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**Environmental impacts of international trade:
the case of industrial emission of Sulfur Dioxide (SO₂)
in Chinese provinces**

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Summary

The economic reform since 1978 has induced rapid integration procedure of Chinese economy into world market. However, China's openness and economic growth success seemed to be accompanied by obvious pollution problem. What is the possible relationship between rapid openness process and deterioration of air pollution situation? Should international trade growth be responsible for China's air pollution situation?

In order to get a better understanding on the environmental impacts of international trade in China, we construct a four-equation simultaneous system. In this system, emission is firstly supposed to be determined by the three famous economic determinants: scale effect (economy's production scale), composition effect (industrial composition) and technical effect (environmental regulation stringency) and directly by trade. Following, by supposing all the three economic determinants are endogenous with respect to international trade, we further check in the other three functions the possible indirect channels through which international trade exerts influences on emission by changing the three emission determinants. As a general characteristics in Asian countries' industrialization history is they often use foreign exchange obtained from export expansion owing to their actual comparative advantage to finance the import of machinery and equipment embodied advanced technologies to support the development of some strategic heavy industries. To distinguish the potential difference in the roles of export and import in the variations of the three emission determinants and in final emission situation changes, we include them separately in the system.

The system is then estimated by the panel data on industrial SO₂ emission in 29 Chinese provinces during 1993-2001, the period during which China experienced tremendous trade growth. Summarizing the force-contrast between the direct and indirect effects of trade on emission going through the intermediation of the three economic determinants, our estimation result reveals totally different overall role of export expansion and accumulation of manufactured goods import in industrial SO₂ emission determination. Given 1% increase in export, the industrial SO₂ emission will *reduce* by 0.077%, while 1%'s increase in imported manufactured goods stock instead will lead industrial SO₂ emission to *increase* by 0.22%.

The estimation results of our simultaneous system do not find supportive evidences for neither the "pollution haven" nor the "racing to the bottom" hypothesis from the case of China's export increase. On contrary, the intense competition pressure on export activity coming from the world market is, in the long run, a positive factor encouraging China's technical progress in pollution abatement activity. At the same time, under the enlargement of export scale, China's industrial composition specialization is dominated by the faster expansion of less polluting labor-intensive industries but not by the increase of the polluting "production-platform" pursuing its relatively lower environmental regulation compliance cost. The emission reduction benefiting from China's integration process to global production division system actually helps China to reduce the pollution problem resulting from its industrial development strategies that gives priorities to some pollution-intensive heavy industries, which is traditionally supported by the policy-guided import activities.

Environmental impacts of international trade: the case of industrial emission of Sulfur Dioxide (SO₂) in Chinese provinces

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 SO₂ emission (1993-2001). Our estimation results reveal totally opposite role of export expansion and accumulation of manufactured goods import in industrial SO₂ 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 development strategy, which is traditionally supported by import activities.

Environmental impacts of international trade: The Case of Industrial Emission of Sulfur Dioxide (SO₂) in Chinese provinces

1. Introduction

The economic reform since 1978 has induced rapid integration procedure of Chinese economy into world market. The trade intensity indicator, defined as sum of export and import over total GDP, starting from the level of 10% at the beginning of 1980, has reached 35% in the second half of 1990's. After entering the new millennium, another cycle of rapid international trade growth was activated by China's accession to WTO. At the end of year 2003, the trade intensity went to another historically new height: about 60%. (SSB, 2004) Chinese government and most of the economists forecast a maintaining and further increasing tendency for China's openness indicators in the near future.

The openness policy is generally considered as one of the most important catalysts for the 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. Although some improvement appeared during 1990's owing to the reinforcement of environmental protection efforts from related administrative agency, 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 3/4 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

by the output ratio of different sectors in total economy. From this expression he indicated the three famous emission determinants: scale, composition and technique effect. Copeland and Taylor (2003) indicated the potential endogeneity of all the three emission determinants with respect to international trade. Trade can affect production scale. Besides the production scale enlargement effect benefiting directly from the enlarged demand from the world market, some economic 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 cannot support as stringent environmental regulation as their rich trade-partners. However, according to traditional comparative advantage theory, developing countries’ rich endowment in cheap labor forces also indicates their comparative advantages in less-polluting labor-intensive industries. Copeland and Taylor (1997) 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 technique effect. Hypothesis of Porter (Porter and Linde, 1995; Xepapadeas and Zeeuw, 1998) believes that 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 the access to advanced technology from developed countries, both of the two aspects contribute in turn to technological progress in emission abatement activities. However, some pessimistic theories anticipate “racing to the bottom” effect of international trade on countries’ environmental regulation strictness by supposing that enhanced world market competition will oblige the countries to relax their environment control

strictness to maintain domestic producers' competitiveness, which will in turn discourage their technique effort on emission abatement.

Given the different theoretical propositions for trade's impacts in environment, which hypothesis mentioned above corresponds to the actual relationship between trade and environment situation in China? How does trade exert its impacts on environment by changing its three economic 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 this model, the emission is firstly determined by the three economic determinants, scale (economy's production scale), composition (pollution performance of industrial composition), 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. These functions will help us 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 in to the model. This simultaneous system is then tested by the panel data of 29 Chinese provinces' industrial sulfur dioxide (SO₂) 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 inconsistency 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. Finally we conclude in Section 5.

2. Current economic growth, industrial SO₂ emission and openness situation in China

Figure 1 shows the detailed regional distribution of industrial SO₂ emission, international trade and economic growth situation in China during year 2001. Clearly, the rapid economic growth catalyzed by intensified international trade activities did not benefit the 30 Chinese provinces in a homogenous way. The pollution situation also shows great regional disparity. The highest international trade intensity in both export and import and highest per capita income are generally concentrated in eastern coastal provinces. While both the trade intensity and per capital GDP show obvious decreasing tendency when we move from eastern costal to western inland provinces, the air pollution situation does not follow the same geographical distribution pattern. The serious SO₂ emission problem seems to appear more frequently in the central northern provinces that had long heavy industrial production tradition and some south provinces as Guizhou and Sichuan, etc., where the coal endowment contains high concentration of sulfur.

(Insert Figure 1 about here)

(Insert Figure 2 about here)

Figure 2 further studies the cross-section potential correlation between economic growth, international trade and industrial SO₂ emission situation by plotting them by pair in the same diagram. Corresponding to Figure 1, excepts the obvious positive correlation between economic growth and openness degree, for provincial-level per capita SO₂ emission, we can not derive its correlation neither with per capita GDP nor with export and import ratios. Obviously, The relationship between emission and international trade is more complicated than a simple positive or negative correlation.

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

The potential endogeneity of the economic determinants of emission with respect to international trade revealed in numerous theoretical propositions reminds us the necessity to

include the intermediation of the economic determinants of emission into trade-emission nexus analysis. In this section we construct a simultaneous system, in which we include the most discussed pollution determinant factors: the scale, composition and technique effect as the intermediation for impact of trade on emission.

