

Is there an inverted U-shaped curve? Empirical analysis of the Environmental Kuznets Curve in agrochemicals

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Abstract As the largest contributor to water impairment, agriculture-related pollution has attracted the attention of scientists as well as policy makers, and quantitative information is being sought to focus and advance the policy debate. This study applies the panel unit root, heterogeneous panel cointegration, and panel-based dynamic ordinary least squares to investigate the Environmental Kuznets Curve on environmental issues resulting from use of agricultural synthetic fertilizer, pesticide, and film for 31 provincial economies in mainland China from 1989 to 2009. The empirical results indicate a positive long-run co-integrated relationship between the environmental index and real GDP per capita. This relationship takes on the inverted U-shaped Environmental Kuznets Curve, and the value of the turning point is approximately 10,000–13,000, 85,000–89,000 and over 160,000 CNY, for synthetic fertilizer nitrogen indicator, fertilizer phosphorus indicator and pesticide indicator, respectively. At present, China is subject to tremendous environmental pressure and should assign more importance to special agriculture-related environmental issues.

Keywords Environmental Kuznets Curve, agrochemical, China

1 Introduction

The usage of agrochemicals has become the symbol of modern agricultural civilization. Agriculture-related pollutants, however, have been identified as the dominant contributor to contamination of water systems globally [1],

such as surface water eutrophication and groundwater nitrate enrichment at both the catchment scale [2–4] and the national or regional scale [2,5–8]. Environmental degradation and social transition issues from agriculture and rural areas have influenced sustainable development around the world, especially in developing countries.

Since the implementation of reform and open-door policy, China has experienced rapid economic growth, especially in key agricultural developments. With China's relatively small arable area per capita, increasing crop production is mainly dependent on the use of agrochemicals. The consumption of agrochemicals has been increasing continuously, up to an annual growth rate of above 10% at many points. At present, China is the largest producer and consumer of agricultural synthetic fertilizer, pesticide, and film. The total synthetic fertilizer consumption has escalated 6 times from 8.693 million tons in 1978 to 54.044 million tons in 2009, accordingly the use of nitrogen fertilizer, phosphate fertilizer and compound fertilizer has an increasing trend wholly. Nitrogen fertilizer consumption rose from 15.368 million tons in 1989 to 23.299 million tons in 2009, and accounted for approximately 50% of the total fertilizer consumption. The fertilizer consumption per hectare of cultivated area reached about 450 kg/hectare in 2009 and has far exceeded the 225 kg/hectare threshold that is commonly regarded in developed countries as the maximum permissible rate if water pollution is to be prevented. A rapid increase in the production of vegetables, fruits and flowers has led to excessive fertilizer consumption, as well as pesticides and film by these crops. The use of agricultural pesticides has been increasing rapidly, from 0.7 million tons in 1989 to 1.709 million tons in 2009. The pesticide consumption per hectare of cultivated area in China reached more than 14 kg/hectare in 2009, in comparison to the 7 kg/hectare in some European countries¹⁾. Agricultural film consumption

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1) The data are available according to <http://faostat.fao.org>.

rose by over 4 times from 0.47 million tons in 1989 to 2.08 million tons in 2009. (See Fig. 1) With a low utilization rate of agricultural input, poor availability of agricultural wastes disposal, and extensive agricultural production mode, pollution from agrochemicals is becoming a serious concern in China, significantly influencing environmental and health issues such as surface water eutrophication, groundwater nitrate enrichment, and food contamination [8–10]. China is thus being confronted with the challenge of addressing special agricultural pollution while in the throes of economic transition.

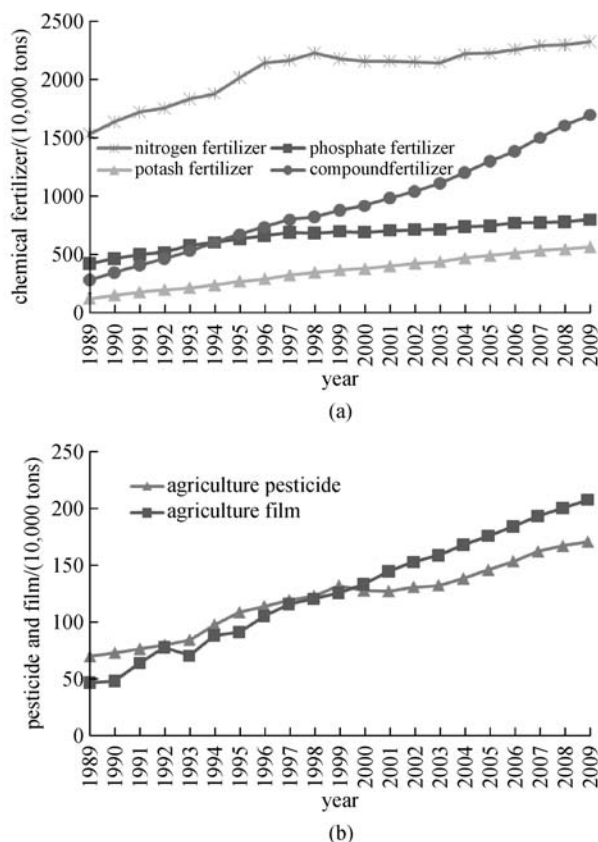


Fig. 1 Consumption of agricultural chemical fertilizer (a), pesticide and film (b) from 1989 to 2009 (Source: China Rural Statistical Yearbooks, various years)

