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Does Air Pollution Respond to Petroleum Price?

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Abstract: Taiwan has implemented a floating oil-price mechanism since 2007, which is aimed at connecting the domestic oil price with the international oil price. Given that the consumers' behavior may change once the price truly responds to its cost and the air quality may consequently be improved, this study investigates the effect of oil price on the concentration of 7 air pollutants, taking the adoption of new price system into account. The results show that pollution is not necessarily reducing associated with the increasing energy cost in Taiwan.
Keywords: floating oil-price mechanism, air pollution, fixed effects model.
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1. Introduction

Energy serves as the base of economic activities in that it provides power resources for production. However, non-renewable energy resources, such as fossil fuels, cannot be used repeatedly once they are transformed into other serviceable energy types. The limited supply of and the infinite demand for fossil fuels inevitably causes their prices to keep increasing. However, the usage of fossil fuels has been suggested to have several disadvantages. In addition to the greenhouse effect and climate change, air pollution harms human beings both directly and immediately. Based on the predictions made by OECD in 2012, deaths due to respiratory failure resulting from exposure to polluted air will be twice the current level in 2050 if no associated policies are implemented. Air pollution will from then on become the major cause of death that is linked to the global environment. To retain a reasonable energy price and reduce the negative effects of air pollution on health, the authorities have to formulate a long-term plan on how to effectively use and restore these non-renewable energy resources.

In Taiwan, the outcomes of conserving energy to reduce carbon emissions are not as good as those in the developed countries or even in nearby competitor countries due to the relatively low energy prices. For example, the housing electricity price is about one half of that in Japan, and lower than that in Hong Kong, South Korea, Singapore, and the US. In addition, the price of unleaded gasoline #92 is only higher than that in the US, but is lower than that in China. The lower energy price is unfavorable to the adoption of energy-conserving products and technologies, and is very likely to encourage energy consumption. Even though per capita GDP in Taiwan is lower than that in Germany, Japan, and South Korea, the per capita energy consumption has been higher than in these countries since 2000. Moreover, per capita emissions of CO_2 have increased rapidly since 2002, and the amount is only lower than in those countries with a lower population density, such as Australia, Canada, and the US. Therefore, the lower energy price, which allows one to consume the amount of fossil fuels one wants, is believed to be one of the major destroyers of the environment.

Tucker (1995) emphasizes the negative relationship between the petroleum price and CO_2 emissions, and Brown et al. (1996) prove this hypothesis by providing empirical evidence. Brown et al. find that CO_2 emissions decreased when the crude oil price increased to 50 USD per barrel (in terms of the price in 1994) during 1979 and 1982, the historical peaks at those moments in time. In 1985, the nominal oil price stabilized around 15-20 USD per barrel, and CO_2 emissions increased steadily. Friedl and Getzner (2003) claim the existence of structural change in CO_2 emissions due to the rising oil price during the first oil crisis. The oil price may be correlated with energy consumption and consequently CO_2 emissions based on the changes in behavior. Agras and Chapman (1999) argue that consumers seemed to drive less and to turn off their air conditioners in order to save energy when the energy price was increasing during 1978 and 1980, and to show their coolness to the environment when the energy price was declining in 1981. In other words, raising the energy price seems to be an effective instrument for reducing emissions of pollutants.

An energy tax, which is a policy of endogenizing the pollution cost shouldered by the whole of society, is one among several environmental strategies aimed at reducing the pollution caused by the use of fossil fuels. The energy tax is believed to have a “double dividend” effect because it can both balance the intertemporal energy consumption under the resource constraint and make it economically attractive for countries to reduce their greenhouse gas emissions. Farrington and Needle (1997) use UK data and conclude that raising the fuel price and taxing the vehicles can depress the use and purchase of cars. In turn, people will take public transportation so that car accidents will fall and energy consumption will decline. Leicester (2005) also reaches the same conclusion.

To sum up, a change in the energy price will exert an influence on the environment. Professor C.-M. Lee of the Institute of Natural Resources Management at Taipei University emphasized at the conference on “Energy Price Strategies and Energy Sustainable Development” in 2008 that an efficient energy price is an important economic tool for improving energy efficiency, and also the best strategy to enable energy consumption to return to the route of sustainability. Therefore, the principle of setting the energy price is to pursue transparency in pricing, and for the price to reflect the energy production cost in a timely manner, as well as the scarcity of resources.

In general, the factors driving the oil price comprise the tax, the cost of refining and the crude oil cost. The literature mostly focuses on the analysis of the effect of tax in terms of reducing pollution, but there are few papers discussing the effect of the price mechanism on the environment. Given that consumers' behavior may be changed and air pollution would be effectively reduced when the domestic oil price follows the international oil price, this study attempts to investigate the effect of oil price on the concentration of 7 air pollutants, taking the implementation of a floating oil price into account.

The remainder of the paper is organized as follows. Section 2 describes the background to oil pricing in Taiwan. Section 3 provides the empirical specification and describes the data. Section 4 presents the results of the analysis. Section 5 provides discussion and Section 6 concludes.

2. Background

2.1 The Oil-Pricing System in Taiwan

The oil market in Taiwan has been monopolized by the Chinese Petroleum Corporation (CPC), a national entrepreneur, since 1946. In 1993, the government set up the oil pricing equation and authorized the CPC to adjust the oil price following the equation when the international oil price varies by less than 3 percent. If the international oil price varies by more than 6 percent in 3 months or by more than 10 percent in 6 months, the CPC must have the new price checked and ratified by the Ministry of Economic Affairs. The oil market subsequently turned into an oligopoly when the oil pricing equation was repealed in 2000 and when another competitor – Formosa Petrochemical Corporation (FPCC) – entered the market. In October 2001, the government introduced the "Petroleum Administration Act", which left the oil price to be determined by the forces of market demand and supply. In August 2005, the CPC registered a loss during the period when it was prevented from adjusting the oil price in order to match the government's goal of stabilizing the local oil price when faced with an upsurge in the international oil price.

