and a lower percentage of participants come from along the Han River, which includes Seoul and its surrounding urban regions.

Table 2. 3. Sample distribution by industry and region

	All facilities	Participants	Non-participants	Difference of means(t-statistics)
Ind1: Primary metals	0.109	0.0588	0.119	-0.0602* (-2.42)
Ind2: Leather, bags, and shoes	0.0172	0.00535	0.0195	-0.0141 (-1.36)
Ind3: Rubber and plastic	0.0714	0.0481	0.0759	-0.0278 (-1.35)
Ind4: Fabricated metals	0.0559	0.0588	0.0554	0.00344 (0.19)
Ind5: Food and beverages	0.0826	0.0481	0.0892	-0.0411 (-1.87)
Ind6: Textiles	0.0955	0	0.114	-0.114*** (-4.90)
Ind7: Chemical	0.263	0.481	0.222	0.260***(7.56)
Ind8: Pulp and paper products	0.0516	0.0160	0.0585	-0.0424* (-2.41)
Ind9: Non-metal minerals	0.0344	0.0481	0.0318	0.0163 (1.12)
Ind10: Printing and publishing	0.0103	0	0.0123	-0.0123 (-1.53)
Ind11: Automobiles and trailers	0.0516	0.0535	0.0513	0.00219 (0.12)
Ind12: Other transportation equipment	0.0112	0	0.0133	-0.0133 (-1.59)
Ind13: Electronic parts, computer & audio/video equip.	0.0783	0.107	0.0728	0.0341 (1.59)
Ind14: Electronics	0.0310	0.0374	0.0297	0.00769 (0.56)
Ind15: Other equipment and machines	0.0120	0.0107	0.0123	-0.00161 (-0.18)
Ind16: Furniture	0.00602	0	0.00718	-0.00718 (-1.16)
Ind17: Wood and wooden products	0.00602	0.00535	0.00615	-0.000806 (-0.13)
Ind18: Cork, coal, and refined oil products	0.00602	0.0214	0.00308	0.0183**(2.97)
Ind19: Apparel	0.00172	0	0.00205	-0.00205 (-0.62)
Ind20: Medical, precision, optic appliances & watches	0.00430	0	0.00513	-0.00513 (-0.98)
MOE1: Keum River	0.107	0.0749	0.113	-0.0380 (-1.54)
MOE2: Nakdong River	0.256	0.364	0.235	0.129*** (3.72)
MOE3: Daegu	0.160	0.134	0.165	-0.0314 (-1.07)
MOE4: Saemankeum	0.0542	0.0695	0.0513	0.0182 (1.01)
MOE5: Youngsan River	0.0628	0.144	0.0472	0.0972*** (5.07)
MOE6: Wonju	0.0189	0.0267	0.0174	0.00930 (0.85)
MOE7: Han River	0.342	0.187	0.371	-0.184*** (-4.91)
Observations	1,162	187	975	

Note: For the difference of means column, *t* statistics are in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

2.5. Econometric model

A linear probability model is estimated for a firm's decision to participate in the 30/50 program at the facility level using the equation below.[12]

[12] The probit model estimation yielded marginal effects similar to those from the linear probability model. According to Angrist and Pischke (2009), while (right) nonlinear models may fit the conditional expectation function of limited dependent variable (LDV) more closely and give the predictions within the LDV boundaries, linear probability models still generate robust estimates of marginal effects even when the

$$Y_{ijk} = \alpha + X_i\beta_1 + Z_j\beta_2 + I_k\beta_3 + \varepsilon_{ijk}$$

The dependent variable, Y_{ijk}, is a dummy variable that takes the value of 1 if a facility i belonging to firm j in industry k participates in the 30/50 program in any year during the recruitment period of 2004–2009 and zero if it never participated. All explanatory variables take the values for 2004[13] except for the voter turnout in the 2002 local elections, which was the most recent local election held up to and including 2004, and facility- and industry-level PRTR releases prior to the program. As the 30/50 program first enrolled participants in December of that year, 2004 is the most recent year before 30/50 program participation status could have any influence on facility, firm, industry, and regional characteristics.

X_i is a vector of facility characteristics which includes the number of employees, aggregate and carcinogenic PRTR releases in 2003 (prior to the program inception), voter turnout in 2002 local elections, and population density in the county in which facility i is located. As hypothesized in Section 3, a facility with higher toxic release levels may be more likely to participate in the program to seek regulatory relief and reduce future compliance costs in expectation of stricter environmental regulations. However, firms with higher aggregate and carcinogenic releases might also be more likely to participate in the program due to MOE officials' targeted persuasion, so including these variables may help distinguish the facilities' revealed preferences for participation from these recruitment effects. A concern with the inclusion of these variables is that they may be endogenous: firms expecting to participate might have exaggerated their emissions in 2003 so that they

predicted probabilities are close to 0 or 1. In this spirit, I use a linear probability model which gives simpler and robust estimates and inference results.

[13] Once the 30/50 program began, participation status may affect the explanatory variables for both participating and non-participating firms. To avoid this endogeneity, this study examines firms' decisions to participate in the program in any year during 2004–2009 instead of their participation in each year of the enrollment period.

could appear to have achieved greater reductions after program participation. However, this is unlikely because firms reported their PRTR releases for 2003 by the end of April in 2004, at which point the 30/50 program was not yet announced.[14]

Z_j is a vector of firm characteristics which includes a chaebol dummy, a foreign-ownership (multinational) dummy, a multi-facility dummy, sales, sales squared, the debt-to-asset ratio, and the profit for firm j. A quadratic term in sales is included to account for the nonlinear effect of firm size on the firm's participation decision. I_k contains industry characteristics, including advertising intensity, R&D intensity, the industry's HHI, and PRTR releases prior to the program for industry k. Each industry's advertising intensity is calculated as the mean advertising intensity, which is given as advertising expenditures divided by shipment values over all firms in an industry. R&D intensity is total industry R&D expenditures divided by total industry values of shipment. An industry's prior PRTR releases are the mean aggregate PRTR releases in 2003 over all firms in the industry. An alternative specification includes industry dummies for the 15 industries that are most heavily represented in the PRTR system and a dummy for all industries representing less than 1% of eligible facilities, including industries such as the furniture; wood and wooden products; corks, coal, and refined oil products; apparel; and medical, precision, optic appliances and watches industries. The industry effects subsume any differences in industry characteristics, including proximity to consumers, knowledge of pollution-abatement technology, and degree of competition. All specifications include dummy variables for the seven regional MOE offices to control for the differences in regional MOE

[14] In addition, the toxic release values from 2003 are used rather than those from 2001 or 2002 because 2003 is the most recent year prior to the start of the 30/50 program. The greatest number of facilities also reported to PRTR in 2003, as the change in reporting requirements was underway (see Appendix for changes in PRTR reporting requirements).

officials' recruitment strategies and efforts and all other regional differences. Finally, ε_{ijk} is an error term which contains all of the unobserved facility, firm, industry, and regional characteristics that randomly affect a facility's participation. Error terms are clustered at the firm level to correct for correlations between facilities within a firm.

2.6. Results and discussion

Table 2.4 presents the results from estimating the linear probability models of a facility's participation in the 30/50 program. Explanatory variables have been added successively from Model 1 to Model 4. Model 1 contains only a chaebol dummy, foreign-ownership dummy, multi-facility dummy, the number of facility employees, and four industry variables (advertising intensity, HHI, R&D intensity, and PRTR releases). This specification shows how much more likely chaebols are to participate in the program than non-chaebols. In Model 2, a facility's aggregate PRTR releases and carcinogenic PRTR releases are added to estimate regulatory pressure effects on participation or/and control for the MOE's persuasion effects. Model 3 adds the measures of firm size, profitability, and financial status, including sales (in quadratic form), profit, and the debt-to-asset ratio. This model provides more controls for other differences between chaebol and non-chaebol firms, but the number of observations is reduced because of missing data on firm characteristics. Model 4 adds facility characteristics measuring the community pressures a facility faces, including voter turnout in the 2002 local elections and population density at the county level. In Model 5, industry effects are included instead of the four industry characteristics used in the previous models to account for all industry-shared characteristics.

In Model 1, controlling for facility size, a chaebol firm appears 16 percentage points (ppt) more likely to join the 30/50 program than a non-chaebol firm. Additionally, both larger facilities with more employees and multi-facility firms are more likely to participate in the program. Foreign-ownership does not have a statistically significant impact on participation. The industry-level advertising intensity, HHI, and R&D intensity have statistically significant positive impacts on participation, and the industry's PRTR releases have a statistically significant negative impact on participation.

In Model 2, facilities' prior releases of both all PRTR pollutants and carcinogenic PRTR pollutants are found to increase the participation probability with statistical significance. Although inclusion of these variables leads to a loss of about 5% of the sample, the estimates of the variables originally included remain similar. Given that facilities with high toxic emissions are in industries with higher R&D intensity, R&D intensity loses statistical significance when including facilities' prior aggregate and carcinogenic PRTR releases. Adding the measures of firm size and capabilities, including sales, debt-to-asset ratios, and profit, removes a further 27% of the full sample used in Model 1. Facilities' employees and the multi-facility dummy then lose statistical significance. However, in Model 3 these changes are likely to be a result of including the controls for firm size rather than sample attrition.[15] Estimates of other variables do not change much. Voter turnout and population density in the facilities' counties in Model 4 do not have statistically significant impacts on participation. As a robustness check, the industry effects are included in Model

[15] To verify that the changes in the estimates from Model 2 to Model 3 (in Table 2.4) are not driven by the sample selection, Models 1 and 2 were run on the subsample used for Model 3. The estimates of Models 1 and 2 run on the subsample do not differ greatly from those run on the full sample.

5 to account for all of the differences across industries. This also does not change the estimation results in a significant way.

Across all specifications, a firm's chaebol status, sales, and profit are found to be statistically significant determinants of the firm's participation decisions. In Models 4 and 5, with the full set of variables, chaebol status increases the participation probability by about 11 ppt. These results support the hypothesis that chaebol firms are more likely to join the program, perhaps in an effort to steer future environmental policies in their favor.[16] Firm size variables are also significant determinants of participation. Sales and its squared term are individually and jointly significant determinants of participation, as indicated by F-statistics of 9.7 in Model 4 and 12.4 in Model 5. A sales increase leads to a higher participation likelihood, but at a decreasing rate. A one standard deviation increase in a firm's sales increases the participation probability by 8–9 ppt, and a one standard deviation increase in firm's profits increases the participation probability by 22–24 ppt. Consistent with the hypothesis, a firm's size and profitability are important determinants of participation, as they determine a firm's ability to allocate resources to participation and pollution abatement upon participation. In addition, because a firm's size is related to its visibility and the size of its initial consumer base, size may also determine how great the firm's potential benefit from public recognition will be.

According to Model 4, which contains industry characteristics and a full set of covariates, a one standard deviation increase in the industry's advertising intensity leads to a 3.3 ppt higher participation probability. This result provides evidence that firms with

[16] In a regression with an interaction term between the chaebol dummy and the industry's advertising intensity, the chaebol and the interaction terms do not have statistically significant impacts on participation. Thus, this study does not find evidence that chaebols have a greater incentive to improve their standing with green consumers or consumers, in general, than non-chaebols.

Table 2. 4. Results from the 30/50 participation equation

	Model 1	Model 2	Model 3	Model 4	Model 5
Chaebol	0.161***	0.143***	0.112**	0.110**	0.109**
	(0.0436)	(0.0431)	(0.0537)	(0.0532)	(0.0506)
Foreign-owned	0.0341	0.0430	0.0459	0.0458	0.0321
	(0.0385)	(0.0400)	(0.0421)	(0.0427)	(0.0408)
Multi-facility	0.0758***	0.0761***	0.0326	0.0348	0.0295
	(0.0280)	(0.0278)	(0.0337)	(0.0337)	(0.0322)
Number of facility employees	0.0267***	0.0247**	0.0131	0.0123	0.0223**
	(0.00917)	(0.00967)	(0.0116)	(0.0115)	(0.0113)
Prior aggregate PRTR releases		0.000153***	0.000167***	0.000166***	0.000174***
		(0.0000510)	(0.0000357)	(0.0000360)	(0.0000333)
Prior carcinogenic PRTR		0.00223***	0.00227***	0.00230***	0.00214***
		(0.000472)	(0.000533)	(0.000525)	(0.000518)
Sales			0.0167***	0.0170***	0.0193***
			(0.00573)	(0.00574)	(0.00576)
Sales squared			-0.00107***	-0.00107***	-0.00109***
			(0.000243)	(0.000244)	(0.000221)
Debt-to-asset ratio			-0.00261	-0.00613	0.0160
			(0.0229)	(0.0229)	(0.0269)
Profit			0.263***	0.263***	0.246***
			(0.0627)	(0.0632)	(0.0603)
Voter turnout				0.196	0.198
				(0.152)	(0.156)
Population density				0.000178	0.00130
				(0.00274)	(0.00276)
Advertising intensity	14.16***	15.68***	19.91***	19.91***	
	(3.819)	(4.426)	(7.647)	(7.533)	
HHI	0.0000864**	0.0000810*	0.0000631*	0.0000594	
	(0.0000438)	(0.0000422)	(0.0000377)	(0.0000376)	
R&D intensity	1.315*	1.209	0.617	0.592	
	(0.751)	(0.757)	(0.808)	(0.816)	
Industry's prior PRTR releases	-0.000961***	-0.00115***	-0.00107***	-0.00107***	
	(0.000212)	(0.000217)	(0.000267)	(0.000271)	
Industry effects	No	No	No	No	Yes
Regional MOE effects	Yes	Yes	Yes	Yes	Yes
R^2	0.147	0.178	0.236	0.241	0.284
Observations	1,162	1,099	789	788	788

Note: The dependent variable is a dummy for participation in the 30/50 program. Standard errors in parentheses are clustered by firms. * $p < .10$, ** $p < .05$, *** $p < .01$.

greater interactions with consumers may be more likely to participate in the 30/50 program as a green marketing strategy. By projecting a green image, firms may look to gain greater profits in a growing market for eco-friendly products in Korea. A one standard deviation increase in facilities' prior aggregate and carcinogenic PRTR releases increases the participation likelihood by 4 ppt and 6 ppt, respectively. This result suggests that the MOE has been successful in persuading the most toxic facilities to participate, and/or that those toxic facilities which were more inclined to join the program to avoid greater regulatory pressures did indeed participate. Even after controlling for facilities' prior releases, industry-level releases are still a significant determinant of participation, with a one standard deviation higher industry release leading to a 6 ppt lower participation probability, indicating that pollution-intensive industries are less likely to participate in the program. The pollution-intensive industries with high toxic emissions may require more expensive pollution-abatement technologies to meet the program's emissions-reduction targets and therefore may be less inclined to participate in the program. In both Models 4 and 5, MOE effects are jointly significant with F-statistics of 4.11 in Model 4 and 3.98 in Model 5, suggesting the existence of regional differences or/and differences in regional MOE officials' recruitment efforts and strategies. In Model 5, which contains industry effects, industry effects are also jointly significant, with an F-statistic of 4.84. Compared to the primary metal industry (base industry group), facilities from five industries had significantly higher participation probabilities. These industries include the chemical; non-metallic mineral; fabricated metal; electronic parts, computers, and audio/video equipment; and other transportation (e.g., other than automobiles and trailers) equipment industries.

This study does not find evidence to support the pollution halos hypothesis. Foreign-ownership does not have a statistically significant effect on participation in the 30/50 program. This result is in line with the studies that find no relationship between multinational ownership and environmental performance, as measured by pollution intensity, compliance with mandatory environmental regulations, and abatement efforts (Dasgupta et al., 2000; Pargal and Wheeler,1996; Hartman et al., 1997; Hettige et al., 1996), but inconsistent with the studies that find the positive impacts of multinational ownership and inward FDI on the adoption of ISO 14001 and energy use in the host countries (Eskeland and Harrison, 2003; Prakash and Potoski, 2007; Chirstmann and Taylor, 2001). In addition, this study does not find evidence to support Bi and Khanna's (2010) argument that the multi-facility firms are more likely to have a low participation rate at the facility level because their incentive to enroll another facility when one facility is already enrolled will be low. The multi-facility dummy is a not a statistically significant predictor of participation. The community involvement measures (voter turnout and population density) have the expected positive point estimates, but neither coefficient is statistically different from zero.