The Environmental Kuznets Curve (EKC) theory, as the classic relationship between environmental pollution and economic growth, has become a key focus and hot topic in environmental science and other related academic fields since the pioneering work of Grossman and Krueger [11,12] and Panayotou [13], where the inverted U-shaped curve was first discovered. This EKC relationship has been the subject of a large number of theoretical and empirical investigations in many countries, as well as in China, where the empirical research has been largely based on one

of the two perspectives: the time series and dynamic panel data approach [13–15]. The results have demonstrated that there is no single relationship that fits all types of pollutants, regions scales, and time periods. For the agricultural pollution-economic growth relationship, Antler [16], McConnell [17] and others first analyzed its theoretical frame, but related researches are scanty in their finding [18–20], and few are related to Environmental Kuznets Curve. Managi [21] has recently investigated the EKC on environmental degradation resulting from pesticide use in US agriculture using panel data. In China, Liu et al. [10] analyzed the EKC in chemical fertilizer at national scale. To our knowledge, there are few other prior studies testing the EKC with regard to these particular agricultural environmental issues, although there are an abundance of studies on air or water pollution, deforestation, and indicator of environmental amenity. Considering the importance of environmental and ecological safety issues (see Shortle and Abler [18], for a comprehensive review of agriculture-related environment and economy), the issue is significant and should be given more attention. Another criticism of the EKC test concern the stationarity properties of the series involved, the co-integration property that must be present for the EKC [15,22,23], and the necessity that it undergo further testing especially for the limitations in the relatively small available time series sample [24,25]. In addition, the limited role theory has in the development of the EKC literature [26] has created difficulties in interpreting the empirical inverted U-shaped curve [21]. There are several key issues that require research and resolution. For example, is there an inverted U-shaped EKC on environmental issues resulting from use of agrochemicals in Chinese agriculture? Where is the turning point of the EKC? How can this agriculture-related environmental-growth nexus be interpreted?

The analysis of EKC relationship, which is not only related to timing sequence dimensions, but also to cross-section dimensions, should be examined strictly and carefully. This study uses the heterogeneous panel cointegration technique to investigate the inverted U-shaped EKC hypothesis across 31 Chinese provincial economies from 1989 to 2009. Contrary with the EKC literature involving cross-country comparisons, an inter-provincial research is undertaken because using provincial-level data may make it safer to assume that all cross-sections adhere to the same EKC, i.e., it may not be reasonable to impose isomorphic EKCs if cross-sections vary much in terms of some endowments [21,22,27]. This study then estimates the cointegration vector for heterogeneous cointegrated panels using the dynamic ordinary least squares (DOLS) technique proposed first by McCoskey and Kao [28,29] and Mark and Sul [30]. It is a more powerful tool and allows us to increase the degrees of freedom. Finally, this paper presents summary and concluding remarks on EKC.

2 Background

Based on the perspective of environment-economy nexus, agricultural pollution can be regarded as a contradiction between economic growth and agriculture-related environment and resources, which is essentially the discrepancy between the infinite demand from economic growth on agro-environmental resources and the limited supply capacity of the environment. Agricultural pollution is a negative externality of agricultural production in nature. The positive and negative external effects of agro-environment goods are the underlying causes of the agricultural pollution, and its public goods properties enable no producer-payment. In addition, there is an unfairness issue of comparative profit and adverse selection risk of the farmer's production, since their short-term risk aversion behaviors will aggravate the agricultural pollution trend, and the information asymmetry of agricultural pollution makes the environmental policies less effective. In addition, as a result of urban-rural dual structure, property rights, and other institutional factors, there is an agriculture-related environmental regulation failure. Economic growth has thus a double impact on the quality of the environment and agriculture-related environmental issues will significantly influence economic growth.

With increased urbanization and industrialization, rapid economic growth can exert considerable influence on agrochemical use and the agriculture-related environmental issues as to some economic effects. There are some main theoretical explanations supporting the empirical evidence that an EKC exists. Each of the following explanations could interact with the explanations [19,23].