Domestic energy prices, including the oil and electricity prices, have for long been suppressed under the concern of the citizens' livelihood, and are not able to reflect costs accurately. However, a small island like Taiwan lacks natural resources and so importing energy is necessary. As the surge in international energy prices pushes up the cost of importing oil, suppressing the energy price can only serve to relieve the short-run inflationary pressure, but will have several drawbacks in the long run. For example, the losses incurred by the nation's entrepreneurs will increase the tax burden of the whole of society, which is not equitable in that nonusers are taxed and users subsidized. Besides, the large users and entrepreneurs may lack the incentives to adopt energy-conserving technologies due to a low energy price. The National Energy Conference in 2005 came to the conclusion that it is essential to establish a mechanism which rationalizes energy pricing by reflecting the rising fuel cost in the short run and that endogenizes the external cost in the long run as a period of high oil prices approaches. The Conference on Sustainable Development in the Taiwan Economy held in 2006 reached a similar conclusion.

To improve the deviation of the domestic oil price from the international oil price, the Taiwan government on September 25, 2006 announced a trial period during which a floating oil-price mechanism would be implemented. The target international oil price was that of West Texas Intermediate (WTI) crude oil posted by Platts. After a review of the trial, the floating oil price was officially implemented on January 1, 2007, and used the WTI crude oil price posted on the NYMEX as the target. Nevertheless, the domestic price could not be stabilized under the large variation in the WTI crude oil posted price. The government therefore announced a new floating oil-price mechanism based on a combination of 70% of the Dubai crude oil price and 30% of the Brent crude oil price as the target price on September 1, 2007, and reviewed the domestic oil price once a week. The floating oil-price mechanism connected the variation in the domestic price with that of the international price, which implied a market mechanism.

However, the floating oil-price mechanism on November 2, 2007 temporarily ceased to be implemented when the domestic oil price was restrained from adjusting in line with the continually rising international oil price. Only after the government consulted professionals did it once again launch the floating oil-price mechanism on May 28, 2008. The CPC has since then adjusted the domestic oil price following the new mechanism. This new mechanism, which states that the government, the CPC and consumers shall equally share the rise in the oil price until the cost breaks even, takes the exchange rate into account and moderates the oil price.

2.2 The Historical Oil Price

Figure 1 displays the historical paths of both the domestic and international oil prices during the period from January 2001 to July 2013. It shows that the three major international crude oil prices – WTI, Dubai, and Brent clearly increase and fluctuate throughout the period. By contrast, the domestic price of unleaded gasoline #95 exhibits a stair-shaped increase before 2007 due to the infrequent adjustment. For example, the hurricanes Dennis, Katrina and Rita raged through the Gulf of Mexico in the summer of 2005 seriously damaging BP’s Deepwater Horizon as well as various petroleum refineries, and consequently raised the oil price as supplies declined. However, the domestic oil price did not follow the international price because of the price stabilization policy adhered to by CPC. A similar phenomenon can be seen when there was political instability in the Middle East from January to March 2006. At that time, Israeli Prime Minister Ariel Sharon was about to die of an illness, a Nigerian rebel army attacked the country’s oil pipes, and the Iranian political situation was unclear. All of these caused the supply of oil to fall, and pushed up the international oil price. Nevertheless, the implementation of the floating oil-price mechanism allowed the variation in the domestic oil price to remain consistent with that of the international oil price from 2007 on.

3. Empirical Strategy and Data

This section provides the empirical strategies regarding how to investigate the impact of oil price on pollution, taking the implementation of floating oil price system into account. Thereafter, the data used in the estimation will be introduced.

3.1 Empirical Strategy

The issues related to economic growth with environmental quality have been followed with interest by researchers over the past two decades, especially since Grossman and Krueger (1995) applied the idea of Kuznets (1955) to construct the environmental Kuznets curve. That is, pollution often appears to first worsen and to later improve as countries' incomes grow. One line of the literature investigates the environmental quality based on the concentration of air pollutants, e.g., López (1994), Selden and Song (1994), Shafik (1994), Suri and Chapman (1998), Aldy (2005), Hung and Shaw (2006), Chary and Bohara (2010), Gassebner et al. (2011), and Lin and Liscow (2013). This study also pays attention to air pollutants because the high share of fossil fuels in the power market and large numbers of motor vehicles for personal use, in addition to the cramped island and its numerous residents, aggravate the air pollution in Taiwan.[1] Besides, the air pollutants produced by human activities cannot be diffused easily, which will seriously harm the ecology and as well as the residents' health.

To analyze the effect of a floating oil price on environmental quality, this study firstly considers the following empirical specification:

$$Y_{it} = \alpha_i + \beta_1 Post_t + \beta_2 Price_t + \beta_3 Post_t \times Price_t + \mathrm{X}'_{it}\gamma + \varepsilon_{it} \quad (1)$$

where i denotes the city indices and t denotes the time indices. Y refers to the concentration of air pollutants. In this study, suspended particulate matter (PM_{10}), sulfur dioxide (SO_2), ozone (O_3), dust fall (DF), carbon monoxide (CO), nitrogen dioxide (NO_2), and hydrocarbons (HC) are examined separately.[2] α_i denotes the city fixed effect, which controls for unobserved permanent differences in the dependent variables. $Post$ refers to the post-effect of the floating oil-price mechanism on air pollutants. $Price$ denotes the price of unleaded gasoline #95 announced by the CPC. The interaction of $Post$ and $Price$ is included to test if the price gives rise to an effect on pollution after the implementation of the floating oil-price mechanism. X_{it} is a set of control variables, including the rainfall, the number of dust storm alert, the number of motor vehicles, the population density, per capita disposable income, and the proportion of population above the age of 15 with a tertiary education. The reasons for controlling these variables are described below.

It has been suggested that rainfall is highly correlated with the concentrations of air pollutants.