3.1 The model

A direct inspiration of the system used in this paper comes from Dean (1998). In her paper she studied the relationship between international trade and industrial wastewater emission in China by a simpler simultaneous system. Her 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 our 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 equipment that embodies new technologies to support the development of some strategic heavy industries. If their export growth is stimulated by the demand from the world market seeking for cheapest goods produced by the country with strongest comparative advantages, their import activity is more policy-oriented. Considering the possible difference in the role of export and import in economic growth, industrial structural transformation and pollution situation; we separately include them into our system. Agras and Chapman (1999) did the same arrangement in their paper.

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

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

$$\text{with } 0 < \alpha < 1, 0 < \beta < 1, EX_{it} = \left(\frac{X_{it}}{GDP_{it}} \right), \varphi > 0, EM_{it} = \left(1 + \frac{\Delta KM_{it}}{KM_{it0}} \right), \Delta KM_{it} = \sum_{T=t_0}^{t-1} M_{iT}, KM_{it0} = \sum_{T=0}^{t_0} M_{iT}, \psi > 0$$

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

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

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

With

E_{it} : emission

L_{it} : total labor employed in production

Y_{it} : scale effect

X_{it} : total export

Ω_{it} : composition effect

GDP_{it} : total GDP

τ_{it} : technique effect

ΔKM_{it} : variation of stock of imported machinery and equipment

$A_t(EX_{it})$: total factor productivity parameter

since base year t_0

EX_{it} : export externality

M_{it} : total annual import of machinery and equipment

K_{it} : total capital stock employed in production

$denpop_{it}$: population density

EM_{it} : import externality

KM_{it_0} : stock of imported machinery and equipment in base year t_0

Equation (1) describes the economic determinants of emission. Following Grossman (1995), we include scale effect (Y_{it}), composition effect (Ω_{it}) and technique effect (τ_{it}) into this equation. Other things kept unchanged, an economy with larger production scale emits more pollution, so we expect a positive coefficient for this term, which means $e_y > 0$. Composition effect (Ω_{it}) reflects the pollution performance of an economy's industrial composition. Given the same production scale, the industrial composition contains higher percentage of polluting sectors emits more pollution. Therefore, a positive coefficient for the composition effect is anticipated, $e_\Omega > 0$. The original technique effect in Grossman (1995) is the average emission intensity. As higher technique effort leads the emission intensity to reduce; most of the previous studies frequently use environmental regulation stringency as an approximation for this effect. Given the other two determinant factors stay unchanged; we expect a negative sign for this determinant, $e_\tau < 0$. For the correspondence to the existing studies on trade-emission relationship, as Antweiler et al (2001), Rock (1996), Suri and Chapman (1998) and Agras and Chapman (1999), etc., we also include export and import in this function to capture their direct determinant role on emission.

Besides the direct role of export and import described by the emission determination function, we equally trace their indirect impacts on emission going through their effect on the scale, composition and technique characteristics of an economy.

The impacts of international trade on economic scale is captured by a de Melo and Robinson style production function as equation (2), in which production scale is supposed to be enlarged by positive externality coming from both export and import growth. The externality of export is captured by the term $A_i \times (X_{it}/GDR_t)^\phi$ with $\phi > 0$, which supposes a higher export intensity with respect to *total* GDP helps to increase total factor productivity of the whole economy by enhancing the competition pressure faced by domestic producer. The externality of import acts differently from that of export. Instead of supposing the import externality to increase productivity of both production factors capital and labor in an average way, basing on the general characteristics among the East Asian Newly Industrializing Economies (NIE's), de Melo and Robinson (1990) assumed faster accumulation of imported machinery and equipment

$K_{it} = \sum_{T=1}^{t-1} M_{iT}$ can increase the effectiveness of capital stock used in the economy K_{it}^e owing to the

learning-by-doing gains from the new technologies embodied in new (largely imported)

equipment. This idea is expressed as $K_{it}^e = K_{it} \times \left(\frac{KM_{it}}{KM_{i0}} \right)^\psi = K_{it} \times \left(1 + \frac{\sum_{T=t_0}^{t-1} M_{iT}}{KM_{i0}} \right)^\psi$ in the production

function (2). KM_{i0} is the value of the imported equipment capital in the base year t_0 and $\sum_{T=t_0}^{t-1} M_{iT}$ is

the accumulation of the previous years imports of machinery and equipment since the base year

t_0 . As the term $\left(1 + \frac{\sum_{T=t_0}^{t-1} M_{iT}}{KM_{i0}} \right)^\psi \geq 1$, the capital productivity gains from accumulation of imported

technologies can be represented as a positive parameter $\psi > 0$, which attributes a higher direct elasticity to physical capital in the production function.

Indirect impact of trade on pollution can also be found from its role on industrial composition transformation modeled in composition determination function (3). As suggested in

Copeland and Taylor (1995), the final role of international trade in industrial composition transformation of one country is determined by the force contrast between its “pollution haven” comparative advantage and its natural endowment situation. We expect the sign of export’s coefficient to reveal the actual composition transformation impact induced by export growth. The consideration for the role of import on composition transformation is a different from the suggestion of Copeland and Taylor (2003) since we use the accumulation of imported machinery and equipment as the measurement for import. Like its Asian neighbors, most of the machinery and equipment import in China is used in some strategic heavy industrial sectors. Therefore, we expect the equipment and machinery import may play a positive role on the pollution performance of the industrial composition, so $z_{EM} > 0$. Wang and Wheeler (1996), World Bank (2000) indicated that “China’s levy system has been working much better than that has been supposed” due to her great flexibility and her complaining citizens acting in an informal way. In this function we also include economic growth Y_{it} to measure the impact of *informal* pollution control efforts on orientation of the new production capacity towards less polluting sectors. As this informal pollution control efforts is positively correlated with income level, we expect a negative coefficient for this variable, $z_y < 0$.

The equation (4) describes the determination of technique effect as suggested in the neo-classical theories. (Selden and Song, 1995; Lopèz, 1994) Here we consider four potential determinants for technique effect. The first is economy growth (Y_{it}), which seizes technical progress in pollution abatement caused by the increasing public demand 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 technical innovation in pollution abatement activity to progress. Therefore, we include population density into this equation and expect $t_{DENPOP} > 0$. The possible impact of export on technique 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 environmental

regulation stringency to maintain the competitiveness of domestic products, which will discourage the research and development activity in pollution abatement, in this case $t_{EXP} < 0$. However, the Porter hypothesis argues supplying world market makes it necessary for domestic producers to meet international environment norm, which will in long-run “trigger innovation (in enhancing production efficiency and improving pollution abatement activities) that eventually increase (domestic) firms’ competitiveness and outweigh the short-run private cost increase due to (environmental) regulation (reinforcement)”.(Xepapadeas and Zeeuw, 1999) In this case, the commercial openness can actually benefit technical progress in pollution abatement, so $t_{EXP} > 0$. As the impact of export on technique effect expected by these two hypotheses tells totally different stories, its final effect will be revealed by its estimation coefficient. If we regard the export’s impact on technique effect as demand-side forces, the impact of machinery and equipment import will play from supply side. As imported machinery and equipment generally embody advanced technology, we expect its increase can strengthen China’s technical capacity in pollution control and abatement, so $t_{IMP} > 0$.

