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Long-term Nexus of Industrial Pollution and Income in China

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Abstract

This study examines the long-run relationship between industrial pollution and income in China using provincial panel data. Four types of pollutants are modelled: waste water, solid wastes, soot and SO₂ emission. Two types of income effects are considered: the scale and growth effects. The study finds little evidence of inverse U shape curves as postulated by EKC models; pollutant emissions may go positively or negatively with income irrespective of income levels whereas certain sign of alleviation in pollutant concentration due to income growth is discernible; trade is found to be insignificant while the hazardous nature of pollutants appears to be an important factor for heterogeneity in the income effect estimates; the heterogeneity cautions us against simple panel model specification.

JEL: C51, O53, Q53, Q56

Keywords: Environmental Kuznets curve, pollution, economic growth, trade, heterogeneity

I. Introduction

The environmental impact of China's phenomenal economic growth over the last few decades has aroused increasing concerns. Independent estimates of the cost to China of environmental degradation and resource depletion range from 8 to 12 percent of GDP growth for the last decade.¹

A popular economic explanation of the situation is the environmental Kuznets curve (EKC). It postulates that environmental degradation is exacerbated during the early stage of economic development of a country and the situation reverses when it progresses into the later stage of development, ie a stage when economic growth becomes environmentally friendly. An interesting issue for empirical studies is to identify the turning point, ie whether, and if so when, China has progressed into such a later stage. A number of recent studies using provincial panel data have presented some evidence of the EKC, e.g. see Zhang and Yang (2008), Llorca and Meunié (2009); but the evidence is weak and inconclusive.

The present study argues that most of the estimated EKC models using Chinese provincial panel data neglect the econometric pitfalls described by Stern (2004a, 2004b). The argument is built upon results of an extensive data-mining exercise which looks into the long-term dynamic relationship between industrial pollution and per capita GDP at the provincial level. Provincial panel data of the period 1990-2007 are used in the study. Four types of pollutants are modelled: waste water, solid wastes, soot and sulphur dioxide (SO₂) emission. The results reveal prominent heterogeneity in the dynamic relationship not only with respect to provinces but also with respect to pollutants, and distinctly different long-run relationships between the ones specified in terms of emission scale and those specified in terms of pollutant concentration. The results highlight the primacy of learning data features before mechanically estimating EKC models and also cast doubts on the empirical adequacy of simple EKC models in explaining pollution primarily by income growth.

The rest of the paper is organised as follows. The next section presents some data features; section 3 looks at the long-term relationship between industrial pollution emissions and income; Section 4 turns to the relationship between pollutant concentration and income growth. The final section summarises the main findings.

II. Data features

¹ See <http://www.pbs.org/kqed/chinainside/nature/greengdp.html> .

As mentioned above, the present study examines Chinese provincial panel data of the period 1990-2007. The provinces are grouped into three regions to reflect the different levels of development: the coastal, the central and western regions (see the table in Appendix).² The pollution data are from industry only. Four types of pollutants are covered: waste water, solid wastes, soot and SO₂ emissions (see the Appendix for more detailed description of the data source). The first three are, to a large extent, local pollutants whereas the last is a global pollutant. It is normally expected that environment protection measures are targeted more at local pollutants than global pollutants, eg see Copeland and Taylor (2004). The implication is that the pollution-income situation should be worse for global pollutants than local pollutants. Table 1 lists the provincial ranks by region, at various years, of per capita real GDP, industrialisation represented by the ratio of industrial output to GDP, per capita waste water, solid wastes, soot and SO₂ emissions respectively. It is interesting to see from the table that the changing ranks of income (per capita GDP) do not go on a par with those of industrialisation, or strictly inversely with those of the pollutant emissions. For example, Shanxi and Neimeng are both above the average in terms of economic development but they rank quite high in terms of pollutant emissions; on the other hand, some provinces in the poorest western region have become the most polluted by the end of the sample in spite of its remaining relatively low ranks in industrialisation. The evidence suggests that China should, by 2007, have already passed the turning point postulated by the EKC.

Since we are the most concerned with how pollution has evolved with economic development, cross-plots of the four types of pollutants with GDP are given in Figures 1 and 2. It is discernible from these figures that there is a great deal of heterogeneity not only between provinces but also between pollutants. Among different pollutants, cross-plots of the solid wastes with GDP demonstrate the most similar upward trends across different province, suggesting that China has not yet passed the turning point as far as solid waste pollution is concerned. Among the cross-plots of the other pollutants, however, almost no hump-shaped nonlinear relationship is discernible, which is what the EKC postulates. It makes us reconsider about our inference on the turning point hypothesis based on Table 1. If we graph the time series of the pollutants and GDP individually (not shown here to restrict the paper length), we see that almost all the series are highly trended, suggesting strong non-stationarity. These data

² Tibet is excluded for severe lack of industrial pollution data. The four autonomous municipalities, Beijing, Tianjin, Shanghai and Chongqing, are treated as provinces.

features should be taken into consideration when we model the relationship between pollution and income.

III. Long-run scale effect of income on pollution level

Standard EKC regression models depict the nonlinear (hump-shaped) relationship between pollution and income via the functional form of quadratic polynomials of income, eg in the case of panel data:

$$\ln(P)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(Y)_{it} + \beta_2 [\ln(Y)_{it}]^2 + \varepsilon_{it} \quad (1)$$

where P stands for per capita pollutant emission, Y per capita real GDP, α_i the individual effect and γ_t the time effect. A key interest in (1) is to estimate the turning-point level of income where emissions are at a maximum: $\tau = \exp[-\beta_1 / (2\beta_2)]$ (see Stern, 2004a).

However, model (1) suffers from two specification weaknesses in view of the gist of the EKC. First, it neglects the dynamics, especially the long-run, information in time-series data. Second, it imposes identical parameters of interest, ie β_1 and β_2 , on all provinces. A simple, albeit tedious, test of the latter is to run the regression model separately for each province, since our data sample contains 18 time-series observations. As for the dynamics, a recent study by Auffhammer and Carson (2007) has rejected static EKC models in favour of a dynamic, partial adjustment model. It shows that the dynamic specification makes the quadratic income variable drop out. Llorca and Meunié (2009) estimate EKC for sulphur dioxide (SO₂) emissions using panel data of the period 1985-2003. Their model consists of cubic polynomial terms of per capita GDP and also a number of other control variables such as the thermal production of electricity, FDI and the share of state-owned enterprises. The main finding is that the EKC seems to show with full sample estimation (though the Chow test fails) but fails to give significant results (only the linear scale GDP remains significant) with subsample data. Here, we opt to go for a more general dynamic model without the time effect dummy variable, since most of the provincial, single time-series of both the pollutant emission data and GDP exhibit non-stationary features, as discussed in the previous section. Stern (2004a, 2004b) suggests the use of cointegration technique to estimate the long-run relationship between pollution and income. Considering the low power of unit-root tests when samples are short, we shall not pursue cointegration. Instead, we adopt the LSE dynamic specification approach. In view of the recent literature, we also try to control for the demand, additional to GDP, which is generated

by the export-led growth strategy. The variable we choose here is the ratio of export to GDP, x , which, we believe, is better than FDI in capturing the export-driven demand. Specifically, the following ADL (autoregressive distributed-lag) model is used for estimating the long-run relationship for each province:

$$\begin{aligned} \ln(P_j)_t &= \alpha_{0j} + \alpha_j(L)\ln(P_j)_{t-1} + \beta_j(L)\ln(Y)_t + \lambda_j(L)x_t + u_{jt} \\ \Rightarrow \ln(P_j) &= \phi_{0j} + \phi_{1j}\ln(Y) + \phi_{2j}x, \quad \phi_{1j} = \frac{\beta_j(L)}{1-\alpha_j(L)}; \phi_{2j} = \frac{\lambda_j(L)}{1-\alpha_j(L)} \end{aligned} \quad (2)$$

where j denotes types of pollutant with $j = 1$ denoting waste water, $j = 2$ solid wastes, $j = 3$ soot and $j = 4$ SO₂ emission; $\alpha_i(L)$, $\beta_i(L)$ and $\lambda_i(L)$ are finite-order lag polynomials. The focal parameters of interest are the long-run coefficients, ϕ_{1j} and ϕ_{2j} . Note that (2) is linear in $\ln(Y)$ because little evidence of nonlinearity is found after performing Ramsey's RESET test on both (2) and its static version ($L=0$), a result which confirms what Auffhammer and Carson (2007) have found. Two lags are considered in estimating (2) due to the short sample size. However, diagnostic tests on residual serial correlation indicate that two lags are dynamically adequate in general. The detailed test results are not reported here to keep the paper short.

