GRÉDI

Groupe de Recherche en Économie et Développement International

Cahier de recherche / Working Paper
07-02

Environmental impacts of international trade: The Case of Industrial Emission of Sulfur Dioxide (SO_2) in Chinese provinces

Jie He

UNIVERSITÉ DE
SHERBROOKE

Environmental impacts of international trade: The Case of Industrial Emission of Sulfur Dioxide (SO_2) in Chinese provinces

Jie HE

Département d'Économique and GREDI
Faculté d'Administration
Université de Sherbrooke
2500 boulevard de l'Université
Sherbrooke QC J1L2W9
Canada
Tel : 1-819-821-8000 ext 62360
Fax : 1-819-821-7934
Email : Jie.He@USherbrooke.ca

Abstract

To get better understanding on trade's impact on environment, we construct a four-equation simultaneous system, in which emission is determined by the three economic determinants: scale, composition and technical effects and directly by trade. Supposing the three economic determinants are also endogenous to trade, we check in the following three functions the indirect impacts of trade on environment through the intermediation of the three effects. The model is then estimated by 29 Chinese provinces' panel data on industrial SO_2 emission (1993-2001). Our estimation results reveal totally opposite role of export expansion and accumulation of manufactured goods import in industrial SO_2 emission determination. The results do not support "pollution haven" hypothesis; the reinforced competition faced by exporters is a positive factor encouraging technology progress in pollution abatement. China's actual comparative advantage resides in labor-intensive industries, exporting to world market actually helps to reduce pollution increasing caused by its heavy-industry-oriented industrialization strategy, which is traditionally supported by government-intervened import activities.

Key words: international trade, industrial SO_2 emission, simultaneous system, scale effect, composition effect, income effect, Hypothesis of "Porter" and "Racing to the bottom", China.

Environmental impacts of international trade: The Case of Industrial Emission of Sulfur Dioxide (SO_2) in Chinese provinces

1. Introduction

The economic reform since 1978 has induced rapid integration of Chinese economy into world market. The openness policy is generally considered as one of the most important catalysts for rapid economy growth and industrialization process in many coastal and inland Chinese provinces. However, China's openness and economic growth success seemed to be accompanied by obvious pollution problems. Air pollution situation in the urban area started deteriorating quickly since the first decade of economic reform in 1980's. Although some improvement appeared during 1990's owing to the reinforcement of pollution control policies, some Chinese cities still have the highest air pollution concentration indicators in the world. 2/3 of Chinese cities fail to meet the air quality standard established by China's Environment Protection Agency (EPA), which signifies that more than ¾ of the urban population are exposed in very polluted air. What is the possible relationship between the rapid openness process and the deterioration of air pollution situation? Should the openness-oriented economic growth path be responsible for China's air pollution situation?

Theoretical analyses explain the trade-pollution relationship in a developing country from different aspects. Grossman (1995) considered emission as a "side-product" of production and expressed it as the results of production scale multiplied with average emission intensity weighted on the output ratio of different sectors in total economy. From this expression he indicated the famous three emission determinants: scale effect, composition effect and technical effect. Copeland and Taylor (2003) indicated the potential endogeneity of all the three emission determinants with respect to international trade. Trade affects production scale. Besides the simple production scale enlargement effect benefiting directly from the demand of world market, some trade-growth analyses further included the positive externality and technology spillover effect of trade in growth function. (Feder, 1983; de Melo and Robinson, 1990 and Rodrigo and Thorbecke, 1997) Trade can also induce industrial composition transformation. According to “pollution haven” hypothesis, developing countries have comparative advantages in polluting sectors, since their relatively lower income level can not support an environmental regulation system as stringent as their rich trade-partners. However, according to traditional international trade theory, developing countries’ rich endowment of cheap labor forces also indicates their comparative advantages in less-polluting labor-intensive industries. Copeland and Taylor (1994) included both aspects in their theoretical analysis and concluded the final industrial composition changes in one country depends on the forces contrast between its traditional comparative advantage reflecting production factor endowment and its “pollution haven” comparative advantage embodied by its environment regulation stringency. Finally, trade can also affect technical effect. In the long run, participating in international trade will encourage domestic producers to update and innovate their production technologies due to intensified competition pressures from world market and facilitate exchanges of advanced technology between countries, both of the two aspects contribute in turn to technological progress in emission abatement activities, therefore make more restrict environmental regulation economically feasible. This impact is quite similar to the proposition of the hypothesis of Porter. (Porter and Linde, 1995; Xepapadeas and Zeeuw, 1998) However, some pessimistic theories anticipate “racing to the bottom” effect of international trade on one country’s environmental regulation strictness by supposing that enhanced world market competition will oblige countries to relax their environment control strictness to maintain domestic competitiveness, which in turn discourages their technical effort on emission abatement.

Given the different theoretical propositions for trade’s impacts in environment, which hypothesis mentioned above corresponds to the actual relation between trade and environment situation in China? How does trade exert its impacts on environment by changing these pollution determinants? What are the direct and indirect channels and their actual impacts on China’s air pollution situation? To answer these questions, we construct a four-equation simultaneous system. In the first equation, the emission is firstly determined by the three economic determinants, scale (economy's production scale), composition (the pollution performance of industrial composition), and technical (environmental abatement efforts) effects and by trade openness degree. The following three equations capture the potential endogeneity of the three pollution determinants with respect to international trade. Through these functions we will be able to obtain the information on the indirect impact of trade on emission going through the three economic determinants. To distinguish the potential different role of export and import in pollution, export and import are separately included into the model. This simultaneous system is then tested by the panel data of 29 Chinese provinces' industrial sulfur dioxide (SO_2) emission from 1993 to 2001, during which both export and import experienced tremendous growth. The time-constant specific effect for each province is captured by fixed effect parameters. To correct potential first-order serial correlation and heteroskedasticity in each estimation function, an instrumentation method inspired by both the GMM-system estimator of Blundell and Bond (1998) and Sevestre and Trognon (1996) for dynamic panel data is used on equation-level. Finally, to employ the full information imparted from the simultaneous system and to avoid inconsistence in estimation caused by the inter-equation residual correlation, we use Generalized Method of Moment (GMM) estimator for simultaneous system to estimate the whole system.

The organization of the paper is the following. In the second section, we give a simple introduction on the actual situation of commercial openness and environment in Chinese provinces. Then we introduce the simultaneous model in the third section. The econometric results are presented and discussed in Section 4. We conclude in Section 5.

2. Current economic growth, industrial SO_2 emission and openness situation in China

China should be considered as a successful case in the developing world, its economic success during the last 27 years (1978-2005) has been remarkable. With an average annual economic growth rate of 9% and over 11.5% in several industrial sectors, China's national economic strength has been largely enhanced. Its per capita GDP at the end of 2003 was 7 times of that at the beginning of the reform in 1978.

China's economic success is generally considered as a result of its rapid industrialisation and openness tendency. When the ratio of primary industry's GDP has undergone important decrease from 28.1% in 1978 to only 14.6% at the end of 2003, the secondary and tertiary industries, on contrary, experienced their unprecedented rapid expansion. The industrialisation and diversification in economic composition significantly reduced the vulnerability of Chinese economy with respect to external shocks. The competitiveness of some Chinese products, especially those whose production processes intensively use labour forces are from now on world widely recognized. The accession to WTO since 2001 further reinforces China's integration process to the world economy. In 2003, her annual total volume of export and import attains 120 times of that in 1979, in which over 90% are manufactured good. At the same time, China is also turning into one of the most attractive destinations for foreign direct investment (FDI) around the world.

Figure 1 summarizes some details in the evolution of China's economic growth, industrialization and openness situation during the 25 years' reform. All the four indicators reported in the figure share an obvious increasing tendency. Another common character between the variation trajectories of the four indicators is the obvious dividing point in year 1992, with the growth tendency in the post-1992 period showing evident acceleration with respect to that in the pre-1992 period. This dividing point corresponds to the milestone of China's economic reform—the beginning of the third stage of China's economic reform, which is characterized by the formalization of the role of market forces in the "socialist economy with Chinese characteristics" in the clarion call of Deng Xiaoping and the start of a major changes in the directions of many economic policies.

Further comparing the evolution of China's total industrial GDP and that of industrial SO_2 since 1991 in Figure 2 shows that, although both variables illustrate increasing tendencies during the period, the increase speed of industrial SO_2 emission is obviously slower than that of industrial GDP.

This actually signifies a decreasing trend in industrial SO_2 emission intensity (emission/GDP), which is shown in the panel b of the figure. Clearly, in China's industrialization process, environmental cost for one unit of product decreases consistently during the time. China actually made obvious progress in its pollution control activities and this improvement tendency still continues today.

What role is trade playing in the determination of the evolution industrial SO_2 emission? Given the continuing rapid increase of international trade flows between China and the rest of the world, what will be trade's impact in China's environment in the future? In the following sections, we try to answer these questions.