To facilitate the measurement of the total environmental impact of trade, we make total differentiation to the four equations and divide each of them by its corresponding dependant variable. Therefore, we get the following new simultaneous system. The positive and negative sign in bracket marked under each coefficient is the expected sign for the corresponding variable.

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

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

(+) (+) (-) (?) (?)

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

(+) (+) (+) (+)

$$(3^*) \frac{\dot{Q}_{it}}{\Omega_{it}} = z_{EX} \times \frac{\dot{EX}_{it}}{EX_{it}} \times \frac{\dot{EX}_{it}}{EX_{it}} + z_{EM} \times \frac{\dot{EM}_{it}}{\Omega_{it}} \times \frac{\dot{EM}_{it}}{EM_{it}} + z_y \times \frac{\dot{Y}_{it}}{\Omega_{it}} \times \frac{\dot{Y}_{it}}{Y_{it}} = \eta_{\Omega,EX} \times \frac{\dot{EX}_{it}}{EX_{it}} + \eta_{\Omega,EM} \times \frac{\dot{EM}_{it}}{EM_{it}} + \eta_{\Omega,y} \times \frac{\dot{Y}_{it}}{Y_{it}}$$

(-) (+) (-)

$$\begin{aligned}
 (4^*) \frac{\dot{\tau}_{it}}{\tau_{it}} &= t_Y \times \frac{\dot{Y}_{it}}{\tau_{it}} \times \frac{\dot{Y}_{it}}{Y_{it}} + t_{denpop} \times \frac{\dot{DENPOP}_{it}}{\tau_{it}} \times \frac{\dot{DENPOP}_{it}}{DENPOP_{it}} + t_{EX} \times \frac{\dot{EX}_{it}}{\tau_{it}} \times \frac{\dot{EX}_{it}}{EX_{it}} + t_{EM} \times \frac{\dot{EM}_{it}}{\tau_{it}} \times \frac{\dot{EM}_{it}}{EM_{it}} \\
 &= \eta_{\tau,Y} \times \frac{\dot{Y}_{it}}{Y_{it}} + \eta_{\tau,DENPOP} \times \frac{\dot{DENPOP}_{it}}{DENPOP_{it}} + \eta_{\tau,EX} \times \frac{\dot{EX}_{it}}{EX_{it}} + \eta_{\tau,EM} \times \frac{\dot{EM}_{it}}{EM_{it}} \\
 &\quad (+) \quad (+) \quad (?) \quad (+)
 \end{aligned}$$

This mathematical adjustment transforms each variables of this simultaneous system into its growth rate. We distinguish four endogenous variables in this system: \dot{E}_{it}/E_{it} , \dot{Y}_{it}/Y_{it} , $\dot{\Omega}_{it}/\Omega_{it}$ and $\dot{\tau}_{it}/\tau_{it}$. There are five exogenous variables: \dot{K}_{it}/K_{it} , \dot{L}_{it}/L_{it} , \dot{EX}_{it}/EX_{it} , \dot{EM}_{it}/EM_{it} and $\dot{DENPOP}_{it}/DENPOP_{it}$. So the system is identified. The coefficients estimated by the new system form are actually the elasticity of the dependant variables with respect to their independent variables. Owing to this arrangement, the indirect impact of trade on emission going through the intermediation of one of the other economic determinants can be simply 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_{ii}) and import (EM_{ii}) with emission (E_{ii}) in the 6 different channels categorized into 4 aspects: direct, scale, technique and composition effects.

For both export and import case, the first terms in equation (5) and (6) signify the potential direct impact of trade on emission, which will be estimated directly from the estimation function (1*). The scale effect captures the emission increase caused by economic growth catalyzed by export and import through their positive externality on productivity. The following two terms indicate the two channels through which international trade modifies emission by changing technique effect. The first one is through international trade's impact on pollution control efforts estimated in equation (4*). The second term reveals the pollution reduction benefiting from the technique effect reinforcement induced by trade-catalyzed economic growth. The last two terms in equation (5) and (6) show the emission modification due to industrial composition transformation. The former indicates industrial composition specialization issuing directly from

enlargement of openness degree. The latter shows the adjustment of industrial composition induced by the informal pollution control efforts measured by economic growth.

(Insert Figure 3 about here)

We illustrate in Figure 3 the trade-emission nexus into the direct, first- and second-level indirect channels. The gray-color cases are used to indicate all emission variations related to international trade. 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 impacts of export (import) on the three economic determinants of emission. The two second-level indirect channels trace the emission variation resulting from the indirect composition and technique changes induced by trade-led economic growth. The total impact of trade on emission should be measured by adding all these different aspects together.

$$\begin{aligned}
 (5) \quad \frac{\partial E}{\partial EX} &= \underbrace{\eta_{E,EX}}_{\substack{\text{direct effect} \\ (?)}} + \underbrace{\eta_{E,Y} \times \varphi}_{\substack{\text{Scale effect} \\ (+)}} + \underbrace{\eta_{E,\tau} \times \eta_{\tau,EX}}_{\substack{\text{Technique effect} \\ (?)}} + \underbrace{\eta_{E,\tau} \times \eta_{\tau,Y} \times \varphi}_{\substack{\text{Indirect technique effect} \\ \text{chained by} \\ \text{economic growth} \\ (-)}} + \underbrace{\eta_{E,\Omega} \times \eta_{\Omega,EX}}_{\substack{\text{Composition effect} \\ (?)}} + \underbrace{\eta_{E,\Omega} \times \eta_{\Omega,Y} \times \varphi}_{\substack{\text{Indirect composition effect} \\ \text{chained by} \\ \text{economic growth} \\ (-)}} \\
 &\qquad\qquad\qquad \underbrace{\hspace{10em}}_{\substack{\text{Technique effect} \\ (?)}} \qquad\qquad\qquad \underbrace{\hspace{10em}}_{\substack{\text{Composition effect} \\ (?)}} \\
 \\
 (6) \quad \frac{\partial E}{\partial EM} &= \underbrace{\eta_{E,EM}}_{\substack{\text{direct effect} \\ (?)}} + \underbrace{\eta_{E,Y} \times \alpha \psi}_{\substack{\text{Scale effect} \\ (+)}} + \underbrace{\eta_{E,\tau} \times \eta_{\tau,EM}}_{\substack{\text{Technique effect} \\ (-)}} + \underbrace{\eta_{E,\tau} \times \eta_{\tau,Y} \times \alpha \psi}_{\substack{\text{Indirect technique effect} \\ \text{chained by} \\ \text{economic growth} \\ (-)}} + \underbrace{\eta_{E,\Omega} \times \eta_{\Omega,EM}}_{\substack{\text{Composition effect} \\ (?)}} + \underbrace{\eta_{E,\Omega} \times \eta_{\Omega,Y} \times \alpha \psi}_{\substack{\text{Indirect composition effect} \\ \text{chained by} \\ \text{economic growth} \\ (-)}} \\
 &\qquad\qquad\qquad \underbrace{\hspace{10em}}_{\substack{\text{Technique effect} \\ (-)}} \qquad\qquad\qquad \underbrace{\hspace{10em}}_{\substack{\text{Composition effect} \\ (?)}}
 \end{aligned}$$