Table 2 lists the estimates of ϕ_{1j} and ϕ_{2j} for the four types of pollutants. A great deal of heterogeneity is immediately noticeable. The long-term income coefficients vary substantially across province as well as pollutants. The majority are negative for waste water pollution irrespective of the regional location of provinces, though many are statistically insignificant. In contrast, most of the income coefficients are positive for solid wastes and SO₂ emission, with those significant ones clustering more heavily in the central and western regions. The results indicate that the nature of pollutants matters more than income. Since waste water pollution is local and highly hazardous, its emission is largely negatively related to income, quite independent of the different development stages of provinces. In fact, the negative relationship is clustered more in the inland regions, possibly reflecting the relative scarcity of water resources there. On the other hand, solid wastes are the least hazardous, albeit local, and hence the income effect becomes more pronounced here. SO₂ emission, though more hazardous than solid wastes, is a global pollutant and therefore exhibit somewhat similar income effect. In comparison, soot pollution is local and visibly unpleasant, but less hazardous than waste water. Its income effect is found to be far less distinct than that of SO₂ or waste water emission. On the whole, the dispersion of coefficient estimates cautions us against applying dynamic panel

regression. It may be feasible to try panel regression for solid wastes and SO₂, especially for the central and western regions. Beijing should be left out as a unique case if panel estimation is to be carried out without regional division. As for the long-term export-led demand effect, the majority of the coefficients are insignificant whereas those found to be significant are either positive or negative. There is some evidence that exports have contributed adversely to solid waste pollution, but there is inadequate evidence for the postulate that the export-led growth strategy has contributed significantly to China's environment degradation in general.

Overall, heterogeneity of the long-run effects is a striking feature of table 2. In fact, the heterogeneity will develop further if we try to build an error-correction model (ECM) consisting not only the long-run effects but also short-run (growth) effects for each province. Although short-run effects are absent from the standard EKC model, their role in explaining the possibly nonlinear, transitional phenomenon of the income effect is undeniable. Experiments with ECMs have thus led us to the issue of how to best represent such transitional features with respect to the existing EKC literature. The next section makes an attempt.

IV. Long-run growth effect of income on pollutant concentration

Many supply-side economic models of pollution decompose the impact into scale, composition and technical effects following the production function approach, eg see Copeland and Taylor (2004).³ Relating the idea to demand-side models, we see that the models of the previous section are essentially focused on the scale effect. Here, we make an attempt to examine the composition or concentration effect.

Most of the composition indicators of pollution are derived from production functions, eg He (2006) and Bao *et al* (2008). Since the present study looks only into the demand-side effect, we choose an alternative route to construct pollutant concentration indicators, using for reference the productivity decomposition method proposed by Nordhaus (2002) and refined by Tang and Wang (2004). Specifically, let us denote the pollutant concentration denominated by industrial output by $Z_I = P_I / Y_I$ and the concentration denominated by the total output by

$Z = P_I / Y$, where P_I stands for industrial pollution. We have:

$$Z = \frac{P_I}{Y} = \frac{P_I}{Y_I} \frac{Y_I}{Y} = Z_I y_I; \quad Y = Y_A + Y_I + Y_S \quad (3)$$

³ Copeland and Taylor also point out that the composition effect can embody the technique effect.

where Y_A , Y_I and Y_S are the outputs of three sectors, ie agriculture, industry and services in GDP. Defining $g(Z_t) = \frac{Z_t - Z_{t-1}}{Z_{t-1}}$ and making use of $\frac{Z_I}{Z} = \frac{1}{y_I}$, we can decompose the changes of pollutant concentration into three parts — its growth against industrial output, $g(Z_{It})$, changes of industrial composition against Y , $g(y_{It})$, and the combined changes, $g(Z_{It})g(y_{It})$:

$$\begin{aligned} g(Z_t) &= \frac{y_{It}(Z_{It} - Z_{It-1}) + Z_{It-1}(y_{It} - y_{It-1})}{Z_{t-1}} = g(Z_{It})y_{It} \frac{Z_{It-1}}{Z_{t-1}} + \Delta y_{It} \frac{Z_{It-1}}{Z_{t-1}} \\ &= g(Z_{It}) + g(Z_{It})g(y_{It}) + g(y_{It}) \end{aligned} \quad (4)$$

The first two parts should represent welfare loss by analogy to the components of ‘welfare gain’ in Nordhaus (2002). We apply (4) to the four types of pollutants in our data set and plot the first two parts in Figures 3 and 4. Notice that the magnitudes of $g(Z_{It})$ dominate those of the second part by a large margin since $g(y_{It})$ tends to be quite small in general. Therefore, we designate $g(Z_{It})$ as the concentration indicator here.

It is also discernible from Figures 3 and 4 that these concentration indicators are far more stationary than the pollution emission series. As the series of $g(Z_{It})$ for different pollutants look quite similar for some provinces, principle components of the four series for each province are calculated to see whether they can be adequately summarised into one or two factors. The results are, unfortunately, negative. Hence, we model $g(Z_{It})$ for each pollutant similarly to what has been done for the scale effect in the previous section. Figures 5 and 6 give the cross-plots of the concentration indicators with GDP growth rates. These are far more randomly distributed than those shown in Figures 1 and 2. Nevertheless, we adopt the same ADL-based model using real GDP growth rate, $g(Y)$, and real export growth rate, $g(X)$, as the explanatory variables:

$$\begin{aligned} g(Z_{Ijt}) &= \alpha_{0j}^z + \alpha_j^z(L)g(Z_{Ij})_{t-1} + \beta_j^z(L)g(Y)_t + \lambda_j^z(L)g(X)_t + u_{jt}^z \\ \Rightarrow \quad g(Z_{Ij}) &= \phi_{0j}^z + \phi_{1j}^z g(Y) + \phi_{2j}^z g(X), \quad \phi_{1j}^z = \frac{\beta_j^z(L)}{1 - \alpha_j^z(L)}; \phi_{2j}^z = \frac{\lambda_j^z(L)}{1 - \alpha_j^z(L)} \end{aligned} \quad (5)$$

As before, two lags are considered but it turns out that one lag is adequate for many provinces. Again, RESET diagnostic test shows little evidence of nonlinearity. Table 3 lists the estimates of ϕ_{1j}^z and ϕ_{2j}^z for the four types of pollutants. The majority of them are statistically insignificant, as can be anticipated from Figures 5 and 6. For those significant ones, there are

some cases of negative income growth effect for waste water in the coastal and central regions, and for SO₂ mainly in the coastal region; there are two cases of positive income growth effect for solid wastes, three cases of positive export growth effect for waste water, all clustering in the central region. It seems that the relatively hazardous nature of waste water and SO₂ are related to the negatively significant income growth effects more than the regional differences in economic growth, a result somehow different from the general finding that ‘concentrations of pollutants may decline from middle income levels’ (Stern, 2004b). As for the export growth effect, it remains largely insignificant, a finding which conforms to the general finding of no substantial role of trade (see Stern, 2004b).

V. Concluding remarks

A number of lessons can be drawn from the present empirical investigation:

1. Industrial pollutant emissions may go positively or negatively with income in the long run quite independent of different income levels of the provinces. There is little evidence for an inverted U shape curve as postulated by simple EKC models. However, there are some signs of alleviation in pollutant concentration as income grows.
2. The hazardous nature of industrial pollutants is found to be a more important factor than income or economic openness. In particular, the income effect for waste water is found to be negative for many provinces in terms of both scale and concentration, while the reverse is notable for solid wastes. The finding casts doubts on the empirical adequacy of simple EKC models in explaining pollution primarily by income growth.
3. The most notable is probably heterogeneity of the income coefficient estimates. In fact, the diversity corroborates and reinforces what Zhang and Yang (2008) have found from modelling four less developed provinces (Mongolia, Guangxi, Ningxia and Xinjiang). The result cautions us against simple panel model specification and estimation.
4. There lacks enough evidence to support the criticism that China’s export-led growth strategy is a key aggravating factor of industrial pollution.

On the whole, the present study suggests that it is importance for future research to consider the dynamic and heterogeneous features in data when modelling the pollution-income relationship. It also indicates the need to control for the geographic differences of the provinces, say in terms of resource scarcity and population density, before imposing panel homogeneity of the income effect.

Appendix

Data sources:

National Bureau of Statistics: *Statistical Yearbook of China*, various issues; *Comprehensive Statistical Data and Materials on 50 Years of New China* (1999)

Definition of industrial pollutants:

Waste Water: total volume of waste water discharge from table ‘Discharge and Treatment of Industrial Waste Water by Region’;

Solid wastes: volume of industrial solid wastes produced from table ‘Production, Treatment and Utilization of Industrial Solid Wastes by Region’;

Soot: volume of industrial soot emission from table ‘Emission and Treatment of Industrial Waste Gas by Region’;

Sulphur dioxide (SO₂): volume of sulphur dioxide emission by industry from table ‘Emission and Treatment of Industrial Waste Gas by Region’.