3. The links between trade and emission: The system of simultaneous equations

In the first section we discussed the potential endogeneity of the pollution determinants with respect to international trade. In this section we construct a simultaneous system that permits us to include the intermediation of the pollution determinants as the scale, composition and technical effect in to the investigation on trade-emission nexus.

A direct inspiration of the system used in this paper comes from Dean (1998). His model studied the relationship between international trade and industrial wastewater emission in China by a simpler simultaneous system. His model supposes that international trade increases pollution through "pollution haven" effect, but trade also contributes to economy growth, which in turn reduces emission since higher income strengthens public exigency for a better environment.

Following similar reasoning, we construct a 4-equation simultaneous system to capture both direct and indirect impacts of trade on emission situation. A general character often observed in Asian countries' industrialization histories is that they often use foreign exchanges obtained from export to finance their import of machinery and equipments for the development of some strategic heavy industries. If their export growth is stimulated by the demand of the world market seeking for cheapest goods produced by the country with strongest comparative advantages, their import activity is more policy-oriented. Considering the potential characteristics differences between export and import; we include them separately into our system. Agras and Chapman (1999) did the same arrangement in their paper.

$$(1) E_{it} = e(Y_{it}, \Omega_{it}, \tau_{it}, EX_{it}, EM_{it})$$

$$(2) Y_{it} = A_i(EX_{it})^{\varphi}\left[(K_{it} \times EM_{it}^{\psi})^{\alpha} L_{it}^{\beta} \right]$$

$$\text{with } 0<\alpha<1,\ 0<\beta<1,\ EX_{it} = \left(\frac{X_{it}}{GDP_{it}}\right),\ \varphi>0,\ EM_{it} = \left(1+\frac{\Delta KM_{it}}{KM_{it0}}\right),\quad \Delta KM_{it} = \sum_{T=t0}^{t-1} M_{iT},\ KM_{it0} = \sum_{T=0}^{t0} M_{iT},\ \psi>0$$

$$(3) \Omega_{it} = z(EX_{it}, EM_{it})$$

$$(4) \tau_{it} = t(Y_{it}, denpop_{it}, EX_{it}, EM_{it})$$

(i: Indicator for different province, t: Indicator for difference years, $t_0=1992$*)*

With

E_{it}: *emission.*

Y_{it} *: scale effect .*

Ω_{it}: *composition effect .*

τ_{it} *: technical effect .*

$A_i(EX_{it})$: *total factor productivity parameter .*

EX_{it}: *export externality.*

K_{it}: *total capital stock employed in production.*

EM_{it}: *import externality.*

L_{it}: *total labor employed in production.*

X_{it}: *total export.*

GDP_{it}: *total GDP.*

ΔKM_{it}:*variation of stock of imported machinery and equipment since base year* t_0.

M_{it}: *total annual import of machinery and equipments.*

$denpop_{it}$ *: density of population*

KM_{it0}: *stock of imported machinery and equipment in base year* t_0

Equation (1) describes the economic determinants for industrial SO_2 emission. We include scale effect (Y_{it}), composition effect (Ω_{it}) and technical effect (τ_{it}) into this equation. As the model studies the determinants for industrial SO_2 emission, the scale effect is measured by the industrial GDP in each province. Other things kept unchanged, an economy with larger production scale emits more pollution, so we expect a positive coefficient for this term, which means $e_Y > 0.$ Different from a pure composition indicator (capital abundant ratio K/L) that is generally used in international economics to reflect factorial endowment and comparative advantage of an economy, in our model the composition effect (Ω_{it}) is, based on the original pollution decomposition idea of Grossman (1995), to measure the pollution performance of the given economic structure. To capture the evolution of such composition effect, we need to summarize the heterogeneous environmental performance of different industrial sectors in each province. We therefore construct a synthetic indicator $\Omega_{it} = \sum_j \left(\frac{Y_{jit}}{Y_{it}} \times e_{j,0} \right)$. Y_{jit} signifies the detailed value added of the 13 industrial sectors j in each province i and $e_{j,0}$ is the initial national average SO_2 emission intensity for each of the 13 sectors in year 1991.[1,2] Given the same production scale, the industrial composition contains higher percentage of polluting sectors emits more pollution. Therefore, we anticipate a positive coefficient for composition effect, $e_\Omega > 0$. The original technical effect in Grossman (1995) is the average pollution intensity. As higher technical effort leads pollution intensity to reduce; most of the previous studies frequently used environmental regulation stringency as an approximation for this effect. In this paper instead, we directly use the stock of industrial capital employed in pollution abatement activities at the beginning of each year to measure the technical effect. Given the other two determinant factors stay unchanged; we expect higher investment in pollution abatement activities to reduce more emission, which means $e_\tau < 0$. To capture some direct impact on emission, we also include export (EX_{it}) and import (EM_{it}) in this function. Their construction will be explained below.

Besides the direct role of export and import described in the emission determination function, their indirect impacts on emission going through their effect on the scale, composition and technical characteristics of an economy are captured by the equation (2)-(4).

The impacts of international trade on economic scale are captured by a de Melo-Robinson (1990) style production function as equation (2). In this function, both export and import growth can result in production scale enlargement through their positive spillover effect. The externality of export is captured by the term $A_i\times(X_{it}/GDP_{it})^{\varphi}$ with $\varphi>0$, which suggests higher export intensity increases total factor productivity by enhancing the competition pressure faced by domestic producer. The externality of import acts differently. Instead of increasing productivity of capital and labor in an average way as export, the accumulation of imported machinery and equipment $KM_{it}=\sum_{T=1}^{t-1}M_{it}$ is supposed to increase the stock of effective capital K^{e}_{it} in the economy. This idea is expressed as $K^{e}_{it}=K_{it}\times(\frac{KM_{it}}{KM_{it0}})^{\psi}=K_{it}\times(1+\frac{\sum_{T=t0}^{t-1}M_{iT}}{KM_{it0}})^{\psi}$ in the production function (2). KM_{it0} is the initial stock of the imported equipment and machinery in the base year t_0 and $\sum_{T=t0}^{t-1}M_{iT}$ is the accumulation of machinery and equipment imports since the base year t_0. The capital productivity gains from the accumulation of imported technologies are captured by the positive parameter ψ. As $(1+\frac{\sum_{T=t0}^{t-1}M_{iT}}{KM_{it0}})\geq 1$, larger import-related externality elasticity ψ can make the same level of capital stock K_{it} more efficient and this will then contribute in total production growth.

Indirect impact of trade on pollution through composition transformation is captured by composition determination function (3). Antweiler, Copeland and Taylor (2001) believe the impacts of international trade on “pollution performance” of industrial composition depend closely on “pollution haven” based and natural endowment based comparative advantages of an economy. As export of one country is also often determined by its comparative advantage situation, we therefore expect the coefficient of the variable export (EX_{it}) to reveal the force-contrast results between these two aspects’ comparative advantages. We consider a positive coefficient of EX_{it} as an evidence for a larger impact of “pollution haven” hypothesis in comparative advantage determination and a negative coefficient as an evidence for the overwhelming of the impact of factorial endowment. The consideration for the role of import in composition transformation is more complicate. On one hand, import can, as suggested by Copeland and Taylor (2003), facilitate China's industrial structure transformation towards its real comparative advantages by complementing the gaps in consumption goods spectrum after specialization. On the other hand, the accumulation of imported machines and equipments might also be serving the development of certain heavy industries often considered as strategic for industrialization process. Consequently, we cannot determine the sign for EM_{it} at the moment.

The equation (4) describes the determination of technical effect as suggested in the neo-classical theories. (Selden and Song, 1995; Lopèz, 1994) We consider four potential determinants for technical effect. The first is economy growth (Y_{it}), which seizes the increase in pollution control investment encouraged by the increasing public demand and supply capacity for better environment as they getting richer, so we expect $t_y>0$. Given the same income level, higher population density intensifies the marginal damage of pollution, which in turn urges more intensive pollution abatement activity. Therefore, we also include population density into this equation and expect $t_{DENPOP}>0$. The possible impact of export on technical effect can be expected differently according to two different hypotheses. The "racing to bottom" hypothesis supposes the competition pressures from world market may force Chinese government to relax its environmental regulation stringency, which will in turn discourage the investment of the producers in pollution abatement activities, in this case $t_{EX}<0$. However, supplying world market makes it necessary for China's domestic producers to meet stricter international environment norm, which can encourage the investment in pollution abatement activities, so $t_{EX}>0$. As the impact of export on technical effect expected by these two hypotheses tells totally different stories, its final impact on technical effect will be revealed by its estimation coefficient. The impact of machinery and equipment import (EM_{it}) on technical effect is also difficult to predict. On one hand, as imported machinery and equipment generally embody advanced production technologies, their participation in production may reduce the necessity to additionally invest in abatement activities. In this case, we expect a negative coefficient. On the other hand, the accumulation of the import machinery and equipment may also facilitate the investment in advanced foreign equipment and machinery designated for pollution abatement; so we can also expect a positive coefficient for import indicator. Therefore, at present, we can not give a clear prediction on this coefficient.

