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Más allá de la Curva Ambiental de Kuznets: comprensión de los determinantes de la degradación ambiental en México

Beyond the Environmental Kuznets Curve: Understanding the Determinants of Environmental Degradation in Mexico

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Introduction

The environmental Kuznets curve (EKC) hypothesizes a simplified relationship between income growth and environmental degradation. According to the EKC hypothesis, environmental quality is expected to worsen as income grows to a certain point (called turning point) and then starts improving as income grows higher. Since this relationship resembled the inverse-U relationship between income and income inequality that Simon Kuznets proposed, this hypothesis was named after Kuznets (Panayotou, 1997).

The conventional method to empirically estimate the EKC is regressing an environmental stress variable (i.e. ambient pollution concentration level or per capita pollution emission volume) with the per capita income level allowing a non-linear relationship such as:

$$E = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \varepsilon \qquad (1)$$

Where, E is a environmental stress variable, Y is the income per capita often represented by Gross Domestic Product (GDP) per capita, and ε is the error term. The inverse-U relationship is found when the β_1 is estimated with a statistically positive sign, and β_2 is estimated with a statistically negative sign.

This model is generally called the "reduced-form" model that estimates the net marginal effect of income per capita over the degree of environmental degradation (Panayotou, 1997). Since the income level and aggregate environmental degradation data are widely available across time and geographic areas, this reduced model has been estimated extensively. Since the early study by Grossman and Kruger (1991) that found EKC empirically for certain types of environmental degradation, the empirical EKC literature expanded dramatically for the last 20 years. There are over 100 articles in EKC literature and many articles focused on the robustness of reduced form models for different pollutants, different sample of countries, and different types of models such as parametric models including cross-section, time series or panel models as well as non-parametric models. A more detailed review of EKC literature is available by Yandle et al. (2004) and Carson (2010).

One of the problems of the reduced form EKC estimation is that it gives little insight about why environmental quality depends on the income growth. In addition, because of this oversimplified presentation, the EKC have caused misleading interpretations such as "economic growth will eventually solve environmental problems" (Arrow *et al.*, 1995, Panayotou, 1995, Carson, 2010). Since the early stage of EKC literature, many important researchers in academia such as Grossman and Kruger (1991), Arrow *et al.* (1995), Panayotou (1995) and Carson (2010) have emphasized that the income growth itself is not an important determinant of environmental degradation, but the factors that often (but not always) accompany income growth, such as changes in the composition of the economy and preferences towards environmental quality, are the important determinants which need to be studied further.

The aforementioned authors proposed to estimate structural models, where underlying factors causing the inverse U-relationship between pollution and income levels are explicitly incorporated. Such models are useful for policy analysis as we can effectively identify the potential effect of changes of socioeconomic factors on the environmental quality. However, a limited number of studies attempted to estimate the structural models.

Other important issues missing from current EKC literature is the analysis for different types of pollution activities. There are two types of pollution activities; production-related and consumption-related. Since the socioeconomic policies are likely to have different impacts on different types of pollution activities, it is important to obtain the structural model for each type of pollution source to have a better understanding about the impact of socioeconomic changes on environmental quality. To our knowledge, there is no study that estimates the structural model for pollution from different types of pollution sources.

In this study, we attempt to estimate the structural model for production-related pollution and consumption-related pollution levels separately to identify the effect of socioeconomic policies on the pollution levels using panel data from Mexico. The following section reviews the key EKC literature to summarize the often hypothesized underlying factors associated with EKC. The third section describes the estimating empirical model and data. The fourth section presents the results of the empirical model followed by conclusions.

1. Underlying causes of EKC relationship

Several important hypotheses have been formed as factors to jointly explain the EKC relationship; the composition of the economy, induced policy response due to the increased demand for a cleaner environment, income inequality, civil freedom and international trade. We summarize each hypothesis and previous empirical evidence in the following section.

Composition of the economy

Cole (2004) and Panayotou (1997) hypothesized that the structure of economy, such as the share of economic activity produced by the manufacturing sector, is expected to affect the level of environmental degradation for the following reason. The secondary sector (manufacturing, mineral, construction, electricity) is more pollution-intensive than the primary sector (agriculture, fishery, forestry) or the third sector (service). If the share of each sector in the economic activity shifts as the economy grows, such as shifting from the primary to the secondary, and the secondary to the third sector, the changes in the composition of the economy leads to the inverse-U curve of pollution pattern since it alters the intensity of pollution per unit production as income level increases.

This hypothesis has been well confirmed by the empirical evidence. For instance, Panayotou (1995) found a positive relationship between sulfur dioxide (SO_2) concentration and the share of secondary industry in a certain range of income levels using cross-country panel data. Cole (2004) also found a positive relationship between various air pollutants including SO_2 and the share of manufacturing sector using cross-country panel data.

Increased demand and supply of cleaner environment

Grossman and Kruger (1995) and Panayotou (1995) hypothesized that as income increases; there is more demand for a cleaner environment as a clean environment is a normal good. At the same time there are more resources to satisfy this demand when the income level increases. Thus a higher income level leads to more environmental regulations to achieve a cleaner environment.

Although it is ideal to use variables representing the stringency or quality of environmental regulations to estimate the effect of demand for a cleaner environment on pollution levels, often this information is not available. Instead, Panayotou (1995) used the GDP per capita to proxy an income-induced pollution abatement effort. He expected a monotonically negative relationship between the GDP per capita and the environmental degradation levels after controlling for factors of the scale and the composition of the economy and found empirical evidence that conforms to the expectation. However, the GDP per capita may not be a good proxy to an income-induced pollution abatement effort. The GDP per capita variable proxies any factors that are correlated with income levels but not explicitly controlled in the model. Thus the GDP per capita variable in his model would represent the composite effect of any factors not controlled for, such as environmental regulation as well as income inequality, civil freedom, technological advancement, international trade and others.