Abbreviation of provinces by region:

Coastal region		Central region		Western region	
BJ	Beijing	SX	Shanxi	SC	Sichuan
TJ	Tianjin	NM	Inner Mongolia	CQ	Chongqing
HB	Hebei	JL	Jilin	GZ	Guizhou
LN	Liaoning	HLJ	Heilongjiang	YN	Yunnan
SH	Shanghai	AH	Anhui	SHX	Shaanxi
JS	Jiangsu	JX	Jiangxi	GS	Gansu
ZJ	Zhejiang	HN	Henan	QH	Qinghai
FJ	Fujian	HUB	Hubei	NX	Ningxia
SD	Shandong	HUN	Hunan	XJ	Xinjiang
GD	Guangdong	GX	Guangxi		
HAN	Hainan				

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Table 1. Ranks: GDP – per capita real GDP; ID/GDP – ratio of industrial value added to GDP; WW – per capita waste water; WS – per capita solid waste; SO₂ – per capita SO₂; Soot – per capita soot

year	1991						2000						2007					
province	GDP	ID/GDP	WW	WS	SO ₂	Soot	GDP	ID/GDP	WW	WS	SO ₂	Soot	GDP	ID/GDP	WW	WS	SO ₂	Soot
BJ	2	7	28	27	22	27	2	18	28	22	28	28	3	25	30	25	30	29
TJ	3	2	30	28	23	28	3	4	30	28	18	23	2	2	28	27	25	25
HB	18	8	23	6	13	11	14	5	23	12	11	14	13	8	15	11	14	17
LN	5	4	16	5	14	9	8	10	12	9	15	16	9	12	19	10	16	15
SH	1	1	19	29	25	29	1	1	26	27	29	30	1	4	29	29	29	30
JS	7	6	13	25	18	24	5	6	19	26	21	25	4	10	16	26	27	24
ZJ	6	9	22	30	24	25	4	2	20	29	25	26	5	9	12	28	26	26
FJ	10	21	10	24	29	19	7	14	25	24	30	27	8	13	4	21	24	28
SD	9	12	29	20	12	18	9	8	27	23	16	24	7	5	25	23	21	23
GD	4	15	26	26	26	22	6	7	29	30	26	29	6	6	22	30	28	27
HAN	13	30	4	18	27	20	11	30	4	25	20	19	15	30	10	24	23	22
SX	17	5	24	3	8	12	18	3	24	2	6	3	16	3	23	3	8	2
NM	16	28	15	2	2	3	16	28	13	3	3	6	10	20	26	2	3	4
JL	12	10	14	16	20	21	13	13	18	16	22	11	12	16	18	16	19	10
HLJ	8	3	25	15	28	26	10	9	21	15	27	13	14	17	24	17	18	8
AH	27	11	9	13	16	6	15	12	22	18	24	22	17	7	21	18	22	20
JX	24	26	3	1	9	1	20	16	16	7	17	17	23	1	13	9	17	19
HN	26	18	17	19	19	16	24	15	8	19	14	9	21	15	11	15	12	11
HUB	15	14	6	22	15	14	12	11	9	21	19	21	11	14	17	22	20	21
HUN	20	24	2	17	10	8	19	19	6	20	13	15	22	19	6	20	15	12
GX	25	29	1	12	4	5	22	23	3	14	5	4	25	21	2	14	10	7
CQ	28	17	7	21	-	-	26	21	1	13	4	20	20	18	3	19	9	18
SC	23	22	5	9	7	7	23	27	5	11	9	7	19	23	8	13	13	16
YN	30	23	12	14	3	4	30	25	11	1	2	2	30	27	27	1	2	5
GZ	21	20	18	7	17	17	29	20	14	6	12	10	29	24	14	4	11	13
SHX	22	16	21	11	5	15	27	17	17	8	8	8	28	11	9	8	7	9
GS	29	13	8	8	6	10	28	22	7	5	7	12	26	28	20	7	6	14
QH	14	25	20	10	21	23	17	29	10	10	23	5	18	26	5	5	5	6
NX	19	19	11	4	1	2	25	24	2	4	1	1	27	22	1	6	1	1
XJ	11	27	27	23	11	13	21	26	15	17	10	18	24	29	7	12	4	3

Table 2. Long-run demand coefficients with respect to real GDP: equation (2)

	Waste Water		Waste solid		SO ₂		Soot	
	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2
BJ	-1.475 (0.694)*	-0.7124 (2.775)	-0.389 (0.756)	1.393 (3.248)	-1.762 (3.262)	-6.86 (19.46)	-1.592 (0.346)*	2.276 (3.687)
TJ	-0.0385 (0.0533)	0.9444 (0.3958)*	0.4501 (0.1587)*	1.1696 (0.5079)*	-0.0141 (0.0678)	0.323 (0.5104)	-0.1513 (0.118)	-0.0424 (0.7401)
HB	0.3087 (0.0773)*	0.4483 (0.4207)	0.7892 (0.0805)*	1.1229 (0.42)*	0.2675 (0.047)*	-0.1412 (0.3811)	0.0336 (0.106)	-0.5478 (0.8296)
LN	-0.1685 (0.0973)	0.871 (0.2606)*	0.9725 (0.6839)	0.4831 (0.2882)	0.1304 (0.1717)	2.1424 (0.7645)*	0.2242 (0.2491)	1.6467 (0.7919)
SH	-0.6676 (0.0708)*	-0.1396 (0.4583)	0.3778 (0.0283)*	0.3113 (0.166)	0.3465 (0.7469)	-1.8903 (5.017)	-0.876 (0.1725)*	1.0341 (1.125)
JS	0.4444 (0.1687)*	-0.9789 (0.7537)	0.3515 (0.2287)	1.4903 (0.9527)	0.4452 (0.2215)	-1.082 (0.9107)	0.0714 (0.0774)	-0.9419 (0.2917)*
ZJ	-1.2047 (3.359)	2.665 (4.458)	0.3833 (0.077)*	1.0036 (0.1716)*	0.245 (0.1969)	0.4511 (0.3379)	-0.4235 (0.5922)	0.6538 (1.01)
FJ	-0.7557 (0.9093)	4.1924 (3.028)	0.2469 (0.7088)	2.5319 (2.234)	0.1287 (0.4898)	1.9251 (1.354)	-0.2676 (0.3221)	1.2083 (0.8517)
SD	0.4091 (0.1878)*	0.1054 (0.9007)	0.5211 (0.0755)*	1.3124 (0.4149)*	0.5054 (0.1323)*	-2.5983 (0.8736)*	0.2258 (0.1548)	-2.466 (1.029)*
GD	0.4657 (0.1886)*	1.0046 (1.112)	0.5797 (0.4169)	5.0164 (7.123)	0.7905 (0.0428)*	-1.2933 (0.3325)*	-0.0385 (0.1313)	-2.2078 (1.108)
HAN	-0.2218 (0.0502)*	-0.2111 (0.1903)	0.955 (0.5496)	-0.0572 (1.046)	0.0556 (0.0995)	-0.1471 (0.3696)	-1.1589 (0.7835)	-0.4011 (1.834)
SX	-0.1347 (0.2377)	2.4126 (2.811)	0.9832 (0.058)*	-0.9964 (0.3236)*	0.5487 (0.0492)*	-0.0382 (0.2405)	0.7759 (0.2813)*	-0.497 (1.281)
NM	-0.2191 (0.262)	0.1025 (1.065)	0.9343 (0.6194)	3.031 (2.323)	0.6574 (0.2155)*	3.0012 (1.3)*	0.4439 (0.1739)*	4.8349 (0.8733)*
JL	-0.0392 (0.3974)	0.3691 (1.322)	-2.1363 (5.503)	-3.3697 (8.029)	0.09 (0.284)	-1.4568 (1.371)	-0.8667 (0.2203)*	-3.295 (1.01)*
HLJ	-0.6305 (0.0567)*	0.0659 (0.0533)	0.0043 (0.0918)	0.5337 (0.0897)*	-0.0286 (0.2155)	0.8595 (0.16)*	-0.0922 (0.0657)	0.2632 (0.0849)*
AH	-0.2661 (0.0601)*	3.1222 (0.99)*	0.6177 (0.4876)	3.5143 (3.322)	0.3585 (0.1474)*	0.413 (1.157)	0.3113 (0.4504)	-5.68 (5.825)
JX	0.7245 (1.62)	2.0908 (2.673)	0.6112 (0.0654)*	-0.392 (0.5899)	0.5357 (0.1459)*	-0.9711 (1.709)	-0.1708 (0.112)	0.3634 (1.324)
HN	0.2118 (0.0546)*	0.6442 (0.8941)	0.8648 (0.1081)*	1.637 (0.6216)*	0.8515 (0.1409)*	0.1463 (3.05)	0.5804 (0.0484)*	-4.4055 (0.9929)*
HUB	-0.2508 (0.0293)*	0.0679 (0.3099)	0.5833 (0.0564)*	1.5567 (0.5857)*	0.2843 (0.0879)*	0.216 (1.425)	-0.053 (0.087)	0.9199 (1.38)
HUN	-0.3095 (0.107)*	0.1066 (0.6375)	0.6293 (0.1654)*	1.17859 (0.9458)	0.2478 (0.0821)*	-0.1269 (0.5745)	0.1669 (0.1565)	-1.1088 (1.092)
GX	0.6075 (0.184)*	-0.0813 (0.5295)	0.7923 (0.0518)*	-0.1921 (0.2317)	0.4929 (0.0709)*	-0.0054 (0.326)	0.4237 (0.186)*	-0.8399 (1.059)
SC	-0.0882 (0.1253)	0.6327 (1.177)	0.6248 (0.1206)*	-0.6231 (0.8607)	-0.0116 (0.1742)	1.0658 (1.418)	0.8861 (0.6186)	-7.9005 (4.94)
CQ	0.3103 (0.1062)*	-0.0525 (0.9067)	0.8656 (0.0797)*	-2.1484 (0.7783)*	2.0516 (0.9317)	-3.8165 (2.678)	1.3285 (0.0644)*	-3.5191 (0.1679)*
GZ	-0.4985 (0.0619)*	1.4895 (0.7933)	1.1244 (0.1013)*	-2.5638 (1.334)	0.1713 (0.1912)	0.5152 (1.621)	-0.029 (0.0737)	-1.1762 (0.7387)
YN	-0.1928 (0.0616)*	1.4621 (0.4249)*	1.9934 (1.795)	5.6356 (9.225)	0.4158 (0.0929)*	0.26 (0.4625)	-0.1587 (0.5941)	-1.3376 (3.015)
SHX	0.1694 (0.2622)	-1.8683 (2.596)	0.9447 (0.1026)*	-0.0436 (0.493)	0.2618 (0.1163)*	-0.9463 (1.878)	-0.1594 (0.1024)	1.5313 (0.5202)*
GS	-0.7054 (0.1005)*	-0.3043 (1.553)	0.5281 (0.1381)*	0.7973 (1.116)	0.4342 (0.1284)*	3.631 (1.885)	-0.299 (0.1715)	3.735 (3.211)
QH	-0.3299 (0.2851)	-0.0318 (1.037)	2.3521 (1.835)	4.447 (4.868)	1.5667 (0.6725)*	3.4699 (2.109)	0.5478 (0.1787)*	0.3177 (0.6022)
NX	0.8396 (0.273)*	-0.9065 (0.8845)	1.5091 (0.6287)*	-3.1084 (1.649)	0.7408 (0.1267)*	-1.0386 (0.4282)*	0.0584 (0.1941)	-0.1371 (0.6104)
XJ	-0.0045 (0.1077)	0.295 (0.1209)	0.6205 (0.1395)*	0.2022 (0.0924)*	0.386 (0.3534)	0.808 (0.4399)	-1.088 (0.5547)	0.9038 (0.3793)*