1) Sources of economic growth, where increasing output requires more inputs, which implies more emissions as a byproduct. Thus, economic growth exhibits a scale effect that has a negative impact on the environment in the early stages of development [26]. With rising economic growth and urbanization in China, the urban population is growing and the agriculture-related industry sector is developing rapidly, the demand for agricultural products is increasing largely, while the farmland area and rural labor are sharply decreasing, marginal farmland use pressure increase, and man-earth conflict keeps intensifying. The above conditions induce overuse and misuse of agrochemicals and the environmental issues consequently. Economic growth, however, also has positive impacts on the environment via a composition effect. As income grows in the later stages of development, there is an increase in cleaner activities that produce less pollution. Whether policies are socially efficient or inefficient, EKC can exist because of increasing returns to scale [31]. In the case of agriculture-related environmental issues, which are the focus of this study, environmental degradation tends to increase with the use of toxic chemical loadings as the economy grows,

and starts to fall as the some sort of scale economy.

2) Income effects, where the shape of the EKC reflects changes in the demand for environmental quality, or agrochemical risk in this study, as income rises. Economic development can transform agriculture-related environmental quality into a consumer utility function, and the market demand constraints induce progressive agricultural producers and government more attention to the environmental concerns. Moreover, economic growth will improve the national education level and environmental awareness of farmers significantly. The relationship between pollution and income should vary across pollutants according to their perceived damage.

3) Threshold effects. An environmental measure is implemented after some threshold has been reached. These effects can arise in either the abatement opportunities [32], or in the political process [33].

The first type of threshold effect is the technology constraint explanation [34]. An economy needs to pass certain threshold levels of development before obtaining access to cleaner production technologies [35]. At present, the extant inefficient agricultural technology extension system in China, which is based on the planned economy model, prevents the timely and effective application of advanced agricultural technology. A strong economic base should provide for the application of environmentally friendly technologies and the skill mastering of farmers, such as soil testing and fertilizer recommendation issues.

The second type of threshold effect is an institutional and policy constraint explanation. It assumes that some obstacle prevents developing countries from establishing the social institutions necessary to regulate pollution [34]. The political or economic barriers are considered to be fixed costs, so that the appointment costs of institutions stick up for the environment [33]. In China, the household contract responsibility system has been implemented in rural areas since reform and opening up, which impose an important role on agriculture. However, rural development, the land property rights system, and other institutional issues result in the serious overuse and abandonment of farm land. Agriculture is characterized at present by the traditional and original production mode with the single farmer household unit, the nearly uncontrolled use of agrochemicals, and the grave agricultural pollution situation. In addition, due to longstanding household registration system with urban-rural division, and the economic development strategy that resulted in a scissors gap in China, the dual social structure is more prominent than other similar countries. Rural environmental protection is consequently neglected, and the supply of environmental policies, environmental agencies, and environmental infrastructure is highly insufficient. Agricultural pollution issues can be regarded as a byproduct of the special urban-rural dualistic structure and accordingly becomes a both extension and aggravation of the social structure and equity issues in China.

3 Model and data

3.1 EKC model

In this paper, a standard EKC model is expressed as a logarithmic quadratic function of the income to examine whether the inverted U-shaped EKC relationship exists. Both the dependent variable and the independent variable are in natural logarithm. Then, the homogeneous EKC model is usually given as [35,36]

$$E_{it} = \alpha_i + \gamma_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \varepsilon_{it}, \quad (1)$$

where E denotes agriculture-related environmental index for different province and year, Y is economic growth. The subscript i stands for a region index ($i = 1, \dots, N$) and t is a time index ($t = 1, \dots, T$), ε_{it} is a stochastic error term which is generally allowed to be serially correlated. The turning point of this curve is computed by $Y^* = -\beta_1 / 2\beta_2$.

3.2 Data description and definition of the variables

In this study, we applied province-by-year panel data from 31 economies in mainland China, to establish the EKC model by using GDP per capita as the economic growth indicator, and nitrogen surplus from synthetic fertilizer per hectare cultivated area, phosphorus surplus from synthetic fertilizer per hectare cultivated area, pesticide use per hectare cultivated area and agricultural film use per hectare cultivated area, as our agriculture-related environmental indices.

We first discuss nitrogen demand for agriculture production based on nutrient balance in agro-ecosystem, and then analyze nitrogen surplus from agricultural synthetic fertilizers. The model specification is given as

$$NS = [\sum F_j NF_j - (\sum Q_k NU_k - B)] / CL, \quad (2)$$

where NS is the nitrogen surplus from synthetic fertilizer per hectare cultivated area for different region, F and NF denote fertilizer consumption and its nitrogen content for fertilizer type j , Q and NU stand for output of farm product and its nitrogen uptake for crop type k . B stands the soil basic fertility, involving natural nitrogen supply with no fertilizer use, CL is the area of cultivated land. The biologic nitrogen fixation and nitrogen consumption of crops are calculated according to the web of fertilization formula by soil testing in China. The phosphorus surplus per hectare cultivated area is estimated similarly. The use of organic fertilizer is not included in these data, the amount of which is much smaller than synthetic fertilizer and can be even ignored, so the surplus in agricultural sector may be underestimated a little.

