THREE ESSAYS ON ENVIRONMENTAL SHOCKS AND POLICY RESPONSE

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Usually, studying abroad provides a lot of experience and knowledge. However, on the other hand, it can bring about feelings of loneliness due to living alone in a foreign country. Some people cannot stand this loneliness and give up. Fortunately, I did not experience loneliness until finishing my degree well because I got help from many people around me. I can't express my gratitude in writing to the people who helped me to come out of this dissertation, but I want to remember those who helped me by leaving a record in my dissertation for the rest of my life.

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Abstract

This dissertation analyzes the economic effects caused by exogenous shocks and focuses on discussing the mechanisms behind them. Though this dissertation does not deal with only one specific topic, each topic may provide valuable insights for policymakers to establish efficient environmental policies in various fields.

Chapter 2 is related to the effect of the expiration of the Korea-Japan Fishery Agreement (KJFA) on Korean long-line hairtail fishery. Since the agreement expired on June 30, 2016, the Korean and Japanese fishing vessels cannot enter the mutual EEZs. The main reason for the expiration is the significant difference of view about the number of Korean long-line hairtail fishing vessels and their catches in Japan's EEZ. This chapter analyzes the impact of the expiration using the catch data of Korean long-line hairtail fishing vessels.

Chapter 3 analyzes the relationship between earthquakes and housing prices. In particular, this chapter focuses on the housing price near a nuclear power plant (NPP) which is the Gori NPP in Korea. By doing so, this chapter addresses how the housing market values the risk of the NPP using two different exogenous shocks, one is the Fukushima accident in Japan (2011) and another is the Pohang earthquake in Korea (2017).

Lastly, Chapter 4 covers the effect of the low emission zone (LEZ) policy on air quality in Seoul, Korea. The LEZ policy has been led by the EU and the main purpose is to prohibit driving old diesel vehicles. Many previous studies support the effectiveness of the policy. However, the purpose of this chapter is to verify the policy effect in Seoul where the air quality is significantly affected by China. Moreover, this chapter handles the cost-benefit analysis of the policy focusing on the secondary PM_{10} formation caused by the reduction of NO_2.

Contents

Chapter 1

Introduction

The evaluation of exogenous shocks has played an important role in empirical economics, providing policy implications in various fields. This dissertation analyzes the economic effects caused by the behavioral changes of individuals who are affected by exogenous shocks. Specifically, this dissertation focuses on addressing the mechanisms behind these behavior changes and suggesting policy implications.

Chapter 2 studies the impact of the expiration of the Korea-Japan Fishery Agreement (KJFA) on the hairtail catch from Korean long-line fishing. Since 1965 when the KJFA was signed, it has played a significant role as a resource management tool to reduce the risk of resource depletion and conflicts between the countries sharing the Exclusive Economic Zone (EEZ). After the KJFA expired on June 30, 2016, Korean and Japanese fishing vessels were prohibited to fish in the mutual EEZ. This prohibition significantly affected Korea's hairtail catch, which depended heavily on Japan's EEZ. Therefore, this chapter analyzes the impact of the expiration using the catch data of Korean long-line hairtail fishing vessels.

Chapter 3 focuses on estimating the willingness to pay for housing to measure the value of the potential risk of nuclear power plants in Korea by using the Hedonic price model. This chapter employed house transaction data with difference-in-differences for estimating the value of NPP's risk by comparing the impacts of two exogenous shocks (the Fukushima nuclear accident in 2011 and the earthquake in Pohang in 2017) on housing prices near Gori NPP in South Korea.

Lastly, Chapter 4 covers the effect of the low emission zone (LEZ) policy on air quality in Seoul, Korea. To improve air quality and reduce the emission of air pollutants, the

Seoul metropolitan government introduced the low emission zone (LEZ) in January 2017. This policy was designed to restrict the number of old diesel vehicles driving in Seoul. The main objective of this study is to identify the effect of the LEZ. To conduct the analysis, daily emissions of air pollutants and weather data sets are employed in this chapter. Using the method of regression discontinuity, this chapter compares the concentration of air pollutants before and after the implementation of the LEZ. Moreover, this chapter handles the cost-benefit analysis of the policy focusing on the secondary PM_{10} formation caused by the reduction of NO_2.

Chapter 2

How Did the Expiration of the Korea-Japan Fishery Agreement Affect Korea's Hairtail Catch?

Abstract

This paper studies the impact of the expiration of the Korea-Japan Fishery Agreement (KJFA) on the hairtail catch from Korean long-line fishing. Since 1965 when the KJFA was signed, it has played a significant role as a resource management tool to reduce the risk of resource depletion and conflicts between the countries sharing the Exclusive Economic Zone (EEZ). After the KJFA expired on June 30, 2016, Korean and Japanese fishing vessels were prohibited to fish in the mutual EEZ. This prohibition significantly affected Korea's hairtail catch, which depended heavily on Japan's EEZ. The main result shows that the average monthly vessel catch decreased by 11.2% to 12% in Korea's EEZ, and the total catch also decreased by 27.9% to 29.1%. Meanwhile, the fishing days increased by 3.25% to 3.75% after the KJFA expiration. These findings support the hypothesis that the long-line hairtail fishing vessels mainly moved back to Korea's EEZ and experienced lower productivity (efficiency) after the KJFA expiration.

2.1 Introduction

The sea surrounding China, Japan, and South Korea (hereafter Korea) has historically been known as the "Golden fishing ground" due to its abundant fishery resources. However, resource depletion of some high-value species is becoming a major issue in this area because of the high fishing catch intensity and climate change (Chen et al., 1997; Jiang et al., 2009; Zhao et al., 2016). Moreover, since those three countries have shared Exclusive Economic Zone (EEZ)s due to their geographical proximity, the fishermen of each country have experienced high competition to catch fish. To conserve the resource and reduce the conflicts among fishermen, they have established bilateral fishery agreements with each other. A bilateral fishery agreement works in two ways. First, it disperses the fishing activities to the counterpart's EEZ, thereby reducing the risk of marine resource depletion. Second, because it expands the fishing grounds of each country, both countries can mutually benefit from the increased fish catch. Among the three countries, Japan and Korea signed a bilateral fishery agreement in 1965 [1]. Despite the revision in 1996, this agreement worked well until 2016. However, the agreement expired on June 30, 2016, and has not been renewed yet. [2] The most controversial issue is the number of Korean long-line fishing vessels catching hairtail in Japan's EEZ. The Japanese government has asked the Korean government to reduce the number of vessels from 206 to 73. However, the request was unacceptable to the Korean government because the drastic drop could affect the decline of the fishermen's income and their output (hairtail catch). Due to the cessation, all Korean fishing gear types that used to operate in Japan's EEZ have been evicted from the area including long-line, purse seine, jigging, and trawler. We expect that this exogenous shock has affected fishery resources around the area and fishing patterns such as fishing intensity, fishing location, and fish catch. Hence, our research starts with the simple basic question: "How does the suspension affect Korean fishery?", and we believe new resource management policies may be required for both countries under the situation.

With regard to fishery resource management across several countries, most literature has focused on the optimal catch per fishing vessel or country by employing the theory of transboundary fishery since Munro (1979) introduced the game theory into cooperative and non-cooperative fishery management. Our study focuses

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[1] This is the fastest one among the agreements signed by the three countries. (China-Japan: 1997, China-Korea: 2000)

[2] There are two controversial issues. First, the number of Korean long-line fishing vessels in Japan's EEZ. Second, changing the private-led fishery council for fishing in intermediate water to the government-led one.

on showing empirical evidence using the conceptual framework based on the Marine Protected Areas (MPAs) under the transboundary fishing environment. MPAs aim to secure the diversity of marine resources by designating specific areas in the sea and prohibiting fishing activities therein. We assume that the suspension of the Korea-Japan Fishery Agreement (KJFA) will play a similar role to MPAs by evicting Korean fishing vessels from Japan's EEZ. The spillover effect of MPAs is controversial. Though most studies have shown the positive spillover effect of MPAs on fish biomass and abundance, the effect is unclear for local fisheries because the establishment of MPAs narrows down the local fishing ground (Di Lorenzo et al., 2020). Based on this argument, we estimate the spillover effect of KJFA expiration on Korean fishing activity. To estimate the effect, this paper focuses on the catch of hairtail caught by Korean long-line fishing vessels. There are two reasons why we only focus on it. The first is that the Korean long-line hairtail fishery is the main reason for the suspension and is highly dependent on Japan's EEZ. The second is to minimize confounding concerns because those fishing vessels only catch hairtail in Japan's EEZ and there is no competitor for hairtail catch in the area. As an empirical method, we apply Difference-in-Differences with average monthly vessel catch and weather data sets from July 2015 to April 2017. We use the hairtail catch caught by different fishing gears to set up the treatment (long-line) and control (stow net and drift gillnet) groups. The target species of these two groups are the same (Scientific name: Trichiurus lepturus), but the fishing depth and grounds are different.

Our baseline model separates the effect of catch in China's EEZ from the catch in Korea's EEZ by including a dummy and an interaction term with the post dummy because the fishing patterns in each EEZ could be different. The fishermen who are willing to operate in China's EEZ are more likely to have higher productivity than others to cover the cost due to the distance fishing. The result shows that the average catch of long-line hairtail decreased by 11.2% to 12% and the total catch also decreased by 27.89% to 29.1% in Korea's EEZ. Also, the average and total catches in China's EEZ increased by 61.7% and by about 100%, respectively. On the other hand, the fishing days increased by 3.25% to 3.76%. Our findings support that even though fishing intensity increased, it did not make up for the catch loss from the KJFA expiration. Moreover, the high intensity of Korean fishing may cause the reduction of the resource not only in Korea's EEZ but also in Japan's or China's EEZ. To support the robustness of the result, we addressed potential issues such as the stable unit treatment value assumption, the El-Nino effect, other policy effects, and the substitution effect of China's fishing vessels in Japan's EEZ.

The implication of this study is linked to the importance of fishery agreements.

As our results showed, bilateral fishery agreements play an important role to secure marine resources. Resource depletion could be accelerated on the local fishing ground without the agreements. This is because fishermen increase the fishing intensity to cover the decrease due to the close. No establishment of bilateral fishery agreements among countries that share local fishing grounds is not beneficial for all of them. In addition, under the fisheries agreements, each fishing vessel must report its catch to the government of the other country and follow the specific rules including fishing location, season, and method (net size, fishing depth). Therefore, the agreements could play a role in managing marine resources by preventing illegal fishing. In this aspect, a bilateral fishery agreement between Korea and Japan should be renewed. This research has several contributions to the previous literature. First, this is the first study addressing the impact of a bilateral fishery agreement expiration on the local fishery environment using vessel-level data. Most bilateral fishery agreements among countries are usually renewed, but what we handle in this study is a rare case in terms of the globalized fishery environment. Second, this is the first empirical study using a vessel-level panel approach in Korea. This approach allows us to control for vessel heterogeneity and analyze changes in the fishing pattern of each vessel due to the exogenous shock. This can be considered a new attempt in the Korean fishery research environment, which is mainly limited to time-series analysis. Third, this study supports that it is difficult to expect a positive effect on fishermen and resource management through simple regulatory policies such as designating restricted fishing areas on local fishing grounds. The expected increment of fish biomass or biodiversity (positive spillover from regulations) due to the policies could be counterbalanced by the increases in fishing intensity in adjacent regulatory areas or illegal fishing activities of regulated fishing gear (negative spillover from fishermen's behavior). Therefore, policymakers need to consider comprehensive systematic management policies in terms of not only the marine ecosystems but also fisheries communities' involvement.

The contents of this chapter consist of the following order. Section 2 introduces the background of KJFA and Korean hairtail fishery. Section 3 illustrates the conceptual framework to support the changes in fishing patterns. Section 4 describes the data we used and the empirical strategy for the regression. Sections 5 and 6 show the regression result and conclusion, respectively.

2.2 Background

Korea-Japan Fisheries Agreement

To secure marine resources and sustainable fisheries, the Korean fishery industry has been changing from coastal fishing oriented to aquaculture since the 1960s, and coastal fishing and aquaculture account for 25% and 60% of the total production in 2021, respectively[3] (See Figure 2.1). Despite this transition, coastal fishing has not decreased significantly, maintaining a production level of about 900,000 metric tons. This is because coastal fishing plays an important role in fishery because it is the basis of claiming maritime sovereignty, supplies non-farmed fish species to the market, and also is one of the major income sources of fishermen. In particular, since the major fishing grounds for Korean fishermen are surrounded by China and Japan, fish production is influenced by the diplomatic relations between them.

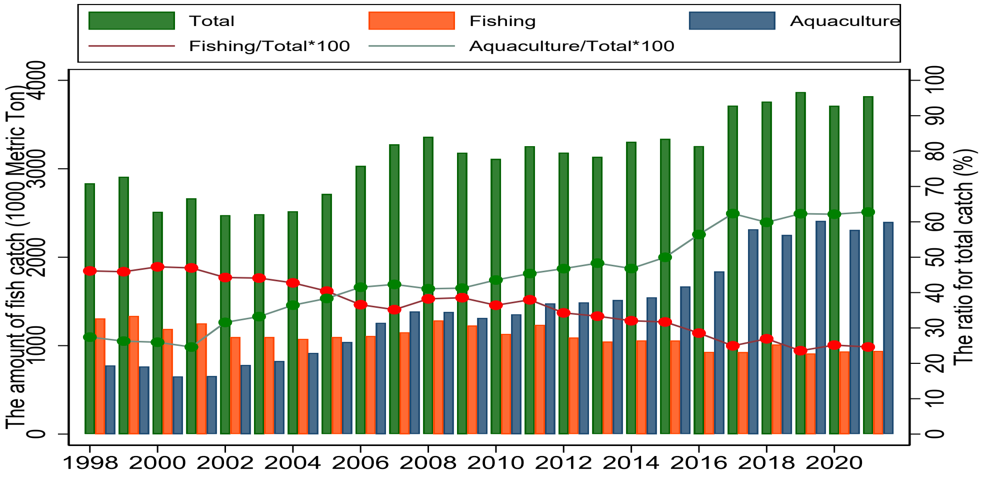

Figure 2.1: Korean Fishery Production from 1998 to 2021

Source: Korean Ministry of Ocean and Fisheries

Note: The lines indicate the changes in the ratio of coastal fishing catch (Red) and aquaculture production (Green) to total production, respectively.

Although the relationship between the three East Asian countries, China, Japan, and Korea, is historically and politically complicated, they made intermediate waters sharing fishing grounds to secure fishermen's productivity and alleviate competition because they are close to each other. In particular, since Korea and Japan are very close to each other[4], they have conflicted with fishing activities in the common fishing

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[3] The other 15% to 17% consists of the production of Deep-sea fishing and land-based aquaculture.

[4] The shortest distance between Korea and Japan is only 49.5 kilometers (from Geoje (Korea) to Tsushima (Japan) island). The distance from the mainland of Korea (Busan) to Japan (Guju) is about 200 km.

Table 2.1: The Quota in Mutual EEZ between Korea and Japan in 2013 Fishing Year

Korea (in Japan's EEZ)		Japan (in Korea's EEZ)	
Species	Quota (tons) 60,000	Species	Quota (tons) 60,000
Saury	7,000	Conger eel	50
Saurel	3,500	Saurel	3,000
Mackerel	23,385	Mackerel	37,814
Sardine	-	Sardine	-
Japanese flying squid	8,750	Japanese flying squid	3,150
Flatfish	1,150	Flatfish	40
Red sea bream	220	Red sea bream	78
hairtail	2,120	hairtail	10
etc	13,875	etc	15,858

Source: Korean Ministry of Ocean and Fisheries

ground. To clarify their maritime boundaries and manage the fishery resource, they signed fisheries agreements in 1965[5]. The agreement determines the size of common fishing ground, species, amount of catch (catch allowance), the number of fishing vessels, and fishing gear types that can operate in the mutual EEZ.

In the relationship, Korean fishery has been highly dependent on Japan's EEZ. Considering the quota of each country, Korea focuses on more diverse fish species than Japan in mutual EEZ (See Table 2.1). Though the assigned catch by the consent for the two countries has decreased since the 2000s, the actual catch of Korean fishing vessels from Japan's EEZ is more than the Japanese catch from Korea's EEZ since 2009. Moreover, the actual number of Korean fishing vessels operated in Japan's EEZ is more than five times of the Japanese ones in Korea's EEZ in 2015. Korean fishing vessels produced 37,395 tons in Japan's EEZ and the number of fishing vessels reached a total of 580. On the other hand, Japanese production in Korea's EEZ was 3,927 tons from only 101 fishing vessels(See Figures 2.2 and 2.3[6]).

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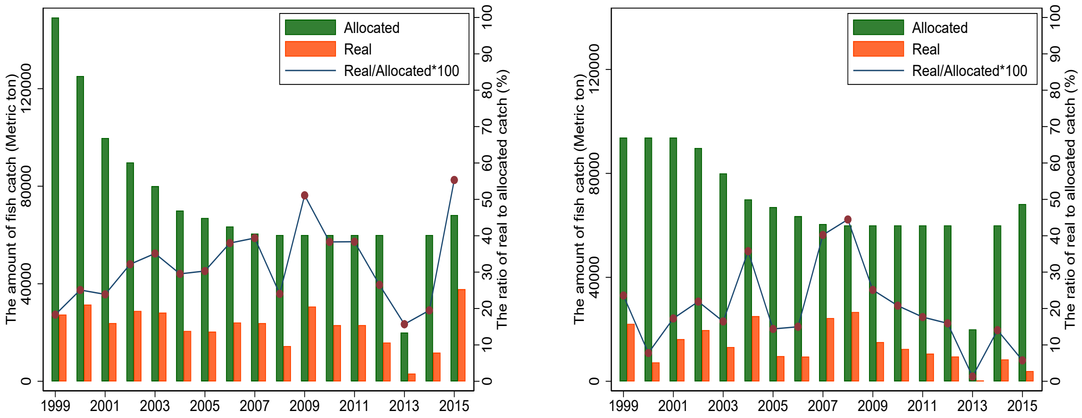
[5] It was revised in 1998 with considerable details related to the common zone near Dokdo Island which is the major fishing ground for squid and crab. On the other hand, China and Japan signed the agreement in 1997 and have shared a Provisional Waters Zone (PMZ). China and Korea also signed the agreement in 2000 and designated a PMZ and Transitional Zone (TZ) on each side of the PMZ to provide some flexibility for fishing activity. After four years, any fishing activity is not allowed in the TZ of the other country (Rosenberg, 2005, see Figure A.1).

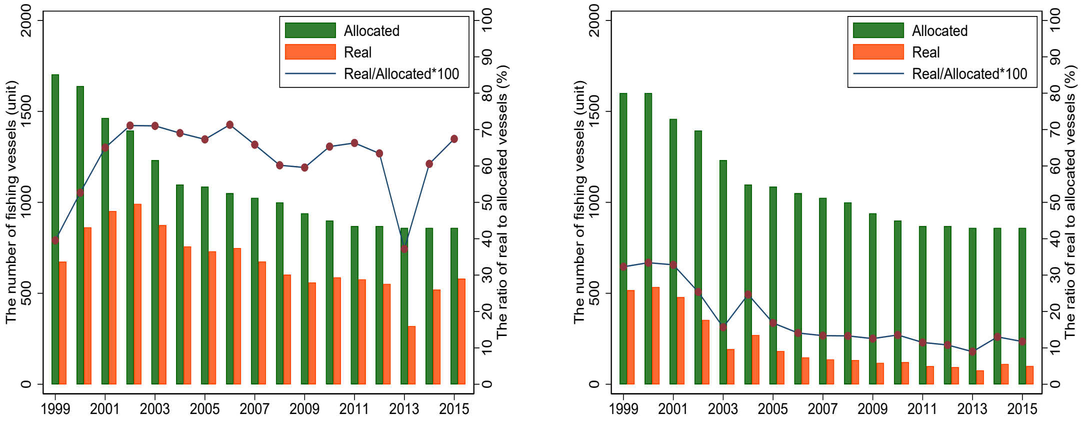
[6] The decline in 2013 is due to the revision of the fishing year in 2012 for efficient negotiation. (because of changing of people in charge in the new year season when personnel appointments occurred) 3.1 2.28



(a) (b)

Figure 2.2: The assigned and actual catch in (a) Japan's EEZ (Korean catch) and (b) Korea's EEZ (Japanese catch)

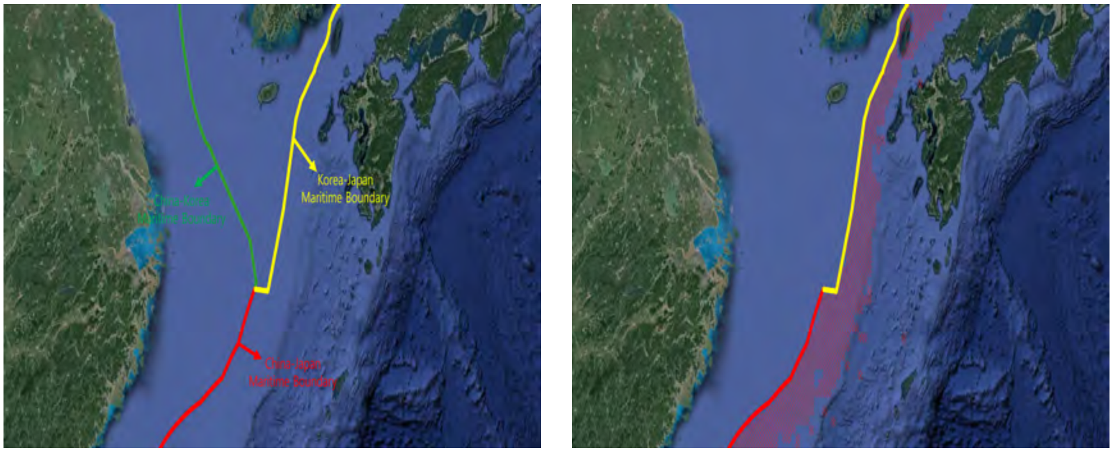
Source: Korean Ministry of Ocean and Fisheries
Note:Fishing year [2013 (2013.3.1 ∼ 2013.6.30), 2014 (2013.7.1 ∼ 2014.6.30), 2015 (2015.7.1 ∼ 2016.6.30)]



(a) (b)

Figure 2.3: The assigned and actual number of vessels to (a) Japan's EEZ (Korean vessels) and (b) Korea's EEZ (Japanese vessels)

Source: Korean Ministry of Ocean and Fisheries
Note: Fishing year [2013 (2013.3.1 ∼ 2013.6.30), 2014 (2013.7.1 ∼ 2014.6.30), 2015 (2015.7.1 ∼ 2016.6.30)]



(a) (b)

Figure 2.4: (a) Maritime Boundaries for the three countries (China, Japan, Korea) (b) The Fishing Area (shaded) in Japan's EEZ for Korean Fishing Vessels Before the Expiration of KJFA

However, since the agreement could not be renewed in 2016, fishing activity in the mutual EEZ has been prohibited after June 30, 2016. (see Figure 2.4). According to the Korean Ministry of Oceans and Fisheries, there are two main reasons for the cessation. One is the number of Korean long-line fishing vessels operating in Japan's EEZ. In 2015, Korea and Japan agreed to reduce the number of fishing vessels gradually until 2019[7]. However, Japan demanded a significant reduction in the number of long-line fishing vessels from 206 to 73. Second, Japan's government has asked to change the private-led fishery council for fishing in intermediate water to the government-led one. The fishermen on the committee have decided on the fishing ground and seasons for the alternative fishing activity in the intermediate water of the East Sea. The changes could become a political issue between Korea and Japan.