Even though there is evidence showing the influence of air pollution on precipitation (Rosenfeld, 2000; Rosenfeld et al., 2007; Creamean et al., 2013), it is also believed that rainfall is able to decrease the intensity of air pollutants. For example, Wen and Cao (2009) claim that cities exporting pollutants have higher concentrations of pollutants, while cities importing pollutants have lower concentrations of pollutants in those years with more rain. Therefore, this study controls for rainfall.

Aside from being affected by fixed pollution sources and moving pollution sources, the air quality in Taiwan is also severely affected by factors from foreign areas, mainly from China's dust storm. Dust storm refers to large amounts of sand lifted into the air by strong winds and is a type of weather that deteriorates visibility. Each year during spring and winter, dust storm often occur in the northern regions of China and the sands from these storms travel east to affect Japan, Korea, and other regions. Only under certain unique conditions do these sand storms affect Taiwan. As dust storm brings abundant suspended micro particles in the air and lowers air quality, which affects the health of seniors and children, the Environmental Protection Agency (EPA) gives dust storm alerts when the intensity of PM_{10} is larger than 100 $\mu g/m^3$.[3] This study hence controls for the number of dust storm alerts since the more the alerts, the lower the air quality.

There is evidence that motor vehicles are the prime cause of air pollution. Blumberg et al. (2003) argue that the heavy use of motor vehicles in urban areas generates exhaust gas, which reduces visibility and negatively affects the ecology. Reports by the EPA suggest that communications and transportation produce 50%~75% of HC, more than 50% of NO_x, 95% of CO, and are major sources of SO_2.[4] In addition, Kittelson (1998) finds that motor vehicles cause 51%~69% of suspended particulate matter in the downtown area of Los Angeles. All of the above air pollutants are primary pollutants. When the sun irradiates the atmosphere, there will be a series of photochemical reactions among NO_x and HC, which results in O_3. Based on the 2012 *Yearbook of Environmental Protection Statistics, Republic of China*, there were 2.22 million motor vehicles registered at the end of 2011, reflecting an annual growth rate of 2.3%. Motor vehicles released 69% of the CO, more than the emissions from stationary pollution sources, and released 45% of NO_x.[5] Motor vehicles appear to be one of the main producers of air pollution, and are therefore controlled for.

The population density is added in equation (1) because an area with more residents usually consumes more resources and damages the environment more than an area with fewer residents. Besides, a higher population density will increase the demand for communications and transportation and increase the expenditure on interpersonal interaction, both of which exacerbate the environmental pressure (Ravallion, Heil and Jalan, 2000). Hence, population density has been suggested to be an important factor for pollution (Cropper and Griffiths, 1994; Selden and Song, 1994; Scruggs, 1998).

As people pursue a better material life, the environmental quality suffers more as incomes increase. Nevertheless, people may protect the environment spontaneously to improve their quality of life as incomes rise. Therefore, equation (1) includes per capita disposable income and its squared term in order to check whether the environmental EKC hypothesis is accepted in the case in Taiwan.

Finally, the proportion of population above the age of 15 with a tertiary education is controlled because it is believed that the perception regarding environmental protection is intensifying as education increases among residents.

In addition to these variables, trend is also included in the regression to control for the influence of economic growth on the demand for energy, which consequently yields the effect on air quality.[6]

3.2 Data Description

The dataset used here covers 19 cities, including Changhua County, Chiayi City, Chiayi County, Hsinchu City, Hsinchu County, Hualien County, Kaohsiung City, Keelung City, Miaoli County, Nantou County, New Taipei City, Pingtung County, Taichung City, Tainan City, Taipei City, Taitung County, Taoyuan County, Yilan County, and Yunlin County, from 1993 to 2011.

In this study, unleaded gasoline #95 at 2011 constant prices is used to represent the oil price, which is obtained from the Bureau of Energy of the Ministry of Economic Affairs. Moreover, the 7 different pollutants are used to display the air quality, and are collected from the EPA.[7] The rainfall and the number of dust storm alerts are also obtained from the EPA.

Furthermore, the number of motor vehicles is defined as the number of licenses issued by the Motor Vehicles Office in each city, and this study records the numbers of cars and motorcycles separately. The population density is defined as the number of registered permanent residents per km^3, while per capita disposable income is defined as average disposable income for registered households divided by average population based on registered households. The above three control variables and the proportion of population above the age of 15 with a tertiary education are collected from the *Statistical Yearbook* issued by each local government.[8]

Table 1 presents the average concentration of air pollutants in each city during 1993 and 2011. Taipei City has the worst air quality in terms of the concentration of DF, CO, NO_2, and HC, which may be the result of the poor air circulation due to the lowest point in the Taipei Basin being located in Taipei City. The number of motor vehicles may also explain the extent of the air pollution. For example, Table 2 shows that Taitung County has the lowest numbers of motor vehicles, and its air quality is the best. Since the characteristics of each city seem to influence the concentration of pollutants in the air, it is essential to have panel data to investigate the environmental issues.

4. Results

Whether there is price mechanism on reducing the intensity of air pollutants, this study firstly reports in Panel A of Table 3 a linear estimation with the controls of city and month dummies using monthly data. The results show that the higher the petroleum price, the lower the concentration of air pollutants, which is relevant at the 1% significance level for most air pollutants. For example, a one percent increase in the oil price will reduce suspended particulate matter and dust fall, the so-called granular pollutants, by 0.516 μg per cubic meter and 0.050 tons per square kilometer, respectively. The concentrations of gaseous pollutants, such as HC, SO_2, NO_2, CO, and O_3, are also falling with the rising oil price. However, this only provides us with a general idea about the influence of oil price since there are missing variables due to the type of monthly data used. To solve the problem, this paper further analyzes the issue using yearly data from 1993 to 2011, which allows us to control other variables suggested in the literature.