4. Econometric analysis

4.1 Data choice

The choice of China's provincial level panel data on industrial emission during 1993-2001 to carry out our analysis is due to the following considerations. Firstly, being a big country, China's national-wide unified statistical system promises for our empirical studies comparable and credible economy and pollution data on provincial level. These regional data can help us to avoid the generally encountered critiques like data incoherence by those studies on international

experience. Secondly, the efficiency of our empirical analysis is also guaranteed by the remarkable regional disparity between provinces in both pollution and economic situation gradually formed during their 25 years' economic reform. Thirdly, given the most important increase in the openness degree in China happened after 1992, focusing our analysis in the period of 1993-2001 will allow us to study the principal impact of international trade on both Chinese economic and pollution situation. Finally, as China is under its industrialisation process, it is also more interesting for us to check the potential impact of trade in China's industrial pollution situation, since the rapid expansion of the Chinese industrial production is both the engine for economic development and international trade growth and the principal source of its air pollution problem.

(Insert Table 1 about here)

(1) The data choice for the endogenous variables

The choice of industrial SO₂ emission as environmental quality variable is based on three reasons. Firstly, given its rich endowment in coal, SO₂ emission from coal combustion is always the most important air pollution source in China. The pollution phenomena as the acid rain and total suspended particulate (TSP) can both be linked to this pollutant. Aiming at monitoring and controlling, detailed statistic record for this pollutant becomes available since 1990s, especially for that emit from industrial production where the coal is intensively used. Secondly, among the available statistic data describing Chinese environment situation, industrial SO₂ emission is also the environmental indicator having the longest time dimension without interruptions. Thirdly, the theoretical hypotheses, such as the "pollution haven" hypothesis that we use to construct the simultaneous model are only applicable to local pollution case. Given China's geographical dimension, the pollution phenomena related to SO₂ emission are largely confined inside of each province. Therefore, industrial SO₂ emission is a local pollution case applicable to our simultaneous system.¹

¹ Heil, M. K. and T. M. Selden (2000) also considered SO₂ emission as a local pollution problem.

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. To capture the evolution of the environmental performance of composition effect for each province, in which we need to summarize the heterogeneous emission performance of different industries belong to the same province, we 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 SO₂ emission intensity for each of the 13 sectors in year 1991.^{2,3} Using this synthetic composition indicator instead of the frequently used capital abundance measured by the capital to labor ratio (K/L) in the similar studies as Copeland and Taylor (1994, 1995), Antweiler et al. (2001), Cole et al. (2003) and Cole (2004) is based on the following considerations. 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, Dinda et al (2000) and He (2003) indicated the potential ambiguity in using capital abundance as measurement for environmental performance of the industrial composition, since the “capital intensive sector could also be more clean technology owner” (Dinda et al, 2000), this is contrary to the underlying fundamental hypothesis of this measurement, which supposes pollution intensive sectors to be generally more capital-intensive. The synthetic indicator constructed on the detailed output ratio and emission characters of the 13 industrial sectors can help us to avoid these two problems. Furthermore, as the sum of value added of the 13 industrial sectors generally counts up to 98% of the total provincial industrial GDP each year, we are also confident in the capability of this synthetic indicator in reflecting the general environmental performance of the whole industrial composition for each province.

² 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 (Data source: China Industrial Economic Statistic Yearbook, 1989-2002)

³ Keller and Levinson (2002) also use the same expression to measure industry composition of each state in order to adjust the measurement for state pollution abatement costs.

The measurement for technique effect in this paper is also different from that used in the previous similar studies due to China's actual situation. Given higher income tends to reinforce environmental regulation strictness and then to encourage producers to reduce their pollution intensity by investing in pollution abatement activities, most of the related studies (Copeland and Taylor, 1994, 1995; Antweiler et al., 2001 and Cole, 2004) generally use per capita income as approximation for technique effect, since there does not exist a uniformed measurement for the technique efforts in different countries on pollution control activities. However, the efficiency of this approximation depends essentially on the validity of two hypotheses. The first hypothesis is the underlying condition supporting the validity to extrapolate environmental regulation stringency by income level. Under this hypothesis, environmental regulation stringency becomes an optimal government decision based on the principle of social utility maximization. That means to define the tax rate on emission to be equal to the marginal disutility caused by emission which has the tendency to increase as people getting richer. The second hypothesis is the essential condition for the validity of extrapolating the actual pollution abatement activity by environmental regulation stringency. It assumes full reaction of producers' pollution abatement activity to the environmental regulation reinforcement.

However, both of the hypotheses cannot be considered as valid for China's actual situation. Firstly, for years, economic growth was the central concerns of Chinese government. For example, China's Environmental Protection Agency (EPA), during years, stayed on a subordinate level comparing to the industrial or energy ministries. The increase of political interests on environment quality only appears in the past several years. Secondly, the SO₂ pollution control system currently implemented in China is the so-called "Total Emission Quantity Control (TEQC)" system. Under this system, the polluters, principally industrial and commercial enterprises, only need to pay for their pollution *emission exceeding the relevant national or local pollution standard*. If there exist several kinds of emission, the polluters just need to pay the emission levy fee for the one surpassing the most the standard (Cao et al, 1999). Wang (2002) indicated the

average levy rate for one unit of emission actually applied in China is only equal to a half of the marginal cost for pollution abatement technology investment. Polluting and paying the levy fee actually costs less expensive to the polluter than investing in pollution abatement activities. This system is more like a financial resource for the environmental protection agency for their own pollution control and technical innovation activities than an efficient system aiming at encouraging the initiative pollution control activity of polluters. Given these considerations, in this paper we use the capital stock employed in air pollution abatement activity to directly measure the current pollution abatement technique effort in each province.