In addition to the GDP per capita, Panayotou (1995) incorporated the general quality of institutions to proxy the quality of environmental regulations such as “respect/enforcement of contracts” or the composite index of multiple variables such as “efficacy of the rule of law”, “efficiency of bureaucracy” and “the extent of government corruption”. By including the interaction term between the GDP per capita and the quality of institutions, the author found that a better quality institution shifts down the position of the EKC, indicating that a good political institution would enable the country to achieve a turning point of EKC at a lower pollution level.

Income inequality/ power inequality

Torras and Boyce (1998) examined the effect of the income inequality on the quality of the environment. The authors hypothesized that the power inequality in the society determines the level of "pollution-generating activities". They hypothesized that the actual policy outcomes are described by the net social benefits weighted by power of individuals, and the power structure is correlated with income levels. The higher the income level, the higher the social power. As higher income people tend to receive more benefits from pollution generating activities (driving automobiles, owning pollution generating companies etc.), they have incentives to maintain such pollution generating activities.

The low income group has less access to the benefit of pollution-generating activities but bear a great deal of the cost from pollution. Thus the incentives to maintain pollution generating activities in society are lower among the low income group. Since the high income group has more socioeconomic power than the low income group, it is hypothesized that the greater the income inequality, the greater the power inequality, and the higher the pollution levels in the society.

Torras and Boyce (1998) used the Gini ratio to represent the level of the income inequality. They also included the literacy level and political rights and civil liberties to control for the remaining factors, which may explain the power inequality. Using a cross-country panel data set, the authors found that the income inequality has a positive effect on SO_2 concentration levels among low-income countries but insignificant effect among high-income countries. The literacy rate and political rights variables show significant negative effects among low-income countries but insignificant impact among high-income countries.

Barret and Craddy (2000) also empirically examined the effect of the power structure in the society using the cross-country panel data.

They used the civil and political freedoms index to proxy the social power structure and found that pollution levels decrease as the country improves democratic freedoms.

Trade openness

According to Cole (2004), there are two competing hypotheses about how international trade affects environmental quality. One theory is called "pollution haven hypothesis". It is hypothesized that as some countries develop economically, there is increased demand for environmental regulations, and the producers need to bear higher pollution abatement costs. Thus the firms in developed countries have incentives to relocate pollution generating factories to less developed countries where the environmental regulations are more relaxed. Some developing countries may even relax the environmental regulations to attract foreign investment. Thus, if the countries with a less developed economy open for international trade, their pollution intensity per production may increase.

The other side of the hypothesis is that the international trade would reduce the pollution intensity per production in less developed countries by allowing them to face the international competition that leads to a more efficient production process and greater access to cleaner technologies as represented by the 2010 speech by Pascal Lamy, director-general of World Trade Organization (WTO).[1]

Several studies that empirically tested both of these hypotheses showed mixed results. Many used the share of imports and exports in the total GDP and others used the foreign direct investment (FDI) data to proxy the trade openness. For example, Jauregui et al. (2010) used the share of exports and imports in the total GDP to proxy the trade openness to explain the level of pollution volume index oriented from the manufacturing industry. Using panel data across 32 states in Mexico, they found that the trade openness has a significant positive

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[1] http://www.wto.org/english/news_e/news10_e/dgpl_05jun10_e.htm, last accessed on April 29, 2012.

impact on the index of pollution volume in some specifications of the model.

Cole (2004) used the share of exports and imports in total Gross National Product (GNP) to proxy the trade openness. In addition, they used a share of exports of pollution intensive products (wood products, chemicals, non-metallic minerals, and metals) to non-OECD countries in total exports and the share of imports of pollution intensive products from non-OECD countries to further examine the flows of pollution activities between developed and non-developed countries. The author found that the trade openness had a negative impact on several air pollutants including SO_2, and found mixed evidences for the pollution haven hypothesis depending on the pollutants examined. Although the estimated impact was relatively marginal, Cole (2004) found a significant evidence that supports the pollution haven hypothesis for the case of SO_2.

Suri and Chapman (1998) examined the impact of trade on the energy use per capita. The authors used the ratio of imports of all manufactured goods to the total domestic manufacturing productions as well as the ratio of exports of all manufactured goods to the total domestic manufacturing production to proxy the trade openness. Using cross-country panel models, authors found evidence of the pollution haven hypothesis as countries with lower income levels with high manufacturing goods exports consume higher energy and the countries with higher income levels with high manufacturing goods imports consume less energy.

Eskeland and Harrison (2003) examined the pollution haven hypothesis using the FDI data. The authors found that the foreign owned manufacturing plants in Mexico show significantly higher energy efficiency than domestically owned plants after controlling for important characteristics of plants such as the size of employee and capital intensity. This result indicates that the higher the FDI in the manufacturing sector, the higher the energy efficiency and thus the lower the air pollution per production level.

Although there are several studies that attempted to estimate the structural model as described above, there is no study that included all important underlying factors in a single model. In this study, we attempt to estimate more comprehensive structural models by including all important underlying factors described above using the cross-state panel data of Mexico.

Using the single country data has certain advantages compared to using the cross-country data which most previous studies used. First, due to the lack of data, the cross-country studies often ignore cultural aspects or the political system of the country, which may be an important determinant of pollution levels. This unobserved heterogeneity may lead to a high unexplained variation of the dependent variable, causing less precise estimations as well as potentially causing bias in estimators. Because of the similar culture and the same political system in a single country model, there would be less unobserved heterogeneity in the single-country model than in the cross-country models.[2] Second, it is much easier to collect various data for one country than across countries.

Mexico is an ideal country with a unique dataset to analyze the structural model since it has detailed inventories of air pollution data, and complete information about state level economic composition, income inequality, quality of institutions, FDI that vary substantially among states. In addition, the air pollution data are created for different pollution sources, which enable us to model the determinants of pollution levels for different types of pollution generating activities.

2. The estimating model and data

In this article, we estimate the following model using the cross-state panel data in 1999 and 2005 in Mexico.