Hairtail fishing

Hairtail (Scientific name: Trichiurus lepturus) or beltfish is a species of warm-water fish distributed in temperate and subtropical seas. In the East-Asia region, hairtails inhabit around Korean peninsula (especially, the southern sea around Jeju Is-

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[7] Korea agreed to reduce the number of the long-line fishing vessels by 40, while Japan agreed to reduce the number of the purse seine and the jigging fishing vessels by 30 and 10, respectively.

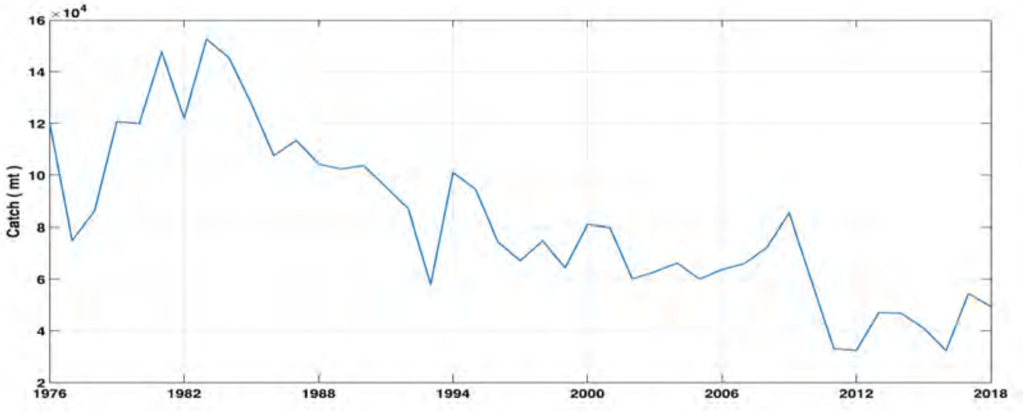

Figure 2.5: Changes in hairtail catch from 1976 to 2018

Source: Statistics Korea

land), the southern area of Honshu (Japan), and the East China Sea. Hairtail has a migration pattern. They are distributed in the southern area of Jeju Island and the northern area of the East China Sea during the winter season (from January to March). They migrate northward in April when the sea temperature rises and spawn in the southern sea of Korea from July to September (National Institute of Fisheries Science[8]). Hairtail is one of the major food resources that is steadily consumed in Korea. However, the Korean hairtail catch has decreased since the 1990s due to climate change and overfishing (see Figure 2.5).

Hairtail fishing is available anytime except the closed season (July), but the main harvest season is from September to January. There are two types of hairtails in Korea which are called "Silver" hairtail and "Black" hairtail for each. Those are not different species but are categorized by fishing methods. If the fish is caught by the long-line fishing vessels, it is called "Silver" hairtail because this fishing method keeps them shiny without damage to their skin. On the other hand, if the fish is caught by other fishing gear such as drift gill net, or stow nets on anchor, it is called "Black" hairtail which has damage on its skin due to the fishing nets (See Figure 2.6). Moreover, those two types of hairtail are caught in different depths and locations. The major fishing grounds for "Silver" hairtail are Juju Island (Korea), Honshu (Japan), and East China Sea (China) where the depth is from 30m to 40m, while "Black" hairtail are normally caught in the southwest area of Korea where the

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[8] https://www.nifs.go.kr/frcenter/species/?_p=species_view&mf_tax_id=MF0004393

depth is over 100m[9].

(a) (b)

Figure 2.6: Difference between (a) “Silver” and (b) “Black” hairtails

Source: https://post.naver.com/viewer/postView.nhn?volumeNo=9113287&memberNo=7066484
Note: The difference caused by fishing methods (between long-line fishing and others)

Due to the differences, the price of the silver hairtail produced by long-line fishing is relatively higher than the black hairtail. In particular, silver hairtail produced from Jeju Island is considered the best product. The size of a long-line fishing vessel is defined as more than 10 tons and less than 90 tons. The number of vessels is 227 in 2019, and the total tonnage is 7,155.1 tons (KOSIS). More than 90% of the longline fishing vessels (203) are concentrated on Jeju Island (Jeju Special Self-Governing Province, 2020). However, after the expiration, Korean long-line fishing vessels can operate only in Korea’s and China’s EEZs (see Figure 2.7)

2.3 Conceptual framework

As mentioned, the fishing ground is shared by three countries. In this chapter, we describe some ideas to explain the distribution of fishing vessels across Korea, Japan, and China’s EEZ.

Assumptions

- There are three fishing sites 1, 2, and 3, managed by different countries. (1: Korea, 2: China, 3: Japan.) Suppose there are no other fishing sites.

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[9] The depth makes a difference in the texture. The texture of the “Silver” hairtail is softer than the “Black” hairtail

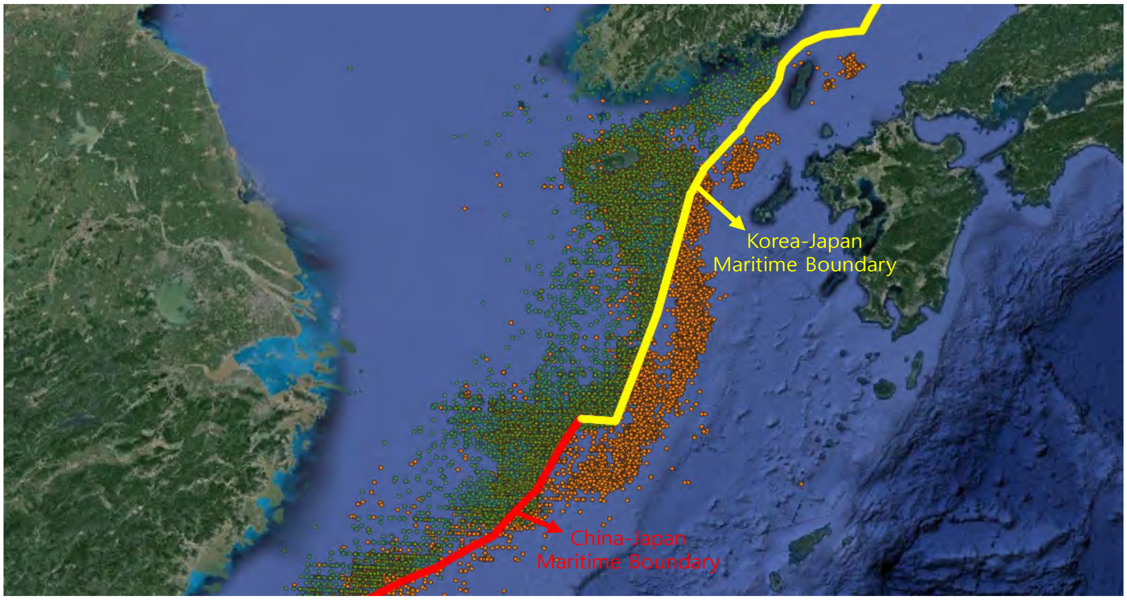


Figure 2.7: Maritime Boundaries and Changes in Hairtail Fishing Vessels' Locations Before (Orange) and After (Green) the Expiration of KJFA

- Countries 2 and 3 issue quotas to vessels from country 1. Let $X_2 > 0$ and $X_3 > 0$ be the total catch quota. In country 1, site 1 is open access to the vessels in country 1.
- Each vessel can exert fishing effort up to $\bar{e}$. Suppose $\bar{e} = 1$.
- Suppose that the fish population dynamics are independent in the fishing areas controlled by each country.

The unit cost of effort is w_i. Suppose $w_3 > w_2 > w_1 > 0$.

Let q be the productivity of the vessel and g the density.

Let $e > 0$ be the

Each firm is endowed with productivity $q \in [q_m, \infty)$ and employs only one input, effort. The catch of vessel with productivity q is given by

$$h = qSe, \tag{2.1}$$

where S is the fish population size.

The upper limit of e is normalized to be equal to one.

Let S_j be the fish population in site j, $j = 1, 2, 3$. Let w_j be the associated cost of efforts, which is proportional to the fuel costs to visit site j.

A vessel with productivity q chooses to fish in site j if

$$qS_j - w_j \geq \max_k (qS_k - w_k) \geq 0.$$

Suppose the following holds for all $q > q_m$:

$$qS_3 - w_3 > qS_2 - w_2 > qS_1 - w_1.$$

Let M be the mass size of the vessels. The entry to site 3 occurs for all $q \geq \underline{q}_3$ such that

$$\int_{\underline{q}_3}^{\infty} qS_3 M f(q) dq = X_3.$$

The entry to site 2 occurs for all $q \in [\underline{q}_2, \underline{q}_3]$ such that

$$\int_{\underline{q}_2}^{\underline{q}_3} qS_2 M f(q) dq = X_2.$$

The active vessels in site 1 have productivity over $\underline{q}_1, \underline{q}_2$ where $\underline{q}_1$ satisfies

$$\underline{q}_1 S_1 - w_1 = 0.$$

So that total catch in site 1 is given by

$$X_1 = \int_{\underline{q}_1}^{\underline{q}_2} qSMf(q)dq.$$

With this setup, there is no crowding externality.

Predictions (short-run impacts where S_j's are given)

A decrease in X_3 (due to the expiration of KFJA) induces those vessels with productivity levels higher than $\underline{q}_3$ to move their fishing locations to either site 2 or site 1. As a result, $\underline{q}_2$ increases, and the total catch in site 1 increases. The average productivity also increases.

Some notes:

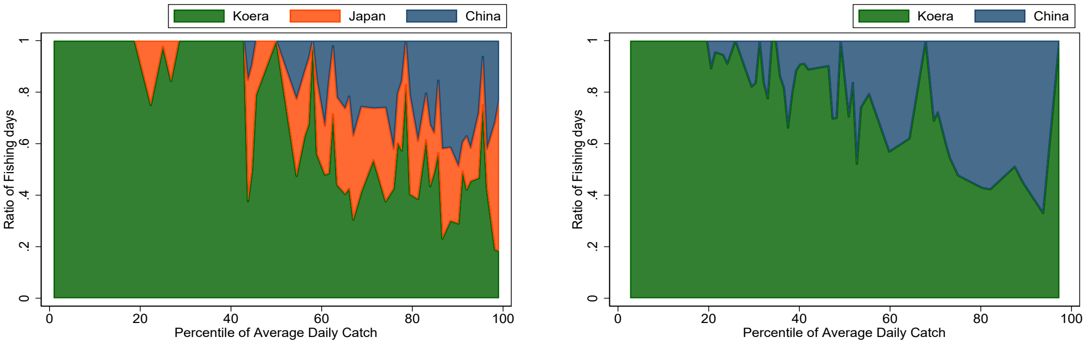
1. An individual fishing vessel has to submit an application for permission to operate in the EEZ. When they submit the application, it includes what the target fish is, how much they will catch, and where the fishing location is (If the information changes, they have to submit the application for the change).
2. Each vessel has to submit the daily report including the fishing locations, and the catch by species, and also inform when they enter and out (including the location, and the catch) to mutual management departments via FAX or Email.
3. There are no entry fees to each site.

Based on this framework, Japan's EEZ is supposed to be a more attractive fishing ground for long-line hairtail fishing vessels than China's EEZ at least which means that the efficiency to operate in Japan's EEZ is higher (less opportunity cost) than in China's EEZ. If operating in China's EEZ is more beneficial than in Japan's EEZ, the fishermen would prefer to operate in China's EEZ, then it could mitigate the effect of the suspension of the KJFA. To support the assumption, we need to know the catch per unit effort (CPUE) in those two EEZs to compare the productivity. However, because of the limitation of the data, this study employs an efficiency index as a proxy of productivity, instead of CPUE, calculating the ratio of the average daily catch to the average distance from Jeju Island where the main harbor for the long-line hairtail fishing vessels. Since the ratio is higher in Japan's EEZ than in China's EEZ before the cease, Japan's EEZ may be a more efficient fishing ground than China's EEZ (See Table 2.2).

Table 2.2: Changes in the catch and fishing days of long-line hairtail fishery Before&After the expiration of the KJFA

EEZ	Korea		Japan		China		Total	
Expiration of KJFA	Before	After	Before	After	Before	After	Before	After
Total Catch (kg) (A)	602,665	718,826	304,013	-	455,293	590,669	1,361,971	1,309,495
Fishing Days (B)	3,257	5,110	1,567	-	1,491	1,929	6,315	7,039
Average Daily Catch (kg) (C) = (A)/(B)	185.03	140.67	194.00	-	305.36	306.20	215.67	186.03
Average Distance from Jeju Island (km) (D)	189.63	142.23	305.36	-	542.91	658.32	301.23	283.66
(C) / (D)	0.97	0.98	0.63	-	0.56	0.46	0.71	0.65

If then, where do the vessels operating in Japan's EEZ move after the suspension? Figure 2.8 shows the share of fishing days according to the average daily catch per vessel before and after the expiration. This indicates how the fishing day of each area changes over the average catch. Therefore, the vessel which has a higher catch spends time more in Japan's and China's EEZ than Korea's EEZ before the closure (See Panel (a) in Figure 7). Meanwhile, the vessels that move from Japan's EEZ to Korea's EEZ and to China's EEZ experience low and high catches, respectively (See Panel (b) in Figure 2.8).



(a)

(b)

Figure 2.8: Fishing Days by Average Daily Catch of long-line hairtail fishing vessels (a) Before and (b) After the expiration of the KJFA

Also, the average efficient index of the upper 50% long-line hairtail fishing vessels significantly decreased in Korea's EEZ after the cease which means the vessels with higher productivity catch less due to the higher competition for catching fish in Korea's EEZ (see Table 2.3).

To identify how the suspension of the Korea-Japan Fishery Agreement changes the fishing pattern of Korean long-line hairtail vessels, this study applies Difference-in-Difference (DD), and the estimator is calculated by the following equation:

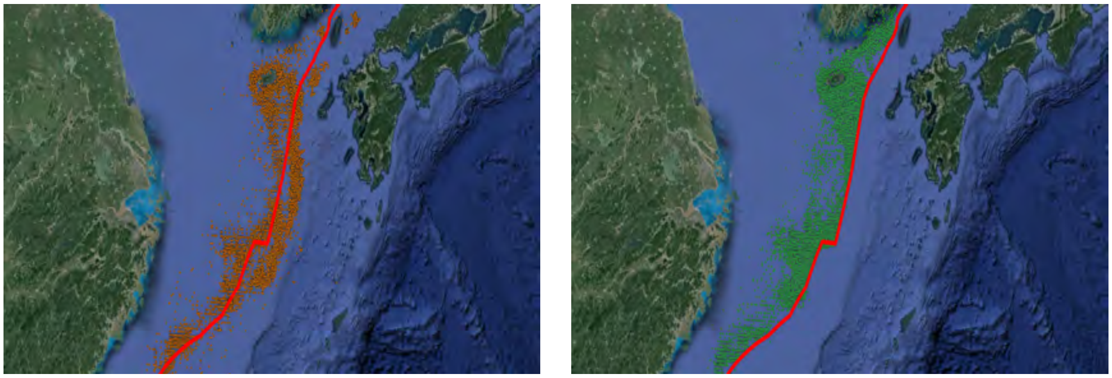
$$DD = E(Y_{after} - Y_{before} \mid T = 1) - E(Y_{after} - Y_{before} \mid T = 0) \tag{2.2}$$

where Y is the average hairtail catch per vessel. $before$ and $after$ indicate the intervention point. $T = 1$ and $T = 0$ represent treated and control groups, respectively. The dilemma of using DD is to find a reasonable comparison group to the treated group. In particular, it is rare for a specific fishing gear to catch only a specific

Table 2.3: Changes in the efficiency index of long-line hairtail fishery Before&After the expiration of the KJFA

KJFA Expiration		Before	After
Average Efficiency Index	EEZ	0.95	0.84
Top 50% (22 vessels)	Total	1.31	0.97
	Korea	1.72	1.13
	China	0.46	0.48
Bottom 50% (23 vessels)	Total	0.60	0.71
	Korea	0.71	0.90
	China	0.53	0.47

Note: The efficiency index indicates the ratio of the average monthly catch to the average distance from fishing locations to Jeju Island. Also, “Top 50%” means the fishing vessels ranked 1st to 22nd in descending order of the efficiency index before the expiration.

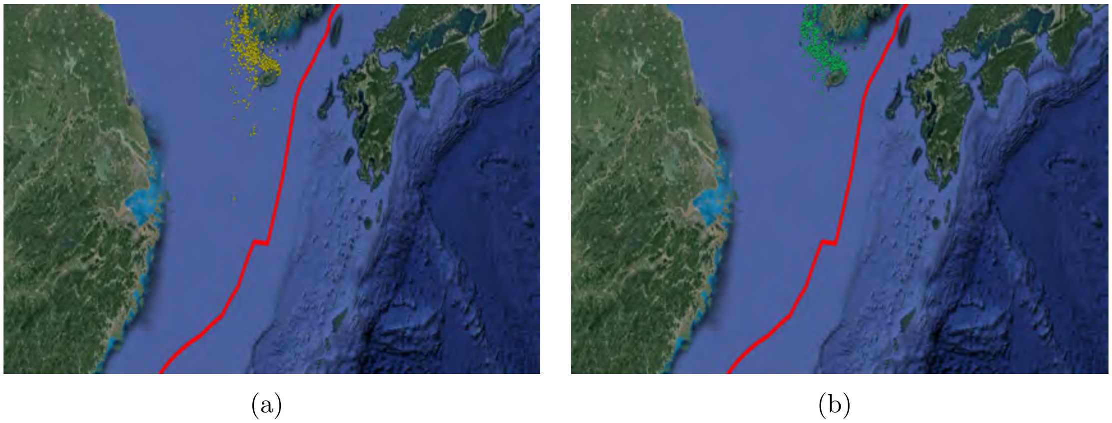


(a)

(b)

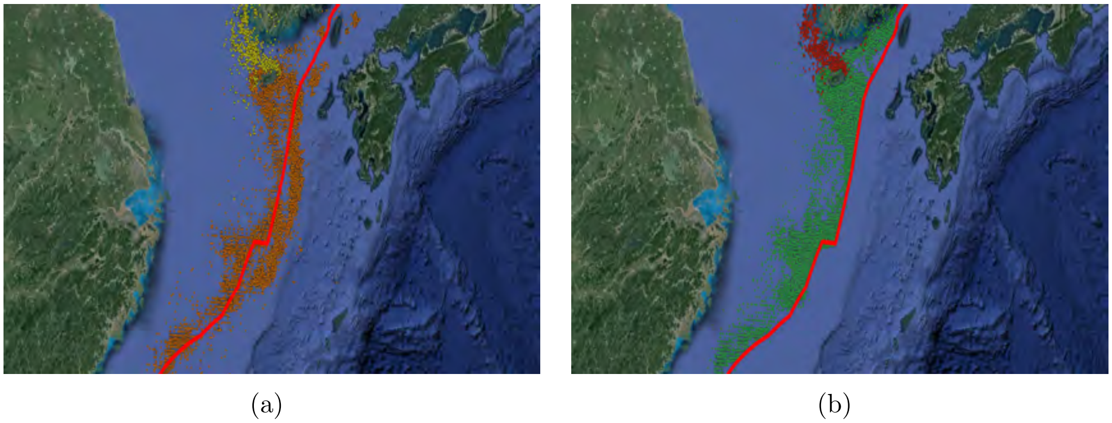
Figure 2.9: Changes in long-line hairtail fishing vessels’ location (a) Before and (b) After the expiration of the KJFA

fish species. Due to this characteristic, setting up treated and control groups in the hairtail fishery is critical to estimate the effects of the shock. Fortunately, as mentioned in the previous section, there are only three types of fishing gear mainly aimed at catching hairtail fishing in Korea which are long-line, stow net, and gill net. The long-line hairtail fishing vessels catch hairtail only and it is classified as “Silver” hairtail. In other words, the hairtail caught by the long-line fishing vessels is called “Silver” hairtail. On the other hand, “Black” hairtail is caught by two types of fishing gear which are a stow net and a gill net. Therefore, in this study, long-line hairtail fishing is selected as the treated group, and stow net and gill net fishing are treated as the control group.



(a) (b)

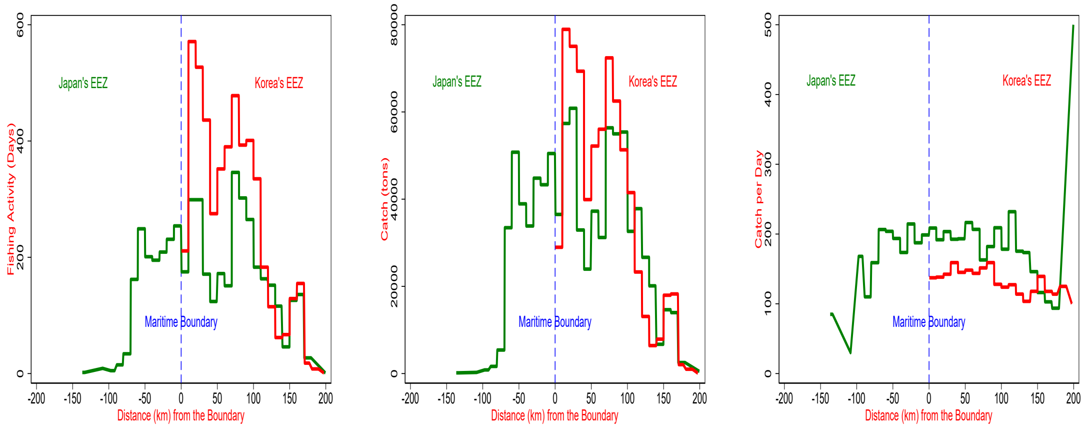
Figure 2.10: Changes in other (stow net and gill net) hairtail fishing vessels' location (a) Before and (b) After the expiration of the KJFA



(a) (b)

Figure 2.11: Changes in hairtail fishing vessels' location (total) (a) Before and (b) After the expiration of the KJFA

They have different fishing grounds, which may support that the control group is not affected by the expiration (See Figures 2.9, 2.10, and 2.11). The fishing ground of the treated group is distributed up and down to the East China Sea and in Japan's EEZ. However, after the expiration, the fishing locations were pushed to the left side of the maritime boundary. On the other hand, the control group has been concentrated around the southwest and Jeju island. As long-line hairtail fishing vessels were evicted from Japan's EEZ, the fishermen might increase fishing activity in Korea's EEZ or long-distance fishing (China's EEZ). To see the pattern, we illustrate the changes in fishing days and catch around Korea-Japan maritime boundary (See Figure 2.12). The main fishing ground for long-line hairtail fishing is within 100km from the boundary of each EEZ before the expiration (Green line). After the closure, the fishing days and the catch increased (Red lines) and were bunched near the boundary. There is another bunching point in Korea's EEZ which is farther from the boundary, this represents the fishing ground around Jeju Island. On the other hand, the average daily catch in Korea's EEZ decreased after the expiration (See Panel (c) in Figure 2.12).



(a) (b) (c)

Figure 2.12: Changes in Fishing Pattern near Korea-Japan Maritime Boundary

Note: (a) Fishing Activity (Days) (b) Catch (c) Catch/Fishing Days

2.4 Data and Empirical Strategy

Data

Usually, the catch data provided by the Korean Statistical Information Service (KOSIS) and the Ministry of Oceans and Fisheries (MOF) are classified by species, fishing gear, and region. Since it is monthly frequency data, there is a limitation in specifying the details about fishing areas and activity. However, this study uses a daily frequency dataset collected by the fisheries cooperative that has information about fishing vessels and their catch. The data includes call sign, ship number, fishing location (coordinates and EEZ area), fishing date, catch (kg), fishing gear, and species. As mentioned in the previous section, this study only considered the fishing activities of the longline fishing vessel catching silver hairtail. However, since the time series is not enough longer, long-term analysis is not available. The valid time series is from July 2015 to April 2017 (22 months), which is 11 months before and after the suspension of the Korea-Japan fishery agreement.