After total differentiation, we get following new simultaneous system (1*)-(4*).

$$(1^*)\ \frac{\dot{E}_{it}}{E_{it}}=e_y\times\frac{Y_{it}}{E_{it}}\times\frac{\dot{Y}_{it}}{Y_{it}}+e_\tau\times\frac{\tau_{it}}{E_{it}}\times\frac{\dot{\tau}_{it}}{\tau_{it}}+e_\Omega\times\frac{\Omega_{it}}{E_{it}}\times\frac{\dot{\Omega}_{it}}{\Omega_{it}}+e_{EX}\times\frac{EX_{it}}{E_{it}}\times\frac{\dot{EX}_{it}}{EX_{it}}+e_{EM}\times\frac{EM_{it}}{E_{it}}\times\frac{\dot{EM}_{it}}{EM_{it}}$$

$$=\underset{(+)}{\eta_{E,Y}}\times\frac{\dot{Y}_{it}}{Y_{it}}+\underset{(+)}{\eta_{E,\Omega}}\times\frac{\dot{\Omega}_{it}}{\Omega_{it}}+\underset{(-)}{\eta_{E,\tau}}\times\frac{\dot{\tau}_{it}}{\tau_{it}}+\underset{(?)}{\eta_{E,EX}}\times\frac{\dot{EX}_{it}}{EX_{it}}+\underset{(?)}{\eta_{E,EM}}\times\frac{\dot{EM}_{it}}{EM_{it}}$$

$$(2^*)\ \frac{\dot{Y}_{it}}{Y_{it}}=\underset{(+)}{\varphi}\times\frac{\dot{EX}_{it}}{EX_{it}}+\underset{(+)}{\alpha}\times\frac{\dot{K}_{it}}{K_{it}}+\underset{(+)}{\alpha\psi}\times\frac{\dot{EM}_{it}}{EM_{it}}+\underset{(+)}{\beta}\times\frac{\dot{L}_{it}}{L_{it}}$$

$$(3^*)\ \frac{\dot{\Omega}_{it}}{\Omega_{it}}=z_{EX}\times\frac{EX_{it}}{\Omega_{it}}\times\frac{\dot{EX}_{it}}{EX_{it}}+z_{EM}\times\frac{E_{M\,it}}{\Omega_{it}}\times\frac{\dot{EM}_{it}}{EM_{it}}+z_\tau\times\frac{\tau_{it}}{\Omega_{it}}\times\frac{\dot{\tau}_{it}}{\tau_{it}}=\underset{(?)}{\eta_{\Omega,EX}}\times\frac{\dot{EX}_{it}}{EX_{it}}+\underset{(?)}{\eta_{\Omega,EM}}\times\frac{\dot{EM}_{it}}{EM_{it}}$$

$$(4^*)\ \frac{\dot{\tau}_{it}}{\tau_{it}}=t_y\times\frac{Y_{it}}{\tau_{it}}\times\frac{\dot{Y}_{it}}{Y_{it}}+t_{denpop}\times\frac{DENPOP_{it}}{\tau_{it}}\times\frac{\dot{DENPOP}_{it}}{DENPOP_{it}}+t_{EX}\times\frac{EX_{it}}{\tau_{it}}\times\frac{\dot{EX}_{it}}{EX_{it}}+t_{EM}\times\frac{EM_{it}}{\tau_{it}}\times\frac{\dot{EM}_{it}}{EM_{it}}$$

$$=\underset{(+)}{\eta_{\tau,Y}}\times\frac{\dot{Y}_{it}}{Y_{it}}+\underset{(+)}{\eta_{\tau,DENPOP}}\times\frac{\dot{DENPOP}_{it}}{DENPOP_{it}}+\underset{(?)}{\eta_{\tau,EX}}\times\frac{\dot{EX}_{it}}{EX_{it}}+\underset{(?)}{\eta_{\tau,EM}}\times\frac{\dot{EM}_{it}}{EM_{it}}$$

This mathematical adjustment transforms each variable in this simultaneous system into its growth rate. We distinguish four endogenous variables: $\dot{E}_{it}/E_{it}$, $\dot{Y}_{it}/Y_{it}$, $\dot{\Omega}_{it}/\Omega_{it}$ and $\dot{\tau}_{it}/\tau_{it}$ and five exogenous variables: $\dot{K}_{it}/K_{it}$, $\dot{L}_{it}/L_{it}$, $\dot{EX}_{it}/EX_{it}$, $\dot{EM}_{it}/EM_{it}$ and $\dot{DENPOP}_{it}/DENPOP_{it}$ in this system. So the system is identified. From a mathematical point of view, the coefficients estimated from this new simultaneous system are elasticity of dependant variables with respect to its independent variables. Owing to this arrangement, the indirect impact of trade on emission going through the intermediation of the three effects can be directly calculated by multiplying the elasticity of emission with respect to the economic determinant with the elasticity of this determinant with respect to trade variation. Based on the simultaneous system (1*) to (4*), we summarize in equation (5) and (6) the total relationship of export (EX_{it}) and import (EM_{it}) with emission (E_{it}) in the 5 different channels categorized into 4 aspects: direct, scale, technical and composition effects.

$$(5)\ \frac{\partial E}{\partial EX} = \underbrace{\eta_{E,EX}}_{\substack{\text{Direct Effect} \\ (\,?\,)}} + \underbrace{\underset{(+)}{\eta_{E,Y}} \times \underset{(+)}{\phi}}_{\substack{\text{Scale Effect} \\ (+)}} + \underbrace{\underbrace{\underset{(-)}{\eta_{E,\tau}} \times \underset{(+)}{\eta_{\tau,EX}}}_{\substack{\text{Technique} \\ \text{Effect} \\ (?)}} + \underbrace{\underset{(-)}{\eta_{E,\tau}} \times \underset{(+)}{\eta_{\tau,Y}} \times \underset{(+)}{\phi}}_{\substack{\text{Indirect technique} \\ \text{effect related} \\ \text{to economic} \\ \text{growth} \\ (-)}}}_{\substack{\text{Total Technique Effect} \\ (?)}} + \underbrace{\underset{(+)}{\eta_{E,\Omega}} \times \underset{(?)}{\eta_{\Omega,EX}}}_{\substack{\text{Compositio} \\ \text{Effect} \\ (?)}}$$

$$(6)\ \frac{\partial E}{\partial EM} = \underbrace{\eta_{E,EM}}_{\substack{\text{Direct Effect} \\ (?)}} + \underbrace{\underset{(+)}{\eta_{E,Y}} \times \underset{(+)}{\alpha\psi}}_{\substack{\text{Scale Effect} \\ (+)}} + \underbrace{\underbrace{\underset{(-)}{\eta_{E,\tau}} \times \underset{(?)}{\eta_{\tau,EM}}}_{\substack{\text{Technqiue} \\ \text{Effect} \\ (?)}} + \underbrace{\underset{(-)}{\eta_{E,\tau}} \times \underset{(+)}{\eta_{\tau,Y}} \times \underset{(+)}{\alpha\psi}}_{\substack{\text{Indirect technique} \\ \text{effect related} \\ \text{to} \\ \text{economic growth} \\ (-)}}}_{\substack{\text{Total Technique effect} \\ (?)}} + \underbrace{\underset{(+)}{\eta_{E,\Omega}} \times \underset{(?)}{\eta_{\Omega,EM}}}_{\substack{\text{Compositio} \\ \text{Effect} \\ (?)}}$$

For both export and import cases, the first term in equation (5) and (6) signifies respectively the potential direct impact of trade on emission, which will be estimated directly from the estimation function (1*). The scale effect is captured by the second term. It captures the emission increase resulting from the economic growth catalyzed by the positive externality of export and import. The following two terms indicate the two channels through which international trade modifies emission by changing technical effect. The first is the direct link between international trade and technical effect estimated in equation (4*). The second term shows a more indirect links. It reveals the pollution reduction benefiting from the technical effect reinforcement induced by trade-catalyzed economic growth. The last terms in equation (5) and (6) show the composition-related emission changes issuing directly from enlargement of openness degree.

The five trade-emission nexus can be further grouped into direct, first- and second-level indirect channels and illustrated in Figure 3. The direct channel reveals the direct relationship between trade and emission. The three first-level indirect channels reflect the indirect emission variation induced by the direct trade-related changes in the three structural effects. The one second-level indirect channels trace the emission variations resulting from the indirect technical changes induced by trade-led economic growth. To calculate the total impact of trade on emission, we only need to add all these different aspects together. We use gray-color cases to indicate all trade-related emission variations impacts in Figure 3.