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[2] The bias caused by the time-invariant unobserved heterogeneity, such as cultural factors and political system, can be removed in the cross-country panel data using fixed effects or first differenced models. However, most previous studies only used a random effects model which does not control such bias.

$$
\begin{aligned}
&In\ E_{it} = \\
&\beta_0+\beta 1IND_{it}+\beta_2 ICGG_{it}+\beta_3 GINI_{it}+\beta_4 FDI_{it}+ \\
&\beta_5 FN+\beta_6 FS+\beta_7 Year2005+\beta_8 GDP_{it}+\beta_9 GDP^2_{it}+\varepsilon \qquad (2)
\end{aligned}
$$

Where *i* indicates state and *t* indicates year.

The term *lnE* is the logarithm of the annual pollution emission volume per capita, *IND* is the secondary (industrial) sector share in total GDP, *ICGG* indicates the quality of institution, *GINI* is the Gini index, *FDI* is the annual foreign direct investment per capita, *FN* is the dummy variable that takes 1 if a state locates on the north-border, and 0 otherwise, *FS* is the dummy variable that takes 1 if a state locates on the south-border, and 0 otherwise, *YEAR2005* is the year dummy variable that takes 1 if the year is 2005 and takes 0 otherwise and *GDP* is the GDP per capita and ε is a the error term.

Table 1 shows the definition of each variable and summary statistics. The following section briefly describes the data for each variable.

Volume f Annual pollution emission per capita (E)

The annual pollution emission volume for 1999 and 2005 is obtained from the *Inventario Nacional de Emisiones de México* (INEM), developed by *Secretaría de Medio Ambiente y Recursos Naturales* and *Instituto Nacional de Ecología*. INEM reports the annual pollution levels by each state and each pollution source including point source, area source, mobile source and natural source. The point source is defined as large industrial sources such as manufacturing factories. The area source includes various smaller scale production activities such as small businesses. The mobile source is defined as automobiles. The natural source measures any naturally occurred pollution levels.

Between 1999 and 2005 data, there are slight changes in the definition of the mobile and area sources. In the 1999 data, the mobile source includes "circulated mobiles on the road", and the area source includes pollution from "area" sources and pollution from "non-circulated mobiles on the road" which includes airplane, agricultural tractors, bus etc. In 2005, "non-circulated mobiles" are categorized in the "mobile" source. There is no information on the proportion of "non-circulated mobiles" in mobile or area sources. Thus we estimate the model for 1999 and 2005 separately for mobile and area sources as well.

The point and area sources represent the pollution generating activities from the production side while the mobile source represents the pollution generating activities from the consumer side. Estimating the structural model for each pollution source provides unique and useful information on how the levels of pollutions from different sources are affected by various socioeconomic factors.

In this article, we focus on analyzing the effect of socioeconomic factors on SO_2 emission, which is the most commonly studied pollutant in ECK literature and often found to have a EKC structure. We exclude the natural-oriented SO_2 emissions from our analysis because the data from natural source is not available for SO_2, and the pollution levels from natural sources are not likely affected by socioeconomic conditions.

We created variables for per capita SO_2 emission levels from non-natural sources (SO_2-total), SO_2 from the point source (SO_2-point), SO_2 from the area source (SO_2-area) and SO_2 from the mobile source (SO_2-mobile) by dividing the emission levels in each source by the population level for the corresponding year obtained from the *Consejo Nacional de Población* (CONAPO).

Table 1 presents the summary statistics of SO_2 emission levels in 1999 and 2005. Over 93% of the SO_2 emissions from human activities come from the point sources. Less than 5% and 1% of the SO_2 emissions from human activities come from the area and mobile sources respectively. The SO_2 emissions per capita from total human activities increased from 47 kg to 63 kg between 1999 and 2005, and the increase was only observed among the point sources.

In the analysis, we use the logarithm of SO_2 emissions per capita to improve the fit of models.

Industrial share in total GDP (IND/MAN_IND/MIN_IND)

Industrial share *(IND)* is defined as the ratio of GDP from the secondary sector (mineral, manufacturing, construction and electricity) to the total GDP for each state. We obtained the sector specific GDP and total GDP for each state from the *Instituto Nacional de Estadística, Geografía e Informática* (INEGI) for year 1999 and 2005 and calculated the industrial share for each year.

This variable is expected to capture the effect of the composition of the economy. After controlling for other factors, we expect a positive relationship between the industrial share and SO_2 pollution levels from the point source since the higher the share of pollution-intensive secondary sector, the higher the per capita SO_2 emission levels should be. We do not expect any significant effect of the industrial share on the area-oriented and mobile-oriented SO_2 emission levels.

We also created the share of the manufacturing sector in the total *GDP (MAN_IND)* and the share of the mineral sector in the total *GDP (MIN_IND)* to examine the sensitivity of our results. We adjust all monetary values to the 2010 price level using the inflation calculator based on the consumer price index obtained from the Bank of Mexico.

Quality of institution (ICGG)

Following Panayatou (1995), we use the quality of institution variable to proxy the quality of environmental regulations. Specifically, we use the index of corruption and good government (*ICGG*) obtained from the *Instituto Nacional para el Federalismo y el Desarrollo Municipal* (INAFED), originally created by the Tranparencia Mexico. This index measures the perception about the corruption of local governments based on the national survey among households about their experience to receive public service or avoid penalty from regulators such as a traffic ticket. The index ranges from 0 to 100, where a higher number indicates a higher level of corruption. Since the data was only available for every two years starting from 2001, we use the 2001 data to proxy the index in 1999.

When all else is equal, better quality environmental regulations would reduce pollution levels from any sources. Thus *ICGG* are expected to have a positive effect on the pollution levels from all sources (the higher the corruption, the higher the pollution levels).

Income inequality (GINI)

The GINI variable is the Gini index for each state obtained from the *Consejo Nacional de Evaluación de la Política de Desarrollo Social* (CONEVAL). The Gini index ranges between 0 and 1, and a higher number indicates a higher income inequality. The 1999 data is not available, so we use the 2000 data to proxy the Gini index of 1999. The income inequality would represent the power inequality of society, and generally it is found that the higher the inequality, the higher the pollution. However, the marginal effect of the Gini index over pollution may vary depending on the income level of the state as Torras and Boyce (1998) found. Previous studies also used political and civil freedom and the literacy rate to analyze the effect of the power inequality. However, since we analyze the single country data where degree of civil freedom and the literacy rate are homogeneous, we do not incorporate these factors into our analysis.