Table 2.4: Summary of Statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Catch (kg)	2,571	258.1093	338.9528	1	5000
Wind Speed (m/s)	2,571	5.953236	1.410444	1.522305	14.9421
Sea Surface Temperature (°C)	2,571	22.02757	4.622608	12.83182	30.98
Temperature (°C)	2,571	19.78286	5.756703	3.35	29.85667
Wave Height (m)	2,571	1.229129	0.29219	0.4698	3.3085
Precipitation (m)	2,571	0.203573	0.24228	-3.47E-15	3.445038
Distance* (km)	2,571	183.0389	169.3656	11.286	1419.824

Note: * means the distance from each fishing point to Jeju Island

The Korea Meteorological Administration (KMA) provides ocean weather data from weather observation buoys installed within maritime boundaries. However, since there are only about 10 buoy sites in the sea around Jeju Island, those cannot cover the fishing ground around the East China Sea where hairtail is mainly caught. Also, since China and Japan do not offer weather data near maritime boundaries, it is difficult to obtain weather observations on the location of each vessel. To handle this issue, this study used the reanalysis of ocean weather data from the European Centre for Medium-Range Weather Forecasts (ECMWF). ECMWF Reanalysis version 5 (ERA5) provides information on the atmospheric weather and ocean waves from a latitude-longitude grid of 0.25 and 0.5 degrees, respectively[10]. In this study, the data is from the area surrounding longitude 122-130 and latitude 27-36, which includes the EEZs of Korea, Japan, and China where hairtail fishing usually operated. Since the ocean weather data is provided as an hourly frequency, the four points of time:

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[10] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview

0, 6, 12, and 18 are selected to make daily frequency data. The variables used are wind speed, sea surface temperature (SST), temperature, wave height, and precipitation. Since it is impossible to get accurate weather observations on the location of each fishing boat, this study uses an interpolation method. Considering elevation or altitude is not necessary on the sea surface environment, this paper uses the Inverse-Distance Weighted (IDW) interpolation method. Lastly, the data set includes the distance from each fishing location to the Han-lim port (located on Jeju island) which is one of the major ports for long-line fishing vessels.

Empirical Strategy

Table 2.5: Test for pre-parallel trend assumption

Dependent Variable	Log Quantity		Log Fishing Days
	Mean	Sum	
	(1)	(2)	(3)
Month*Treatment	.014	-.031	-.008
	(.013)	(.021)	(.015)
Treatment	.013	1.009***	1.299***
	(.084)	(.135)	(.096)
Month	-.044***	-.081***	-.037***
	(.008)	(.014)	(.010)
Constant	5.325***	7.001***	1.676***
	(.048)	(.076)	(.054)
Observation	1,262	1,262	1,262
R^2	.026	.127	.339

This research applies difference-in-differences as an empirical method. As mentioned in the previous sections, the intervention is 30 June 2016 when the agreement expired. The treated group is Korean long-line hairtail fishing vessels, and the control group is Korean stow net and gill net fishing vessels. The regression model is expressed by the following equation:

$$log(Y_{rdt}) = \beta_0 + \beta_1 Post_t + \beta_2 Treat_d + \beta_3(Post_t \times Treat_d) + \gamma X_{rdt} + \lambda_t + \eta_d + \varepsilon_{rdt} \quad (2.3)$$

where $log(Y_{idt})$ is logged average hairtail catch of vessel i, group d, at month t. $Post_t \times Treat_d$ is the interaction term which is DD estimator. If the long-line hairtail fishing vessels operate after the expiration, $Post_t \times Treat_d = 1$, otherwise $Post_t \times Treat_d = 0$. X_{idt} indicates weather and distance variables including wind speed, sea surface temperature (SST), temperature, wave height, precipitation, and distance from each fishing location to the Han-lim port on Jeju-island. To control the seasonality, the model includes time-fixed effects (season, month) and Harvest season dummy, λ_t. η_i is vessel level fixed effects and ε_{idt} is error term clustered vessel level. Prior to the empirical results, we check the pre-parallel trend assumption between the treated and the control groups (see Table 2.5). To confirm the assumption, we use logs of average catch, total catch, and fishing days per vessel as dependent variables for the pre-intervention sample period (August 2015 $\sim$ May 2017). Since the interaction terms are insignificant for all specifications, we can say that the treatment and control groups have a parallel trend before the intervention (Also see Figure A.3).

2.5 Result

Main Result

The baseline result we take a look at is the case that a dependent variable is a log average catch (See Table 2.6). Because of the possible issue of endogeneity among weather variables, columns 2, 3, 4, and 6 only include wind speed and sea surface temperature (indicated as "partial" in the "covariates" row). Also, to control the effect of the catch from China's EEZ, columns 6 and 7 include a China EEZ dummy and the interaction term with the intervention dummy. The DD estimators in the models without the China EEZ dummy are positive (See from columns 1 to 5 in Table 2.6). On the other hand, in the models that include a china EEZ dummy and the interaction term with the intervention dummy, the coefficients are negative (See columns 6 and 7 in Table 2.6). The reason why the columns without the China EEZ dummy show positive DD estimators is that the model specification absorbs the effect of catch from China's EEZ. Therefore, the DD estimator from our baseline model specification is -0.128 (See column 7 in Table 2.6). Meanwhile, the DD estimator for the total catch and the fishing days are -0.327 and -0.192, respectively (See column 7 in Tables 2.7 and 2.8). The results exactly match the changes in the pattern of Korean long-line hairtail fishing vessels illustrated in the previous section (See Figure 2.12). To add more supporting evidence for the changes in the fishing days, we use the sample from Korea's EEZ only and the DD estimator is 0.037 (See Table 2.9)[11].

Robustness Check

Even though the treated and the control groups are visually distinguishable (See Figure 2.11), there are still possible issues for this setting. One is the violation of the stable unit treatment value assumption (SUTVA) which means there may be a

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[11] For this specification, season cluster standard errors are used. Then, we got the positive DD estimator for all models

Table 2.6: DD estimator (Average Catch)

D. Variable Log Catch (Mean)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post*Treat	.057	.094	.092*	.092*	.082	-.119**	-.128**
	(.074)	(.071)	(.052)	(.054)	(.050)	(.055)	(.055)
Treat	.028	-.034	4.208***	4.208***	4.209***	4.034***	4.025***
	(.052)	(.059)	(.064)	(.120)	(.122)	(.110)	(.112)
Post	-.115***	-.161***	-.035	-.035	-.012	-.017	.003*
	(.047)	(.045)	(.035)	(.050)	(.050)	(.050)	(.050)
China EEZ						.253***	.257***
						(.064)	(.065)
China EEZ*Post						.474***	.481***
						(.074)	(.074)
Covariates	x	partial	partial	partial	full	partial	full
Fixed Effect (Season, Month, Vessel)	x	x	o	o	o	o	o
Cluster (Vessel)	x	x	x	o	o	o	o
Observation	2,571	2,571	2,571	2,571	2,571	2,571	2,571
R^2	.003	.098	.656	.656	.659	.671	.673

Table 2.7: DD estimator (Total Catch)

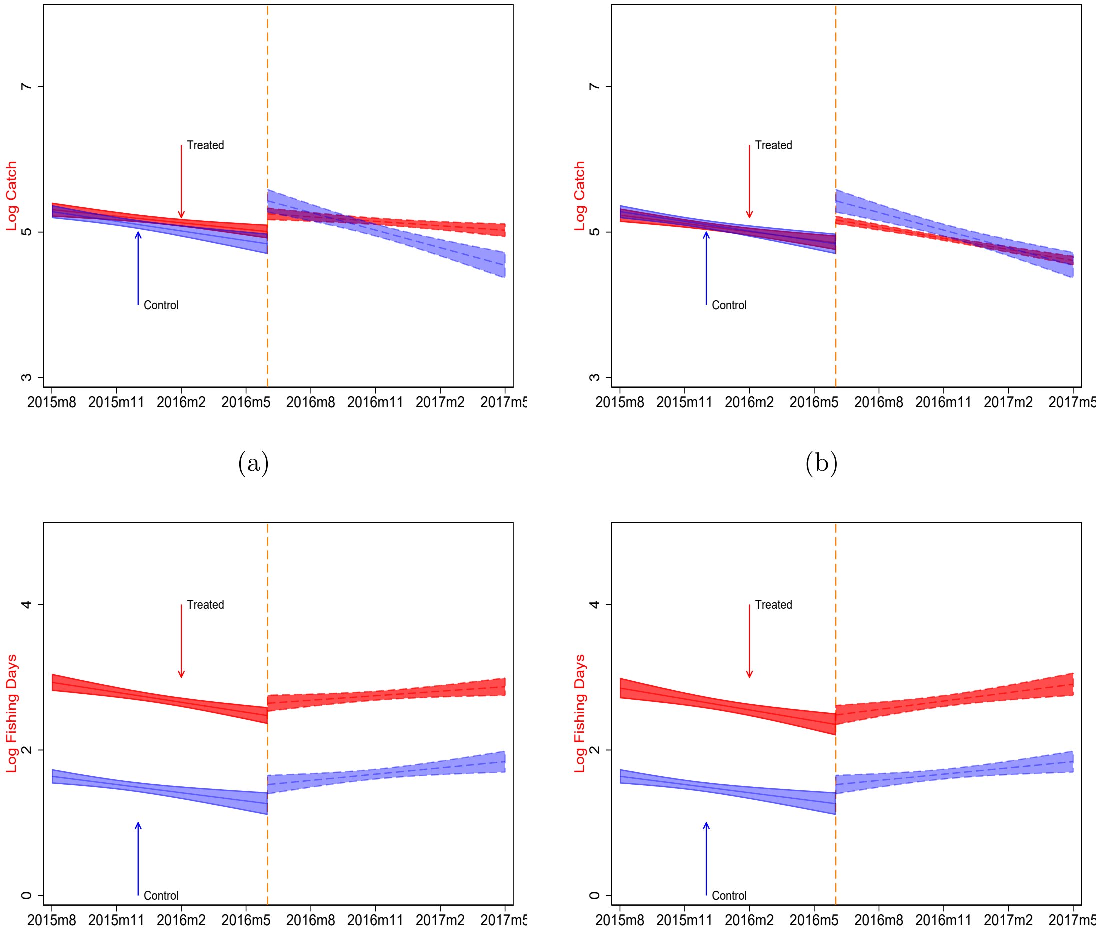
D. Variable Log Catch (Total)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post*Treat	.021	-.012*	-.103	-.103	-.082	-.344***	-.327***
	(.115)	(.113)	(.097)	(.110)	(.108)	(.123)	(.121)
Treat	.687***	.790***	5.703***	5.703***	5.657***	5.618***	5.558***
	(.081)	(.093)	(1.122)	(.148)	(.146)	(.145)	(.144)
Post	.092	.056	.374***	.374***	.375***	.383***	.383***
	(.073)	(.071)	(.066)	(.108)	(.105)	(.107)	(.105)
China EEZ						-.137	-.118
						(.148)	(.148)
China EEZ*Post						.700***	.711***
						(.168)	(.166)
Covariates	x	partial	partial	partial	full	partial	full
Fixed Effect (Season, Month, Vessel)	x	x	o	o	o	o	o
Cluster (Vessel)	x	x	x	o	o	o	o
Observation	2,571	2,571	2,571	2,571	2,571	2,571	2,571
R^2	.054	.110	.537	.537	.541	.541	.546

Table 2.8: DD estimator (Fishing Days)

D. Variable Log Fishing Days	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post*Treat	-.162**	-.158**	-.211***	-.211***	-.209***	-.192**	-.192**
	(.072)	(.072)	(.062)	(.076)	(.077)	(.084)	(.086)
Treat	1.191***	1.156***	1.918***	1.918***	1.905***	1.923***	1.907***
	(.051)	(.060)	(.716)	(.127)	(.124)	(.130)	(.127)
Post	.207***	.200***	.355***	.355***	.367***	.354***	.367***
	(.045)	(.045)	(.042)	(.075)	(.075)	(.075)	(.075)
China EEZ						.016	.028
						(.062)	(.064)
China EEZ*Post						-.056	-.057
						(.075)	(.079)
Covariates	x	partial	partial	partial	full	partial	full
Fixed Effect (Season, Month, Vessel)	x	x	o	o	o	o	o
Cluster (Vessel)	x	x	x	o	o	o	o
Observation	2,571	2,571	2,571	2,571	2,571	2,571	2,571
R^2	.271	.283	.628	.628	.632	.628	.632

Table 2.9: DD estimator (Fishing Days (Korean EEZ))

D. Variable Log Fishing Days	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Post*Treat	.173*	.067	.032	.032*	.037*	.032*	.037*
	(.089)	(.088)	(.082)	(.098)	(.371)	(.353)	(.371)
Treat	.473***	.656***	1.249	1.249	1.223	1.249	1.223
	(.065)	(.069)	(.812)	(.513)	(.712)	(.718)	(.712)
Post	.207***	.234***	.351***	.351***	.360***	.351***	.360***
	(.049)	(.048)	(.048)	(.273)	(.054)	(.030)	(.054)
China EEZ							
China EEZ*Post							
Covariates	x	partial	partial	partial	full	partial	full
Fixed Effect (Season, Month, Vessel)	x	x	o	o	o	o	o
Cluster (Season)	x	x	x	o	o	o	o
Observation	2,204	2,204	2,204	2,204	2,204	2,204	2,204
R^2	.085	.124	.507	.507	.512	.507	.512



(a)

(b)

(c)

(d)

Figure 2.13: The trends of the catch and fishing day (linear)

Note: Panels (b) and (d) exclude the sample from China EEZ spillover effect on the control group caused by the treatment group. To address this possible issue, we introduced three assumptions. First, the resources do not change dramatically in the short run. Second, fishing grounds and gear are different. Third, the overlapping area between the treated and the control groups on the map (Figure 2.11) has already been a competitive area, so there are no more additional fishing vessels. Therefore, in the area, the possible amount of catch is fixed all the time. In addition, there are possible exogenous shocks to consider which are Super El-Nino which occurred from 2015 to 2016, TAC policy, and China's fishing activity. Hairtail is a warm-water fish basically. If the El-Nino has affected hairtail catch, it should increase. However, the total hairtail catch in Korea was relatively stable during that time (2013 $\sim$ 2015)[12]. Also, since hairtail TAC was implemented in 2019, there is no effect on the sample period. The most important issue is that China's fishing vessels may have replaced Korean hairtail fishing vessels. As the Korean fishing vessels were evicted from Japan's EEZ, the fishing activity of China's fishing vessels in Japan's EEZ and the number of the vessels may increase. Unfortunately, since we don't have Chines fishing activity data, we cannot measure the possible impact. However, Chinese fish catch from the East China Sea has not changed dramatically but rather decreased (See Table A.2). Therefore, there is a low possibility that China's fishing activity has increased in Japan's EEZ after the expiration. Also, China's fishing activity is concentrated near the Mainland of China (See Figure A.2).

2.6 Conclusion

In the global fishing environment, it is very rare to cease an already concluded fisheries agreement. This paper shows how important it is to maintain fishery agreements to manage resources and secure productivity in local fishing grounds by analyzing the spillover effects of the suspension of KJFA. We found that the average monthly long-line hairtail catch decreased by 11.2% to 12%. Also, our result shows that the long-line hairtail fishing vessels are evicted from Japan's EEZ more to Korea's EEZ than to China's EEZ. The suspension of the fishery agreement resulted in increased fishing intensity and reduced productivity by reducing the fishing grounds. If this condition continues, the hairtail resource in Korea's EEZ may decrease in the long run. The results of this study are limited to Korean long-line hairtail fishing, but we expected that similar effects were seen in purse seine or trawler fishing operated in Japan's EEZ.

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[12] 2013: 46,904 tons, 2014: 46,024 tons, 2015: 40,452 tons

Our results show some policy implications. First, if the bilateral fishery agreement is maintained to expand each other's fishing grounds, the fishing intensity decreases. Therefore, apart from historical and political conflicts between Korea and Japan, the renewal of KJFA is beneficial for both countries and resources management. Second, restriction policies such as the establishment of prohibited fishing areas in local fishing grounds can increase the fishing intensity around the areas, so an in-depth policy review is required for application. Thoughtless establishment of resource-protected areas is likely to drain resources in the long run.

This study has a few limitations. First, long-term effects cannot be estimated using a time series of 11 months before and after the event. Second, we only showed changes in fishing patterns of Japanese and Chinese fishing vessels indirectly because we could not get vessel-level data for those two countries. If sufficient time series and fishing data of other countries are secured in the future, we will be able to not only estimate the long-term effect of the suspension of the agreement but also analyze the optimal catch among the three countries and their fishing vessels.

Chapter 3

The Impact of Earthquake on Housing Prices near Nuclear Power Plants: Focusing on Pohang City in Korea

Abstract

This study focuses on estimating the willingness to pay for housing to measure the value of the potential risk of nuclear power plants in Korea by using the Hedonic price model. This paper employed house transaction data with difference-in-differences for estimating the value of NPP's risk by comparing the impacts of two exogenous shocks on housing prices near Gori NPP in South Korea. One is the Fukushima nuclear accident in 2011 and another is the earthquake in Pohang in 2017. The Fukushima accident does not affect housing prices near the NPP. On the other hand, there was a long-term negative effect of the Pohang earthquake. The result shows that the potential risk of the NPP is well reflected in the South Korean real estate market after the Pohang earthquake.

3.1 Introduction

With almost zero marginal costs and zero CO_2 emission, nuclear power has been one of the popular energy sources to generate electricity. However, since the Fukushima accident in 2011, concerns about having nuclear power plants (NPP) has been also emerged. Those concerns might not be fully reflected in the value of constructing and operating NPP. Estimating the proper value of NPP is a complicated problem because NPP entails various external costs such as future financial liabilities arising from decommissioning and dismantling of nuclear facilities, health and environmental impacts of radioactivity releases in routine operation, radioactive waste disposal, and effects of severe accidents (OECD/NEA, 2003). Also, individuals' concerns or psychological costs which are attributed to living near NPPs make estimating the value of NPPs difficult since those are subjective and can be varied over time.

In this study, we estimate how people value the risk of NPP when a natural disaster entangles the plant in a dangerous situation. For estimating, we employ cases in South Korea. Since the 1970s, South Korea has constructed four NPPs. Although the number of NPPs in South Korea is relatively small compared to that of other developed countries, the accumulation level of NPPs is high considering the small territory of South Korea[1]. However, there are only a few studies examining the value of NPP in South Korea with respect to the potential hazard of living in the vicinity of NPP.

In doing so, this paper applies the hedonic method by using housing prices. This method has been used in many studies. Nelson (1981) and Gamble and Downing (1982) examined the impact of the accident of NPP at Three Mile Island (TMI) in the US on housing prices. Merz et al. (2015) and Tanaka and Zabel (2018) researched the impact of the Fukushima accident (March 2011) on housing values. Also, Davis (2011) studied the effect of power plants on local housing values and rents. This paper makes some differences from the previous studies by using two exogenous variables. One is the Fukushima accident likewise previous studies, another is the earthquake in Pohang in South Korea which occurred in 2017.

There are two reasons why the two shocks are chosen. First, the Fukushima accident is an out-country shock and the earthquake of Pohang is an in-country shock, so, I can assume the impacts of each shock on what people feel are different. Actually, the anxiety people felt from NPPs in South Korea might be much higher after the earthquake of Pohang than after the Fukushima accident because the perception people have is that South Korea is safe from earthquakes before the earthquake of Pohang. So, I assume that the Fukushima accident just reminded people that NPP is dangerous and the earthquake of Pohang really affects housing values near NPP

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[1] The United States has 97 nuclear reactors which are distributed in 58 NPPs and France has 58 nuclear reactors in 19 NPPs. On the other hand, South Korea has 24 reactors in 4 NPPs.

in South Korea. Also, this assumption is supported by Seo and Cho (2018) who found that there is only a short-term (3 months) effect of the Fukushima accident on housing prices. Second, the earthquake in Pohang is the most devastating one in South Korea since the 1970s. It made some injured people and huge property damage.

There are some studies about the impact of the risk of NPP on the housing market, but the results were not consistent. Nelson (1981) and Gamble and Downing (1982) studied the impact of the TMI accident on housing values. They found that there is no statistical difference between housing value near NPP (treatment group) and the value of another area (control group). But, Clark et al. (1997) found that the housing value of the treatment group is higher than the control group. On the other hand, Tanaka and Zabel (2018), which uses the Fukushima accident as an external shock, found the value of the treatment group is lower than the control group, but the impact was temporary. It seems that the potential hazard people feel can be affected not only by the distance between the epicenter and the region near NPPs but also by different characteristics that each region has such as amenities, infrastructure, and transportation system.

To estimate the impact of the shocks on housing prices, this paper employs the difference-in-differences method with repeated cross-section house transaction data. In this study, I only focus on the housing prices of apartments. There are some reasons for that. First, most people usually prefer apartments to other types of houses due to the price stability in South Korea. Second, it has relatively simple house characteristics than normal houses. Third, it is possible to make panel data by averaging the repeated cross-section data at the apartment complex level. For the distance of amenities, I use distances from each house to the nearest central business district (CBD), community service center (CSC), court, library, public health office (PHO), fire station, post office, and schools by using Geographic Information System (GIS).

The main potential issue in this study is how to set up a treatment group and a control group. Seo and Cho (2018) divided into the treatment group (within 20km) and the control group (over 20km) by sample size. On the other hand, Tanaka and Zabel (2018) found a certain point (4km) where the gap in housing prices between before and after a shock is getting larger. So, they used an area within 4km as a treatment group and between 4km to 10km as a control group. However, 10km is a very short distance to get rid of the individual's concern about NPP. In this study, I employ the zone criteria from the International Atomic Energy Agency (IAEA) to divide the area into treated and control groups as a threshold point (21km)[2]. I compare it to different scenarios by applying the zone buffer of 500m. Also, this paper limits the radius from the Gori NPP from 18km to 30km since the people who live within 5km of the NPP get subsidies from the government and the area over 30km is close to another NPP (Wolseong NPP). Also, I only consider the sample from 18km to 30km because the average housing price located within 18km of the Gori NPP is way lower than the housing price over 18km. The result shows that the Fukushima accident does not impact on the housing price near the Gori NPP. However, the Pohang earthquake decreases the price by 2.1% after a year the shock.

The implication of this study is that people are more likely sensitive to in-country shocks than out-country which means the learning effect by exogenous shocks does not work with the Fukushima accident but does with the Pohang earthquake. Therefore, the risk value of Gori NPP might be not fully reflected in the housing market before the Pohang earthquake and the negative long-term effect of the Pohang earthquake can be explained by the re-estimating process of the value of NPP.

This study has some contributions to previous works. First, this is the first study of estimating the potential risk of NPP with considering the in-country earthquake as information in the South Korean housing market. Second, I use the IAEA zone criteria to set a treatment group and a control group as a geographic threshold. Third, I analyze the empirical model with the housing price panel structure data to handle unobserved heterogeneity by averaging the data at the apartment complex level.

This paper is organized as follows. Section 2 illustrates the background of the two shocks and NPPs in South Korea. In section 3, I provide a conceptual framework. Section 4 describes the data used and sections 5, and 6 introduce an empirical strategy and results. In section 7, I finally discuss policy implications and future studies.