(2) The data choice for the exogenous variables

The data choices for the five exogenous variables are simpler. The production factor as capital and labor are measured by real value of capital stock and number of labor employed in industry, separately. Population density is calculated by dividing provincial population by provincial surface. Given the unavailability of the detailed data on provincial level export of industrial goods, 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 also measured slightly different from that defined in de Melo and Robinson (1989), in this paper we use the increasing rate of the imported manufactured goods stock in each province with respect to its base value of year 1992 to measure it.⁴

4.2 The empirical method

Based on a simultaneous model and provincial level panel data, our empirical analysis need to take care of three potential 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

⁴ 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 1993 and that our empirical analysis also bases on the data of the period 1993-2001. The accumulation of the imported manufacturing can be tracked back till 1980.

require us to employ dynamic GMM estimator proposed by Blundell and Bond (1998) for each equation. It 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 $y_{i,t-1}-y_{i,t-2}=\rho(y_{i,t-2}-y_{i,t-3})+(x'_{i,t-1}-x'_{i,t-2})\beta+(\varepsilon_{i,t-1}-\varepsilon_{i,t-2})$. Therefore $E(dy_{i,t-1}d\varepsilon_{it})\neq 0$, the estimator will be biased. The principal development of Blundell and Bond (1998) compared to Anderson and Hsiao (1982) and Arellano and Bond (1991) is their instrumentation method to the lagged endogenous variables $(y_{i,t-1}-y_{i,t-2})$. Besides of using the level instruments $y_{i,t-2}$ for the differenced lagged endogenous regressor $(y_{i,t-1}-y_{i,t-2})$ as Anderson and Hsiao (1982), Blundell-Bond further exploits all the available additional moments restrictions to enlarges the set of instruments as Arellano and Bond (1991), which means the instruments for the lagged endogenous variables $(y_{i,t-1}-y_{i,t-2})$ is enlarged to $y_{i,t-2}, y_{i,t-3}, y_{i,t-4}, \dots, y_{i1}$. Due to the low efficiency of Arellano-Bond estimator's instruments as only the information contained in difference is used, another innovation of Blundell and Bond (1998) is to make use of the additional level information besides the differences. "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, it means for each of the four equations in our system, we use both first difference and level function form in estimation by confining the coefficient for each variable to be the same in both the first

difference and level function. The lagged endogenous variable $(y_{i,t-1}-y_{i,t-2})$ in first difference function is instrumented by the level moment $y_{i,t-2}, y_{i,t-3}, \dots, y_{i,t-2}, y_{i,t-1}$ and the lagged endogenous variable $y_{i,t-1}$ is instrumented by difference moments $(y_{i,t-2}-y_{i,t-3}), (y_{i,t-3}-y_{i,t-4}), \dots, (y_{i,t-2}-y_{i,t-1})$.

The preoccupation for the third bias is related to the simultaneous system. Given the potential correlation between the residuals of different functions in the same system due to the intercorrelation between the endogenous variables, which means $cov(\varepsilon_i, \varepsilon_j) \neq 0, i \neq j$, i and j indicate different equations in the system, we need to use the traditional Generalized Method of Moment (GMM) estimator for simultaneous system, which is able to control 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 GMM estimator for simultaneous system with 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 carry out the instrumentation step in the linear auto-regressive fixed-effect estimation function for the dynamic panel data, which allows us to exploit the maximal availability of moments restriction in both level and first difference for each estimation function and the GMM estimator for the whole system.

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 function for each of the four equations by restricting the coefficients for the same variables to be the same.

4.3 Estimation results

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) and J-statistic proves the orthogonality conditions of the instruments used for the lagged endogenous variables on equation-level and the efficiency of the instrumentation used for the whole system. Adding the lagged dependant variables to the right side of the equation also removes successfully the first-order serial correlation problem from most equations. The tiny inter-equation residual covariance shows the high efficiency of the GMM estimator for the simultaneous system.

(Insert Table 2 about here)

The first column shows the estimation results on the economic determination of SO₂ emission. Confirming to theoretical anticipation of Grossman decomposition, we prove all the three economic determinants in industrial SO₂ emission to be significant and their coefficients correspond well to our expectations. 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 0.119%. 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, industrial SO₂ emission will reduce by 0.434%.

The estimation result for production function confirms both positive externality of export and import on industrial GDP. The parameter for export externality in total factor productivity φ is equal to 0.021. While the expected positive parameter for the import externality ψ is approach

to 0.125.⁵ Compared to the ex-ante export and import externality elasticities (generally supposed to be equal to 0.1) used in several related CGE studies on Asian countries' case, as de Melo and Robinson (1990) for the case of South Korea and Rodrigo and Thorbecke (1996) in Indonesia, the import externality elasticity estimated from China's industrial economy shows good coherence, but the estimated export externality seems to be lower. The might because the discrepancy in variable measurement since we use in this paper the growth rate of the annual total export ratio to total GDP as measurement of export while the original export externality defined in de Melo and Robinson production function is only the export from the industrial sector itself.

The negative coefficient before export variable in composition equation reveals 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 will improve by 0.073%. We equally find a significantly positive coefficient for import. It confirms that Chinese government did use import as an support for its heavy industry development strategy. The significantly negative coefficient found for economic growth variable Y_{it} also reflects the existence of an efficient role of informal air pollution control in China's industrial composition transformation.

The last column of Table 2 shows the potential determinants for China's technique effect. As we anticipated, the stronger pollution control effort is positively correlated with economic growth and population density increase. 1% of increase in the industrial production growth rate leads to a 0.6%'s increase in the strength of pollution control and 1%'s increase in population density also urges the technique effect to rise by 0.269%.⁶ This finding actually provides an explanation for the relatively earlier appearance of EKC turning point in China's case with

⁵ 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 $\psi = \alpha\psi / \alpha = 0.035 / 0.272 = 0.125$.

⁶ In this paper we use industrial GDP to mean the economy growth due to the coherence necessity of the system design. However, regarding the industrial GDP occupies actually a very important ratio in total GDP in almost all the provinces (over 75%), we have the confidence to say that with this industrial GDP growth rate, we can capture the principal role of total economy growth in reinforcing the pollution control efforts.

respects to the international cross-country experiences (He, 2003) and for the success in China's de-sulfur policies during 1990s discussed in Wang and Wheeler (1996) and World Bank (2000). Come to the trade's impact on technique effect, only export shows a significant positive coefficient 0.042. This finding actually confirms the Porter hypothesis and indicates the absence of the "racing to bottom" hypothesis. We do not find a significant role of import in technique effect. This result is not surprising since we have already seen from composition effect function that import is actually political instrument for China industrial development strategy, which gives priority to some relatively polluting sectors as metal product, machinery and equipment, petroleum and chemical industries, etc. Although the imported equipment and machinery are generally more efficient in reducing pollution intensity, as most of them are used in more pollution-intensive industries, this two aspects cancel off each other and leave the total impact of imported manufacturing goods stock to be negligibly small.