Foreign direct investment per capita (FDI)

The FDI variable represents the per capita volume of annual foreign direct investment. The total volume of annual foreign direct investment is obtained from the *Centro de Estudios de las Finanzas Públicas de la Cámara de Diputados* for 1999 and 2005 and measured in US dollars. The value is divided by the population level of the corresponding year and adjusted to the 2010 price level using the inflation calculator based on the consumer price index obtained from the U.S. Bureau of Labor Statistics.

The FDI variable is included to proxy the trade openness. The expected sign of this variable in the point source models is ambiguous as there are competing hypotheses. We expect to observe a negative impact of the FDI variable on SO_2 from the point source if the negative effect from adapting clean technology dominates. However, if the "pollution haven hypothesis" effect dominates, we expect a positive sign.

As for the area and mobile source models, we expect a positive sign from the FDI variable. There would not be any direct benefit (such as from adapting clean technologies) for the area and mobile sources as this benefit only incurred among factories that directly receive the foreign direct investment. However, if the "pollution haven hypothesis" is true and local governments relax the environment regulations in the area in general to attract FDI, the pollution from the area and mobile sources may increase as well.

Regional dummies (FN, FS)

The regional dummy variables are included to control for any regional specific characteristics. Specifically, we include dummy variables for the north-border states *(FN)* and the south-border states *(FS)*. The north-border states include Baja California, Sonora, Chihuahua, Coauhila, Nuevo Leon, and Tamaulipas. The south-border states include Chiapas, Tabasco, Campeche, Quintana Roo, and Yucatan.

Year dummy (YEAR2005)

The year dummy variable captures the different quality of environmental regulations over time. Between 1999 and 2005, there have been drastic changes in environmental protection related spending in Mexico. Figure 1 shows the historical chart of the government environmental spending per capita at the national level (adjusted to the 2010 price level). The environmental spending has increased dramatically since 2000. The per capita environmental spending increased as much as 350% from 185 pesos to 647 pesos from 1999 to 2005. The higher spending means a stricter implementation of the environmental regulations. There is no state-government environmental spending data, but we can assume that Mexico generally had a stricter implementation of environmental regulation in 2005 than 1999 across states.

The year dummy variable is created in such a way that it takes one if the data comes from the year 2005, and 0 otherwise. After controlling all other factors, we expect a negative effect of the year dummy variable, as we expect that stricter environmental regulations in 2005 would reduce SO_2 emissions levels from all sources compared to the 1999 level.

GDP per capita (GDP)

GDP data for each state for 1999 and 2005 is obtained from the *Sistema de Cuentas Nacionales de México, INEGI*. We divide the state GDP data with corresponding population level and adjust to the 2010 price level. The parameters of GDP per capita and squared GDP per capita may capture residual effects from some socioeconomic factors that we fail to control explicitly in the model.

For example, one of the important factors that may explain the EKC relationship is technological advancement (Grossman and Kruger, 1995). Higher income levels allow producers and consumers to access newer and cleaner technologies. The FDI variable may capture some technological advancement impacts for the point sources, but any part not captured by the FDI variable will be captured by the GDP variables. Also the GDP variable may capture the composition of automobiles or equipment. Newer automobiles or equipment are more energy efficient and pollute less than older models. Higher income enables people to access newer models to replace old ones, and the GDP variable may capture this effect.

Also, we have an inaccurate measure of the quality of environmental regulations or demand for a cleaner environment. Any factor that indicates the actual quality of environmental regulations but is not explained by the ICGG or the year dummy variable will be captured by the GDP variables.

3. Results

This section presents the estimating results for point, mobile, area and total sources using panel data models. According to Wooldridge (2004), there are generally two approaches to analyze panel data. One approach includes the random effects model, and the other includes the fixed effects or first differenced model. The random effects model assumes that all explanatory variables are exogenous. In other words, unobserved effects contained in the error term are not correlated with any of the explanatory variables. When this assumption is satisfied, the random effects models generate the most efficient and consistent estimators in addition to controlling for serial correlation and heteroskedasticity.

When the assumption of exogeneity is not satisfied, the random effects model leads to biased and inconsistent estimators. If the unobserved effects that are correlated with explanatory variables are time-invariant, fixed effects or first differenced models may be used to obtain an unbiased estimator. We estimate equations (1) and (2) with both random effects and fixed effects models. In all models except one, we fail to reject the Hausman test, indicating that there are no statistically significant differences between results from the random effects and fixed effects models.[3] Thus we only present the results from the random effects models for each pollution source in Table 2 and make conclusions based on them. The following section summarizes the main findings from the analysis for each pollution source.

Point sources

Model 1 specifies the reduced form EKC model (equation 1), regressing the logarithm form of SO_2 emission volume per capita with the GDP per capita, as a reference. Model 1 shows that the SO_2 emission levels from the point source have a significant inverse-U relationship with the GDP per capita.

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[3] The only time Hausman test is rejected is model 1 of area-oriented pollution where the fixed effects model estimates insignificant coefficient for GDP and GDP2.

In model 2, we estimate equation (2), the structural model with more policy relevant variables such as the share of industry, quality of institution, income inequality, FDI, and dummy variables for region and year. Once we control for policy relevant variables, we no longer observe an inverse-U relationship between the GDP per capita and the SO_2 emission levels from the point source. However, none of the explanatory variables showed a statistically significant impact either.

To improve the model specification, model 3 includes the share of the mineral industry in GDP instead of the share of the secondary industry and dropped the dummy variable for south-border states (FS). The coefficient of the share of the mineral industry shows a positive significant effect, indicating that the states with a higher petroleum production have a higher level of SO_2 emissions from the point source. This result is as expected, as the mineral industry is more pollution intensive than other sectors in the secondary industries.