3.2 Background

After the Fukushima accident due to the 9.0 magnitude earthquake and tsunami from the Pacific Ocean on March 2011, people have doubted the safety of NPP because the media broadcasted the accident as top news and reported additional damages related to radioactive contamination. Especially, since South Korea not only is very

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[2] The criteria are divided into two zones. One is the Precautionary Action Zone (PAZ) and another is the Urgent Protective Action Planning Zone (UPZ). The details are illustrated in Section 3.

close to Japan but also had imported substantial amounts of fishery products from Japan, people have been sensitive to NPP. Figure 3.1 indirectly shows how people have cared about the NPP. The values indicate the popularity of the word "Nuclear Power" during the analysis time period (from March 2010. to November 2018.) from Google Trends. All cities in the list are closed to NPP except Seoul, the capital of South Korea[3]. So, the concern may affect housing prices near NPPs.

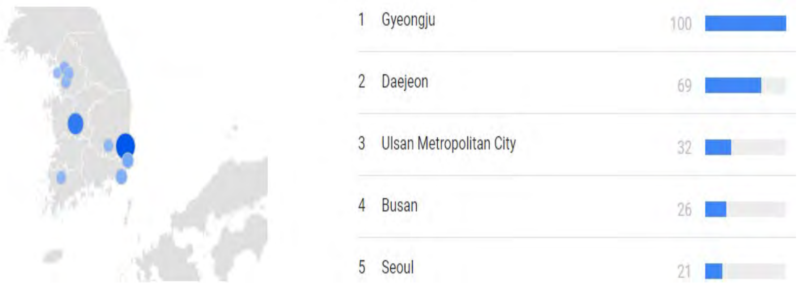

Figure 3.1: The Frequency of the Search Word "Nuclear Power" in Google Trends

Source: Google Trend (https://trends.google.com/)
Note: The scale is from 0 to 100, where 100 is the location with the most popularity as a fraction of total searches in that location (Google Trends). The thicker color indicates the higher value of popularity of the searched term. The southeastern area includes cities that are close to NPPs.

However, based on the result of Seo and Cho (2018), the shock of the Fukushima accident on housing prices in South Korea has a short-term effect. Actually, the result is not surprising because South Korea was a relatively safe country from the risk of earthquakes though an accumulation level of NPP is relatively high due to the small territory because there were no strong earthquakes before 2017[4]. However, after the earthquake on November 2017 in Pohang, people's perception of the risk of NPPs might be changed. The magnitude was 5.4, property damage was about 217 million dollars, and 135 people got injured. The damages of the earthquake are definitely smaller than the Fukushima accident, but I assume that people in South Korea may feel the shock of Pohang is stronger than the Fukushima accident because the Fukushima accident is an out-county shock but the earthquake of Pohang is an in-country shock. So, I choose the Fukushima accident and the earthquake of

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[3] Daejeon has a nuclear reactor for research purposes and otherwise for generating electricity.

[4] Actually, there was another earthquake in Kyungju city in 2016, but the damage is smaller (9 million dollars and 23 people got injured) than Pohang's case and occurred in short time interval before Pohang earthquake. Also, it might make people know that earthquakes can also happen in South Korea and think that no more safe from them. So, the Kyungju earthquake is not considered in this study (see Table B1 in Appendix).

Pohang as exogenous shocks with the assumption that the Fukushima accident just led people to remind the risk of NPPs and the earthquake of Pohang significantly affects housing prices near NPPs.

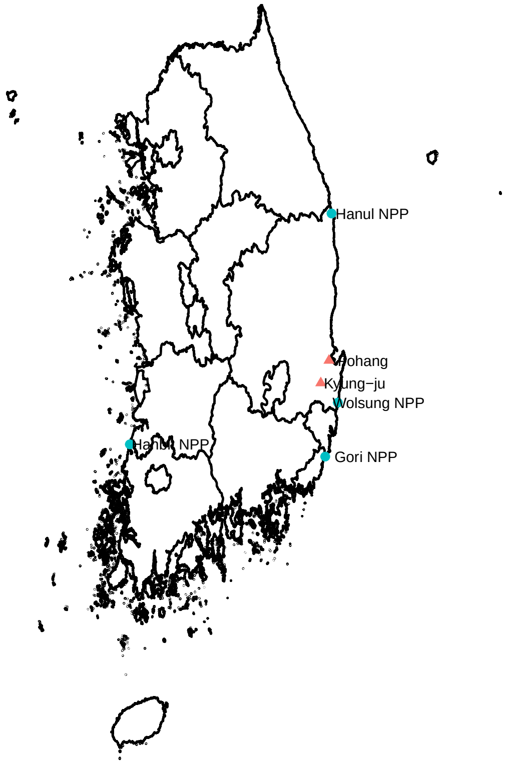

Figure 3.2: Location of NPPs and Earthquakes

There are four NPPs in South Korea[5]. However, this paper only focuses on housing prices near the Gori NPP. There are several reasons why I choose the NPP. First, since two metro-cities, Busan and Ulsan[6], are included within a 30km radius from those of the NPP, the number of transactions of the house is relatively larger than other cities near NPPs. Second, though the Gori NPP is relatively close to where the earthquake of Pohang (Figure 3.2 shows the location of each NPP and earthquake), there is no direct physical damage to houses by the earthquake. Third, there are

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[5] Gori, Wolsung, Hanul, and Hanbit NPPs.

[6] The population of Busan and Ulsan is 3.41 million and 1.14 million in 2019, respectively.

some issues with malfunctioning and extension of the operation. Also, since there was corruption related to supplying parts, it made people who live near the NPP concerned the safety. So, people are more likely to recognize the risk of the NPP and they may participate in the housing market with the perception (Seo and Cho, 2018).

3.3 Conceptual framework

The individual's willingness to pay (WTP) for certain housing and location characteristics can be estimated by using the Hedonic price method (Gamble and Downing (1982)). The main assumption is that the closer a house is to a NPP, the greater risk of the NPP, and natural disasters negatively affect the price of each house near NPPs. From this point of view, the potential risk of a NPP measured as the distance should be reflected in the housing price. A theoretical concept used in this paper is based on Tanaka and Zabel (2018). According to Tanaka and Zabel (2018), the WTP can be described by using a Von Nuemann-Morgenstern expected utility model with the hedonic price model because individuals reflect the concern of the potential risk in the housing market. The maximized expected utility can consist of an individual's subjective assessment of the risk probability of NPP based on the information before and after a disaster, house characteristics, distance from each house to NPP, and other goods. Therefore, housing prices could be increased or decreased depending on how people feel whether the disaster influences their subjective assessment temporarily or permanently.

This research is based on the concept of how distance from the Gori NPP varies the housing prices as it changes before&after the Fukushima accident and the Pohang earthquake. To do this, this paper applied difference-in-difference (DD). Normally, DD is used with panel data, but since repeating transaction records for a house in the short term is not common, house transaction data has a repeated cross-sectional structure in ordinary circumstances. So, measuring the DD estimator is possible by using the following equation:

$$DD = E(Y_{after} - Y_{before} \mid R = 1) - E(Y_{after} - Y_{before} \mid R = 0) \tag{3.1}$$

where Y is each housing price traded. $before$ and $after$ indicate the time point of the shocks. If the house is close to the nearest NPP, $R = 1$, which means a treated region (group), $R = 0$ otherwise, which means a control region (group).

There are many papers that used this framework, but no one explicitly mentioned what is the exact criteria to classify a treated group and a control group. Tanaka and Zabel (2018) set the groups by using non-parametric local linear regression of the variation of housing prices by distance to the nearest NPP before and after a shock. They found a certain point (4km) where the gap in housing prices between before and after the shock is getting larger. On the other hand, Seo and Cho (2018) divided the groups by sample size. They said the number of samples is getting larger at a certain distance point (20km). However, the classification standards have some limitations. First, those are not based on objective standards. Second, the area adjacent to a NPP may have significantly different characteristics from another. This violates the assumption that the two groups are similar. Third, they used repeated cross-sectional data. Since the cross-sectional variation in housing prices can be attributed to various other factors (Tanaka and Zabel, 2018), it is hard to handle unobserved heterogeneity.

Figure 3.3 shows the relationship between distance from the Gori NPP and housing prices per square meter for 1 year before and after each shock. The two groups are distinguished at the threshold point (18km or 19km). However, it is difficult to say that the two groups are homogeneous because the price cannot be explained by only the distance from the NPP (see Figure 3.3)[7]. For this reason, I only consider the area above 18km from the Gori NPP and apply the International Atomic Energy Agency (IAEA) zone criteria to divide the treatment and control groups.

According to the IAEA, they have a safety standard about the distance from NPP. They set two zones, one the Precautionary Action Zone (PAZ) and another the Urgent Protective Action Planning Zone (UPZ). The former is a 5km radius area, the latter is from 5 to 30km from NPP. Though the recommended size of the UPZ is based on experts' decisions made in consideration of the IAEA's threat categories (IAEA, 2007), it can be varied depending on regional characteristics such as population, and distribution of buildings. Based on the standard, there is a possibility that the zones affect an individual's choice to buy a house and its price.

The PAZ of the Gori NPP is from 3km to 5km. However, since the UPZ differs depending on administrative districts since Busan and Ulsan share the UPZ (Figure

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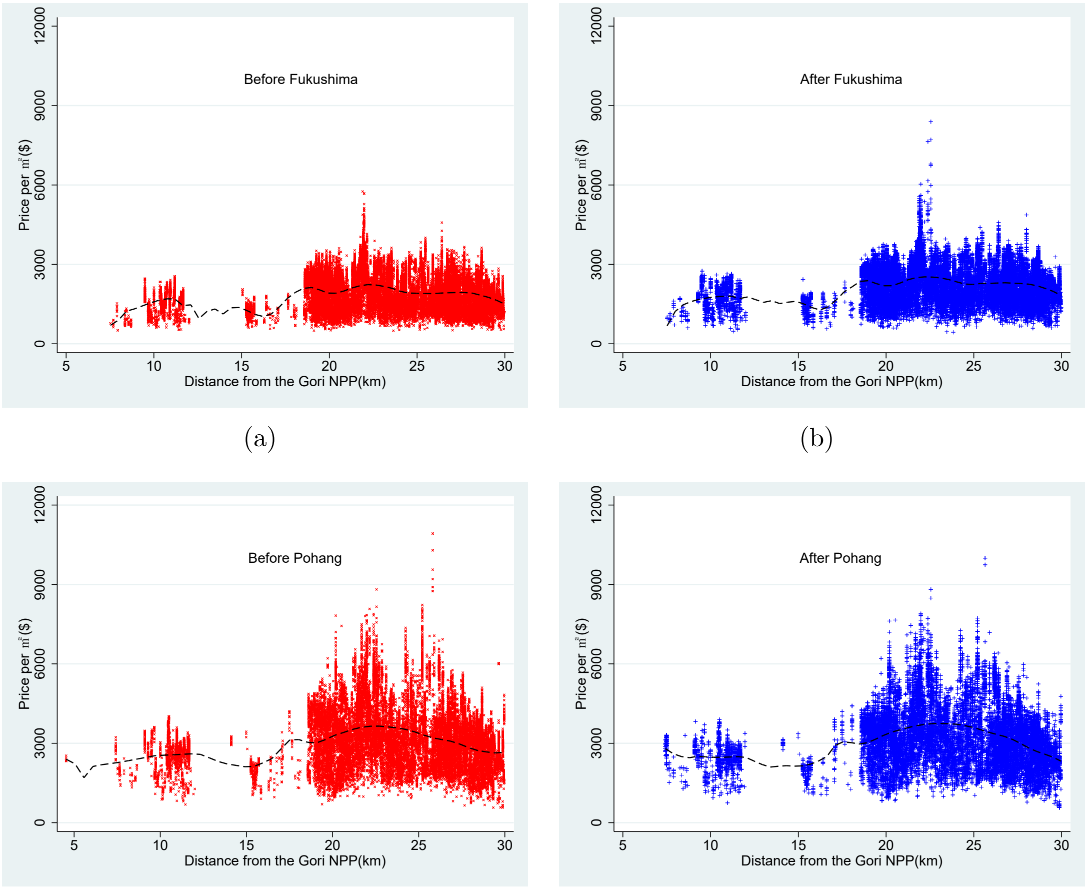
[7] Normally, housing prices tend to decrease when the house is closer to NPP due to the potential risks and a low population rate. However, the price of the area within 13km (close to NPP) is higher than the area between 13km to 18km. It is not surprising when we consider a NPP can increase the population rate by offering jobs to people. A high population rate entails business districts or amenities near the NPP even though it has a potential risk. So, the higher housing prices in the area near NPP can be explained by what the NPP can offer to local communities.



(a) (b)

(c) (d)

Figure 3.3: The Average Housing Prices over Distance from the Gori NPP before&after each shock

Note: Each panel includes a sample in 1 year before&after each shock

(a)

(b)

Figure 3.4: (a) The Emergency Planning Zone (PAZ + UPZ) of Gori NPP (b) The Location of House Transactions

Source: Busan Metropolitan City (https://www.busan.go.kr/safety/ahprevention02)

3.4, Panel (a)), this study only considers Busan[8]. The panel (b) in Figure 3.4 shows the locations of traded houses and the radius representing PAZ and UPZ of the Gori NPP[9]. Comparing panels (a) and (b) in Figure 3.4, the number of transactions varies depending on the zones and distance from the Gori NPP. Therefore, I classify the area from 18km to 21km from the Gori NPP as a treated group, and from 21km to 30km as a control group.

Showing the parallel trend between a treatment group and a control group is essential for DD. Before that, I modified the house transaction data. As I mentioned above, the house transactions data is hard to catch the time-varying value of each house. Hence, the data does not have a panel data structure because repeated transactions for a house are not common in the short term. Fortunately, in South Korea, apartment account for a high proportion of housing transactions, and in Busan, there are many apartment transactions due to the characteristics of a metropolitan city. Though the prices of apartments can vary depending on their floor or scale, many transactions happen in the same apartment complex. Therefore, I obtained panel data through the prices averaging by each apartment complex. Figure 3.5 illustrates the variation of the house prices over 1 year before for each shock with a 95% confidence interval,

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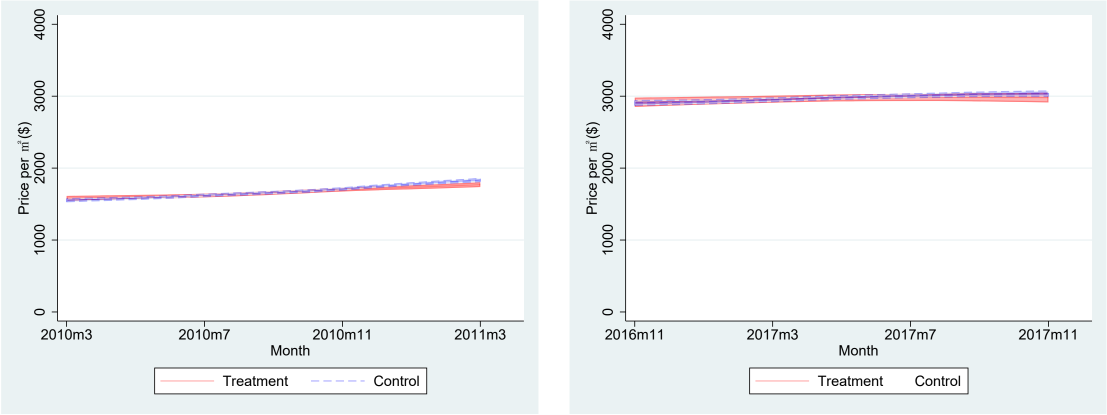
[8] Busan sets the UPZ from 5km to 20 or 21km from the Gori NPP and Ulsan sets it from 5km to 22 or 24km.

[9] The southwest area from the Gori NPP is Busan.



(a)

(b)

Figure 3.5: The Variation of Averaged Housing Prices (per m^2) over Time before (a) the Fukushima Accident, (b) the Pohang Earthquake

respectively. In the figure, the treated group and the control group have similar trends before the shocks. This graphical evidence supports the parallel trend between treated and control groups which is a key identification assumption for the difference-in-differences model.

3.4 Data

This paper uses house transaction data from the "Real-Time House Transaction System" of the Ministry of Land, Infrastructure, and Transport (MOLIT). It provides daily cross-sectional data, but I used monthly-based data to reduce standard error. The time period is from March 2010 to March 2012 for the Fukushima accident and from November 2016 to November 2018 for the Pohang earthquake which includes 1 year before and after each shock. The data provides three types of houses (apartment, townhouse/multi-unit house, detached house/multi-household house), but as I mentioned in the previous sections, this paper only focused on apartment transaction data for some reasons. First, most Koreans generally prefer apartments to other types of houses due to the price stability. Second, apartments have relatively simple house characteristics compared to normal houses. Third, panel structure data can be made by each apartment complex level.

Table 3.1: Summary of Statistics

Variable	Fukushima Accident				Pohang Earthquake			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Panel A. House Characteristics								
Size (m^2)	78.08	24.35	18.09	244.69	74.76	26.13	14.86	250.89
Price (per m^2)	1844.14	618.59	438.18	5896.18	2991.58	1041.50	570.77	7845.90
Floor	8.49	5.44	0	49	9.50	6.37	-1	62
Building Age	14.65	8.71	0	49	18.29	10.89	0	56
Scale	2.95	.80	1	5	2.81	.85	1	5
Panel B. Distance Characteristics (Unit: m)								
Gori NPP	24.12	3.23	18.06	29.99	24.28	3.25	18.06	29.97
CBD	1.93	1.17	.08	6.92	1.94	1.18	.06	6.92
CSC	.43	.25	0	1.87	.43	.25	0	1.87
Court	5.07	2.57	.17	11.26	5.10	2.51	.17	11.26
Library	3.00	1.74	.05	7.87	3.02	1.76	.05	7.97
PHO	1.47	.77	.03	4.84	1.46	.77	.03	4.84
Fire Station	.91	.45	.03	2.74	.90	.44	.02	2.73
Post Office	.43	.24	0	1.78	.43	.24	0	1.78
High-School	.71	.38	.02	2.45	.72	.38	.02	2.45
Mid-School	.53	.27	.01	1.65	.53	.27	.01	1.65
Ele-School	.35	.16	.04	1.38	.35	.16	.46	1.38
Observation	20,150				18,425			
Before	10,389				10,217			
After	9,761				8,208			

Note: Following a classification of house size from Statistics Korea, I made a scale dummy (scale 1:∼ $40m^2$, scale 2: 40∼$60m^2$, scale 3: 60∼$85m^2$, scale 4: 85∼$135m^2$, scale 5: $135m^2$ ∼)

Table 3.2: Number of Transactions

	Before Fukushima		After Fukushima		Before Pohang		After Pohang	
Month	Treated (1)	Control (2)	Treated (3)	Control (4)	Treated (5)	Control (6)	Treated (7)	Control (8)
0	241	708	241	708	153	565	153	565
1	211	687	237	700	143	536	159	466
2	222	684	182	619	173	576	152	539
3	240	648	189	572	176	596	147	529
4	228	701	162	548	216	651	164	616
5	217	739	165	541	199	732	123	488
6	184	628	177	577	211	740	127	485
7	164	578	188	588	192	710	112	459
8	187	584	184	575	204	764	122	432
9	185	601	161	506	190	678	128	443
10	183	633	131	379	160	579	127	462
11	218	696	187	494	176	651	146	497
12	230	741	172	578	217	752	128	436
Total	2,710	8,628	2,376	7,385	2,410	8,530	1,788	6,417

Table 3.1 shows a summary of statistics. The data includes the date of transaction, size (m^2), floor, price, building age, and address. To measure the distance from the NPP to each house, I used coordinates by using the address of each house. There are two limits to the data. One is that the average prices by apartment complex level cannot explain extreme cases such as unfair sales or penthouses. To handle this, I removed the bottom and top 1 percent of sale prices for each year to further guard against the outliers (Tanaka and Zabel, 2018) and divided prices by size to get the house prices per square meter. Another is there are not many house characteristics. To consider amenity characteristics, the distances from each house to the nearest central business district (CBD), community service center (CSC), court, library, public health office (PHO), fire station, post office, and schools are combined in the data. Also, I followed a classification of house size from Statistics Korea to reduce the bias from the price by size.

Table 3.2 shows the number of transactions 1 year before and after the shocks by month. There is a decreasing pattern after both shocks. However, the number of transactions after the Pohang earthquake is much smaller than the Fukushima accident. It can be possible if the supply of houses is decreased. Measuring the supply of houses is impossible but the traded house in a certain year which is constructed

Table 3.3: The number of Transaction of New House in Traded Year

	Before Fukushima		After Fukushima		Before Pohang		After Pohang	
Building Age	Treated (1)	Control (2)	Treated (3)	Control (4)	Treated (5)	Control (6)	Treated (7)	Control (8)
0	19	48	13	63	53	59	229	172
1	25	47	37	109	22	65	200	174
Total	44	95	50	172	75	124	429	346

Note: The number of transactions was occurred during 1 year before and after each shock

in that year could represent some portion of the housing supply. Table 3.3 shows the number of transactions of houses which are constructed and traded in the same year during the analysis period and it shows that there is no shortage of new house supply after the Pohang earthquake compared to the Fukushima accident.

3.5 Regression method

The distance range of the treatment group is from 18km to 21km and the control group is from 21km to 30km. I apply a 500m zone buffer to control the heterogeneity of the groups in a narrow distance range. After applying the buffer zone, the treatment group is from 18km to 20.5km and the control group is from 21.5km to 30km. For estimating the impact of each shock, the samples of 1 year before and after each shock are used[10]. The hedonic model is specified as the following equation:

$$ln(p_{idt}) = \beta_0 + \beta_1 Post_t + \beta_2 Treat_d + \beta_3(Post_t \times Treat_d) + \gamma X_{idt} + \lambda_t + \eta_i + \varepsilon_{idt} \quad (3.2)$$

where $ln(p_{idt})$ is a dependent variable, the natural log of the average housing price of an apartment complex i, region d, at time t. $Post_t$ is a dummy variable for each shock. If the house is sold after the shocks $Post_t = 1$, otherwise $Post_t = 0$, and if the house is located in the treated group $Treat_d = 1$, otherwise $Treat_d = 0$. The interesting variable is the interaction term which is $Post_t \times Treat_d$. This term captures the impact of the shocks on the house price depending on the location. If the house located in the treated zone is sold after the shock, $Post_t \times Treat_d = 1$, otherwise $Post_t \times Treat_d = 0$.

X_{ijt} includes house characteristics which are size(m^2), building age, its square, floor,

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[10] For the Fukushima accident the time period of the sample is from March 2010 to March 2012, and for the Pohang earthquake, is from November 2016 to November 2018, respectively

Table 3.4: Testing for Parallel Trend

Dependent Variable (Log Price)	Fukushima Accident (1)	Pohang Earthquake (2)
Month	.015***	.005***
	(.001)	(.001)
Treated Area	.010	-.001*
	(.015)	(.018)
Treated*Month	-.002	-.001
	(.002)	(.002)
Observations	10,389	10,217
R2	.027	.002

and distance from amenities. To capture time trends, seasonality, and policy changes in the region, the model controls time-fixed effects (year, season, month), λ_t. To control time-invariant heterogeneity, the model includes city and village-level fixed effects, η_t, which are considered. The error term, ε_{idt}, is clustered for considering the effect of apartment complexes.

I graphically showed the parallel pre-trend between the treatment and the control groups in Section 3. Before detailed analysis, testing the parallel pre-trend is needed by using the regression method. For the test, only 1-year samples before each shock are used without any explanatory variables, fixed effects, or clustering method. I regress $ln(p_{idt})$ only on $Post_t$(each month), $Treat_d$ and $Post_t \times Treat_d$. If the interaction term is insignificant, the null hypothesis of parallel trends is not rejected. The result of the test shows that the pre-trend between the treatment and the control groups is parallel (see Table 3.5, B.2 and Figure B.1).

After regressing the baseline area (with/without the zone buffer) classification, I will show another result by changing the range of the control area to check whether the baseline result is robust. To do this, I will use two distance ranges, one from 21km to 23km and another from 21km to 24km for the control group.

