Master's Thesis

Examining 50-year Time Series Data of Kitakyushu City, Japan: An Aggregate Microeconomic Approach for Environmental Kuznets Curve

by

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Abstract

As the economy grows, the living standard is improved, but some externalities are released into the environment threatening the sustainable development of the society. One of the most impactful externalities is air pollution. Recognizing the severe effects of air pollution, the United Nations has mentioned air pollution in three Sustainable Development Goals by 2030 as a significant negative factor that needs preventing. This study aims to examine the relationship between the average firm's size and air pollution as well as the effect of road infrastructure development in Kitakyushu city, well-known as a green city, using a dataset within the time from 1967 to 2015. The Auto-Regressive Distributed Lag model was employed along with pre-estimation and post-estimation tests for model specification, model stability and robustness checks. The results exhibit two different patterns among air pollutants as industrial firms grow. In particular, NO_2 and O_x emissions per capita possessed a downward trend relationship or inverted N-shaped curve when plotted with the average industrial firm's size, whereas SOx and falling dust emissions possessed an opposite trend or U-shaped curve when plotted with the average industrial firm's size. Also, the current study points out the trilemma among the industrial firm's growth, road infrastructure development, and air pollution prevention. However, we also found evidence that air pollution can be controlled while keeping industrial growth and road infrastructure development. Theoretically, the current study might be the first study to examine the Environmetal Kuznets Curve from the perspective of aggregate microeconomic behavior (average industrial firm's size). Practically, current findings point out the complexity and difficulties of pursuing sustainable development and suggest the importance of green growth policies and agenda set up for the city's sustainable development.

Keywords: Environmental Kuznets Curve; firm's size; air pollution; paved road; infrastructure development; Kitakyushu; Japan

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Certification Page

I, Nguyen Minh Hoang (Student ID 51217618) hereby declare that the contents of this Master's Thesis / Research Report are original and true, and have not been submitted at any other university or educational institution for the award of degree or diploma.

All the information derived from other published or unpublished sources has been cited and acknowledged appropriately.

NGUYEN, Hoang Minh

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1. Introduction

Due to the dramatic consequences of air pollution on the humankind, the United Nations have declared war on it. According to the World Health Organization (WHO), air pollution causes the deaths of 8 million global mortalities annually, in which more than 4 million people die because of ambient air pollution, while other deaths are due to exposure to smoke from cookstoves and fuels (United Nations, 2019). Despite the severe effect of air pollution, more than 90% of the world's population is still living in the area where air emissions exceed WHO standards (United Nations, 2019). Concerning the severity of air, United Nations has considered air pollution as an essential factor in three Sustainable Development Goals (SDGs) for Health (3), Energy (7), and Cities (11) (United Nations, 2019). The primary source of air pollution is industrial activities and transportation, which fuel the economic and social development of our world today. As the United Nations SDGs are set based on the interconnection of three different aspects: economic, social, and environmental aspects, concerning one of these aspects alone, might lead to incorrect judgement and unfavourable outcomes (Strange & Bayley, 2008). Thus, the problem of air pollution should not be judged alone, but other factors need to be taken into consideration as well, especially the economic factor.

Activities of industrial firms are ones of the primary sources contributing to air pollution, but researchers have not entirely clarified the effect of industrial firm's size on environmental degradation. Perhaps, there might be a common-sense that small industrial firms only contribute a small portion to environmental pollution (McPherson, 2008). Even though small firms are found to be more pollution-intensive on average than large firms, the negative impact of emissions from large plants is more substantial than small firms (Dasgupta, Lucas, & Wheeler, 2002). To elaborate, within the same manufacturing sector, the emission of air-borne and suspended particulate per employee from small plants (20 or fewer employees) is higher than that from larger plants. However, emissions from large plants result in most of the projected deaths. A study of Merlevede, Verbeke, & De Clercq (2006) points out a positive association between pollution and the firm's size, which confirms the impact of a large firm to the environment is more substantial than a small firm. There is a lack of studies that can demonstrate a holistic relationship between industrial firm's size and air pollution, in which economies of scale and technological advancement are included. In order to make sure that industrial firms might use the economies of scale and technological development to control pollution, the study site needs to be a location where pollution is considered as a type of cost. In other words, the study site has to pursue green growth development, which promotes pollution reduction in the manufacturing process. We selected Kitakyushu as the study site to examine the relationship between industrial firm's size and air pollution, because the green growth development in Kitakyushu city, one of four green growth cities in the world and a pilot city for OECD's Territorial Approach to the Sustainable Development Goals project (City of Kitakyushu, 2018), matches our presumption considering pollution as a type of cost. In Kitakyushu, industrial activities are strictly regulated, and financial incentives are given to investment into green technologies, which might make the industrial sector believe that the more they pollute, the more cost they bear and the more benefit they lose (OECD, 2013)

The Environmental Kuznets Curve (EKC) hypothesis was employed to better explain the relationship between industrial firm's size and air pollution. The EKC hypothesis is one of the most well-known propositions for the relationship between environmental pollution and economic development, whereas the industrial growth is one of the backbones of economic development (Dinda, 2004; Kijima, Nishide, & Ohyama, 2010). However, to the best of our knowledge, there are some studies of EKC between the share of industry in GDP and pollution (Apergis & Ozturk, 2015; Zhang & Zhao, 2014), but there have been no study of EKC employing the industrial firm's size as an indicator for industrial growth. A limitation of using a share of the industrial sector in GDP as an indicator for the industrial development is that the index can be affected by changes in other sectors of the economy, which makes it hard to demonstrate the changes of air pollution according to industrial growth. Besides that, according to the review of Kijima et al. (2010), there has been no study employing the aggregation of microeconomic behavior in the examination of EKC. Therefore, we utilized the average industrial firm's size as the indicator of economic development in order to fill in the suggested gap in the literature. Therefore, it is plausible to examine the relationship between industrial firm's size and air pollution.

Another factor that might significantly affect the level of air pollution is the development of infrastructure. Infrastructure is the backbone of any countries, with a good design infrastructure expansion can contribute to the sustainable development; otherwise it will result in negative consequences on society and environment (Thacker et al., 2019). On the one hand, the expansion of high-quality road may increase travelling demand (Cervero, 2003). On the other hand, building a more high-quality road will help enhance manufacturing productivity (Duran-Fernandez & Santos, 2014), which will indirectly facilitate air pollution reduction. To our knowledge, the study regarding of the effect of infrastructure development on air pollution has been limited; thus, it is essential to examine the impact of infrastructure development, specifically high-quality road, on the level of air pollution in Kitakyushu city, in which industrial activities occupy a substantial role in boosting the economy.

From the points mentioned above, this study has two main objectives:

1. Examining the shape of the relationship between air pollution and industrial firm's size in Kitakyushu city employing the Environmental Kuznets Curve model.

2. Examining the impact of road infrastructure development on the level of air pollution.

The results of this study are expected to provide insights into the EKC from an aggregate microeconomic approach, which has been limited in the literature. Moreover, policymakers could also employ the results of this study as references for their current and future sustainable development plans and policies.

2. Literature Review

This section aims at providing an overview of the theoretical and empirical findings related to the Environmental Kuznets Curve hypothesis. Theoretically, the EKC hypothesis stated there is an inverted U-shaped relationship between economic development and air pollution. The curve is quite intuitive, and there are many explanations for it. In the early stage of economic development, pollution emission increases rapidly due to industrialization. In the later stage, as income rises beyond a certain level, stricter regulations were imposed, and R&D in clean technologies is increased, which help reduce the impact of pollution. Regarding empirical studies, many supporting along with countering pieces of evidence have been found. The relationship between industrial growth-related factors and air pollution has been also examined, but there have been no studies employing an aggregate microeconomic indicator. Moreover, there is also a lack of studies regarding the impact of road infrastructure on air pollution.

2.1. Theoretical background

2.1.1. Kuznets Curve in economics

The idea of the Kuznets Curve was initially presented by Simon Kuznets at the 67th annual meeting of the American Economic Association in 1954 (Kijima et al., 2010). In his presentation, he explained the relationship between “Economic Growth and Income Inequality”, which denotes the change of income inequality according to economic growth. According to (Kuznets, 1955) as income per capita increases, income inequality increases accordingly at first and then starts declining at a certain point. The changing of income inequality according to the change of income per capita can be illustrated by an inverted U-shaped curve, which is well-known as the Kuznets Curve.

The theoretical idea of Simon Kuznets was later tested by other researchers using various methods in different regions. Not only do Randolph & Lott (1993), Barro (2000), Jovanovic (2018) and many others found empirical evidence for the existence of inverted U-shape curve relationship between economic growth and income inequality, but Ram (2017) also found the inverted U-shape curve for economic growth and happiness inequality. Ahluwalia (1976) used multiple regression to estimate the cross-country relationship for inequality and found some evidence supporting the hypothesis of Simon Kuznets. Barro (2000), (Jovanovic, 2018), and Randolph & Lott (1993) examined the hypothesis and found the inverted U-shape relationship between inequality and economic development under some conditions. Findings of Ram (2017) also showed the Kuznets Curve shape in the relationship between average happiness and happiness inequality. However, theoretical analyses for the existence of the Kuznets Curve are quite limited (Kijima et al., 2010).

In general, the idea of the Kuznets Curve has been examined not only in economics but also across multiple disciplines.

2.1.2. Environmental Kuznets Curve

The term Environmental Kuznets Curve (EKC) first appeared in the early 1990s, as Kuznets Curve relationship was found again in the environmental context. The findings of some empirical studies resulted in the inverted U-shaped pattern of Kuznets Curve in the relationship between environmental degradation and income per capita. The term was first mentioned independently in three working paper: (i) an NBER working paper about environmental impact of NAFTA (Grossman & Krueger, 1991), (ii) the World Development Report 1992 of World Bank (Shafik & Bandyopadhyay, 1992), and (iii) a Development Discussion report for International Labor Organization (Panaǐotou, 1993). Those three studies reached the same conclusion that some environmental pollutants had an inverted U-shaped relationship with income per capita by using cross-country analysis. However, Panaǐotou (1993) was the first to refer to the term 'Environmental Kuznets Curve' (EKC) due to its similarity with Kuznets Curve. Since then, the Environmental Kuznets Curve has become a term to describe the relationship between level of impact on environment and income per capita.

To explain the EKC relationship, researchers proposed four major explanations. First, when a country achieves a sufficient level of living standard, people in that country starts to pay more attention to the value of environmental amenities (Pezzey, 1992; Selden & Song, 1994). Therefore, when the income per capita is beyond the amount required for a sufficient living standard, people are more willing to pay more to clean environment. Second, the level of pollution rises according to the structural transformation of the economy from rural to urban or from agriculture to industrial, and then the pollution drops as the economy transforms from energy-intensive industry to services or knowledge-based technology-intensive industry (Grossman & Krueger, 1991). Third, a wealthier nation can invest more in R&D, which leads to the occurrence of technological progress along with economic growth. As a result, other dirty and unprogressive technology will be replaced and upgraded to new and cleaner technologies, which eventually produce less impact on the environment (Komen, Gerking, & Folmer, 1997). Fourth, the adaptation of environmental-friendly policies is usually constrained by the political system or some cultural values, but such policies are more likely to be accepted after the economy grow high enough (Ng & Wang, 1993).

Overall, the logic of the EKC hypothesis is quite intuitive, which suggests that environmental degradation problems can be solved by economic development.

2.2. Empirical background

The relationship between environmental degradation and economic growth was first mentioned by Grossman & Krueger (1991). In the paper prepared for the conference on the free trade agreement between the US and Mexico, they mentioned that further trade liberalization would ease the environmental problems. With an expansion of economic activities, alteration of economical composition, and technical advancement in production due to trade liberalization, air pollutants might be reduced. Employing a cross-sectional study from data collected from urban areas in 42 countries, the authors examined the relationship between economic development and air pollution. Among three air pollutants being used, two pollutants which are sulfur dioxide and smoke concentration were found to have an inverted U-shaped relationship with economic development. The turning points of two curves were at around $4,000 and $5,000 per capita. Since the first empirical evidence of EKC, the debate of the "grow first and clean later" idea has become heated than ever with many supporting and countering theories as well as empirical evidence.

Shortly after that, another empirical evidence of the relationship between environmental degradation and economic growth was found by Shafik & Bandyopadhyay (1992)in a background paper for World Development Report 1992. The authors used the data collected from 149 countries during the period from 1960 to 1990 to examine the association between economic growth and environmental quality. The indicators for environmental quality included the lack of clean water, the lack of urban sanitation, the level of suspended particulate matter (SPM), the level of sulfur dioxide (SO_2), forest area from 1961 to 1986, the annual rate of deforestation, e.g. Economic development was measured by GDP per capita according to Power Purchasing Power (PPP) and technology was proxied by time trend. Using the log-linear, quadratic, and cubic models, the study presented three significant results. First, clean water and urban sanitation were found to be positively correlated with economic development. Second, the rise of income led to the monotonical increase in the level of dissolved oxygen in rivers, municipal waste, and level of carbon dioxide (CO_2). Lastly, the bell-shaped relationship between economic development and environmental quality was found in SPM and SO_2. In particular, the quadratic relationship between GDP per capita and SO_2 possessed a turning point at around $3,670 per capita.

Panaĭotou (1993) later examined the empirical evidence of an inverted U-shaped relationship between environmental degradation and economic development. Besides Sulphur Dioxide (SO_2) and solid particulate matter (SPM), he also proxied Nitrogenous Oxides (NO_x) and deforestation for air pollution and natural depletion respectively. Similar to the research by Grossman & Krueger (1991), Panaĭotou also implemented a cross-sectional analysis using data from 27 developed and 41 developing countries for which data are available. His findings confirmed the existence of an inverted U-shaped relationship between deforestation and economic growth, SO_2 and economic growth, NO_x and economic growth, and SPM and economic growth. However, as the squared term of the model in which SPM was a dependent variable only explained 12% of the variation, the result was rejected. The turning points of the inverted U-shaped curves of the relationships of economic development with deforestation and air pollution were found at between $800 - $1,200 per capita and $3,800 – $5,500 per capita. Notably, Panaĭotou was the first who coined the term "Environmental Kuznets Curve" for the inverted U-shaped relationship between economic growth and environmental degradation.

Since the first three studies viewed as cornerstones of the EKC hypothesis, many more environmental economists have actively engaged in enriching the literature for the hypothesis. Selden & Song (1994) are some of the first to identify an inverted U-shape curve between air pollution and economic development. The air pollution consists of suspended particulate matter, sulfur dioxide, oxides of nitrogen, and carbon monoxide. They use the cross-sectional panel of data on emissions of four pollutants and find out that GDP per capita exhibit inverted U-shape relationships with emission per capita of all four pollutants. Besides, they also forecast that the emissions will decrease in a very long-run, and the global emission will continue to grow significantly over the next several decades.

In the same year with the publication of Selden & Song (1994), Cropper & Griffiths also provided empirical evidence for the EKC by doing a panel data analysis in the relationship between deforestation and level of economic development. As deforestation is usually a significant problem in non-OECD countries, the research was limited among African, Asian, and Central and South America countries. Employed deforestation data were drawn from the Food and Agriculture Organization's Production Yearbook, while the data on population and per capita GDP were taken from the dataset of Summers and Heston. The analysis results exhibited an EKC between deforestation and per capita GDP for Africa and Latin America and a positive association between population density and deforestation in Africa. In Africa, the level of tropical deforestation started to drop when GDP per capita grew beyond $4,760, whereas the level of tropical deforestation in Latin America started declining as GDP per capita reached $5,420.

Since the several first scientific cornerstones of the idea “grow first, clean later”, EKC has become more and more popular among scientist around the world, which leads to the increase in quantity as well as the quality of scientific studies about EKC. Environmental scientists and economists started to use not only many other proxies for economic development as well as environmental degradation but also employ new analysis techniques to investigate the possibility and robustness of the EKC.

Not using the typical parametric analysis, (Azomahou, Laisney, & Nguyen Van, 2006) employed a nonparametric approach analysis to check the robustness the EKC. The study looked at the EKC between GDP per capita and CO_2 emissions per capita using the panel data of 100 countries during the period between 1960 and 1996. The relationship between GDP per capita and CO_2 emissions per capita was found to be monotonically correlated, which rejected the hypothesis of EKC. Azomahou, Laisney, & Nguyen Van (2006) recommend developed countries should join hands with developing countries to control pollution utilizing their excessive resources (capitals, technologies, etc.), as the economic development cannot solely solve the environmental problems.

Unlike other studies before, the work of (Galeotti & Lanza, 2005) aimed to recheck the robustness of EKC by doing analysis under different parametric setups and using different types of air pollution. The results indicated that there were different shapes of EKC between OECD countries and non-OECD countries. While OECD possessed evidence of EKC regardless of the dataset, non-OECD countries experienced a slowly concave based on International Energy Agency (IEC) and a more bell-shaped curve based on the Oak Ridge National Laboratory.

Employing new variables to explain the relationship between environmental degradation and economic development, Dutt (2009) added new variables like population density, governance, political institutions, government expenditure on education, years of schooling, socio-demographic factors into the model. Dutt collected his data from multiple sources, such as the World Bank, Political Risk Services Group, and Education Policy & Data Center. In overall, the dataset contains the information during the period 1985 – 2000 in 94 countries. The obtained findings from three different specifications (Robust OLS, FE Year, or FE Country) exhibited an existence of EKC between income and CO_2 emission, of which the turning point was expected to be around $27,000 to $30,000. Moreover, the impact of the interaction between the quality of governance and political institutions was found. The interaction was negatively correlated with the CO_2 emission, solidifying the importance of policy and government intervention in control environmental degradation.

Gassebner, Lamla, & Sturm (2011) believed that we should not focus on one hypothesis and limit the number of control variables. They, therefore, took variables of all hypothesis (economic, social, political, demographic variables) into account to check the sensitivity between them to ensure they have a robust impact on air and water pollution. Biochemical Oxygen Demand (BOD) was a measure of water pollution, while the measure of air pollution was CO2 and SO2. Gassebner et al. initially reviewed recent literature to seek variables proposed to be significant determinants of pollution. Then, they applied the Extreme Bound Analysis (EBA), a neutral means to check robustness issues and compare the validity of conflicting findings in empirical research, on a panel of 120 countries from 1960 to 2001. The eventual outcome of their study captured the existence of EKC for water pollution with a turning point around $26.800 per capita (in constant 1995 prices) but shows no evidence of EKC for the presence of air pollution.

Also augmenting the conventional EKC, Zhang & Zhao (2014) inputted the new variables into the model in order to explain the mechanism of EKC regarding the income inequality, the share of the industrial sector, the urbanization rate, and technological improvement. The dataset comprises of panel data of 28 provinces in China from 1995 to 2010 collected from China Statistical Yearbook, China Compendium of Statistics, and China Energy Statistical Yearbook. The study’s findings illustrated an N-shaped relationship between economic growth and CO_2

emission, which meant economic growth increased air pollution. Furthermore, income inequality was found to be a statistically significant predictor of CO_2 emission. In other words, equal income distribution could lead to a decline in CO_2 emission. the

Another research testing the impact of the industrial sector's share in the economy on environmental degradation was conducted by Apergis & Ozturk (2015). The authors executed the dataset of 14 Asian countries spanning from 1990 to 2011 by applying the GMM method. The selected independent variables included GDP per capita, land, industry share in GDP, and five other indicators of demographic and institutional factors. After the analysis, the EKC between economic growth (GDP per capita and industry share in GDP) and CO_2 emission was found.

On the other hand, the EKC was rejected in another study investigating the relationship between income and CO_2 emission. The study of Özokcu & Özdemir (2017) came up with two different models employing the data of 26 OECD countries from 1980 to 2010 and the data of 52 developing countries during a similar period. The results were relatively consistent and robust, indicating an N-shaped relationship between GDP per capita and CO_2 emission.