Model 4 examines the robustness of the results of the model 3. As Torras and Boyce (1998) found, the effect of income inequality may vary by the income level. We estimate the separate effect of the GINI variable for 26 states with the lowest GDP per capita (Gini-low) and 26 states with the highest GDP per capita (GINI-high) in model 4. There is no significant impact from the income inequality even after allowing the separate effects for different income levels. The share of the mineral industry still has a positive significant effect, and the GDP variable recovered an inverse U-shape relationship.

The quality of institutions in terms of the level of corruption does not show a significant effect in any model specification. There may be two reasons. One reason is that since the point sources are large firms with high visibility to regulators, the regulation process may be more transparent than that of the small businesses. The other reason is because we use the corruption index to measure the quality of institutions. The corruption index is based on the survey among household heads about their experiences of the corruption in their daily lives such as bribing the public officers to avoid traffic tickets or obtain the permits. This perception about the level of corruption based on daily life experience may not reflect the actual corruption levels between government and large firms accurately, if there is any.

The FDI variable does not show a significant effect on SO_2 emission levels from point sources either. This may be because two competing effects from applying clean technology (negative effect) and the realization of the pollution haven hypothesis (positive effect) may have cancelled out each other.

Mobile sources

Model 1 of the mobile source model also presents the reduced form ECK estimation (equation 1) as a reference. We found a significant inverse-U relationship between the GDP per capita and the SO_2 emission per capita from the mobile source. This relationship is persistent even after including more policy relevant variables.

Model 2, 3 and 4 include a set of policy relevant variables with similar variations as point source models except that we use the industry share instead of the mineral industry share in models 3 and 4. The industry share variable does not show any significant effects across all three models. This is expected as the composition of the economy is not likely to affect the consumption behavior once other factors are controlled.

The quality of institutions has a positive effect on SO_2 emission from mobile sources, indicating that a higher level of corruption leads to a higher level of pollution from mobile sources. The effect is significant at the 1% level across three models. This is as expected, since a higher level of corruption at daily life levels enables citizens to bypass the required emission tests or driving ill-conditioned cars by bribing the public officers.

The GINI variable shows a significant negative coefficient in models 2 and 3 at the 5% significance levels. These results indicate that the higher the income inequality, the lower the SO_2 emissions from mobile sources. To examine the effect of income inequality in different income levels, we use GINI-low and GINI-high in model 4. We still found a consistently negative significant effect from income inequality among low income and high income states. This implies that the power inequality hypothesis, which expects that the higher the income inequality the higher the pollution levels, does not apply for the case of mobile sources-oriented pollution in Mexico.

This may be because the accessibility to automobiles has a non-linear relationship with the distribution of income. The people in the lowest income group will not be able to own an automobile, while the people in the upper-low income group may have access to at least one automobile per family given the cheap secondary automobile markets in Mexico. People in the middle class may have access to at least one automobile per adult family member. High income individuals may own more than one automobile per person; however, only one automobile can be driven by one individual at a time. The less extent of income inequality means there are less people in the extreme end of the income distribution. As the income inequality lessens, there are more people in a higher than the lowest income group, thus there are more automobiles driven in the state. At the same time, there are less people in the highest income group, meaning more people in the middle income group, but this change does not reduce the average number of automobiles driven per person. This explains why the GINI variable has a negative significant coefficient on the automobiles-related pollution levels.

The FDI variable shows a significant positive coefficient estimate across three models. These results indicate that the higher the FDI, the higher the SO_2 emissions from mobile sources. This is somewhat surprising, since the FDI does not have a direct impact on the efficiency of automobiles or number of automobiles driven in the state after controlling for the income level of the state. However, this could be explained by the pollution haven hypothesis where the FDI tends to go to states with less severe environmental regulations in general.

The dummy variable of the north-border states shows a positive significant coefficient at the 10% levels across three models, indicating that the per capita SO_2 emissions in the north-border states is higher than other states. This may be due to the higher number of automobiles per person in north-border regions than other areas. The dummy variable for south-border states is not significant.

The dummy variable of Year2005 shows a consistently negative coefficient significant at the 1% level across three models. This result indicates that the per capita SO_2 emission from mobile sources is lower in 2005 compared to 1999, likely due to a higher efficiency of the automobiles and stricter environmental regulations in 2005. The GDP variables still indicate a significant inverse-U curve relationship even after controlling for various policy relevant variables.

Since the definition of the mobile sources changed slightly between 1999 and 2005, we also estimate the same set of models for 1999 and 2005 data separately as shown in appendix A. We use heteroskedasticity-corrected standard error. The estimated signs are consistent across all variables as our combined data models. However, the effects of socioeconomic factors with statistical significance are not observed in 1999 data while strongly observed in 2005 data models.

Area sources

Model 1 of the area source data shows the usual inverse-U curve relationship between the SO_2 emission per capita and the GDP per capita.[4] This relationship is persistent even after including more policy relevant variables. Model 2 includes all policy relevant variables, but only the GDP and Year 2005 variables are significant in this model. The Year 2005 dummy variable shows a positive significant effect, indicating increased pollution levels from area sources over time. Model 3 drops the FS variable, and the FDI variable shows a positive significant effect. Since the FDI variable will not have a strong direct impact on the economic activities among small businesses in the state, the positive effect from the FDI is likely to show evidence in favor of the

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[4] The Hausman test indicates that the estimation result from the random effects model for model 1 with area source data is inconsistent. The fixed effects model for the same model estimates insignificant coefficients for GDP and GDP2. We only use the estimation results from the random effects model for this specific model just to present the impact of adding socioeconomic factors in the model on the estimation of the coefficients of GDP variables.

pollution haven hypothesis due to the relaxed environmental regulations of states to attract the FDI.

The industry composition, the quality of institutions, income inequality, and regional dummies are consistently insignificant. It is expected that the industry composition does not have any impact on the area sources, as the area sources represent small businesses. The insignificance of the quality of institution variable is likely explained by the miss-measurement of the quality of institution factor as in the case for the point source models. The GINI variable has a negative sign, regardless of the income levels, but the effect is not significant.