Panel B of Table 3 reports the results of a linear estimation of price effect on air quality with the control of other variables using yearly data. The price mechanism on reducing the intensity of air pollutants has been eliminated once controlling for other variables, except for O_3.[9] The positive correlation between pollutants and oil price may reveal the fact that the rising oil price does not make the energy price in Taiwan be comparable to other countries, and therefore generates no constraints on energy consumption. Hence, there appears a contradiction to what we expected about the price effect on air quality.

To have a more complete overlook, Table 4 provides an estimation of equation (1) by controlling for city dummies. A positive oil price effect in relation to the concentration of air pollutants is found before 2007, which may indicate a relaxation of the consumers' budget constraints resulting in more pollution when the authorities exercised control over oil pricing before 2007 following an upsurge in the international oil price. Nevertheless, the oil price has significantly decreased the intensity of PM_{10}, SO_2, O_3, and CO following the introduction of the floating oil price. A one percent increase in the oil price during the period of the new pricing system has reduced PM_{10}, SO_2, O_3, and CO by -0.315μg/m^3, 0.260 ppb, 0.121 ppb and 9.498 ppb, respectively. Other air pollutants have also declined along with the rising oil price after 2007, but the effects are not relevant. Normally, the implementation of a floating oil-price mechanism is likely to reduce the concentration of air pollutants by relating the domestic oil price to the international oil price and influencing human behavior, which is in line with Jorgenson et al. (1992) in that the rising fuel price will reduce the demand for fuel due to the substitution effect and result in less pollution. Yet, it is worth noticing that the total effect of price is still positive for most of air pollutants, except for O_3.

As for the other controls, rainfall is found to be negatively correlated with the gaseous pollutants, such as SO_2, CO, NO_2, and HC, and the relationships are significant, except for NO_2.

Inversely, rainfall is positively correlated with the granular pollutants. Although the relationship is not significant, it may accord with the viewpoint of Creamean et al. (2013) that dust enhances cloud ice and precipitation. In addition, there is no evidence showing a positive impact of dust storm alerts on the intensity of air pollutants. Since the authority gives dust storm alerts according to the intensity of PM_{10}, and dust storm alerts occurs seasonally, it seems to have limited impacts on air quality.

The number of registered motor vehicles is positively related with the concentration of pollutants in the air, except for O_3 and HC. The residents of Taiwan tend to ride motorcycles because of their mobility and convenience on an island with a high population density. Nevertheless, the large number of motorcycles with a higher proportion of aged ones pollute the air seriously. By contrast, the number of registered cars negatively affects the air quality as the amendments to the Air Pollution Control Act on the restrictions of emissions from mobile pollution sources in recent years may explain.[10] Moreover, the construction of public transportation both locally and nationally may reduce the incentive to drive in Taiwan, which accords with Miller and Hoel (2002). Kenworthy and Laube (1999) suggest that the exhaust emissions mainly result from the frequency of using cars, instead of owning cars, which may also explain the negative coefficient observed in this study. In actual fact, Wu et al. (2006) point that the concentration of SO_2 in developed countries decreases significantly after a period of time even with an increasing number of cars, and such a phenomenon can also be found in other pollutants caused by cars, such as suspended particulate matter, smoke, and NO_x.

In addition, there is evidence that higher population density aggravates air pollution, which accords with Cropper and Griffiths (1994), Selden and Song (1994) and Scruggs (1998). In addition, the air quality will be significantly improved if there are more educated residents. Finally, the income variables explain whether the EKC hypothesis holds. They show that PM_{10}, DF, CO and HC rise with per capita disposable income at low levels of personal income, and then fall as per capita disposable income grows. The turning points for each of them are $30,030, $45,815, $233,092 and $227,276 NTD (at 2011 prices), respectively. The estimated curves imply an inverted U-shaped relationship. NO_2 exhibits a U-shaped correlation with per capita disposable income with the turning point at $214,958 NTD (at 2011 prices). Although the correlation between SO_2 and per capita income is also inverted U-shaped, it is not significant, which is the same as the finding in Hung and Shaw (2006).

5. Discussion

5.1 No Price Mechanism?

In the previous section, it shows no price mechanism on reducing the intensity of air pollutants in general, but the implementation of a floating oil-price system is very likely to enhance the price impact. Since there may exist some variables influencing air quality but are excluded in the regression, and the introduction of a floating oil-price system is an exogenous event, it will help to conclude the price effect on air pollution by instrumenting the oil price with such an institution change. We consider the following specification:

$$Price_t = \alpha_i + \delta Post_t + X'_{it}\theta + \epsilon_{it}$$
$$Y_{it} = \alpha_i + \beta \widehat{Price}_t + X'_{it}\gamma + \varepsilon_{it} \quad (2)$$

An estimation of equations (2) using two stage least squares (TSLS) is provided in Table 5. The implementation of a floating oil-price system explains the oil price very well that the *p*-value of F-statistics at the first stage is all below the 5% significance level. To rise the oil-rice can only effectively reduce the intensity of O_3, but have either positive or no impact on other pollutants, which is in concert with the baseline result of no price mechanism on reducing the intensity of air pollutants.

5.2 Individual Price Effect?

Even though the oil price is identical in every city in Taiwan, the price may exert different effects to each city according to some factors. For example, the well-developed public transportation system will allow residents to change the transportation approach when the energy price is increasing, which is believed to improve the air quality. The following specification is under the consideration:

$$Y_{it} = \alpha_i + \sum_{i=1}^{19} \beta_i \times Price_t + X'_{it}\gamma + \varepsilon_{it} \quad (3)$$

Table 6 reports the estimation of equation (3). The joint test of oil price shows a relevant impact on air pollution. However, these effect are more likely to be positive since the individual price coefficient are mostly positive. Hence, there is no evidence supporting a positive oil-price influence on air quality.