2.7. Conclusion

This study examines the effectiveness of Korea's 30/50 voluntary program in terms of participation by eligible facilities. Although many studies consider firms' incentives to participate in a similar program in the US (the 33/50 program), this study provides the first formal analysis of Korean firms' incentives to join the 30/50 program in their unique political and socio-economic environments. The estimation results indicate that firms may have joined the 30/50 program to alleviate both regulatory and non-regulatory pressures, as has been found with VEPs in developed countries. A higher likelihood of participation in industries that are in greater contact with consumers suggests that firms may participate in the program to attract green consumers by projecting an image of environmental consciousness. The program has been successful in recruiting facilities that release large amounts of toxic substances and especially facilities with high releases of carcinogens, which may be the source of the greatest health concerns. This success may be due to the MOEs' effective persuasive efforts towards targeted polluters, who also might have felt greater pressure in anticipation of tighter regulations. A considerably higher likelihood of participation by chaebols, the family-controlled conglomerates in Korea, is a unique feature of the 30/50 program. Through participation in the program, chaebols with significant economic and political power may have sought to influence the setting of environmental regulations that would give them an advantage over their rivals.

The results of this study imply that successful VEPs in Korea require credible regulatory threats and public recognition. A caution may be issued, however, that while smaller non-chaebol firms' VEP participation is likely to be limited by their lack of resources (as in the case of the 30/50 program found in this study), large chaebol firms' VEP participation may allow them to claim greater dominance in the markets. To level the playing field and prevent VEPs from increasing economic concentration, it may be important for the MOE to encourage smaller firms' participation by providing them with technical and financial assistance.[17]

[17] While the MOEs held workshops in which the participants of the 30/50 program shared their information on pollution abatement technologies, they did not offer financial assistance to small firms.

Appendix

*PRTR reporting requirements from 1999 to present

Year	Number of PRTR industries	Number of PRTR facility employees	Number of PRTR chemicals
1999	2	100 or more	80
2000	23	100 or more	80
2001	23	50 or more	160
2002 ~ 2003	28	50 or more	240
2004 ~ 2007	36	30 or more	388
2008 ~ 2010	39	30 or more	388
2011 ~ 2012	39	30 or more	415
2013 ~ present	39	1 or more	415

Chapter 3. Toxic Releases and Infant Health in Korea

3.1. Introduction

A substantial amount of toxic pollutants is released into the environment in Korea on a daily basis. Some of these pollutants are known to have harmful effects on human health, causing various diseases, including cancers and developmental or reproductive disorders, while many other toxic pollutants are only suspected of posing threats to human health. The Korean Ministry of Environment (MOE) has been regulating the storage, handling, transportation and disposal of toxic chemicals as well as their release into the environment. It has also been strengthening the regulations by expanding the set of chemicals to be regulated as studies reveal more about the toxicity of new chemicals. To control toxic emissions, the MOE has also relied on market-based policy instruments. The most comprehensive and large-scale market-based program MOE has implemented thus far is a public disclosure program called the Pollution Release and Transfer Register (PRTR), which has tracked the list of chemicals released by industrial facilities since 1999. The MOE has also implemented voluntary environmental programs. The first such program, the 30/50 program, was introduced in 2004 and challenged PRTR-listed facilities to reduce their toxic emissions by 50% over a 5-year period. The second voluntary program that the MOE introduced was the Stewardship-Based Management for Area-Specific Risk Reduction Target program, which replaced the 30/50 program in 2013 and has focused on reducing the emissions of chemicals which were problematic in specific locations (MOE, 2013; Lee, 2019).[1] As MOE updates its regulations and policies to reduce emissions of chemicals, it requires evidence regarding the human health effects of chemicals at the levels released into the environment. The results of animal testing in laboratories may not apply to humans, and it is difficult to measure an individual's lifetime exposure to toxicants accurately when she/he is mobile.

This study examines the effects of pregnant mothers' toxic pollution exposures on their newborns' health in Korea using the county-level PRTR toxic release data and birth microdata. Looking at infant health rather than adult health outcomes is advantageous in terms of identifying the effects of pollution on human health. Since an infant's health is affected by his/her time in utero, it is possible to measure the infant's lifetime exposure to pollutants, assuming that the pregnant mother's mobility is low. In particular, the probabilities of low (<2.5kg) and very low (<1.5kg) birth weights will be used to indicate infant health outcomes. These birth outcomes depend solely on the infants' in utero experiences and not on anything that these infants experience after birth (although mother's toxic exposures prior to conception might be important as well).

Most of the existing literature on the health effects of both toxic and non-toxic pollution is based on studies conducted in the U.S., and studies done in developing or less-developed countries are sparse. However, the results of the studies conducted in the U.S. cannot be applied to other countries with different characteristics because the impact of pollution on infant health may depend on the baseline levels of pollution and infant health. For example, the marginal impact of pollution on infant health may be greater at higher levels of pollution. Also, countries with higher infant mortality rates may have weaker

[1] The Stewardship-Based Management for Area-Specific Risk Reduction Target program also allowed participating facilities more flexibility in terms of their targeted emission reductions.

infants from the start due to malnutrition or poor health care services than countries with a lower infant mortality rate, and weaker infants may be more vulnerable to air pollution. Therefore, when making policy decisions regarding toxic release regulations, it will be helpful to consider the effects on infant health from toxic pollution exposure found in a variety of settings rather than relying on the results for a single country. In 2005, the infant mortality rate in Korea was lower than that in the U.S., and Korea's county-average toxic emission density was higher than in the U.S.[2]

To estimate the effect of fetal exposure to toxic pollution on the probability of infant health outcomes, a dataset of individual-level births merged with county-level annual toxic release data for the period of 2004-2007 is constructed and a linear probability model is estimated. A large set of covariates, including a newborn's gender, an indicator for multiple births, parental characteristics, county time-varying characteristics, year effects, county fixed effects, and region-year fixed effects, are included. The underlying assumption for identifying the effects of toxic exposure on infant health outcomes is therefore that variations in toxic pollution emission densities within counties over time are exogenous to unobserved determinants of infant health outcomes conditional on all of the covariates included.

The findings indicate that toxic water and carcinogenic water emission densities have statistically significant positive effects on the probabilities of low birth weight.

[2] The county average number of infant deaths from internal causes in Korea in 2005 was 396 per 100,000 live births (calculated from infant mortality data provided by Statistics Korea), while it was 686 per 100,000 live births in the US. (MacDorman and Mathews, 2013) Total toxic releases (into air, water and land) reported to PRTR in Korea in 2005 equaled 47 million kg, and total toxic releases reported to the U.S. Toxics Release Inventory in 2005 totaled 1.6 billion kg (EPA, 2007). Although the total toxic release level is much higher in the U.S, than in Korea, the 2002 county average toxic emission density (weighted by live births) in the U.S. reported by Agarwal et. al. (2010) was 294 kg/km^2, which is lower than the comparable figure in Korea in 2004, which was 3,442 kg/km^2.

Interquartile increases in the toxic water emission density and carcinogenic water density are found to increase the probability of low birth weight by 0.3% and 0.1%, respectively. Toxic water emissions have greater detrimental effects on infant health than non-toxic water emissions. Heavy metal air emission densities increase the probabilities of both low birth weight and very low birth weight. An interquartile increase in heavy metal air emission density increases the probability of low birth weight by 0.3% and the probability of very low birth weight by 1%. The greater effects of heavy metal air emissions as opposed to those of toxic and carcinogenic emissions, coupled with other types of air emissions having no effect, supports that heavy metals persist longer in the air and in the body once inhaled, thus causing greater harm to pregnant mothers and fetuses. The estimated effects of a 1kg/km^2 increase in heavy metal air emission density from the mean on the probabilities of low birth weight and very low birth weight in Korea found in this study are similar to the point estimates of the corresponding effects for the U.S. found in Currie and Schmieder (2009).

The rest of this paper is organized as follows. In section II, a review of the literature on the effects of toxic pollution exposure on infant health is conducted. Next, the data sources, data construction method, and variables used in the estimations are described, and descriptive statistics are provided in Section III. The estimation methods are described in Section IV, and the estimation results are presented in Section V. Finally, concluding remarks are provided in Section VI.

3.2. Literature Review

Several biological mechanisms by which toxic pollution exposure affects fetal and infant health are discussed in environmental and epidemiological studies. These studies document a number of reasons why infants are more vulnerable to environmental toxins than adults. First, infants drink water, eat food, and breathe in air in much larger quantities relative to their body weight, resulting in relatively heavier exposures to the toxins contained in water, food, and air (Landrigan et al., 2004; Landrigan and Goldman, 2011). Second, the blood–brain barrier of the fetus is not fully developed until 6 months after birth; thus, toxic agents can enter the central nervous system of fetuses or infants more easily (Choi et al., 2006). Further, if the central nervous system is damaged, all the developmental processes which rely on signals sent by the brain will be disrupted. Because rapid and highly-choreographed development takes place in prenatal life and the first years after birth, brain damage or inappropriate hormonal signals caused by toxic chemicals can easily disrupt an infant's developmental process and lead to permanent functional impairments (Landrigan and Goldman, 2011). Therefore, the relatively brief period of life before and after birth is critical for growth and development.

Recent studies find that certain types of environmental toxicants may be more hazardous to fetal and infant health than others. Among the types of toxicants found to have adverse effects on infant health are heavy metals such as lead and methyl mercury. Landrigan et al. (2004) document that prenatal exposure to even low levels of lead and methyl mercury can impair the neurodevelopment of fetuses. González-Cossío et al. (1997) find that higher maternal bone lead levels predict lower birth weights. In addition to the studies linking maternal lead exposure and birth outcomes, several epidemiological studies have identified impacts of paternal lead exposure on low birth weight in their offspring (Min et al., 1996; Bellinger, 2005). Other heavy metals, such as cadmium and arsenic, have also been found to have deleterious effects on fetal and infant development (Hopenhayn et al., 2003; Kippler et al., 2012; Grandjean and Landrigan, 2006; Gundacker et al, 2010; Gilbert-Diamond, 2016). Not only do heavy metals have high toxicity, but they also persist in the human body for decades (Hu, 2002; Duruibe et al., 2007; Glick, 2001), causing long-lasting hazardous effects on human health.

A few economic studies exist that examine the relationship between toxic exposure and infant health. Currie and Schmieder (2009) and Agarwal et al. (2010) examine the effects of fetal exposure to environmental toxins on infant health using the toxic release data from the U.S. Toxics Release Inventory (TRI), which is a public disclosure system similar to Korea's PRTR. Using the 1988-1999 TRI data merged with birth and infant mortality data and aggregated at the county level, Currie and Schmieder (2009) look at air releases only and find that developmental toxicants have larger adverse effects than non-developmental chemicals on an array of infant health outcomes. They further divide the developmental toxicants into heavy metals and volatile organic compounds (VOCs), which are expected to have different actions in the body. Both VOC and heavy metal air releases were found to have adverse effects, and toluene, lead, and cadmium, in particular, were found to have the largest effects on infant health.

Agarwal et al. (2010) also use the county-year panel dataset of TRI releases merged with birth and infant mortality records. For the period 1989-2002, they examine the effects on infant health of toxic releases by various media (air, water, and land) and type (carcinogens, developmental/reproductive toxins). To account for the pollution from other sources, they control for the amounts of non-toxic air pollutants, such as particulate matter and ozone, and for the amounts of toxic chemicals released by the TRI-non-reporting facilities. They find statistically significant adverse effects of various chemical groupings (based on media and type) on infant health outcomes. They also find greater effects of air releases than water or land releases on infant health and the largest effects for carcinogenic air releases on infant mortality. Both Currie and Schmieder (2009) and Agarwal et al. (2010) use a large set of covariates, including parental characteristics, county characteristics, year effects, and county fixed effects, for the identification of causal health effects of toxic pollution exposure.

This is the first study that uses the MOE's PRTR data to examine the effects on infant health of toxic pollution in Korea. This study will provide the estimates of the effects of toxic pollution exposure on infant health at the current (2004-2007) levels of toxic releases in Korea as well as information on which types of toxicants have larger deleterious effects on infant health than others. For Korean policymakers regulating toxic pollution emissions, this study may serve as guidance in identifying the chemicals to regulate more strictly and setting target amounts of reductions in chemical releases.

3.3. Data and Descriptive Statistics

Data from various sources is combined to examine the effects of toxic substances on infant health outcomes for the period 2004 to 2007. The individual-level birth records provided by Statistics Korea[3] cover virtually all live births in Korea in a given period and carry information on parental age, education, and occupation; maternal marital status; gestation period; county of residence; infant gender and birth weight; and whether a given

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[3] Individual birth data were purchased from the Microdata Integrated Service (MDIS) website maintained by Statistics Korea. https://mdis.kostat.go.kr

birth is a multiple birth. Individual-level birth data are merged with the toxic release data based on the mother's county of residence.

Toxic release data come from the PRTR website maintained by MOE. Currently, the MOE uses the PRTR program, which is similar to the U.S. TRI program, to track 416 kinds of chemicals released by facilities with more than 30 employees in 39 industries. The PRTR program requires the facilities that use or manufacture any of the listed chemicals in excess of the threshold levels to report their releases to MOE, which then verifies the reported releases and publishes them on their website for public access. In 1999, the first year of the PRTR program, facilities with more than 100 employees in only 2 industries were required to report their releases of 80 chemicals on the list. Over the course of the program, the reporting requirements have expanded to cover a greater number of chemicals, facilities, and industries. During the sample period 2004 to 2007, the PRTR reporting requirements did not change the 388 toxic substances to be reported by facilities with more than 30 employees in 36 industries.

PRTR data provide information on the amount of chemicals that facilities either release into the environment on-site or transfer to off-site for disposal. It also reports chemical releases into the air, water, and land separately. The PRTR classifies the reported chemicals into toxic chemicals, which are known to have harmful effects on human health and are regulated by law, and carcinogens, which are known to cause a specific set of cancers. There are a small number of chemicals that are not classified as toxic that have been listed on the PRTR because their toxicity has been delineated by international organizations such as the International Uniform Chemical Information Database (IUCLD)[4]

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[4] IUCLD was developed, and is maintained, by the European Chemicals Agency in collaboration with the Organisation for Economic Co-operation and Development.

and Globally Harmonized System of Classification and Labeling of Chemicals (GHS).[5] During the 2004-2007 period, 227 out of the 338 PRTR-listed chemicals were released into the environment. Out of the 227 released chemicals, 158 were toxic and 58 were carcinogens. Further, a category for developmental or reproductive toxicants is developed using the list provided by the California Office of Environmental Health Hazard Assessment and further divided into subgroups of heavy metals (including lead, cadmium, mercury, arsenic, and chromium) and VOCs (including benzene, butadiene, chloroform, methanol, and toluene). By disaggregating the chemicals into several groups in terms of the reactions they cause in the body and toxicity, done in lieu of applying weights, the extent to which the aggregate effects mask the effects of more detrimental types of chemicals can be mitigated.[6] Considering that counties are of different sizes, all the pollution measures are rescaled by dividing chemical releases by the county area.

Other county-level characteristics to be used as controls include population, percentage of county budget spent on welfare, number of registered motor vehicles per area, and an index of each county's financial independence, which is calculated as the sum of local taxes and revenues other than from taxes divided by the amount of the county's budget. These data are taken from the Korean Statistical Information Service.