(Insert Figure 4 about here)

In Figure 4 we calculate the total impact of trade on industrial SO₂ emission by using the estimated coefficients in Table 2. Corresponding to the estimation results, except for the common role in enlarging production scale through their positive externality, export and import exert very different impact in both composition and technique effect and this results in the final results for the impact of export and import to be completely opposite. With 1%'s increase in export/GDP ratio, the total percentage change in industrial SO₂ emission realized by all the 6 channels comes to be negative number, -0.071%, while the overall SO₂ emission variation resulting from 1%'s increase in imported manufactured goods accumulation is, on contrary a positive number, 0.22%. Totally speaking, export is an environment-friendly factor but that is not the case for import. The details of Figure 4 show that, the total emission reduction impact issuing from export growth is actually owing to the domination of the emission reduction result from technique and composition effect over the emission increasing result from its direct impact on

emission and on scale effect. For import, its emission-increasing role is due to the domination of the scale and composition effect.

5. Conclusion

Recognizing the endogeneity of the three economic determinants of industrial SO₂ emission with respect to international trade and inspired by Dean (1998), in this paper, we constructed a simultaneous model, in which industrial production scale, industrial composition and environment protection efforts are all influenced by trade and these variation caused by trade changes will in turn induce pollution to vary. With the aid of this model, we get a more structural idea about the real impact of export and import, separately, on emission situation, which is carried out through 6 different channels that can be categorized into three levels according to the indirectness of the relation describe in them.

The estimation result of the model based on the panel data of China's 29 provinces showed that, although the impact of trade on industrial SO₂ emission exerts through various channels, corresponding to the related empirical literatures as Antweiler et al (2001), the total impact of international trade on China's industrial SO₂ emission are proven to be relatively small. We found totally opposite role of export and import on industrial SO₂ emission determination. With 1%'s increase in export intensity to total GDP, the industrial SO₂ will *reduce* by 0.071%, while if imported manufactured goods stock increases by 1%, the industrial SO₂ will on contrary *increase* by 0.22%.

Our result equally revealed the significant externality played by export and import on Chinese industrial economy. 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 is in fact caused by her industry development strategy that uses import as an instrument to facilitate the introduction of the advanced foreign equipment and machinery to some strategic polluting heavy industries. Participating 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 negative pollution impacts of her strategic industrial development policies. Concerning the technique effect, we do not find proof for “racing to the bottom” hypothesis. In the long run, as expected by the hypothesis of Porter, technology progress and production efficiency improvement encouraged by the intensified competition from world market are actually the efficient ways for China to realize higher competitiveness, higher economy growth and at the same time, to alleviate its industrial pollution problem.

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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 _I /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

Note: (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. The simultaneous model estimation results
(GMM for simultaneous system, Fixed effect, 29 provinces during 9 years, 203 observations)

Variables	\dot{E}_{it}/E_{it}	Scale effect	Composition effect	Technique effect
		\dot{Y}_{it}/Y_{it}	$\dot{\Omega}_{it}/\Omega_{it}$	$\dot{\tau}_{it}/\tau_{it}$
Lagged \dot{E}_{it}/E_{it}	-0.436*** (0.000)			
Lagged \dot{Y}_{it}/Y_{it}		0.708*** (0.000)		
Lagged $\dot{\Omega}_{it}/\Omega_{it}$			-0.245*** (0.000)	
Lagged $\dot{\tau}_{it}/\tau_{it}$				0.483*** (0.000)
\dot{Y}_{it}/Y_{it}	2.201*** (0.005)		-0.279** (0.019)	0.600*** (0.000)
$\dot{\Omega}_{it}/\Omega_{it}$	2.173*** (0.000)			
$\dot{\tau}_{it}/\tau_{it}$	-1.171 ** (0.014)			
\dot{K}_{it}/K_{it}		0.273*** (0.000)		
\dot{L}_{it}/L_{it}		0.030 (0.211)		
\dot{EX}_{it}/EX_{it}	0.119*** (0.007)	0.021*** (0.000)	-0.073*** (0.002)	0.042*** (0.004)
\dot{EM}_{it}/EM_{it}	-0.434*** (0.007)	0.035** (0.031)	0.292*** (0.000)	0.009 (0.592)
$\dot{denpop}_{it}/denpop_{it}$				0.269*** (0.000)
Hausman (first-difference)	17.99 (0.006)	25.71 (0.000)	13.82 (0.008)	4.94 (0.432)
Hausman (level)	9.46 (0.149)	6.84 (0.233)	1.47 (0.832)	0.31 (0.997)
Autocorrelation ($\hat{\rho}$)	-0.540*** (0.000)	-0.557*** (0.000)	-0.415*** (0.000)	-0.177** (0.013)
J-statistic (System identification)			0.622	
Residual covariance			2.76E-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: $\hat{e}_{it} = \hat{\rho}\hat{e}_{i,t-1} + error_{it}$, $t=3,4,\dots,T$; $i=1,2,\dots,N$.
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 $126.27=0.622 \times 203$ 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 1.000.