Different from other peers using panel data the estimate the Kuznets curve in environmental degradation, De Bruyn, Van Den Bergh, & Opschoor (1998) were some of the first to use time-series data. CO_2, NO_x, and SO_2 emissions were indicators for environmental pollution; economic development was represented by GDP per capita, structural and technological changes; energy price was also included as a predictor of environmental pollution. The data used covered several time intervals between 1960 and 1993 in four countries: the Netherlands, Western Germany, the UK, and the USA. The result implied that CO_2, NO_x, and SO_2 emissions were positively correlated with the GDP per capita, but those emissions would decline due to the structural and technological changes.

Akbostancı, Türüt-Aşık, & Tunç (2009) formulated time-series data and panel data models of the relationship between environmental pollution and economic development based on the studies of De Bruyn et al. (1998) and Dinda (2004). The time-series model was tested within the time interval from 1968 to 2003, while the panel data model covered 58 Turkish provinces during the period between 1992 and 2001. The model employed the emissions of SO_2, SPM, and CO_2 as indicators for environmental pollution, GDP per capita as an economic indicator and population density. Data of air pollution, GDP of provinces and population densities were drawn from Turkish Statistical Institute (TURKSTAT); data of CO2 per capita and GDP per capita in constant 2000 US were drawn from World Bank World Development Indicators (WDI). Applying the Johansen's cointegration analysis technique, the time-series data model implied a monotonical relationship between CO_2 per capita and income. On the other hand, the panel data model pointed out an N shaped curved relationship between air pollutants (PM_{10} and SO_2) and income. Particularly, the two turning points of the curve were at $1,609 and $5,746 for the relationship between PM10 and income, while for the relationship between SO2 and income, the turning points were at $1,934 and $5,817. Both time-series data and panel data provided evidence countering the hypothesis of EKC.

The heat from the debate whether the EKC exists or not has elevated rapidly by the number of supporting articles as well as countering articles added to the literature review. In Cambodia, the EKC was rejected again. Investigating the validity of EKC utilizing the annual data from 1996 to 2012, Ozturk & Al-Mulali (2015) found that the relationship between GDP per capita and air pollution was a U-shaped curve. Besides, they suggested that the total electricity consumption, corruption control, and government effectiveness were significant determinants of air pollution.

Rafindadi (2016) recently reexamined the existence of EKC in Japan by using the Zivot-Andrew structural break test, ARDL bound test to analyze the data from 1961 to 2012. The study confirmed the existence of EKC in Japan despite the country's energy disaster in Fukushima and deteriorating income. The finding also addressed energy consumption to be a major contributor to environmental degradation in Japan.

In general, among investigations of EKC, GDP per capita is the most frequently used proxy for economic development. Even though some studies mentioned the impact industry share in GDP on environmental degradation, it seems like no studies have examined the impact of average industrial firm's size on environmental degradation. The industry share in GDP can represent the impact of industrial production, but cannot explain the heterogeneity at the firm level, which might be possibly a significant determinant of air pollution. Moreover, to our knowledge, the impact of infrastructure on air pollution has been limited. For those reasons, this study aims to fill in these gaps in the literature.

3. Methodology and Materials

3.1. Kitakyushu

This study selected Kitakyushu city as a study site for several reasons. Besides being featured as one of four green growth cities in the world besides Paris, Chicago, and Stockholm, and the first green growth city in Asia, Kitakyushu city was also selected as a pilot city for OECD's Territorial Approach to the Sustainable Development Goals project (City of Kitakyushu, 2018). The model developed from data collected in Kitakyushu could be applied in other and future green-growth oriented cities and regions. Second, Kitakyushu city is a green-growth oriented city, in which sticks and carrots are making the private sector to consider pollution as a type of cost. Third, the data regarding industrial firms are available.

Kitakyushu was founded in 1963 by merging five cities into one centre-of-industry to develop heavy chemical industry and fuel the miracle economic growth of Japan after wartime destruction. It is situated in the northern part of Kyushu and facing Honshu over the Kanmon channel (The World Bank, 1996). Due to Kitakyushu's strategic location, exporting manufacturing products to other Asian countries has become one of the major economic driving forces of the city.

The development of Kitakyushu is closely connected with its massive chemical industrial corporations. Before the Second World War, many enormous mental, chemical, ceramics manufacturing firms and power plants already concentrated within the area of Kitakyushu, which dramatically polluted the air and water conditions. "The seven-colored smoke", which was created by dust and sulfur dioxide, was formerly considered as a symbol of prosperity, especially when Kitakyushu was selected as one of four key-driven areas including Tokyo, Nagoya, Osaka, and Kitakyushu, to form a "Pacific Belt Zone" in order to reconstruct the economy after the wartime. The success of that plan was apparent by increasing the national income by 3.3 times from 1960 to 1970 (Yoshioka & Kawasaki, 2016). However, the negative impact of that plan was also no less transparent. The environmental degradation in the Kitakyushu's region was substantially intensified and resulted in a severe decline of the health of citizens. The measured amount of soot, dust, Nitrous Oxide (NOx), particulate matter, and Sulphur Oxides (SOx) concentrating in the environment very much surpassed the standard of World Health Organization (WHO).

In order to counter environmental degradation, the engagement of citizens played a crucial role. Many citizens sent their complaints to the manufacturing organization, and some even set up petitions to the administration calling for improvement. Many woman's associations were formed to combat pollution and degradation of health due to local industrial production (OECD, 2013). Notably, the campaign "We want our Skies back" in 1965 was launched by the federation of 13 women's organizations to support the public sector and private companies to collaborate in order to fight industrial pollution. Because of the public pressure and political competition from Communist party with its environmental-friendly agenda, local authority and private sector had to reach a general compromise by the first pollution control agreement in 1967 (Fujikura, 2007). The enactment of "Pollution Diet" law at the late 1970s marked the transformation of Kitakyushu's pollution management system to be more "comprehensive, systematic, and steady" (The World Bank, 1996, p. vii).

Due to the continuous efforts of the public sector, private companies, and local government, the environmental conditions in Kitakyushu were rapidly recovered and improved. By 1985, the city was introduced to OECD's White Paper as a successful transformation from "city of gray" to "city of green". A few years later, the city was selected as "starlight town" by the Environment Agency for its clean air environment (The World Bank, 1996)

In order to continue the success of keeping the environment clean while developing industrial production, Kitakyushu city initiated a plan investing in the recycling industry as one of the first steps to promote green growth development. This movement laid a strong foundation for Kitakyushu to be qualified for the "Eco-Town" pilot project in 1997. As of 2012, the total private and public investments into the project reached around $607,3 million; 72% of that amount was from private companies, 15% was from the national government, 10% was from local government, and the rest was from other sources (OECD, 2013). The next step of Kitakyushu toward green growth was increasing energy efficiency among primary industries to reduce the amount of pollutant. By implementing energy-efficient and resource-saving in heavy-industrial firms, a significant volume of air emission has been cut off during their production process. Companies that contribute to the pollution reduction is qualified as "Eco-Premium"; labelling the product as

“Eco-Premium” helps increase product awareness and growth through branding (OECD, 2013). Additionally, investing in Research and Development (R&D) of semiconductor, Information and Communication Technologies (ICT), and green technologies also helps the city orient green growth development. The expenditure of Kitakyushu city for green technologies R&D grew 4.6% annually from 2006 to 2011; the expenditure on green technology R&D was $17.3 million in 2011, accounting for 0.05% of the city’s GDP (OECD, 2013).

By investing comprehensively and strategically in green growth development, Kitakyushu aims to transform from a heavily polluted industrial city to a leading eco-city worldwide. In 2004, the city launched “The Grand Design for a World Capital of Sustainable Development” with a vision to make Kitakyushu become a “World Capital of Sustainable Development”. Therefore, Kitakyushu is a typical worth studying site for the examination of EKC between air pollution and industrial firm’s size as well as urban infrastructure development.

3.2. Data

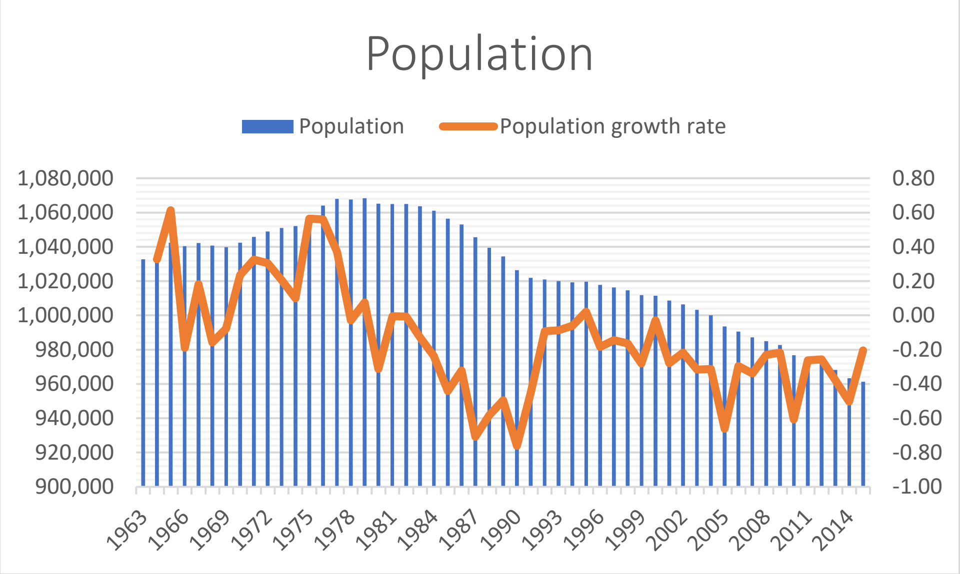
This study examined the EKC between industrial firm's size and air pollution, and the impact of infrastructure development on the level of air pollution by data provided by the city of Kitakyushu. The dataset contains the population in Kitakyushu, the amount or concentration of air pollutants, the information of the industrial statistics survey. For proxying the air pollution in Kitakyushu, this study employed all five types of air pollutants that were given by Kitakyushu city's Environment Bureau, namely: dust, Nitrogen dioxide (NO_2), Photochemical Oxidant (Ox), Carbon Monoxide (CO), and Sulfur Oxides (SOx). The data of the number of firms and shipments of manufactured goods were drawn from the industrial statistics survey. The dataset mainly ranges from 1963 to 2015; however, data of some indicators were not available in several years. For example, the concentration of SOx only covers the period from 1967 to 1999. Details of each indicator were explained coherently in the following subsections.

3.2.1. Population

The dataset of population provided by the city of Kitakyushu includes four significant indexes, which are the number of households, the number of citizens, the number of males, and the number of females. The dataset covers the period between 1932 and 2016. However, in this study, only the data of population ranging from 1967 to 2015 were employed.

During the period from 1967 to 2015, Kitakyushu's population declined by 6.91% from 1,032,648 to 961,286 people (see Figure 1). Kitakyushu's population peaked in 1979 with 1,068,415 people but kept on decreasing until now by 0.29% per year, which was opposite the number of households. This difference could be explained by the escalation of single people who do not want to get married. Moreover, the migration of young people to a bigger city, such as Tokyo, Osaka, or Fukuoka, might be another reason for the difference between the number of households and population.

Figure 1: Population and its growth rate from 1963 to 2015



3.2.2. Air pollutants

The data of air pollution provided by Kitakyushu city's Environment Bureau consists of five types of air pollutants (dust, NO_2, Ox, CO, and SOx). According to Environmental Quality Standards of Ministry of the Environment in Japan, five major indicators of the environmental quality standard are Sulfur dioxide (SO_2), Carbon Monoxide (CO), Suspended Particulate Matter (SPM), Nitrogen dioxide (NO_2), and Photochemical Oxidants (Ox) (Ministry of the Environment Government of

Japan, 2019). Even though the dataset given by the city of Kitakyushu was not utterly similar to indicators in the Environmental Quality Standards list, it can still proxy for air pollution due to its characteristics. However, due to the difficulty in measuring air pollutants, the covering year of each type of air pollutants is different. As the level of pollution might change according to the size of the population in the city, the level of all types of air pollution was measured by the amount of the air pollutant in Kitakyushu divided by the population in Kitakyushu.

The amount of dust. The dust measured in Kitakyushu city is called the falling dust particle, which is large and easy to settle on the ground by the effect of gravity and rain (The Government of Japan, 2019). The amount of dust is measured in tons/ km^2/month per capita. To measure the amount of falling dust, Kitakyushu set up 11 measurement stations within the city (Environment Bureau Environment Monitoring Department Environment Monitoring Division, 2019). The falling dust particles mainly come from the burning of coal, coke, and heavy oil (Living Environment Division, 2019) for electricity or heavy-industrial production.

The amount of falling dust per capita and its growth rate from 1963 to 2015 are displayed in Figure 2. There was a clear decreasing trend during the period between 1963 and 1977, in which the amount of dust per capita declined by 72.28%. However, after a steep decrease, the amount of dust in Kitakyushu city seemed to be stationary around 0.000005 tons/km^2/month per capita.

The concentration of NO_2. NO_2 is one of the most common air pollutants in metropolitan areas. It is mainly produced by the combustion of fossil fuels of vehicles and industrial factories or the burning of the organic component containing nitrogen during human activities. The high concentration of NO_2 can lead to acid rain, photochemical air pollution, and adverse effects on human health, especially respiratory problems (Environment Bureau Environment Monitoring Department Environment Monitoring Division, 2019). The concentration of NO_2 can be measured by colorimetry utilizing Saltzman reagent or chemiluminescent method employing ozone (Ministry of the Environment Government of Japan, 2019). In Kitakyushu, there are 19 measuring spots the concentration of NO_2.

Figure 3 presents the concentration of NO_2 per capita and its growth rate from 1970 to 2015. The measuring unit of the concentration of NO_2 per capita was parts per million per capita. In general, the concentration of NO_2 per capita decreased by 29% during the period from 1970 to 2015, and the trend was fluctuating. The concentration of NO_2 per capita even rose up to 0.0000000304 ppm per capita in 1973 before it started to decline.

The concentration of Ox. Along with NO_2, the concentration of Ox in the atmosphere are measured to assess the standard environmental condition in Japan (Ministry of the Environment Government of Japan, 2019). Ox is a secondary air pollutant created by the impact of sunlight on the sophisticated photochemical reaction between nitrogen oxides and reactive hydrocarbon as precursors (Guderian, 1985). The concentration of Ox can cause negative consequences on vegetation and ecological performance of plant life (Guderian, 1985). Nineteen measuring stations were used to measure the concentration of Ox in Kitakyushu (Environment Bureau Environment Monitoring Department Environment Monitoring Division, 2019). The concentration of Ox can be measured in many ways, such as using a neutral potassium iodide solution to absorb spectrophotometry, ultraviolet absorption spectrometry, or chemiluminescent method using ethylene (Ministry of the Environment Government of Japan, 2019).

Figure 4 displays the concentration of Ox per capita during the period from 1971 to 2015, measured by parts per million per capita. Unlike other types of air pollutants, the concentration of Ox per capita increased by 12.3% after 44 years. The concentration of Ox per capita was relatively fluctuating over time. Its bottom was at 0.0000000207 ppm per capita in 1980, while its peak reached 0.0000000354 ppm per capita in 2015.

The concentration of CO. The concentration of CO in the atmosphere is also listed as one of five substance indicating the environmental quality standard of Japan (Ministry of the Environment Government of Japan, 2019). The measuring method of the concentration of CO is nondispersive infrared analyzer method. Some of the major causes of CO emission are vehicles exhaust and industrial activities, like producing steel. CO can negatively affect human health by reducing the amount of oxygen in red blood cells which results in a shortage of oxygen in vital organs, such as the heart, the brain, etc. (The Government of Japan, 2019).

Even though the concentration of CO per capita measured by ppm per capita declined by 66.48%, it was not stationary in the period between 1975 and 2015 (see Figure 5). From 1975 to 2003, the change in the concentration of CO per capita was very high, but it gradually had more stability from 2004 until now. Notably, the growth rate was significantly high in 1980 and 1992 with 40.38% and 40.29% respectively.

The concentration of SOx. Although the data of SOx, one of five indicators of environmental quality standard in Japan, was not available, there is an availability of SOx. The concentration of SOx refers to one or more kind of compounds containing oxygen and sulfur, such as SO, SO_2, SO_3, etc. These compounds are mainly created by burning fuels containing sulfur, like heavy oil. Reducing lung function, increasing incidence of respiratory symptoms and diseases, irritation of the eyes, nose, throat, etc. are some of the impacts of SOx on human health. The concentration of SOx was collected at 19 measuring spots in Kitakyushu (Ministry of the Environment Government of Japan, 2019).

As for the concentration of SOx per capita, the trend was relatively stable from 1967 to 1999 (see Figure 6). After the sharp increase of 58.58% in 1968, the concentration of SOx dropped steadily from 1968 to 1999 by -7.98% annually. In total, the concentration of SOx per capita declined dramatically by 91.01% from 1968 to 1999, which was the most considerable decline among the five air pollutants.