4. Econometric analysis

4.1 Data choice

We use China's provincial level panel data on industrial emission during 1993-2001 to carry out our analysis. We generally believe China's unified statistical system promises for our empirical study comparable and credible provincial-level economy and pollution data. The ever-increasing regional disparity between provinces in both pollution and economic situation can also guarantee in certain sense the efficiency of our empirical analysis. Given the most important increase in both export and import in China happened after 1992, focusing our analysis in the period of 1993-2001 will allow us to study principal influence of trade on both economic and pollution situation. Finally, the reason for us to concentrate only on industrial emission is due to the fact that the rapid expansion of industrial sector is the engine for economic development and the most principal source of its air pollution problems.

As already mentioned in the last section, corresponding to the environmental indicator, the three emission determinants are also measured in the scale of industrial sector. We use real industrial GDP to measure the scale effect and the total capital stock employed in air pollution abatement activity to directly measure the current pollution abatement technical effort in each province. The composition effect is measured by a synthetic indicator $\Omega_{it} = \sum_{j} \left(\frac{Y_{jit}}{Y_{it}} \times e_{j,0} \right)$, whose construction requires the detailed information about the structural and emission characteristic of each province.[3] Using this synthetic composition indicator instead of the frequently used capital abundance measured by the capital to labor ratio (K/L) as in Copeland and Taylor (1994), Antweiler et al. (2001), Cole et al. (2003) and Cole (2004) is based on the following consideration. Firstly, the simultaneous system used in this paper requires composition effect to be endogenous variable but the production factor capital and labor to be exogenous ones. Using capital abundance (K/L) to measure composition effect obviously does not meet this exigency. In addition, the underlying fundamental hypothesis that enables us to use K/L ratio as composition effect measurement is the presumption that pollution intensive sectors are generally more capital-intensive. However, both Dinda et al (2000) and He (2005) indicated the potential ambiguity of this presumption, since some "capital intensive sectors could also be more clean technology owner" (Dinda et al, 2000). The synthetic indicator constructed on the detailed structural and emission characters can help us to avoid this ambiguity.

Concerning the data choices for the 5 exogenous variables, the production factor as capital and labor are measured respectively by capital stock of 1990 constant price and number of labor employed in industry. Population density is calculated by dividing provincial population with provincial surface. As the detailed data on provincial level industrial goods export are not available, the export (EX_{it}) is measured by the ratio of annual total export flow to total GDP in each province. The variable import (EM_{it}) is measured slightly different from that defined in de Melo and Robinson (1990). In this paper we use the ratio of the stock of imported manufactured goods in each province to its base value in 1992 to measure it. [4,5]

Table 1 supplies the detailed statistical description for the data used in this model. All the variables are actually included into the estimation in their growth rate form except $\dot{F}_{it}/Y_{it}$ according to the function transformation result.

(Please insert table 1 about here)

4.2 Empirical method

Based on a simultaneous model and provincial level panel data, our empirical analysis needs to take care of three aspects’ estimation biases. The first and second come from the dynamic panel data characteristics of our database. On one hand, to capture the time-invariable specific effect, we need to employ fixed effect estimator for each province. On the other hand, we also need to take care of the potential serial correlation inside of each province. Both considerations require us to employ dynamic GMM estimator proposed by Blundell and Bond (1998) for each equation.

This is a new development from Anderson and Hsiao (1982) and Arellano and Bond (1991). This method proposes to include to the right-hand side of each function the one-period lagged dependant variable to remove the first-order serial correlation in the residuals. At the same time, to deal with the time-invariable fixed effect, it uses first-difference transformation as suggested by Arellano and Bond (1991). Therefore the actual estimation function form for each equation becomes $y_{it}-y_{i,t-1}=\rho(y_{i,t-1}-y_{i,t-2})+(x'_{it}-x'_{i,t-1})\beta+(\varepsilon_{it}-\varepsilon_{i,t-1})$, where y_{it} signifies the dependant variable and x_{it} indicates the vector of independent variables. ε_{it} is the residual. While the serial-correlation and fixed effect are both cancelled out in this new estimation function, the difference of the lagged endogenous variable $(y_{i,t-1}-y_{i,t-2})$ is obviously correlated with the error term $(\varepsilon_{it}-\varepsilon_{i,t-1})$, since $y_{i,t-1}-y_{i,t-2}=\rho(y_{i,t-2}-y_{i,t-3})+(x'_{i,t-1}-x'_{i,t-2})\beta+(\varepsilon_{i,t-1}-\varepsilon_{i,t-2})$. So $E(dy_{i,t-1}d\varepsilon_{it})\neq 0$, the estimator will be biased. Arellano and Bond (1991) suggests to use all the available additional moments restrictions to enlarges the set of instruments, which means the instruments for the lagged endogenous variables $(y_{i,t-1}-y_{i,t-2})$ is enlarged to $y_{i,t-2}$, $y_{i,t-3}$, $y_{i,t-4}$,…, y_{i1}.

The principal development of Blundell and Bond (1998) compared to Arellano and Bond (1991) is their new innovation in the instrumentation method and its suggestions to further make use of the additional level information. “This combination of the moment restrictions for differences and levels results in the so-called GMM-system-estimator by Arellano and Bond”.(Behr, 2003) Concretizing to the estimation functions in this paper, this estimation method means for each of the four equations, we use both first-difference and level function form in estimation by confining the coefficient for the same variable to be the same in both functions. The lagged endogenous variable $(y_{i,t-1}-y_{i,t-2})$ in first difference function will be instrumented by the level moment $y_{i,t-2}, y_{i,t-3},\ldots,y_{i,2}, y_{i,1}$ and the lagged endogenous variable $y_{i,t-1}$ will be instrumented by difference moments $(y_{i,t-2}-y_{i,t-3}), (y_{i,t-3}-y_{i,t-4}),\ldots, (y_{i,2}-y_{i,1})$.

The preoccupation for the third bias is related to the simultaneous system. Facing the intercorrelation between the endogenous variables in this system, we suspect the existence of correlation between the residuals of different functions, which means $cov(\varepsilon i,\varepsilon j)\neq 0$, $i\neq j$, i and j indicate different equations in the system. The existence of this correlation can make the separate single-equation estimation results biased. Therefore, we need to use the traditional Generalized Method of Moment (GMM) estimator for simultaneous system, which controls the covariance matrix of the four residuals of the system as a whole by instrumenting all the endogenous variables by all the exogenous variables available in the system.

However, there does not exist an already-made econometrical package that combines the traditional GMM estimator for simultaneous system with the Blundell-Bond GMM-system estimator for dynamic panel data. Luckily, the instrumentation method developed by Balestra and Nerlove (1966) and Sevestre and Trognon (1996) indicate a compatible way to combine the Blundell-Bond-style instrumentation step with the traditional GMM estimator.

The concrete estimation is actually carried out in two steps. In the first step, following Sevestre and Trognon (1996), we separately instrument each of the four lagged dependant variables of the simultaneous system, in both the level and first difference terms, year by year, on cross-province level, by all of its available moments of instruments. In the second step, we included the instrumented lagged dependent variables as exogenous variables into their corresponding estimation functions to carry out the GMM estimation for simultaneous system, where the system endogenous variables are then instrumented by all the exogenous variable of the system. In practice, we actually estimate both the first difference and level functions for each of the four equations by restricting the coefficients for the corresponding variables to be the same in both functions.

4.3 Estimation results for the simultaneous equation system

Table 2 gives the system estimation results. The overall fit of the system is satisfactory. Most coefficients show expected signs and high significance. The specification test of Hausman (1978) proves the orthogonality conditions of the instruments used for the lagged endogenous variables on equation-level are respected. The J-statistic also proves the efficiency of the instrumentation used for the whole system. Adding the lagged dependant variables to the right side of the equation also successfully removes the first-order serial correlation problem in most equations. The tiny inter-equation residual covariance shows the high efficiency of the GMM estimator for the simultaneous system. For the purpose of comparison, we also regress the simultaneous system by 3SLS (Three-Stage Least Square) estimator. The results shows most of the coefficients are not affected by the changes of estimation method, but those obtained by GMM shows obviously better convergence efficiency. Therefore we only comment the results obtained by GMM estimator that reported in the right part of Table 2.

The first column illustrates the estimation results for the economic determination of SO_2 emission. The signs and the significance of all the three economic determinants for industrial SO_2 emission confirm the theoretical anticipation of Grossman decomposition (1995). The attempt to separately detect the impacts of import and export on emission already shows its efficiency. In the direct emission determination function, we find significant but opposite signs for export and import.