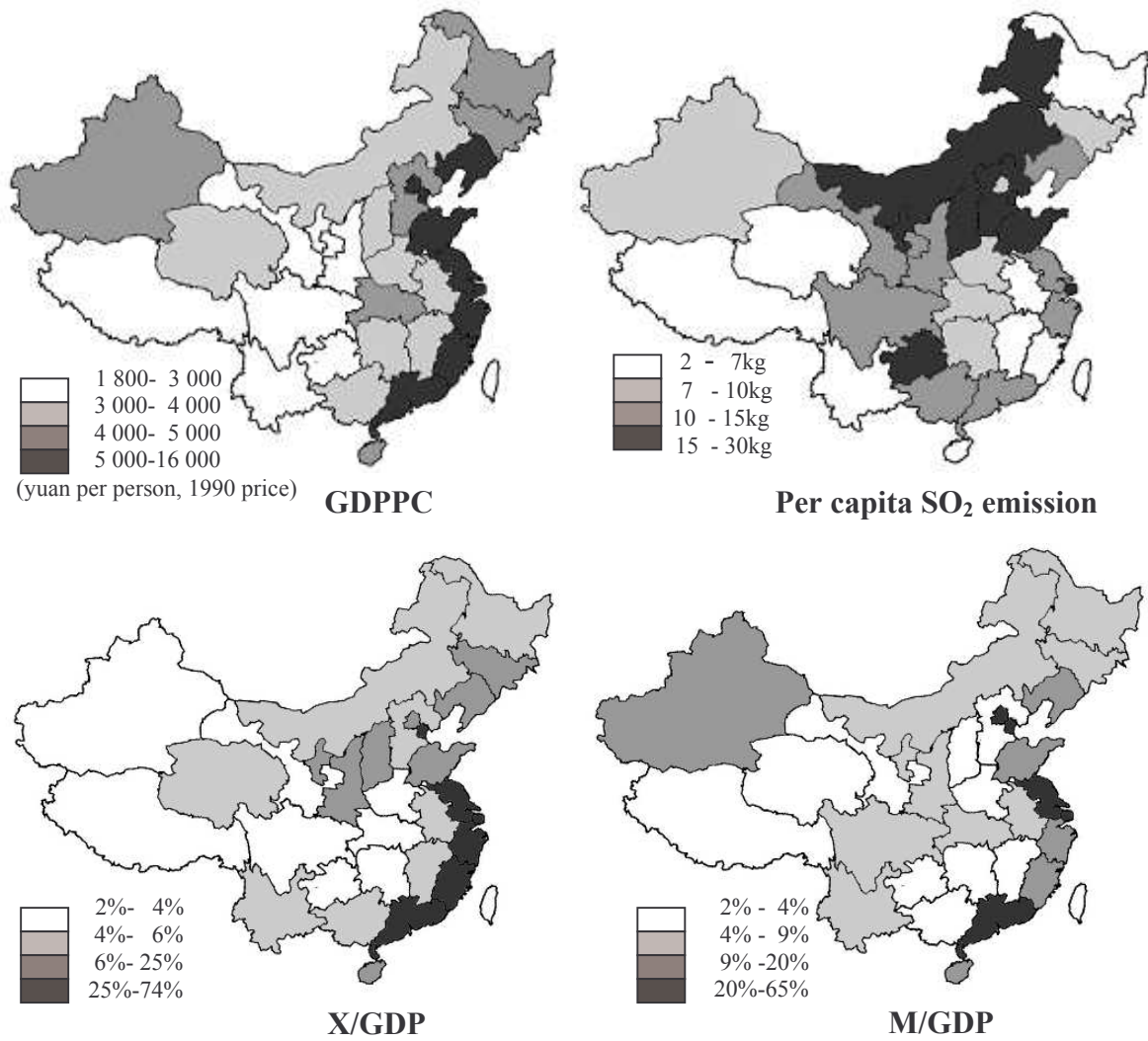


Figure 1. Geographical distribution of economic growth, trade and industrial SO₂ emission in 2001

(Data source: China Statistic Yearbook, 2002)

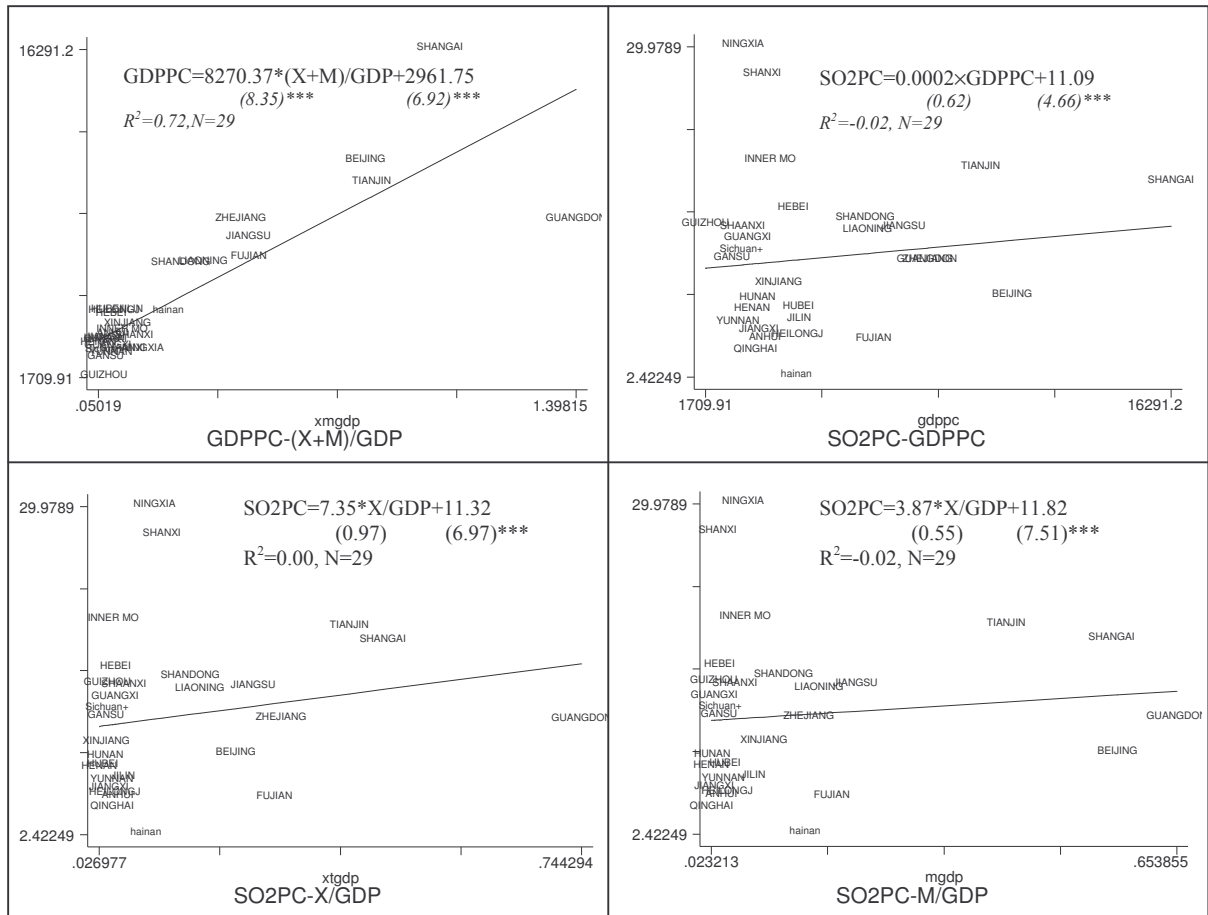


Figure 2. Correlation between economic growth, international trade and emission (2001)