Figure 2: The amount of dust per capita from 1963 to 2015

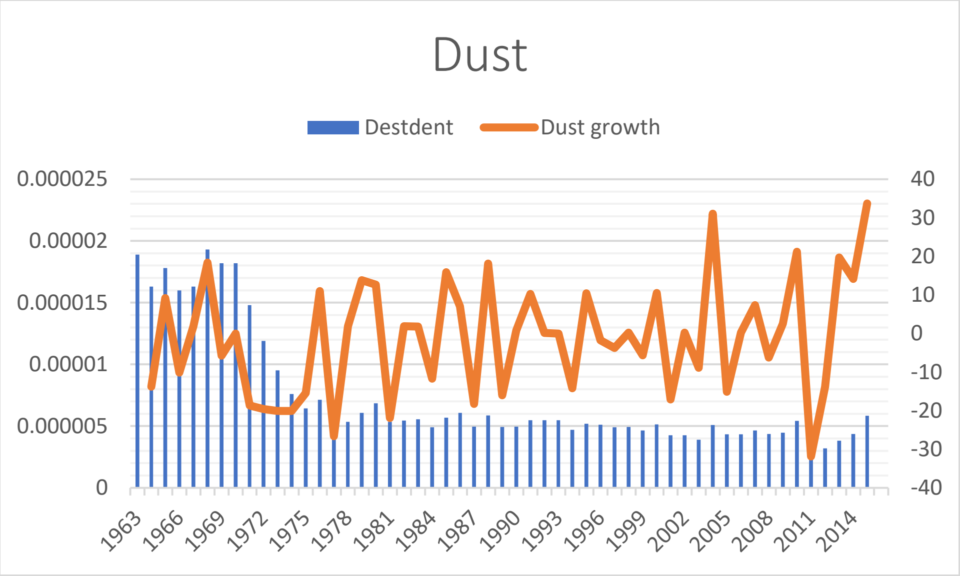


Figure 3: The concentration of NO_2 per capita from 1970 to 2015

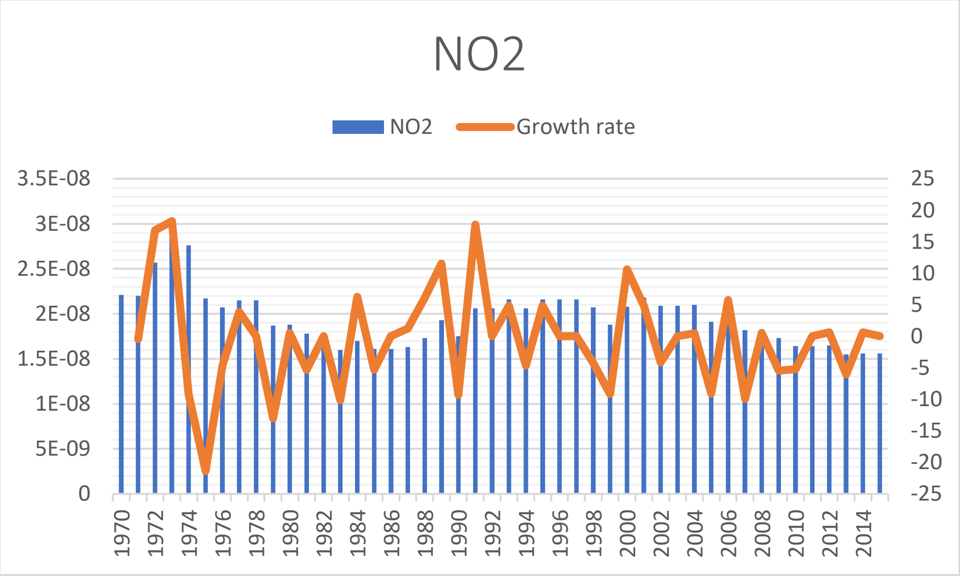


Figure 4: The concentration of PO per capita from 1971 to 2015

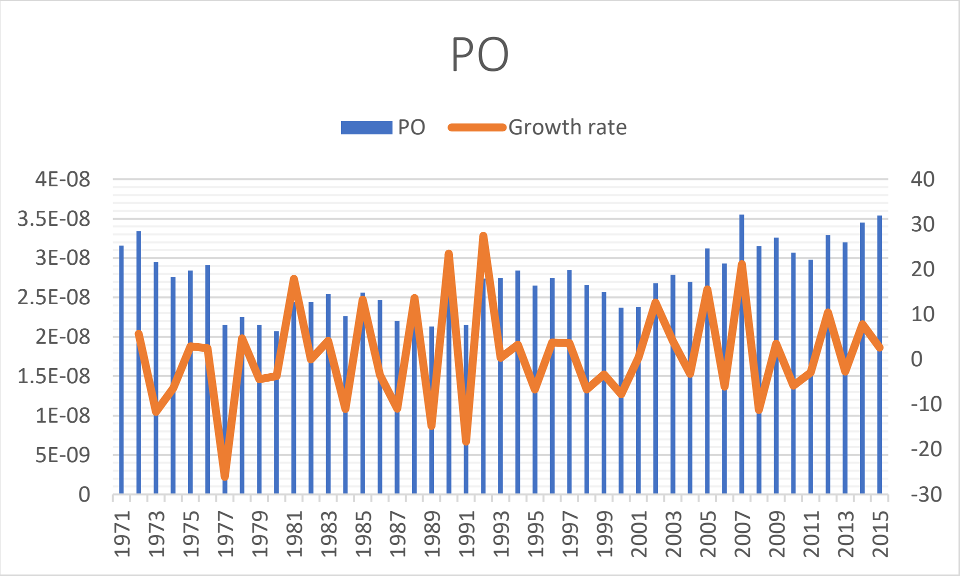


Figure 5: The concentration of CO per capita from 1975 to 2015

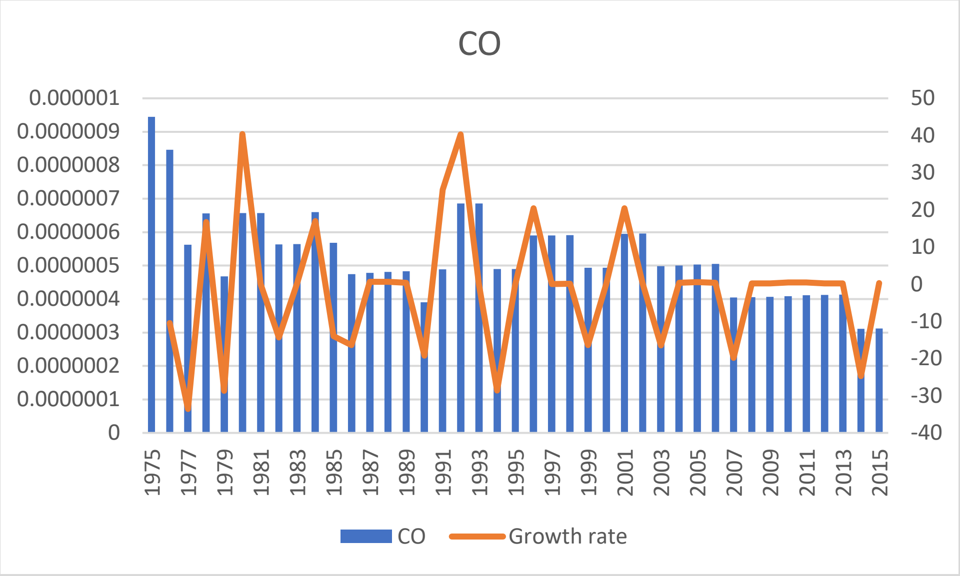
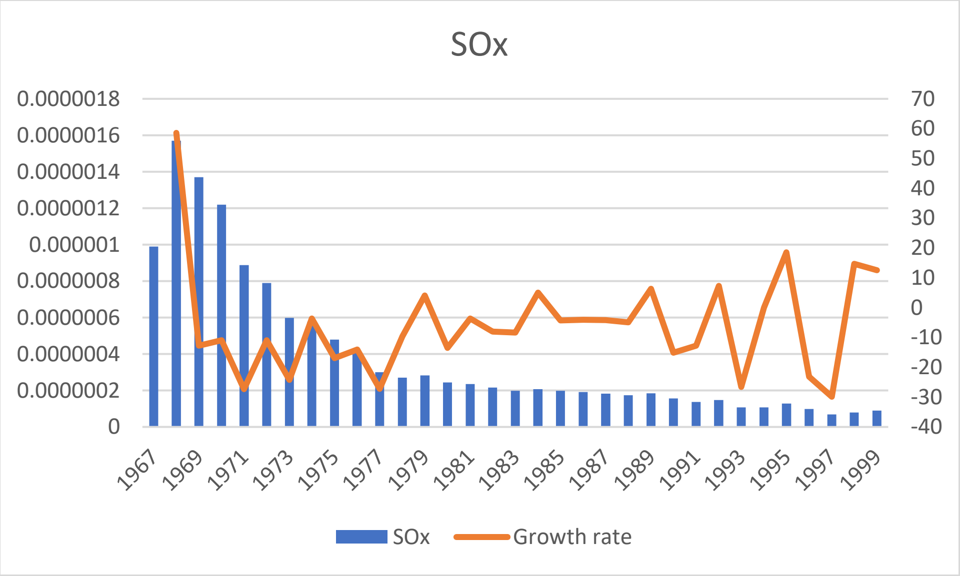


Figure 6: The concentration of SO_x per capita from 1967 to 1999



3.2.2. Firm's size

The data regarding industrial firms in Kitakyushu were drawn from the Industrial Statistics Survey. The Industrial Statistics Survey is conducted annually to collect necessary information of manufacturing firms for administrative purpose of local government. Based on the data in the Industrial Statistics Survey, policies for industries, small and medium-sized enterprises will be implemented (Ministry of Economy, Trade and Industry, 2019). The Industrial Statistics Survey distributed in Kitakyushu contains eight necessary information regarding of industrial firms' conditions, namely: number of firms, number of employees, total cash payment, amount of raw materials used, the shipment of manufactured goods, inventory value, depreciation amount, and value-added amount.

In this study, the number of firms and the shipment value of manufactured goods was taken used for calculating the average of the firm's size of Kitakyushu city. The average firm's size was calculated by the division of the shipment value of manufactured goods by the number of firms. The data of both the number of firms and shipment of manufactured goods covered the range from 1963 to 2015. The shipment value of manufactured goods was measured using million JPY. However, for better interpretation, the measuring unit was exchanged to million US dollar using the constant rate of 2019 (1 US dollar = 110 JPY).

As can be seen from Figure 7, Figure 8, and Figure 9, even though the shipment value of manufactured goods stopped increasing and became fluctuating after 1980, the shipment value of manufactured goods per firm kept on rising because of the decline in the number of firms. The fluctuation in both the number of firms and the shipment value of manufactured goods illustrated a high heterogeneity of firm.

Figure 7: Number of industrial firms

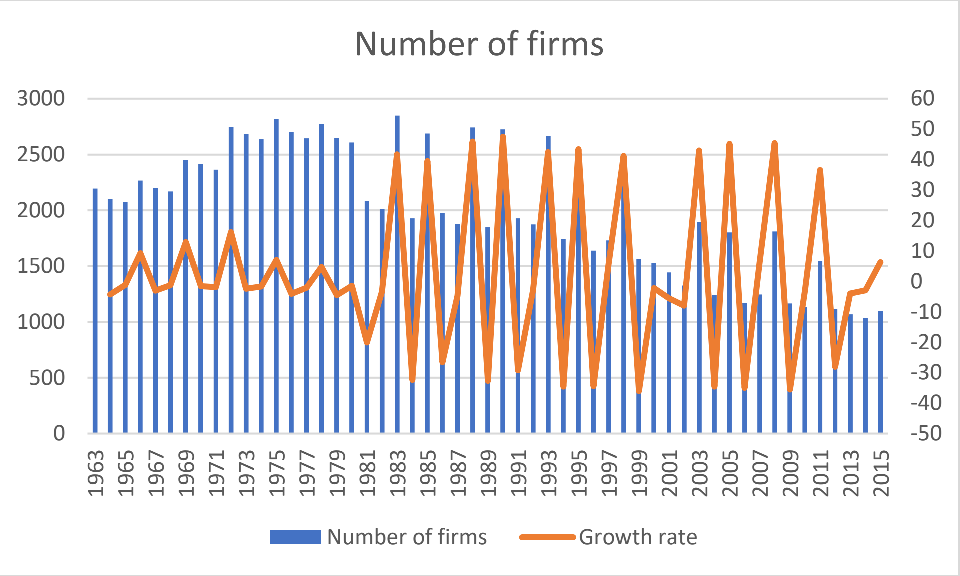


Figure 8: Shipments of manufactured goods

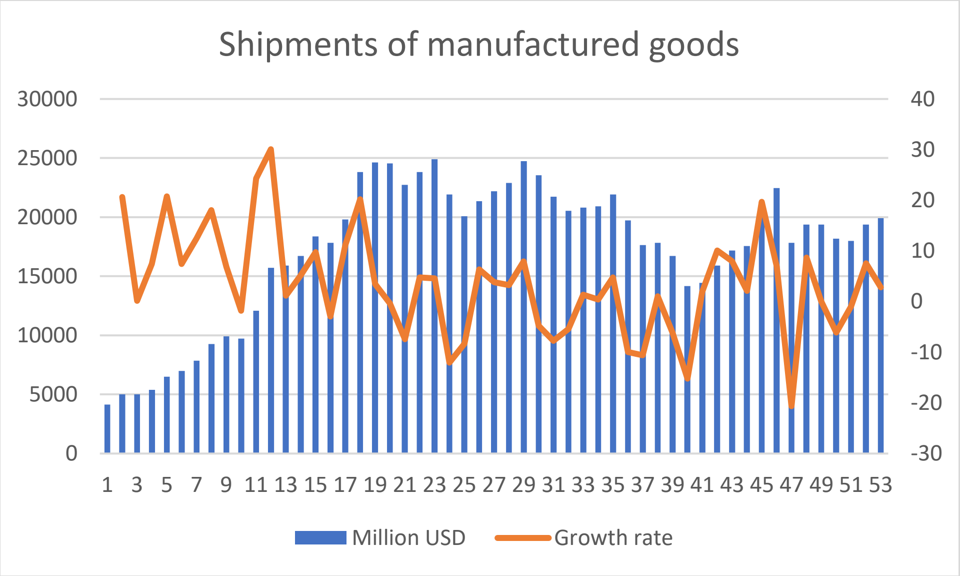
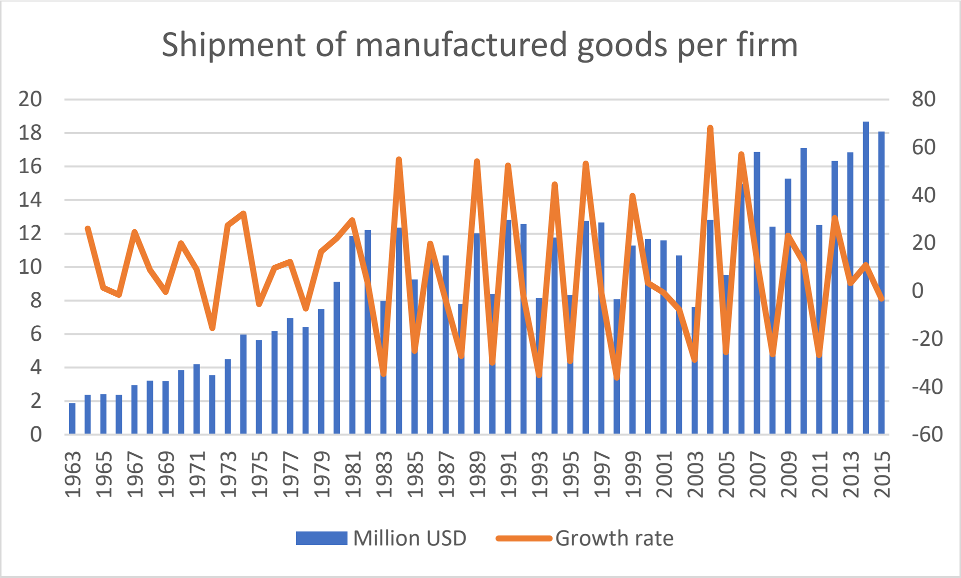


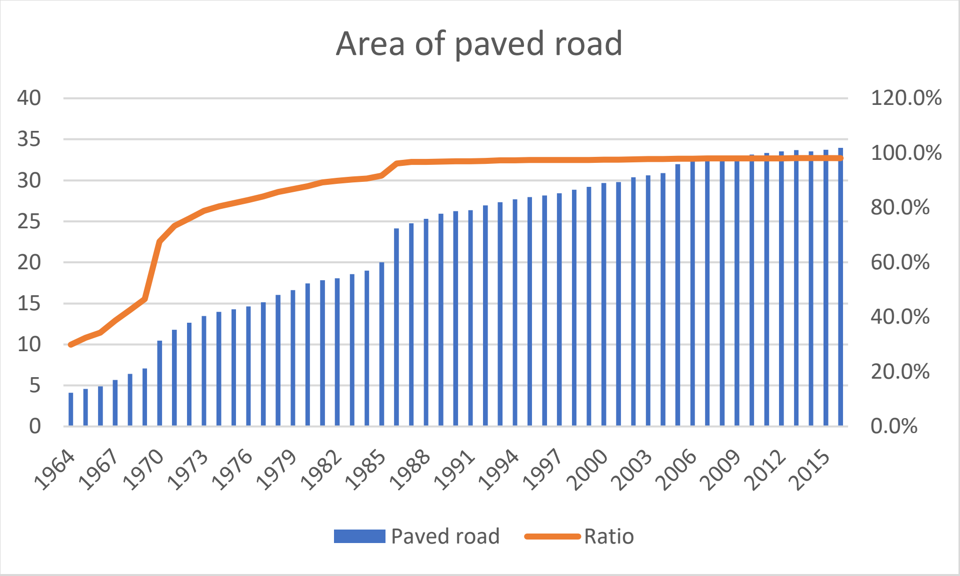
Figure 9: Shipment of manufactured goods per firm



3.2.3. Area of paved road

The data of the area of the paved road also derived from the dataset of road extension and area of Kitakyushu city. There were five categories in the dataset, including total road extension, total road area, total gravel road area, total paved road area, and the ratio of paved road area. In this study, the total paved road area was employed as this indicator could present the infrastructure development of the city. The paved road area was measured in km^2 and ranged from 1964 to 2015 (see Figure 10). From 1964 to 1986, the total area of paved increased rapidly and occupy almost 100% of the total road area in Kitakyushu. The total paved road area kept increasing steadily until 2010 and became stationary later on.

Figure 10: The total area and ratio of paved road



3.3. Methodology

Many of the previous studies employed panel data to examine the shape of EKC, while the number of researchers using time series analysis has increased recently. In this study, time series data were collected and analyzed using Auto-Regressive Distributed Lag (ARDL) method, which was already applied in other works of literature (Ali, Abdullah, & Azam, 2017; Bölük & Mert, 2015; Ahmad et al., 2017).

There were three steps in the current analysis. In the first stage, some pre-estimation tests were conducted, namely: lag-selection test, Augmented Dickey and Fuller unit-root test, and bound test for the cointegration of the model. In the second stage, the ARDL model was employed to examine the short-run and long-run relationships between air pollutants and two independent variables (average firm's size and infrastructure development measured by road area). Lastly, the robustness, autocorrelation, heteroscedasticity, etc. were examined by several post-estimation tests, such as the Durbin-Watson test, Breusch Godfrey Serial Correlation Lagrange Multiplier (LM) test, etc.

The raw data from separate files were initially combined and curated in one Excel file. The Excel file was later stored as CSV format before importing to STATA software (version 15.1) for in-depth analysis. In term of the level of significance, 10% was chosen as the significance level for short-run and long-run analysis, while 5% was chosen as the significance level for the results of pre-estimation, post-estimation tests.

3.3.1. Variables

The general form of the model testing the shape of the relationship between air pollution and the average industrial firm's size and the effect of road density on air pollution can be written as follows:

$$AirPollution = F(FirmSize, FirmSize2, FirmSize3, Road)$$

Where dependent variables in the regression model consist of the amount or concentration of five types of air pollutants (dust, NO2, Ox, CO, and SO2) per capita proxying the degree of air pollution (see Table 1). As different measuring units measure each air pollutant, log-transformation will help measure all air pollutants on the same percentage scale. The variables being log-transformed will be added "*ln*-". For example, the variable "*Dustper*" after log-transformation is written as "*lnDustper*". Moreover, as the first agreement between the government and private sector was signed in 1967, the restrictions and incentives Kitakyushu might have started since 1967. Therefore, in this analysis, we only employed data from 1967 to the most updated time in which the data was available.

Table 1: Dependent variables

Year	**Air pollutants**	**Variable**	**Measuring unit**	**Description**
1967 – 2015	Dust	*"Dustper"*	ton/km^2/month/person	The amount of dust per capita

1970 – 2015	Nitrogen dioxide	*“NO2per”*	ppm/person	The concentration of NO_2 per capita
1971 – 2015	Photochemical Oxidant	*“Oxper”*	ppm/person	The concentration of Ox per capita
1975 – 2015	Carbon Monoxide	*“COper”*	ppm/person	The concentration of CO per capita
1967 – 1999	Sulfur Oxides	*“SOxper”*	mg/100 cm^2/day	The concentration of SO_x per capita

There are four independent variables in this analysis. The first three independent variables are the average firm’s size, its quadratic and cubic numbers. Those three independent variables are illustrated by *“Firmsize”*, *“Firmsize2”* and *“Firmsize3”* respectively. The average firm’s size was calculated by dividing the total shipment value of manufactured goods of industrial firms by the number of industrial firms in Kitakyushu city. Another independent variable is *“Road”*, which represents the density of paved road being built within the city area. The measuring unit of the road density is km^2.

Table 2: Independent variables

Year	**Variable**	**Measuring unit**	**Description**
1967 – 2015	*“FirmSize”*	Million USD per firm	The average industrial firm’s size measured by the division of total income by the number of firms
1967 – 2015	*“FirmSize2”*	Million USD per firm	The quadratic number of average industrial firm’s size measured by the division of total income by the number of firms
1967 – 2015	*“FirmSize3”*	Million USD per firm	The cubic number of average industrial firm’s size measured by the division of total income by the number of firms
1967- 2015	*“Road”*	Km^2	The area of the paved road has been built within the city

3.3.2. Models

Reduced-form function. In this study, the reduced-form function was chosen to test the shape of the relationship between air pollution and the average firm's size, along with the impact of road density because of several reasons. First, the reduced-form function is more comfortable to apply than other non-linear functional forms or non-parametric and semi-parametric models. Second, some drawbacks of the parametric method cannot be solved by applying another type of methods, such as the use of spline or semiparametric methods (Özokcu & Özdemir, 2017). Third, the reduced-form has been widely used to test the EKC in various relationships between income and environmental degradation (Kijima et al., 2010).