Export seems to exert direct deterioration impact on emission. Estimation result shows if the annual export ratio to GDP increases by 1%, the total emission will increase by 0.115%. On contrary, the acceleration in imported manufactured goods accumulation seems to be an environment-friendly factor, 1% increase in its accumulation with respect to the base value of year 1992 leads industrial SO_2 emission to reduce by 0.395%.

The estimation result for production function confirms the positive externality for both export and import. The parameter for export externality in total factor productivity φ is found to be 0.021. While the parameter for import externality ψ is approach to 0.143.[6] Compared to the export and import externality elasticity (generally supposed to be equal to 0.1) that were used in several related CGE studies on Asian countries' case as de Melo and Robinson (1990) for South Korea and Rodrigo and Thorbecke (1996) for Indonesia, the import externality elasticity estimated from China's industrial economy shows good coherence, but the estimated export externality seems to be lower.

The negative coefficient before the export variable in composition equation confirms the domination role of factor endowment comparative advantages in the composition determination impact of export. With 1% of increase in export/GDP ratio, the pollution performance of the composition effect improves by 0.083%. We equally find a significantly positive coefficient for import. Based on the discussed in the section 3, we regard this as evidence supporting the fact that import is actually serving for China's industrialization strategy.

The last column of Table 2 shows the potential determinants for China's technical effect. As we anticipated, the stronger pollution control effort is positively correlated to economic growth and population density increase. 1% of increase in the industrial production growth rate leads to a 0.609%'s increase in the strength of pollution control and 1%'s increase in population density also urges the technical effect to rise by 0.257%. Come to the trade's impact on technical effect, only export shows a significantly positive coefficient 0.044. This finding confirms the hypothesis that facing the external competition is a positive factor for environment, since it encourages the producers to invest in pollution abatement activities. However, we do not find a significant coefficient for import.

Figure 4 concretize Figure 3 by using the estimated coefficients in Table 2.[7] Though both playing positive roles in production scale enlargement, export and import exert very different impact through composition and technical effect. Their final environmental impacts are completely opposite. With 1%'s increase in export/GDP ratio, the total percentage change in industrial SO_2 emission realized by all the 5 channels is a negative number, -0.076%, while the overall SO_2 emission variation resulting from 1%'s increase in imported manufactured goods accumulation is 0.075%. From Figure 3 we also see that, the total emission reduction impact issuing from export is actually owing to the domination of emission reduction result contributed by technical and composition effects. For import, its environment-unfriendly role should be explained by the emission-increasing impact intermediated by scale and composition effects.

5. Conclusion

Recognizing the potential endogeneity of the three economic determinants of industrial SO_2 emission with respect to international trade and the underlying interaction between them, in this paper, we constructed a simultaneous system. In this system, the impacts of trade on emission are captured in a structural way. On the first level, the system permits us to capture the direct impact of trade on emission through an emission determination function. Following, the indirect impact of trade on emission through its intervention in production scale changes, industrial composition transformation and evolution of pollution control efforts is captured separately in the determination function of the three effects. Furthermore, this system also offers us the possibility to study the further indirect impact of trade on environment through the interaction between the three effects. Owing to this system, we succeed in constructing a more structural and detailed story about how export and import affect the environment.

Our estimation result firstly revealed the direct impact of export and import on emission, which are in opposite directions. We found a direct emission increasing role for export but an emission-decreasing role for import. These direct impacts of international trade are then cancelled/strengthened by the indirect impact of trade exerting through the three structural determinants of emission. First of all, our results confirmed the existence of the “spillover” effect of international trade on economic growth. Concerning composition effect, we did not find the “pollution haven” evidence for the commercial openness case of China. The pollution-increasing tendency revealed from China’s industrial composition transformation seems to be caused by the import of equipment and machinery to facilitate the development of some strategic heavy industries. Participation in the international production division system, by guiding Chinese economy to specialize in less polluting labor-intensive sectors where its comparative advantages reside, actually helps China to alleviate the potential pollution increase that her strategic industrial development process presumes. Concerning the technical effect, we did not find supportive proof for “racing to the bottom” hypothesis. Facing the intensified competition from world market and benefiting from the facilitated technology import process, China’s technical effort in pollution abatement is actually reinforced.

Combining these direct and indirect impacts of trade on environment together, the final conclusion of this paper shows the total impact of international trade on China’s industrial SO_2 emission is relatively small. We found totally opposite role of export and import on industrial SO_2 emission determination. With 1%’s increase in export intensity to total GDP, the industrial SO_2 will *reduce* by 0.076%, while if imported manufactured goods stock increases by 1%, the industrial SO_2 will on contrary *increase* by 0.075%.

Reference

Agras, J. and Chapman, D. (1999), 'A dynamic approach to the Environmental Kuznets Curve hypothesis'. Ecological Economics 28(2), 267-277.

Anderson, T. and Hsiao, C. (1982), 'Formulation and estimation of dynamic models using panel data', Journal of Econometrics 18, 67-82.

Antweiler, W., Copeland, B. R. and Taylor, M.S. (2001), 'Is Free Trade Good for The Environment?', American Economic Review, 91(4), 877-908.

Arellano, M. and Bond, S.R. (1991), 'Some Tests of Specification for panel Data: Monte Carlo Evidence and an Application to Employment Equations', Review of Economics Studies. 58, 277-297.

Balestra, P. and Nerlove, M. (1966), 'Pooling Cross-Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas', Econometrica, 34, 585-612.

Baltagi, B.H. (1995), Econometric Analysis of Panel Data, Wiley and Sons, Ltd, West Sussex, England, 304pp.

Behr, A. (2003), 'A Comparison of Dynamic Panel Data Estimators: Monte Carlo Evidence and an Application to the Investment Function'. Discussion paper 05/03. Economic Research Centre of the Deutsche Bundesbank.

Blundell, R. and Bond, S.R. (1998), 'Initial Conditions and Moment Restrictions in Dynamic Panel Data Models', Journal of Econometrics, 87, 115-143.

Cao, D., Yang, J. and Ge, C. (1999), 'SO_2 Charges and Taxation Policies in China: Experiments and Reforms', in OECD, eds., Environmental Taxes: Recent Developments in China in OECD Countries, OECD, Paris, pp233-257.

Cole, M.A. (2004), 'Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages', Ecological Economics, 48(1), 71-81.

Cole. M.A. and Elliott, R. J. R. (2003), 'Determining the trade–environment composition effect: the role of capital, labor and environmental regulations', Journal of Environmental Economics and Management, 46(3), 363-383.

Copeland, B. and Taylor, M. S. (1994), 'North-South Trade and the Environment', The Quarterly Journal of Economics, 109(3), 755-787.

Copeland, B.R. and Taylor, M.S. (2003), Trade and the Environment: Theory and Evidence, Princeton and Oxford: Princeton University Press.

De Melo, J., and Robinson, S. (1990), 'Productivity and Externalities: Models of Export-led Growth', Memo. 90.10, University of Geneva, Geneva.

Dean, J. M. (1998), 'Testing the Impact of Trade Liberalisation on the Environment : theory and evidence', in Fredriksson, P. G. ed., Trade, Global Policy, and the Environment, Chapitre 4, pp.55-63.

Dinda, S., Coondoo, D. et Pal, M. (2000). Air Quality and Economic Growth: An Empirical Study. *Ecological Economics* 34, 409-423.

Feder, G. (1983), 'On exports and economic growth', Journal of Development Economics, 12(1-2), 59-73.

Grossman, G. (1995), 'Pollution and growth: What do we know?', in Goldin and Winter eds., The Economics of Sustainable Development, Cambridge University Press.

Hausman, J. (1978), 'Specification Tests in Econometrics', Econometrica, 46, 1251-1271.

He, J. (2005). Impacts environnementaux de l'industrialisation et du commerce international en Chine : cas de l'émission industrielle de SO_2. Thèse en doctorat, CERDI/Université d'Auvergne, Clermont-Ferrand, France. 310pp.

Lopez, R. (1994), 'The Environment as a Factor of production: The Effects of Economic Growth and Trade Liberalisation', Journal of Environmental Economics and Management, 27, 163-184.

Porter, M.E. and van der Linde, C. (1995). 'Toward A New Conception of the Environment-Competitiveness Relationship', Journal of Economic Perspective, 9, 97-118.

Rogrigo, G. C., and Thorbecke, E. (1997), 'Sources of Growth: A Reconsideration and General Equilibrium Application to Indonesia', World Development, 25(10), 1609-1625.

Selden T. M. and Song, D. (1994), 'Environmental Quality and Development: Is there a Kuznets Curve for Air Pollution Emission?', Journal of Environmental Economics and Management, 27, 147-162.

Sevestre, P. and Trognon, A. (1996), 'Dynamic Linear Models'. in L. Matyas and P. Sevestre eds., The Econometrics of Panel Data, Chapter 7, Kluwer Academic Publishers.