As in the case for the mobile sources, the definition of area sources changed slightly between 1999 and 2005, and thus we estimate the same set of models for 1999 and 2005 data separately as shown in appendix B. There are few notable differences between 1999 data models and 2005 data models. The 1999 data models show similar results as combined data models where the FDI and the GDP show significant relationship with the SO_2 per capita. However, 2005 data models show significant positive effects from the industry share on the SO_2 emission from area sources, as well as significantly higher SO_2 emission from area sources in north-border states. It is not clear if these changes are due to the changes in the definition of the area sources or due to the structural changes between 1999 and 2005.

Total sources

Since over 90% of SO_2 emission comes from the point sources, the estimated structural models for the total sources are similar to the ones of point sources. The only differences are that the significant positive effects of the FN variable found in model 3 and model 4 are likely coming from the mobile source, and model 4 does not show a significant inverse-U relationship between the SO_2 emission level and the GDP per capita.

4. Conclusions

This study attempts to estimate the comprehensive structural model that determines the SO_2 emission levels from various pollution sources in Mexico. We form hypotheses based on the previous studies that the composition of the economy, the quality of institutions, income inequality, trade openness, regional differences, time trend and income levels affect the SO_2 emission levels from various sources differently. To our knowledge, this is the first study that systematically examines the comprehensive structural model of the determinants of SO_2 emissions for each pollution source.

Mexico maintains detailed inventories for various air pollutants overtime which enable us to conduct this unique analysis. Using the state-level panel model, we find evidence of the pollution haven hypothesis. That is, the pollution level from the mobile and area sources are significantly higher among the states with higher level of FDI. This result implies that the FDI tends to go to the areas with less stringent environmental regulations. The evidence of the pollution haven hypothesis is not found for the pollution from large factories. Our study also questions the common claim that the international trade promotes environmental protection. Our results found that the international trade may improve the efficiency of the production process, but there is a significant risk of simply shifting the pollution burden from developed countries to developing countries.

The industry composition affects the SO_2 emission levels from the point sources, but only the mineral industry is responsible for the increased levels of SO_2 emission, not the manufacturing sector in Mexico.5 This may reflect the unique characteristics of the Mexican manufacturing industry. An important proportion of manufacturing sectors in Mexico is called maquiladoras, specializing for the assembly of temporary imported parts and export assembled goods. Since

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[5] This conclusion comes from the models where the *MAN_IND* variable replaces the *IND* variable (not presented in table 2). We did not find significant coefficient estimations for *MAN_IND* variable.

the main activity of the maquiladora industry is assembly, they are less pollution-intensive than the common manufacturing production process.

We find empirical evidence that the quality of institutions affects the level of some types of pollution activities significantly. The analysis with mobile-oriented pollution data indicates that the higher the daily-life level corruption, the higher the pollution levels. Although we did not find the same evidence for the point source-oriented pollution levels, it is likely because our measure of the quality of institutions does not reflect the level of corruption between government and businesses. This brings an important challenge in Mexico as well as many other developing countries where the quality of institutions is still in the developing stage.

We found that the automobile-oriented pollution levels per capita have reduced while the area-oriented pollution levels per capita have increased over time. This result raises many questions for examination in the future such as if the stricter environmental regulations have been applied unevenly across sectors in Mexico; if the benefits of technological advancement have not reached to small businesses; and if the increased number of businesses simply dominated the negative effect from the regulation or technological advancements.

Generally, we found that the socioeconomic factors have distinct effects on pollution from various sources. We found that the automobile-oriented pollution is particularly sensitive to the changes of socioeconomic factors. On the other hand, total SO_2 emission levels do not provide much useful information between the changes of socioeconomic factors and SO_2 levels. This is an important finding because the structural model using the total SO_2 emissions data, as commonly done previously, is likely to have a limited use to predict the SO_2 emission levels in the future. The structural model using the total SO_2 emission levels can be only used if the composition of point, area and mobile sources are assumed to be constant. In the case that the composition of pollution sources changes, such as increased proportion of automobile sources in the future, we need to use pollution source specific structural models to predict SO_2 emission levels.

We attempted to decompose the possible socioeconomic factors that explain the EKC hypothesis. However, after controlling for important socioeconomic factors proposed by previous studies, we still found a persistent inverse-U relationship between the GDP per capita and the SO_2 emission levels per capita from the point, area and mobile sources. It indicates that there are still substantial amounts of unexplained socioeconomic effects that determine the SO_2 emission levels. The possible factors may include political factors, technological advancement, and actual quality of environmental regulations. In addition, we observed structural changes in the effect of socioeconomic conditions among mobile and area sources between 1999 and 2005. Further effort needs to be made to identify the remaining factors that explain the EKC relationship between the GDP and the SO_2 emission levels as well as the factors that explain the change of socioeconomic effects over time.

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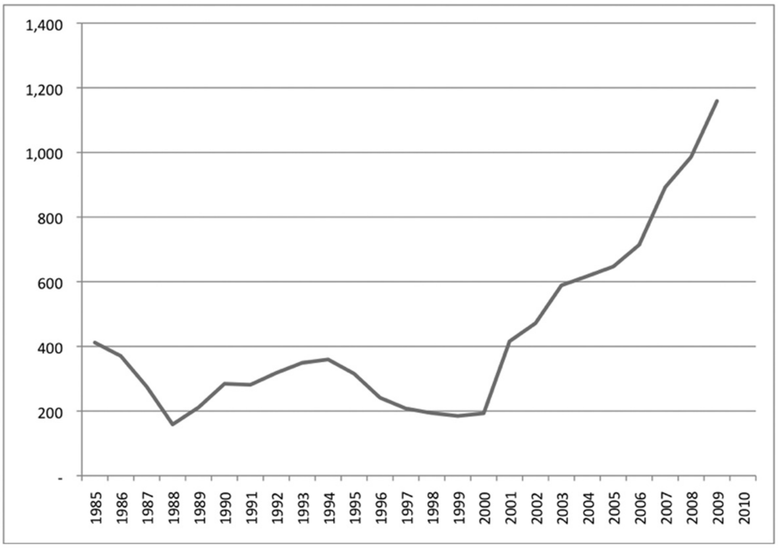
Figure 1. National level environmental protection spending per capita in Mexico (2010 price level in peso).