In 2009, the pesticide use per hectare cultivated area was more than 14 kg/hectare and agriculture film use per hectare reached over 17 kg/hectare. With excessive and inappropriate application of pesticide in China, there are

only 1% of pesticide droplets acting on target diseases and insect pests for crops, most of which contribute to increasing pesticide draining loss and the pesticide residual in crops [37]. And, almost all the residual mulch films are burned down or discarded randomly in the field with no treatment. Then, we take pesticide use per hectare cultivated area and agricultural film use per hectare as measurement indicators on environmental pressure of agricultural pesticide and film use [38]. Table 1 shows the agriculture-related environmental indices and economic indices.

Table 1 Agriculture-related environmental indices and economic indices

index	abbreviation of index
GDP per capita/CNY	<i>GDP</i>
gross agricultural output per capita/CNY	<i>GAO</i>
nitrogen surplus from synthetic fertilizer per hectare cultivated area/kg	<i>NS</i>
phosphorus surplus from synthetic fertilizer per hectare cultivated area/kg	<i>PS</i>
agricultural pesticide use per hectare cultivated area/kg	<i>AP</i>
agricultural film use per hectare cultivated area/kg	<i>AF</i>

The sample includes Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang and Tibet. Chongqing was upgraded to a municipality (provincial level) in the late 1990s, and it is seen as a part of Sichuan Province in this study. The empirical period depends on the availability of data, but overall, the data cover the 1989–2009 periods. Since all the provincial data for the variables reported in *Chinese Statistical Yearbooks* are calculated at current price, we adjusted every provincial data by considering the official price index.

4 Results

In this section, we estimate the relationship between agriculture-related environmental index and GDP per capita using the model of EKC. The econometric methods used and the resulting empirical findings would be introduced.

First, before employing panel cointegration techniques, since cointegration regressions require non-stationary data of the same order of integration, unit roots properties of the panel data are properly examined. Cointegration analysis, as the classic method to test for a long-run equilibrium relationship between the variables, introduced the idea that

even if underlying time series are non-stationary, linear combinations of these series might be stationary [39]. It is well known that the traditional unit root tests or cointegration tests method (e.g., ADF or residual-based cointegration tests) involves the low power problem for non-stationary data. The primary motivation for panel data unit root tests as proposed to traditional unit root tests is to take advantage of the additional information provided by pooled cross-section time series to increase test power [40].

Secondly, if the variables are integrated of the same order, the next step will consist of testing for cointegration among the variables. The existence of a cointegrating environment-economy relationship is tested using the panel cointegration technology. The time series panel regression is considered as

$$Y_{it} = \alpha_{it} + \theta_{it}t + X_{it}\eta_{it} + \varepsilon_{it}, \quad (3)$$

where Y_{it} and X_{it} are the observable variables. The asymptotic and finite-sample properties of testing statistics are developed to examine the null hypothesis of non-cointegration in the panel. The tests allow for heterogeneity among individual members of the panel, including heterogeneity in both the long-run cointegrating vectors and in the dynamics [41].

Finally, the OLS and DOLS estimators are used to evaluate the long-run relationship among the variables considered. The DOLS is an ordinary least squares estimation of an expanded equation including not only the explanatory variables but also leads and lags of their difference terms to control for endogeneity and to calculate the standard deviations using a covariance matrix of errors that is robust to serial correlation [42]. The DOLS estimators have a normal asymptotic distribution and their standard deviations provide a valid test for the statistical significance of the variables [43]. It has the following form

$$y_{it} = \alpha + x_{it}\beta + \sum_{j=-\rho_1}^{\rho_2} \gamma_{ij}\Delta x_{it+j} + \mu_{it}, \quad (4)$$

where Δx_{it} asymptotically eliminates the effect of endogeneity of x_{it} on the distribution of OLS estimator of β , ρ_1 is the maximum lag length, ρ_2 is the maximum lead length, μ_{it} is a Gaussian vector error process.

Above all, we chose the two panel unit root methods, namely Levin-Lin-Chu (LLC) test and Im-Pesaran-Shin (IPS) test proposed by Levine et al. [44] and Im et al. [45], respectively. In addition, we follow the procedures developed first by Maddala and Wu [46] and Choi [47] by using the Fisher-ADF and Fisher-PP statistics to enhance the robustness of the results. Table 2 reports the results for the four panel unit root tests. The tests fail to reject the null of a unit root in levels. When the tests are applied to the first order differences, the null of unit root is easily rejected indicating that the series (GDP, GDP²,

GAO, GAO², NS, PS, AP, AF) are I (1) process on the whole.