Xepapadeas, A. and de Zeeuw, A. (1999). 'Environmental Policy and Competitiveness: The Porter Hypothesis and the Composition of Capital'. Journal of Environmental Economics and Management, 37, 165-182.

Appendix 1 A detailed introduction on the synthetic composition indicator

The original idea for the construction of this synthetic composition indicator is due to the unsatisfactory estimation results of the composition indicator—(K/L), the capital abundance ratio in industrial sector. We believe an efficient composition measurement must include both the detailed production structure and the emission performance of each industrial sector that actually exist in industrial economy.

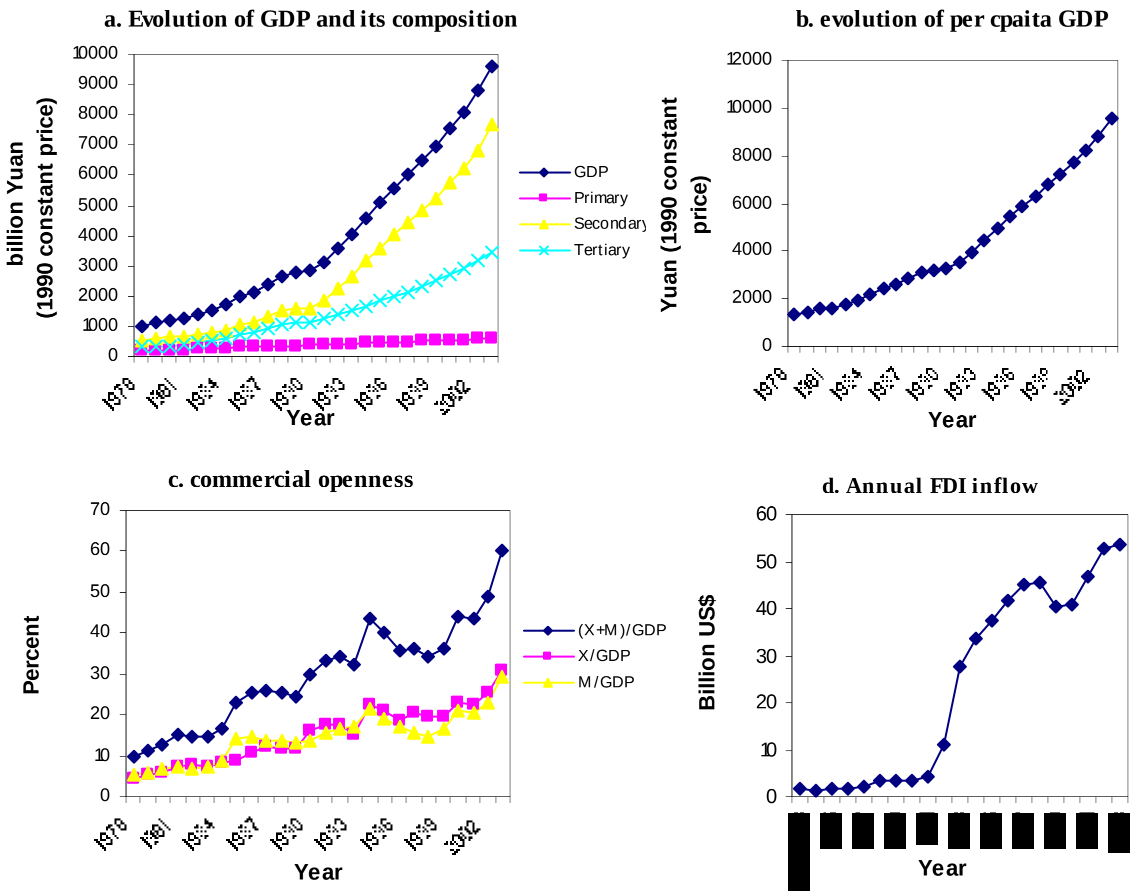
Inspired by the Grossman (1995), the

$$SO2_{it} = \underbrace{Y_{it}}_{scale} \times \underbrace{\sum_{j} \left(\frac{Y_{j,it}}{Y_{it}} \times e_{j,it} \right)}_{Composition} \times \underbrace{\frac{SO2_{,it}}{Y_{it}}}_{Technique}$$

where $e_{j,it}$ is the emission efficiency indicator for each sector *j* of province *i*, we define the synthetic composition indicator by fixing the emission efficiency indicator $e_{j,it}$ to equal to the I_{j0}—the national level average emission intensity of each industrial sector j at base year 1990, so $e_{j,it}=I_{j,1990}$. Therefore, for a province i in each t, we can construct an indicator as $\Omega_{it}= \sum_{j} \frac{Y_{j,it}}{Y_{it}} \times I_{j,1990}$. In this indicator, as the sector-specific emission intensity is fixed at the initial level, for each province, its variations during the time actually reveal the changes of the ratio of the different industrial sectors. Therefore, when the ratio of a relatively more polluting sector experiences an increase during period t, we can expect an increase in this indicator, so $\Omega_{it}>\Omega_{i0}$. Therefore, we use this indicator as a synthetic composition index.

Figure 1 Evolution of some major macroeconomic indicators

(Source: China Statistic Yearbook, various years)



a. Evolution of GDP and its composition

b. evolution of per cpaita GDP

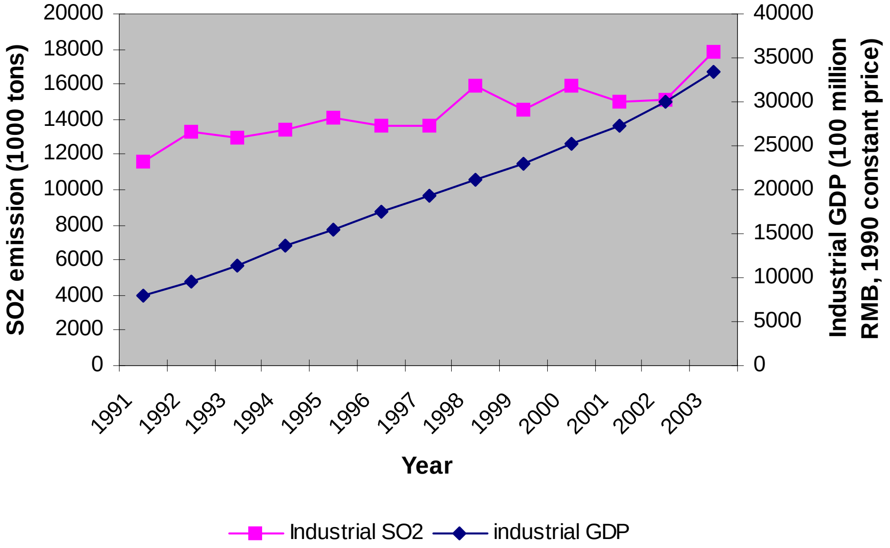
c. commercial openness

d. Annual FDI inflow

Figure 2 Evolution of real industrial GDP and industrial SO_2

(Data source: China Statistical Yearbook and China Environment Yearbook, various years)