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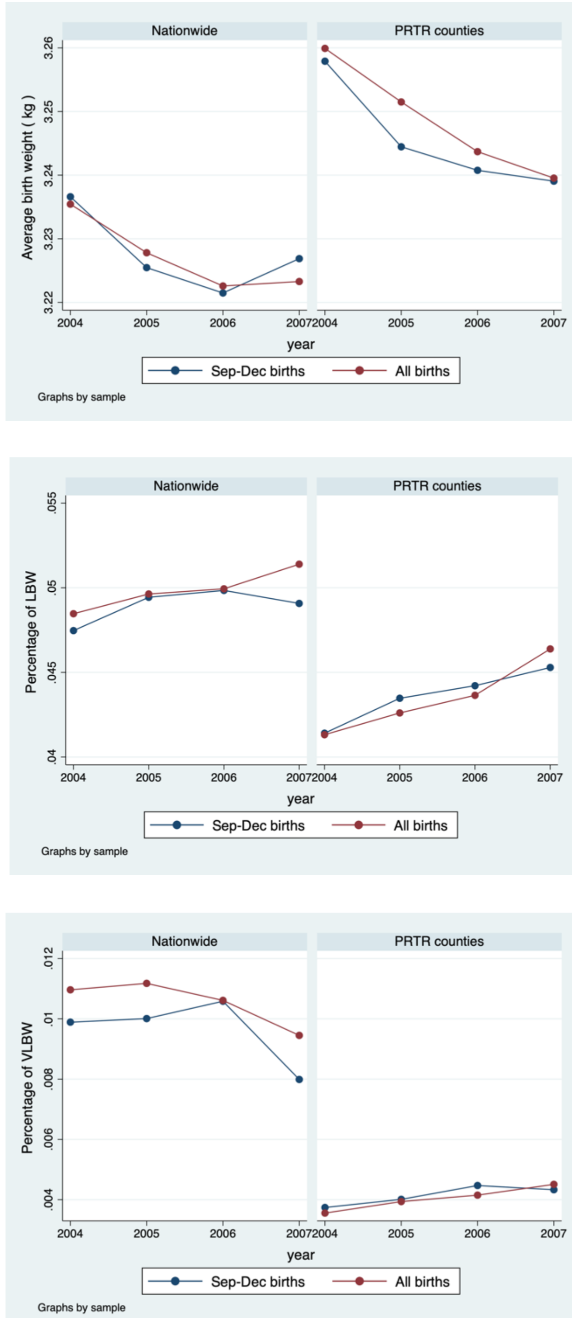
[5] GHS was developed by an international team of hazard communication experts organized by the United Nations.

[6] Toxicity weights are not available for about half of the PRTR chemicals. Using the sum of chemical releases unweighted by their toxicity factors will likely yield obscure estimates of health effects because 1kg of a highly toxic chemical is treated the same as 1kg of a mildly toxic chemical. For example, the health effect triggered by 1kg of a highly toxic chemical may be obscured by 1,000 kg of mildly toxic chemicals. For this reason, when using unweighted measures of toxic chemical emissions, it is crucial to divide aggregate chemicals into groups based on the reactions that they cause in the body and their levels of toxicity. This categorization is also necessary in order to identify which types of chemicals are responsible for adverse birth outcomes.

Figure 3. 1. Trends in birth outcomes for all vs PRTR counties (weighted by live births)

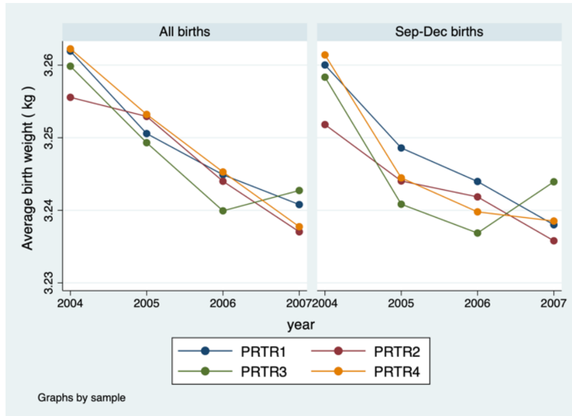


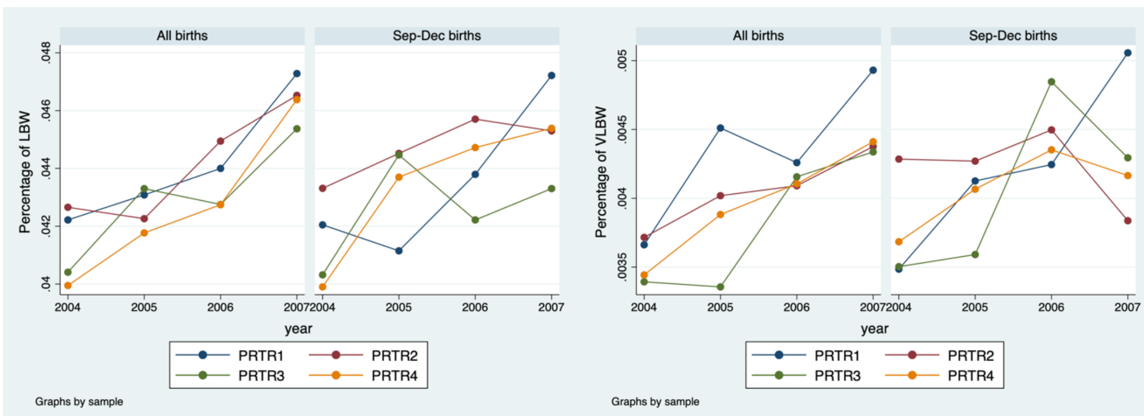
The merged birth and PRTR dataset contains 1,532,728 live births in 174 counties from 2004 to 2007. The analysis is then further restricted to 483,539 September to December births in the 2004-2007 period to match birth outcomes to chemical releases in the relevant years. Looking at 483,539 births that occurred in September-December only can ensure that the entire pregnancy period of mothers giving birth in a given year was subject to the pollutant releases in the same year. However, it is not known what time period within a pregnancy is critical in terms of a newborn's birth weight and what months of the year the pollution level was high enough to cause harmful effects on fetuses. After deleting the observations with missing variables that are important for the analysis, the final regression sample consists of 481,516 live births in 173 counties.

Figure 3.1 shows the yearly mean county-level birth outcomes for a total of 232 counties nationwide and for the 173 counties in which releases of PRTR chemicals were reported from 2004 to 2007. The birth outcomes are reported for all births and the September to December births for both nationwide and PRTR counties and have been weighted by the number of live births. The average yearly county-level birth weights in the PRTR counties are a little higher than the nationwide averages throughout the sample period. However, the averages show a decreasing trend both nationwide and in PRTR counties during this period. The county-level percentage of low birth weights (LBWs) for all births increased from 4.8% in 2004 to 5.1% in 2007 nationwide. The figure is a little lower in the PRTR counties in each year, but it shows a larger increase from 4.1% in 2004 to 4.6% in 2007.[7] PRTR counties also have lower percentages of very low birth weights (VLBWs) throughout the sample years than are seen nationwide. However, the percentage

[7] About 10 percent increase in the mean county-level percentage of LBW over 4 years is fairly large. A crude data analysis (without county fixed effects) shows that maternal characteristics explain about 0.05 percentage points (ppt) of the 0.5ppt increase in the LBW rate between 2004 and 2007, but mother's age explains almost all of the 0.05ppt. Maternal characteristics plus an indicator for multiple births explain 0.23ppt of the 0.4ppt increase. The LBW rate in Korea has increased from 3.9% in 2000 to 5.9% in 2013. Beginning in 2008, Korea Ministry of Health and Welfare (KMHW) has been subsidizing the university hospitals to increase their neonatal intensive care units to meet the demand for the low birth weight infant care that had ever been growing since 2000. KMHW remarks in the announcement of their subsidy plan that the increasing low birth weight rate in Korea since 2000 is due to a growth of older-age pregnancies and a growth of multiple births as a result of infertility treatment called in vitro fertilization.

Figure 3. 2. Mean county-level birth outcomes by PRTR quartiles weighted by live births (All births vs September-December births)





Note: The figures are only for the PRTR counties that reported positive amounts of emissions from 2004-2007.

of VLBWs in the PRTR counties increased from 0.4% in 2004 to 0.5% in 2007, while it decreased from 1.1% in 2004 to 0.9% in 2007 nationwide. The levels and trends in birth outcomes for the September-December births are similar to those for all births nationwide and in PRTR counties. In Figure 3.2, the annual changes in the average county-level birth weights and percentages of LBWs and VLBWs are graphed by the quartiles of PRTR pollution emission densities (which are the pollution releases divided by county area) for the sample containing births in all months and the regression sample containing only the

September-December births. There appear to be no systematic differences in both levels and trends in percentages of LBWs and VLBWs between PRTR counties at different quartiles of PRTR pollution emission densities.

Figure 3. 3. Trends in chemical emission densities by chemical type and environmental medium weighted by live births

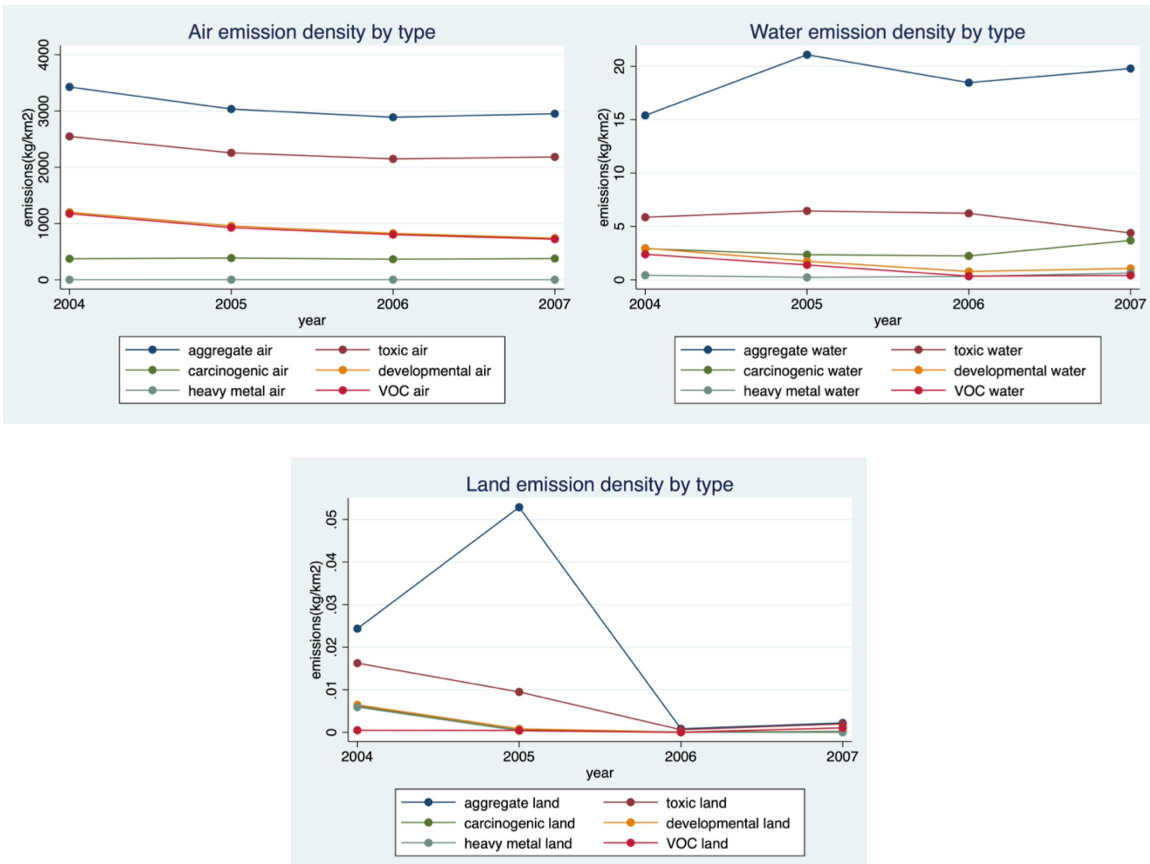


Figure 3.3 shows the trends in average county-level emission densities by medium and type. As shown in Figure 3.3, most types of chemical releases into the air and water declined over the 2004-2007 period. However, carcinogenic air and water emission densities and heavy metal water emission densities increased over the period. VOC and heavy metal water emission densities are very low and close to zero, so their effects on

birth outcomes are not examined. Since land emission densities, even when considered in aggregate, are close to zero during the entire 2004-2007 period, the effects of land emission density on birth outcomes are also not examined. The county-year-level summary statistics are presented in Table 3.1 for both the birth/PRTR-merged sample of all births during the period 2004-2007 and the subsample of September-December cohorts (regression sample).

Table 3. 1. Descriptive Statistics (weighted by live births)

	Sep-Dec births	All births
Birth weight	3.25 (0.024)	3.25 (0.019)
Low birth weight	0.044 (0.0087)	0.044 (0.0056)
Very low birth weight	0.0041(0.0027)	0.0040 (0.0015)
Mother's age	29.8 (0.58)	29.8 (0.55)
Father's age	32.6 (0.51)	32.6 (0.48)
Multiple	0.023	0.024
Male	0.52	0.52
Married	0.99	0.99
Mother's edu: primary school or no school	0.0039	0.0041
Mother's edu: middle school	0.018	0.019
Mother's edu: high school	0.41	0.42
Mother's edu: college or graduate school	0.57	0.56
Father's edu: primary school or no school	0.0059	0.0062
Father's edu: middle school	0.021	0.022
Father's edu: high school	0.36	0.36
Father's edu: college or graduate school	0.61	0.61
Mother's occ: manager	0.0012	0.0011
Mother's occ: professional	0.19	0.18
Mother's occ: service	0.034	0.033
Mother's occ: farming/fishing	0.0039	0.0043
Mother's occ: mechanic	0.00081	0.00072
Mother's occ: technician	0.0030	0.0029
Mother's occ: laborer	0.0012	0.0011
Mother's occ: unemployed/out of labor force	0.77	0.78
Father's occ: manager	0.0091	0.0089
Father's occ: professional	0.61	0.60
Father's occ: service	0.22	0.22
Father's occ: farming/fishing	0.017	0.018
Father's occ: mechanic	0.026	0.027
Father's occ: technician	0.063	0.064
Father's occ: laborer	0.020	0.021
Father's occ: unemployed/out of labor force	0.042	0.043
Population	583399.2 (559154.7)	583847.2 (559993.7)

Area (km^2)	291.1 (315.2)	290.9 (315.7)
Number of motor vehicles per area	2207.5 (2306.8)	2209.0 (2306.5)
Welfare share of county budget	21.4 (10.4)	21.4 (10.4)
Financial independence index	72.2 (10.5)	72.2 (10.5)
Aggregate air emission density (kg/km^2)	3074.5 (7970.0)	3072.0 (7963.6)
Aggregate water emission density	18.7 (69.9)	18.7 (69.8)
Aggregate land emission density	0.019 (0.14)	0.020 (0.14)
Toxic air emission density	2283.3 (6092.8)	2279.2 (6083.3)
Toxic water emission density	5.68 (20.6)	5.72 (20.8)
Toxic land emission density	0.0070 (0.049)	0.0072 (0.049)
Carcinogenic air emission density	376.8 (1044.9)	378.3 (1048.8)
Carcinogenic water emission density	2.84 (14.5)	2.80 (14.3)
Carcinogenic land emission density	0.0017 (0.026)	0.0018 (0.026)
Developmental air emission density	927.3 (2718.5)	929.1 (2737.2)
Developmental water emission density	1.63 (8.15)	1.65 (8.26)
Developmental land emission density	0.0021 (0.028)	0.0022 (0.029)
VOC air emission density	902.8 (2700.1)	904.5 (2718.9)
VOC water emission density	1.12 (7.24)	1.15 (7.36)
VOC land emission density	0.00052 (0.0049)	0.00052 (0.0049)
Heavy metal air emission density	1.97 (7.18)	1.99 (7.27)
Heavy metal water emission density	0.42 (2.15)	0.41 (2.07)
Heavy metal land emission density	0.0016 (0.026)	0.0016 (0.026)
Observations	692	692

Note: Standard deviations are in parentheses.