The potential problem is whether the shock affects the number of house transactions or not since when house prices decreased. Sellers normally tend to keep their house until the price is increased to the previous level of price at least and buyers might hesitate to buy a house near NPPs due to the risk or expect the price will be decreased, so these behaviors may bring sample selection issue to the result of this study. To handle this issue, I will also use the logarithmic number of house transaction as the dependent variable instead of the logarithmic house prices and see whether house transaction is random or not.

3.6 Result

This study is based on the assumption that the housing price near the Gori NPP is more affected by the Pohang earthquake than by the Fukushima accident. Tables 3.5 and 3.6 make the assumption more robust. Tables 3.5 and 3.6 show the result of the Fukushima accident and the Pohang earthquake, respectively. All results are clustered by apartment complex level. The interaction terms (DD estimator) show different results for each shock. The DD estimators for the Fukushima accident (see Table 3.5) show that there is a small decrease in the housing price in the treatment area but statistically insignificant. Also, there is no difference between the baseline estimator without the buffer zone (column 4 in Table 3.5) and with the buffer zone (column 8 in Table 3.5). Though there is a big difference (0.067 ∼ 0.215) among the coefficients on the "post" dummy (with/without covariates), those are positive and statistically significant which suggests that the Fukushima accident does not affect the housing market within 30km from the Gori NPP.

On the other hand, the Pohang earthquake negatively affects housing prices. The baseline estimator (column 4 in Table 3.6) suggests that the Pohang earthquake resulted in a 2.1% decrease in the housing price near the Gori NPP. With the buffer zone (column 8 in Table 3.6), the housing price decreases by 2.7% which is not much different from the baseline estimator. This result suggests that the people who live near NPPs only reacted to the Pohang earthquake and the impact of the Fukushima accident was ignored, unlike previous literature which found negative impacts on the housing market.

The potential problem with the result is that the difference in sample size between the treatment (18km ∼ 21km) and control groups (21km ∼ 30km) can lead to incorrect estimates. To confirm the sensitivity of the baseline result, I use the different ranges of control areas with and without the buffer zone. Table 3.7 shows the estimators with the different control groups for each shock. First, I choose the sample from the range of 2km (21km ∼ 23km), then use the range of 3km (21km ∼ 24km) as the control group[11]. The estimates are quite similar to the baseline result. The DD estimators for the Fukushima shock are positive and statistically insignificant which means there is no impact of the shock on the housing price. Meanwhile, for the Pohang earthquake, the DD estimators for the control group without the buffer zone are -0.025 for both criteria (columns 5 and 7 in Table 3.7). Comparing the

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[11] Since there is a small sample from 18km to 19km, I assume that using the sample from the range of 2km (21km ∼ 23km) at first is reasonable. However, to make the same distance areas, I also use the range of 3km (18km ∼ 21km)

Table 3.5: The Effect of Fukushima Accident on House Price

Dependent Variable	Fukushima Accident							
(Log Price)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Treated	-.005	-.007	-.006	-.007	-.013	-.014*	-.007	-.008
	(.008)	(.008)	(.007)	(.006)	(.009)	(.008)	(.007)	(.007)
Post	.215***	.211***	.068***	.070***	.216***	.211***	.067***	.069***
	(.004)	(.004)	(.004)	(.005)	(.004)	(.004)	(.005)	(.005)
Treated	-.007	-.220***	.004	-.112***	-.000***	-.446***	.010	-.153**
	(.021)	(.063)	(.015)	(.034)	(.024)	(.164)	(.017)	(.073)
Covariates	x	x	o	o	x	x	o	o
Fixed Effect	x	o	x	o	x	o	x	o
Cluster	o	o	o	o	o	o	o	o
Buffer (500m)	x	x	x	x	o	o	o	o
Observations	20,150	20,150	20,150	20,150	18,209	18,209	18,209	18,209
R^2	.100	.286	.489	.609	.098	.308	.495	.619

Note: The covariates include house size (m^2), floor, building age and its square, the distances from each house to the nearest central business district, community service center, court, library, public health office, fire station, post office, and schools. Also, to control time trends and time-invariant heterogeneity, I include third-order time variables and county and town fixed effects. *, **, *** are representing 10%, 5%, 1% significant level, respectively. Standard errors are in parentheses.

Table 3.6: The Effect of Pohang Earthquake on House Price

Dependent Variable	Pohang Earthquake							
(Log Price)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Treated	.001	-.012	-.004	-.021***	.009	-.008	-.009	-.027***
	(.012)	(.011)	(.009)	(.008)	(.013)	(.013)	(.010)	(.009)
Post	.020***	.021***	-.009	-.009	.020***	.021***	-.007	-.008
	(.005)	(.004)	(.006)	(.005)	(.005)	(.005)	(.006)	(.006)
Treated	-.012	-.219***	.016	-.101***	-.020	-.545***	.014	-.265***
	(.023)	(.060)	(.019)	(.039)	(.027)	(.130)	(.022)	(.009)
Control	x	x	o	o	x	x	o	o
Fixed Effect	x	o	x	o	x	o	x	o
Cluster	o	o	o	o	o	o	o	o
Buffer (500m)	x	x	x	x	o	o	o	o
Observations	18,425	18,425	18,425	18,425	16,676	16,676	16,676	16,676
R^2	.001	.274	.372	.574	.001	.298	.381	.586

Note: The covariates include house size (m^2), floor, building age and its square, the distances from each house to the nearest central business district, community service center, court, library, public health office, fire station, post office, and schools. Also, to control time trends and time-invariant heterogeneity, I include third-order time variables and county and town fixed effects. *, **, *** are representing 10%, 5%, 1% significant level, respectively. Standard errors are in parentheses.

Table 3.7: The Sensitivity Test for the Control Area

Dependent Variable	Fukushima				Pohang			
(Log Price)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Control Area	21km ∼ 23km		21km ∼ 24km		21km ∼ 23km		21km ∼ 24km	
Post*Treated	.014	.018	.008	.010	-.025**	-.034***	-.025**	-.033***
	(.010)	(.011)	(.008)	(.009)	(.010)	(.012)	(.009)	(.010)
Post	.051***	.045***	.056***	.053***	-.010	-.003	-.009	-.004
	(.010)	(.011)	(.008)	(.008)	(.010)	(.012)	(.009)	(.009)
Treated	-.108***	-.192***	-.115**	-.188***	-.084**	-.257***	-.097**	-.281***
	(.035)	(.063)	(.033)	(.060)	(.039)	(.091)	(.038)	(.085)
Covariates	o	o	o	o	o	o	o	o
Fixed Effect	o	o	o	o	o	o	o	o
Cluster	o	o	o	o	o	o	o	o
Buffer (500m)	x	o	x	o	x	o	x	o
Observations	8,100	6,159	10,077	8,136	7,321	5,572	8,895	7,146
R^2	.666	.697	.640	.659	.611	.653	.579	.605

Note: The covariates include house size (m^2), floor, building age and its square, the distances from each house to the nearest central business district, community service center, court, library, public health office, fire station, post office, and schools. Also, to control time trends and time-invariant heterogeneity, I include third-order time variables and county and town fixed effects. *, **, *** are representing 10%, 5%, 1% significant level, respectively. Standard errors are in parentheses.

baseline DD estimator, -0.021, the result does not vary with the size of the control group. With the buffer zone, the coefficients decrease to -0.034 (column 6 in Table 3.7) and to -0.033 (column 8 in Table 3.7), respectively. From the sensitivity test for the control group, the baseline result is fairly stable with sample size.

Table 3.8 shows the time-varying treatment effect of the shocks. I apply the interaction terms including month dummies, $Treat_{ij} \times M$ ($M = 0$: the month before the shocks.), for 1 year after the shocks. Though the coefficients with the baseline model for the Fukushima accident (column 1) are negative and statistically significant first two months, the values of others do not have consistency and are not statistically significant. However, with applying the alternative model with the adjusted control group (column 2), the time-varying effect is much more noticeable. The coefficients are positive except for the first month when the Fukushima accident occurred. On the other hand, the time-varying effect of the Pohang earthquake is not clear for both the baseline model (column 3) and the alternative model (column 4), but the coefficients have negative values for all months after the shock and some of them are statistically significant[12]. However, concluding that the Fukushima accident affects the housing price for only a short period (a month or two months) may be ambiguous because there is a possibility that the effect of the shocks has a time lag due to the

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[12] There is a possibility that government policy may affect housing price since Korean government implemented a real-estate policy to regulate increasing housing prices in Sep 2018. I will address this concern in the Appendices section

Table 3.8: The Effect of Both Shocks on Housing Price by Month

Dependent Variable (Log Price)		Fukushima Accident		Pohang Earthquake	
		(1)	(2)	(3)	(4)
Control Group		21km ∼30km Baseline	21km ∼23km	21km ∼30km Baseline	21km ∼23km
Treated*Month (Shock)	1	-.050***	-.025*	-.022	-.023
		(.010)	(.014)	(.015)	(.016)
	2	-.019*	.007	-.020	-.024
		(.011)	(.013)	(.015)	(.017)
	3	.009	.033**	-.009	-.013
		(.012)	(.014)	(.015)	(.016)
	4	.003	.029**	-.011	-.014
		(.011)	(.014)	(.016)	(.017)
	5	-.009	.016	-.021	-.025
		(.016)	(.018)	(.015)	(.017)
	6	.008	.034**	-.012	-.021
		(.012)	(.014)	(.018)	(.019)
	7	.008	.030**	-.041**	-.048**
		(.011)	(.014)	(.018)	(.019)
	8	-.011	.007	-.016	-.017
		(.013)	(.015)	(.018)	(.020)
	9	.012	.032**	-.040**	-.039*
		(.013)	(.015)	(.020)	(.021)
	10	-.002	.015	-.008	-.013
		(.013)	(.016)	(.017)	(.018)
	11	.000**	.020	-.019	-.024
		(.015)	(.017)	(.016)	(.018)
	12	-.014	-.001*	-.012	-.012
		(.013)	(.016)	(.016)	(.019)
	13	-.004	.005	-.055***	-.056***
		(.013)	(.017)	(.017)	(.020)
Post		.072***	.053***	-.011*	-.014
		(.005)	(.011)	(.005)	(.011)
Treated		-.112***	-.108***	-.100***	-.084**
		(.034)	(.035)	(.039)	(.039)
Covariates		o	o	o	o
Fixed Effect		o	o	o	o
Cluster		o	o	o	o
Observations		20,150	8,100	18,425	7,321
R^2		.608	.666	.575	.612

Note: The covariates include house size (m^2), floor, building age and its square, the distances from each house to the nearest central business district, community service center, court, library, public health office, fire station, post office, and schools. Also, to control time trends and time-invariant heterogeneity, I include third-order time variables and county and town fixed effects. *, **, *** are representing 10%, 5%, 1% significant level, respectively. Standard errors are in parentheses.

characteristics of the housing market for sale[13]. Meanwhile, the Pohang earthquake may have a long-term effect even though the coefficients are statistically insignificant for the first few months.

To confirm whether the house transactions are affected by the shocks, I use a simple

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[13] House rent market may react to the shocks quickly (Seo and Cho, 2018).

regression model. I replace the housing price with the number of transactions for the dependent variable (logarithmic) and only include $Post_t$, $Treat_d$, and $Post_t \times Treat_d$. Table 3.9 shows the effect of each shock on the number of transactions. Based on the result, the house transaction near the Gori NPP is not affected by both shocks. Though the DD estimator of the baseline model with the buffer zone for the Fukushima accident is statistically significant, but the magnitude is negligible. So, the shocks do not bring sample selection bias from people who might hesitate to buy a house. This result suggests that the house transactions are not a non-random sample and the effect of the Fukushima accident and the Pohang earthquake on the housing market can be explained better in the housing price model than house transaction model[14].

Table 3.9: The Effect of Pohang Earthquake on House Transaction

Dependent Variable	Fukushima				Pohang			
(Ln Trade)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Control Area	21km ∼30km		21km ∼23km		21km ∼30km		21km ∼23km	
Post*Treated	-.036	.000***	-.170	-.114	.023	.123	.068	.179
	(.137)	(.144)	(.139)	(.145)	(.131)	(.138)	(.137)	(.145)
Post	-.148	-.199	-.028	-.084	-.062	-.102	-.122	-.190
	(.133)	(.140)	(.144)	(.146)	(.126)	(.133)	(.143)	(.144)
Treated	-1.145***	-1.383***	.498***	.450***	-1.332***	-1.602***	.153	.073
	(.098)	(.105)	(.107)	(.113)	(.110)	(.117)	(.113)	(.121)
Cluster	o	o	o	o	o	o	o	o
Buffer (500m)	x	o	x	o	x	o	x	o
Observations	50	50	50	50	50	50	50	50
R^2	.888	.905	.667	.642	.917	.927	.634	.562

Note: For transaction analysis, I only include third-order time variables. *, **, *** are representing 10%, 5%, 1% significant level, respectively. Standard errors are in parentheses.

3.7 Conclusion

This study implies that exogenous shock increases the potential risk that people feel about NPPs and it can be valued by decreasing housing prices. To see the risk value, this paper focuses on estimating the effect of the Pohang earthquake (in-country shock) on housing prices by comparing the effect of the Fukushima accident (out-country shock). The IAEA zone criteria are used for the geographical threshold to divide the area into the treatment group and the control group with and without the distance buffer of 500m. The baseline model uses 21km from the NPP as a geographical threshold without the zone buffer.

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[14] There is a possibility that housing rent may affect the supply of house since sellers tend to keep their house and lend it to tenants due to decreasing housing price. I will address this concern in the Appendices section.

Unlike previous literature such as Tanaka and Zabel (2018) and Seo and Cho (2018), this study shows the different aspects of the Fukushima accident. The baseline result supports that the Fukushima accident does not affect the average housing price near the Gori NPP, while the Pohang earthquake decreases the housing price by 2.1% and it shows a long-term effect. Though the buffer zone is applied, the result is stable (2.7%). The implication of this study is that people are more likely sensitive to in-country shocks than out-country even though the latter is tremendously strong. So, the learning effect of exogenous shocks does not work with the Fukushima accident but does with the Pohang earthquake. This finding means that the people who live near the NPP well perceived the risk of the NPP after the Pohang earthquake, but not for the Fukushima accident. Therefore, I conclude that the risk value of Gori NPP might be not fully reflected in the housing market before the Pohang earthquake and the negative long-term effect of the Pohang earthquake can be explained by the re-estimating process of the value of NPP.

Chapter 4

Does Diesel Vehicle Regulation Improve Air Quality?: Low Emission Zone from Seoul, South Korea

Abstract

Air pollution has been one of the serious social problems in South Korea, and the increasing number of diesel vehicles has been identified as one of the reasons. In order to improve air quality and reduce the emission of air pollutants, the Seoul metropolitan government introduced the low emission zone (LEZ) in January 2017. This policy was designed to restrict the number of old diesel vehicles driving in Seoul. The main objective of this study is to identify the effect of the LEZ. To conduct the analysis, the study employs daily emissions of air pollutants and weather data sets. Using the method of regression discontinuity, the study compares the concentration of air pollutants before and after the implementation of the LEZ. The result shows that the policy is effective in reducing the concentration of NO_2, SO_2, and PM_{10}.

4.1 Introduction

Seoul, the capital of South Korea (hereafter Korea), has rapidly developed since the 1980s, with a primary focus on the economy and less emphasis on environmental issues. Coal and diesel fuel were the main sources of heating and transportation, resulting in air pollution that has the potential to harm people's health. However, we can tell the present air quality of Seoul is much better than in the 1980s due to the advanced technology which reduces emissions from a tailpipe of cars, smokestacks of factories, and individual households. Despite this improvement, air pollution remains an ongoing problem in not only Seoul but also in Korea as a whole. In an effort to reduce pollutants, the Seoul metropolitan government enacted the SPECIAL ACT ON THE IMPROVEMENT OF AIR QUALITY IN SEOUL METROPOLITAN AREA in 2003, and the Korean Ministry of Environment (KME) established the Basic Plan on the Improvement of Air Quality in Seoul Metropolitan Area (BPIAM) every 10 years since 2005. However, the level of particulate matter (PM) has frequently stagnated, and high-PM-level days have increased since 2012 (Seoul, 2019). To address this issue, the Special Plan on The Improvement of Air Quality in Seoul was established in 2016. This plan includes various programs, such as reducing the number of old diesel vehicles, supporting electric vehicle infrastructure, controlling dust scattering on construction sites and roads, and managing the demands of transportation.

The low emission zone (LEZ) is a policy aimed at restricting the driving of vehicles that do not meet specific conditions in the zone. This policy is intended to improve air quality by reducing pollutants emitted from vehicles. London's LEZ, implemented in 2008, is the largest in the world, and various studies have been conducted on its effectiveness. Ellison et al. (2013) assessed the effect of the LEZ by using vehicle registrations and enforcement data. They found that the LEZ not only reduced PM concentration by $2.46 \sim 3.07\%$ but also decreased pre-Euro III rigid and light commercial vehicles by 20% and 10%, respectively. Zhai and Wolff (2021) found that PM_{10} was reduced by 14.8% in the short term and 5.5% in the long term. Meanwhile, Qadir et al. (2013) studied the LEZ in Munich, Germany, and found that it reduced pollutants from traffic sources by 60%. Wolff (2014) identified that it reduces PM emissions by 9% in Germany. Da Silva et al. (2014) also found Lisbon's LEZ reduced PM and Nitrogen dioxide (NO_2) concentration by 16% and 6%, respectively.

Seoul's LEZ started on January 1, 2017. It focuses on restricting driving old diesel vehicles with emission grades of 5 or higher in the zone to reduce pollutants from it such as particulate matter (PM), and oxides of nitrogen (NO_x). However, it is a controversial policy because the air quality in Seoul can be significantly affected by the air quality of China due to meteorological seasonality even though many countries in the EU have implemented the policy and shown the positive effect we mentioned above.[1]

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[1] According to the "Joint Research Project for Long–range Transboundary Air Pollutants in

The purpose of this study is to identify the effect of Seoul's LEZ on air quality and to uncover the underlying mechanism. There is some literature related to the impacts of traffic regulation policies including the LEZ policy. Davis (2008) analyzed the effect of the alternate no-driving policy in Mexico City with ordinary least squares (OLS) and Regression discontinuity in Time (RDiT), but found no evidence of improving air quality. Percoco (2015) showed the limited effect of congestion traffic fees in London LEZ with RDiT, and Li et al. (2020) demonstrated the effect of fuel standard changes in China with both Difference-in-Differences (DD) and RDiT methods. On the other hand, Wolff (2014) showed the effect of LEZ in Germany with DD. Although most of the previous studies about LEZ policy used DD, finding a control group comparable with Seoul for DD analysis is almost impossible in Korea, considering the population density, the transportation system, and the size. For this reason, RDiT is used as an analysis tool, and this study basically follows Hausman and Rapson (2018), but it is more similar to Li et al. (2020).

I set the average daily frequency data from hourly based air pollution and weather data. For air pollution data, the five pollutants (PM_{10}, CO, NO_2, SO_2 and O_3) from 40 observation stations in Seoul city are used. For weather data, I used temperature, rainfall, and wind pattern information from 27 observation stations. However, since the locations of the stations are not identical, I use Inverse-Distance-Weighted (IDW) interpolation method to reduce measurement bias and interpolate the weather data based on each air pollution station by using the observations from the three nearest air pollution observation stations.

The baseline result shows that Seoul's LEZ reduces NO_2 by 4.7% and SO_2 by 11.7%. To examine the time heterogeneity, I divided the data into four time intervals: daytime (9 a.m. $\sim$ 6 p.m.), nighttime (8 p.m. $\sim$ 7 a.m.), morning rush hour (7 a.m. $\sim$ 9 a.m.) and evening rush hour (6 p.m. $\sim$ 8 p.m.). The results show that PM_{10} decreased by 14.6% during the daytime, and we found that the LEZ had a stronger impact during the traffic-intensive time interval. Although I did not conduct further empirical analyses related to traffic and vehicle registration, indirect evidence supports the effectiveness of Seoul's LEZ policy, as it not only reduces traffic and diesel vehicle purchases but also increases the number of diesel vehicles that are scrapped.

This paper consists of the following contents. Section 2 illustrates the background of pollutants from diesel vehicles and LEZ policy. Section 3 describes the data used and section 4 introduces an empirical strategy. The result is included in section 5 and we discuss the significance and limitations of the study in section 6.

Northeast Asia", the contribution of China's $PM_{2.5}$ to major cities in Korea are 32.1%.

4.2 Background

Diesel engine systems are used in various sectors such as transportation, power plant, and construction site. Although the improvement of diesel engine technology has reduced the pollutants from diesel vehicles, the risk of the pollutants from diesel emissions remains a concern worldwide. Emissions from diesel vehicle include exhaust smoke, PM, NOx, unburned hydrocarbon (HC), CO and SO_2 (Tan et al., 2013). Furthermore, diesel engine systems produce lower emissions of CO_2, HC, CO, but higher emissions of PM, NOx (Kozina et al., 2020). Research on the risk of pollutants on human health has been conducted in various fields. According to the report from the International Agency for Research on Cancer (IARC) in 2012, there is a positive relationship between the pollutants from diesel exhaust and cancer. Also, diesel exhaust causes irritation of the eyes and nose, headaches, nausea, and respiratory illnesses including lung cancer (U.S. Department of Labor, 2013). Especially, the U.S. Environmental Protection Agency (EPA) notifies that NOx reacts with other chemicals in the air to form both PM and ozone (O_3) which affects the risk of respiratory and cardiovascular diseases such as heart attack, and asthma. To reduce diesel pollutants, many countries have established the diesel emission standard, South Korea has mainly followed the European emission standards (EURO). In doing so, the manufacturers cannot sell vehicles that exceed the emission standard of 0.46g/kWh for NO_x and 0.01g/kWh for PM since 2015. However, there are many diesel vehicles manufactured before 2015 in Seoul, and emissions from the old diesel vehicles have been managed as one of the critical pollutants.

The LEZ policy is one of the effective ways to improve air quality in Seoul, and it started in Jan 2017. The policy restricts the driving of old diesel vehicles in the designated zone. Old diesel vehicles are cars that have a 5th or higher emission grade, were manufactured before 2006, do not have a Diesel Particulate Filter (DPF), or have not passed vehicle inspection.[2] Violators are charged a penalty of approximately \$200. Seoul city has implemented supporting policies for diesel vehicle owners, such as providing subsidies to replace their cars (maximum \$3,000) or to install a DPF in their own cars (maximum 90% of the installation cost). Figure 4.1 shows a map of Seoul and the locations of LEZ enforcement cameras by year. Before 2017, only 12 cameras were installed, but after 2017, the total number of cameras increases to 34 in 2017, 43 in 2018, 67 in 2019, and 100 in 2020, respectively. The increase in cameras suggests that the LEZ policy is becoming more stringent than other traffic

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[2] There are various types of diesel vehicles in Korea (varied by vehicle's engine capacity), but they are typically categorized into two types: light duty diesel (for passenger) and heavy-duty diesel (for commercial).