a. Industrial GDP vs. industrial SO2 emission



b.SO2 emission intensity

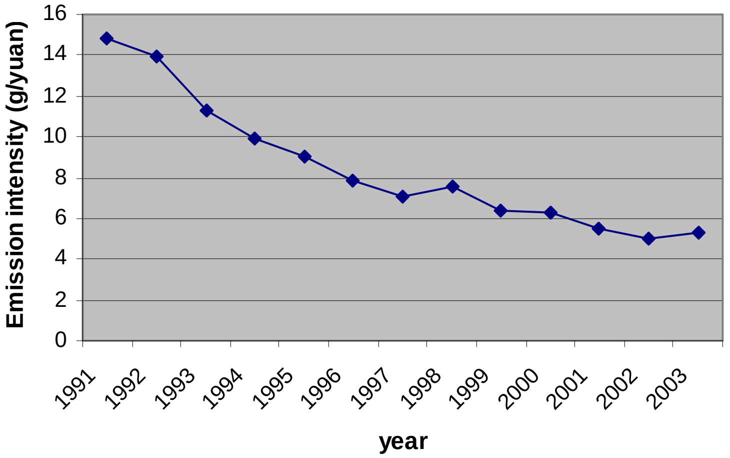


Figure 3 Illustration of the different Channels of trade's impact on pollution

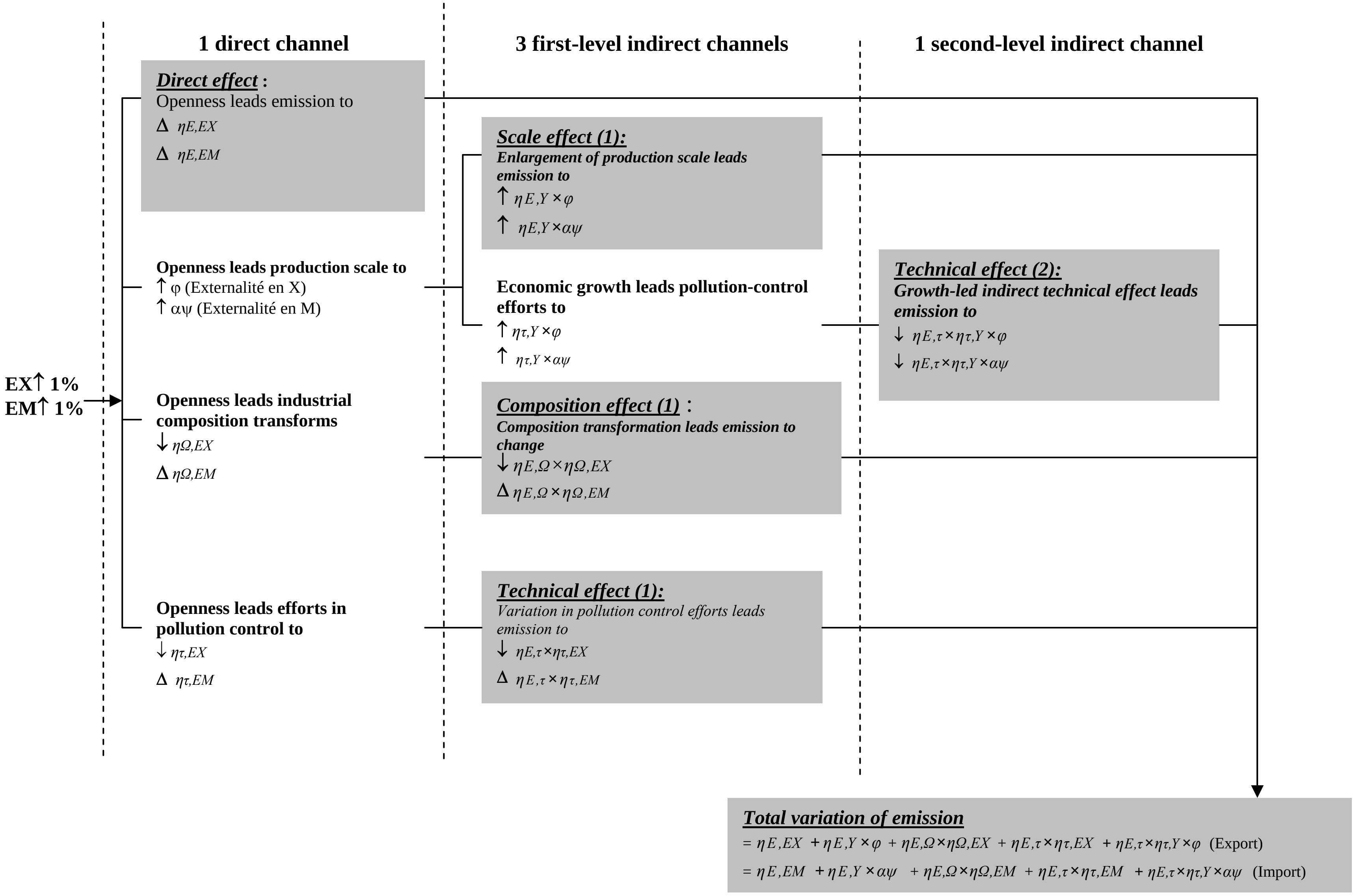


Figure 4. Différents canaux de transmission du commerce sur la pollution

(Based on estimation results of Table 2 GMM Dynamic estimator)

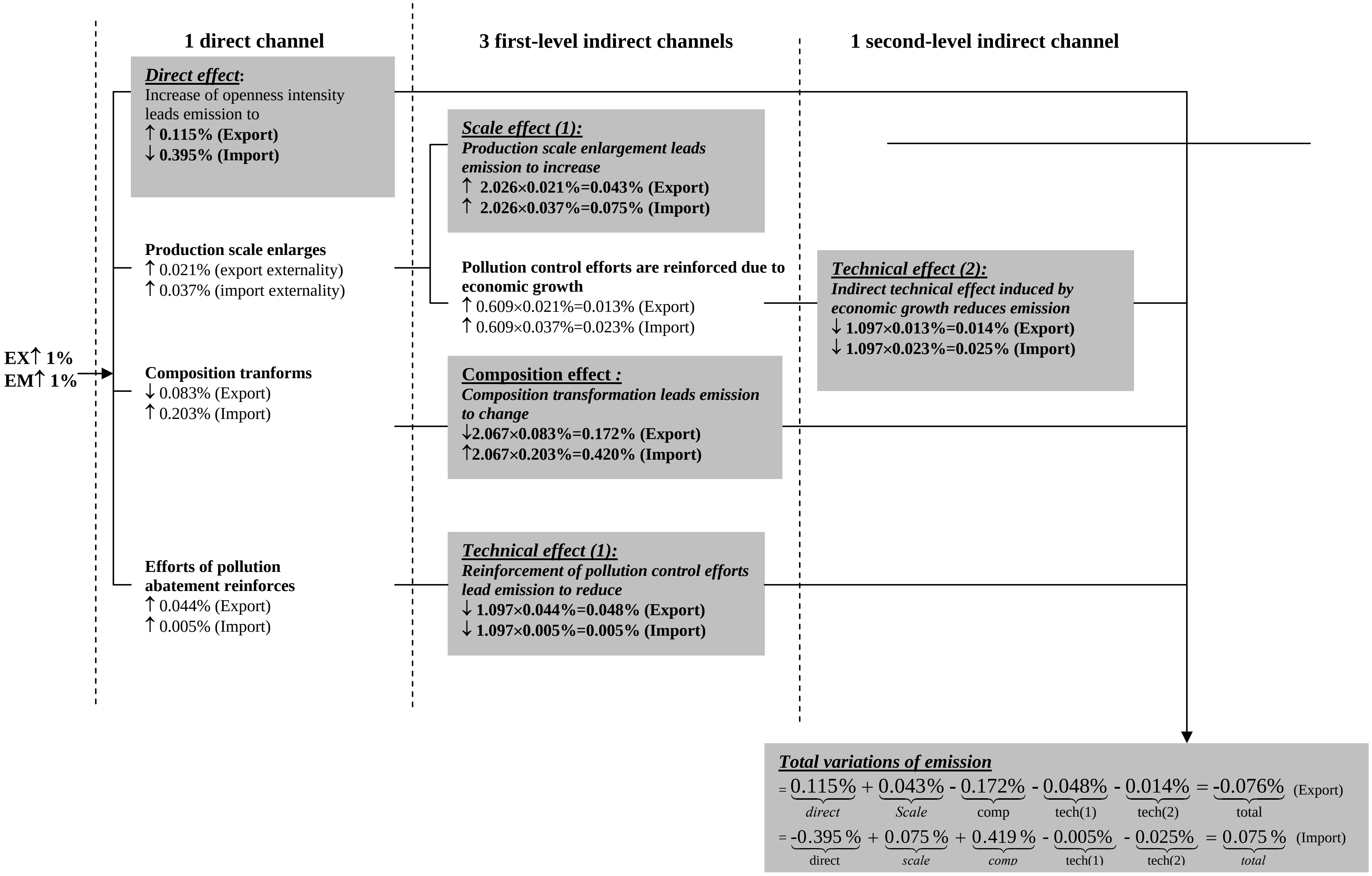


Table 1 Statistical description of the data

Variables	Corresponding Data	Obs.	Ave.	Sta. Dev.	Min.	Max.
Endogenous Variables (in level)						
E	Annual industrial SO_2 emission, 1000 tons	261	494.49	363.01	16.68	1760.06
Y	Real industrial GDP, 10^9 Yuan, 1990 price	261	70.10	65.90	2.72	353.00
Ω	Synthetic industrial composition indicator	261	24.27	5.53	13.02	44.25
τ	Average levy rate on industrial SO_2 emission	261	0.059	0.039	0.011	0.247
Endogenous Variables (in growth ratio)						
$\dot{E}/E$		232	0.025	0.155	-0.337	0.688
$\dot{Y}/Y$		232	0.120	0.047	-0.059	0.344
$\dot{\Omega}/\Omega$		232	0.041	0.128	-0.254	0.705
$\dot{\tau}/\tau$		232	0.095	0.666	-0.849	8.077
Exogenous Variables (in level)						
K	Industrial Capital stock, 10^9 Yuan, 1990 price	261	128.000	125.000	12.200	776.000
L	Staffs and workers employed in industrial sector	261	344.68	249.78	19.60	1002.00
EX	Export intensity with respect to total GDP (X/GDP)	261	8.77	15.51	0.21	96.13
EM	Ratio of stock of imported manufacturing good to its base year value (KM_t/KM_{1992})	261	5.847	4.326	1.158	30.279
$denpop$	Population density per km^2	261	357.04	421.29	5.99	2700.20
Exogenous Variables (in growth ratio)						
$\dot{K}/K$		232	0.042	0.041	-0.034	0.176
$\dot{L}/L$		232	-0.022	0.065	-0.300	0.127
$\dot{EX}/EX$		232	0.090	0.282	-0.461	1.369
$\dot{EM}/EM$		232	0.284	0.177	0.057	1.309
$\dot{denpop}/denpop$		232	0.012	0.024	-0.099	0.189

(1) Due to lack of data, Tibet is excluded from the sample; all the other provinces have 9 observations (1993-2001).