The reduced-form function of EKC can be formulated as a linear equation, quadratic equation and cubic equation (Shafik & Bandyopadhyay, 1992). In this study, the cubic equation is formulated according to previous works (G. M. Grossman & Krueger, 1995; Panayotou, 1997; Sander M. De Bruyn, 1997; Dinda, 2004; Galeotti & Lanza, 2005; Akbostancı et al., 2009; Özokcu & Özdemir, 2017) as follows:

$$Y_t = \alpha_t + \beta_1 X_t + \beta_2 X_t^2 + \beta_3 X_t^3 + \beta_4 Z_t + \mu_t \quad (1)$$

In Equation (1), Y represents the volume of environmental degradation; X denotes economic development indicators (income or GDP per capita); β_1-β_4 are coefficients; Z might be one or various exploratory variables; t symbolizes time; μ is the conventional error term. In order to determine the shape of the relationship between environmental degradation and economic development, signs of coefficients β_1, β_2 and $\beta_3$are taken into consideration. The shape of the curve can be verified as follows:

- Linear relationship: the curve demonstrates a monotonically increasing relationship between X and Y, when $\beta_1 > 0,\ \beta_2 = \ \beta_3 = 0$.
- Linear relationship: the curve demonstrates a monotonically decreasing relationship between X and Y, when $\beta_1 < 0,\ \beta_2 = \ \beta_3 = 0$.
- Quadratic relationship: the curve demonstrates an inverted U-shaped relationship between X and Y, when $\beta_1 > 0,\ \beta_2 < 0$, and $\beta_3 = 0$. This result indicates the existence of EKC.
- Quadratic relationship: the curve demonstrates a U-shaped relationship between X and Y, when $\beta_1 < 0,\ \beta_2 > 0$, and $\beta_3 = 0$.
- Cubic relationship: the curve demonstrates an N-shaped relationship between X and Y, when $\beta_1 > 0,\ \beta_2 < 0$, and $\beta_3 > 0$.
- Cubic relationship: the curve demonstrates an inverted N-shaped relationship between X and Y, when $\beta_1 < 0,\ \beta_2 > 0$, and $\beta_3 < 0$.

Each type of relationship implies a different meaning. If the relationship between environmental degradation and economic development is linear, the increase of economic development will lead to a decrease or increase in environmental degradation corresponding to the sign of β_1. When the relationship possesses an inverted U-shaped curve, the EKC hypothesis is validified. In other words, environmental degradation rises according to the increase of economic development or in this study firm's size, until a certain level, or so-called "turning point", it starts to decline as the economy continues growing.

On the contrary, if the shape of the relationship is a U-shaped curve, environmental degradation initially declines and rises after the "turning point" as the economic development increases. Besides the linear and quadratic relationships, environmental degradation and economic development may also obtain a cubic relationship which indicates an inverted N-shaped or N-shaped curve. The N-shaped curve is partially similar to EKC, but after the decreasing period, environmental degradation increases again when the economic development reaches the second “turning-point”. On the other hand, the inverted N-shaped curve denotes an initially decreasing trend of environmental degradation according to economic development and a similar trend with EKC after the first turning point.

In this study, the average size of the industrial firm was used instead of economic development. By employing the average size of the industrial firm and the infrastructure development proxied by road density as indicators of air pollution, the reduced-form function of this study can be displayed as Equation 2:

$$lnAirPollution_t = \alpha_t + \beta_1 FirmSize_t + \beta_2 FirmSize2_t + \beta_3 FirmSize3_t + \beta_4 Road_t + \mu_t \quad (2)$$

One notable point is that all dependent variables are log-transformed.

Expected results. We expected that there would be two most possible scenarios. First, environmental degradation might decline according to industrial development, but then start increasing due to the diseconomies of scale. This scenario could be exhibited by a U-shaped curve relationship between the average industrial firm size and air pollution. After the air pollution prevention agreement between the private sector and the government, there were several things the industrial firms needed to do, namely: 1) increasing energy efficiency by replacing inefficient and polluting equipment with newer and energy-saving ones; and 2) integrating cleaner technologies into their production process, such as End-of-pipe technology. Such implementation and changes could be less difficult and more effective to be done by larger companies due to the economies of scale effects (OECD, 2013). Moreover, because 66% of energy is consumed by industrial activities (OECD, 2013), and the economies of scale have a substantial effect on electric power production, the economies of scale of industrial firm's size also dramatically affect air pollution emitted from electric power generation (Machado, de Sousa, & Hewings, 2016).

The second scenario is similar with the first scenario, but eventually, the air pollution might decline again when the firm grows to a specific size, which could be presented by an inverted N-shaped curve relationship between the average industrial firm size and air emission. This scenario could happen if the technological progress in industrial firms keeps on occurring, which in turns maintains the economies of scale effects of industrial development.

As for the relationship between the total paved road and air pollution, we expected to have contradicted outcomes. To elaborate, the establishment of the new paved road might be positively correlated with urban sprawl and the number of private vehicles in Kitakyushu, which might increase traffic-related air pollution (NO_2 and O_x emissions). On the other hand, the increase in the paved road area might make industrial firms more connected, which might improve their production efficiency. Especially, Kitakyushu is also famous as a recycling city, where municipal, industrial wastes, and by-products could be recycled instead of incineration which possibly creates air pollution (SO_x, NO_2, CO, and Dust emissions). Therefore, building more road might be negatively correlated with air pollution. However, we expected the NO_2 emission to increase as the more paved road is built, as road transportation is the most significant contributor to NO_2.

Auto-Regressive Distributed Lag. The Auto-Regressive Distributed Lag (ARDL) model was created by Pesaran, Shin, & Smith (2001) to examine the cointegration between a dependent variable and a set of independent variables. Scientists have widely used it for almost two decades to model relationships between economic variables based on time-series analysis (Kripfganz & Schneider, 2016). Other techniques examining the cointegration between dependent and independent variables restrict that all variables have to be stationary at the same level. For example, techniques based on the residuals by Engle & Granger (1987), the semiparametric method by Phillips & Hansen (1990), and cointegration analysis at I(1) by Johansen (1988), etc. Unlike them, ARDL model bound test approach of Pesaran, Shin, & Smith (2001) is used to solve the non-stationary variables in the dataset and employable if variables are stationary at I(0), I(1), or both I(0) and I(1) at the same time. However, the model will become inapplicable if any one of the variables is stationary at I(2) or higher.

Besides the superiority of ARDL in examining cointegration of variables stationary at different levels, ARDL was also chosen for several other reasons. First, the fact that the ARDL model can provide unbiased results for small sample size has been verified by Monte Carlo Simulation (Ahmad et al., 2017; Pesaran & Shin, 1999). Second, the ARDL model can fit well with endogenous variables, because it can solve the problem of endogeneity by selecting correct lag length for the variable and increasing the model dynamic (Pesaran & Shin, 1999). Third, the ARDL model provides not only an explanation for the long-run relationship but also a view on short-run dynamics through a simple linear function based on the Error Correction Mechanism (ECM).

In this study, the ARDL models of long-run and short-run relationships between air pollutants and independent variables are designed as follows:

$$\Delta lnDustper_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i}\Delta lnDustper_{t-i} + \sum_{i=1}^{p} \beta_{2i}\Delta FirmSize_{t-i} + \sum_{i=1}^{p} \beta_{3i}\Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \beta_{4i}\Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \beta_{5i}\Delta Road_{t-i} + \beta_6 lnDustper_{t-i} + \beta_7 FirmSize_{t-i} + \beta_8 FirmSize2_{t-i} + \beta_9 FirmSize3_{t-i} + \beta_{10} Road_{t-i} + \varepsilon_t \quad (3.1)$$

$$\begin{aligned}\Delta lnNO2per_t &= \alpha_0 + \textstyle\sum_{i=1}^{p} \beta_{1i} \Delta lnNO2per_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta FirmSize_{t-i} + \\ &\textstyle\sum_{i=1}^{p} \beta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \beta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \beta_{5i} \Delta Road_{t-i} + \beta_6 lnNO2per_{t-i} + \\ &\beta_7 FirmSize_{t-i} + \beta_8 FirmSize2_{t-i} + \beta_9 FirmSize3_{t-i} + \beta_{10} Road_{t-i} + \varepsilon_t\end{aligned} \tag{3.2}$$

$$\begin{aligned}\Delta lnOxper_t &= \alpha_0 + \textstyle\sum_{i=1}^{p} \beta_{1i} \Delta lnPOper_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \beta_{3i} \Delta FirmSize2_{t-i} + \\ &\textstyle\sum_{i=1}^{p} \beta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \beta_{5i} \Delta Road_{t-i} + \beta_6 lnPOper_{t-i} + \beta_7 FirmSize_{t-i} + \\ &\beta_8 FirmSize2_{t-i} + \beta_9 FirmSize3_{t-i} + \beta_{10} Road_{t-i} + \varepsilon_t\end{aligned} \tag{3.3}$$

$$\begin{aligned}\Delta lnCOper_t &= \alpha_0 + \textstyle\sum_{i=1}^{p} \beta_{1i} \Delta lnCOper_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \beta_{3i} \Delta FirmSize2_{t-i} + \\ &\textstyle\sum_{i=1}^{p} \beta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \beta_{5i} \Delta Road_{t-i} + \beta_6 lnCOper_{t-i} + \beta_7 FirmSize_{t-i} + \\ &\beta_8 FirmSize2_{t-i} + \beta_9 FirmSize3_{t-i} + \beta_{10} Road_{t-i} + \varepsilon_t\end{aligned} \tag{3.4}$$

$$\begin{aligned}\Delta lnSOxper_t &= \alpha_0 + \textstyle\sum_{i=1}^{p} \beta_{1i} \Delta lnSOxper_{t-i} + \sum_{i=1}^{p} \beta_{2i} \Delta FirmSize_{t-i} + \\ &\textstyle\sum_{i=1}^{p} \beta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \beta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \beta_{5i} \Delta Road_{t-i} + \beta_6 lnSOxper_{t-i} + \\ &\beta_7 FirmSize_{t-i} + \beta_8 FirmSize2_{t-i} + \beta_9 FirmSize3_{t-i} + \beta_{10} Road_{t-i} + \varepsilon_t\end{aligned} \tag{3.5}$$

Equations (3.1) to (3.5) show the ARDL models of air pollutants and their predictors, where α_0 is the constant, p is the length of lag and ε_t is the error term. In the first half of each model, the dynamics of the short-run is explained by variables with summation signs. The second half of the model represents the long-run relationship. The dynamic of the short-run relationship is examined by the Error Correction (EC) model.

$$\Delta lnDustper_t = \delta_0 + \sum_{i=1}^{p} \delta_{1i} \Delta lnDustper_{t-i} + \sum_{i=1}^{p} \delta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \delta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \delta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \delta_{5i} \Delta Road_{t-i} + \gamma ECT_{t-i} + \tau_t \quad (4.1)$$

$$\Delta lnNO2per_t = \delta_0 + \sum_{i=1}^{p} \delta_{1i} \Delta lnNO2per_{t-i} + \sum_{i=1}^{p} \delta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \delta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \delta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \delta_{5i} \Delta Road_{t-i} + \gamma ECT_{t-i} + \tau_t \quad (4.2)$$

$$\Delta lnPOper_t = \delta_0 + \sum_{i=1}^{p} \delta_{1i} \Delta lnPOper_{t-i} + \sum_{i=1}^{p} \delta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \delta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \delta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \delta_{5i} \Delta Road_{t-i} + \gamma ECT_{t-i} + \tau_t \quad (4.3)$$

$$\Delta lnCOper_t = \delta_0 + \sum_{i=1}^{p} \delta_{1i} \Delta lnCOper_{t-i} + \sum_{i=1}^{p} \delta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \delta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \delta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \delta_{5i} \Delta Road_{t-i} + \gamma ECT_{t-i} + \tau_t \quad (4.4)$$

$$\Delta lnSOxper_t = \delta_0 + \sum_{i=1}^{p} \delta_{1i} \Delta lnSOxper_{t-i} + \sum_{i=1}^{p} \delta_{2i} \Delta FirmSize_{t-i} + \sum_{i=1}^{p} \delta_{3i} \Delta FirmSize2_{t-i} + \sum_{i=1}^{p} \delta_{4i} \Delta FirmSize3_{t-i} + \sum_{i=1}^{p} \delta_{5i} \Delta Road_{t-i} + \gamma ECT_{t-i} + \tau_t \quad (4.5)$$

The EC models of this study are presented in Equation (4.1) to (4.5), where δ_0 is the constant; δ_1, δ_2, δ_3, δ_4, δ_5 are coefficients; ECT_{t-i} is the error correction term of the EC models; γ is the coefficient of ECT; τ is the error term. The error correction term (ECT) in these equations is the speed of the adjustment parameter reflecting the speed adjusting to the long-run equilibrium of the model. If the ECT is negative, higher than -1, and statistically significant, there is a cointegration in the long run if the bound test indicates the inconclusive result. The long-run ARDL relationship of all dependent variables can be presented in Equations (5.1) to (5.5) as follows:

$$lnDustper_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} lnDustper_{t-i} + \sum_{i=1}^{q} \beta_{2i} FirmSize_{t-i} + \sum_{i=1}^{r} \beta_{3i} FirmSize2_{t-i} + \sum_{i=1}^{s} \beta_{4i} FirmSize3_{t-i} + \sum_{i=1}^{u} \beta_{5i} Road_{t-i} + \varepsilon_t \qquad (5.1)$$

$$lnNO2per_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} lnNO2per_{t-i} + \sum_{i=1}^{q} \beta_{2i} FirmSize_{t-i} + \sum_{i=1}^{r} \beta_{3i} FirmSize2_{t-i} + \sum_{i=1}^{s} \beta_{4i} FirmSize3_{t-i} + \sum_{i=1}^{u} \beta_{5i} Road_{t-i} + \varepsilon_t \qquad (5.2)$$

$$lnOxper_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} lnPOper_{t-i} + \sum_{i=1}^{q} \beta_{2i} FirmSize_{t-i} + \sum_{i=1}^{r} \beta_{3i} FirmSize2_{t-i} + \sum_{i=1}^{s} \beta_{4i} FirmSize3_{t-i} + \sum_{i=1}^{u} \beta_{5i} Road_{t-i} + \varepsilon_t \qquad (5.3)$$

$$lnCOper_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} lnCOper_{t-i} + \sum_{i=1}^{q} \beta_{2i} FirmSize_{t-i} + \sum_{i=1}^{r} \beta_{3i} FirmSize2_{t-i} + \sum_{i=1}^{s} \beta_{4i} FirmSize3_{t-i} + \sum_{i=1}^{u} \beta_{5i} Road_{t-i} + \varepsilon_t \qquad (5.4)$$

$$lnSOxper_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} lnSOxper_{t-i} + \sum_{i=1}^{q} \beta_{2i} FirmSize_{t-i} + \sum_{i=1}^{r} \beta_{3i} FirmSize2_{t-i} + \sum_{i=1}^{s} \beta_{4i} FirmSize3_{t-i} + \sum_{i=1}^{u} \beta_{5i} Road_{t-i} + \varepsilon_t \qquad (5.5)$$

Where p, q, r, s, and u are lag values of each independent variable respectively.

Cointegration test. According to Pesaran, Shin, & Smith (2001), the bound test tests the cointegration of the dependent and independent variables through a joint F-stat or Wald test. When the null hypothesis of the bound test is accepted, $\beta_6 = \beta_6 = \beta_6 = \beta_6 = \beta_6 = 0$, there is no cointegration. On the other hand, if the null hypothesis is rejected, $\beta_6 \neq \beta_6 \neq \beta_6 \neq \beta_6 \neq \beta_6 \neq 0$, the cointegration exists. In order to determine whether to accept or reject the null hypothesis, the joint F-stat needs to be compared with lower bound and upper bound of the model. The lower bound considers all variables as I(0), while the upper bound considers all variables as I(1). The null hypothesis is not rejected if the F stat is lower than the lower bound critical value of I(0). On the other hand, if the F statistic is higher than the upper bound critical value of I(1), the null hypothesis can be rejected. If the F statistic is between the lower bound critical value of I(0) and the upper critical value of I(1), the result of cointegration becomes inconclusive. In this situation, to decide whether the model is cointegrated or not, the significance of ECT in the short-term linear function need to be taken into account. Banerjee, Dolado, & Mestre (1998) implied that if the coefficient of lagged dependent variable, or so-called ECT, is negative and statistically significant, the cointegration of the model is confirmed. In addition to that, if the coefficient of ECT is neither negative nor statistically significant, there will be no cointegration, despite a significant bound test.

Pre-estimation tests. Before conducting the ARDL analysis, Vector Auto-Regression (VAR) and Augmented Dickey-Fuller tests are utilized for selecting the optimal lag for each variable and checking whether the variable is stationary at I(0), I(1), or beyond I(1).

The lag length implies the level of delay of a variable in a time-series set up. It is essential to select the most suitable lag length for each variable in the model because using not enough lag will lead to the autocorrelated errors while using too many lags will lead to over-fitting which raise the mean-square-forecast errors of the model (Lütkepohl, 2005). In order to select an appropriate lag length for the model, the model selection criteria are used. The three most widely employed criteria are the Akaike Information Criterion (AIC), Schwarz Bayesian Information Criterion (BIC), and the Hannan-Quinn Information Criterion (HQIC) (Vrieze, 2012). In this study, all three model selection criteria were employed, namely: Akaike Information Criterion (AIC), Schwarz Bayesian Information Criterion (SBIC), and the Hannan-Quinn Information Criterion (HQIC). Eventually, the minimum lag length will be selected regardless of the type of criteria.

The Augmented Dickey-Fuller test is a unit root test that is commonly used to examine the stationarity and trend-stationarity in time-series set up. There are several unit root tests that have been introduced, such as the Cointegrating Regression Durbin Watson (CRDW) test, the Dickey-Fuller test, the augmented Dickey-Fuller (ADF) test, etc. (Harris, 1992). Each type of test has its advantages and disadvantages. For example, Cointegrating Regression Durbin Watson (CRDW) test can be considered as one of the most persuasive tests of the stationary first-order auto-regressive error process, which also makes the test less generalized compared to other types of test. The ADF test was originally developed from the Dickey-Fuller test to explain a more extensive and more complicated set of time-series models. The statistic of the ADF test is negative, and the null hypothesis of the ADF test is that there is a unit root at some level of confidence. The more negative the statistic is, the more likely the null hypothesis is rejected. Therefore, the ADF test was used in this study to determine whether all variables are stationary at below I(2).

Post-estimation tests. After running the ARDL and EC analyses for estimating the long-run and short-run of the relationship, some diagnostic tests need to be employed to test whether the model is acceptable. Some diagnostic tests are Durbin-Watson test, Breusch Godfrey serial Correlation Lagrange Multiplier (LM) test, Breusch-Pagan / Cook-Weisberg test for heteroskedasticity, Engle’s Auto-Regressive Conditional Heteroscedastic (ARCH) test, and Ramsey Reset test. To elaborate, the Durbin-Watson test provides Durbin-Watson statistic reflecting the autocorrelation in the residuals and limiting between 0 and 4 with a value of 2 indicating no autocorrelation; Breusch Godfrey serial Correlation Lagrange Multiplier (LM) test, like its name, examine whether the model has a serial correlation or not; Breusch-Pagan / Cook-Weisberg test for heteroskedasticity and Engle’s ARCH test imply whether the model is homoscedastic or heteroscedastic; and Ramsey Reset test points out whether the model has omitted any variable.

Besides the above-mentioned diagnostic test, the study also utilizes the cumulative sum (CUSUM) developed by Brown, Durbin, & Evans (1975) to check the stability of the coefficients on the graphical demonstration. If the CUSUM statistic is displayed within the critical bound of the 5% level of significance, the null hypothesis that the model is stable cannot be rejected.