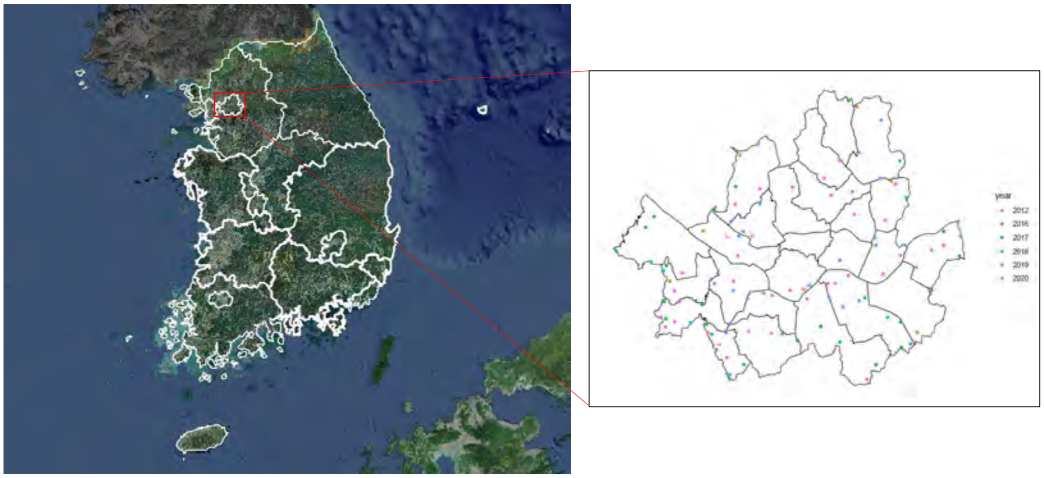

Figure 4.1: The Map of Seoul and the Locations of Enforcement Cameras

Note: The year indicates when the cameras are installed.

regulation policies implemented before 2017 in Seoul.

The details may differ by country, but the LEZs have shown positive effects on air quality in many European countries.[3] For example, London's LEZ reduced PM_{10} by 1.9% and NOx by 2.4%. Berlin reduced 58% of diesel particles, and NOx decreased by 20% with the LEZ. Stockholm's LEZ also reduced concentrations of $PM_{0.2}$ by between 0.5% and 9%.

However, this study assumes that Seoul's LEZ policy will have no impact or a minor impact on air quality because air pollution concentration in Korea is also affected by air pollutants from China in the winter and spring seasons. Details of the weather seasonality are described in Section 3.

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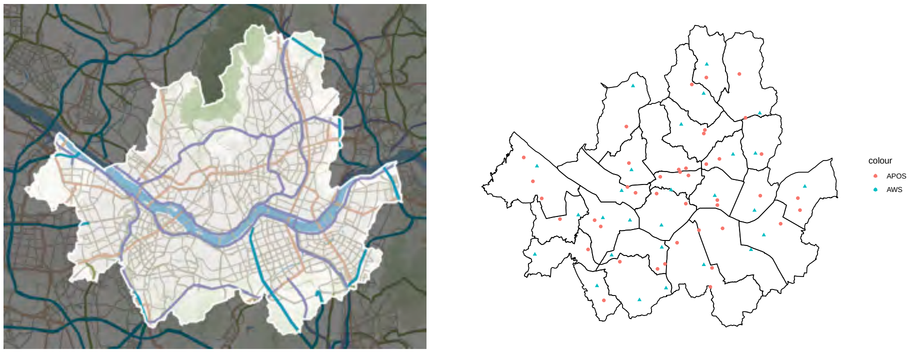
[3] Sadler Consultants Ltd offers information about low emission zone policy on the CLARS website. This paper refers to the details of the effects of LEZ in EU countries (https://urbanaccessregulations.eu/).

4.3 Data

The weather data is from the Korean Meteorological Administration (data.kma.go.kr) and it consists of temperature, precipitation, and wind pattern (wind speed, wind direction) collected from the 510 Automatic Weather Stations (AWS) over the country. On the other hand, the air pollution data is collected by the Korea Environment Corporation (airkorea.or.kr) and it covers 162 prefectures with about 600 Air Pollution Observation Stations (APOS). The observed pollutants are SO_2 (ppm), NO_2 (ppm), O_3 (ppm), CO (ppm), PM_{10} ($\mu g/m^3$) and $PM_{2.5}$ ($\mu g/m^3$). However, since $PM_{2.5}$ is a subset of PM_{10}, this study focuses on PM_{10} to measure the level of PM.

The daily frequency data is collected from 27 AWSs and 40 APOSs that cover Seoul. The data includes weather observations from 27 AWSs and air pollution observations from 40 APOSs in Seoul (see Figure 4.2), collected over the two-year period before and after the implementation of the LEZ policy on Jan 1, 2017 (i.e., from 2015 to 2018).



(a) (b)

Figure 4.2: The Map of (a) Seoul and (b) the Locations of AWSs and APOSs

To create the daily frequency dataset, a few more steps are required. Since the number of observation stations for the two data sets (weather, air pollution) and the locations are not identical, accurate weather observation at a specific APOS cannot be measured, which can increase bias. To address this issue, an interpolation method is used. There are some interpolation methods such as Natural Neighbor, Nearest Neighbor, Inverse Distance Weighting (IDW), and Kriging. In this study, IDW is used because it is intuitive, efficient (Azpurua and Dos Ramos, 2010), and also commonly used for spatial analysis though it increases error for mountainous areas.[4] To perform the interpolation, the hourly frequency (24 hours based) dataset and interpolated weather observations based on each APOS are used[5]. The resulting dataset is then collapsed to daily frequency because the pattern of hourly frequency data is volatile. The data is then averaged for the entire Seoul area.

Table 4.1: Summary of Statistics

Variables	Obs.	Mean	SD	Min	Max
Panel A: Weather Variables					
Temperature (°C)	1,461	13.49	10.58	-14.34	33.35
Rainfall (mm)	1,461	.119	.446	0	6.17
Wind Speed (m/s)	1,461	1.65	.515	.762	4.12
Wind Direction (°)	1,461	176.74	53.69	60.33	296.68
Panel B: Air Pollution Variables					
PM_{10} ($\mu g/m^3$)	1,461	46.75	27.30	6.18	555.69
CO (ppm)	1,461	.558	.169	.280	1.253
NO_2 (ppm)	1,461	.036	.011	.011	.082
SO_2 (ppm)	1,461	.005	.001	.002	.012
O_3 (ppm)	1,461	.020	.010	.002	.064

Table 4.1 provides a summary of statistics. As noted in Section 2, weather conditions in Korea vary significantly by season. Temperature and precipitation exhibit large variations depending on the seasons, with high temperatures and significant rainfall occurring in the summer, and low temperatures and little rainfall in winter. The northwestern wind is the dominant wind direction in the winter, while the northeastern wind is dominant in other seasons. Figure 4.3 illustrates the seasonality. The mean wind speed is weaker in the winter and spring seasons, with values below about 2 m/s. Wind direction is reported in cardinal directions, with 0 or 360 degrees indicating north wind, while 180 degrees represents south wind.

Table 4.2 shows the air quality standards of Korea, the USA, and the EU. The Korean air quality standard is similar to the USA, although the vehicle emission standard follows that of the EU. Most average levels of pollutants appear to meet the standard, even though the averaging time for measurement is not identical. However, seasonality critically affects the variation in the air pollutant level. Figure 4.4 shows the seasonality of air pollutants. The pattern is usually higher in the winter and spring seasons, except for ozone.[6]

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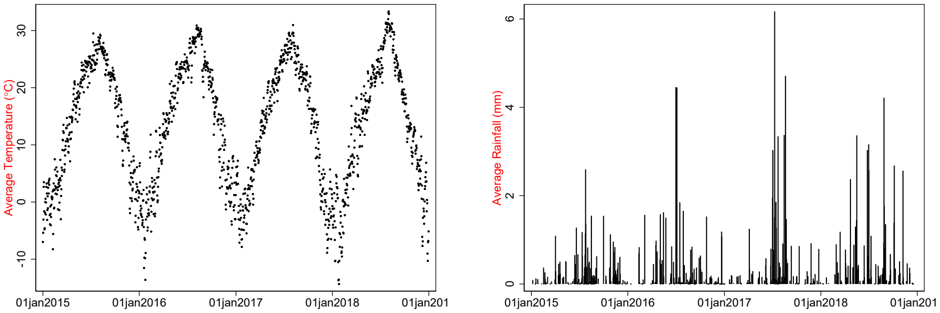
[4] Since there are only a few AWSs at the high elevation area (3 AWSs), it is dropped before the interpolation.

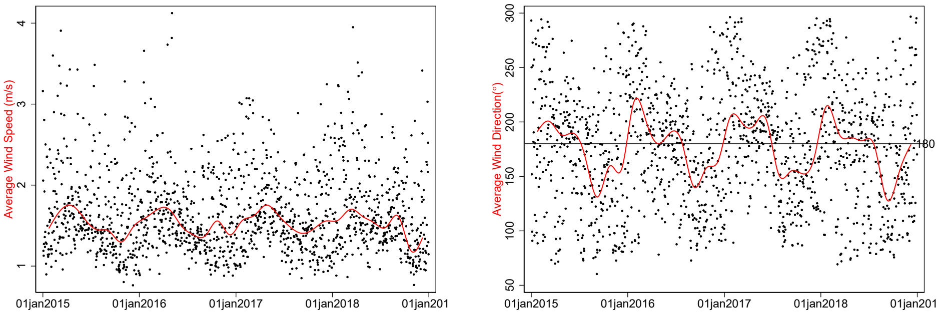
[5] The observation from three nearest AWSs are used for interpolation.

[6] Ozone is affected by high temperature and strong sunlight.



(a) Temperature

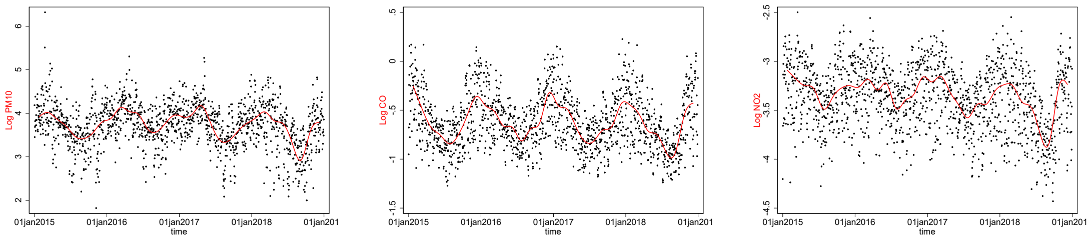
(b) Rainfall



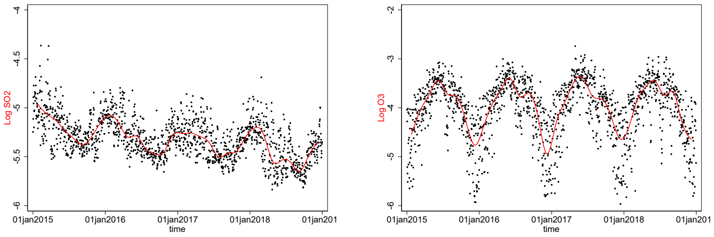
(c) Wind Speed

(d) Wind Direction

Figure 4.3: The Pattern of the Weather Conditions over Time



(a) $\ln(PM_{10})$ (b) $\ln(CO)$ (c) $\ln(NO_2)$



(d) $\ln(SO_2)$ (e) $\ln(O_3)$

Figure 4.4: The Seasonal Pattern (spline) of the Air Pollutants

Table 4.2: Air Quality Standard

Pollutant	Unit	Korea		USA		EU	
		Level	Averaging Period	Level	Averaging Period	Level	Averaging Period
PM_{10}	$\mu g/m^3$	50	1y	50	1y	40	1y
CO	ppm	9	8 hour	9	8 hour	.01	8 hour
NO_2	ppm	0.03	1y	.053	1y	.04	1y
SO_2	ppm	0.05	1 year	.03	1 year	.125	24 hour
O_3	ppm	0.06	8 hour	.07	8 hour	.12	8 hour

4.4 Regression Strategy

Many studies have employed Difference-in-Difference (DD) to measure the effectiveness of an air quality policy, but this study used Regression Discontinuity in Time (RDiT) as an empirical analysis tool. Davis (2008) used RDiT to estimate the impact of a weekly-car-free-day system ($HoyNoCirrcula$) on air quality in Mexico City. He mentioned why he used the RDiT for analysis for two reasons. First, RDiT can address endogeneity from unobserved factors by using OLS. Second, comparing Mexico City to any other city can address time-varying omitted variables, but no city would have a credible counterfactual because Mexico City has unique characteristics such as geography, transportation system, and high population. Considering the reasons, RDiT would be reasonable for this study since there are no valid comparison groups with Seoul in Korea.

In traditional RD, the treatment is as good as random within a narrow bandwidth (Hausman and Rapson, 2018). The RD method compares one group with another group at the same time with the concept that both groups have similar characteristics at narrow bandwidth of a specific threshold point. Using this concept, in RDiT, the running variable is time. However, since unobservable variables correlated with the running variable (time) may have discontinuous impacts on the potential outcome, RDiT may need to include as many as control variables (Hausman and Rapson, 2018). This paper follows the method proposed by Li et al. (2020) based on Hausman and Rapson (2018). According to the literature, RDiT includes two steps called the "Augmented Local Linear Approach". The first step is to regress log-dependent variables on the control variables to obtain residuals ($\overset{resd}{Y}$). For this step, the following equation is used:

$$log(p_t) = \alpha_0 + X_t + \omega_d + \epsilon_t \tag{4.1}$$

where $log(p_t)$ is each logged pollutant and the subscript t indicates time. X_t and ω_d

mean control variables and fixed effects, respectively.[7]

The second step is to apply RD to get estimators ($\hat{\beta}_{RD}$) with the following equation (Li et al., 2020).

$$\begin{aligned} \hat{\beta}_{RD} &= \lim_{d \to d_0^+} E[\overset{resd}{Y} \mid D = d] - \lim_{d \to d_0^-} E[\overset{resd}{Y} \mid D = d] \\ &= \hat{\beta}_+ - \hat{\beta}_- \end{aligned} \tag{4.2}$$

where D indicates dates (time), d_0 is the threshold which means the initiation date of the LEZ. $\hat{\beta}_{RD}$ is calculated by the following minimization problem as mentioned in Calonico et al. (2014; 2015 ;2020) and Li et al. (2020):

$$\hat{\beta}, \hat{\theta}, \hat{\gamma} = \min_{\beta,\theta,\gamma} \sum_{d=1}^{n} [\overset{resd}{y_d} - \beta - \theta(d - d_c) - \gamma Z_d]^2 K(\frac{d - d_c}{h}) \tag{4.3}$$

where $K(\cdot)$ indicates kernel function and we used a uniform kernel function. h is a bandwidth.

Hausman and Rapson (2018) mentioned that showing how dependent variables are serially correlated is necessary because air pollutants take time to dissipate. He pointed out that including lagged variables in the second step can mitigate bias. Table 4.3 shows each air pollutant's first-order autoregressive (AR(1)) regression. The coefficients are positive and statistically significant.[8] From the result, I confirm that including Z_d which means a lagged variable is necessary.

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[7] For the control variables and fixed effects in the first step, this study follows Auffhammer and Kellogg (2011). X_t includes cubic polynomials in maximum/minimum of temperature, wind speed, and mean rainfall. For lagged variables, we added max/min temperature, max wind speed, and mean rainfall. Also, various interaction terms are applied. It includes interactions of max temperature with min temperature, mean rainfall, max wind speed, and its lagged term, and we also added interactions of max wind speed with min wind speed. To allow weather effects, X_t include interactions of all of these variables with season dummies. There were two thermal power plants in Seoul, but it has not operated anymore since March 2017. Therefore, a dummy is considered to reflect it. For the wind direction variable, we treated it to a dummy which means the northwestern wind is 1 or 0 otherwise. ω_d includes holiday, weekend, day-of-week, week of the month, month of year fixed effects.

[8] see Section 5 for details about the placebo test.

Table 4.3: AR(1) Parameters

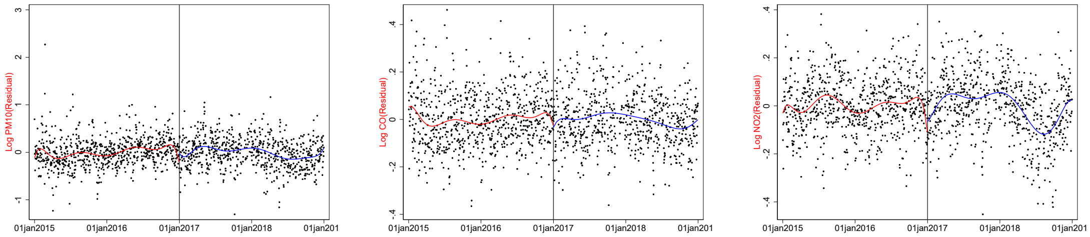
Log lagged pollutants	Dependent Variable: Log pollutants		
	Baseline Estimates	Placebo	
		1 Year Before	1 Year After
PM_{10}	.437*** (.036)	.407*** (.035)	.513*** (.047)
CO	.380*** (.039)	.305*** (.035)	.393*** (.020)
NO_2	.321*** (.043)	.237*** (.024)	.328*** (.031)
SO_2	.436*** (.044)	.344*** (.022)	.555*** (.027)
O_3	.279*** (.033)	.286*** (.047)	.322*** (.062)

4.5 Result

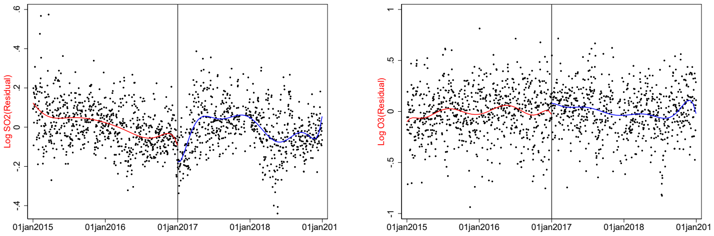
Figure 4.5 shows an eight-order global polynomial trend for each pollutant with the red vertical line indicating the initiation date of the policy. However, Hausman and Rapson (2018) cautioned that expanding the time window increases the probability of bias, as data from further away from the threshold may be added, and researchers cannot perfectly specify a treatment effect that may vary by time (a time-varying treatment effect). They also noted that there is a risk of overfitting when using a global polynomial approach due to potential confounders. Therefore, in this study, a local polynomial approach was used.

Finding an optimal bandwidth is important for a local polynomial trend. To determine this, this study employs the method used by Calonico et al. (2020) and Gelman and Imbens (2019), who recommend using a low-order polynomial time trend to avoid noisy estimates and poor coverage of confidence intervals from a high-order polynomial. Therefore, a first-order polynomial time trend is applied in this study.

Figure 4.6 shows a first-order local polynomial trend. Seemingly, there is an improvement in the air pollutants concentration except for ozone. Table 4.4 shows the RD results for each air pollutant. As mentioned in section 2, the main targeted pollutants of the LEZ policy are PM and NO_2, which are mainly generated by diesel vehicles. Therefore, this study anticipated that PM_{10} and NO_2 concentration would decrease. However, the results show a slight difference from what was expected. Looking at the baseline estimates in column 1 in Table 4.4, all coefficients are negative except O_3, but statistically significant only for NO_2 and SO_2 (at the 10%and 1% significant level, respectively). The LEZ policy decreases NO_2 and SO_2 concentration in Seoul



(a) PM_{10} Residual (b) CO Residual (c) NO_2 Residual



(d) SO_2 Residual (e) O_3 Residual

Figure 4.5: The Global Polynomial Trend (eight-order) of the Air Pollutants (Residual)

to 4.9% and 11.6%, respectively.[9] To support the reliability of the results, some robustness checks are necessary.

Placebo test: There may have been other critical policy changes during the period that could have affected air pollution concentration besides the LEZ policy. To account for this possibility, placebo tests were conducted using one year before and after the actual policy dates as fake treatments. If the RD result does not pass the placebo test, it is difficult to conclude that the pollutants were directly affected by the policy. The results of placebo tests are reported in columns 3 and 4 in Table 4.4. All coefficients are statistically insignificant for both placebo tests, indicating that there were no other policy changes during the total period.

Donut RD specification: According to Barreca et al. (2011), RD estimates should be stable at the threshold. To check the stability of the RD estimates, this study

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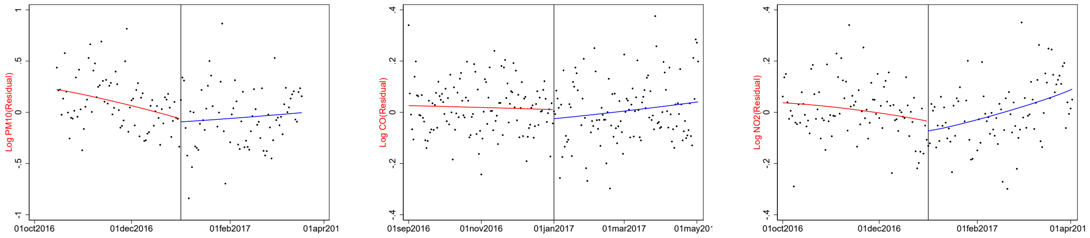
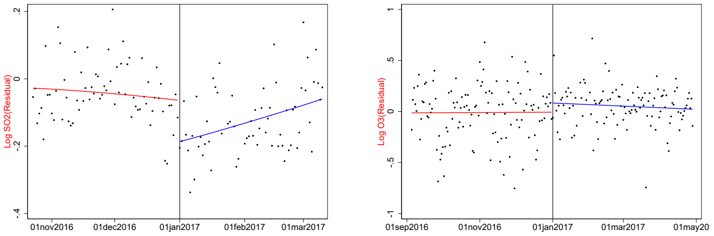
[9] The main pollutants from diesel vehicles are PM_{10} and NO_2, but as mentioned Section 2, diesel vehicles also generate SO_2.



(a) PM_{10} Residual (b) CO Residual (c) NO_2 Residual



(d) SO_2 Residual (e) O_3 Residual

Figure 4.6: The Local Polynomial Trend (first-order) of the Air Pollutants with Optimal Bandwidth (Residual)

re-estimates the RD results by systematically dropping one day, seven days, and fourteen days from the threshold, which is called a "Donut RD". In doing so, this study confirms whether there are short-run selection, anticipation, or avoidance effects (Hausman and Rapson, 2018). Columns 5, 6, and 7 in Table 4.4 show the re-estimated results. The coefficients of NO_2 and SO_2 remain negative and statistically significant, which means that the baseline RD estimates are not affected by any other effects.

Policy overlapping: If there are overlapped policies that intend a similar effect to the LEZ during the total time period, the result may be distorted. To check the potential issue, reviewing the timeline of other traffic regulations and air quality control policies is required (see Tables C.1 and C.2). Most traffic regulation policies have been applied in Seoul since 2019 except the LEZ policy and no policy can affect air quality directly.

Time heterogeneity: This study uses daily data for analysis because air pollutants are volatile on an hourly frequency base. However, since the LEZ policy is operated

Table 4.4: RD Result

Dependent Variables (Residual)	Baseline estimates		Placebo Test		Donut RD dropping		
	RD estimator	Optimal Bandwidth	1Y before	1Y after	1 day	7 days	14 days
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
PM_{10}	-.035	77	.119	-.101	-.059	-.041	.026
	(.092)		(.097)	(.070)	(.096)	(.139)	(.135)
CO	-.037	122	-.044	.003	-.038	-.044	-.034
	(.028)		(.027)	(.020)	(.028)	(.035)	(.039)
NO_2	-.049*	92	.027	.008	-.051*	-.093***	-.124***
	(.027)		(.028)	(.037)	(.028)	(.019)	(.017)
SO_2	-.124***	69	-.005	-.036	-.125***	-.153***	-.163***
	(.025)		(.020)	(.038)	(.024)	(.039)	(.060)
O_3	.071	118	.032	-.055	.065	.082	.063
	(.071)		(.074)	(.067)	(.075)	(.088)	(.079)

Note: *, **, *** indicate 10%, 5%, 1% significant level, respectively. The week cluster standard error is in parentheses.