Note: Standard errors in brackets; estimates significant at 5% are marked by stars.

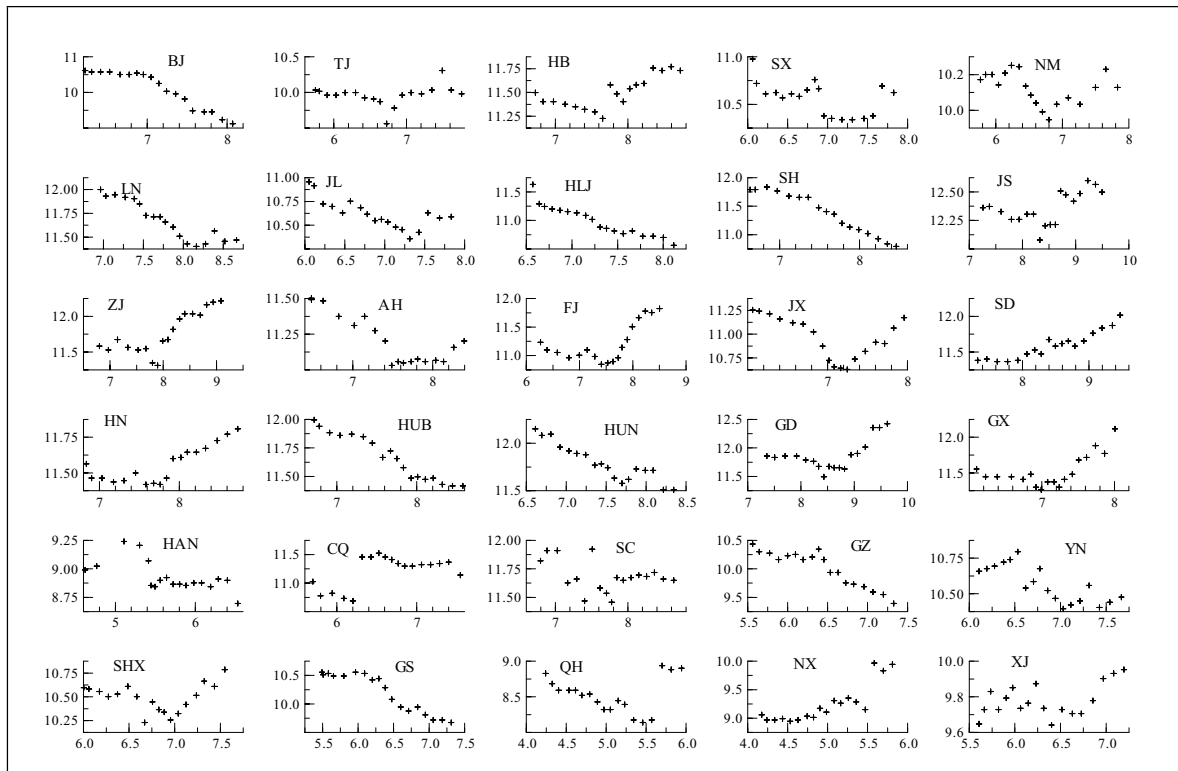
Table 3. Long-run demand coefficients for GDP growth: equation (5)

	Waste Water		Waste solid		SO ₂		Soot	
	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2	ϕ_1	ϕ_2
BJ	-0.1084 (0.3367)	0.049 (0.0176)	0.1114 (0.3129)	0.018 (0.0135)	1.184 (0.5417)	0.0535 (0.0179)*	0.092 (0.282)	0.0802 (0.0178)*
TJ	0.9822 (0.9165)	-0.1588 (0.2588)	-1.38 (1.169)	0.536 (0.2855)	-0.4852 (1.046)	0.3934 (0.295)	-2.265 (1.749)	0.4352 (0.5677)
HB	-2.0948 (1.081)	0.0348 (0.1705)	-2.439 (1.825)	0.46 (0.3056)	-0.346 (0.5005)	0.0011 (0.0787)	-1.108 (2.243)	-0.2966 (0.3511)
LN	-0.3734 (0.5456)	-0.0094 (0.1025)	-0.8798 (1.28)	0.1808 (0.2436)	0.6581 (1.39)	0.266 (0.2701)	0.1886 (0.9809)	-0.3549 (0.1866)
SH	0.2105 (0.0929)*	-0.0304 (0.0461)	-0.3993 (0.3802)	0.1652 (0.1397)	-0.319 (0.44)	0.766 (0.4952)	-0.4319 (0.5127)	0.3402 (0.2637)
JS	-1.5918 (0.485)*	0.2425 (0.1502)	-1.4681 (0.8059)	0.2714 (0.2266)	-0.952 (0.3639)*	0.087 (0.0977)	0.4186 (1.272)	-0.157 (0.29)
ZJ	-2.6735 (0.4117)*	0.088 (0.2174)	-1.9356 (0.6168)*	0.1479 (0.2355)	-2.731 (0.6052)*	0.2692 (0.2772)	-1.8608 (3.004)	-0.7069 (1.01)
FJ	-2.6123 (0.6466)*	0.6911 (0.3237)	-3.983 (1.989)	-0.7162 (0.9156)	-3.8304 (1.314)*	0.6923 (0.4858)	-2.0763 (1.119)	-0.134 (0.589)
SD	-1.0572 (0.6547)	0.0786 (0.1736)	-1.4913 (1.14)	0.4959 (0.3728)	0.2022 (0.4082)	-0.1903 (0.1068)	-2.087 (1.407)	-0.2398 (0.3721)
GD	-2.5821 (1.527)	0.6525 (0.7967)	-1.8284 (1.669)	0.5245 (0.8637)	-1.3431 (0.7408)	-0.03 (0.3109)	-3.2994 (3.023)	0.3446 (1.28)
HAN	-0.878 (0.6178)	-0.1533 (0.333)	-0.7749 (0.6299)	-0.1204 (0.3788)	-0.6575 (0.8683)	0.1601 (0.5343)	-0.587 (2.015)	-0.6507 (0.9102)
SX	0.7387 (0.8682)	-0.0755 (0.1156)	-0.7386 (0.8577)	-0.2641 (0.1292)	-1.2858 (0.3968)*	-0.163 (0.0634)*	-8.2123 (1.047)*	-0.8205 (0.1676)*
NM	-0.5113 (0.2763)	-0.0964 (0.1605)	1.9208 (0.3055)*	-0.8059 (0.214)*	1.1755 (0.8964)	-1.1603 (0.5387)	0.2079 (0.8401)	-0.0242 (0.2721)
JL	0.0153 (1.225)	-0.1142 (0.1943)	0.7945 (1.27)	-0.2562 (0.2607)	0.2765 (1.754)	-0.214 (0.2947)	-0.5905 (2.101)	-0.3504 (0.3008)
HLJ	-0.1929 (0.4132)	-0.0043 (0.0542)	2.5643 (0.5589)*	-0.0819 (0.0512)	-1.001 (1.437)	0.2527 (0.1685)	-0.6045 (0.8084)	0.0309 (0.0724)
AH	-1.6078 (0.5307)*	0.4066 (0.1809)*	-1.2503 (0.7318)	0.2104 (0.2317)	0.3121 (0.8195)	-0.9091 (0.4775)	1.388 (2.427)	-1.9814 (1.239)
JX	-6.5942 (2.305)*	1.3046 (0.4569)*	-2.1685 (0.6328)*	0.047 (0.0816)	0.61 (3.8)	-0.3918 (0.8579)	-3.9037 (2.34)	0.5095 (0.5296)
HN	-0.2987 (1.209)	-0.3423 (0.4609)	0.2974 (0.7839)	0.1491 (0.143)	0.2736 (0.8795)	-0.4197 (0.3099)	-0.1062 (0.6874)	-0.7391 (0.2884)*
HUB	-1.2145 (0.4704)*	0.2517 (0.1057)*	-1.7782 (1.158)	0.4402 (0.2834)	-2.0012 (1.382)	0.1954 (0.2439)	-1.7063 (2.363)	-0.1695 (0.3944)
HUN	-1.886 (0.8786)	0.0502 (0.1234)	-0.558 (1.679)	0.0786 (0.2437)	-0.5451 (1.121)	-0.0616 (0.2097)	-3.0879 (3.132)	-0.0511 (0.4591)
GX	-1.9517 (1.609)	0.172 (0.5719)	-1.7469 (0.3457)*	-0.0733 (0.0878)	-0.3582 (0.6753)	-0.4283 (0.2015)	-2.7168 (2.108)	0.227 (0.8217)
SC	-2.3703 (1.472)	0.0228 (0.2534)	0.7485 (1.45)	-0.2643 (0.21)	-3.7218 (1.845)	0.3073 (0.3327)	-4.8973 (4.429)	-0.9234 (0.7971)
CQ	0.9588 (2.607)	0.3328 (0.3232)	-0.6791 (0.8667)	-0.5549 (0.1131)*	1.4403 (1.77)	-0.1093 (0.1623)	2.1474 (3.646)	-1.2289 (0.4931)*
GZ	-0.6095 (0.8829)	0.1786 (0.1194)	0.3788 (4.776)	-1.0594 (0.7615)	3.1809 (1.282)*	-0.1829 (0.1601)	-1.3764 (4.194)	-0.1498 (0.5464)
YN	1.3326 (0.8505)	-0.133 (0.1138)	0.8067 (2.548)	0.1387 (0.3824)	-0.1153 (1.019)	-0.0363 (0.1309)	-1.1216 (4.004)	-1.5536 (0.7022)*
SHX	-0.1836 (1.434)	0.1611 (0.1364)	2.3677 (1.998)	-0.0448 (0.1971)	-2.1782 (1.155)	0.2581 (0.0868)*	4.3668 (3.41)	-0.1332 (0.396)
GS	0.8683 (1.088)	0.10411 (0.1181)	0.2 (1.025)	0.1656 (0.1313)	-0.3677 (1.689)	0.1009 (0.1872)	-1.3296 (2.119)	0.4086 (0.276)
QH	-2.9524 (2.799)	0.12 (0.3485)	3.534 (22.29)	-4.5493 (15.89)	1.2265 (2.565)	0.5287 (0.3092)	-0.3145 (1.719)	-0.1582 (0.1472)
NX	5.8247 (3.621)	-0.1218 (0.3584)	2.1124 (1.052)	-0.2091 (0.1111)	1.2038 (1.832)	-0.1268 (0.1141)	-1.5822 (2.867)	0.1572 (0.2945)
XJ	-0.343 (0.5164)	0.0978 (0.0561)	0.532 (0.9344)	0.0956 (0.0973)	-0.0767 (3.424)	0.2147 (0.382)	3.0339 (2.761)	0.1376 (0.2743)