Then we proceed to test environmental and growth variables respectively, for cointegration in the data using the heterogeneous panel cointegration test developed first by Pedroni [41,48,49], which allows for cross-sectional interdependence with different individual effects. Four statistics namely panel-v, panel- ρ , panel-PP and panel-ADF are based on pooling along the “within-dimension” and the remaining group- ρ , group-PP, and group-ADF statistics are based on averaging along the “between-dimension.” Each of these tests is able to accommodate individual specific short-run dynamics, individual specific fixed effects and deterministic trends, as well as individual specific slope coefficients [41,48]. The panel ADF-statistic, group ADF-statistic, panel PP-statistic and group PP-statistic tests have better small sample properties than the others, with the findings in the Monte Carlo simulation experiments [41,49], and hence, they are more reliable.

Table 3 presents the panel cointegration test results. The Panel ADF-statistic, group ADF-statistic, Panel PP-statistic and Group PP-statistic all reject the null of no cointegration significantly at 1% critical values strongly. There is generally strong evidence of cointegration among these series. Thus, it can be concluded that the four types of agriculture-related environmental indices tested, GDP and the GDP square move together in the long-run, respectively. And, there is a steady-state relationship among those variables. The next step is to estimate this relationship.

The EKC relationship can be further estimated by several methods for panel cointegration estimation, e.g. the ordinary least squares (OLS) estimator, the fully modified ordinary least squares (FMOLS) estimator proposed first by McCoskey and Kao [28,29], Phillips and Moon [50] and Pedroni [49,51], the dynamic ordinary least squares (DOLS) estimator developed first by McCoskey and Kao [28,29] and Mark and Sul [30]. Kao and Chiang [52] and McCoskey and Kao [29] suggested the panel DOLS procedure exhibits less bias than the other estimators in small samples using Monte Carlo simulations. We use the dynamic ordinary least squares developed by Kao and Chiang [52] and Mark and Sul [30] to estimate the long-run cointegrating vector between environmental economic relations. The DOLS estimator corrects the standard pooled OLS for serial correlation and for endogeneity of regressors, and has a normal asymptotic distribution and its standard deviations provide a valid test for the statistical significance of the variables [43].

Table 4 provides the panel cointegration estimation results by OLS and DOLS tests. A panel data model with fixed effects is adopted, including both individual specific and time specific effects. Often the DOLS estimator has the drawback that its results are sensitive to the choice of number of lags and leads, but for our sample we find that

Table 2 Panel unit root test results

		LLC ^{a)}	IPS ^{b)}	Fisher-ADF ^{c)}	Fisher-PP
<i>GDP</i>	individual effects	7.68	13.40	3.87	2.80
	individual effects and linear trends	8.81	6.82	15.79	18.98
<i>D</i> ^{d)} (<i>GDP</i>)	individual effects	−2.04** ^{c)}	−2.95***	112.86***	156.37***
	individual effects and linear trends	−1.32*	−1.72**	87.89**	143.22***
<i>GAO</i>	individual effects	2.64	8.20	13.01	13.47
	individual effects and linear trends	4.19	3.03	36.03	35.49
<i>D</i> (<i>GAO</i>)	individual effects	−3.32***	−5.04***	127.30***	272.48***
	individual effects and linear trends	−10.24***	−7.32***	169.21***	216.52***
<i>GDP</i> ²	individual effects	11.25	15.13	1.17	0.70
	individual effects and linear trends	8.86	9.56	5.44	10.03
<i>D</i> (<i>GDP</i> ²)	individual effects	−1.68**	−1.58**	86.95**	123.93***
	individual effects and linear trends	−1.69**	−1.56**	81.39**	131.40***
<i>GAO</i> ²	individual effects	4.61	10.27	9.70	9.59
	individual effects and linear trends	6.55	4.96	26.61	28.68
<i>D</i> (<i>GAO</i> ²)	individual effects	−3.40***	−4.62***	120.10***	249.11***
	individual effects and linear trends	−9.68***	−6.85***	160.41***	206.32***
<i>NS</i>	individual effects	−7.28***	−2.51	90.27	141.31***
	individual effects and linear trends	−2.68**	0.11	60.91	87.34
<i>D</i> (<i>NS</i>)	individual effects	−15.74***	−13.29***	291.53***	711.24***
	individual effects and linear trends	−14.95***	−10.20***	243.23***	400.71***
<i>PS</i>	individual effects	−8.45***	−2.54	117.13	177.57***
	individual effects and linear trends	−4.15***	−0.50	80.77	110.71***
<i>D</i> (<i>PS</i>)	individual effects	−6.47***	−8.34***	208.61***	442.82***
	individual effects and linear trends	−12.15***	−8.65***	219.30***	356.07***
<i>AP</i>	individual effects	−3.64***	−0.12	73.29	187.91***
	individual effects and linear trends	−3.06***	−1.28	83.69	136.49***
<i>D</i> (<i>AP</i>)	individual effects	−19.70***	−13.55***	357.32***	516.35***
	individual effects and linear trends	−19.96***	−12.83***	259.72***	378.57***
<i>AF</i>	individual effects	−4.20***	0.07	71.40	124.85***
	individual effects and linear trends	−10.08***	−3.39	80.81	126.17***
<i>D</i> (<i>AF</i>)	individual effects	−24.61***	−14.46***	498.98***	1039.26***
	individual effects and linear trends	−31.19***	−15.65***	216.96***	361.91***