3.4. Estimation methodology

The net effect of the amount of chemical releases into the environment on the incidence of LBW is estimated with the following linear probability model (LPM):

$$(V)LBW_{ict} = \alpha + \beta_1 T_{ct} + \beta_2 T_{ct}^2 + \beta_3 X_{ict} + \beta_4 Z_{ct} + \theta_c + \tau_t + \delta_R * \tau_t + \epsilon_{ict}$$

where $(V)LBW_{ict}$ is an indicator for (very) low birth weight which is equal to 1 if a newborn i in county c and year t weighs less than (1.5kg) 2.5kg and 0 if he/she weighs (1.5kg) 2.5kg or more. T_{ct} is the independent variable of interest, which is the amount of chemicals released into the environment per 1km^2 of area, and T_{ct}^2 is its squared term. X_{ict} represents the set of parental characteristics such as parental age, the indicators for parental education and occupation and maternal marital status, and birth characteristics, including the indicators for male and multiple births. Z_{ct} represents the set of county time-varying characteristics such as the number of registered motor vehicles per county area, population, welfare percentage of a county's budget, and the index of a county's financial independence (calculated as the sum of local taxes and revenues from other than taxes divided by the budget amount). The θ_c are county fixed effects, τ_t are year effects, and $\delta_R * \tau_t$ are region-year fixed effects. The term ϵ_{ict} contains the unobserved characteristics that randomly affect the outcome of LBW. The standard errors are clustered on the county to correct for error correlations over time within a county and to obtain consistent estimates of standard errors.

The LPM approach is used instead of a probit or logit model to avoid making assumptions about the distribution and homoscedasticity of the error terms.[8] In addition, in line with Agarwal et al. (2010)'s approach, the effect of pollution on infant health outcomes is assumed to be nonlinear, and quadratic terms of emissions variables are included to allow for the marginal effects on the probability of LBW to differ with the levels of emissions. Although a linear model is used widely in the research on the health effects of pollution (Greenstone and Chay, 2003), a nonlinear approach seems more reasonable in the case of Korea, which has a higher level of toxic emissions than the U.S.

Since parental age, education, occupation, and whether a county is urban or rural

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[8] The probit and logit models yielded estimates of the marginal effects that were similar to those obtained from the LPM model. According to Angrist and Pischke (2009), while a probit or logit model may fit the data more closely (when the underlying model is nonlinear), the LPM still generates robust estimates of marginal effects. However, when the distributional assumption is incorrect, the probit and logit models yield biased coefficients. In addition, heteroscedastic errors in the LPM model only bias standard errors, which can be easily fixed, whereas heteroscedastic errors in the probit model cause biased coefficients as well and various methods of correcting for the bias are not robust.

are correlated with the chemical emission densities (although the correlations are not large) and affect the infant health outcomes themselves, omitting these factors would lead to biased estimates of the pollution effects on the probabilities of LBW outcomes. For example, counties may have a lower percentage of LBWs despite having a higher toxic emission density because they also have younger mothers who are more likely to give birth to healthy babies or because they have parents whose income levels are higher. Although parental education and occupation should serve as proxies for their income, the county-level population, welfare share of the county budget, and the county's financial independence index have also been included to account for income effects on infant health. To account for pollution from mobile sources, the number of registered vehicles per area is included.

A multiple-birth dummy is also included as a control. Whether or not a newborn is part of a multiple birth is an important predictor of LBW. The Korea Ministry of Health and Welfare attributes the rapid growth in incidences of LBW in Korea in the past decade to the growth of both older-age pregnancies and multiple births resulting from infertility treatments such as in vitro fertilization (IVF). The preliminary analysis of the data (without accounting for any county differences) confirms that the multiple birth indicator explains a large portion of the variations in the probabilities of low and very low birth weights. Controlling for multiple births is important because one of the natural causes of multiple births is a mother's older age; therefore, multiple births are correlated with maternal age. Also, there might be a positive income elasticity associated with multiple births due to the high cost of IVF treatment, implying that multiple births might be correlated with pollution as well (since pollution is correlated with income). However, a possible drawback of including a multiple birth indicator is that if pollution causes infertility and thus multiple births, then controlling for multiple births may limit a pathway through which pollution affects the LBW outcome.

To address the problem of omitted variable bias further, county fixed effects are included to control for permanent differences across counties related to the quality of health care providers, climate, percentage of immigrants, and tradition. Year effects account for any nationwide shocks to the economy or changes in environmental laws or regulations nationwide. By adding region-by-year effects, I also control for the unobserved characteristics that are common to all counties in the same region in each year.[9] For example, there may be changes in the regional policies in a given year which may affect both infant health and toxic release amounts of all counties in that region.

3.5. Estimation results

Table 3.2 presents the estimated effects of the aggregate emission density, which is all PRTR chemical releases per area. The aggregate chemical emission density does not have a statistically significant effect on either the probability of LBW or the probability of VLBW. Finding no health effects of chemical emission densities in the aggregate gives rise to a need for unpacking varying health effects of chemicals of different types and media.

Table 3.3 presents the results from estimating the effects on the probability of LBW from toxic emission densities (including only the chemicals belonging to the "toxic" category by Korean law) by media. It shows the results from five different specifications from column (1) with only year effects and county characteristics to column (4) with the

[9] Korea consists of 16 regions (or provinces). Due to missing variables, the sample used for this analysis excludes one province, Jeju, which is a remote island off the coast of Korea.

full set of controls. The pollution variables of interest in all specifications are the linear and quadratic terms of toxic air and water emission densities probability of LBW in all specifications (1)-(4), but the magnitude of the effect is reduced with added controls. From the final specification in column (4) with the full set of controls, the coefficient on the linear term is 0.0639, and the coefficient on the quadratic term is -0.447. [10] These coefficients on the linear and quadratic terms of toxic water emission density are individually significant at the 1% level and jointly significant at the 5% level.

Table 3.4 reports the marginal effects of toxic and non-toxic emission density variables evaluated at their mean levels and the effects of changes from the 25th to 75th percentile emission variables or interquartile effects on the probability of LBW. A 1 kg/km^2 increase in the toxic water emission density from the mean would increase the probability of LBW by 0.0059 percentage points (ppt). From another perspective, an interquartile increase in toxic water emission density would increase the probability of LBW by 0.013 ppt. The non-toxic water emission density is found to lead to a smaller increase in the probability of LBW than the toxic water emission density. A 1kg/km^2 increase in non-toxic water emission density from the mean leads to a 0.0044 ppt increase in the probability of LBW, and an interquartile change leads to an increase of 0.0053 ppt. The marginal effects of the toxic water emission density at the 10th and 90th percentiles on the probability of LBW are both positive and statically significant at the 1% level, and the counterparts of the non-toxic water emission density are also positive and statically significant at the 5% level. These results are reassuring in terms of the quadratic

[10] The pollution units are in 1,000 kg/km^2 in all of the regressions run in this study. Therefore, to obtain the coefficients in terms of a 1kg/km^2, one should multiply the coefficient of the linear term by 1,000 and the coefficient of the quadratic term by 1,000,000.

form of the emission variables fitting the data well.

The coefficients on all parental characteristics, including mother and father's ages, maternal marital status, indicators for both mother and father's education, indicators for father's occupation, and some categories of mother's occupations, are statistically significant, and their signs are as expected. In the final specification (4) in Table 3.3, which includes the full set of controls, the coefficient for the mother's age is 0.00068, which implies that a one-year increase in a mother's age would increase the probability of LBW by 0.068 ppt. The negative coefficient for marital status implies that a married mother is less likely to have a LBW outcome than an unmarried mother. The positive signs on the parents' education indicators suggest that probability of LBW is higher for the parents who had no schooling or are primary school graduates, middle school graduates, or high school graduates than for the base group of parents who obtained a college degree or higher level of education. Among the mother's occupation dummies, only the professional and technician categories were found to be statistically significant. The estimates indicate that both professional and technician mothers have a higher probability of LBW than non-working mothers, and technician mothers are at a higher risk than professional mothers. The negative coefficients on all dummies for father's occupation indicate that the probability of LBW is higher for the base group of non-working fathers (which include those who are unemployed or out of the labor force) than for the fathers who work in any of the occupation categories used. The coefficient on the multiple birth dummy is highly statistically significant (at the 1% level) and large, indicating that being part of a multiple birth is a strong predictor of LBW. All of the county time-varying characteristics, including the population, number of registered motor vehicles per area, welfare percentage of budget, and index of financial independence, are statistically insignificant.

For both carcinogens and developmental toxicants, the effects of emission densities by medium on the probabilities of LBW and VLBW and birth weight are examined using the full set of controls. (all regressions hereafter include the full set of controls). The marginal effect of carcinogenic water emission density on the probability of LBW is statistically significant at the 5% level (and their regressions coefficients are jointly significant at the 10% level) (see Table 3.5). A 1kg/km^2 increase in carcinogenic water emission density from its mean level increases the probability of LBW by 0.022 ppt, and an interquartile change would lead to an 0.0048 ppt increase in the probability of LBW (see Table 3.6 and Table 3.7). The developmental air emission density has a marginal effect with an unexpected sign on the probability of LBW, and the marginal effect is statistically significant as well (See Tables 3.8-3.10). The unexpected signs of developmental coefficients may result from developmental toxicants being correlated with unobserved factors such as the county employment rate or business cycle. For example, during an economic boom, the increased production in a county would boost the employment rate while generating a greater amount of pollution in that county. If higher employment rates lead to better nutrition and care of the pregnant mothers and thus a reduction in the incidence of low birth weight, omitting the employment rate from the regression would lead to the underestimation of the impact of pollution.

Next, I examine the effects of subgroups of developmental toxicants: heavy metal air emissions and VOC air emissions. Tables 3.11-3.13 show the results from the estimation with the heavy metal air emission density, residual (non-heavy metal) air emission density, and aggregate water emission density. The aggregate water emission density has been included in lieu of the heavy metal water emission density, which is close to zero. Heavy metal air emission density has a statistically significant effect on both the probabilities of LBW and VLBW. A 1kg/km^2 increase in heavy metal air emission density increases the probability of LBW by 0.036 ppt, and an interquartile change increases the probability of LBW by 0.012 ppt. A 1kg/km^2 increase in heavy metal air emission density increases the probability of VLBW by 0.013 ppt, and an interquartile change increases it by 0.0043 ppt. The marginal effects of the heavy metal air emission density on both the probability of LBW and probability of VLBW at the 10th and 90th percentile emission densities are all positive and statistically significant. Tables 3.14 -3.16 present the estimated effects of the VOC and residual (non- VOC) air emission densities and aggregate water emission density. The marginal effect of VOC air emission density on the probability of LBW has an unexpected sign and is statistically significant, which raises the concern of endogeneity, as in the regression with the total developmental chemical emission density. The estimated coefficients on the control variables in all of the regressions run in this study are not reported because the same set of variables are found to have statistically significant effects on the LBW outcomes, and their effects have the same signs and similar magnitudes as in the estimation with toxic emission densities by medium (for which the estimated coefficients on the control variables are reported in Table 3.3).

In all of the regressions, no relationship was found between chemical emissions and birth weight. LBW and VLBW are conventional measures of infant health because epidemiological and clinical studies find that babies weighing less than 2.5kg are at increased risks for poor health compared to babies weighing from 2.5 kg- 4 kg, which is defined to be the normal range (McCormick et al., 1992; Nelson and Grether, 1997; Lucas, Morley, and Cole, 1998; Brooks et al., 2001; Richards et al.; 2001). Therefore, it is likely that only the weaker and more vulnerable babies are affected by toxic emissions while healthier babies in the upper range of the birth weight distribution are not affected. Since LBW is infrequent, we might find no relationship when looking at the whole distribution of birth weights.

In sum, toxic water emission density and carcinogenic water emission density were found to have statistically significant adverse effects on the probabilities of LBW outcomes. Toxic water emission has a larger effect on LBW than non-toxic water emission does. An interquartile change in toxic water emission density and carcinogenic water emission density lead to 0.3% and 0.1% increases in the probability of LBW, respectively while non-toxic water emission density leads to a 0.1% increase in the probability of LBW. Pregnant mothers may be exposed to the toxins in the air more easily through breathing than to the toxins in the water. However, toxic chemicals released into water also are likely to affect pregnant mothers because about 98.6% of the drinking water in Korea is from surface water, which is more susceptible to pollution than groundwater. According to the waterworks statistics published by MOE in 2007, 52.1% of the water which is filtered and then distributed to local residents for drinking purposes comes from the local rivers, 45.2% comes from water stored behind dams, 1.4% comes from local reservoirs, and only 1.2% comes from groundwater. Considering that 92.1% of the population nationwide had access to the filtered water in 2007 (although the access rate is 45.2% in the most remote rural areas) and that toxic water emissions are found to have adverse effects on birth outcomes leads to the question as to what the possible channels through which mothers are exposed to toxic water pollution are. It may be that some toxic chemicals cannot be filtered and remain in the water mothers drink, that they eat fish from contaminated water, or that some mothers drink unfiltered water.

Heavy metal air emission density was found to have statistically significant adverse effects on the probabilities of both LBW and VLBW. An interquartile change in heavy metal air emission density leads to a 0.3% increase in the probability of LBW and a 1% increase in the probability of VLBW. Heavy metal air emission density has a considerably higher effect on the birth outcomes than toxic or carcinogenic water emission densities, and other types of air emission densities do not affect birth outcomes. This finding suggests that heavy metals are more detrimental than other types of chemicals because of their higher levels of toxicity and persistence. In terms of marginal effects, a 1kg/km^2 increase in heavy metal air emission density would increase the probability of LBW by 0.036 ppt and the probability of VLBW by 0.013 ppt in Korea during the 2004-2007 period. These estimates are similar to Currie and Schmieder's (2009) counterpart estimates for the U.S. in the period 1988-1999. As shown in Table 3.17, Currie and Schmieder's estimate of the marginal effect of heavy metal air releases on the probability of LBW and the probability of VBLW in the U.S. during 1988-1999 are 0.032 ppt and 0.006 ppt, respectively (although these estimates are imprecise). The F-test cannot reject that the effects of heavy metal air emissions on the probability of LBW and the probability of VLBW in Korea are the same as the corresponding effects for the U.S. at any conventional significance level. However, it should be noted that the effects in Korea are found for a higher mean level of heavy metal air emission density (and higher mean levels of all other chemical groups) and at lower percentages of LBW and VLBW than the corresponding levels in the U.S..

3.6. Conclusion

The empirical analysis reveals that toxic water, carcinogenic water, and heavy metal air emission densities have statistically significant adverse effects on infant health in Korea. The estimated coefficients imply that an interquartile increase in toxic water emission density would lead to 0.3% increase in the probability of LBW. An interquartile increase in carcinogenic water emission density would increase the probability of LBW by 0.1%. Toxic water emission densities increase the probability of LBW more than the non-toxic water emission density does, which suggests greater harmful effects from the classified chemicals. Pregnant mothers may be exposed to toxins in their drinking water, almost all of which comes from the surface water in Korea. Despite a high rate of access to filtered water in Korea, not all toxins may be eliminated from filtering.

The heavy metal air emission density has statistically significant adverse effects on both the probabilities of LBW and VLBW. An interquartile increase in the heavy metal air emission density would increase the probability of LBW by 0.3% and would increase the probability of VLBW by 1%. While other types of air emission densities have no impact on birth outcomes, the heavy metal air emission density was found to increase the probabilities of both LBW and VLBW. These results suggest that heavy metals are more hazardous to infant health due to their greater toxicity and persistence in the air and the human body than other types of chemicals. The estimated effects of heavy metal air emission density on the probabilities of LBW and VLBW in Korea are similar to the estimated effects for the U.S. obtained by Currie and Schmieder (2009). The effects of the heavy metal air emission in Korea are found at the higher levels of heavy metal air emission density (and all other emissions) and the lower percentages of LBW and VLBW than in the US.