Note: The national level environmental protection spending is obtained from INEGI. The per capita spending level is calculated by authors, by dividing the total annual spending with the population level in the corresponding year.

Table 1. Definition of variables and summary statistics.

Variable	*Definition*	*Mean of 1999 data (Standard deviation) (n=32)*	*Mean of 2005 data (Standard deviation) (n=32)*
SO_2-total	Per capita emission volume of total SO_2 for 1999 and 2005. (unit: ton)	0.047 (0.075)	0.063 (0.173)
SO_2-point	Per capita emission volume of SO_2 from point sources for 1999 y 2005. (unit: ton)	0.044 (0.075)	0.060 (0.173)
SO_2-area	Per capita emission volume of SO_2 from area sources for 1999 y 2005. (unit: ton)	0.002 (0.002)	0.002 (0.001)
SO_2-mobile	Per capita emission volume of SO_2 from mobile sources for 1999 y 2005. (unit: ton)	0.0002 (0.00008)	0.0002 (0.0001)
POP	Population in 1999 y 2005 (unit: million)	3.034 (2.615)	3.248 (2.806)
IND	Share of secondary sector in total GDP (unit: %)	28.426 (9.677)	26.352 (9.567)
MAN_ IND	Share of manufacturing sector in total GDP (unit:%)	18.008 (10.540)	16.598 (10.117)
MIN_IND	Share of mineral sector in total GDP (unit:%)	3.001 (8.228)	2.768 (7.842)
ICGG	Index of Corruption and Good Government for 2001 and 2005.	7.950 (3.894)	8.353 (3.517)
GINI	Index of Gini reported for 2000 and 2005.	0.516 (0.035)	0.479 (0.030)
FDI	Per capita foreign direct investment in 1999 and 2005 (unit: US dollar)	139.658 (212.448)	200.882 (417.130)
GDP	Per capita gross domestic product (GDP) for 1999 y 2005 unit: thousands pesos)	77.297 (35.906)	84.656 (38.873)

Table 2. Random effects model estimation results (n=64)
(standard errors reported in parentheses).

	Point sources				*Mobile sources*			
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
IND		0.0461 (0.0376)				-0.0049 (0.0047)	-0.0051 (0.0047)	-0.0055 (0.0047)
MIN_IND			0.1044** (0.0472)	0.1039** (0.0472)				
ICGG		0.0023 (0.0519)	0.0091 (0.0520)	0.0037 (0.0522)		0.0607*** (0.0152)	0.0599*** (0.0149)	0.0590*** (0.0151)
GINI		0.9272 (4.9619)	1.3009 (4.9403)			-3.8441** (1.7174)	-3.6288** (1.6181)	
GINI-low				2.8001 (5.1463)				-3.5931** (1.6262)
GINI-high				0.1804 (5.0532)				-3.8531** (1.6559)
FDI		-0.0005 (0.0006)	-0.0004 (0.0006)	-0.0004 (0.0006)		0.0004** (0.0002)	0.0004* (0.0002)	0.0004* (0.0002)
FN		0.9029 (1.2033)	1.4295 (1.1285)	1.4827 (1.1296)		0.2538* (0.1389)	0.2467* (0.1367)	0.2405* (0.1376)
FS		0.8767 (1.1127)				0.0517 (0.1294)		
Year2005		-0.1902 (0.2586)	-0.2109 (0.2435)	-0.3120 (0.2622)		-0.2991*** (0.1026)	-0.2919*** (0.1002)	-0.3078*** (0.1031)
GDP	0.0709** (0.0316)	0.0611 (0.0401)	0.0523 (0.0386)	0.0882* (0.0520)	0.0196*** (0.0055)	0.0250*** (0.0062)	0.0252*** (0.0061)	0.0293*** (0.0084)
GDP^2	-0.0003*** (0.0001)	-0.0003 (0.0001)	-0.0002 (0.0001)	-0.0003* (0.0002)	-0.00006*** (0.00002)	-0.0001*** (0.00003)	-0.0001*** (0.00003)	-0.0001*** (0.00003)
constant	-7.2904*** (1.5335)	-9.0303** (3.5782)	-7.6835** (3.4702)	-9.7219** (3.9919)	-9.3662*** (0.2635)	-7.7837*** (1.0588)	-7.8889*** (1.0177)	-8.0424*** (1.0449)
R2-overall	0.15	0.25	0.31	0.30	0.29	0.58	0.58	0.58

*, **, ***: significant at the 10%, 5% and 1% levels, respectively

Table 2. (cont.) Random effects model estimation results (n=64) (standard errors reported in parentheses).

	Area source				*Total*			
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 1*	*Model 2*	Model 3	Model 4
IND		0.0125 (0.0094)	0.0124 (0.0092)	0.0117 (0.0093)		0.0431* (0.0247)		
MIN_IND							0.0988*** (0.0280)	0.0985*** (0.0282)
ICGG		-0.0300 (0.0287)	-0.0310 (0.0281)	-0.0324 (0.0283)		-0.0276 (0.0397)	-0.0212 (0.0386)	-0.0230 (0.0390)
GINI		-4.6656 (3.1770)	-4.4890 (2.9957)			-1.5347 (3.8509)	-1.2135 (3.7312)	
GINI-low				-4.4035 (3.0160)				-0.7953 (3.8564)
GINI-high				-4.8095 (3.0660)				-1.5768 (3.8285)
FDI		0.0006 (0.0004)	0.0006* (0.0004)	0.0006* (0.0004)		-0.0002 (0.0004)	-0.0001 (0.0004)	-0.0001 (0.0004)
FN		0.3440 (0.2748)	0.3356 (0.2669)	0.3262 (0.2685)		0.6217 (0.7674)	1.1535* (0.6697)	1.1538* (0.6751)
FS		0.0424 (0.2546)				0.5847 (0.7036)		
Year2005		0.2936* (0.1777)	0.2996* (0.1740)	0.2757 (0.1802)		-0.0941 (0.1942)	-0.1140 (0.1813)	-0.1471 (0.1949)
GDP	0.0740*** (0.0102)	0.0537*** (0.0121)	0.0540*** (0.0119)	0.0604*** (0.0163)	0.0418* (0.0216)	0.0205 (0.0272)	0.0142 (0.0246)	0.0256 (0.0343)
GDP^2	-0.0003*** (0.00004)	-0.0002*** (0.00006)	-0.0002*** (0.00005)	-0.0003*** (0.00006)	-0.0002** (0.0001)	-0.0001 (0.0001)	-0.0001 (0.0001)	-0.0001 (0.0001)
constant	-9.5503*** (0.4843)	-6.4657*** (1.9684)	-6.5548*** (1.8900)	-6.8121*** (1.9526)	-5.6846*** (1.0396)	-5.1119* (2.6637)	-3.9527 (2.5185)	-4.5784 (2.8514)
R2-overall	0.55	0.68	0.68	0.69	0.18	0.29	0.44	0.44