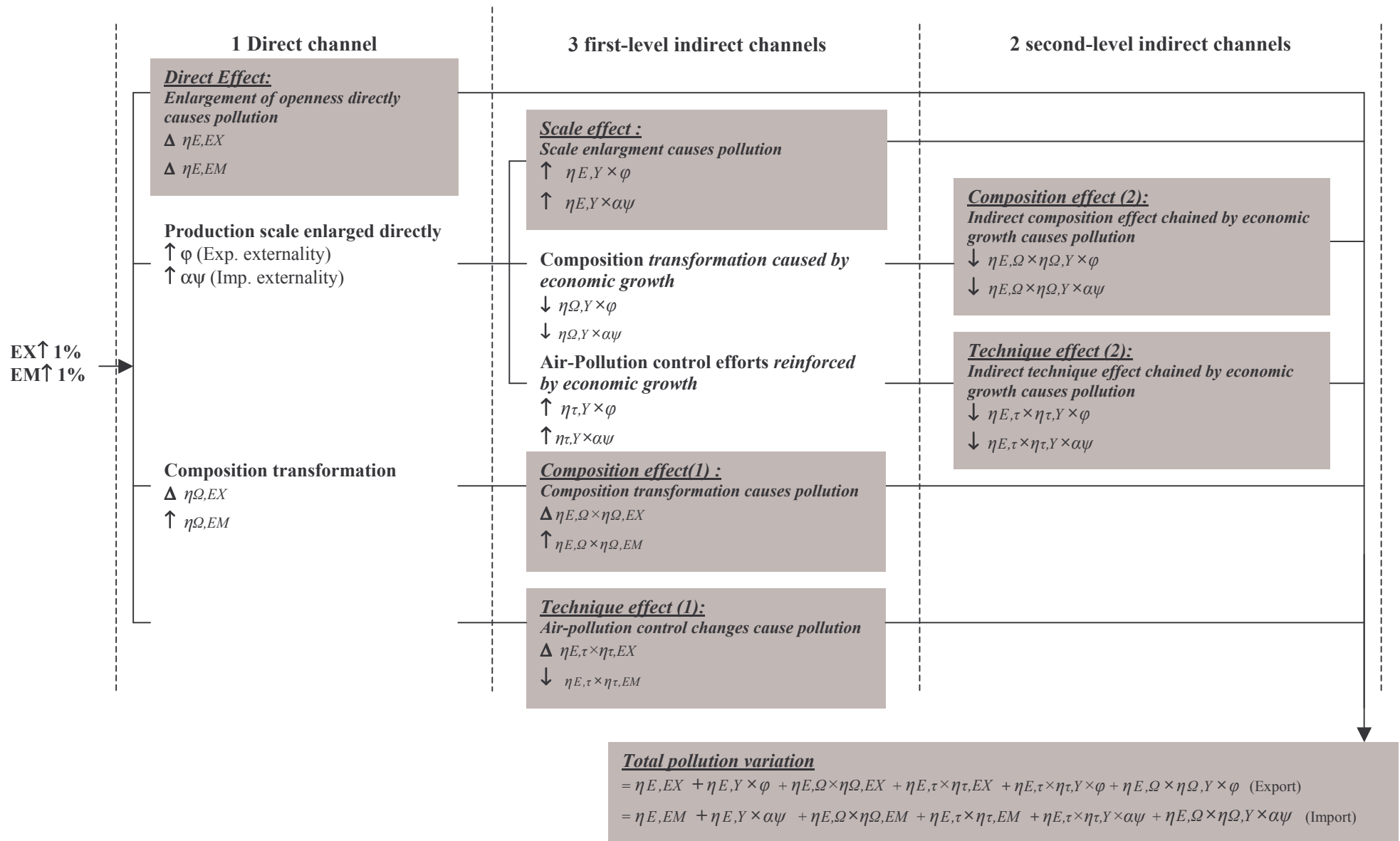


Figure 3. Illustration of the different Channels of trade's impact on pollution

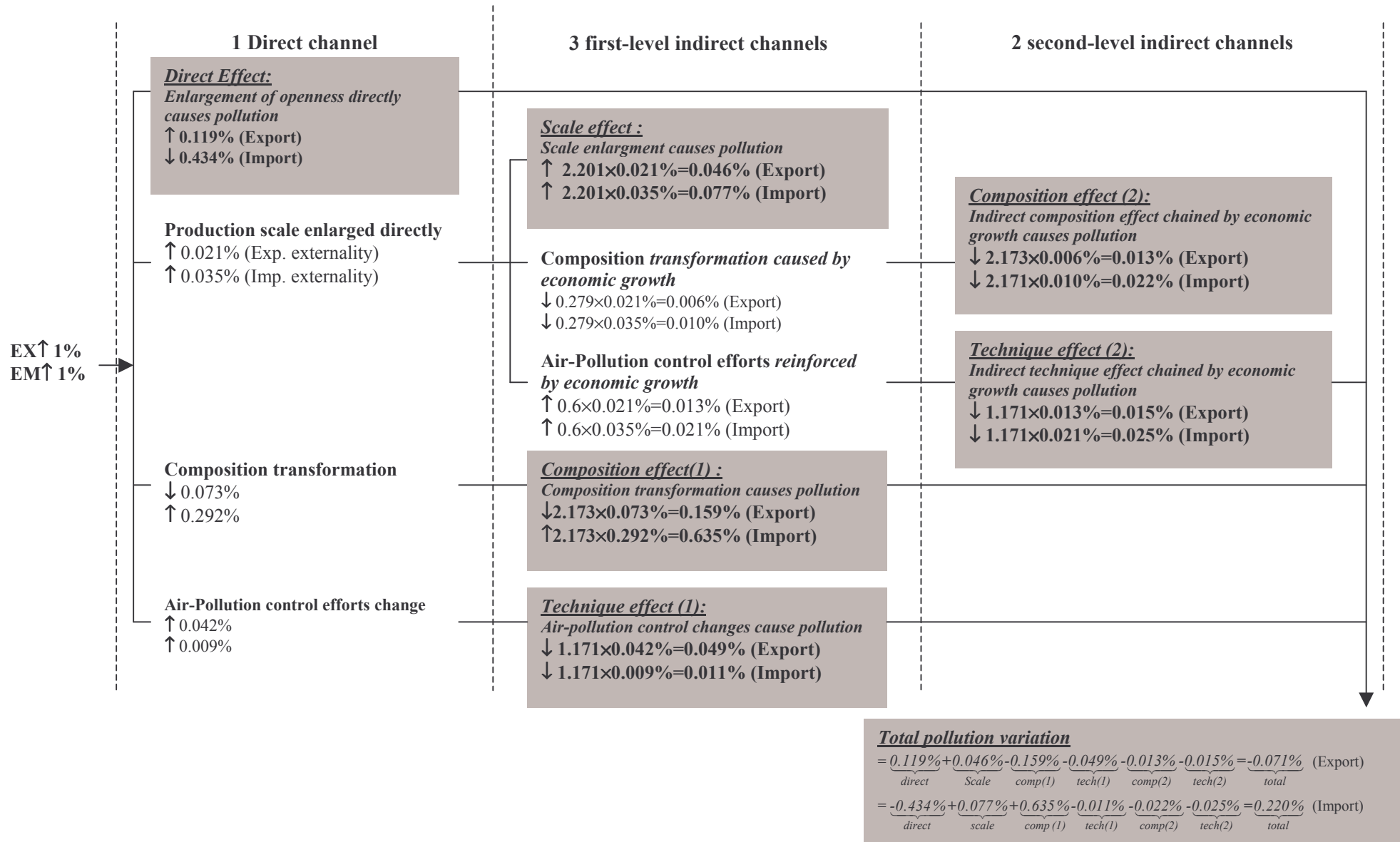


Figure 4. Different Channels of the impacts of trade on pollution