However, these estimates may be subject to bias to the extent that the changes in the composition of at-risk pregnant mothers (measured in terms of drinking, smoking, or other health-related behaviors) within counties is non-random. That is, if pregnant mothers living in counties with higher toxic emissions take more precautions concerning their health, omitting the mothers' health habits will underestimate the adverse effects of toxic emissions on their birth outcomes. Also, counties will have both higher toxic emissions and higher incomes during economic booms. Mothers' health may improve with higher incomes while also deteriorating due to higher toxic emissions at the same time. Another possibility is that there is a systematic pattern in the amount of toxic chemicals released by the non-reporting facilities. There may be more non-PRTR facilities in the areas with more PRTR facilities. If there are high correlations between non-PRTR pollutant emissions and PRTR pollutant emissions, omitting non-PRTR pollutants will underestimate the adverse effects of chemicals on birth outcomes. These possible sources of bias can be explored in future research.

Table 3. 2. Effects of aggregate emission density (air, water, and land combined) on birth outcomes

	LBW	VLBW	Birth weight
Aggregate emission density	0.000100	0.0000537	0.000483
	(0.000307)	(0.000119)	(0.000740)
(Aggregate emission density)^2	-0.00000289	9.24e-08	0.000000825
	(0.00000285)	(0.00000120)	(0.00000692)
R^2	0.13	0.01	0.09
Observations	481,516	481,516	481,516
F-stat for joint significance of aggregate emissions	1.58	0.43	1.56

Notes: The pollution units are in 1,000 kg/km^2. To obtain the coefficients in terms of 1 kg/km^2, multiply the coefficients for the linear terms of pollution variables by 1,000 and the squared terms by 1,000,000. Dependent variables are the probability of low birth weight (<2.5kg), the probability of very low birth weight (<1.5kg), and birth weight. The regressions include the full set of controls, including infant gender and multiple birth dummies, parental characteristics, county characteristics, year effects, county fixed effects, and region-by-year effects. Standard errors are clustered at the county level.

* p < .10, ** p < .05, *** p < .01

Table 3. 3. Estimated effects of toxic emission densities on low birth weight (<2.5kg)

	(1)	(2)	(3)	(4)
Toxic air	0.0000577	-0.0000190	0.000182	0.0000952
	(0.000214)	(0.000186)	(0.000433)	(0.000482)
(Toxic air)^2	0.000000132	0.00000117	-0.00000393	-0.00000151
	(0.00000319)	(0.00000298)	(0.00000410	(0.00000474)
Non-toxic air	-0.000236	0.00000516	0.00109	0.000744
	(0.000609)	(0.000515)	(0.000856)	(0.000780)
(Non-toxic air)^2	-0.00000571	-0.0000236	-0.0000668	-0.0000535**
	(0.0000283)	(0.0000303)	(0.0000434)	(0.0000247)
Toxic water	0.0913**	0.0859***	0.0759***	0.0639***
	(0.0448)	(0.0291)	(0.0147)	(0.0237)
(Toxic water)^2	-0.529**	-0.521***	-0.487***	-0.447***
	(0.262)	(0.180)	(0.0989)	(0.153)
Non-toxic water	-0.0108	-0.00409	0.0603***	0.0471**
	(0.0250)	(0.0235)	(0.0231)	(0.0238)
(Non-toxic water)^2	0.00888	-0.00391	-0.0712**	-0.102*
	(0.0531)	(0.0494)	(0.0319)	(0.0582)
Population	-1.72e-09*	-7.49e-10	-3.97e-09	-3.85e-09
	(9.00e-10)	(7.69e-10)	(2.58e-09)	(2.97e-09)
Motor vehicles per area	-0.000000409**	-0.000000411**	0.00000200	5.39e-08
	(0.000000206)	(0.000000191)	(0.00000404	(0.00000498)
Welfare share of budget	0.000114**	0.000134***	-0.0000529	-0.000338
	(0.0000511)	(0.0000472)	(0.000184)	(0.000212)
Financial independence	0.000122**	0.0000896*	-0.0000583	0.00000888
	(0.0000566)	(0.0000524)	(0.000108)	(0.000146)
Male		-0.00884***	-0.00886***	-0.00887***
		(0.000602)	(0.000601)	(0.000601)
Multiple birth		0.478***	0.478***	0.478***
		(0.00678)	(0.00678)	(0.00678)
Mother’s age		0.000662***	0.000674***	0.000675***
		(0.000105)	(0.000106)	(0.000106)
Father’s age		0.000154*	0.000161*	0.000160*
		(0.0000895)	(0.0000906)	(0.0000907)
Married		-0.0167***	-0.0168***	-0.0168***
		(0.00378)	(0.00378)	(0.00378)
Mother’s edu: no/primary		0.0196***	0.0195***	0.0195***
		(0.00565)	(0.00565)	(0.00566)
Mother’s edu: middle		0.0154***	0.0153***	0.0153***
		(0.00280)	(0.00281)	(0.00281)
Mother’s edu: high		0.00337***	0.00337***	0.00337***
		(0.000708)	(0.000716)	(0.000717)
Father’s edu: no/primary		0.0192***	0.0191***	0.0191***
		(0.00528)	(0.00527)	(0.00527)
Father’s edu: middle		0.0115***	0.0116***	0.0116***
		(0.00264)	(0.00265)	(0.00265)

Father's edu: high		0.00438***	0.00440***	0.00439***
		(0.000766)	(0.000763)	(0.000764)
Mother's occ: manager		0.00545	0.00573	0.00559
		(0.00935)	(0.00938)	(0.00940)
Mother's occ: professional		0.00152*	0.00162*	0.00160*
		(0.000851)	(0.000843)	(0.000843)
Mother's occ: service		0.000565	0.000522	0.000515
		(0.00158)	(0.00157)	(0.00157)
Mother's occ: farm/fish		0.00312	0.00278	0.00287
		(0.00530)	(0.00533)	(0.00533)
Mother's occ: mechanic		-0.00280	-0.00380	-0.00397
		(0.0108)	(0.0107)	(0.0107)
Mother's occ: technician		0.0103**	0.00995*	0.00994*
		(0.00518)	(0.00519)	(0.00518)
Mother's occ: laborer		-0.000165	-0.000759	-0.000769
		(0.00841)	(0.00847)	(0.00845)
Father's occ: manager		-0.00930***	-0.00922***	-0.00923***
		(0.00333)	(0.00331)	(0.00331)
Father's occ: professional		-0.00903***	-0.00892***	-0.00893***
		(0.00155)	(0.00157)	(0.00157)
Father's occ: service		-0.00980***	-0.00976***	-0.00976***
		(0.00177)	(0.00178)	(0.00178)
Father's occ: farm/fish		-0.00536*	-0.00544*	-0.00548*
		(0.00313)	(0.00320)	(0.00319)
Father's occ: mechanic		-0.00623***	-0.00639***	-0.00639***
		(0.00219)	(0.00222)	(0.00221)
Father's occ: technician		-0.00850***	-0.00830***	-0.00833***
		(0.00194)	(0.00189)	(0.00190)
Father's occ: laborer		-0.00508**	-0.00510**	-0.00514**
		(0.00255)	(0.00254)	(0.00254)
Year effects	Y	Y	Y	Y
County effects	N	N	Y	Y
Region-by-year effects	N	N	N	Y
R^2	0.01	0.12	0.13	0.13
Observations	481,516	481,516	481,516	481,516
F-stat for joint significance of toxic air emissions	0.58	0.23	0.87	0.07
F-stat for joint significance of nontoxic air emissions	1.51	1.08	1.20	4.68
F-stat for joint significance of toxic water emissions	2.08	4.36	13.37	4.27
F-stat for joint significance of nontoxic water emissions	4.30	3.45	4.44	2.09

Notes: The pollution units are in 1,000 kg/km^2. To obtain the coefficients in terms of 1 kg/km^2, multiply the coefficients for the linear terms of pollution variables by 1,000 and the squared terms by 1,000,000. Dependent variables are the probability of low birth weight (<2.5kg), the probability of very low birth weight (<1.5kg), and birth weight. The regressions include the full set of controls, including infant gender and multiple birth dummies, parental characteristics, county characteristics, year effects, county fixed effects, and region-by-year effects. Standard errors are clustered at the county level. * p < .10, ** p < .05, *** p < .01

Table 3. 4. Marginal and interquartile effects of toxic emission densities on the probability of low birth weight

	ΔLBW from marginal change in emissions from the mean	ΔLBW from interquartile change in emissions
Toxic air	0.0000883	0.000141
	(0.000462)	(0.000740)
Non-toxic air	0.000659	0.000487
	(0.000746)	(0.000551)
Toxic water	0.0589***	0.000128***
	(0.0221)	(0.0000481)
Non-toxic water	0.0444*	0.0000525*
	(0.0228)	(0.0000269)

Notes: The results in this table are obtained from regression (4) in Table 3.3. The pollution units are in 1,000 kg/km^2. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 3. 5. Estimated effects of carcinogenic emission densities on birth outcomes

	LBW	VLBW	Birth weight
Carcinogenic air	-0.00117	-0.000000630	0.00163
	(0.00180)	(0.000600)	(0.00451)
(Carcinogenic air)^2	0.000198	0.0000487	-0.000409
	(0.000212)	(0.0000696)	(0.000524)
Non-carcinogenic air	0.000215	0.0000819	0.000711
	(0.000340)	(0.000138)	(0.000827)
(Non-carcinogenic air)^2	-0.00000402	-0.000000281	0.000000918
	(0.00000361)	(0.00000146)	(0.00000891)
Carcinogenic water	0.230**	0.0741	0.0616
	(0.106)	(0.0455)	(0.313)
(Carcinogenic water)^2	-2.212**	-0.676*	1.015
	(1.108)	(0.407)	(3.044)
Non-carcinogenic water	0.0173	0.00682	-0.0237
	(0.0132)	(0.00813)	(0.0362)
(Non-carcinogenic water)^2	-0.0792	-0.0173	0.0887
	(0.0566)	(0.0148)	(0.0771)
R^2	0.13	0.01	0.09
Observations	481,516	481,516	481,516
F-stat for joint significance of carcinogenic air emissions	0.60	2.15	0.63
F-stat for joint significance of non-carcinogenic air emissions	1.09	0.33	2.00
F-stat for joint significance of carcinogenic water emissions	2.49	1.39	1.81
F-stat for joint significance of non-carcinogenic water emissions	1.08	0.70	0.74

Notes: The pollution units are in 1,000 kg/km^2. To obtain the coefficients in terms of 1 kg/km^2, multiply the coefficients for the linear terms of pollution variables by 1,000 and the squared terms by 1,000,000. Dependent variables are the probability of low birth weight (<2.5kg), the probability of very low birth weight (<1.5kg), and birth weight. The regressions include the full set of controls, including infant gender and multiple birth dummies, parental characteristics, county characteristics, year effects, county fixed effects, and region-by-year effects. Standard errors are clustered at the county level.
* $p < .10$, ** $p < .05$, *** $p < .01$

Table 3. 6. Marginal effects of carcinogenic emission densities on birth outcomes

	LBW	VLBW	Birth weight
Carcinogenic air	-0.00102	0.0000361	0.00133
	(0.00165)	(0.000551)	(0.00415)
Non-carcinogenic air	0.000194	0.0000803	0.000716
	(0.000322)	(0.000132)	(0.000785)
Carcinogenic water	0.218**	0.0702	0.0674
	(0.100)	(0.0433)	(0.297)
Non-carcinogenic water	0.0148	0.00627	-0.0209
	(0.0120)	(0.00776)	(0.0343)

Notes: The marginal effects are evaluated at the mean levels of emission densities. The pollution units are in 1,000kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 7. Effects of an interquartile change in carcinogenic emission densities on birth outcomes

	LBW	VLBW	Birth weight
Carcinogenic air	-0.0002469	8.76e-06	0.000322
	(0.000401)	(0.000134)	(0.00101)
Non-carcinogenic air	0. 000417	0.000173	0.00154
	(0.000694)	(0.000283)	(0.00169)
Carcinogenic water	0.0000484**	0.0000156	0.000015
	(0.0000222)	(9.61e-06)	(0.000066)
Non-carcinogenic water	0.0000336	0.0000143	-0.0000474
	(0.0000272)	(0.0000176)	(0.000078)

Notes: The pollution units are in 1,000 kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 8. Estimated effects of developmental emission densities on birth outcomes

	LBW	VLBW	Birth weight
Developmental air	-0.00141**	0.0000474	0.000919
	(0.000668)	(0.000307)	(0.00170)
(Developmental air)^2	0.0000130	-0.00000518	0.00000146
	(0.00000917)	(0.00000407)	(0.0000240)
Non-developmental air	0.000670*	0.0000928	-0.0000253
	(0.000357)	(0.0000977)	(0.000846)
(Non-developmental air)^2	-0.00000696**	0.000000679	0.00000497
	(0.00000301)	(0.000000751)	(0.00000748)
Developmental water	-0.0192	-0.0744	0.619
	(0.141)	(0.0557)	(0.412)
(Developmental water)^2	0.503	1.084**	-5.380
	(1.258)	(0.523)	(3.678)
Non-developmental water	0.0294*	0.0114	-0.0589
	(0.0151)	(0.0105)	(0.0451)
(Non-developmental water)^2	-0.102*	-0.0269	0.107
	(0.0560)	(0.0164)	(0.0867)
R^2	0.13	0.01	0.09
Observations	481,516	481,516	481,516
F-stat for joint significance of developmental air emissions	4.57	17.35	1.64
F-stat for joint significance of non-developmental air emissions	2.69	13.87	0.65
F-stat for joint significance of developmental water emissions	1.96	20.66	1.16
F-stat for joint significance of non-developmental water emissions	2.13	1.45	0.91

Notes: The pollution units are in 1,000 kg/km^2. To obtain the coefficients in terms of 1 kg/km^2, multiply the coefficients for the linear terms of pollution variables by 1,000 and the squared terms by 1,000,000. Dependent variables are the probability of low birth weight (<2.5kg), the probability of very low birth weight (<1.5kg), and birth weight. The regressions include the full set of controls, including infant gender and multiple birth dummies, parental characteristics, county characteristics, year effects, county fixed effects, and region-by-year effects. Standard errors are clustered at the county level.