24/7, the effect of the LEZ policy on the air pollutant concentration may vary with the time of day. Therefore, this study separates two-time intervals of the day (daytime&nighttime) and rush hour(morning&evening) to analyze the effect. The results are reported in Table 4.5. The LEZ policy decreases PM_{10} by 13.6% during the daytime and it is statistically significant, unlike the baseline result. NO_2 and SO_2 remain statistically significant, but the effect is greater than the baseline result, 7.1% and 14.8%, respectively. However, during the nighttime, only SO_2 remains statistically significant and the effect is smaller than the baseline result, 8.7%. Meanwhile, while PM_{10} and NO_2 are decreased by 0.8%, 10.5%, respectively, NO_2 and SO_2 are decreased by 8.5%, 19.3%, respectively. Considering the time heterogeneity, the effect of the LEZ policy on air pollution tends to be greater during times of increased traffic.

Table 4.5: RD Result by Time of Day

Dependent Variables (Residual)	Daytime (9 a.m. ∼6 p.m.)	Nighttime (8 p.m. ∼7 a.m.)	Rush hour (Morning) (7 a.m. ∼9 a.m.)	Rush hour (Evening) (6 p.m. ∼8 p.m.)
PM_{10}	-.146**	.058	-.009*	-.129
	(.071)	(.114)	(.123)	(.119)
CO	-.047	-.035	-.082	-.017
	(.057)	(.037)	(.053)	(.077)
NO_2	-.074***	-.008	-.111***	-.089**
	(.028)	(.033)	(.030)	(.039)
SO_2	-.161***	-.091***	-.035	-.215***
	(.037)	(.013)	(.037)	(.045)
O_3	.057	.016	.155	.013
	(.097)	(.094)	(.115)	(.066)

Note: *, **, *** indicate 10%, 5%, 1% significant level, respectively. The week cluster standard error is in parentheses.

Indirect Evidence Supporting the Result:

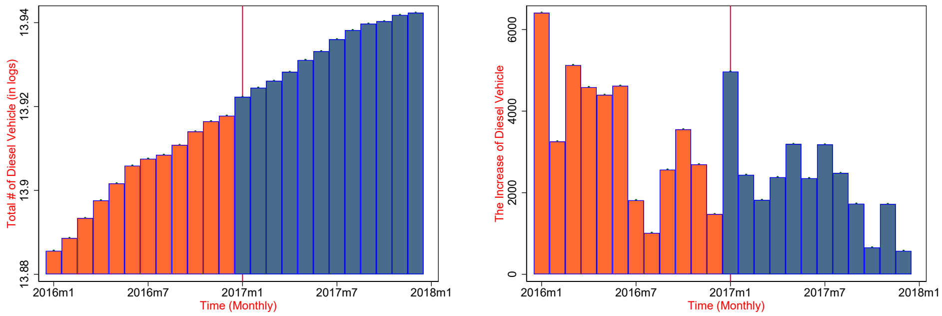
Korea has been using ultra-low sulfur diesel since 2005, resulting in an average SO_2 level of nearly zero, which is 0.005 ppm (see Table 4.1). Since the SO_2 air quality standard of Korea is 0.05 ppm, the baseline result, 11.6% reduction is a very small amount. However, the reduction in SO_2 can still occur due to the reduction of pollutants from diesel vehicles since there are no coal power plants or heavy industrial areas around Seoul city. On the other hand, NO_2 concentration is affected by various factors such as the number of diesel vehicles, installation of DPF, or traffic. Although it is not easy to identify which factor is mainly affected by the LEZ policy, this paper reviews how these factors have changed after the implementation of the LEZ policy.

A. The number of diesel vehicles

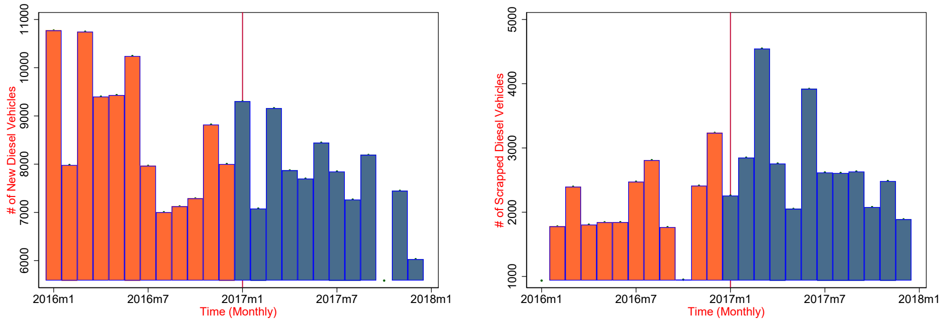
Since decision-making for purchasing or changing a vehicle usually takes some time, it is difficult to identify significant changes in diesel vehicle registration or consumption patterns immediately after the implementation of the LEZ policy. However, this study may provide meaningful findings from statistics related to diesel vehicles. Panel (a) through (c) in Figure 4.7 shows the total number of diesel vehicles, new diesel vehicles, and scrapped diesel vehicles for 1 year before and after the policy, respectively. The total number of diesel vehicles continues to increase over time, and the increase is much greater than the month right before the policy (see panels (a) and (b) in Figure 4.7). The increase is accounted for by the gap between new and scrapped diesel vehicles. Identifying the exact patterns from the statistics is difficult, but there is a decreasing trend in new diesel vehicles and an increasing trend in scrapped diesel vehicles over time after the LEZ policy. As mentioned in section 2, Seoul city gives subsidies to diesel vehicle owners who replace them with new ones, but the subsidies also can be offered to vehicle owners who purchase new or used diesel vehicles, which means "not old vehicles". Therefore, even though the number of registered diesel vehicles may be reduced because the shorter the vehicle year, the less pollutant it produces. Meanwhile, Figure 4.8 shows the number of diesel vehicles that have installed DPF. Although more old diesel vehicle owners are expected to install DPF, the graph does not show any noticeable effect of the policy.

B. The Traffic Changes

The Seoul Metropolitan Government publishes annual traffic analysis reports, which include average hourly traffic data from each traffic measurement camera. These cameras are categorized into five areas: central (A), border (B), main road (C), bridge (D), and inter-city highway (F) (see Figure 4.9). However, since the statistics are only collected from cameras that operate 24/7, they may not be representative of



(a) Total Diesel Vehicles (b) The Increase in Diesel Vehicles



(c) New Diesel Vehicles (d) Scrapped Diesel Vehicles

Figure 4.7: The Number of Total, New, and Scrapped Diesel Vehicles in Seoul

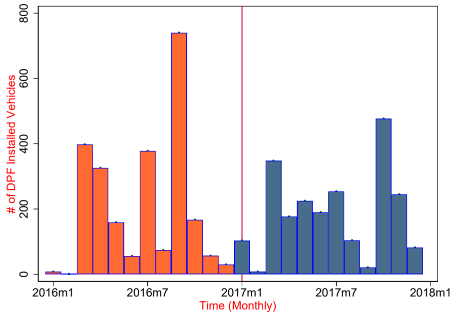


Figure 4.8: The Number of DPF Installed Diesel Vehicles

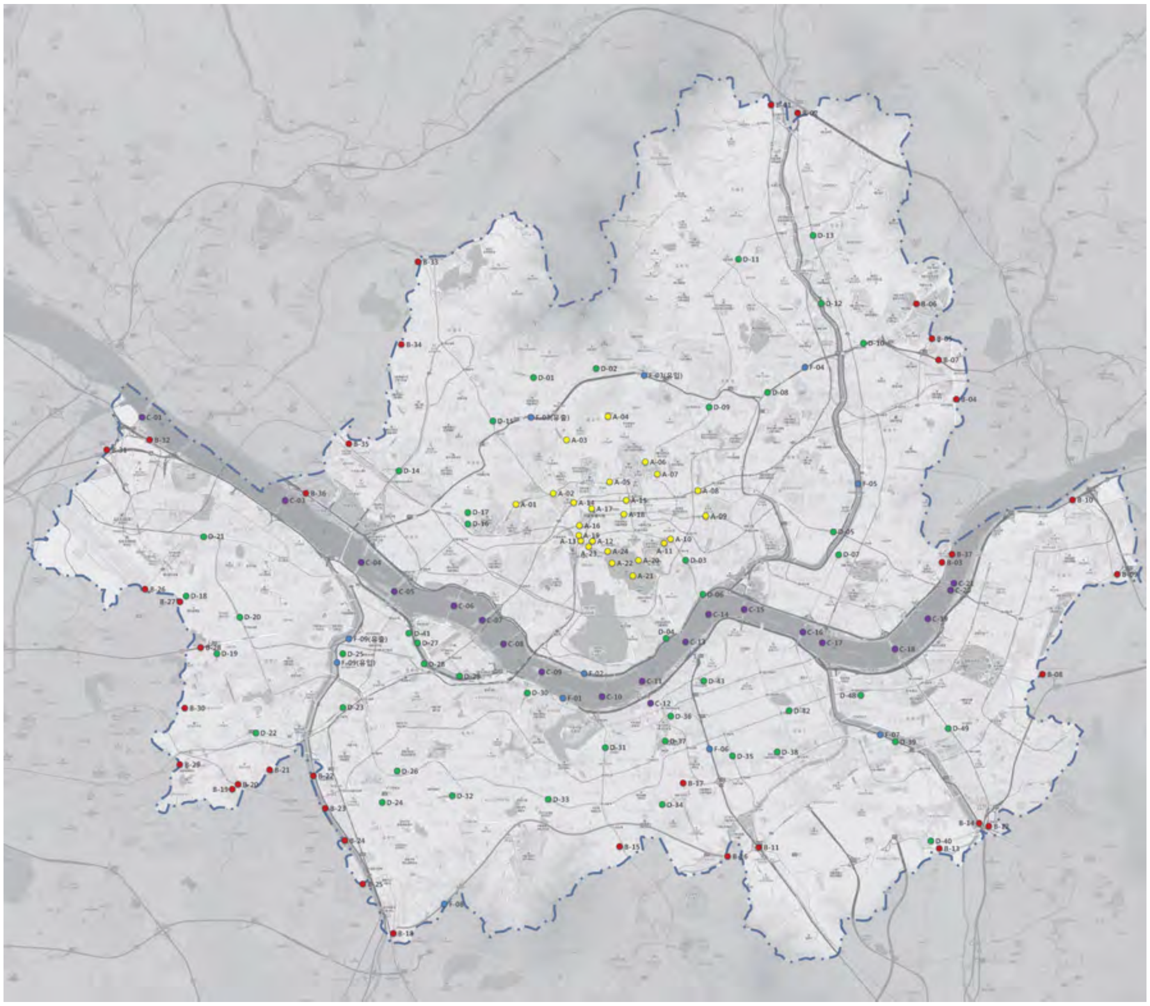


Figure 4.9: The Location of Traffic Cameras

Note: Central Area (A: Yellow), Border (B: Red), Main Road (C: Green), Bridge (D: Purple), Inter-City Highway (F: Blue)

total traffic in Seoul. Table 6 compares the traffic changes for four years, with each year compared to the previous year. Notably, there was a significant drop in traffic in 2017, especially in central and border areas, indicating that the LEZ policy may have contributed to reducing the number of diesel vehicles on the road in Seoul.

Table 4.6: Traffic Variation

Year	2015	2016	2017	2018
Total	2.6%	-0.5%	-2.6%	-3.0%
Central Area	-0.3%	-2.9%	-7.7%	-4.1%
Border (Boundary)	12.6%	1.0%	-6.2%	0.1%
Main Road	-0.1%	-0.3%	0.2%	-2.6%
Bridge	-1.9%	-1.1%	0.4%	-5.6%
Inter-City Highway	-	-0.1%	-3.1%	-2.3%

To support the traffic reduction in 2017, we use a simple regression model using raw traffic data used for the traffic analysis reports. The data has an hourly frequency from 2016 to 2017 in each traffic measurement camera. For the regression, we collapse it to daily average traffic data by the 5 areas and use the model as the following equation:

$$ln(traffic_{it}) = \beta_0 + \beta_1 Policy_t + \beta_2 Holiday_t + \lambda_t + \eta_i + \varepsilon_{idt} \tag{4.4}$$

where $ln(traffic_{it})$ is a log of average traffic in area i, at time t. $Policy_t$ is a dummy for the intervention. To explain time-varying traffic patterns, the model includes a holiday dummy, $Holyday_t$, and time-fixed effects (month, week of the month, day of the week), λ_t. Also, area fixed effect, η_t, is included to control time-invariant heterogeneity. The result shows that the traffic in the central area, the main road, and the inter-city highway are reduced by 6.9%, 12.8%, and 7.9%, respectively (see Table 4.7). Though the coefficient for total traffic shows a negative sign, it is statistically insignificant. Therefore, we can say that the change in traffic contributes to the NO2 reduction in the baseline result[10].

Benefit of Seoul's LEZ Policy

I use the estimates to calculate the benefit of reducing air pollutants (See Table 4.8). The "Update of the Handbook on the External Costs of Transport" (RICARDO-AEA, 2014) provides estimates of the social unit cost of each pollutant using Impact Pathway Analysis (IPA) method. Kang and Kim (2015) analyzed the cost in Korea using the estimates from RICARDO-AEA (2014). According to the National Institute of Environmental Research (NIER) in Korea, the total emission of NO_x in Seoul

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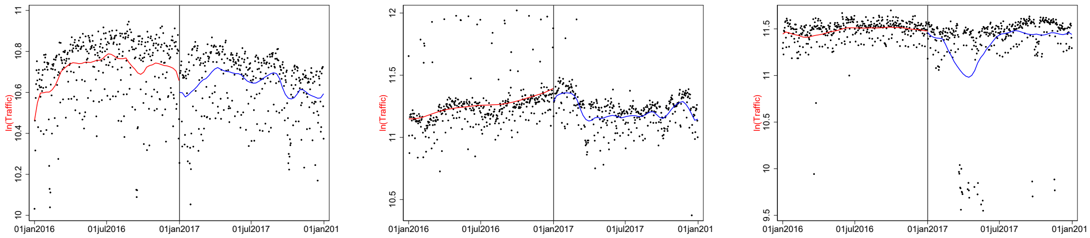
[10] As of 4 October 2018, the number of registered total 5th-grade diesel vehicles in Seoul is 279,709 and 5th-grade diesel vehicles account for 96% (268,922) of them. If we assume that the diesel vehicles are not operated, the reduction of traffic may highly account for NO_2 concentration.

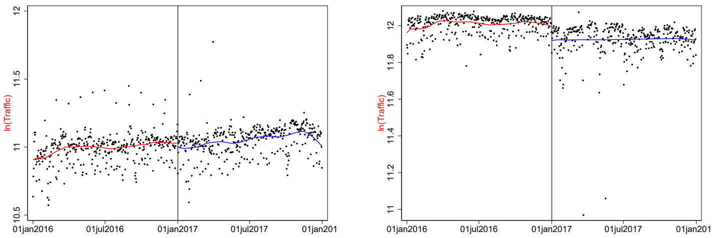
Table 4.7: Result of the Traffic Change

D. Variable ln Traffic (Mean)	Total (1)	Central Area (2)	Border (3)	Main Road (4)	Bridge (5)	Inter-City Highway (6)
Policy (LEZ)	-.055 (.033)	-.072*** (.005)	-.041 (.032)	-.137** (.039)	.059** (.015)	-.083*** (.004)
Holiday	-.179* (.072)	-.413*** (.028)	.031 (.042)	-.187*** (.013)	-.217*** (.010)	-.111*** (.010)
Fixed Effect						
Area	o	-	-	-	-	-
Time (Month, Week, Day)	o	o	o	o	o	o
Cluster						
Area	o	-	-	-	-	-
Week	-	o	o	o	o	o
Observation	3,614	730	727	727	728	702
R2	.864	.715	.266	.223	.586	.477

Note: *, **, *** indicate 10%, 5%, 1% significant level, respectively. The week cluster standard error is in parentheses.



(a) Central Area (b) Border (c) Main Road



(d) Bridge (e) Inter-City Highway

Figure 4.10: The Changes in Traffic from Each Area

city in 2016 was 73,042 tons. Considering the baseline result that the LEZ policy reduced the daily average NO_2 concentration by 4.7%, the social benefit due to the reduction of NO_x can be calculated using the expression below:

[The total NO_x emission of Seoul in 2016 (73,042 tons)] * [1,000(kg)] * [0.3 (NO_2/NO_x ratio)][11] * [0.047] * [$38.31 ($/kg)] = $39,455,170.18.

So far, we have not discussed $PM_{2.5}$ due to the data limitation. However, many studies mentioned secondary $PM_{2.5}$ formation caused by chemical and physical reactions between SO_2, NO_x, $VOCs$, and NH_3 (Hodan and Barnard, 2004; Guerra et al., 2014; Kim et al., 2017). Moon et al. (2021) estimated the $PM_{2.5}$ contribution rate of emission of each pollutant (NO_x, SO_x, $NH_3$3, $VOCs$, $PM_{2.5}$) and each source (factory smokestacks, tailpipes on roads, others) from 17 local prefectures in Korea. They found that the $PM_{2.5}$ contribution rate of NO_x emission in Seoul was -0.4% from roads. The negative contribution rate means that the reduction of NO_x emission leads to an increase in $PM_{2.5}$ emission. This is called as 'NO_x disbenefit', which occurs in big cities where the emission of NO_x per unit area is high. Under the condition of being 'NO_x-rich' in big cities, the reduction of NO_x concentration causes chemical reactions, such as generating O_3 (Kim et al., 2017; Moon et al., 2021). Therefore, the cost of the secondary $PM_{2.5}$ caused by the reduction of NO_2 concentration can be calculated using the expression below:

[The total NO_x emission of Seoul in 2016 (73,042 tons)] * [1,000(kg)] * [0.3 (NO_2/NO_x ratio)] * [0.047] * [-0.004 ($PM_{2.5}$ contribution rate)] * [$376.07 ($/kg)] = 1,549,246.24

Therefore, the LEZ policy makes the benefit of 37.9 million dollars ($= \$39,455,170.18 - \$1,549,246.24$) and it is worth 39.2 million dollars in 2017 (Average interest rate = 1.68%).

Table 4.8: Social cost of each pollutant per unit (₩/kg)

$PM_{2.5}$			NOx	$NMVOC$	SO_2	CO
Rural (150 ppl/km2)	Suburban (300 ppl/km2)	Urban (1,500 ppl/km2)				
117,009	174,967	451,284	45,971	2,825	37,459	27,719
($97.51)	($145.81)	($376.07)	($38.31)	($2.35)	($31.22)	($23.10)

Note: The converted cost to US currency is in the parenthesis ($1 = ₩1,200). NMVOC means Non-methane volatile organic compounds.
Source: Kang and Kim, 2015, as cited in Kang et al., 2016.

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[11] Since the NO_2/NO_x ratio from diesel vehicles is between 0.1 to 0.5 depending on speeds and vehicle types (Kim et al., 2017), 0.3 is used as the proportion of NO_2 in NO_x emission.

Table 4.9: NO_x Emission from each Source in Seoul Metropolitan Area from 2012 to 2016

Year	2012	2013	2014	2015	2016
Total	274,027	283,851	269,199	269,783	325,005
Energy Industry	25,320	24,406	18,111	17,157	18,585
Non-Industry	40,541	42,743	39,298	39,608	41,699
Manufacturer	11,121	11,506	11,681	9,712	9,065
Production	3,938	4,056	3,838	3,893	3,790
Motor	128,571	129,861	138,235	143,642	175,089
Non-Motor	56,807	68,355	54,988	80,016	73,675
Disposal	7,667	2,944	3,048	2,755	3,102

Source: NIER (2016)

Table 4.10: The Emission of each Pollutant in Seoul Metropolitan Area in 2016

Pollutants (ton)	PM_{10}	$PM_{2.5}$	NO_x	SO_x	VOC	NH_3
Total	233,085	100,247	1,248,309	358,951	1,024,029	301,301
Metropolitan	47,777	15,897	326,086	31,822	300,244	57,332
Seoul	8,571	2,524	73,042	4,039	63,098	3,946
Incheon	6,306	2,247	49,389	12,368	52,014	6,958
Gyung-gi	32,900	11,127	203,655	15,415	185,131	46,428

Source: NIER (2016)

4.6 Conclusion

Vehicle emission standards have gradually strengthened around the world. To meet the standards, automobile manufacturers have developed engines and emissions systems. However, although diesel engine technology has advanced so far, it cannot be free from air pollution issues. Diesel vehicles reduce emissions by installing various post-processing devices such as DPF and ERG but emit significant pollutants if the devices are old or malfunctioning. To solve this problem fundamentally, major cities around the world are making efforts to reduce diesel vehicles. The LEZ policy is one of several policies to reduce diesel vehicles and it has proved its effectiveness in many countries.

This paper focuses on evaluating the effectiveness of Seoul's LEZ policy. The results show that the LEZ policy affects the improvement of air quality in Seoul. NO_2 concentration decreased by 4.7% and SO_2 decreased by 11.7% due to the policy. Although there is no effect on PM_{10} in the baseline result, the effectiveness of the policy could be confirmed during the daytime (13.6%) and morning rush hour (0.8%). Also, this study could indirectly identify that the LEZ policy affects the behavior of diesel vehicle owners such as purchasing, disposal, and driving vehicles.

Various policies have been implemented to improve Seoul's air quality, but many people have doubted and criticized the effect because the air quality is greatly influenced by external and seasonal factors. However, the results support that the policies related to traffic regulation have significant effects and, in particular, can contribute to planning policies related to diesel vehicles and air pollution.

This study did not include spatial heterogeneity analysis in Seoul as it only focused on changes in air quality within Seoul, and there is a limitation in that it could not fully control all air pollutants coming from the areas surrounding Seoul. Moreover, if the traffic data could specify vehicles by fuel type, it would be possible to analyze the impact of the policy on each fuel type of vehicle. However, since there are no relevant data, conducting such an empirical analysis will be part of future research.

Chapter 5

Conclusion

This dissertation provides insights into the economic effects of environmental and policy shocks in Korea. In Chapter 2, I analyze the effect of the expiration of the Korea-Japan Fishery Agreement on Korean long-line hairtail fishery. The finding implies that maintaining the bilateral fishery agreement decreases the fishing intensity. Also, since prohibiting fishing in local fishing grounds can increase the fishing intensity around the areas, policymakers need to consider comprehensive restriction policies to ensure a productive fishing environment. In Chapter 3, I estimate the risk of the Gori NPP using the housing prices comparing the Fukushima accident with the Pohang earthquake. The result shows that the people who live near the NPP well perceived the risk of it after the Pohang earthquake, but not for the Fukushima accident. It also implies that the risk value of Gori NPP is not fully reflected in the housing market before the Pohang earthquake. In Chapter 4, I evaluate the effect of the LEZ policy on air quality. Based on the result, prohibiting driving old diesel vehicles in Seoul improves air quality by reducing NO_2 concentration. Even though the reduction of NO_x emission leads to an increase in $PM_{2.5}$ emission, the result shows that the value of LEZ policy is positive.

This dissertation focuses on the impact evaluation of exogenous shocks and discusses the underlying mechanisms of behavior changes. Though the dissertation only addresses the evidence from Korea, the findings may offer valuable insights to policymakers addressing the issues in various sectors to improve the environment surrounding us.