Note: ^{a)} LLC represents the panel unit root test of Levine et al. (2002); ^{b)} IPS represents the panel unit root test of Im et al. (2003); ^{c)} Fisher-ADF and Fisher-PP represents the Maddala and Wu (1999) and Choi (2001) Fisher-ADF and Fisher-PP panel unit root test, respectively. Probabilities for Fisher-type tests were computed by using an asymptotic χ^2 distribution; ^{d)} D denotes first difference; ^{e)} LLC, IPS, Fisher-ADF and Fisher-PP examine the null hypothesis of non-stationarity, and ***, ** and * indicates statistical significance at the 1%, 5% and 10% level, respectively

most estimation results vary only little when the leads and lags are changed again. The parameters are quite significant mostly at a 1% level of significance. From the sign of the parameters, the results show that there is the inverted U-shaped curve relationship between the GDP per capita and NS, PS and AP (See Fig. 2), respectively, but AF increases linearly with economic growth. Then, a transition is expected at a crucial point, i.e., the turning point, the value of which calculated is about 10,000–13,000, 85,000–89,000 and over 160,000 CNY, for NS, PS

and AP, respectively. Based on the results provided in Table 4 where the independent variable is GAO, the panel estimator is 0.55–0.62 where the dependent variable is AP, and 1.28–1.42 where the dependent variable is AF. Implicit here is that a 1% increase in GAO is associated with a 0.55%–0.62% increase in AP and a 1.28%–1.42% increase in AF in China.

Based on the EKC results, in general, an economy is associated with smaller levels of pollution after some threshold income point. Except for AF, the other three sorts

Table 3 Panel cointegration test results ^{a)}

	$NS(GDP, GDP^2)$		$PS(GDP, GDP^2)$		$AP(GDP, GDP^2)$		$AF(GDP, GDP^2)$		$AP(GAO)$		$AF(GAO)$	
	NDT ^{b)}	DIT ^{c)}	NDT	DIT	NDT	DIT	NDT	DIT	NDT	DIT	NDT	DIT
Panel v	-1.30	-4.50	-0.14	-3.40	-1.64	-4.83	0.20	-3.00	-1.11	-4.32	1.03	-0.87
Panel p	-1.99** ^{d)}	0.24	-3.51***	-1.17	-3.48***	-0.53	-1.76**	1.05	-2.90***	-0.24	-1.53*	0.60
Panel PP	-5.87***	-6.99***	-7.49***	-8.34***	-8.19***	-8.76***	-7.67***	-8.15***	-8.23***	-10.86***	-6.39***	-8.00***
Panel ADF	-7.63***	-8.52***	-8.48***	-6.18***	-8.32***	-8.37***	-8.78***	-7.93***	-6.95***	-7.02***	-6.32***	-11.37***
Group p	0.54	2.26	-0.78	1.53	-0.50	1.98	0.71	2.99	-0.43	1.31	0.48	2.69
Group PP	-5.49***	-6.62***	-6.65***	-6.26***	-8.04***	-9.21***	-7.41***	-8.22***	-8.46***	-14.40***	-7.28***	-8.24***
Group ADF	-9.98***	-7.38***	-10.29***	-5.14***	-12.26***	-9.57***	-11.54***	-8.84***	-7.17***	-9.83***	-7.69***	-13.26***

Note: ^{a)} For the formulas used in the panel cointegration test statistics, it is described in details in Pedroni (1999, 2004). Statistics are asymptotically distributed as normal. The variance ratio test is right-sided, while the others are left-sided; ^{b)}NDT stands for no deterministic trend; ^{c)}DIT stands for deterministic intercept and trend; ^{d)}***, ** and * rejects the null of no cointegration at the 1%, 5% and 10% level, respectively