* p < .10, ** p < .05, *** p < .01

Table 3. 9. Marginal effects of developmental emission densities on birth outcomes

	LBW	VLBW	Birth weight
Developmental air	-0.00139**	0.0000378	0.000922
	(0.000652)	(0.00030)	(0.00166)
Non-developmental air	0.000640*	0.0000957	-3.93e-06
	(0.000346)	(0.0000946)	(0.000820)
Developmental water	-0.0176	-0.0709	0.601
	(0.137)	(0.0540)	(0.400)
Non-developmental water	0.0260*	0.0105	-0.0553
	(0.0139)	(0.0101)	(0.0427)

Notes: The marginal effects are evaluated at the mean levels of emission densities. The pollution units are in 1,000kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 10. Interquartile effects of developmental emission densities on birth outcomes

	LBW	VLBW	Birth weight
Developmental air	-0.000868**	0.0000236	0.000575
	(0.000407)	(0.000187)	(0.00104)
Non-developmental air	0.00108*	0.000162	-6.64e-06
	(0.000584)	(0.000160)	(0.00138)
Developmental water	-1.74e-06	-7.02e-06	0.0000596
	(0.0000136)	(5.35e-06)	(0.0000397)
Non-developmental water	0.0000773*	0.0000311	-0.000164
	(0.0000412)	(0.0000299)	(0.000127)

Notes: The pollution units are in 1,000 kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 11. Estimated effects of heavy metal air emission densities on birth outcomes

	LBW	VLBW	Birth weight
Heavy metal air	0.382**	0.136*	-0.686
	(0.172)	(0.0734)	(0.460)
(Heavy metal air)^2	-6.250**	-2.154**	10.04
	(2.500)	(0.943)	(6.673)
Non-heavy metal air	0.000133	0.0000556	0.000444
	(0.000313)	(0.000116)	(0.000760)
(Non-heavy metal air)^2	-0.00000296	9.55e-08	0.000000982
	(0.00000287)	(0.00000120)	(0.00000700)
Aggregate water	0.0216	0.00630	0.0141
	(0.0140)	(0.00841)	(0.0428)
(Aggregate water)^2	-0.0924*	-0.0179	0.0159
	(0.0551)	(0.0154)	(0.0859)
R^2	0.13	0.01	0.09
Observations	481,516	481,516	481,516
F-stat for joint significance of heavy metal air emissions	3.48	3.05	1.14
F-stat for joint significance of non-heavy metal air emissions	1.42	0.43	1.37
F-stat for joint significance of aggregate water emissions	1.53	0.74	0.37

Notes: The pollution units are in 1,000 kg/km^2. To obtain the coefficients in terms of 1 kg/km^2, multiply the coefficients for the linear terms of pollution variables by 1,000 and the squared terms by 1,000,000. Dependent variables are the probability of low birth weight (<2.5kg), the probability of very low birth weight (<1.5kg), and birth weight. The regressions include the full set of controls, including infant gender and multiple birth dummies, parental characteristics, county characteristics, year effects, county fixed effects, and region-by-year effects. Standard errors are clustered at the county level.
* p < .10, ** p < .05, *** p < .01

Table 3. 12. Marginal effects of heavy metal air emission densities on birth outcomes

	LBW	VLBW	Birth weight
Heavy metal air	0.357**	0.128*	-0.647
	(0.163)	(0.0699)	(0.435)
Non-heavy metal air	0.000115	0.0000562	0.000450
	(0.000297)	(0.000111)	(0.000722)
Aggregate water	0.0182	0.00563	0.0147
	(0.0126)	(0.00794)	(0.0402)

Notes: The marginal effects are evaluated at the mean levels of emission densities. The pollution units are in 1,000kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 13. Interquartile effects of heavy metal air emission densities on birth outcomes

	LBW	VLBW	Birth weight
Heavy metal air	0.000121**	0.0000433*	-0.000219
	(0.0000552)	(0.0000237)	(0.000147)
Non-heavy metal air	0.000271	0.000132	0.00106
	(0.000698)	(0.000260)	(0.00170)
Aggregate water	0.0000775	0.000024	0.0000626
	(0.0000536)	(0.0000338)	(0.000171)

Notes: The pollution units are in 1,000 kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 14. Estimated effects of VOCs air emission densities on birth outcomes

	LBW	VBLW	Birth weight
VOC air emission	-0.00143**	-0.0000137	0.00130
	(0.000618)	(0.000326)	(0.00159)
(VOC air)^2	0.0000129	-0.00000462	-0.00000474
	(0.00000854)	(0.00000444)	(0.0000224)
Non-VOC air	0.000704**	0.000144	-0.0000111
	(0.000343)	(0.0000989)	(0.000866)
(Non-VOC air)^2	-0.00000725**	0.000000324	0.00000448
	(0.00000293)	(0.000000767)	(0.00000778)
Aggregate water	0.0332***	0.0103	-0.00268
	(0.0120)	(0.00742)	(0.0409)
(Aggregate water)^2	-0.107*	-0.0253*	0.0384
	(0.0544)	(0.0143)	(0.0839)
R^2	0.13	0.01	0.09
Observations	481,516	481,516	481,516
F-stat for joint significance of VOC air emissions	5.47	17.15	1.50
F-stat for joint significance of non-VOC air emissions	3.08	13.34	0.53
F-stat for joint significance of aggregate water emissions	3.81	1.57	0.23

Notes: The pollution units are in 1,000 kg/km^2. To obtain the coefficients in terms of 1 kg/km^2, multiply the coefficients for the linear terms of pollution variables by 1,000 and the squared terms by 1,000,000. Dependent variables are the probability of low birth weight (<2.5kg), the probability of very low birth weight (<1.5kg), and birth weight. The regressions include the full set of controls, including infant gender and multiple birth dummies, parental characteristics, county characteristics, year effects, county fixed effects, and region-by-year effects. Standard errors are clustered at the county level.
* p < .10, ** p < .05, *** p < .01

Table 3. 15. Marginal effects of VOCs air emission densities on birth outcomes

	LBW	VLBW	Birth weight
VOC air	-0.00141**	-0.000022	0.00129
	(0.000604)	(0.000318)	(0.00156)
Non-VOC air	0.000673**	0.000146	8.40e-06
	(0.000332)	(0.0000958)	(0.000838)
Aggregate water	0.0292***	0.00932	-0.00124
	(0.0106)	(0.00701)	(0.0384)

Notes: The marginal effects are evaluated at the mean levels of emission densities. The pollution units are in 1,000kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 16. Interquartile effects of VOCs air emission densities on birth outcomes

	LBW	VLBW	Birth weight
VOC air	-0.000839**	-0.0000131	0.000768
	(0.000360)	(0.000190)	(0.000929)
Non-VOC air	0.0011743**	0.000254	0.0000147
	(0.000580)	(0.000167)	(0.00146)
Aggregate water	0.000124***	0.0000397	-5.29e-06
	(0.0000452)	(0.0000299)	(0.000164)

Notes: The pollution units are in 1,000 kg/km^2. Standard errors are clustered by counties.
* p < .10, ** p < .05, *** p < .01

Table 3. 17. Marginal effects of heavy metal air emissions (in kg/km^2) on the probabilities of low (<2.5kg) and very low (<1.5kg) birth weights in Korea and U.S.

	Korea	US
ME of heavy metal air emissions on LBW	0.036 ppt	0.032 ppt
	(0.016)	(0.021)
ME of heavy metal air emissions on VLBW	0.013 ppt	0.006 ppt
	(0.007)	(0.0056)

Notes: The estimated marginal effects for the U.S. are from Currie and Schmieder (2009), which used the county-level TRI data from 1988 to 1999.

Chapter 4. Hedonic Valuation of Air Quality in Korea

4.1. Introduction

Particulate matter is solid or liquid matter floating in the air. It is given off directly by burning fossil fuels in diesel vehicles, manufacturing facilities, and coal power plants or is generated when the SOx or NOx released from these sources undergoes a chemical reaction with water vapors and ammonia in the air. Many environmental and epidemiological studies have stressed the harmful effects of particulate matter on vegetation, ecosystems, and the climate, and human health is at risk as well (Grantz et al., 2003). Small particulate matter can be inhaled and penetrates deep into lungs and bloodstreams, causing respiratory and cardiovascular diseases.[1] The International Agency for Research on Cancer (IARC) designated particulate matter as a Group 1 carcinogen in 2013, and the World Health Organization (WHO) announced that 7 million people die prematurely every year due to exposure to fine particles in both indoor and outdoor air. Further, in 2016, 4.2 million premature deaths worldwide were caused by ambient air pollution (WHO, 2018). In addition, a study in Korea identified 18,148 premature deaths in 2015 which could be attributed to ambient fine particulate matter ($PM_{2.5}$) exposure (Kim, 2018). The WHO 2005 Guidelines (WHO, 2006) indicated that there is no safe concentration of particulate matter below which there are no health effects.

[1] Two types of particulate matter which are monitored world-wide for their health effects are coarse particles with diameters of 10 micrometers or less (PM_{10}) and fine particles with diameters of 2.5 micrometers or less ($PM_{2.5}$). These particles are so small that they can be inhaled and penetrate deep into lungs and bloodstreams.

PM concentration has been highest in low- and middle- income countries because of their large dependence on fossil fuels as energy sources for industries and households and, having no or lax environmental policies in order to stimulate or maintain economic growth. Although South Korea is considered a high-income country, its PM_{10} concentration is among the highest in the world due to its high level of manufacturing activities, high population density from urbanization, and pollution spillover from China. The Organization for Economic Cooperation and Development (OECD) has announced that South Korea is the only county in the "rich nations club" that is projected to have more than 1,000 premature deaths per million by 2060 as a result of air pollution (Field and Seo, 2017). Although South Korea's implementation of the first phase of the Clean Air Act (2005-2014)[2] helped reduce its PM_{10} concentration greatly, Korea's annual average PM_{10} concentration is still twice as higher as the WHO standard[3] and has been on the rise again since 2012. South Koreans' concerns over PM_{10} pollution have been rising, especially since the Korea Ministry of Environment (MOE) started issuing daily forecasts of PM_{10} concentrations in 2014. As Korea has strengthened its particulate pollution-control policies for the second phase of the Clean Air Act (2015-2024), it needs to evaluate the effectiveness of different policy options by conducting a cost-benefit analysis, of which individuals' valuations of air quality form a crucial component. However, hedonic literature estimating the value of air quality in the Korean housing market is sparse.

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[2] The Korea Ministry of Environment (MOE) undertook the first phase of the Clean Air Act (CAA), which was designed to improve the ambient air quality in metropolitan areas, from 2005 to 2014. The CAA focused on reducing PM_{10}, NO_2, SO_2, and volatile organic compounds (VOCs). The second phase of the CAA began in 2015 and will end in 2024. It added $PM_{2.5}$ and ozone to the list of pollutants targeted for reduction.

[3] The WHO standards for PM_{10} concentrations are a 20 $\mu g/m^3$ annual mean and a 50 $\mu g/m^3$ 24-hour mean.

This study will be among the few studies that estimate South Korean households' marginal willingness to pay (MWTP) for improvements in local air quality. It contributes to the existing literature in several ways. First, it estimates the MWTP to avoid PM_{10} air pollution, which was documented as a major concern of Korean households in the most recent data period, i.e., 2006 to 2016. It also uses data on all apartment transactions which occurred during the sample period rather than relying on survey data, which is likely to suffer greater reporting bias.

A major challenge in the hedonic estimation of MWTP for air quality is to address the omitted variable bias. For example, a city's pollution level may be highly correlated with other determinants of housing prices such as the economic activity of the city. Therefore, economic activity, when omitted, will confound the effect of pollution on housing prices. Due to the difficulty in controlling for all relevant variables, the estimated MWTPs based on cross-sectional approaches are likely to be biased.[4] This paper addresses these issues by controlling for apartment fixed effects and exploiting a natural phenomenon called Asian dust as an exogenous source of variation in PM_{10} concentration. Using apartment unit-level data allows finer control of apartment structural characteristics and the use of apartment-complex fixed effects. In the IV specification, using all apartments sold in the 22 counties with dust stations during the 2006-2016 period, the annual changes in apartment prices in response to annual changes in the county-level PM_{10} concentrations

[4] Another source of bias in estimating the MWTP for air quality improvement is the heterogeneity in tastes for clean air across the population. For example, if individuals with stronger preferences for clean air sort to lower-pollution areas while individuals with weaker preferences for clean air sort to higher-pollution areas, a failure to account for the nonrandom sorting may lead to a biased estimation of the average MWTP in the population. Chay and Greenstone (2005) probe the selection bias issue using a random coefficient model. Although they find evidence of negative assortative matching between people and locations, they also find that most of the selection bias is explained by conventional county-level, observable variables and that the estimated selection bias is much smaller than the estimated omitted-variables bias. This paper focuses on addressing the omitted variables.

caused by Asian dust storms are examined. Originating in Northern China and Mongolia, Asian dust storms are transported to Korea by the westerly winds from March to May (and far less frequently in other months), carrying dust and pollutants over to Korea. Asian dust storms are natural phenomena which vary in frequency and strength vary across locations and years; therefore, these storms are likely to affect housing prices only through their effects on the PM_{10} concentration. However, Asian dust days (or the annual total number of days with dust events) is a weak instrument, and the weak-instrument robust estimates are reported.

Adding the apartment-complex fixed effects to the pooled-OLS estimation provides a statistically significant, counter-intuitive coefficient for the PM_{10} concentration. The coefficient on PM_{10} remains statistically significant and positive even with an interaction term between PM_{10} and a post-2014 indicator. These results suggest that there may be omitted time-variant factors which bias the estimates. Asian dust days constitute a weak instrument, and the weak-instrument robust test does not provide a defined confidence interval for the PM_{10} coefficient. No conclusion about Koran households' MTWP for air quality can be made based on the IV estimates.

The rest of this paper is structured as follows. Section 4.2 describes previous literature, and Section 4.3 discusses the background and data. In Section 4.4, hedonic theory and the estimation methods used are described. Estimation results are presented in Section 4.5, and the conclusion is found in Section 4.6.

4.2. Previous literature

Since Ridker and Henning (1967) first used residential properties to evaluate the value of environmental amenities, there have been abundant hedonic studies on property values in the US. More recently, there have been a growing number of hedonic studies estimating the value of air quality. Most of the older US studies[5] and some recent Chinese studies (Chen et al., 2018; Zheng et al., 2009; Zheng et al., 2010), however, are based on cross-sectional data and/or the OLS method and are therefore likely to be biased due to omitted variables and taste-based sorting.

Many studies that provide more reliable estimates of the value of air quality employed the quasi-experimental method or instrumental variable approach. Chay and Greenstone (2005) use a county's non-attainment status under the Clean Air Act (in the US) as an instrumental variable for changes in total suspended particles (TSPs). The Clean Air Act mandated that all counties meet the TSP standards, and the counties failing to meet the standards had to implement more stringent abatement programs than the attainment counties. Based on the instrumental method, they find that non-attainment counties had a larger reduction in TSPs and a larger increase in housing prices than the attainment counties and estimate the MWTP for a $1\mu g/m^3$ reduction in TSP to be $243 (elasticity 0.2-0.35). Bayer et. al. (2009) use the pollution from distance sources as an instrumental variable for local air pollution to find a median US household's MWTP to be $149-$185 (elasticity 0.34-0.42). Exploiting a discontinuity in air quality between the northern and southern cities of China from a policy subsidizing coal-fired winter heating in northern cities only, Huang and Lanz (2018) estimate the elasticity of housing prices with respect to PM_{10} concentration in 2011 to be 0.71. Zheng et al. (2014) also find a negative effect of PM_{10} on

[5] See Smith and Huang (1995), which provides a meta-analysis of 37 studies produced between 1967 and 1988.

housing prices for 85 large Chinese cities from 2006 to 2009 using multiple instrumental variables which measured pollution externalities, including the distance to the Asian dust storm origin and imported pollution from nearby cities. Similar to Zheng et al.'s (2014) approach, this study uses the annual number of days with Asian dust events as an instrumental variable for local PM10 concentration.

There are only a few studies on value of air quality in Korea using hedonic pricing methods.[6] Using 1993 survey data on the Seoul housing market and a spatial lag model that accounts for the effect of neighboring housing prices on local housing prices, Kim et al. (2003) find that a 4% reduction in local SO_2 concentration leads to a 1.4% increase in the housing prices from the mean. Also using spatial hedonic models, Jun (2018) finds significant negative effects of PM_{10} and NO_2 concentrations on housing prices in the Seoul metropolitan area in 2010. Park (2016) estimates the impacts of announcements of industrial park openings and their actual operation on apartment prices using the apartment data from the Ministry of Land, Infrastructure, and Transport (MOLIT) and the data on industrial parks whose openings were announced between 2006 and 2013. Employing a difference-in-difference estimation with apartment-complex fixed effects, Park finds a housing premium farther away from an industrial park from the time of the announcement till the years observed thus far of actual operation. However, this study focuses on the effects of pollution from stationary sources only and estimates the integrated effects of several types of pollution, including air, water, soil, and noise. This study adds to this existing literature by measuring the association of ambient PM_{10} air pollution and housing prices using the most recent housing transaction data and exploiting the exogenous

[6] There are also a few studies (Yoo and Chae, 2001; Lee et al., 2011) that find the value of air quality in Korea based on a contingent valuation survey.

temporal variations in pollution concentrations triggered by dust storms while accounting for apartment- complex fixed effects.