Note: Standard errors in brackets; estimates significant at 5% are marked by stars.

Figure 1. Cross-plots:

Waste water and real GDP (in logarithm)



Solid wastes and real GDP (in logarithm)

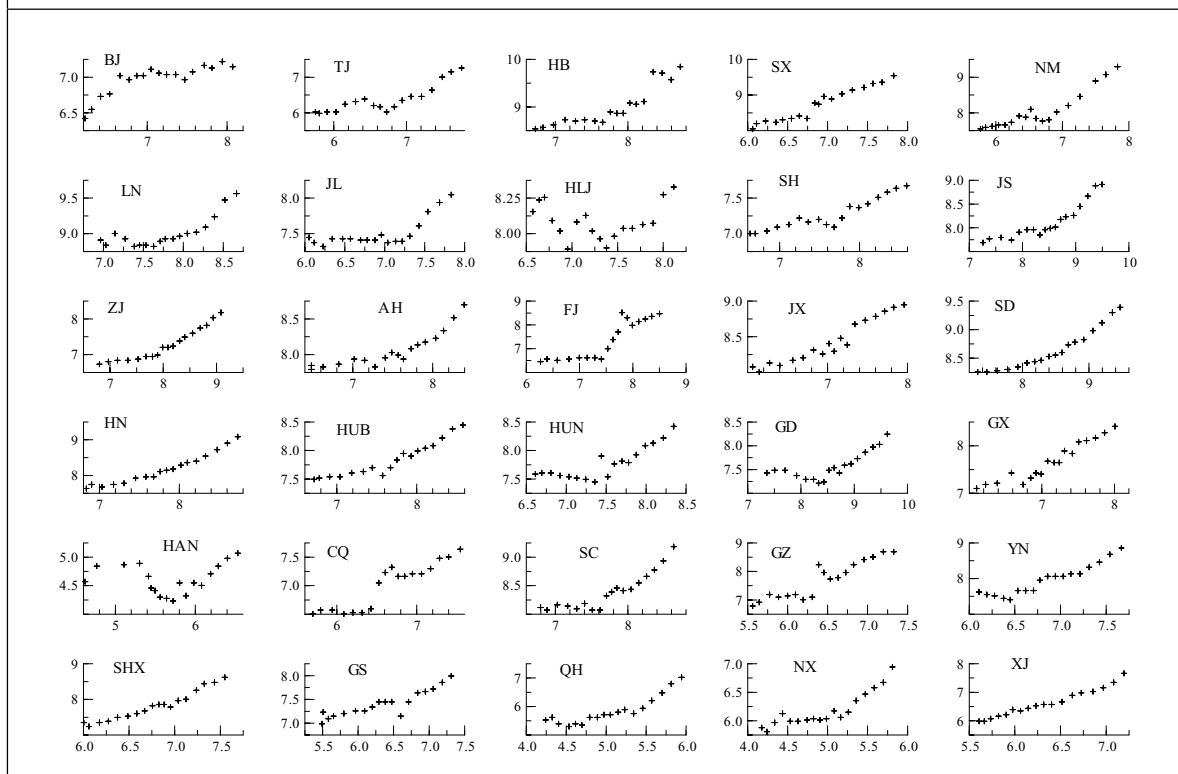
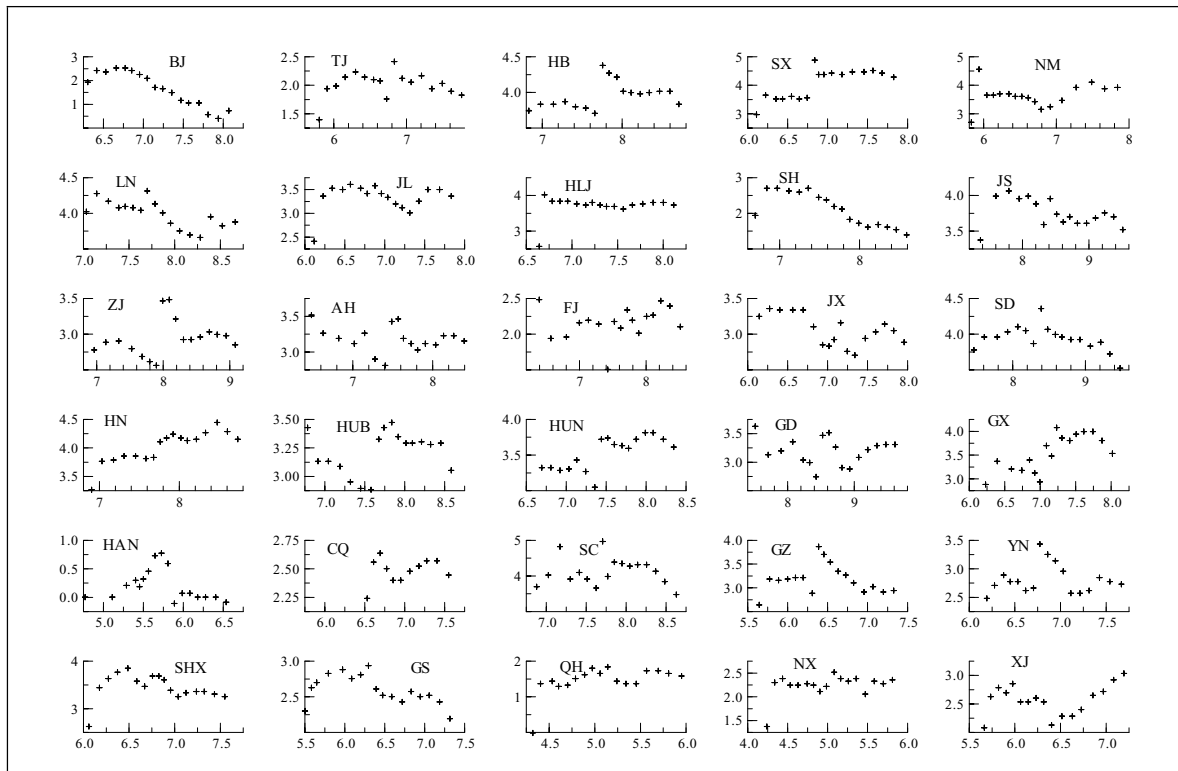