4. Results

4.1. Pre-estimation test

Before conducting the Augmented Dickey-Fuller unit root test for testing the level of stationarity of the model, the optimal lag length for each equation was tested using Vector Auto-Regression (VAR) based on Akaike Information Criterion (AIC), Schwarz Bayesian Information Criterion (SBIC), and the Hannan-Quinn Information Criterion (HQIC). The smallest optimal lag length will be selected regardless of criteria. The optimal length of lag for Equation (3.1) to Equation (3.5) is presented in Table 3. For Equation (3.1) to Equation (3.4), the results of all criteria point out that 1 is the most appropriate delay, while only the result of Equation (3.5) indicates different optimal lag length according to different criteria. The optimal lag of Equation (3.5) was selected based on the BIC criterion, due to smaller lag prioritization. Therefore, one was used as the optimal lag length for all Equation (3.1) to (3.5).

Table 3: Lag-order selection statistics

Models	AIC best statistic	AIC lag	HQIC best statistic	HQIC lag	SBIC best statistic	SBIC lag
Model (3.1)	22.87	1	23.3165	1	24.0441	1
Model (3.2)	20.32	1	20.78	1	21.57	1
Model (3.3)	21.02	1	21.47	1	22.27	1
Model (3.4)	21.50	1	21.96	1	22.81	1
Model (3.5)	17.30	4	18.85	4	20.64	1

The Augmented Dickey-Fuller unit root test was employed to examine the level of stationarity of all models if they were stationary at level series or first-order difference series (see

Table 4). The level form and first difference of each dependent and independent variables were tested under two conditions respectively: unrestricted intercept – no trend and unrestricted intercept – trend. The results from unit root tests concluded that all variables of this study are stationary at I(1) with 1% of the significance level. Therefore, the ARDL analysis can be utilized in all equations.

Table 4: Augmented Dickey-Fuller unit root test results

Variables	**Level series**		**First-order difference series**	
	Intercept	**Trend and intercept**	**Intercept**	**Trend and intercept**
lnDDust	-3.185**	-2.681	-5.384***	-5.944***
$lnNO_2$	-1.403	-1.882	-5.381***	-5.300***
lnOx	-0.979	-2.908	-4.950***	-5.404***
lnCO	-3.233**	-4.516***	-7.058***	-6.957***
$lnSO_2$	-2.389	-2.034	-4.780***	-5.301***
FirmSize	-0.923	-3.131	-9.704***	-9.615***
FirmSize2	-0.423	-2.881	-9.754***	-9.917***
FirmSize3	-0.059	-2.089	-9.519***	-9.971***
Road	-2.579	-1.162	-4.001***	-4.914***

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

In order to test the cointegration of Equations (3.1) to (3.5), the joint F-stat of each Equation was computed. The F-stats, critical values of the lower bound, and upper bound of all equations are shown in Table 5. The critical values of the lower bound and upper bound were provided by Pesaran, Shin, & Smith (2001). The F-stats computed from the regression analyses following specifications of the baseline of models (3.1) to (3.5) were higher than the critical value of upper bound at 5% level of significance, which meant the null hypotheses that there is no cointegration of all baseline model could be rejected. The cointegration of variables in Equations (3.1) to (3.5) was also confirmed by the negative and significant coefficients of the ECT in the EC models.

Table 5: Bound test for cointegration

Models	Dependent variable	Optimal lag	ECT$_{t-1}$ (t-stat)	F-stat	Results
Model (3.1)	F(Dust/FirmSize, FirmSize2, FirmSize3, Road)	1	-0.529 (-4.37)***	5.773	Cointegration
	F(FirmSize/FirmSize2, FirmSize3, Road, Dust)		-0.179 (-1.88)*	4.961	Cointegration
	F(FirmSize2/FirmSize3, Road, Dust, FirmSize)		-0.217 (-1.99)*	4.571	Cointegration
	F(FirmSize3/Road, Dust, FirmSize, FirmSize2,)		-0.261 (-2.18)**	3.559	Cointegration
	F(Road/Dust, FirmSize, FirmSize2, FirmSize3)		-0.008 (-0.34)	3.436	Inconclusive
Model (3.2)	F(NO2/FirmSize, FirmSize2, FirmSize3, Road)	1	-0.355 (-3.66)***	4.216	Cointegration
	F(FirmSize/FirmSize2, FirmSize3, Road, NO2)		-0.278 (-2.12)**	2.488	No Cointegration
	F(FirmSize2/FirmSize3, Road, NO2, FirmSize)		-0.360 (-2.53)**	2.808	No Cointegration
	F(FirmSize3/Road, NO2, FirmSize, FirmSize2,)		-0.435 (-2.96)***	3.555	Cointegration
	F(Road/NO2, FirmSize, FirmSize2, FirmSize3)		-0.026 (-1.26)	2.149	No Cointegration
Model (3.3)	F(Ox/FirmSize, FirmSize2, FirmSize3, Road)	1	-0.813 (-6.31)***	8.825	Cointegration
	F(FirmSize/FirmSize2, FirmSize3, Road, Ox)		-0.497 (-3.91)***	4.367	Cointegration
	F(FirmSize2/FirmSize3, Road, Ox, FirmSize)		-0.545 (-3.91)***	4.277	Cointegration
	F(FirmSize3/Road, Ox, FirmSize, FirmSize2,)		-0.567 (-3.85)***	4.042	Cointegration
	F(Road/Ox, FirmSize, FirmSize2, FirmSize3)		-0.046 (-1.78)*	1.421	No Cointegration
Model (3.4)	F(CO/FirmSize, FirmSize2, FirmSize3, Road)	1	-0.654 (-4.57)***	5.888	Cointegration
	F(FirmSize/FirmSize2, FirmSize3, Road, CO)		-0.566 (-4.30)***	5.397	Cointegration
	F(FirmSize2/FirmSize3, Road, CO, FirmSize)		-0.603 (-4.41)***	5.654	Cointegration
	F(FirmSize3/Road, CO, FirmSize, FirmSize2,)		-0.635 (-4.49)***	5.861	Cointegration

	F(Road/CO, FirmSize, FirmSize2, FirmSize3)		-0.049 (-2.10)**	1.768	No Cointegration
Model (3.5)	F(SOx/FirmSize, FirmSize2, FirmSize3, Road)	1	-0.379 (-3.40)***	4.284	Cointegration
	F(FirmSize/FirmSize2, FirmSize3, Road, SOx)		-0.380 (-2.11)**	2.010	No Cointegration
	F(FirmSize2/FirmSize3, Road, SOx, FirmSize)		-0.406 (-2.22)**	1.927	No Cointegration
	F(FirmSize3/Road, SOx, FirmSize, FirmSize2,)		-0.502 (-2.74)**	2.497	No Cointegration
	F(Road/SOx, FirmSize, FirmSize2, FirmSize3)		-0.039 (-0.51)	1.236	No Cointegration

Critical values for Bound test – F stat	Lower Bound I (0)	Upper Bound I (1)
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Note: *, **, and *** represent 10%, 5%, and 1% statistical significance respectively

4.2. ARDL results and post-estimation tests

Table 6: Short run and long run estimations with $\Delta lnDustper$ dependent on cubic equation (1, 0, 0, 0, 1)

Long run	**Coefficients**	**p-value**	**Short run**	**Coefficients**	**p-value**
FirmSize	-0.5223	0.002***	$\Delta FirmSize$	-0.2962	0.033**
FirmSize2	0.0394	0.017**	$\Delta FirmSize^2$	0.0223	0.072*
FirmSize3	-0.0009	0.073*	$\Delta FirmSize^3$	-0.0005	0.150
Road	-0.0170	0.036**	$\Delta Road$	0.0522	0.076*
Constant	-5.5192	0.000***	ECT_{t-1}	-0.5670	0.000***

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

R-squared	0.4132
Number of observations	48
Durbin-Watson statistics (7, 48)	1.71

Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey serial Correlation LM test	H_0: No serial correlation	0.94 (0.33)	Not reject H_0

Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	1.45 (0.22)	Not reject H_0
ARCH test	H_0: Homoskedasticity	1.07 (0.29)	Not reject H_0
Ramsey Reset test	H_0: the model has no omitted variables	4.99 (0.00)	Reject H_0

Note: p-value is put in parentheses.

The logarithm of dust emission per capita. The long-run and short-run estimation results with *lnDustper* as the dependent variable are shown in Table 6. The optimal lag length of each variable was 1, 0, 0, 0, one respectively, when the optimal lag length was set as 1. The model acquired 44% goodness of fit, while the Durbin – Watson statistic was close to 2 representing low autocorrelation in the model. Other post-estimation test conducted also supported the acceptability of the model. However, as the null hypothesis of Ramsey Reset test was rejected, the model would be better estimated by another polynomial order. Therefore, we conducted another estimation with *lnDustper* dependent on variables without *FirmSize3* by replicating all the analysis stages that had been conducted. The VAR test based on AIC, BIC, and HQIC implied that the optimal lag length should be 1, whereas the F-stat computed from the regression analyses following specifications of the baseline of the new model was 6.501 which was higher than the upper bound. Thus, the new model with *lnDustper* as the dependent variable was cointegrated. The new estimation is shown in Table 7.

Table 7: Short run and long run estimations with $\Delta lnDustper$ dependent on quadratic equation (1, 0, 0, 1)

Long run	**Coefficients**	**p-value**	**Short-run**	**Coefficients**	**p-value**
FirmSize	-0.2466	0.000***	$\Delta FirmSize$	-0.1051	0.003***
FirmSize2	0.0110	0.000***	$\Delta FirmSize^2$	0.0047	0.001***
Road	-0.0195	0.067*	$\Delta Road$	0.0484	0.102
Constant	-4.4822	0.000***	ECT_{t-1}	-0.4265	0.000***

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

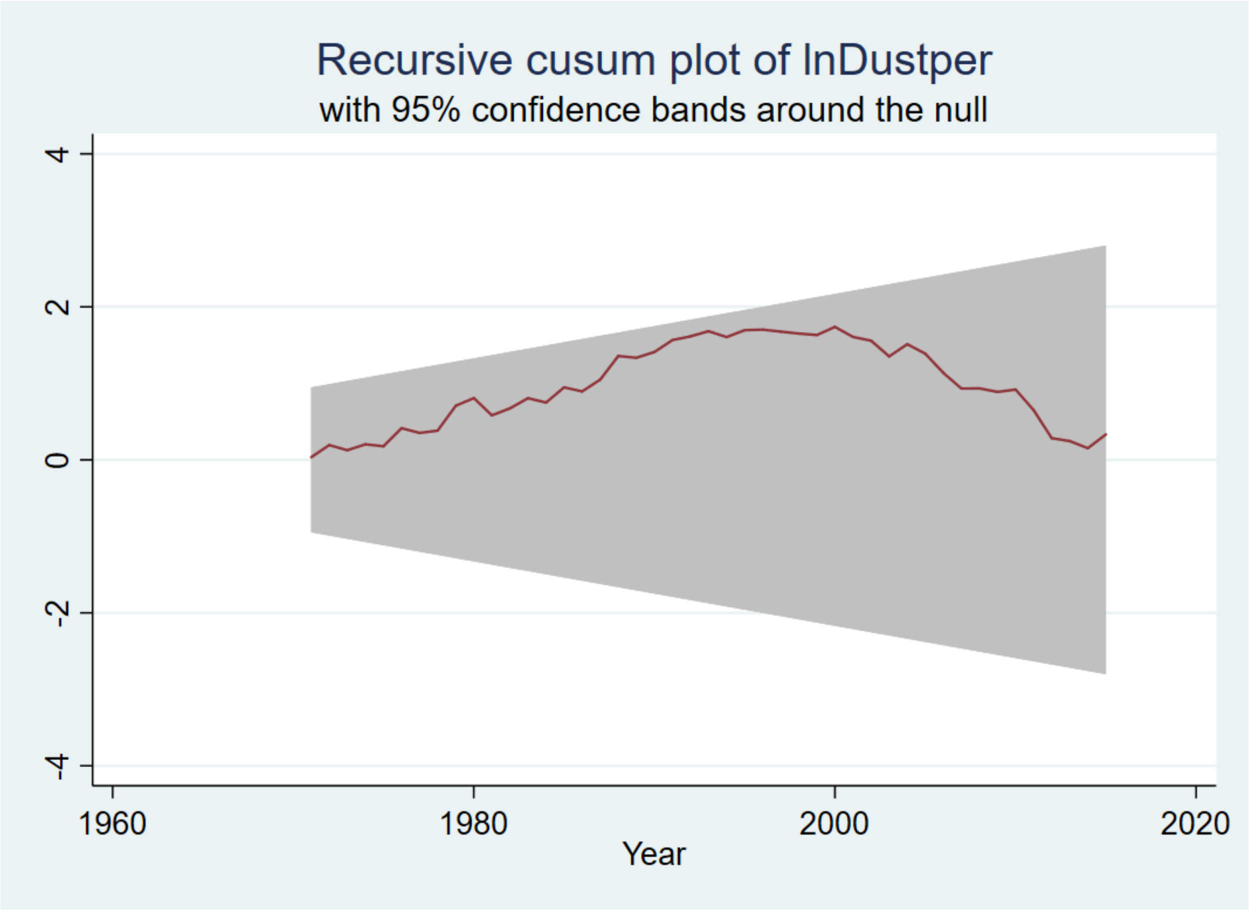
R-squared	0.3824
Number of observations	48
Durbin-Watson statistics (7, 48)	1.77

Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey serial Correlation LM test	H_0: No serial correlation	0.275 (0.59)	Not reject H_0
Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	0.04 (0.84)	Not reject H_0
ARCH test	H_0: Homoskedasticity	0.50 (0.47)	Not reject H_0
Ramsey Reset test	H_0: the model has no omitted variables	1.98 (0.13)	Not reject H_0

Note: p-value is put in parentheses.

After estimating the long-run and short-run of *lnDustper* dependent on variables without *FirmSize3*, the new goodness of fit was 38.24%, which was slightly lower than the old model. However, no null hypotheses of post-estimation tests were rejected, implying high appropriateness of the model. The CUSUM test also indicated that the coefficients of all variables were stable (see Figure 11).

Figure 11: CUSUM test for the model with Δ*lnDustper* as the dependent variable



In the long-run estimation, all the variables were found to be statistically significant at 5% or lower. The coefficient of variables *FirmSize* was negative, while the coefficient of *FirmSize2* was positive, illustrating a U-shaped relationship between the firm's size and the logarithm of the amount of dust per capita. Therefore, the EKC was not valid in this circumstance, and the curve obtained one turning point. Two steps calculated the turning point. First, the derivative of the equation was computed. Second, the turning point of the model was calculated by finding the root of the derivative when equaling 0. The calculated turning point of the equation was at $11.20 million per firm. In other words, the logarithm of the amount of dust per capita declined as firms grow; after the turning point, at around $11.20 million per firm, the decreasing trend stopped, and the amount of dust per capita started rising. Besides, the total area of the paved road was also negatively associated with the logarithm of the amount of dust per capita, which means the more paved road was built, the less amount of dust was emitted. An increase of one km^2 in area of the paved road would lead to a drop of 1.95% of the amount of dust per capita.

In the short-run, the ECT was negative and significant at 1% significance level as expected. The speed of adjustment was around 42.65% when the change in the amount of dust was far from the long-run equilibrium. Similar to the long-run, all the coefficients of independent variables were statically significant. However, the total area of the paved road was positively correlated with the logarithm of the amount of dust per capita. As a result, the relationship between the logarithm of the amount of dust per capita and firm's size possessed a U-shaped curve, while the expansion of paved road might not affect the rise of the logarithm of the amount of dust per capita in the short-run even though the *p*-value was very close to statistical significance at 1%.

Table 8: Short run and long run estimations of $\Delta lnNO2per$ based on selected ARDL model (1, 1, 0, 0, 0)

Long run	**Coefficients**	**p-value**	**Short run**	**Coefficients**	**p-value**
FirmSize	-0.5265	0.016**	$\Delta FirmSize$	-0.1769	0.008***
FirmSize2	0.0435	0.036**	$\Delta FirmSize^2$	0.0154	0.013**
FirmSize3	-0.0012	0.044**	$\Delta FirmSize^3$	-0.0004	0.017**
Road	0.0166	0.045**	$\Delta Road$	0.0059	0.05**
Constant	-5.715	0.002***	ECT_{t-1}	-0.3555	0.001***
Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.					
R-squared				0.3732	
Number of observations				45	
Durbin-Watson statistics (7, 48)				1.992	

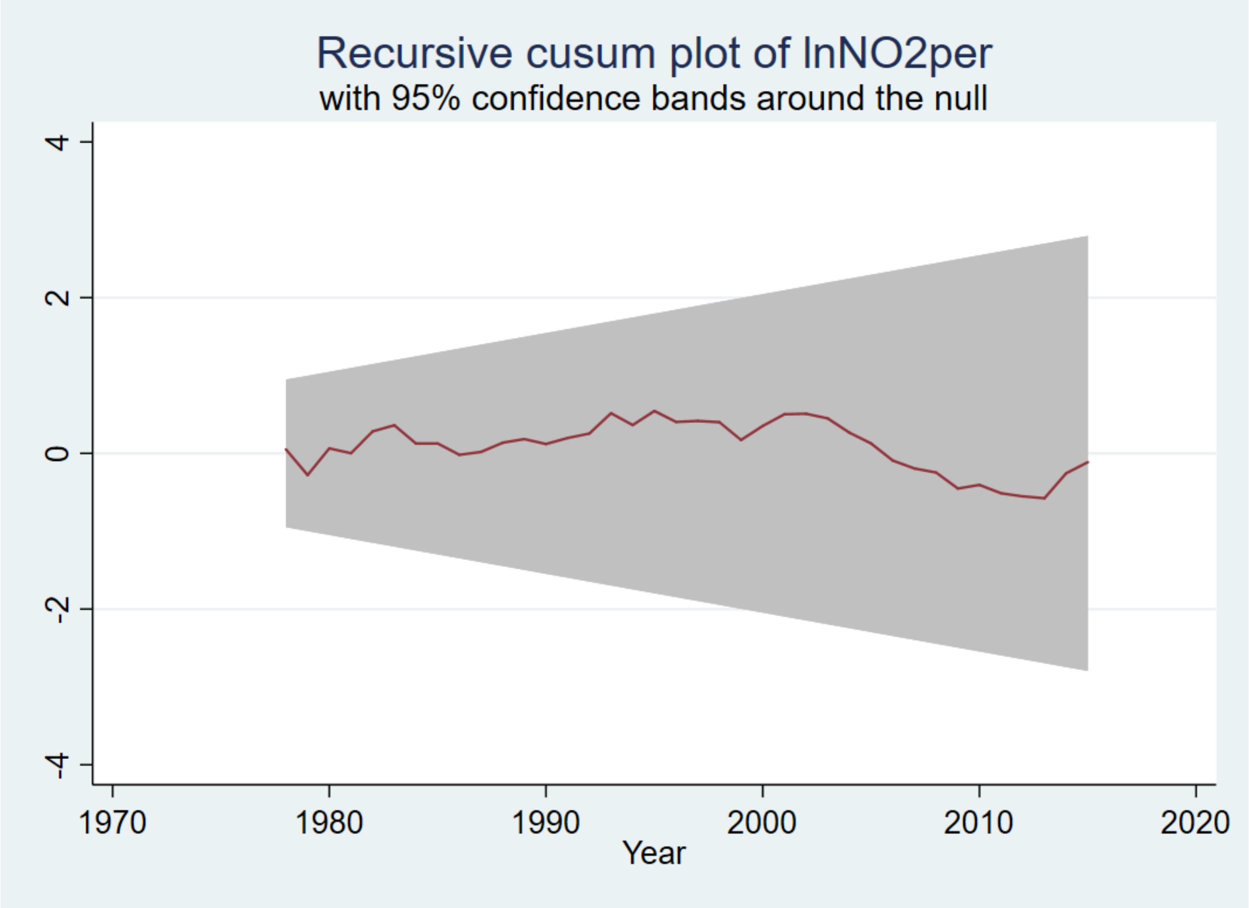
Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey serial Correlation LM test	H_0: No serial correlation	0.04 (0.84)	Not reject H_0
Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	0.22 (0.64)	Not reject H_0
ARCH test	H_0: Homoskedasticity	1.83 (0.17)	Not reject H_0

Ramsey Reset test	H_0: the model has no omitted variables	0.29 (0.83)	Not reject H_0

Note: p-value is put in parentheses.