4.3. Background and Data

South Korea first set a PM_{10} standard in 1995; however, it was not until 2005 that more comprehensive efforts were put into controlling PM_{10} pollution. Passed in 2002, the Special Act on Metropolitan Air Quality Improvement (or the first phase of the Clean Air Act) set out a 10-year plan to improve the air quality in metropolitan areas from 2005 to 2014. During the 10-year plan, MOE enforced an array of policies and measures which focused on vehicle- and manufacturing facility-related PM_{10} pollution. Some of the vehicle-related measures included establishing emission standards for new motor vehicles, subsidizing hybrid or electricity cars, subsidizing the retrofitting of vehicle emission reduction equipment, subsidizing scrapping in-use diesel vehicles, and setting a cap on the sulfur content in vehicle emissions. Also, large manufacturing facilities releasing 30 tons of NO_x and 20 tons of SO_x or more annually were subject to annual total emission standards, while small to medium manufacturing facilities received subsidies for the installation of low-NOx burners. In 2006, MOE also started releasing ambient PM_{10} concentrations to the public in real time. From 2006 to 2016, MOE expanded the installation of air quality monitors throughout the country and published PM_{10} concentrations recorded by these monitors on their website (airkorea.or.kr). In 2014, after the IARC declared PM_{10} to be a Group 1 carcinogen, MOE started issuing daily forecasts of PM_{10} conditions via four categories: good (0-30 $\mu g/m^3$), okay (31-80 $\mu g/m^3$), bad (81-150 $\mu g/m^3$), and very bad (>151 $\mu g/m^3$). In 2015, MOE started issuing advisories and warnings when the average ambient PM_{10} concentration in a designated region had exceeded 150 $\mu g/m^3$ and 300 $\mu g/m^3$ for at least 2 hours, respectively.[7]

The Special Act on Metropolitan Air Quality Improvement contributed to the PM_{10} reduction in Seoul from 76 $\mu g/m^3$ in 2002 to 41 $\mu g/m^3$ in 2012. However, since 2012, when it was at its lowest level of 41μg/m3, the PM_{10} concentration has been on the rise again, reaching 46 μg/m3 in 2013 due to more frequent dust incidences, meteorological factors unfavorable for the dissipation of air pollutants, growing urbanization, an increasing number of vehicles, increased manufacturing activities, and increasing pollution spillover from China (MOE, 2017). Korea's PM_{10} concentration still amounts to double that of other developed countries, and it is more than twice the WHO standard concentration.

Originating naturally in Inner Mongolia and northern China, Asian dust storms are transported to Korea mostly during the spring and irregularly during the winter months. The high-speed winds pick up and carry dust and other pollutants on their way and elevate PM_{10} concentrations in the affected locations. The dust storms hit different locations in Korea with varying frequencies and strengths every year (Kim et al., 2016; Altindag et al., 2017). As shown in Figure 4.1, the maps of locations with fewer and more dust days than the nationwide mean dust days in 2006, 2011, and 2016 demonstrate that there are non-systematic changes occurring in the spatial variations in dust days over the years. Dust storms are monitored separately from PM_{10} and other air pollutants at 28 dust stations under the control of the Korean Meteorological Administration (KMA).[8] Data on the monthly

[7] While PM_{10} concentrations (in level and category) are forecasted for each air quality monitor, advisories and warnings are issued at 38 geographical units nationwide.
[8] KMA started issuing advisories and warnings against Asian dust incidences in 2002.

number of dust days are available from the KMA website and are aggregated to the annual level for the analysis.

Housing prices and characteristics come from the housing transaction records provided by the MOLIT. The records contain information on the prices of all houses sold and rented since 2006 as well as housing characteristics, including the type of house (e.g., apartment or single, detached, or row house), year of construction, size, and floor. The sample used for analysis includes only the apartments sold during the 2006-2016 period. Almost 50% of all homes in Korea are apartments, and most of the single, detached, and row houses are located in rural areas. The sample of apartment transactions which occurred in the counties with PM_{10} monitors during the 2006-2016 period, excluding apartment complexes with fewer than 20 transactions, contains 3,066,373 apartment transactions in 15,279 apartment complexes in 119 counties. Descriptive statistics for this sample are presented in Table 4.1. For IV analysis, the sample is limited to apartment complexes with dust stations located in the same county. This sample contains 899,976 apartment transactions in 4,894 apartment complexes in 22 counties.

The outcome variable is the log of apartment price. The control variables include housing characteristics (i.e., logs of apartment age, size, and floor), county characteristics (i.e., logs of business establishments per 1000 people, student-teacher ratios, and doctors per 1000 people), and the log of the town-level population density. Data on the local attributes are provided by the Korean Statistical Information Service.

As shown in Table 4.1, apartment prices rose during most of the 2006-2016 period, except in 2012 and 2016. The upward trend in apartment prices is observed along with aging stock almost in real time over the years since 2008, suggesting little new construction. In addition, the average county production level increased throughout the 2006-2016 period, except for in 2009 and 2015. The number of businesses per 1000 people also rose, except for in 2010. From 2006 to 2009, the average annual PM_{10} concentration declined from 55 μg/m3 to 50μg/m3 and plateaued throughout 2010 and 2011. After a brief decline in 2012, the average annual PM_{10} concentration went back up to 50 μg/m3 and stayed around that level, although went down slightly to 49 μg/m3 in 2015 and 2016. There does not appear to be any systematic correlation between apartment price and PM_{10} concentration based on the descriptive statistics. Figure 4.2. shows the trends in the log of apartment price, log of PM_{10} concentration, and the other control variables over the years for the full sample containing 119 counties and IV sample containing 22 counties. The figure shows that there are a few years in which housing prices, PM_{10} concentration, production, and population density are going up in the IV sample while they are going down in the full sample, and a few years in which businesses per 1000 people, population density, and doctors per 1000 people are going down in the IV sample while they are going up in the full sample. However, the overall trends of the two sample are similar. It is worth noting that the IV sample exhibits greater production levels and businesses per 1000 people, but less expensive housing and lower population densities, on average.

4.4. Hedonic theory and econometric models

The hedonic pricing theory established by Rosen (1974) is used to infer the marginal willingness to pay for a nonmarket good such as air quality. It views a nonmarket good as one of the characteristics of a differentiated market good whose price is observed explicitly. For example, a house is viewed as a market good with a bundle of characteristics, including structural attributes (e.g., size, age, floor) and local amenities (e.g., local school quality, access to medical care, air quality). The marginal price of air quality is the price differential across houses with identical characteristics in all but air quality. In other words, the price of air quality is embedded in the price of a house. In a competitive market, the equilibrium housing price-air quality points, or the hedonic price schedule, will be the conjunctions of consumers' bid functions and suppliers' offer functions, and the gradient of the hedonic price function will be the marginal price of air quality. Therefore, the marginal price of air quality at a given point on the hedonic price schedule is equal to a consumer's willingness to pay for a marginal improvement in air quality and a supplier's marginal cost of providing it.

The pooled cross-sectional estimate of the effect of PM_{10} concentration on apartment prices is obtained by running the following model.

$$(1) \quad lny_{aijkt} = \upsilon + Z_{at}'\pi + \delta lnPM_{jt} + \kappa lnPop_{jt} + X_{kt}'\lambda + \sigma_t + \mu_{aijkt}$$

where lny_{ajkt} is the log of the price of apartment a belonging to apartment complex i in town j and county k in year t, $lnPM_{jt}$ is the PM_{10} concentration (in $\mu g/m^3$), Z_{at} is a vector of apartment structural attributes (e.g., the logs of size, age, and floor), $lnPop_{jt}$ is the log of the town-level population density, and X_{kt} is a vector of time-varying county characteristics (e.g., the logs of county production, number of business establishments per 1000 people, student-teacher ratio, and number of doctors per 1000 people), σ_t is the year effect, μ_{aijkt} is the unobserved random determinant of apartment price, and δ is the average MWTP for the reduction in PM_{10} pollution across the population if PM_{jt} is uncorrelated with the error term μ_{ajkt}. However, δ is likely biased due to the unobserved variables that co-vary with the PM_{10} concentrations and apartment prices. For example, apartments in locations that have higher economic activities or incomes may have higher PM_{10} concentrations but also higher apartment prices; therefore, failure to account for local economic activity or incomes will lead to an underestimation of the effect of pollution on housing prices.

The inclusion of apartment-complex fixed effects in Equation (1) yields Equation (2) below.

$$(2)\quad lny_{aijkt} = a + Z_{at}'b + clnPM_{jt} + dlnPop_{jt} + X_{kt}'e + \xi_i + \eta_t + \nu_{aijkt}$$

where ξ_i is the apartment-complex fixed effect. In this OLS model with apartment-complex fixed effects, permanent differences across apartment complexes (and therefore town and county permanent effects as well) are dropped; therefore, c is a consistent estimate of the average MWTP for the reduction in PM_{10} pollution across the population only if there exists no changes in the unobserved determinants of apartment prices correlated with the changes in PM_{10} concentrations. However, if towns with reduced PM_{10} pollution also experienced improvements in other unobserved amenities that would raise apartment prices, c may be an over-estimate of the average MWTP for the PM_{10} reduction in the population. Further, if towns had increases in both PM_{10} concentrations and housing prices due to economic booms, c may be an under-estimate of the average MWTP for the PM_{10} reduction in the population.

An instrumental variable approach which exploits the exogenous portion of changes in the PM_{10} concentration associated with changes in the number of dust days is also used. The main equation to be estimated for this approach is given below.

$$(3) \quad lny_{aijkt} = \alpha + Z_{at}'\beta + \theta lnPM_{kt} + \varphi lnPop_{jt} + X_{kt}'\gamma + \rho_i + \tau_t + \varepsilon_{aijkt}$$

where $lnPM_{kt}$ is the PM_{10} concentration in county k in year t.[9] The annual total number of days with Asian dust incidences (using an inverse hyperbolic sine transformation[10]) is used as an instrumental variable for the average annual PM_{10} concentration. If the number of dust days is correlated strongly with PM_{10} concentration conditional on all other control variables being included and it increases PM_{10} concentration without affecting housing prices directly, then the IV estimate of the effect of PM_{10} concentration on housing prices will be unbiased. Since Asian dust is a natural phenomenon which impacts different parts of Korea with varying frequency and strength, it is unlikely to be correlated with other determinants of local housing prices. The coefficient of interest is θ, which captures the average MWTP for PM_{10} reduction across the population under the assumption that Asian dust days meets the assumption of a strong correlation with PM_{10} pollution and the exclusion restriction. Standard errors in the main equation are clustered at the county level.

In addition, in the OLS specification with apartment-complex fixed effects, this study examines whether the PM_{10} concentration is capitalized into apartment prices after

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[9] Dust events are only known at the county level, which allows the county-level changes in PM_{10} concentrations to be used for identification of the MWTP for PM_{10} reduction.

[10] The inverse hyperbolic sine transformation is defined as $\log(x + \sqrt{x^2 + 1})$. I used the inverse hyperbolic sine transformed dust days instead of log because it is defined at zero and can be interpreted as a log except for very small values of the original variable (Woolley, 2011; Pence, 2006; MacKinnon and Magee, 1990; John et al., 1988).

2014, at which point the MOE had started forecasting PM_{10} concentrations and the public had better information regarding the hazards of PM_{10} pollution and their local PM_{10} concentrations. To examine this, Equation (4) was estimated, where $lnPM_{jt} * Post2014$ is an interaction term between the log of annual average PM_{10} concentration and an indicator for apartment transaction occurring in 2014 or later years. The coefficient of interest is g, which measures the difference in the impacts of PM_{10} pollution on apartment prices before and after 2014.

$$(4)\ lny_{aijkt} = e + Z_{at}'f + g(lnPM_{jt} * Post2014) + hPop_{jt} + X_{kt}'i + \zeta_i + \pi_t + k_{aijkt}$$

4.5. Estimation Results

A. OLS

The results from OLS estimation of housing price equations with and without apartment-complex fixed effects are reported in Table 4.2. The estimation was run on the full sample of apartments which have PM_{10} monitors in their counties. Columns (1) and (3) show the OLS results for county effects and apartment-complex fixed effects, respectively. The coefficients for all of the structural characteristics, including apartment size, age, and floor, have the expected signs and are statistically significant in both the specifications with and without apartment-complex fixed effects, but the apartment-complex fixed effects change the magnitudes of the impacts. When apartment-complex fixed effects are included, apartment prices fall with age at a faster rate, and the price premiums on larger apartments and on higher floors become smaller. Accounting for apartment-complex fixed effects also results in a near-zero, statistically insignificant effect of the population density and a more strongly positive, statistically significant (at the 5% level) effect of the PM_{10} concentration. This counter-intuitive coefficient for $\ln(PM_{10})$ suggests that the apartment-complex fixed effects alone do not fix the problem of omitted variable bias. In addition to the included control variables that measure towns' population densities, county-level amenities, and economic activity, there seem to exist time-varying factors within apartment complexes that are correlated with PM_{10} and apartment prices. Columns (2) and (4) present the results from including an interaction term between $\ln(PM_{10})$ and an indicator for post-2014. The coefficient for this interaction term is negative and statistically significant in both specifications with and without apartment-complex fixed effects. However, in the specification with apartment- complex fixed effects, the counter-intuitive coefficient for $\ln(PM_{10})$ persists.

B. Instrumental Variable Approach

IV estimation was run on the sample of apartments in only 22 counties with both PM_{10} monitors and dust stations (IV sample). To test if this sample has systematic differences from the full sample of apartments in 119 counties with only PM_{10} monitors (on which OLS estimations were run), the OLS estimations with apartment-complex fixed effects were run on the IV sample. Unlike the OLS results for the full sample in columns (3) and (4) in Table 4.2, the OLS results for the IV sample (presented in Table 4.3) show the positive and statistically significant effects of county production and businesses per 1000 people on apartment prices and negative and statistically insignificant estimates on $\ln(PM_{10})$. The differences in the OLS estimation results between the full sample and IV sample seem to be due the fact that IV sample consists of apartments in business districts which have a higher level of production, more businesses per 1000 people, but lower apartment prices and population densities.

Although an exclusion restriction assumption cannot be tested in an exactly identified model, it is likely to be satisfied because naturally occurring dust days will not affect the desirability of living in a county except through their influence on the pollution level. However, the number of dust days was found to be a weak instrument, with a Kleibergen-Paap statistic (robust to clustering and heteroscedasticity) of 0.39, and the coefficients and standard errors reported in Table 4.4 are likely biased. A weak-instrument robust Anderson-Rubin test cannot determine a confidence interval for the coefficient for $\ln(PM_{10})$.[11] Therefore, no conclusion can be made based on the IV estimates.

4.6. Conclusion

This study estimates the effect of PM_{10} pollution on apartment prices in South Korea during the 2006-2016 period. Controlling for apartment-complex fixed effects still yields counter-intuitive effects of PM_{10} on apartment prices. The coefficient for PM_{10} remains positive and statistically significant with the inclusion of an interaction term between PM_{10} and a post-2014 indicator. These counter-intuitive estimates suggest that there may exist a time-varying factor(s) which is correlated with both PM_{10} pollution and apartment prices that has been omitted. An attempt was also made to identify the effects of PM_{10} pollution on apartment prices using naturally occurring Asian dust to create an

[11] Although Olea-Pflueger efficient F-statistic is a correct weak instrument test for non-iid errors in general case, Kleibergen-Paap statistic is same as Olea-Pflueger efficient F-statistic for a single endogenous regressor and a single instrument case (Olea et al. 2013, 2015).

instrumental variable. However, the number of Asian dust days was found to be a weak instrument, and a weak-instrument robust AR test failed to provide a parameter estimate. Therefore, no conclusions could be made based on the IV results. While Kim et. al. (2003) and Jun (2018) find negative effects of air pollution on housing prices in Seoul using spatial models with cross-sectional data, this study that attempted to control for fixed differences among apartment complexes (and higher-level geographical units) but cannot provide evidence that Korean households are willing to pay a price for a reduction in PM_{10} concentration in their residential areas.