Figure 2. Cross-plots:
SO₂ and real GDP (in logarithm)



Soot emission and real GDP (in logarithm)

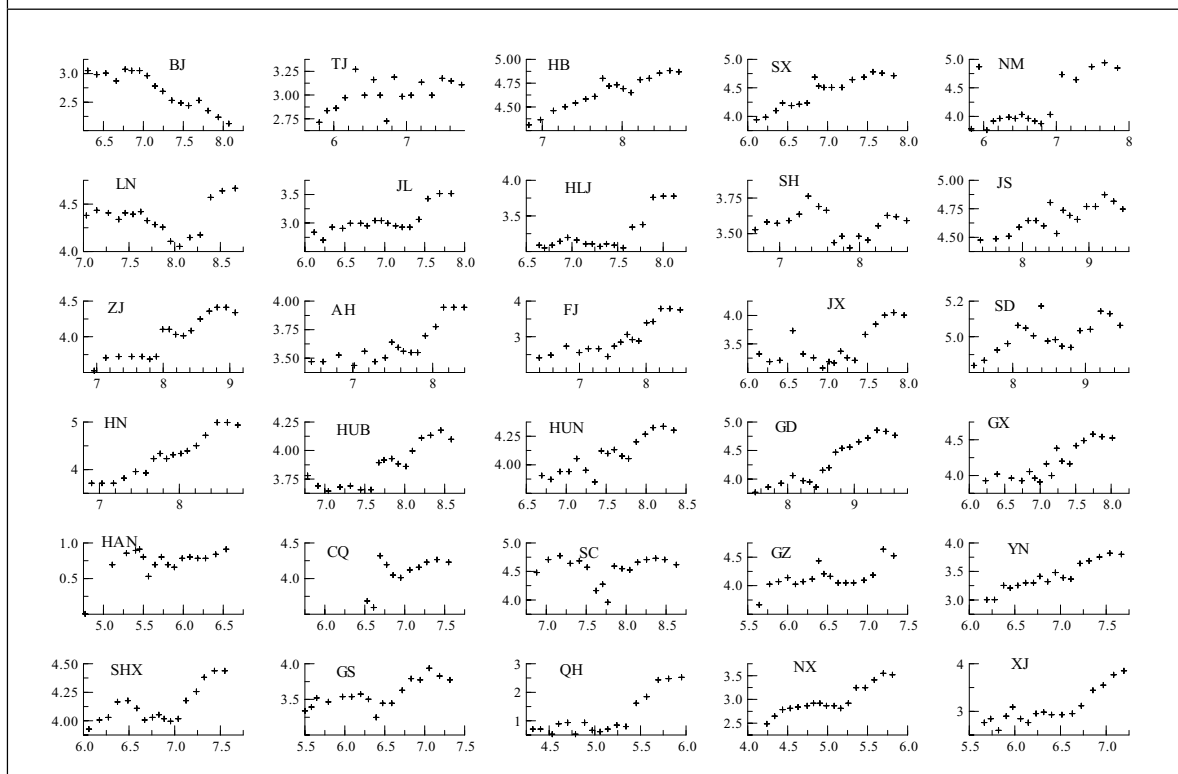
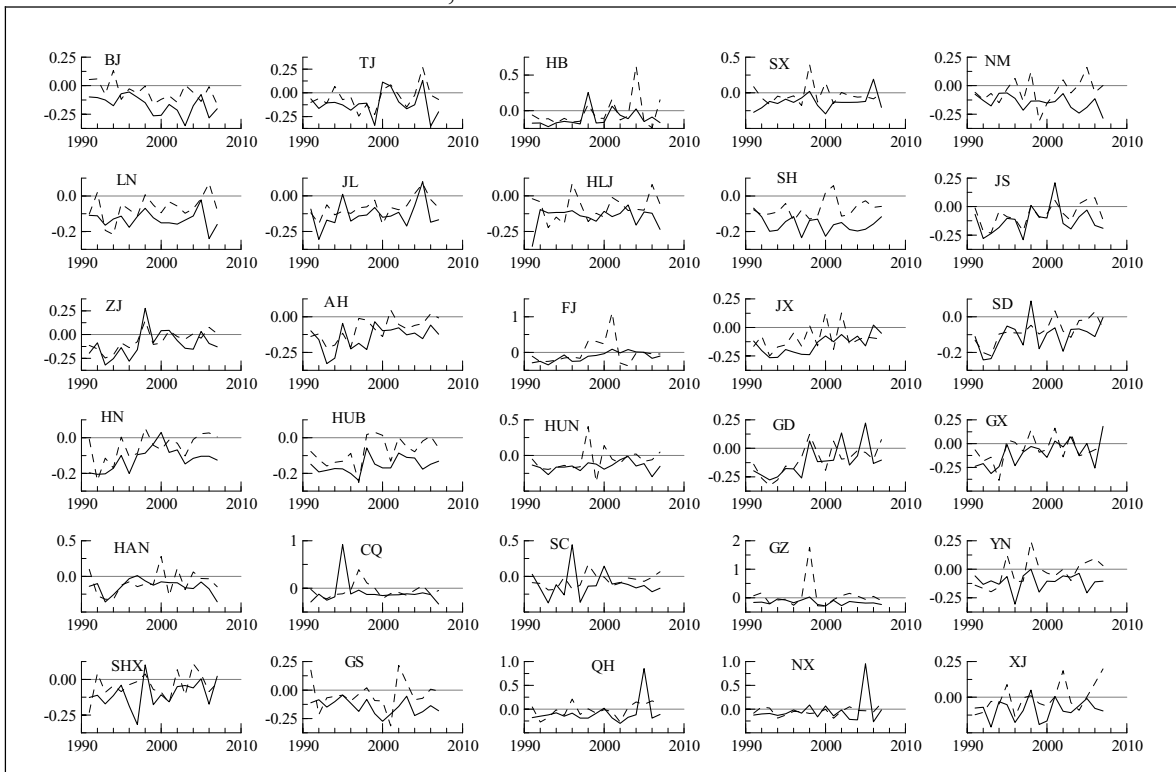