5.3 Why O_3 Performs Differently?

In the previous section, the control variables in the estimation of O_3 perform very differently from other pollutants. This may result from some chemical processes. There are two chemical reactions in regard to O_3. As mentioned above, HC and NO_x are precursor pollutants of O_3 in that the concentration of O_3 will keep on rising as its precursors follow the photochemical reaction. When O_3 is titrated with NO according to the reaction $NO + O_3 \rightarrow NO_2 + O_2$, the so-called “the titration effect” occurs. That is, the supply of O_3 will be exhausted and NO_2 will increase during the titration process. Therefore, Table 4 contains information explaining why O_3 performs differently from other pollutants. In Table 4, NO_2 and O_3 have opposite signs in terms of the coefficients of rainfall, mist, motor vehicles, cars, population, income and squared income, which is consistent with the titration effect. HC and O_3 have the same signs in the coefficients of motor vehicles, cars, population density, education, income and squared income, which is consistent with the photochemical reaction.

6. Conclusion

Energy is essential for economic development. However, the burning of fossil fuels results in extreme climate change by exacerbating air pollution. Since the energy price influences consumption behavior and consequently the concentration of pollutants in the air, this study attempts to investigate the effect of oil price on air quality in Taiwan, taking the introduction of a floating oil-pricing mechanism since 2007 into account.

The results show that the oil price can effectively reduce the concentration of air pollutants during the period when the floating oil pricing mechanism is applied due to the connection between the domestic oil price and the international oil price. That is, the price is likely to serve as a signal to encourage consumers to save energy when the domestic price can rationally respond to the import cost, and the concentration of pollutants can thereafter be reduced. However, the total price effect is still positive. In other words, there seems to have no price mechanism on reducing energy consumption and relieving the pressure of climate change in Taiwan so far. Moreover, the results reveal that the EKC hypothesis holds for PM_{10}, DF, CO and HC. These pollutants mainly result from the usage of internal combustion engines in transportation so that a technological innovation, such as the introduction of hybrid vehicles, may nowadays improve fuel efficiency and reduce exhaust emissions.

Even though other methods have been put forward to improve air quality, including an energy tax and tradable emission permits, Taiwan provides a specific case to study the effect of an oil pricing policy on air pollution. Nevertheless, the frequent yearly data may only allow a general perception of the oil-price effect, which is expected to improve in the future.

Endnotes

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1. The fossil fuels used in the thermal power plants accounted for 77% of the power supply in Taiwan in 2011. The density of motor vehicles was 548.88 units per square kilometer in 2005, which was 21.2, 2.28 and 3.61 times that in the US, Japan, and Germany, respectively.
2. This study does not consider CO_2 because the panel data could not be obtained. There are two groups of suspended particulate matter, namely, $PM_{2.5}$ and PM_{10}. The diameter of $PM_{2.5}$ is less than 2.5 mm so that it can enter the pulmonary alveolus. The diameter of PM_{10} is less than 10 mm and will infect the upper and lower respiratory tracts.
3. The information is provided by the EPA in Taiwan (http://taqm.epa.gov.tw/taqm/en/b0301.aspx).
4. See the EPA reports "Technical support document: Control of emissions of hazardous air pollutants from motor vehicles and motor vehicle fuels" published in 2000, "Regulatory Impact Analysis: Heavy-duty engine and vehicle standards and highway diesel fuel sulfur control requirements" in 2000, "2000 air quality trends report" in 2001, and "Latest findings on national air quality: 2001 status and trends" in 2002.
5. The *Yearbook of Environmental Protection Statistics, Republic of China in 2012* lists four factors that worsen the environmental quality, including the density of motor vehicles, the population density, the density of operating factories, and the density of reared pigs. The former two factors are obviously increasing, while the density of operating factories only changes slightly during 2002 and 2010. Besides, the data for factory-related variables are missing in the years of the industry, commerce and service census. Therefore, this study does not consider factory-related variables over concerns of insufficient sources. The density of reared pigs is not taken into consideration because it is more related to water pollution, but is less related to air pollution.
6. The economy in Taiwan has a relatively better performance during the period before 1999, which has been believed to results in server pollution due to a large consumption of petrochemicals.
7. The Environmental Protection Administration sets up monitoring stations in each city to collect the data, and reports it in the *Yearbook of Environmental Protection Statistics, Republic of China*.
8. The definitions of variables and data sources are provided in Table A1 in the appendix.

9. While the primary air pollutants are man-made, a secondary air pollutant, ozone, is generated through photochemical reactions. In other words, the hours of sunshine are very likely to be related to the intensity of O_3. To solve the problem of missing variables, this study takes the hours of sunshine into account. The results with 14 cities, which is not reported here, show no price effect on O_3.
10. Article 40 states that "In-use motor vehicles shall undergo regular air pollutant emissions testing; the owner of a motor vehicle for which testing reveals a failure to comply with the emissions standards in Article 34 shall make repairs and apply for retesting within one month; the owner of a motor vehicle that has not undergone regular testing or for which retesting still reveals a failure to comply may be prohibited from renewing his/her vehicle license." Article 42 states that "Those in-use motor vehicles for which air pollutant emissions are determined through visual determination, visual inspection or remote sensing performed by competent authority inspection personnel that fail to meet the emissions standards in Article 34 or the remote sensing screening standards officially announced by the central competent authority shall be repaired and undergo testing at a designated location by the deadline designated in the competent authority notification. Citizens may report the air pollutant emissions of in-use motor vehicles to the competent authority; those vehicles which have been reported and notified by the competent authority shall undergo testing at a designated location by a designated deadline; the central competent authority shall determine regulations for reporting and incentives."