*, **, ***: significant at the 10%, 5% and 1% levels, respectively

Appendix A. Estimation results for mobile sources for 1999 and 2005 data (n=32)
(Robust standard errors reported in parentheses).

	Mobile source 1999				Mobile source 2005			
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
IND		0.0010 (0.0033)				-0.0054 (0.0084)	-0.0062 (0.0077)	-0.0069 (0.0087)
MIN_IND			0.0010 (0.0032)	0.0009 (0.0032)				
ICGG		0.0171 (0.0128)	0.0186 (0.0127)	0.0184 (0.0137)		0.0929*** (0.0303)	0.0919*** (0.0299)	0.0909*** (0.0298)
GINI		-0.6892 (0.8422)	-1.0033 (0.7405)			-6.8067** (3.2969)	-6.2625* (3.2062)	
GINI-low				-0.9906 (0.7252)				-6.3125* (3.3127)
GINI-high				-1.0785 (0.7759)				-6.6898* (3.6391)
FDI		0.0005 (0.0003)	0.0005* (0.0003)	0.0005 (0.0003)		0.0005** (0.0002)	0.0005** (0.0002)	0.0004* (0.0002)
FN		0.1077 (0.1145)	0.1129 (0.1072)	0.1112 (0.1076)		0.3726* (0.1842)	0.3529* (0.1798)	0.3436* (0.1916)
FS		-0.0759 (0.0768)				0.1224 (0.2095)		
GDP	0.0105*** (0.0032)	0.0119** (0.0054)	0.0118** (0.0054)	0.01337*** (0.0046)	0.0292*** (0.0105)	0.0322** (0.0118)	0.0331*** (0.0114)	0.0383** (0.0143)
GDP^2	-0.000025* (0.0001)	-0.00005* (0.00002)	-0.00005* (0.00002)	-0.00005** (0.0002)	-0.0001** (0.00004)	-0.0001*** (0.00005)	-0.0001*** (0.00005)	-0.0001*** (0.00005)
constant	-8.8986*** (0.1480)	-8.7091*** (0.5984)	-8.5641*** (0.5467)	-8.6221*** (0.5130)	-9.8979*** (0.5812)	-7.2005*** (2.0834)	-7.4680*** (2.0701)	-7.6366*** (2.0274)
R2-overall	0.54	0.71	0.70	0.71	0.30	0.68	0.67	0.68

*, **, ***: significant at the 10%, 5% and 1% levels, respectively

Appendix B. Estimation results for area sources for 1999 and 2005 data (n=32)
(Robust standard errors reported in parentheses).

	Area source 1999				*Area source 2005*			
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 1*	*Model 2*	*Model 3*	*Model 4*
IND		-0.0003 (0.01587)	-0.0007 (0.0158)	-0.0023 (0.0172)		0.0227*** (0.0061)	0.0233*** (0.0055)	0.02335*** (0.0057)
MIN_IND								
ICGG		-0.0384 (0.0462)	-0.0438 (0.0447)	-0.0463 (0.0456)		-0.0099 (0.0191)	-0.0092 (0.0210)	-0.0093 (0.0214)
GINI		-7.1759 (4.5027)	-6.0422 (4.1743)			-1.5747 (3.1082)	-1.9860 (2.8835)	
GINI-low				-5.9162 (4.3511)				-1.9876 (2.9493)
GINI-high				-6.7919 (4.7663)				-1.9997 (2.9955)
FDI		0.0021* (0.0012)	0.0019* (0.0011)	0.0018 (0.0012)		0.0005** (0.0002)	0.0005*** (0.0001)	0.0005*** (0.0001)
FN		-0.0715 (0.6420)	-0.0904 (0.6304)	-0.1076 (0.6225)		0.5290*** (0.1709)	0.5439*** (0.1721)	0.5436*** (0.1765)
FS		0.2740 (0.2742)				-0.0925 (0.1959)		
GDP	0.0840*** (0.0133)	0.0705*** (0.0165)	0.0707*** (0.0164)	0.0857*** (0.0239)	0.0692*** (0.0073)	0.05331*** (0.0097)	0.0526*** (0.0093)	0.0527*** (0.0129)
GDP^2	-0.0004*** (0.00006)	-0.0004*** (0.00008)	-0.0004*** (0.00008)	-0.0004*** (0.00009)	-0.0003*** (0.00003)	-0.0002*** (0.00003)	-0.0002*** (0.00004)	-0.0002*** (0.00004)
constant	-9.9496*** (0.5976)	-5.2828* (2.7061)	-5.8060** (2.6054)	-6.3843** (2.5948)	-9.2493*** (0.3687)	-8.1836*** (1.8246)	-7.9814** (1.6915)	-7.9868*** (1.7631)
R2-overall	0.55	0.65	0.64	0.65	0.75	0.89	0.89	0.89

*, **, ***: significant at the 10%, 5% and 1% levels, respectively