Figure 3. Concentration indicator: $g(Z_{it})$

Solid curve: waste water; dotted curve: solid wastes



Solid curve: SO₂; dotted curve: soot

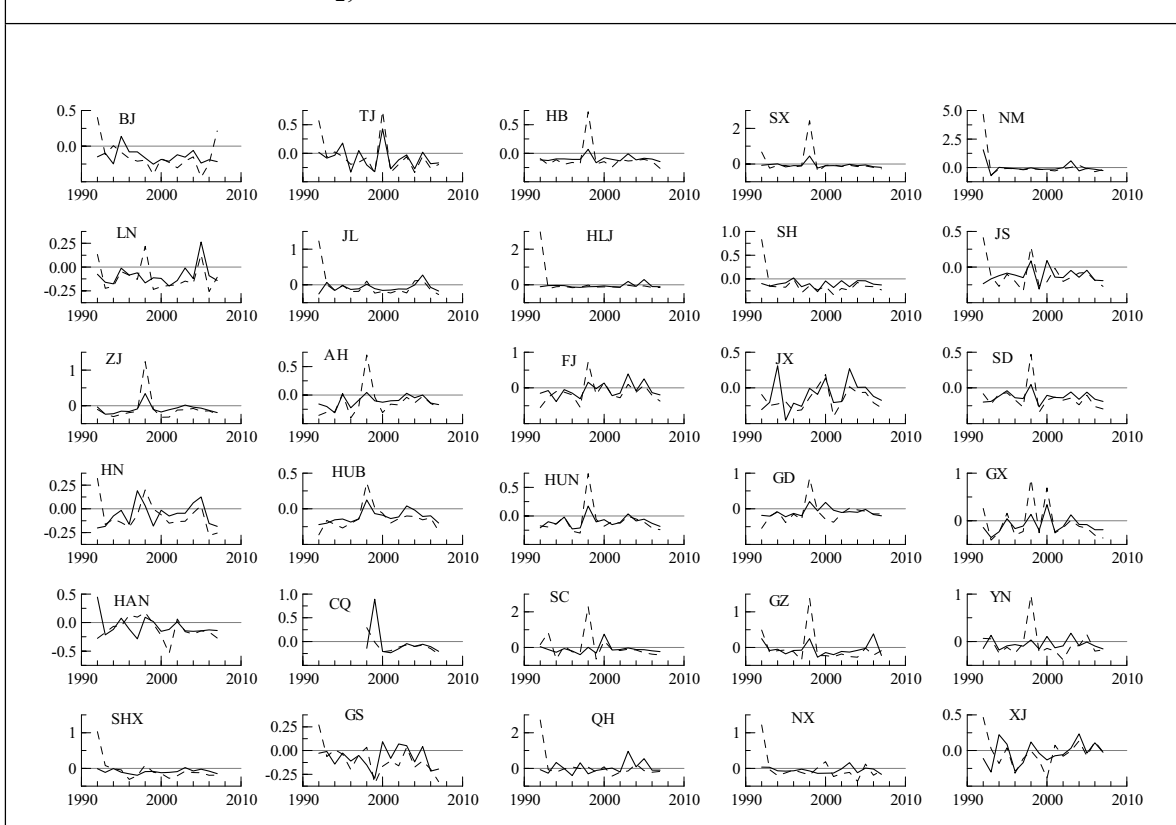
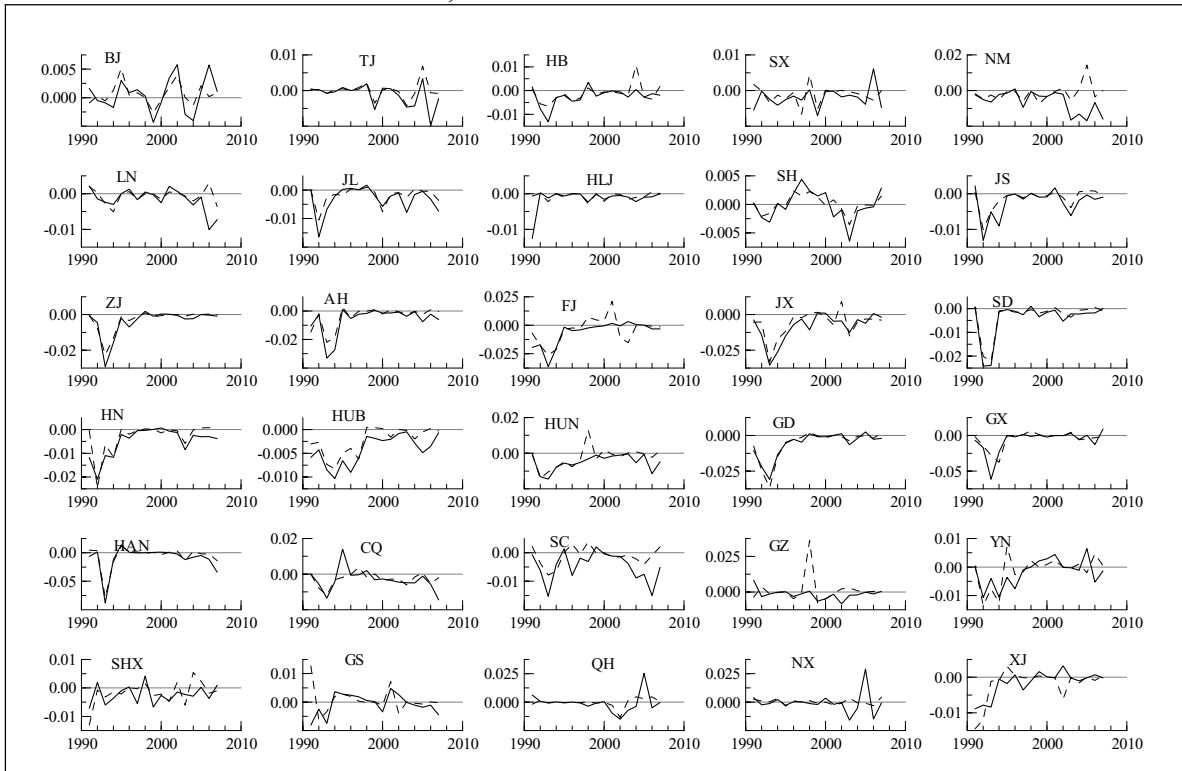


Figure 4. Combined concentration indicator: $g(Z_t)g(y_t)$

Solid curve: waste water; dotted curve: solid wastes



Solid curve: SO₂; dotted curve: soot

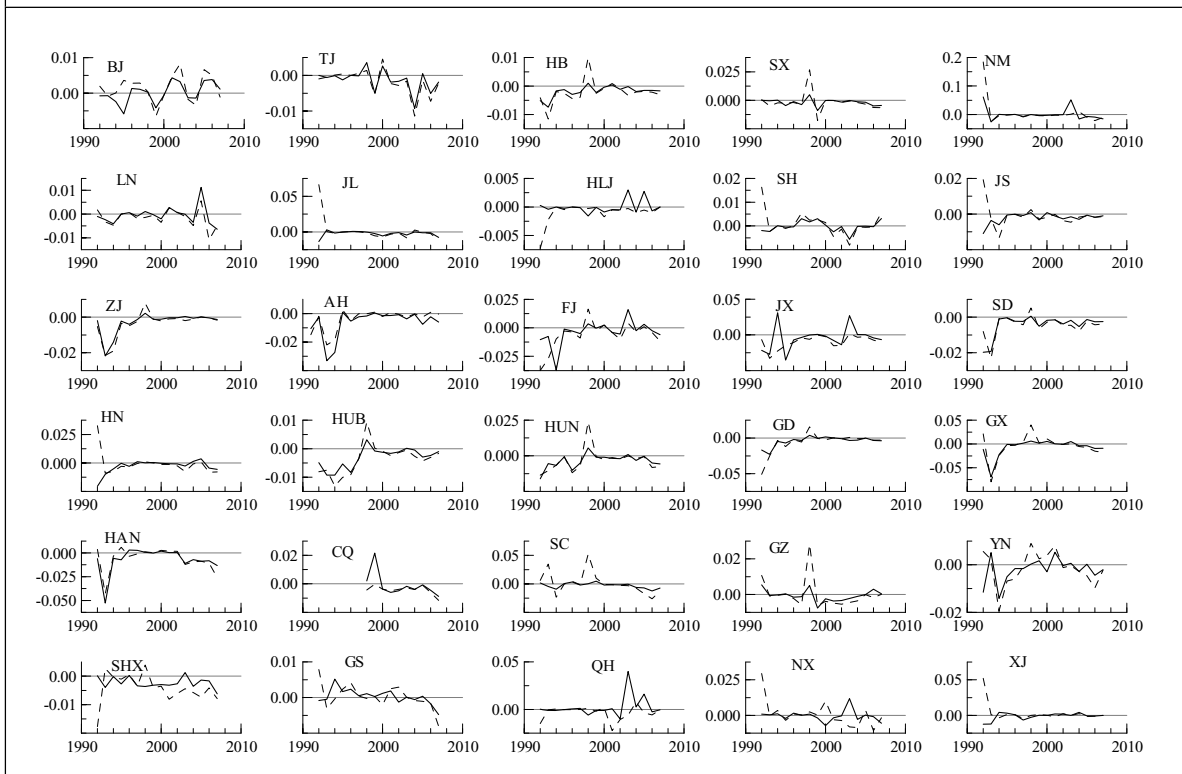
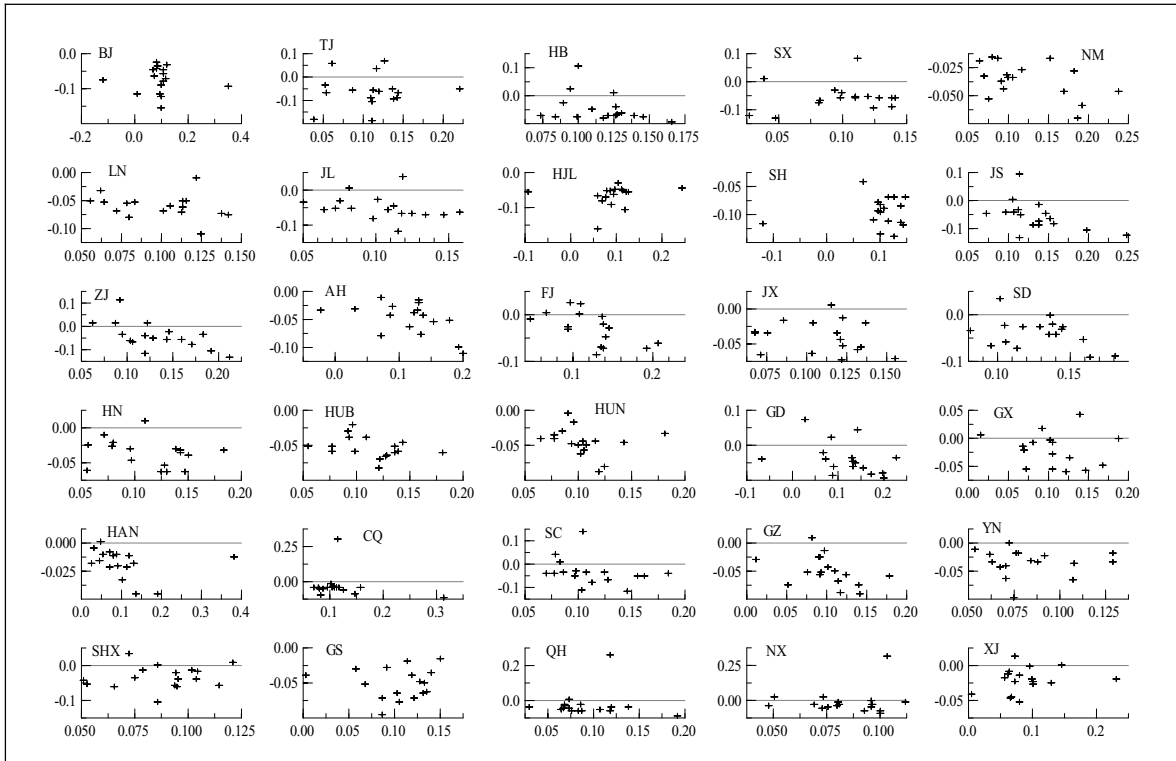