Appendix A

Chapter 1

Table A.1: The amount of assigned Korean vessels and catch allowance in Japan's EEZ in 2015

Agreement Result		Assignments							reserved
		Busan	Ulsan	Gangwon	Gyeongbuk	Gyeongnam	Jeonnam	Jeju	
# of vessels	860	252	19	70	151	30	4	178	
Sum (tons)	68,204	46,946	1,046	2,529	3,626	531	90	5,156	1,275
Saury	7,000	0	0	0	0	0	0	0	
Saurel	4,017	4,017	0	0	0	0	0	0	
Mackerell	24,694	24,694	0	0	0	0	0	0	
Sardine	0	0	0	0	0	0	0	0	
Japanese flying squid	10,391	3,938	960	2,106	2,957	169	0	261	
Flatfish	1,448	1,448	0	0	0	0	0	0	
Red sea bream	224	137	3	27	37	1	0	19	
hairtail	3,450	0	0	0	1	147	54	3,108	140
etc	16,980	12,712	83	396	631	214	36	1,768	1,135

Source: Korean Ministry of Ocean and Fisheries

(a) (b)

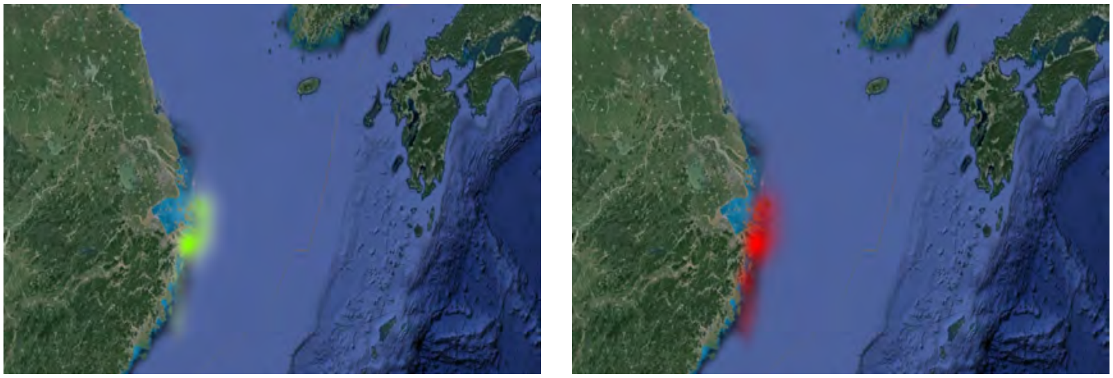
Figure A.1: (a) Fisheries Regime in East Asia (China, Japan, Korea) (b) Maritime Boundaries for the three countries

Source: Based on the map from the Maritime Awareness Project (https://map.nbr.org/)
Note: Provisional Measures Zone (PMZ), Transitional Zone on the Chinese side (TZC), Transitional Zone on the Korean side (TZK), Common Zone (CZ)

Table A.2: Chinese Fish Catch by Sea Areas & by Fishing Gears

Year	2013	2014	2015	2016	2017	2018	2019
By sea area (tons)							
Bohai Sea	975,257	1,023,741	1,039,627	735,124	698,002	790,300	629,572
Yellow Sea	3,185,005	3,315,958	3,350,841	2,656,281	2,529,459	2,385,959	2,292,305
East China Sea	5,022,719	4,898,709	4,999,644	4,883,270	4,513,623	4,172,797	4,075,847
South China Sea	3,460,841	3,569,963	3,757,699	3,597,354	3,383,119	3,095,591	3,003,791
By fishing gear (tons)							
Trawl	6,064,359	6,118,041	6,208,928	5,608,740	5,355,104	4,887,102	4,766,005
Seine	1,027,111	1,015,444	1,036,603	1,028,374	927,676	931,291	823,311
Gillnet	2,716,695	2,865,252	2,950,556	2,591,242	2,420,958	2,280,103	2,241,845
Tension net	1,621,802	1,596,455	1,585,462	1,414,727	1,286,275	1,220,525	1,150,760
Fishing tackle	349,750	384,343	401,546	376,691	332,304	369,058	352,894
Other fishing gear	864,105	828,836	964,716	852,255	801,886	756,568	666,700
Total Production (tons)	12,643,822	12,808,371	13,147,811	11,872,029	11,124,203	10,444,647	10,001,515

Source: Chinese National Fisheries Statistics (http://data.cnfm.com.cn/web/moa/fishTotal/default.aspx)

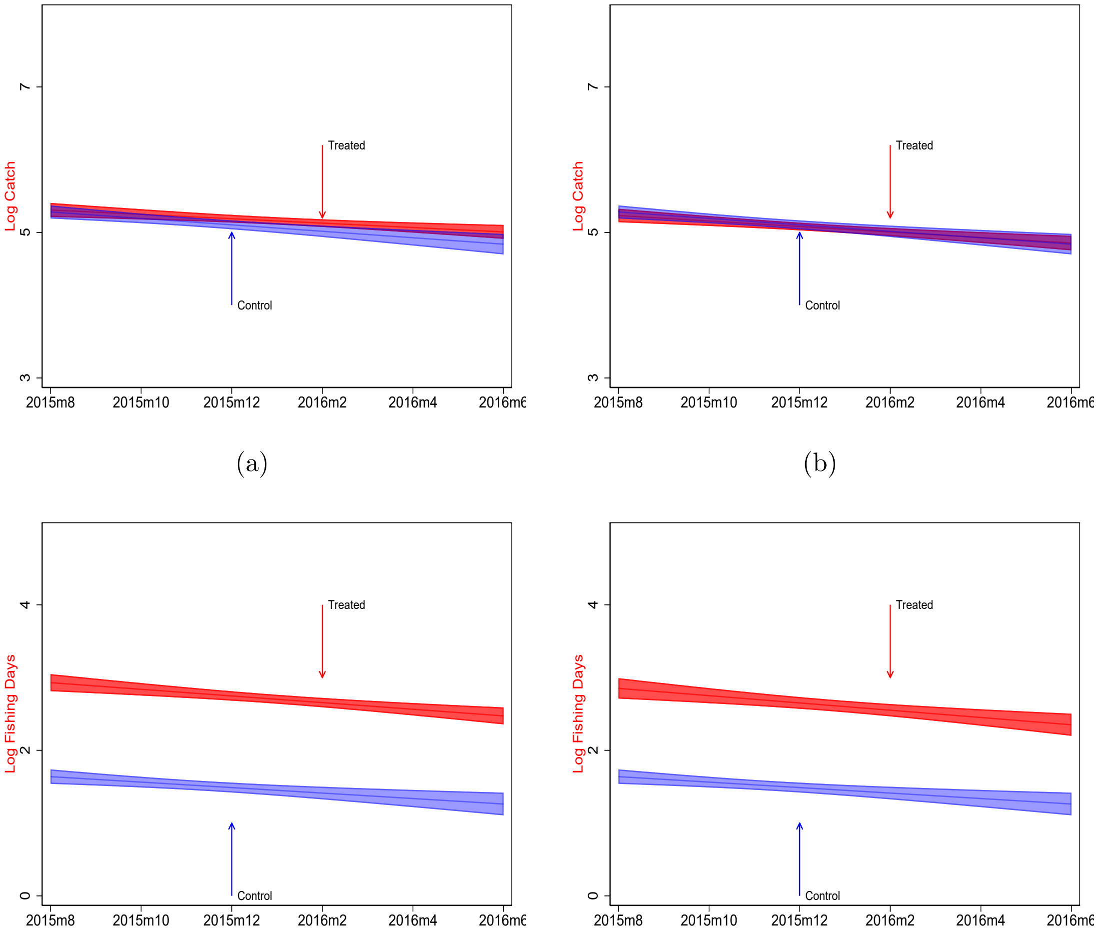


(a) (b)

Figure A.2: China's Fishing Activities (Heatmap) (a) Before and (b) After the expiration of the KJFA

Source: Global Fishing Watch (GFW)

Note: The data from GFW is not quite reliable, but we can see the fishing activity indirectly. The sample period is the same as our data.

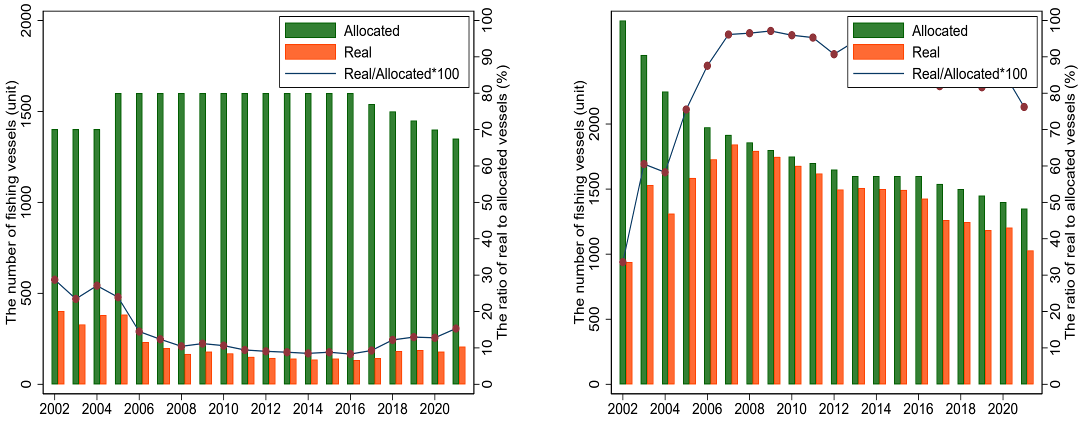


(a) (b)

(c) (d)

Figure A.3: The pre-trends of the catch and fishing day (local-polynomial)

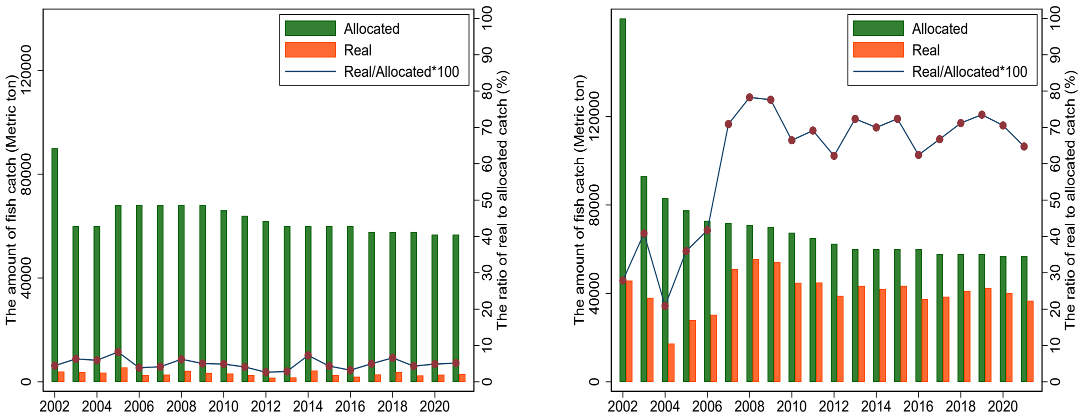
Source:
Note: Panels (b) and (d) exclude samples from China EEZ



(a) (b)

Figure A.4: The assigned and actual number of vessels to (a) China's EEZ (Korean vessels) and (b) Korea's EEZ (Chinese vessels)

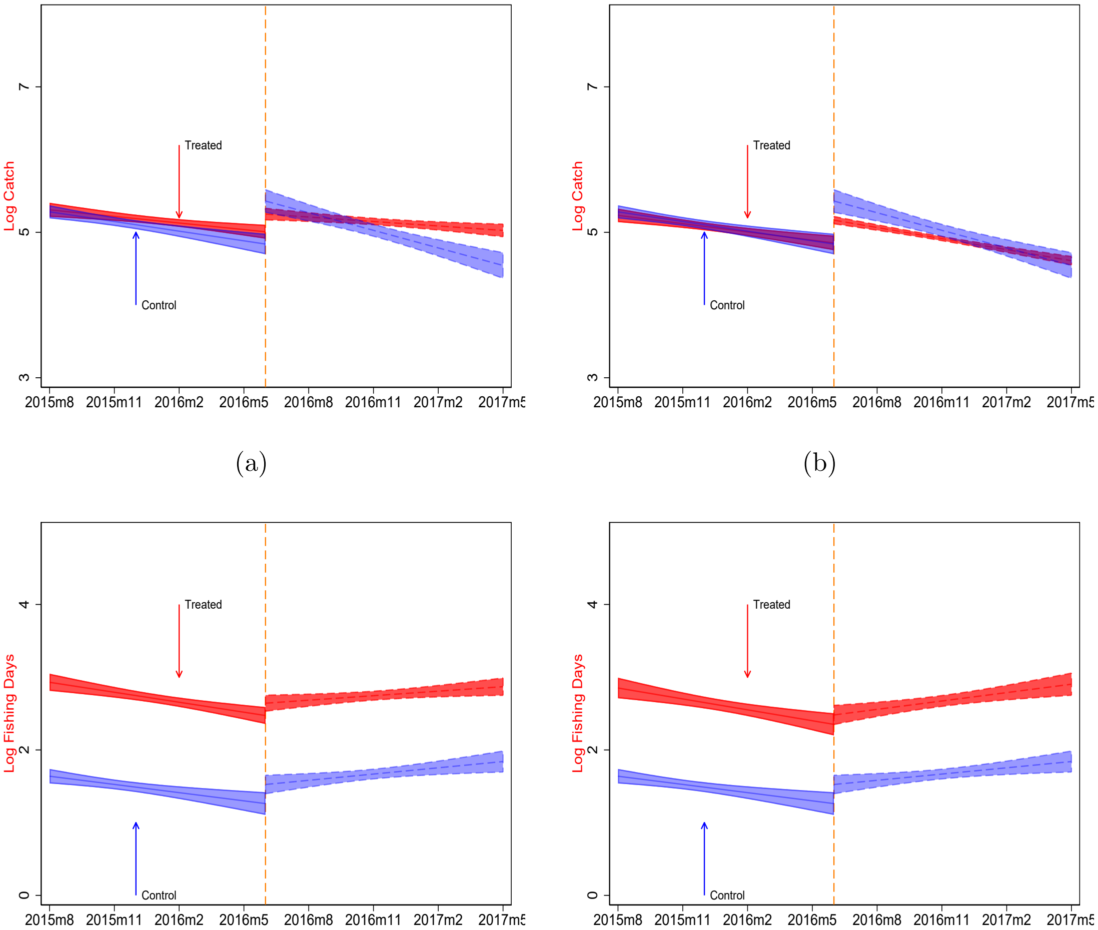
Source: Korean Ministry of Ocean and Fisheries
Note: Fishing year [2002 (2001.6.1 ∼ 2002.12.31)]



(a) (b)

Figure A.5: The assigned and actual catch in (a) China's EEZ (Korean catch) and (b) Korea's EEZ (Chinese catch)

Source: Korean Ministry of Ocean and Fisheries
Note: Fishing year [2002 (2001.6.1 ∼ 2002.12.31)]



(a) (b)

(c) (d)

Figure A.6: The trends of the catch and fishing day (local-polynomial)

Source:
Note: Panel (b) and (d) exclude sample from China EEZ

Appendix B

Chapter 2

Effect of Kyungju Earthquake: The Kyungju earthquake occurred in September 2016, and the Pohang earthquake occurred in November 2017. As mentioned in the previous section, I did not consider the Kyungju earthquake as an exogenous shock. However, there is a possibility that the shock may have affected housing prices near the NPP. Table A1 shows the effects of the Kyungju earthquake on housing prices for different cases (for 1 year). The coefficients of the interaction terms have positive values except for models 5 and 6 (columns 5 and 6), but those are not statistically significant. Therefore, considering the Kyungju earthquake as an exogenous shock is not reasonable to estimate the risk of the Gori NPP in the housing market.

Government Policy: On September 13, 2018, the Korean government announced the "Real Estate Comprehensive Plan" to regulate the increasing housing prices. The plan includes various regulation measures such as increasing the comprehensive real estate holding tax (CREHT) and transfer taxes, supplying houses to real demanders, and reducing the loan-to-value (LTV) ratio. The increasing house prices decrease the house supply due to the expectation of rising prices, resulting in suppliers having the upper hand over real house demanders. To address this issue, the government designated a speculation zone and a speculation-prone zone and applied the policy to these zones.

The main purpose of the policy is to eradicate speculative demand and protect real house demanders, as speculative demands have accelerated the unstable real estate market. To be specific, the policy includes increasing the comprehensive real estate holding tax (CREHT) rate on high-value houses (adding 0.2 to 0.7% tax rate to

Table B.1: The Effect of Kyungju Earthquake on House Price

Dependent Variable	Kyungju Earthquake							
(Log Price)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Treated	.001*	.006	.012	.016**	-.005	-.001	.004	.006
	(.009)	(.009)	(.007)	(.007)	(.010)	(.010)	(.008)	(.007)
Post	.123***	.124***	.017***	.022***	.121***	.122***	.017***	.024***
	(.004)	(.003)	(.004)	(.004)	(.004)	(.003)	(.004)	(.004)
Treated	-.010	-.223***	.007	-.125***	-.007	-.514***	.015	-.242***
	(.021)	(.057)	(.016)	(.036)	(.024)	(.121)	(.018)	(.075)
Covariates	x	x	o	o	x	x	o	o
Fixed Effect	x	o	x	o	x	o	x	o
Cluster	o	o	o	o	o	o	o	o
Buffer (500m)	x	x	x	x	o	o	o	o
Observations	22,523	22,523	22,523	22,523	20,347	20,349	20,349	20,349
R^2	.032	.300	.414	.597	.030	.322	.419	.607

Note: The covariates include house size (m^2), floor, building age and its square, the distances from each house to the nearest central business district, community service center, court, library, public health office, fire station, post office, and schools. Also, to control time trends and time-invariant heterogeneity, I include third-order time variables and county and town fixed effects. *, **, *** are representing 10%, 5%, 1% significant level, respectively. Standard errors are in parentheses.

people who own a house valued above \$1,800,000 and to people who own more than 2 houses which are valued above \$1,400,000), imposing an additional tax rate (0.1 to 1.2%) on people who own more than 3 houses or 2 houses in the zone, prohibiting purchases of houses for people who own more than 2 houses in the zone, stopping loan-to-value ratio (LTV) for purchasing high-value houses for non-residential purposes, reinforcing the criteria of transfer tax exemption for people who temporarily own 2 houses, increasing CREHT and transfer tax rates for lease business operators, and supplying 300,000 houses by alleviating regulation in downtown.

If the policy affects the housing prices used in this study, the results may be biased. However, fortunately, there are no areas designated as ”speculation zone” or ”speculation-prone zone” in the sample used in this study.

Parallel Trend: Though the coefficient of the second-month interaction term for Fukushima and the 12^{th} month interaction term are significant, those can be ignored because of the small number (.001 and .004, respectively).

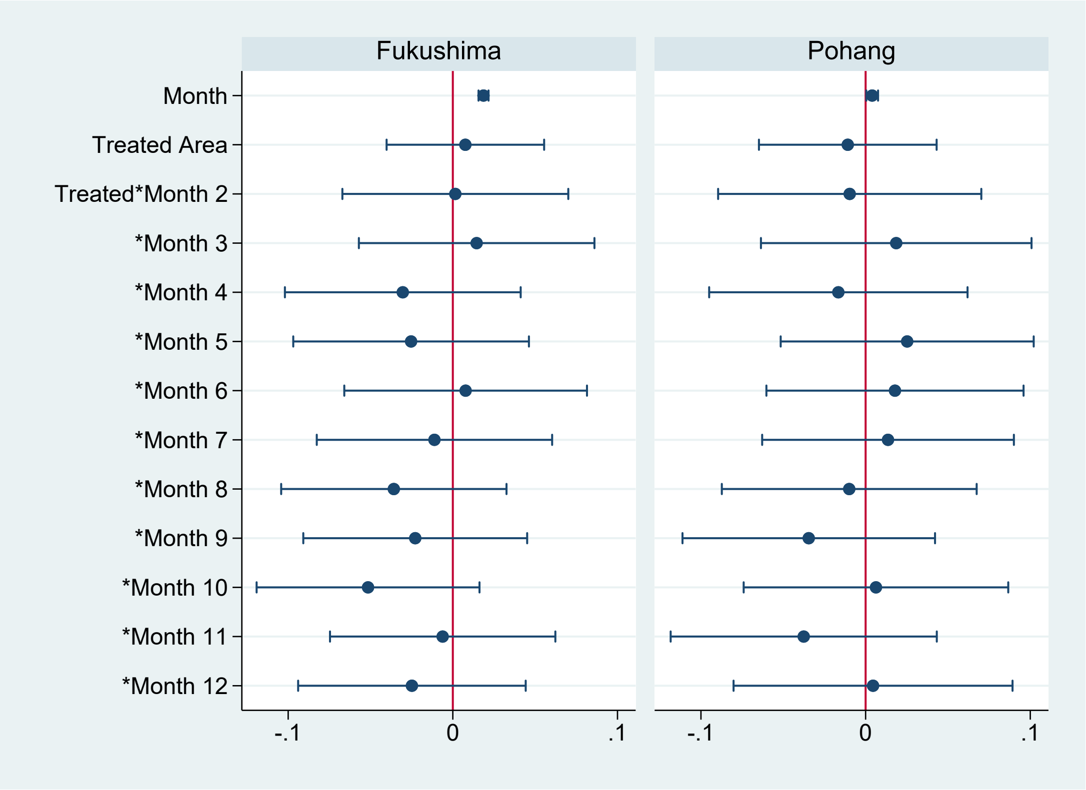


Figure B.1: The Coefficient Graph for Parallel Trend Test

Table B.2: Testing for Parallel Trend

Dependent Variable (Log Price)		Fukushima Accident (1)	Pohang Earthquake (2)
Month		-.018***	.003**
		(.001)	(.001)
Treated Area		.007	-.010
		(.024)	(.027)
Treated*Month	2	.001**	-.009
		(.034)	(.040)
	3	.014	.018
		(.036)	(.041)
	4	-.030	-.016
		(.036)	(.040)
	5	-.025	.025
		(.036)	(.039)
	6	.007	.017
		(.037)	(.039)
	7	-.011	.013
		(.036	(.038)
	8	-.035	-.009
		(.034)	(.039)
	9	-.022	-.034
		(.034)	(.039)
	10	-.051	.006
		(.034)	(.040)
	11	-.006	-.037
		(.034)	(.041)
	12	-.024	.004*
		(.035)	(.043)
Observations		10,389	10,217
R^2		.029	.004

Appendix C

Chapter 3

Table C.1: Time-line of Traffic Regulation Policies

Timeline	Policy	Applied Regions
Before 2017	Low Emission Zone	All (not strict)
Jan 2017		Seoul
Jan 2019		Incheon, 17 cities of Gyung-gi province
Jan 2020		11 cities of Gyung-gi province
Feb 2019	Emergency Reduction Operation	Seoul
Feb 2019		Gyung-gi province
Apr 2019		Incheon
Feb 2020	Seasonal Air Quality Control	All
Dec 2019	Green Transportation Zone	15 towns in Seoul

Table C.2: Time-line of Other Air Quality Control Policies

Timeline	Policy	Details
Jan 2006	Total amount of Pollutants Control from Stacks	Cap & Trade
Jan 2006	Low NOx burner Installation	Industrial sector
Jan 2017	Changing relative price of fuel by type	Increasing price of diesel
Jun 2017	Regulation of Coal Power Plant	No operation during winter and spring seasons
Jan 2020	Intensive Standard of Air Pollutant from Stacks (30% increase)	

Table C.3: SOx Emission from each Source in Seoul Metropolitan Area

Year	2012	2013	2014	2015	2016
Total	36,772	37,940	31,455	33,159	31,809
Energy Industry	8,188	11,088	7,573	8,896	9,174
Non-Industry	9,198	8,652	7,529	9,127	6,798
Manufaturer	4,805	3,941	6,023	4,591	4,763
Production	3,972	4,657	5,072	5,157	5,766
Motor	84	76	72	82	92
Non-Motor	8,720	8,837	4,455	4,422	4,348
Disposal	1,804	689	731	884	868

Source: NIER (2016)

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