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Table 1. Average concentration of air pollutants in each city

	PM_{10}	SO_2	O_3	DF	CO	NO_2	HC
Changhua County	67.48	5.58	52.74	4.35	560.0	19.53	292.2
Chiayi City	77.23	6.58	61.16	4.06	726.8	23.00	327.6
Chiayi County	71.18	3.39	60.50	3.78	418.3	14.56	190.0
Hsinchu City	49.51	4.95	48.63	7.56	617.4	20.11	258.8
Hsinchu County	49.76	2.89	54.44	6.75	461.7	15.72	---
Hualien County	34.74	1.84	35.72	3.84	592.6	13.37	247.5
Kaohsiung City	82.73	10.79	66.00	4.28	705.0	24.37	387.9
Keelung City	48.28	8.00	47.11	8.35	785.8	20.21	258.9
Miaoli County	53.39	8.37	53.84	5.01	481.6	17.74	308.3
Nantou County	69.47	2.78	69.67	3.57	595.6	19.94	272.9
New Taipei City	49.92	5.89	50.74	7.10	820.5	22.53	416.3
Pingtung County	64.35	3.28	65.67	4.44	464.4	13.00	276.5
Taichung City	62.07	5.89	57.11	6.18	724.1	23.32	281.7
Tainan City	73.26	7.05	63.21	7.33	573.7	18.89	298.9
Taipei City	52.74	5.47	47.16	10.24	1290.0	26.89	522.1
Taitung County	34.18	1.17	38.44	4.62	472.2	7.83	149.2
Taoyuan County	52.77	7.79	49.58	7.25	653.2	21.32	340.0
Yilan County	39.73	2.28	44.06	4.38	497.8	12.56	187.3
Yunlin County	71.58	3.61	60.72	4.34	472.2	15.89	178.3

Table 2. Mean value of control variables in each city

	Rain	Mist	Motor	Car	Pop	Educ	Income
Changhua County	1316.5	1.6	77.94	36.36	1214.66	18.65	210770
Chiayi City	1832.8	1.9	17.42	7.22	4458.56	35.49	253260
Chiayi County	1435.7	1.9	32.03	14.65	293.36	15.13	207058
Hsinchu City	1502.4	1.15	21.78	10.99	3617.96	32.47	312098
Hsinchu County	1808.7	1.15	21.93	14.12	319.73	23.59	259061
Hualien County	2108.3	0.35	21.21	9.36	75.70	19.77	245513
Kaohsiung City	1916.1	1.7	185.55	70.35	921.80	26.13	262547
Keelung City	3620.9	1.6	15.90	7.63	2888.80	23.89	259621
Miaoli County	1973.4	1.15	30.45	16.32	307.71	18.26	224983
Nantou County	2359.5	1.6	30.28	15.94	131.26	18.72	219895
New Taipei City	2041.9	1.6	181.77	79.89	1758.07	26.63	268429
Pingtung County	2035.5	1.7	59.16	21.72	324.02	18.21	234434
Taichung City	1834.4	1.6	134.65	76.14	1116.02	27.60	253122
Tainan City	1677.4	1.9	115.92	49.54	839.24	24.47	235477
Taipei City	2342.2	1.6	98.13	68.44	9677.12	46.61	381593
Taitung County	1769.9	0.35	15.31	5.66	69.14	12.04	217893
Taoyuan County	1896.1	1.6	85.45	51.37	1449.52	24.47	269606
Yilan County	2784.5	0.5	26.03	11.45	216.18	18.93	233074
Yunlin County	1673.8	1.9	42.57	19.47	572.27	16.15	217219

Panel A	PM_{10}	SO_2	O_3	DF	CO	NO_2	HC
Price	-0.516***	-0.019***	-0.115***	-0.050**	-6.942***	-0.237***	-2.534***
	(0.066)	(0.006)	(0.039)	(0.024)	(0.427)	(0.019)	(0.360)
R-squared	0.8084	0.7627	0.7268	0.3045	0.8586	0.8249	0.6252
Observations	2661	2669	2672	2606	2673	2658	1909
Panel B	PM_{10}	SO_2	O_3	DF	CO	NO_2	HC
Price	0.184***	0.146***	-0.055**	0.038**	6.822**	0.032**	1.381
	(0.045)	(0.029)	(0.056)	(0.017)	(2.608)	(0.013)	(0.850)
Rain	0.002*	-0.000	0.000	0.000	-0.016	0.000	-0.022***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.013)	(0.000)	(0.007)
Mist	-0.328	-0.559***	0.324*	-0.038	-32.575**	-0.077	-15.092*
	(0.255)	(0.176)	(0.173)	(0.120)	(14.084)	(0.126)	(7.518)
Motor	0.058	0.174***	-0.137***	0.040**	6.175*	0.021	-0.441
	(0.053)	(0.060)	(0.028)	(0.017)	(2.987)	(0.016)	(0.679)
Car	-0.316	-0.630***	0.441***	-0.168*	-23.826**	-0.167*	2.906
	(0.208)	(0.164)	(0.119)	(0.088)	(9.200)	(0.089)	(4.178)
Pop	0.007	-0.006	0.005	0.002	0.965	-0.000	0.259**
	(0.006)	(0.007)	(0.007)	(0.002)	(0.640)	(0.004)	(0.113)
Educ	0.678*	0.273	-0.237	-0.058	-24.616*	-0.293**	-17.55***
	(0.359)	(0.387)	(0.209)	(0.101)	(13.359)	(0.135)	(4.382)
Ln(Income)	1570.4***	368.03	-439.72	276.51**	118953*	-477.79**	17220**
	(437.33)	(372.72)	(314.43)	(129.18)	(57238)	(171.51)	(7875.14)
Ln(Income)^2	-62.69***	-14.78	17.34	-11.18**	-4813.7*	19.44**	-697.94**
	(17.364)	(14.936)	(12.721)	(5.185)	(2813.43)	(6.901)	(316.74)
Trend	-1.909***	-0.903	0.960***	-0.167	-18.530	-0.206	0.630
	(0.582)	(0.615)	(0.268)	(0.163)	(18.098)	(0.163)	(4.983)
R-squared	0.8200	0.4046	0.8271	0.4997	0.6499	0.8659	0.6306
Observations	354	354	353	345	354	353	267

Table 3. Effect of oil price on air pollutants with monthly data

Notes: 1. Standard errors are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively. 2. Standard errors are corrected for clustering at the city level. 3. All the regressions in Panel A control for city and month dummies, and all the regressions in Panel B control for city dummies.