Figure 5. Cross-plots:

Waster water concentration and GDP growth



Solid waste concentration and GDP growth

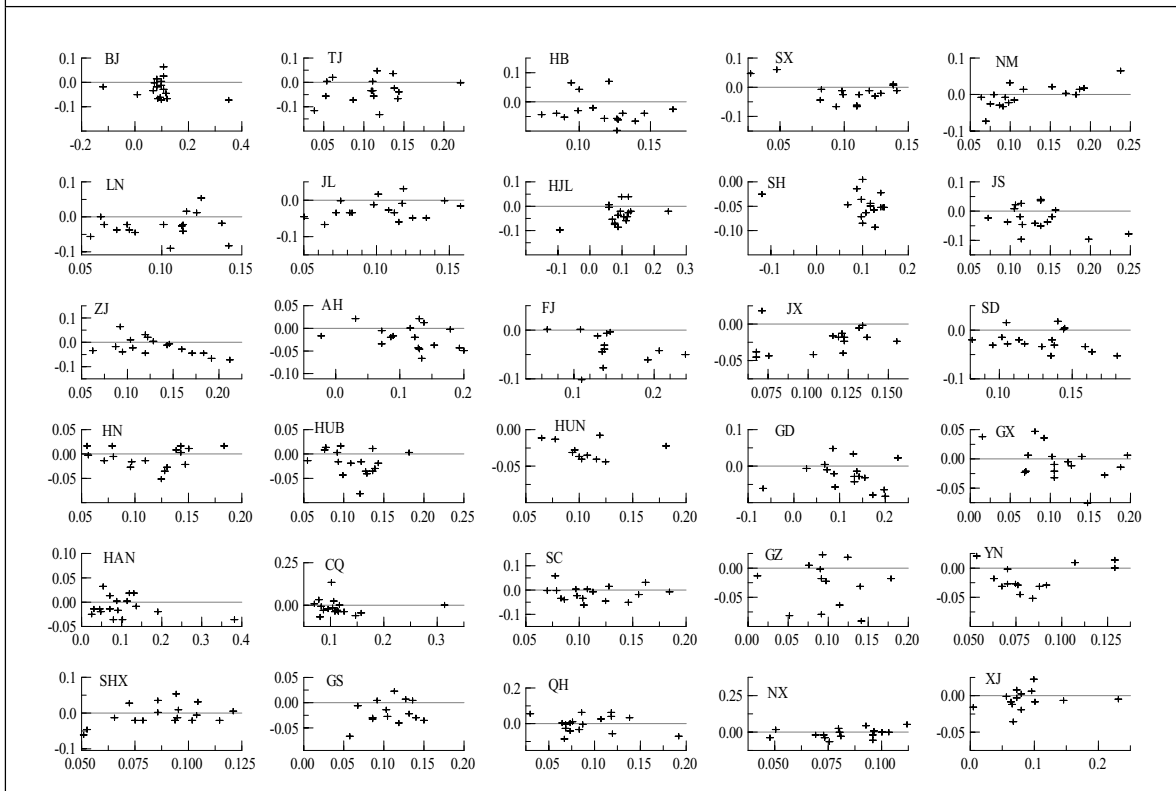
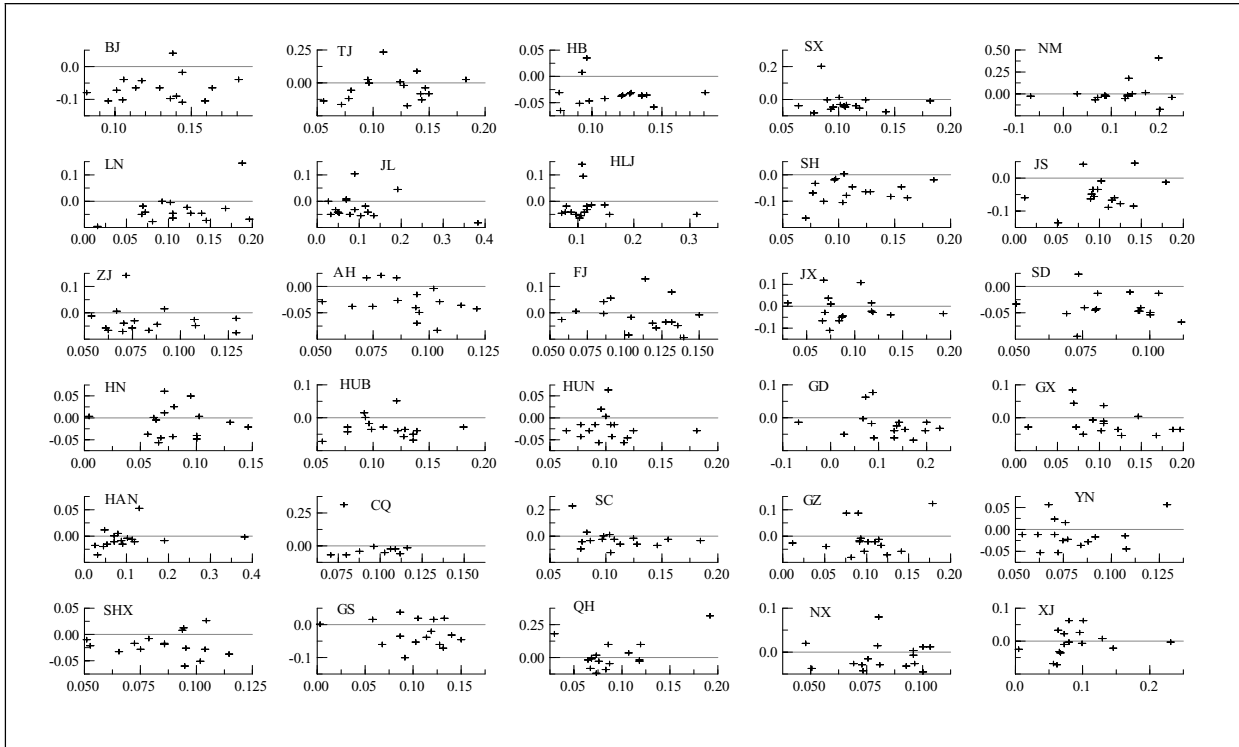
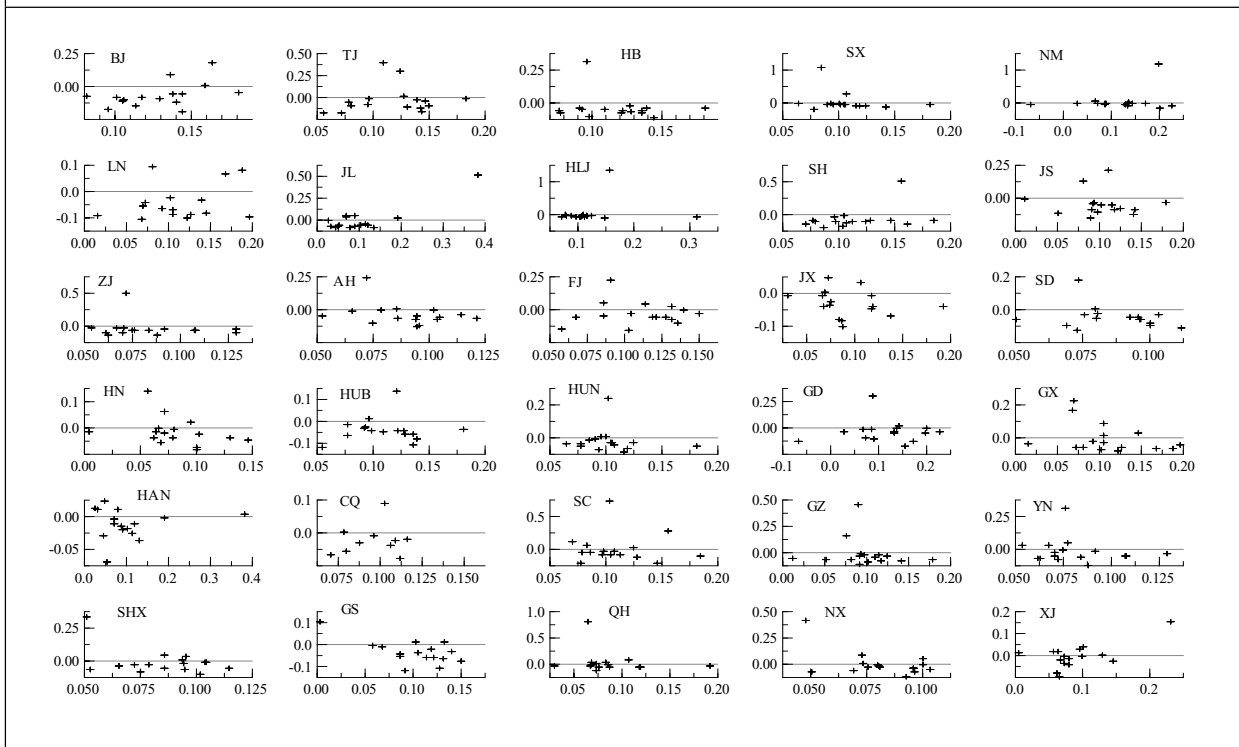


Figure 6. Cross-plots:

SO₂ concentration and GDP growth



Soot concentration and GDP growth



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