The logarithm of NO_2 emission per capita. Table 8 provides information on long-run and short-run estimations of the logarithm of the concentration of NO_2 per capita according to the firm's size and area of paved road. By choosing one as the maximum lag length for the model, 1, 1, 0, 0, 0 were selected as optimal lag length for each variable in the model respectively. The model accounted for 37.32% of the variance. The Durbin – Watson statistic, which was 1.992, was very close to 2, indicating low autocorrelation in the model. The null hypotheses of post-estimation tests could not be rejected, showing the model was not serial correlated, homoscedastic, and appropriately specified. Figure 12 displays the result of the CUSUM test for stability of coefficients within the model. The statistics are between the critical bounds, signifying the stability of coefficients.

Figure 12: CUSUM test for the model with $\Delta lnNO2per$ as the dependent variable



All the variables in the long-run estimations were found to be significant at 5% of the significance level. The coefficients of variables *FirmSize* and *FirmSize3* were negative, while the coefficient of *FirmSize2* was positive, illustrating an inverted N-shaped relationship between the logarithm of the concentration of NO_2 per capita and the firm's size in the long-run. The method computing turning point was similar to the method as mentioned earlier. However, as cubic Equation (5.2) only had one root, and the first derivative of the equation does not have any real root, Equation (5.2) obtained the third fundamental cubic shape which has only one inflection point. Therefore, the turning point of the curve can be computed by the maximum value on the parabola of the model's derivative. The turning point of the model or point of reflection was at \$12.083 million per firm. The curve was symmetric at the turning point, so the amount of NO_2 per capita declined according to the development in firm's size; until the turning point, the declining flattened out and continued rising again shortly after that. The area of the paved road was also found to be significantly cointegrated with the logarithm of the concentration of NO_2 per capita, but the cointegration was positive, which means an increase of 1km^2 in paved road area will lead to 1.66% increase in the amount of NO_2 per capita.

The ECT shown in Table 5 are negative and statistically significant at 1%, which confirms the cointegration of the model. The adjustment speed to the long-run equilibrium was about 35%. The dynamics of the firm's size in the short-run obtained a similar shape with the long-run relationship illustrating an inverted N-shaped curve. The area of the paved road also has a significantly positive correlation with the logarithm of the concentration of NO_2 per capita.

Table 9: Short run and long run estimations of $\Delta lnOxper$ based on selected ARDL model (1, 1, 0, 0, 0)

Long run	**Coefficients**	**p-value**	**Short-run**	**Coefficients**	**p-value**
FirmSize	-0.3772	0.000***	$\Delta FirmSize$	-0.3208	0.001***
FirmSize2	0.0299	0.002***	$\Delta FirmSize^2$	0.0243	0.004***
FirmSize3	-0.0007	0.01***	$\Delta FirmSize^3$	-0.0005	0.016**
Road	0.0102	0.013**	$\Delta Road$	0.0083	0.022**
Constant	-13.2616	0.000***	ECT_{t-1}	-0.8132	0.000***

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

R-squared	0.5656
Number of observations	44
Durbin-Watson statistics (7, 48)	2.08

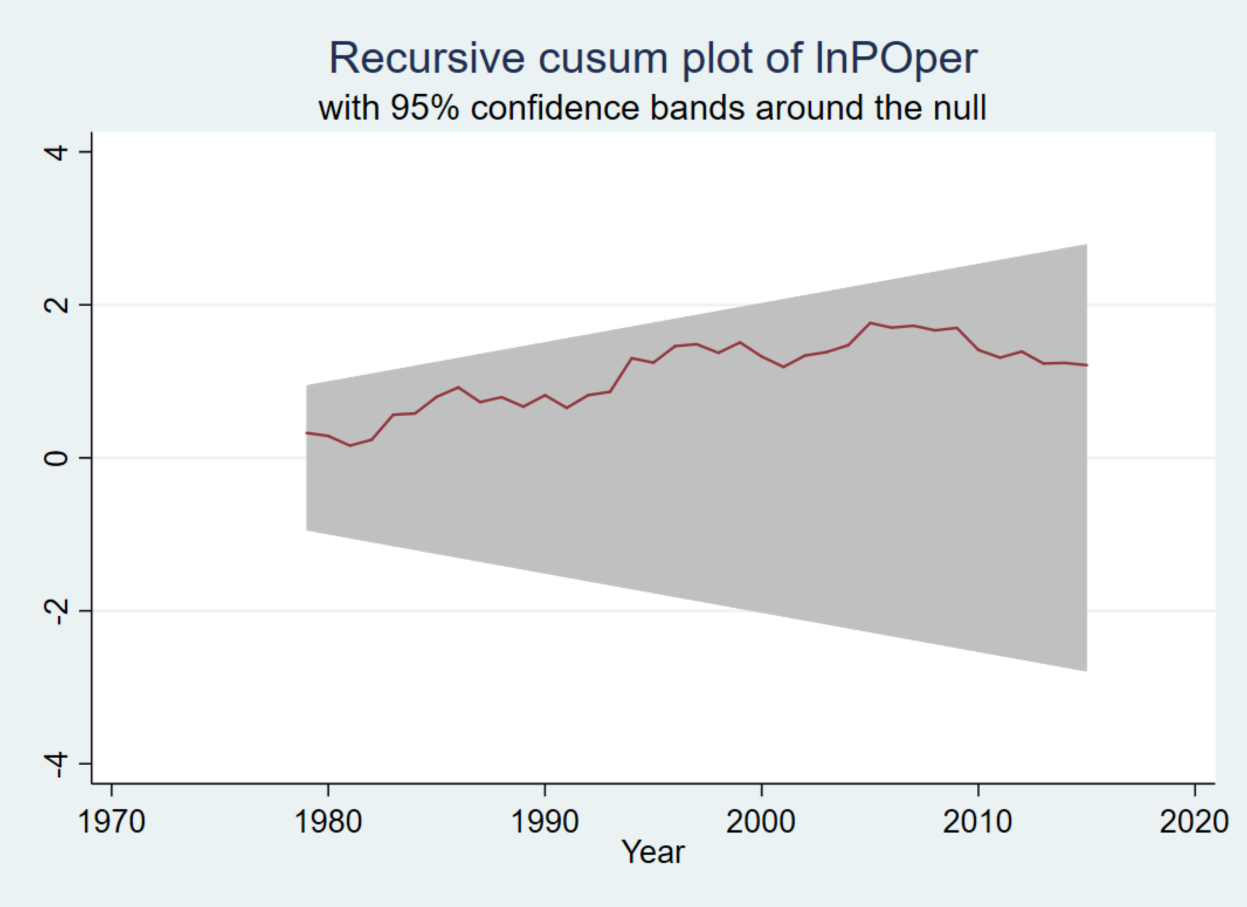
Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey serial Correlation LM test	H_0: No serial correlation	0.20 (0.65)	Not reject H_0
Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	1.65 (0.19)	Not reject H_0
ARCH test	H_0: Homoskedasticity	1.00 (0.31)	Not reject H_0

Ramsey Reset test	H_0: the model has no omitted variables	1.73 (0.17)	Not reject H_0

Note: p-value is put in parentheses.

The logarithm of Ox emission per capita. The short-run and long-run relationship between the logarithm of the concentration of Ox per capita and independent variables are displayed in Table 9. The model with selected lag values 1, 1, 0, 0, 0 obtained 56.56% goodness of fit. The Durbin – Watson statistic was acceptable at 2.08. Diagnostic tests conducted showed that the model has no problems regarding serial correlation, heteroskedasticity, and functional form. The results of the CUSUM test also implied the stability of the coefficients (see Figure 13).

Figure 13: CUSUM test for the model with *lnOxper* as the dependent variable



In the long-run relationship between Ox and the firm's size, a cubic function was confirmed at 1% of the significance level. With the fact that the coefficients of variables *FirmSize* and *FirmSize3* were negative (-0.3772 and -0.0007 respectively), while the coefficient of *FirmSize2* was positive (0.0299), the long-run relationship between the firm's size and the logarithm of the concentration of Ox per capita was an inverted N-shaped curve. However, unlike the inverted N-shaped curve of Equation (5.2), the derivative of Equation (5.3) had two real roots. The first and second turning points of Ox emission per capita were at $9.431 million per firm and $19.045 million per firm. The finding pointed out that when the firm's size was below $9.431 million, the logarithm of the concentration of Ox per capita declined; when the firm's size grew more massive than $9.431 million, the logarithm of Ox emission per capita increased until the second turning point, at $19.045 million per firm, and dropped afterwards. The long-run relationship between the total area of paved road and the logarithm of Ox emission per capita was significantly negative. This result suggested that an increase of one km^2 of the paved road might lead 1.02% of the logarithm of Ox emission per capita.

As for the short-run relationship, the ECT was negative and statistically significant, confirming the cointegration of the model. The adjustment speed of the short-run to the long-run equilibrium was relatively high with the rate of approximately 81%, denoting a relatively explosive adjustment. Moreover, the dynamics of coefficients of all variables were not different from those in the long-run estimation. The curve formed by the logarithm of Ox emission per capita and firm's size also displayed an inverted N-shaped curve, while the area of road positively affected the logarithm of the concentration of Ox per capita in the short run.

Table 10: Short run and long run estimations of $\Delta lnCOper$ based on selected ARDL model (1, 0, 0, 0, 0)

Long run	**Coefficients**	**p-value**	**Short run**	**Coefficients**	**p-value**
FirmSize	-0.6520	0.134	$\Delta FirmSize$	-0.4265	0.137
FirmSize2	0.0620	0.097*	$\Delta FirmSize^2$	0.0405	0.096*
FirmSize3	-0.0018	0.067*	$\Delta FirmSize^3$	-0.0012	0.064*
Road	-0.0136	0.065*	$\Delta Road$	-0.0089	0.089*
Constant	-7.811	0.001***	ECT_{t-1}	-0.6541	0.000***

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

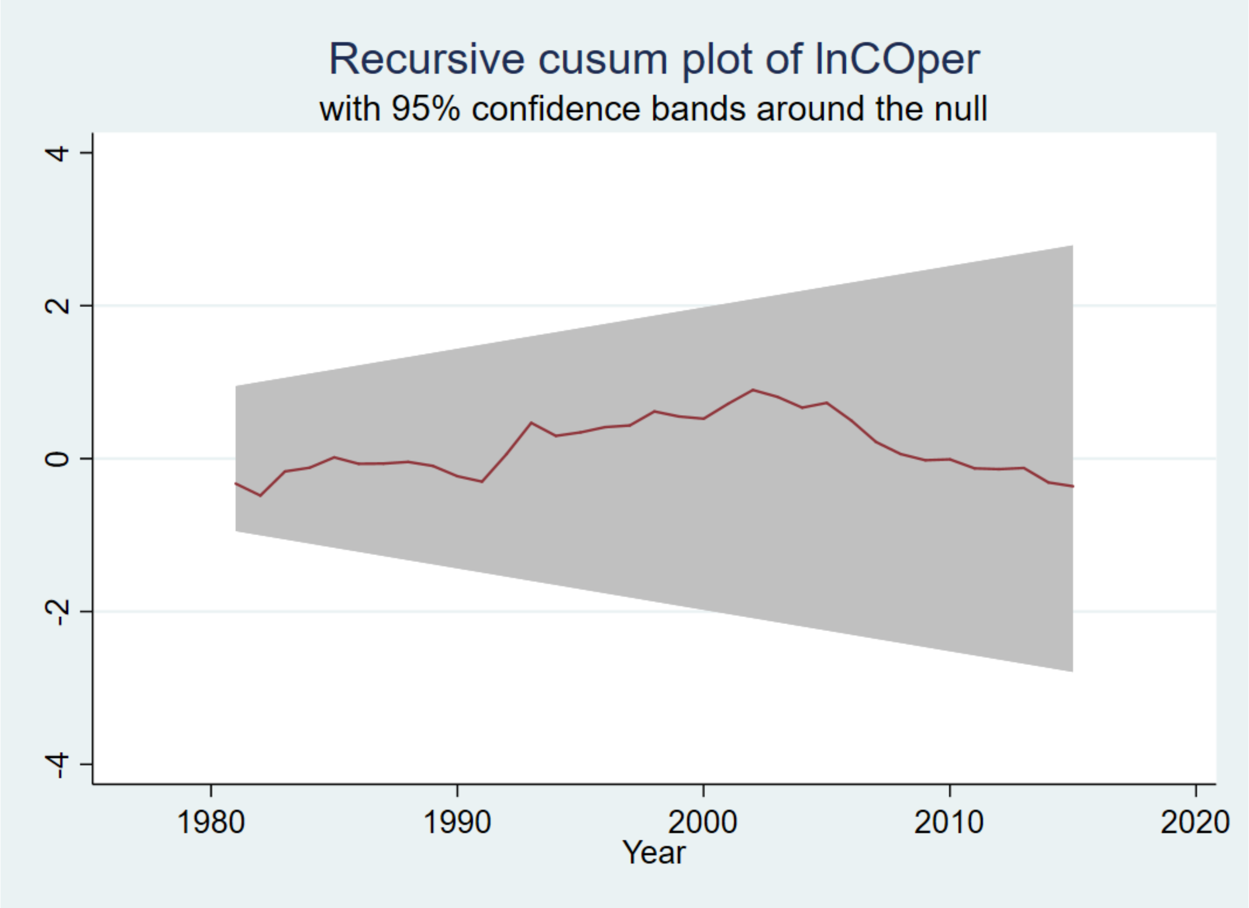
R-squared	0.4641
Number of observations	40
Durbin-Watson statistics (7, 48)	2.04

Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey serial Correlation LM test	H_0: No serial correlation	0.17 (0.67)	Not reject H_0
Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	0.07 (0.79)	Not reject H_0
ARCH test	H_0: Homoskedasticity	1.17 (0.27)	Not reject H_0
Ramsey Reset test	H_0: the model has no omitted variables	0.23 (0.87)	Not reject H_0

Note: p-value is put in parentheses.

The logarithm of CO emission per capita. The results of the ARDL model estimating the logarithm of the concentration of CO per capita with selected lag values 1, 0, 0, 0, 0 are presented in Table 10. The model with 40 observations obtained 46.41% of the goodness of fit. The Durbin – Watson statistics was 2.04, illustrating almost no autocorrelation happen in the model. Other post-estimation tests confirmed the robustness and the stability of the model. The CUSUM test also indicated that the coefficients of all variables were stable (see Figure 14).

Figure 14: CUSUM test for the model with *lnCOper* as dependent variable



In the long-run estimation, the *p*-values of *FirmSize2* and *FirmSize3* were lower than 0.1, while the *p*-value of *FirmSize1* was only 0.134. The signs of three coefficients denoted an inverted N-shaped relationship between industrial firm's size and the logarithm of CO emission per capita. Even though *FirmSize1* was not statistically significant at 10%, it almost reached that significance level. Therefore, the inverted N-shaped relationship between the logarithm of CO emission per capita and industrial firm’s size was worth considering. Two turning points of the curve were at \$8.152 million per firm and \$14.811 million per firm. Regarding the effect of paved road's area, the logarithm of CO emission per capita was negatively impacted by the increase in the area of paved road. Notably, with every newly built km^2 of paved road, the CO emission per capita would decline by 1.36%.

As the coefficient of ECT was negative and statistically significant at 1% significance level, the relationship between the logarithm of CO emission per capita and other independent variables was cointegrated. The adjustment speed of the model is around 65% annually. The relationship between the firm's size and CO emission per capita in the short-run was similar to the long-run. The area of the paved road also significantly negatively affected the logarithm of CO emission per capita in the short-run.

Table 12: Short run and long run estimations of $\Delta lnSOxper$ based on selected ARDL model (1, 0, 0, 0, 0)

Long run	**Coefficients**	**p-value**	**Short run**	**Coefficients**	**p-value**
FirmSize	-2.0946	0.022**	$\Delta FirmSize$	-0.7957	0.003***
FirmSize2	0.2506	0.042**	$\Delta FirmSize^2$	0.0952	0.007***
FirmSize3	-0.0095	0.059*	$\Delta FirmSize^3$	-0.0036	0.013**
Road	-0.0787	0.000***	$\Delta Road$	-0.0299	0.01***
Constant	-3.1419	0.043**	ECT_{t-1}	-0.3799	0.002***

Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.

R-squared	0.4517
Number of observations	32
Durbin-Watson statistics (7, 48)	2.10

Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey Serial Correlation LM test	H_0: No serial correlation	0.51 (0.47)	Not reject H_0
Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	0.13 (0.71)	Not reject H_0
ARCH test	H_0: Homoskedasticity	0.20 (0.64)	Not reject H_0
Ramsey Reset test	H_0: the model has no omitted variables	0.63 (0.07)	Reject H_0

Note: p-value is put in parentheses.

The logarithm of SO_x emission per capita. Estimated results of Equation (3.5) using the ARDL analysis are shown in Table 12. The goodness of fit of the model was 45.17%, while the Durbin – Watson statistic showed relatively low autocorrelation in the model. Post-estimation tests confirmed the model had no problem with serial correlation and heteroskedasticity. However, the null hypothesis of Ramsey Reset test was rejected, denoting the model was not appropriately specified. Therefore, we conducted another estimation with *lnSOxper* dependent on the quadrative polynomial equation by replicating all the analysis stages that were conducted. The VAR test based on AIC, BIC, and HQIC implied that the optimal lag length should be 4, 1, and one respectively. Thus, one was selected as the maximum lag length due to lowest lag length prioritization, whereas the F-stat computed from the regression analyses following specifications of the baseline of models was 2.938 which was not higher than the upper bound as well as lower than the lower bound. Thus, the new model with *lnSOxper* as the dependent variable was considered inconclusive. The coefficient of ECT was -0.4171 and significant at 1%, confirming the cointegration of the new model. The new estimation is shown in Table 13.