Table 4. Influence of floating oil price on air pollutants with yearly data

	PM_{10}	SO_2	O_3	DF	CO	NO_2	HC
Price	0.401***	0.318***	0.047	0.074	13.088**	0.035	2.589
	(0.104)	(0.047)	(0.044)	(0.052)	(5.362)	(0.024)	(1.544)
Post	27.400***	24.100***	6.859**	4.482	884.568**	1.067	167.003
	(8.992)	(3.598)	(3.213)	(4.343)	(356.689)	(1.813)	(103.491)
Price*Post	-0.315***	-0.260***	-0.121***	-0.051	-9.498**	-0.007	-1.892
	(0.098)	(0.035)	(0.038)	(0.054)	(4.149)	(0.021)	(1.182)
Rain	0.001	-0.001**	0.000	0.000	-0.033**	-0.000	-0.024***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.015)	(0.000)	(0.007)
Mist	-0.254	-0.417**	0.155	-0.026	-27.218*	-0.052	-14.589*
	(0.242)	(0.165)	(0.155)	(0.116)	(14.361)	(0.127)	(7.406)
Motor	0.051	0.160**	-0.118***	0.044**	5.616*	0.018	-0.492
	(0.051)	(0.056)	(0.027)	(0.017)	(2.895)	(0.016)	(0.715)
Car	-0.310	-0.590***	0.356***	-0.167*	-22.305**	-0.156	2.940
	(0.213)	(0.157)	(0.118)	(0.082)	(9.760)	(0.092)	(4.338)
Pop	0.009	-0.005	0.005	0.002	1.021	-0.000	0.264**
	(0.007)	(0.007)	(0.006)	(0.002)	(0.623)	(0.004)	(0.114)
Educ	0.561	0.130	-0.169	-0.079	-29.931**	-0.310**	-18.25***
	(0.363)	(0.338)	(0.191)	(0.098)	(13.006)	(0.136)	(4.589)
Ln(Income)	1257.4***	296.2	-366.6	273.4*	116253**	-489.9**	16965.8**
	(419.3)	(319.8)	(273.39)	(137.5)	(54801)	(177.32)	(7641.56)
Ln(Income)^2	-60.98***	-11.84	14.24	-11.06*	-4703.1**	19.95**	-687.77**
	(16.642)	(12.795)	(11.030)	(5.520)	(2220.4)	(7.145)	(307.298)
Trend	-2.285***	-1.264*	0.938***	-0.227	-31.833	-0.230	-1.412
	(0.585)	(0.644)	(0.279)	(0.187)	(20.755)	(0.162)	(5.005)
R-squared	0.8260	0.4317	0.8352	0.5038	0.6604	0.8662	0.6327
Observations	354	354	353	345	354	353	267

Notes: 1. Standard errors are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively. 2. Standard errors are corrected for clustering at the city level. 3. All the regressions control for city dummies.

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	PM_{10}	SO_2	O_3	DF	CO	NO_2	HC
Price	0.285	0.589**	-0.919**	0.057	23.846**	0.149	2.247
	(0.326)	(0.299)	(0.421)	(0.012)	(12.067)	(0.111)	(4.657)
Rain	0.002**	0.000	-0.001	0.000	0.007	0.000	-0.021*
	(0.001)	(0.001)	(0.001)	(0.000)	(0.027)	(0.000)	(0.007)
Mist	-0.377	-0.780**	0.755*	-0.049	-41.06***	-0.141	-15.49***
	(0.363)	(0.350)	(0.415)	(0.133)	(14.228)	(0.131)	(5.368)
Motor	0.047	0.129*	-0.048	0.039**	4.416	0.009	-0.526
	(0.053)	(0.067)	(0.061)	(0.016)	(2.887)	(0.025)	(0.875)
Car	-0.285*	-0.502*	0.193	-0.162***	-18.919*	-0.133	3.086
	(0.174)	(0.257)	(0.198)	(0.053)	(10.298)	(0.093)	(2.791)
Pop	0.008	-0.002	-0.004	0.002	1.144**	0.001	0.265**
	(0.006)	(0.006)	(0.007)	(0.002)	(0.561)	(0.003)	(0.104)
Educ	0.591	-0.060	0.409	-0.073	-37.497**	-0.386***	-18.26***
	(0.407)	(0.371)	(0.436)	(0.116)	(15.489)	(0.124)	(6.145)
Ln(Income)	1498.4***	236.57	-197.94	272.87**	113588***	-524.4***	16952*
	(430.58)	(346.20)	(420.21)	(123.33)	(41573)	(181.85)	(8737.06)
Ln(Income)^2	-59.78***	-9.40	7.44	-11.03**	-4594***	21.34***	-686.96*
	(17.217)	(13.873)	(16.904)	(4.974)	(1682.60)	(7.330)	(351.898)
Trend	-2.112**	-1.854**	2.814***	-0.205	-54.918**	-0.451*	-1.025
	(0.898)	(0.859)	(0.931)	(0.255)	(28.078)	(0.265)	(9.702)
F-statistics (p-value)	0.0179	0.0179	0.018	0.0123	0.0179	0.0204	0.0329
Observations	354	354	353	345	354	353	267