Table 4 Panel cointegration estimation results by OLS and DOLS

		C	GDP	GDP ²	shape of curve	TP(2009 CNY)	C	GAO	shape of curve
NS	OLS	-7.31*** ^{a)}	2.50***	-0.15***	inverted U-shaped	20,000	—	—	—
		-5.71	7.48	-6.76					
	DOLS(1, 1)	-4.12***	1.81***	-0.11***		13,000	—	—	—
		-6.73	11.32	-10.40					
	DOLS(2, 2)	-4.23***	1.89***	-0.12***		10,000	—	—	—
		-5.84	9.72	-8.89					
PS	OLS	-12.30***	3.59***	-0.22***	inverted U-shaped	16,000	—	—	—
		-8.71	9.74	-9.04					
	DOLS(1, 1)	-3.75***	1.31***	-0.07***		89,000	—	—	—
		-4.88	6.52	-4.84					
	DOLS(2, 2)	-3.01***	1.14***	-0.06***		85,000	—	—	—
		-3.34	4.72	-3.39					
AP	OLS	-8.72***	2.12***	-0.10**	inverted U-shaped	245,000	-2.63***	0.66***	linear
		-3.65	3.44	-2.44			-12.80	28.26	
	DOLS(1, 1)	-4.87***	1.39***	-0.07***		160,000	-2.29***	0.62***	
		-4.73	5.23	-3.74			-12.40	22.62	
	DOLS(2, 2)	-3.70***	1.09***	-0.05**		550,000	-1.85***	0.56***	
		-2.96	3.32	-2.07			-8.11	16.12	
AF	OLS	-3.51***	0.70***	—	linear	—	-5.69***	1.13***	linear
		-10.82	18.48	—			-13.45	19.34	
	DOLS(1, 1)	-3.46***	0.69***	—		—	-6.65***	1.28***	
		-9.101	12.54	—			-13.59	17.65	
	DOLS(2, 2)	-3.21***	0.66***	—		—	-7.49***	1.42***	
		-6.75	9.31	—			-12.78	16.07	

Note: ^{a)}***, ** and * denotes the estimator of a parameter is significant at 1%, 5% and 10% level, respectively

of agricultural environment-economy nexus all show the inverted U-shaped EKC relationship, indicating that NS, PS and AP increase at first, then may decline with economic growth. Moreover, the turning points of these inverted U-shaped curves vary between different indicators. For NS, the nexus in most areas is now within the right-side of the EKC up to 2009. However, PS and AP have an increasing trend in most regions of China, far from turning points. The largest turning point appears in AP, and this estimated value is more than 22,200 USD, similar to

Managi [21] results for pesticide in agriculture sector of United States, where estimated point of peak is about 20,900–24,900 USD. Obviously, there is much more pressure of pollution abatement for current China development mode. Furthermore, compared with EKC results, across indicators and studies, these turning points for agricultural environmental indices are much higher than those for pollutants such as NO_x and SO₂ generally. The EKC takes various shapes depending on the type of pollutants and is more likely to hold for short-term and

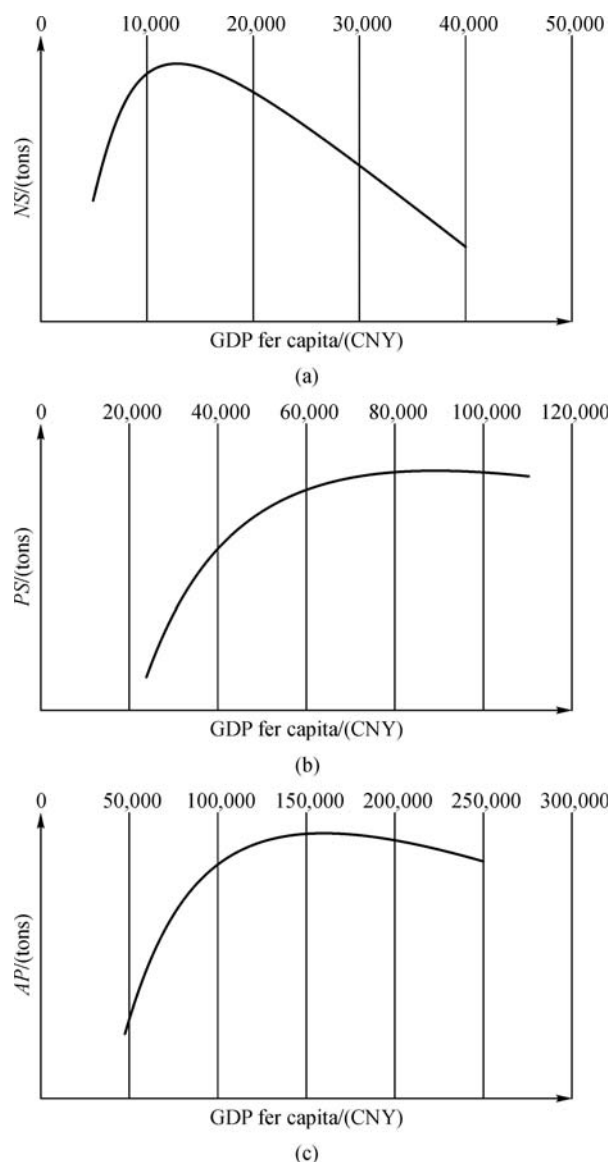


Fig. 2 Inverted U-shaped EKC relationship simulation for NS (a), PS (b) and AP (c)

local impact pollutants than for those with more global, indirect, and long-term impacts [21,53,54]. It is emphasized that agricultural pollution reduction is much more difficult than those such as urban-related NO_x and SO_2 , to a certain sense, and should be paid more attention in the future. It should be also noticed the new problems caused by agricultural pollutants whose direct sources are untraceable, in contrast to the traditional problems derived from the traceable pollutants. The environmental policies need to be formulated concerning each substance, such as its origin, manageability, and the like, rather to be standardized [55], especially with little effective agriculture-related environmental management in China.