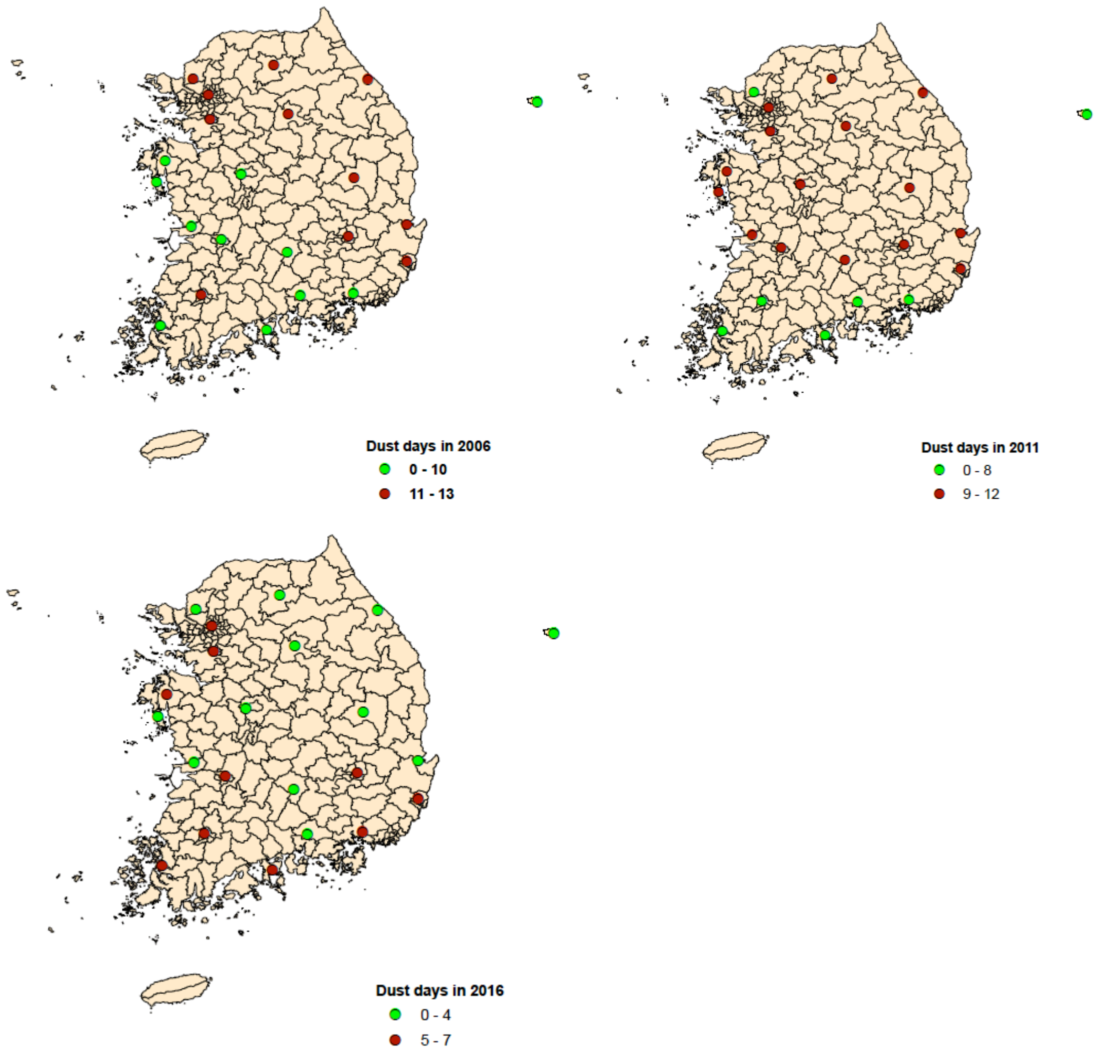
Table 4. 1. Descriptive Statistics

Year	2006	2007	2008	2009	2010	2011
Apt price (million won)	112.2	116.3	119.5	139.5	212.9	223.4
	(74.3)	(76.8)	(79.5)	(97.7)	(203.1)	(183.3)
PM_{10} concentration ($\mu g/m^3$)	55.1	54.8	51.4	49.7	50.2	49.9
	(10.3)	(9.13)	(8.21)	(7.71)	(8.22)	(8.06)
Dust days	10.3	8.13	6.13	7.74	12.4	8.34
	(2.17)	(2.76)	(1.45)	(0.74)	(2.50)	(2.43)
Apt age	10.2	10.2	10.1	10.5	11.5	12.1
	(6.07)	(6.00)	(6.44)	(6.87)	(7.20)	(7.32)
Apt size (m^2)	70.8	71.7	71.7	76.1	75.8	76.3
	(23.6)	(24.1)	(24.2)	(27.0)	(27.1)	(27.9)
Apt floor	8.15	8.28	8.31	8.47	8.50	8.56
	(5.36)	(5.39)	(5.48)	(5.65)	(5.67)	(5.80)
County production (bill. won)	7578.5	7886.5	8409.0	8350.1	12517.3	12802.1
	(5173.1)	(5533.3)	(5583.3)	(5637.8)	(10142.0)	(9795.3)
Pop density (people/km^2)	5477.5	5576.0	5625.2	5508.2	5855.1	5842.0
	(5528.0)	(6216.3)	(6679.0)	(5166.4)	(5879.3)	(5994.9)
Businesses per 1000 people	65.6	66.8	67.0	67.8	65.5	66.2
	(16.2)	(15.7)	(15.6)	(15.9)	(16.4)	(16.1)
Student-teacher ratio	23.5	22.9	22.6	22.2	21.4	20.4
	(2.49)	(2.48)	(2.73)	(2.86)	(2.84)	(2.72)
Doctors per 1000 people	1.92	1.98	2.12	2.19	2.32	2.36
	(1.00)	(1.04)	(1.20)	(1.14)	(1.36)	(1.30)
Observations	137,922	142,991	179,723	196,131	320,968	362,910

Year	2012	2013	2014	2015	2016
Apt price (million won)	218.2	234.2	244.3	270.2	233.3
	(176.1)	(178.6)	(186.2)	(205.8)	(145.2)
PM_{10} concentration ($\mu g/m^3$)	45.5	49.9	49.8	49.0	48.6
	(8.18)	(8.07)	(7.49)	(6.92)	(7.20)
Dust days	1.60	1.86	7.61	9.39	4.67
	(0.75)	(1.20)	(2.53)	(4.19)	(2.37)
Apt age	13.1	13.9	15.1	16.0	16.5
	(7.61)	(7.55)	(7.83)	(8.05)	(8.04)
Apt size (m^2)	75.5	75.7	75.0	75.4	73.8
	(28.0)	(26.6)	(27.2)	(27.0)	(26.5)
Apt floor	8.59	8.77	8.66	8.76	8.83
	(5.89)	(5.88)	(5.88)	(5.94)	(5.95)
County production (bill. won)	12683.9	13436.7	14230.2	13874.3	14771.3
	(9539.1)	(10056.6	(10637.9	(10807.6	(10408.9)
Pop. density (people/km^2)	5881.7	6041.7	6040.0	6173.6	5201.3
	(6664.5)	(6368.6)	(6280.7)	(6998.5)	(4579.3)
Businesses per 1000 people	68.8	69.3	71.0	71.5	72.7
	(18.7)	(20.3)	(20.0)	(20.8)	(18.1)
Student-teacher ratio	19.5	18.9	18.3	17.8	17.4
	(2.60)	(2.63)	(2.60)	(2.56)	(2.29)
Doctors per 1000 people	2.42	2.53	2.60	2.70	2.55
	(1.41)	(1.52)	(1.51)	(1.53)	(1.28)
Observations	263,849	348,496	400,423	447,842	265,118

Note: Standard deviations are in parentheses. The sample consists of a total of 3,066,373 transactions for apartments in 119 counties with PM_{10} monitors.

Figure 4. 1. Distribution of Asian dust days in 2006, 2011, and 2016



Note: The figures above map the spatial distributions of the annual total number of dust days recorded by 22 dust stations located nationwide in 2006, 2010, and 2016. For each year, green dots show the locations with total numbers of dust days lower than the national mean number in that year, and red dots show the locations with more dust days than the national mean number.

Figure 4. 2. Comparison of trends in PM_{10} concentrations, apartment prices, and other variables for the full sample and the IV sample

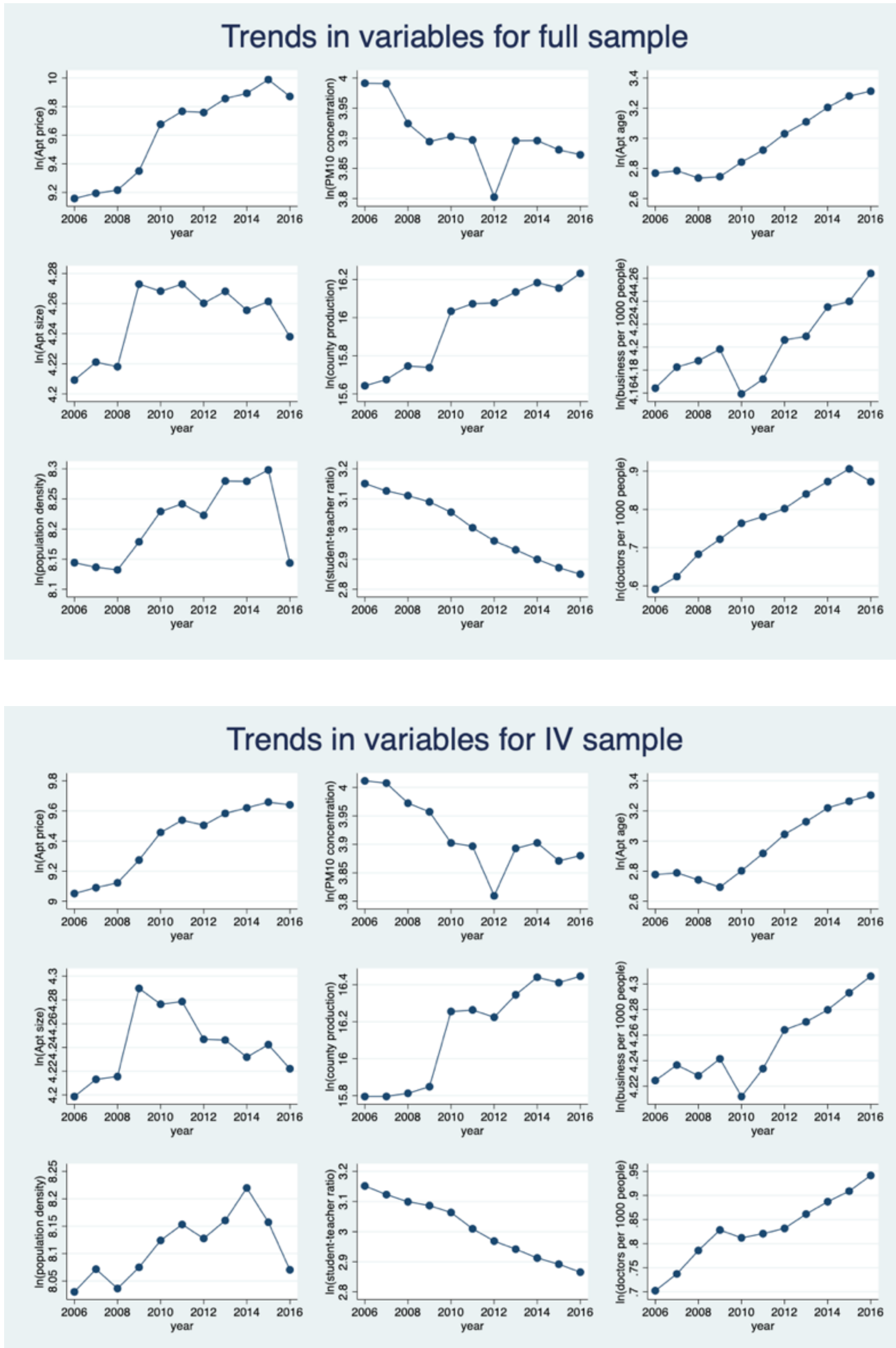


Table 4. 2. OLS results for housing price

	(1) OLS	(2) OLS	(3) OLS w/ APT complex FE	(4) OLS w/ APT complex FE
$\ln(PM_{10})$	0.0440	0.0699	0.0668^{**}	0.0881^{**}
	(0.0535)	(0.0514)	(0.0332)	(0.0374)
$\ln(PM_{10})$ *post2014		-0.0950^{**}		-0.0799^{*}
		(0.0460)		(0.0444)
ln(apt age)	-0.184^{***}	-0.184^{***}	-0.0972^{***}	-0.0973^{***}
	(0.00669)	(0.00670)	(0.00742)	(0.00740)
ln(apt size)	1.031^{***}	1.031^{***}	0.838^{***}	0.838^{***}
	(0.0138)	(0.0138)	(0.00856)	(0.00855)
ln(apt floor)	0.0442^{***}	0.0442^{***}	0.0321^{***}	0.0321^{***}
	(0.00259)	(0.00259)	(0.000604)	(0.000605)
ln(county production)	0.0366	0.0491	0.0253	0.0368
	(0.0447)	(0.0449)	(0.0460)	(0.0462)
ln(pop. density)	0.0579^{***}	0.0579^{***}	-0.000582	0.000281
	(0.00874)	(0.00874)	(0.0180)	(0.0181)
ln(businesses per1000)	-0.0929	-0.0942	-0.0689	-0.0725
	(0.128)	(0.128)	(0.136)	(0.134)
ln(student-teacher ratio)	-0.0309	-0.0284	-0.0424	-0.0395
	(0.101)	(0.0997)	(0.0965)	(0.0952)
ln(doctors per1000p)	0.218^{***}	0.209^{***}	0.232^{***}	0.225^{***}
	(0.0647)	(0.0665)	(0.0555)	(0.0554)
County effects	Yes	Yes	No	No
APT complex effects	No	No	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
R^2	0.882	0.882	0.967	0.967
Observations	3066373	3066373	3066373	3066373

Notes: The dependent variable is the log of apartment price. Standard errors in parentheses are clustered by towns. * $p < .10$, ** $p < .05$, *** $p < .01$

Table 4. 3. OLS results for housing price for the IV sample

	(1) OLS w/ APT complex FE	(2) OLS w/ APT complex FE
$\ln(PM_{10})$	-0.0636	-0.0550
	(0.0430)	(0.0494)
$\ln(PM_{10})$ *post2014		-0.0238
		(0.0769)
ln(apt age)	-0.0911***	-0.0910***
	(0.0142)	(0.0142)
ln(apt size)	0.859***	0.859***
	(0.0181)	(0.0180)
ln(apt floor)	0.0313***	0.0313***
	(0.00118)	(0.00118)
ln(county production)	0.202***	0.209***
	(0.0624)	(0.0634)
ln(pop. density)	-0.00150	-0.00116
	(0.0358)	(0.0358)
ln(businesses per1000)	0.344*	0.334*
	(0.200)	(0.198)
ln(student-teacher ratio)	-0.277	-0.267
	(0.174)	(0.181)
ln(doctors per1000p)	0.267*	0.271*
	(0.155)	(0.156)
APT complex effects	Yes	Yes
Year effects	Yes	Yes
R^2	0.958	0.958
Observations	899,972	899,972

Notes: The dependent variable is the log of apartment price.
Standard errors in parentheses are clustered by counties.
* $p < .10$, ** $p < .05$, *** $p < .01$

Table 4. 4. IV estimation results for housing price

	IV
ln(PM_{10})	-0.724
	(0.911)
ln(aptage)	-0.0895***
	(0.0160)
ln(aptsize)	0.860***
	(0.0196)
ln(aptfloor)	0.0313***
	(0.00122)
ln(county production)	0.286**
	(0.145)
ln(pop. density)	0.00787
	(0.0473)
ln(businesses per1000 people)	0.817
	(0.698)
ln(student-teacher ratio)	-0.437
	(0.321)
ln(doctors per1000p)	0.220
	(0.161)
APT complex effects	Yes
Year effects	Yes
R^2	0.547
Observations	899,972
Kleibergen-Paap first-stage F-statistic	0.390
AR statistic for H_0: coefficient on ln(PM_{10})=0	0.19
AR confidence set for ln(PM_{10})	Unidentified

Note: The coefficients and standard errors above are not the weak instrument- and clustering- robust estimates. The AR statistic and AR confidence set for ln(PM_{10}) are robust to weak instruments and clustering.

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