Table 5. Influence of oil price on air pollutants with yearly data by TSLS

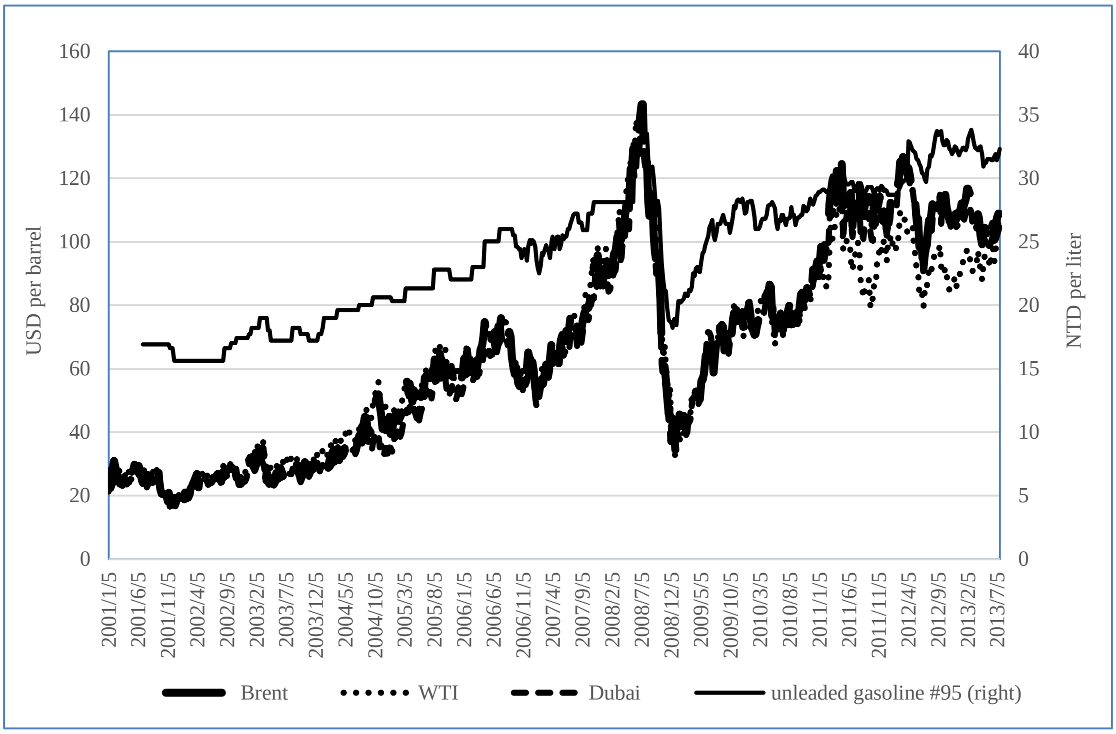
Notes: 1. Robust standard errors are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively. 2. All the regressions control for city dummies.

Table 6. Influence of oil price on air pollutants with yearly data by OLS

	PM_{10}	SO_2	O_3	DF	CO	NO_2	HC
Rain	0.002**	-0.000	0.000	0.000	-0.018	0.000	-0.022***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.014)	(0.000)	(0.008)
Mist	-0.215	-0.410**	0.228	-0.041	-25.781	-0.014	-13.280*
	(0.267)	(0.146)	(0.183)	(0.121)	(15.669)	(0.126)	(7.470)
Motor	0.134**	0.229***	-0.152***	0.004	9.596**	0.053***	0.202
	(0.056)	(0.077)	(0.024)	(0.015)	(4.092)	(0.015)	(0.544)
Car	-0.717**	-0.819***	0.728***	-0.152	-30.150*	-0.350***	4.505
	(0.289)	(0.212)	(0.188)	(0.105)	(14.982)	(0.109)	(4.265)
Pop	-0.000	-0.021	0.013	0.002	0.501	-0.005	-0.159
	(0.009)	(0.015)	(0.013)	(0.003)	(1.173)	(0.005)	(0.195)
Educ	0.858*	0.752	-0.473	0.035	-10.836	-0.189	-10.796**
	(0.452)	(0.495)	(0.288)	(0.121)	(19.853)	(0.110)	(5.124)
Ln(Income)	1365.0***	380.03	-522.16	196.51	119249	-389.35**	17067
	(364.76)	(361.56)	(392.34)	(171.52)	(70141)	(136.35)	(11516)
Ln(Income)^2	-54.38***	-15.21	20.50	-7.94	-4823.33	15.91***	-690.02
	(14.460)	(14.530)	(15.861)	(6.927)	(2841.64)	(5.462)	(463.58)
Trend	-1.794**	-1.195	0.952***	-0.242	-28.283	-0.167	-5.270
	(0.657)	(0.729)	(0.331)	(0.176)	(19.284)	(0.129)	(4.425)
H_0: Price=0 (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R-squared	0.8500	0.4862	0.8425	0.5805	0.6947	0.8963	0.6700
Observations	354	354	353	345	354	353	267

Notes: 1. Standard errors are in parentheses. *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively. 2. Standard errors are corrected for clustering at the city level. 3. All the regressions control for city dummies.

Figure 1. Time series of oil price with weekly data from 2001/01/05 to 2013/07/19



Source: Taiwan Economic Journal (TEJ)

Table A1. Definitions of variables and data sources

Variable	Code	Unit	Source
suspended particulate matter	PM_{10}	μg／m^3	Environmental Protection Administration
sulfur dioxide	SO_2	ppb	Environmental Protection Administration
trioxygen	O_3	ppb	Environmental Protection Administration
dust fall	DF	ton／km^2	Environmental Protection Administration
carbon monoxide	CO	ppb	Environmental Protection Administration
carbon dioxide	CO_2	ppb	Environmental Protection Administration
nitrogen dioxide	NO_2	ppb	Environmental Protection Administration
hydrocarbon	HC	ppb	Environmental Protection Administration
oil price	Price	indexed	Bureau of Energy
sunshine	Sun	hours	Central Weather Bureau
rain	Rain	mm	Water Resources Agency
dust storm alerts	Mist	frequency	Environmental Protection Administration
motorcycles registered	Motor	ten thousands	Statistical Yearbook
cars registered	Car	ten thousands	Statistical Yearbook
population density	Pop	per km^2	Statistical Yearbook
per capita disposable income	Income	NTD	Statistical Yearbook
proportion of population above the age of 15 with a tertiary education	Educ	%	Statistical Yearbook