Table 13: Short run and long run estimations with Δ*lnSOxper* dependent on quadratic equation (1, 0, 0, 0)

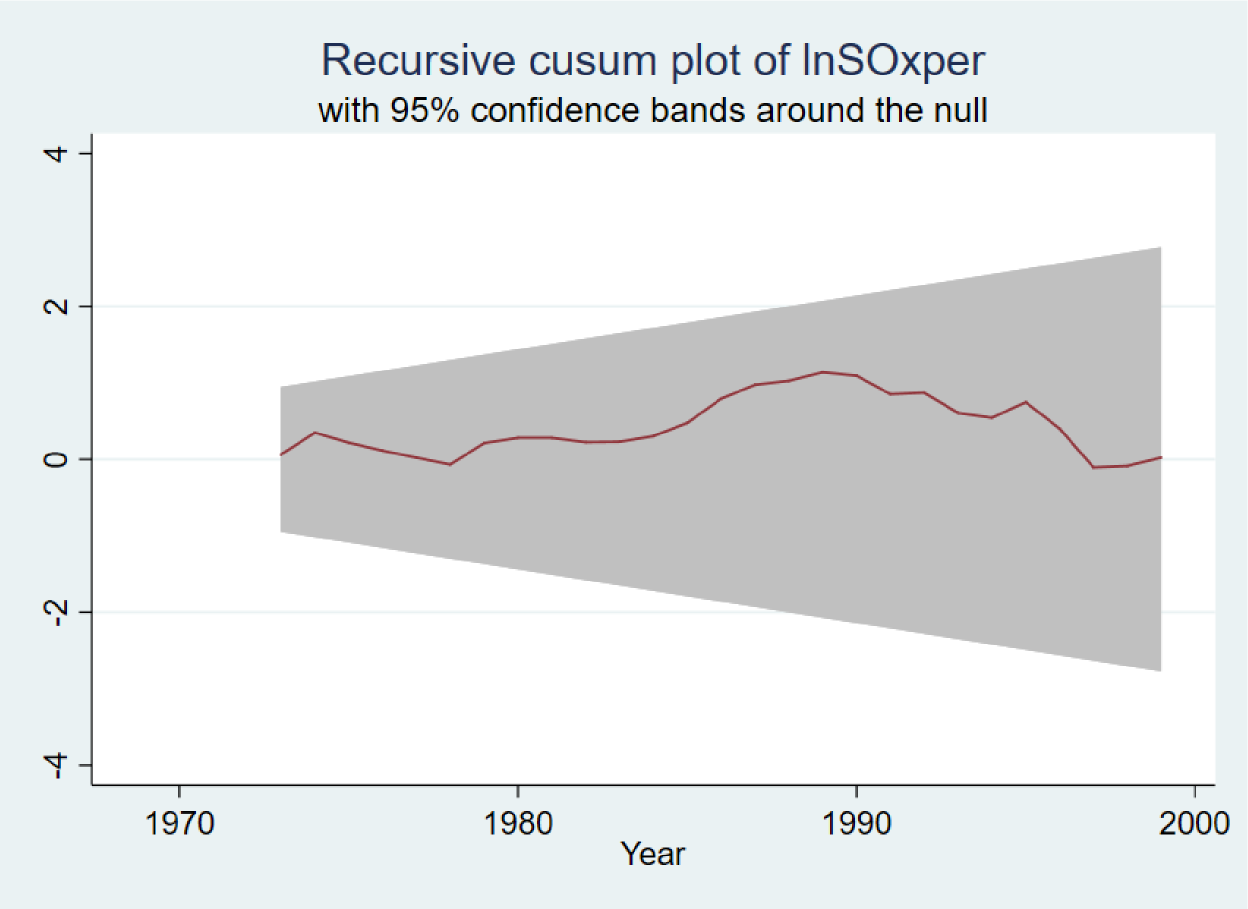
Long run	**Coefficients**	**p-value**	**Short-run**	**Coefficients**	**p-value**
FirmSize	-0.4308	0.01***	Δ*FirmSize*	-0.1797	0.034**
FirmSize2	0.0210	0.019**	$\Delta FirmSize^2$	0.0087	0.045**
Road	-0.0772	0.000***	Δ*Road*	-0.0322	0.012**
Constant	-4.928	0.002**	ECT_{t-1}	-0.4171	0.002***
Note: *, ** and *** represent statistical significance at 10%, 5% and 1% respectively.					
R-squared				0.3032	
Number of observations				32	
Durbin-Watson statistics (7, 48)				2.10	

Diagnostic tests	**Null hypothesis**	**F-statistic**	**Decision**
Breusch Godfrey Serial Correlation LM test	H_0: No serial correlation	0.40 (0.52)	Not reject H_0
Breusch-Pagan / Cook-Weisberg test for Heteroskedasticity	H_0: Homoskedasticity	2.33 (0.12)	Not reject H_0
ARCH test	H_0: Homoskedasticity	0.01 (0.89)	Not reject H_0
Ramsey Reset test	H_0: the model has no omitted variables	1.85 (0.16)	Not reject H_0

Note: p-value is put in parentheses.

After estimating the long-run and short-run of *lnSOxper* dependent on polynomial order 2, the new goodness of fit was 30.32%, which was lower than the old model. However, no null hypotheses of post-estimation tests were rejected, implying that the model was appropriately specified. The CUSUM test also indicated that the coefficients of all variables were stable (see Figure 15).

Figure 15: CUSUM test for the model with *lnSOxper* as the dependent variable



The long-run results showed that *FirmSize* had negative coefficients (-0.4308), while FirmSize2 had a positive coefficient (0.0210). While the coefficients of *FirmSize* and Road were statistically significant at 1%, the coefficient of *FirmSize2* was only statistically significant at 5%.

As the coefficients of *FirmSize* and *FirmSize2* were negative and positive respectively, and the derivative of the new model had one real root, indicating that the long-run relationship between the logarithm of SOx emission per capita and firm's size was a U-shaped curve. The computed turning point was around $10.257 million per firm. The coefficient of *Road* was significantly negative (-0.0772) at 1%. This finding meant that SOx emission per capita would be reduced by 7.72% if one km^2 of the paved road was constructed.

In the short-run estimation, the negative and statistically significant coefficient of ECT confirmed the cointegration of the model without *FirmSize3*. The adjustment speed to long-run equilibrium was about 41%. The coefficients of independent variables in the short-run estimations also possessed the same trend with the coefficients in the long-run estimation. Specifically, the firm's size and the logarithm of SOx emission per capita also possessed a U-shaped curve relationship, while the area of the paved road had a negative impact on the logarithm of SOx emission per capita in short-run.

In general, the firm's size and the area of the paved road had a significant impact on all types of air pollutants concerned in this study. The models with *lnNO2per* and *lnOxper* as dependent variables implied an inverted N-shaped relationship between industrial firm's size and the logarithm of air pollutant's emission per capita, whereas the models with *lnDustper* and *lnSOxper* as dependent variables implied a U-shaped relationship between industrial firm's size and the logarithm of air pollutant's emission per capita. Only the model with *lnCOper* implied an inverted U-shaped relationship between the industrial firm's size and the logarithm of air pollutant's emission per capita, validating the existence of EKC.

Even though the model with *lnNO2per* as a dependent variable possessed an inverted N-shaped relationship between the firm's size and the logarithm of air pollutant's emission per capita, it only had one inflection point at \$12.083 million per firm, while the first and second turning points of the model with *lnOxper* as a dependent variable were \$9.431 and \$19.045 million per firm respectively. The turning point of EKC between the logarithm of *lnCOper* emission per capita and industrial firm's size was \$11.052 million per firm. The turning points of models with *lnDustper* and *lnSOxper* as dependent variables were at \$11.27 and \$10.257 million per firm, respectively.

As for the impact of constructing the paved road on air pollutions, it varied according to the type of the pollutants. For every newly built km^2 of the paved road, the logarithm of dust emission per capita, CO emission per capita, and SOx emission per capita would decrease by 2.02%, 1.61%, and 7.72% respectively, whereas the logarithm of NO_2 emission per capita and Ox emission per capita would increase by 1.66% and 1.02%.

5. Discussion

By using an almost fifty-year time-series data received from the City of Kitakyushu, the current study presents a primary investigation in the EKC hypothesis between the average industrial firm's size and air pollution as well as the impact of infrastructure development on air pollution. The relationship was examined after 1967 when the first air pollution was signed between the government and private sector, as it is believed that 1967 was the starting point of the transformation process from "gray" to "green" of Kitakyushu city. We found two different patterns among air pollution as firms grow larger. In particular, from the long-run view, NO_2 and Ox emission might be reduced as firms grow, whereas SOx and dust emission possess a contrary trend. Moreover, even though there is a trilemma among the growth of industrial firms, road infrastructure development, and air pollution in a green growth-oriented city, evidence that environmental degradation (CO emission) can be controlled through green growth policies and the setting up of low-carbon society agenda was found.

5.1. EKC of industrial firm's size and air pollution

This study found out that the logarithm of NO_2 (β_1=-0.5265, *p*-value<0.05; β_2=0.0435, *p*-value<0.05; and β_3=-0.0012, *p*-value<0.05) and Ox (β_1=-0.3772, *p*-value<0.01; β_2=0.0299, *p*-value<0.01; and β_3=-0.0007, *p*-value<0.01) emission per capita formed an inverted N-shaped relationship with the average size of the industrial firm. These results validated the EKC hypothesis that economic development, or more particularly industrial growth, would lead to pollution reduction, even though the curve was not an inverted-U shaped curve, but distorted (inverted N-curve) (see Figure 18). Also, the relationship between the logarithm of CO emission per capita (β_1 =-0.6520, *p*-value=0.134; β_2 =0.0620, *p*-value<0.1; and β_3 =-0.0018, *p*-value<0.1) and industrial firm's size also illustrates an inverted N-shaped curve, even though its β_1 was not statistically significant.

The emissions of NO_2 and CO are usually closely correlated as their primary source is the burning of fossil fuels of vehicles (Atkinson et al., 2016; Brito et al., 2018; Schmitz et al., 2019). However, a part of CO emission might also come from industrial activities. In case of Ox emission, it is created through a complex photochemical reaction of NO_2 with other substances in the air, so the concentration of Ox might be determined by the concentration of NO_2 in the air (Guderian, 1985).

The current study also found out the logarithm of dust emission per capita (β_1=-0.2466, *p*-value<0.01; and β_2=0.0110, *p*-value<0.01) and SOx emission per capita (β_1=-0.4308, *p*-value<0.01; and β_2=0.0210, *p*-value<0.05) formed a U-shaped relationship with the firm's size, which provides evidence against the EKC hypothesis. Dust and SOx emissions are primarily released from the industrial production process.

The first half of the inverted N-shaped curve and the U-shaped curve might be explained by the following reasons. After 1967, when the first pollution prevention agreement between the government and private sectors was signed, the regulation started to take effect (Fujikura, 2007; Low, 2013). As a result, air pollution emission control and monitoring became more stringent through financial punishment of pollution emission and incentives to replace new technologies; industrial firms were forced to utilize cleaner production and energy-efficient technologies (OECD, 2013). To elaborate, larger firms might be able to replace new technologies more rapidly and invest in R&D due to the economies of scale effects (Machado et al., 2016; Merlevede et al., 2006; Nielsen, 2018; Oh & Lee, 2016; Park, Lee, & Yoo, 2016). Also, usually, regulatory inspections focus on the large firm, as it is a cost-effective strategy for the government (Dasgupta et al., 2002), which might make the large firm less pollution-intensive than a small firm. This finding is also confirmed by Merlevede et al. (2006) that large firms have a greater impact on decreasing air pollution than small firms after the regulations are strictly imposed. The decrease of NO_2 and PO emission might also result from the fact that larger industrial firm will have an immense network and capacity to export to territories outside the border.

After the first negative relationship between air emission and the industrial firm size, the declining trend of air pollution stopped and began to increase again. This change might result from the effect of diseconomies of scale and the insufficiencies of policies to control and monitor air pollution.

When the economies of scale effects ran out, and the policies became insufficient due to rapid change within the structure of industrial systems, two different trends among air pollution started to emerge. The SOx and Dust emissions per capita kept increasing according to the increase in firm size because of the complex and rapidly changing within the structure of the industrial system. Mainly, a rising number of large firms in iron steel, chemical, and automobile sectors, etc. has outsourced their activities to smaller firms which receive many incentives and less stringent regulation's restriction and inspection from the government (OECD, 2013). Based on the finding, we suggest that local government should strengthen the monitoring and controlling dust and SOx emission through more stringent regulations, especially with small- and medium-sized firms, and support the private sector to replace or invest in R&D of dust and SOx treatment technology.

On the other hand, the NO_2 and PO emissions per capita can be reduced as the firm size grows more massive because of the reinforcement of regulations and development of another mode of transport, which produces less air pollution. Most importantly, the law controlling the automobile's NOx emission, which was enacted in 1992, could be a strong influencer (Ministry of the Environment, 1992). It is notable that in 1992, the average firm's size was around \$12.57 million per firm, while the estimated turning point of the curve of NO_2 emission was around \$12.083 million per firm. Furthermore, Kitakyushu has a strategic port location, which facilitates the development of water transport. In recent years, the size of road freight transport sector in Kitakyushu declined by 53%, while size and specialization index of water transport sector increased by 50% and 104%, respectively (OECD, 2013). The expansion of average industrial firm's size together with the rapid development of water transport sector hints a changing of the mode of transport in Kitakyushu from road transport to water transport, which could significantly reduce the emission of NO_2, CO, and PO due to road freight transport.

Interestingly, even though the primary sources of CO emission per capita are both industrial activities and transportation. CO emission per capita can still be controlled as firm size increases, which suggest that the policies and regulations in Kitakyushu are sufficient to control CO emission.

5.2. Infrastructure development

Another striking finding of this study is that the total area of the paved road can impact air pollution emission. Notably, the increasing total area of the paved road may lead to the increase in the concentration of NO_2 and Ox per capita, whereas the amount of dust per capita and concentration of SO_x, and CO per capita is negatively correlated with the expansion of paved road (see Figure 19). The positive associations between the total area of paved road and concentration of NO_2 and Ox per capita might be explained by the increase travelling demand if a high-quality road is constructed (Cervero, 2003) and NO_2 is the precursor of Ox (Guderian, 1985). According to a report of OECD, there is an urgent need to enact a policy which facilitates the densification of the population (OECD, 2013). On the other hand, building more road also corresponds to the decline of air pollution emissions, such as the amount of dust per capita, the concentration of $SO_{x,}$ and CO per capita. This result can be explained by the fact that high-quality road expansion may increase manufacturing productivity, which in turn may help reduce air pollution emission from industrial activities (Duran-Fernandez & Santos, 2014).

5.3. The trilemma and a hope

The trilemma among infrastructure development industrial firm's size, environmental degradation reduction is what can be seen from this study. As firms expand, a more complex and enormous infrastructure needs to be built for facilitating the transportation of manufactured products as well as enhancing the impacts of economies of scale. A well-designed and high-quality road network can boost manufacturing productivity, especially when a great proportion of industrial firms are recycling firms. However, a well-designed and high-quality road network can also enhance the demand of travel of people living in the same urban neighborhoods. An increasing demand of travel would in turn lead to the emissions of other air pollutants. Whichever we choose, either industrial development, road infrastructure development, or air pollution reduction, there might be adverse effects on other issues.

However, the evidence on CO emission per capita sheds light for an optimistic future of green growth development, in which goals of industrial development and road infrastructure expansion can be achieved while maintaining a good quality of air condition. To continue achieving such success in controlling pollution while maintaining industrial and infrastructure development, more and better science should be done (Vuong, 2018). Indeed, due to the lack of AI readiness, which could be improved through a combination of adequate technical/technological expertise, financial sustainability, and socio-political commitment, data storage and data management was not sufficient (Vuong et al., 2019). Consequentially, our study could not provide results estimated from sufficient data from 1967, and the result could only exhibit a superficial tendency regarding the relationship among air pollution, industrial growth, and infrastructure development. Yet, there is still a way to improve the quality of findings by employing Bayesian Hierarchical Model (La & Vuong, 2019; Vuong et al., 2018; Vuong & La, 2019).

Figure 16: The shape of the relationship between aggregate industrial firm's size and the logarithm of the amount of air pollution per capita

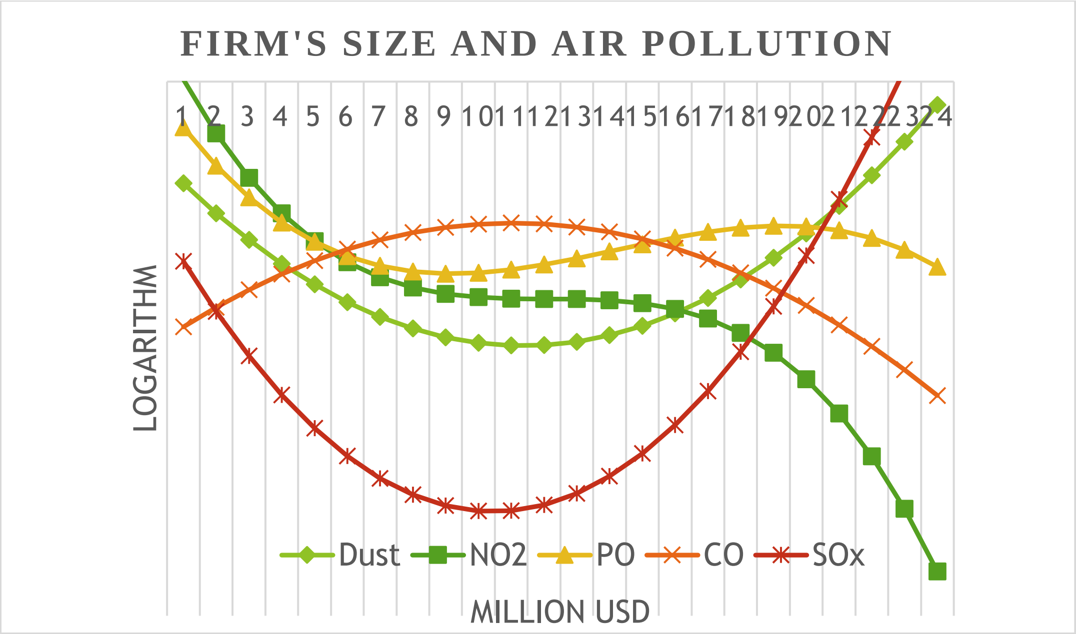
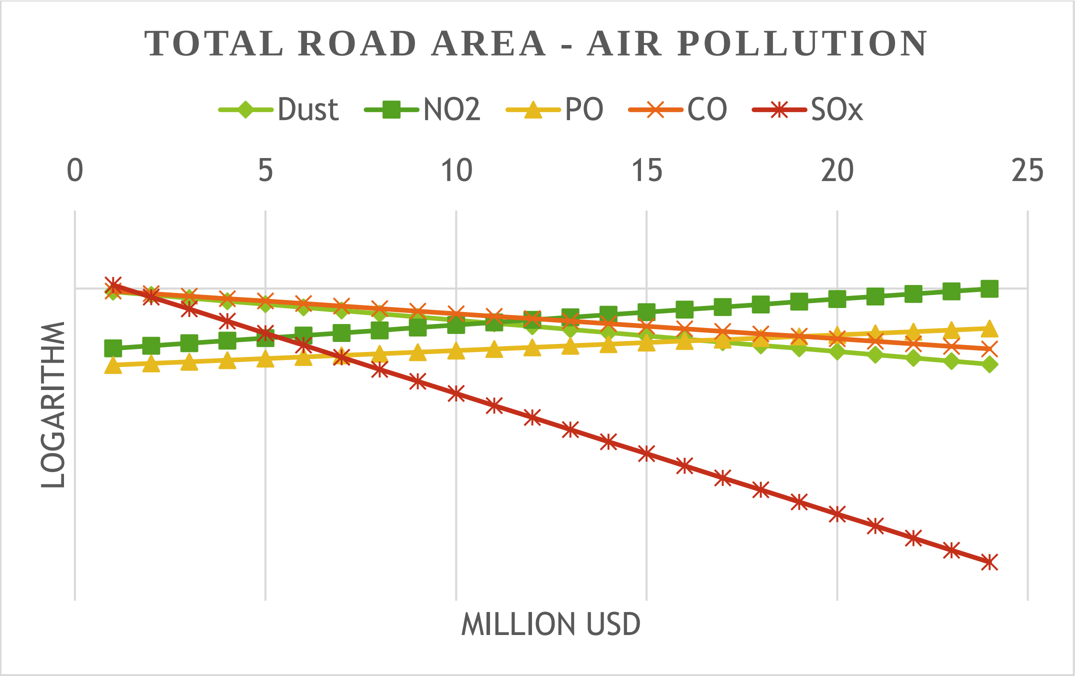


Figure 17: The shape of the relationship between the total area of paved road and the logarithm of the amount of air pollution per capita



References

Ahluwalia, M. S. (1976). Inequality, poverty and development. *Journal of Development Economics*, *3*(4), 307–342. https://doi.org/10.1016/0304-3878(76)90027-4

Ahmad, N., Du, L., Lu, J., Wang, J., Li, H.-Z., & Hashmi, M. Z. (2017). Modelling the CO 2 emissions and economic growth in Croatia: Is there any environmental Kuznets curve? *Energy*, *123*, 164–172. https://doi.org/10.1016/j.energy.2016.12.106

Akbostancı, E., Türüt-Aşık, S., & Tunç, G. İ. (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve? *Energy Policy*, *37*(3), 861–867. https://doi.org/10.1016/j.enpol.2008.09.088

Ali, W., Abdullah, A., & Azam, M. (2017). Re-visiting the environmental Kuznets curve hypothesis for Malaysia: Fresh evidence from ARDL bounds testing approach. *Renewable and Sustainable Energy Reviews*, *77*, 990–1000. https://doi.org/10.1016/j.rser.2016.11.236

Apergis, N., & Ozturk, I. (2015). Testing Environmental Kuznets Curve hypothesis in Asian countries. *Ecological Indicators*, *52*, 16–22. https://doi.org/10.1016/j.ecolind.2014.11.026

Atkinson, R. W., Analitis, A., Samoli, E., Fuller, G. W., Green, D. C., Mudway, I. S., … Kelly, F. J. (2016). Short-term exposure to traffic-related air pollution and daily mortality in London, UK. *Journal of Exposure Science & Environmental Epidemiology*, *26*(2), 125–132. https://doi.org/10.1038/jes.2015.65

Azomahou, T., Laisney, F., & Nguyen Van, P. (2006). Economic development and CO2 emissions: A nonparametric panel approach. *Journal of Public Economics*, *90*(6–7), 1347–1363. https://doi.org/10.1016/j.jpubeco.2005.09.005

Banerjee, A., Dolado, J., & Mestre, R. (1998). Error-correction mechanism tests for cointegration in a single-equation framework. *Journal of Time Series Analysis*, *19*(3), 267–283. https://doi.org/10.1111/1467-9892.00091

Barro, R. J. (2000). Inequality and growth in a panel of countries. *Journal of Economic Growth*, *5*(1), 5–32. https://doi.org/10.1023/A:1009850119329

Bölük, G., & Mert, M. (2015). The renewable energy, growth and environmental Kuznets curve in Turkey: An ARDL approach. *Renewable and Sustainable Energy Reviews*, *52*, 587–595. https://doi.org/10.1016/j.rser.2015.07.138

Brito, J., Carbone, S., A. Monteiro dos Santos, D., Dominutti, P., de Oliveira Alves, N., V. Rizzo, L., & Artaxo, P. (2018). Disentangling vehicular emission impact on urban air pollution using ethanol as a tracer. *Scientific Reports*, *8*(1), 10679. https://doi.org/10.1038/s41598-018-29138-7

Brown, R. L., Durbin, J., & Evans, J. M. (1975). Techniques for testing the constancy of regression relationships over time. *Journal of the Royal Statistical Society*, *37*(2), 149–192.