(2) The total industrial capital stock is calculated by the permanent inventory method by using real value of fixed investment data (on the constant price of 1990) of each province in each year deflated by the corresponding fixed investment price index. More details about the permanent inventory method are in Wu (1999).

(3) The capital stock used in industrial air pollution treatment is calculated from simple accumulation of the real value of the investment in industrial air pollution treatment (on constant price of year 1990) deflated by fixed investment price index. Data source: China Environment Yearbook (1987-1997), China Environmental Statistic Yearbook (1998-2002).

(4) The export data is on the total provincial economy level instead of industrial sector level. Given what we interested in the externality of export and its impact on pollution through the pollution determinants, we do not think to use the corresponding industrial level data will be necessary for the objective of this paper.

(5) The provincial level annual imported manufactured goods stock is compiled by author according to the provincial level statistical report in Almanac of China's Foreign Economic Relationship and Trade (1984-2001).

(6) The construction of the composition effect is based on detailed industrial sectors' statistics provided in Chinese Industrial Economic Statistics Yearbook from 1985 till 2002.

(7) The other data comes from China Statistic Yearbook (1985-2004).

Table 2 Estimation results on the simultaneous model (Fixed effect, 29 provinces over 10 years (1994-2003), 203 observations due to first difference)

Variables	**3SLS**				**Dynamic GMM applied on simultaneous system**			
		Scale effect	**Composition effect**	**Technical effect**		**Scale effect**	**Composition effect**	**Technical effect**
	$\dot{E}_{it}/E_{it}$	$\dot{Y}_{it}/Y_{it}$	$\dot{\Omega}_{it}/\Omega_{it}$	$\dot{\tau}_{it}/\tau_{it}$	$\dot{E}_{it}/E_{it}$	$\dot{Y}_{it}/Y_{it}$	$\dot{\Omega}_{it}/\Omega_{it}$	$\dot{\tau}_{it}/\tau_{it}$
Lagged $\dot{E}_{it}/E_{it}$	-0.182***				-0.435***			
	(2.993)				(6.427)			
Lagged $\dot{Y}_{it}/Y_{it}$		0.655***				0.711***		
		(19.555)				(19.279)		
Lagged $\dot{\Omega}_{it}/\Omega_{it}$			-0.073**				-0.236***	
			(2.016)				(4.162)	
Lagged $\dot{\tau}_{it}/\tau_{it}$				0.718***				0.484***
				(10.306)				(7.010)
$\dot{Y}_{it}/Y_{it}$	2.303***			0.379***	2.026***			0.609***
	(2.755)			(3.576)	(2.654)			(8.376)
$\dot{\Omega}_{it}/\Omega_{it}$	2.580***				2.067***			
	(5.373)				(4.502)			
$\dot{\tau}_{it}/\tau_{it}$	-1.012**				-1.097**			
	(1.978)				(2.313)			
$\dot{K}_{it}/K_{it}$		0.272***				0.258***		
		(5.806)				(6.139)		
$\dot{L}_{it}/L_{it}$		-0.040°				0.021		
		(1.566)				(1.112)		
$\dot{EX}_{it}/EX_{it}$	0.129**	0.026***	-0.038°	0.057****	0.115**	0.021***	-0.083***	0.044***
	(2.495)	(3.459)	(1.437)	(4.642)	(2.575)	(3.462)	(3.571)	(2.662)
$\dot{EM}_{it}/EM_{it}$	-0.704***	0.029**	0.205***	-0.023	-0.395***	0.037***	0.203***	0.005
	(4.453)	(2.296)	(9.441)	(1.108)	(2.575)	(2.715)	(8.376)	(0.310)
$\dot{denpop}_{it}/denpop_{it}$				0.362***				0.257***
				(3.603)				(3.760)
Hausman	17.99	25.71	11.36	4.94	17.99	25.71	11.36	4.94
(first difference)	(0.006)	(0.000)	(0.010)	(0.432)	(0.006)	(0.000)	(0.010)	(0.432)
Hausman	9.46	6.84	6.16	0.31	9.46	6.84	6.16	0.31
(level)	(0.149)	(0.233)	(0.104)	(0.997)	(0.149)	(0.233)	(0.104)	(0.997)
Autocorrelation ($\hat{\rho}$)	-0.577***	-0.559***	-0.498***	-0.219***	-0.541***	-0.555***	-0.419***	-0.178***
	(9.11)	(10.52)	(8.21)	(2.94)	(8.35)	(10.12)	(6.54)	(2.53)
J-statistic	--				0.612			
Covariance residual	1.36×10^{-18}				2.78×10^{-18}			

Notes : (1) *** indicates the significance of 99%, ** indicates the significance of 95% and * means significance of 90%. (2) As the fixed effect of each province is removed by the first-difference transformation and the serial correlation between the observations for the same province is also controlled by the inclusion of instrumented lagged dependant variables to the right-hand side of the equations, the simultaneous system in this paper is estimated by the cross-section GMM estimator for system of equations, the heteroskedasticity is corrected by the White's heteroskedasticity consistent covariance matrix. (3) The equation-level identification test is the Hausman test, which verifies the validity of the instruments used for the lagged dependant variables. (4) Autocorrelation test is from Woodridge (2002), P282-283. It is a simple test for potential serial correlation problem in first-difference fixed effect estimation based on the simple regression on T-2 time periods of the following equation: $\hat{e}_{it} = \hat{\rho}\hat{e}_{i,t\text{-}1} + error_{it}$, t=3,4,…,T; i=1,2,…,N. When the value of the coefficient $\hat{\rho}$ approaches to –0.5, it will warrant computing the robust variance matrix for the first-difference estimator. (5) The J-statistic serves to verify the validity of all the instruments used in simultaneous system GMM estimator. Multiplying the J-statistic with observation number 126.27=0.622×203 derives an approximation for Chi-2 value, which can then be used in Sargan test statistic. Given the number of the instruments used in this system counts up to 236 (the instruments for lagged dependant variables are also included), the probability for this Chi-2 value to be smaller than the critical value 183.79 is 1.

Note

---

[1] The 13 industrial sectors are total mining industry, food and beverage, textile, paper, total power industry, chemical materials, pharmacy, fiber, non-metal products, metal processing and smelting, metal products, machinery and the other industry (source of data: China Industrial Economic Statistic Yearbook, 1989-2002)

[2] Keller and Levinson (2002) also use the same expression to measure industry composition for each state in order to adjust the measurement for the state-level pollution abatement costs. A more detailed introduction about this synthetic composition indicator is given in appendix 1.

[3] As the sum of value added of the 13 industrial sectors included into the construction of the indicator generally covers up to 98% of the total provincial-level industrial GDP each year, we are quite confident in the capability of this synthetic indicator in reflecting the general environmental performance of the whole industrial composition.

[4] Due to data unavailability, we use the stock of imported manufacture goods as an approximation for the stock of imported equipment and machinery goods. This data series is compiled by the author according to the provincial level statistical report in *Almanac of China's Foreign Economic Relationship and Trade* (1984-2001). We consider the stock of imported manufacture goods as a good approximation of the stock of imported equipments and machinery due to two reasons. Firstly, many of the imported manufacture goods in China are desalinated to re-export after being assembled. This type of imports is obviously helpful in increasing the productivity of Chinese industries. Secondly, the manufactured goods importation and the equipment and machinery importation data on the national level data are available since 1985, comparing these two series of data shows that the imports of the equipment and machinery always occupied a very important and table percentage in total manufacture good import (over 50%). A simple correlation test between these two series also reveals very strong correlation between these two data series by a coefficient of 0.9985.

[5] The reason to choose 1992 as base year is principally due to the fact that China’s foreign trade policies and administrative system experienced big reforms since this year. The accumulation of the imported manufacturing can be tracked back till 1980.

[6] The parameter for the externality of import can not be obtained directly from the estimation results, actually the coefficient before the import term is actually $\alpha\psi$. So $\psi=\alpha\psi/\alpha=0.029/0.272=0.107$.

[7] For the purpose of comparison, we equally illustrate the result of the GMM method in Table 3 in appendix Figure A. The impacts of the total role of export and import on environment seem to be rather stable, though certain changes in the transmission channels and the strength of certain effects can be observed between them.