Cervero, R. (2003). Road expansion, urban growth, and induced travel: A path analysis. *Journal of the American Planning Association*, *69*(2), 145–163. https://doi.org/10.1080/01944360308976303

City of Kitakyushu. (2018). *Kitakyushu City the Sustainable Development Goals Report 2018*. Kanagawa, Japan: Institute for Global Environmental Strategies.

Dasgupta, S., Lucas, R. E. B., & Wheeler, D. (2002). Plant size, industrial air pollution, and local incomes: Evidence from Mexico and Brazil. *Environment and Development Economics*, *7*(2), 365–381. https://doi.org/10.1017/S1355770X02000220

De Bruyn, Sander M. (1997). Explaining the environmental Kuznets curve: Structural change and international agreements in reducing sulphur emissions. *Environment and Development Economics*, *2*(4), 485–503. https://doi.org/10.1017/S1355770X97000260

De Bruyn, S.M, Van Den Bergh, J. C. J. M., & Opschoor, J. B. (1998). Economic growth and emissions: Reconsidering the empirical basis of environmental Kuznets curves. *Ecological Economics*, *25*(2), 161–175. https://doi.org/10.1016/S0921-8009(97)00178-X

Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. *Ecological Economics*, *49*(4), 431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Duran-Fernandez, R., & Santos, G. (2014). Regional convergence, road infrastructure, and industrial diversity in Mexico. *Research in Transportation Economics*, *46*, 103–110. https://doi.org/10.1016/j.retrec.2014.09.007

Dutt, K. (2009). Governance, institutions and the environment-income relationship: A cross-country study. *Environment, Development and Sustainability*, *11*(4), 705–723. https://doi.org/10.1007/s10668-007-9138-8

Engle, R. F., & Granger, C. W. J. (1987). Co-Integration and Error Correction: Representation, estimation, and testing. *Econometrica*, *55*(2), 251. https://doi.org/10.2307/1913236

Environment Bureau Environment Monitoring Department Environment Monitoring Division. (2019). 平成 26 年度 環境の現況. [Current status of fiscal 2014 environment].

Fujikura, R. (2007). Administrative guidance of Japanese local government for air pollution control. In T. Terao & K. Otsuka (Eds.), *Development of Environmental Policy in Japan and Asian Countries*. https://doi.org/10.1057/9780230624931

Galeotti, M., & Lanza, A. (2005). Desperately seeking environmental Kuznets. *Environmental Modelling & Software*, *20*(11), 1379–1388. https://doi.org/10.1016/j.envsoft.2004.09.018

Gassebner, M., Lamla, M. J., & Sturm, J.-E. (2011). Determinants of pollution: What do we really know? *Oxford Economic Papers*, *63*(3), 568–595. https://doi.org/10.1093/oep/gpq029

Grossman, G., & Krueger, A. (1991). *Environmental impacts of a North American Free Trade Agreement* (No. w3914; p. w3914). https://doi.org/10.3386/w3914

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, *110*(2), 353–377. https://doi.org/10.2307/2118443

Guderian, R. (1985). *Air pollution by Photochemical Oxidants: Formation, transport, control, and effects on plants*. Retrieved from http://public.eblib.com/choice/publicfullrecord.aspx?p=3091349

Harris, R. I. D. (1992). Testing for unit roots using the augmented Dickey-Fuller test. *Economics Letters*, *38*(4), 381–386. https://doi.org/10.1016/0165-1765(92)90022-Q

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control*, *12*(2–3), 231–254. https://doi.org/10.1016/0165-1889(88)90041-3

Jovanovic, B. (2018). When is there a Kuznets curve? Some evidence from the ex-socialist countries. *Economic Systems*, *42*(2), 248–268. https://doi.org/10.1016/j.ecosys.2017.06.004

Kijima, M., Nishide, K., & Ohyama, A. (2010). Economic models for the environmental Kuznets curve: A survey. *Journal of Economic Dynamics and Control*, *34*(7), 1187–1201. https://doi.org/10.1016/j.jedc.2010.03.010

Komen, M. H. C., Gerking, S., & Folmer, H. (1997). Income and environmental R&D: Empirical evidence from OECD countries. *Environment and Development Economics*, *2*(4), 505–515. https://doi.org/10.1017/S1355770X97000272

Kripfganz, S., & Schneider, D. C. (2016). *ARDL: Stata module to estimate autoregressive distributed lag models*. Presented at the Stata Conference, Chicago. Retrieved from https://www.stata.com/meeting/chicago16/slides/chicago16_kripfganz.pdf

Kuznets, S. (1955). Economic growth and income inequality. *The American Economic Review*, *45*(1), 1–28.

La, V.-P., & Vuong, Q.-H. (2019). bayesvl: Visually learning the graphical structure of Bayesian networks and performing MCMC with “Stan” (Version 0.8.5) [The Comprehensive R Archive Network (CRAN)]. Retrieved from https://CRAN.R-project.org/package=bayesvl

Living Environment Division. (2019). 用語説明. [Glossary].

Low, M. (2013). Eco-cities in Japan: Past and future. *Journal of Urban Technology*, *20*(1), 7–22. https://doi.org/10.1080/10630732.2012.735107

Lütkepohl, H. (2005). *New introduction to multiple time series analysis*. Berlin: New York : Springer.

Machado, M. M., de Sousa, M. C. S., & Hewings, G. (2016). Economies of scale and technological progress in electric power production: The case of Brazilian utilities. *Energy Economics*, *59*, 290–299. https://doi.org/10.1016/j.eneco.2016.06.017

McPherson, M. A. (2008). Small firms and the environment in developing countries. *Economic Development and Cultural Change*, *57*(1), 203–204. https://doi.org/10.1086/590449

Merlevede, B., Verbeke, T., & De Clercq, M. (2006). The EKC for SO2: Does firm size matter? *Ecological Economics*, *59*(4), 451–461. https://doi.org/10.1016/j.ecolecon.2005.11.010

Ministry of Economy, Trade and Industry. (2019). 工業統計調査. [Industrial Statistics Survey].

Ministry of the Environment. (1992). *The law concerning special measures for total emission reduction of Nitrogen Oxides from automobiles in specified areas*. Retrieved from http://www.env.go.jp/en/laws/air/amobile.html

Ministry of the Environment Government of Japan. (2019). Environmental quality standards in Japan Air Quality.

Ng, Y.-K., & Wang, J. (1993). Relative income, aspiration, environmental quality, individual and political myopia. *Mathematical Social Sciences*, *26*(1), 3–23. https://doi.org/10.1016/0165-4896(93)90008-7

Nielsen, H. (2018). Technology and scale changes: The steel industry of a planned economy in a comparative perspective. *Economic History of Developing Regions*, *33*(2), 90–122. https://doi.org/10.1080/20780389.2018.1432353

OECD. (2013). *Green growth in Kitakyushu, Japan*. https://doi.org/10.1787/9789264195134-en

Oh, D., & Lee, Y.-G. (2016). Productivity decomposition and economies of scale of Korean fossil-fuel power generation companies: 2001–2012. *Energy*, *100*, 1–9. https://doi.org/10.1016/j.energy.2016.01.004

Özokcu, S., & Özdemir, Ö. (2017). Economic growth, energy, and environmental Kuznets curve. *Renewable and Sustainable Energy Reviews*, *72*, 639–647. https://doi.org/10.1016/j.rser.2017.01.059

Ozturk, I., & Al-Mulali, U. (2015). Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia. *Ecological Indicators*, *57*, 324–330. https://doi.org/10.1016/j.ecolind.2015.05.018

Panaÿotou, T. (1993). *Empirical tests and policy analysis of environmental degradation at different stages of economic development*. Geneva.

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: Turning a black box into a policy tool. *Environment and Development Economics*, *2*(4), 465–484. https://doi.org/10.1017/S1355770X97000259

Park, S.-Y., Lee, K.-S., & Yoo, S.-H. (2016). Economies of scale in the Korean district heating system: A variable cost function approach. *Energy Policy*, *88*, 197–203. https://doi.org/10.1016/j.enpol.2015.10.026

Pesaran, M. H., & Shin, Y. (1999). An Autoregressive Distributed-Lag Modelling approach to cointegration analysis. In S. Strom (Ed.), *Econometrics and Economic Theory in the 20th Century* (pp. 371–413). https://doi.org/10.1017/CCOL521633230.011

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/jae.616

Pezzey, J. (1992). Sustainability: An interdisciplinary guide. *Environmental Values*, *1*(4), 321–362. https://doi.org/10.3197/096327192776680034

Phillips, P. C. B., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I(1) processes. *The Review of Economic Studies*, *57*(1), 99. https://doi.org/10.2307/2297545

Rafindadi, A. A. (2016). Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: Empirical evidence from Japan. *Energy Policy*, *94*, 274–284. https://doi.org/10.1016/j.enpol.2016.03.040

Ram, R. (2017). Kuznets curve in happiness: A cross-country exploration. *Economic Modelling*, *66*, 272–278. https://doi.org/10.1016/j.econmod.2017.06.006

Randolph, S. M., & Lott, W. F. (1993). Can the Kuznets effect be relied on to induce equalizing growth? *World Development*, *21*(5), 829–840. https://doi.org/10.1016/0305-750X(93)90036-9

Schmitz, O., Beelen, R., Strak, M., Hoek, G., Soenario, I., Brunekreef, B., … Karssenberg, D. (2019). High resolution annual average air pollution concentration maps for the Netherlands. *Scientific Data*, *6*, 190035. https://doi.org/10.1038/sdata.2019.35

Selden, T. M., & Song, D. (1994). Environmental quality and development: Is there a Kuznets Curve for air pollution emissions? *Journal of Environmental Economics and Management*, *27*(2), 147–162. https://doi.org/10.1006/jeem.1994.1031

Shafik, N., & Bandyopadhyay, S. (1992). *Economic growth and environmental quality: Time-series and cross-country evidence* (Working Papers No. WPS 904). Washington: World Bank.

Strange, T., & Bayley, A. (2008). *Sustainable development: Linking economy, society, environment*. Paris: OECD.

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., … Hall, J. W. (2019). Infrastructure for sustainable development. *Nature Sustainability*, *2*(4), 324–331. https://doi.org/10.1038/s41893-019-0256-8

The Government of Japan. (2019). 環境白書. [Environment White Paper]. Retrieved May 9, 2015, from 環境白書 website: https://www.env.go.jp/policy/hakusyo/h14/12923.html

The World Bank. (1996). *Japan's experience in urban environmental management: Kitakyushu, a case study* (No. 17942). Washington: Environment & Natural Resources Division.

United Nations. (2019). About the Sustainable Development Goals. Retrieved May 8, 2019, from About the Sustainable Development Goals. United Nations Sustainable Development website: https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Vrieze, S. I. (2012). Model selection and psychological theory: A discussion of the differences between the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). *Psychological Methods*, *17*(2), 228–243. https://doi.org/10.1037/a0027127

Vuong, Q.-H. (2018). The (ir)rational consideration of the cost of science in transition economies. *Nature Human Behaviour*, *2*(1), 5–5. https://doi.org/10.1038/s41562-017-0281-4

Vuong, Q.-H., Bui, Q.-K., La, V.-P., Vuong, T.-T., Nguyen, V.-H. T., Ho, M.-T., … Ho, M.-T. (2018). Cultural additivity: Behavioural insights from the interaction of Confucianism, Buddhism and Taoism in folktales. *Palgrave Communications*, *4*(1). https://doi.org/10.1057/s41599-018-0189-2

Vuong, Q.-H., Ho, M.-T., Vuong, T.-T., La, V.-P., Ho, M.-T., Nghiem, K.-C. P., … Ho, R. C. M. (2019). Artificial Intelligence vs. Natural Stupidity: Evaluating AI readiness for the Vietnamese medical information system. *Journal of Clinical Medicine*, *8*(2), 168. https://doi.org/10.3390/jcm8020168

Vuong, Q.-H., & La, V.-P. (2019). BayesVL package for Bayesian statistical analyses in R (Version V0.8.4) [Github]. Retrieved from https://github.com/sshpa/bayesvl

Yoshioka, S., & Kawasaki, H. (2016). *Japan’s high-growth postwar period: The role of economic plans*. Economic and Social Research Institute - The Government of Japan.

Zhang, C., & Zhao, W. (2014). Panel estimation for income inequality and CO2 emissions: A regional analysis in China. *Applied Energy*, *136*, 382–392. https://doi.org/10.1016/j.apenergy.2014.09.048

Appendix

Figure A: Scatter plot of lnDustper, lnCOper, and lnSOxper against the total paved road area

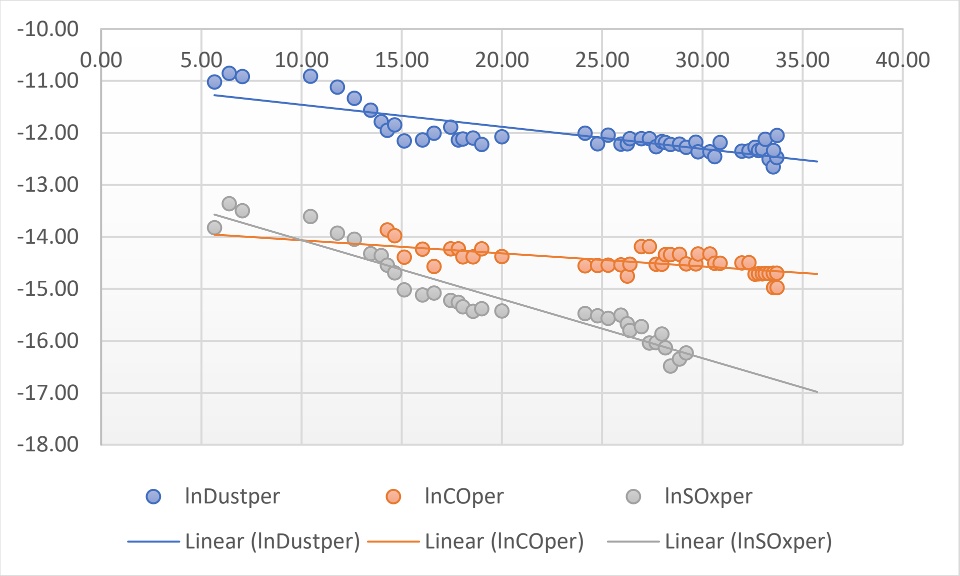


Figure B: Scatter plot of lnNO$_2$per and lnPOper against the total paved road area

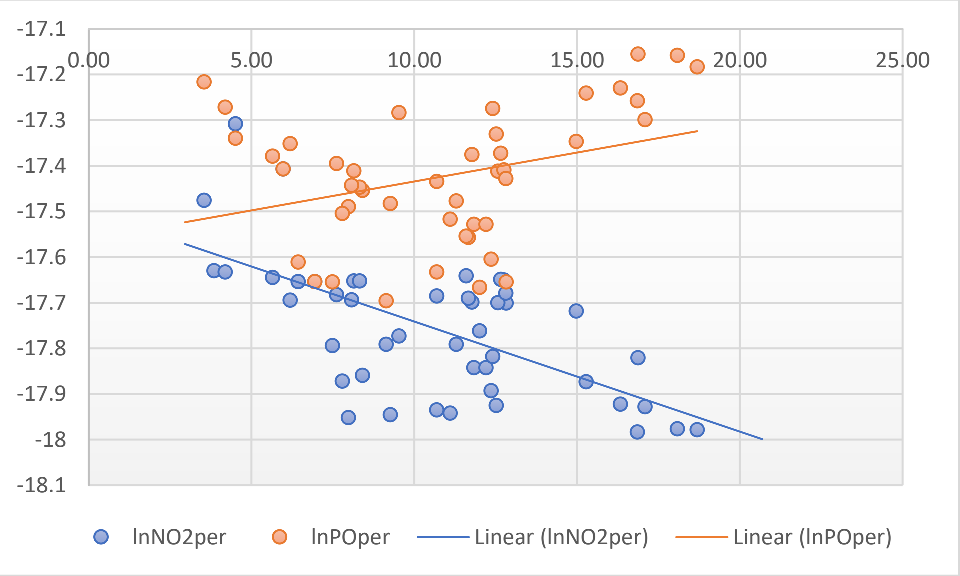


Figure C: Scatter Plot of lnDustper, lnDustper and lnDustper against the industrial firm size

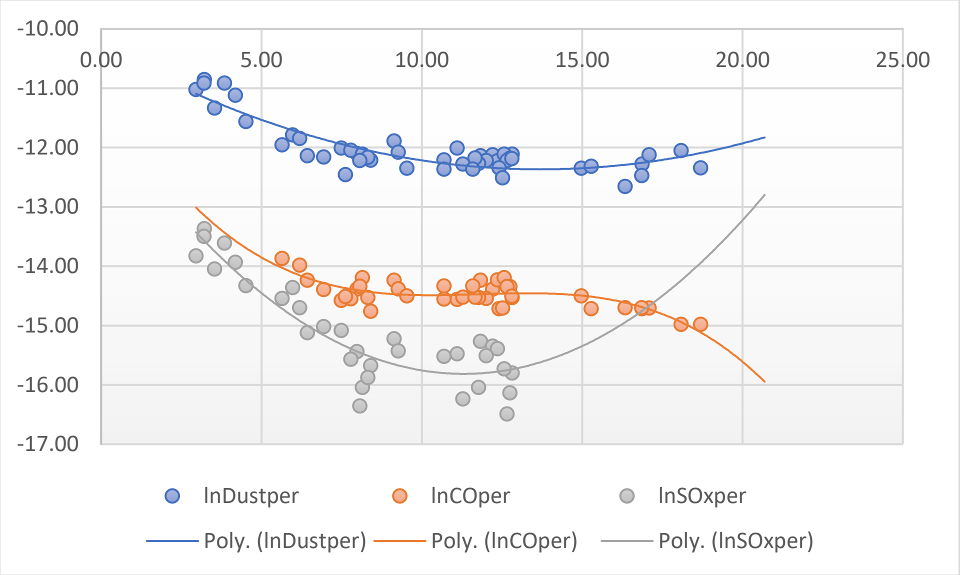


Table D: Scatter Plot of lnNO2per and lnPOper against the industrial firm size