The empirical evidence of an Environmental Kuznets Curve for pesticides in US agriculture was explained as

increasing returns to scale by Managi [21]. This pattern of EKC in Chinese agriculture may be interpreted as follows: First, environmental pressure decreases with industrial adjustments [12,56,57]. The emerging EKC trend could be a result of the decline of agricultural sector. This effect is more evident in aggregate studies due to the change in macro-sectoral shares [15], the “compensating effects” [23]. As income grows and structure changes in some developed areas, there is an increase of cleaner activities with less pollution, and environmental degradation tends to fall for the focus of this study. Secondly, “learning by doing” offers several interpretations to the growth-environment relationship, as the costs of pollution reduction be altered [15]. In some developed provinces of East China, as the marginal cost of pollution reduction and ecological agriculture decreased, there is an environmental improvement. Thirdly, it is thought to be one of the main determinants for the shape of EKC to introduce strong environmental policies [58,59]. Fourthly, the transition of socio-economic dual structure is the fundamental way for agriculture-related pollution reduction in China. Fifthly, with the lack of management system, the unbalanced nutrient input to agro-eco system still exists, although the nitrogen over-fertilization begin to be controlled in many areas. Sixthly, pesticide use is rigid and takes on non-substitutability. Besides, pesticide price is very low and there is no effective management system. The EKC may be lowering and flattening out, as a result of several factors, mainly including formal and informal regulation, dual structure transition and the consequent improvement of agricultural management and technology. And, the statistical significance of the estimated intercept terms may indicate the need to take integrated environmental policies [60]. In addition, regional differentiation results in the different agriculture-related environmental spatial features in eastern, central and western region of China to some extent, and the agriculture-related environmental policies should consequently differ over time and region.

5 Conclusions and discussion

This study estimates the inverted U-shaped Environmental Kuznets Curve hypothesis empirically, relating GDP per capita to four types of agricultural environmental variables, for a panel data set comprising 31 provincial economies for the period from 1989 to 2009, using the panel unit root test, the cointegration test and panel-based dynamic OLS, which have the advantage of higher power and a more robust result with the short time spans of typical data sets. The empirical results show that there is a positive long-run cointegrated relationship between the environmental index and real GDP per capita. This relationship takes on the inverted U-shaped Environmental Kuznets Curve, and the value of turning point is about 10,000–13,000, 85,000–

89,000 and over 160,000 CNY, for synthetic fertilizer nitrogen indicator, fertilizer phosphorus indicator and pesticide indicator, respectively. These results may provide a picture of agriculture-related environment-economy nexus and might be helpful to focus and advance the policy debate in China.

The numerical results show that the long-equilibrium relationship exists between agriculture-related environmental indices and GDP per capita in China, and provide support in favor of the past changes in economic growth that have a significant impact on environmental issues. The relationships between the three types of environmental indices studied and economic growth show the inverted U-shaped Environmental Kuznets Curve in China. As a whole, the increase in income is the driving force for agricultural pollution reduction. However, the agriculture-related environmental degradation has led to a havoc of water quality and biogeocenose, and the large cost of environmental management. Economic growth has not yet reached turning points of the inverted U-shaped EKC on most indicators, and still has a long way to go, especially in the central and western region of China, where agriculture-related environmental issues should be attached more importance. Above all, with rapid economic growth and urbanization, the farmland and rural labor are sharply decreasing, and the farmland-human conflict increases, in addition, urban-rural gap and regional disparity are enlarging. The above conditions induce overuse and misuse of agrochemicals and the environmental issues consequently. Furthermore, for a long time, with urban-rural dualistic structure, industrialization has been paid too much attention and how to promote rural development is neglected in many areas of China. Besides, there exist little management of agricultural production, and the agriculture-related environmental policies, agencies and infrastructure. The efficient environmental measures have been enforced in city and industry, and a more discreet approach is required in agriculture and rural areas. Moreover, with lack of agricultural management system, trade liberalization and market internationalization have an influence on agricultural production and the environment. With economic growth, pressure and irreplaceability of agriculture is increasingly great, however, the agricultural output will still depend upon the agrochemicals use in a large part. There will be many major challenges to address special environmental issues in China. A package of efforts should be taken to reduce agricultural dependence on agrochemicals, and to increase contribution of capital and technology to agriculture.

According to the results of EKC, agricultural pollution pressure may decrease in Beijing, Shanghai and other developed areas. It seems one of the most important environmental strategies to promote economic growth, however, the estimation of an EKC and its turning point is only based on empirical data, and the relationship between agriculture and the environment is complex, such regional-

specific characteristics as agricultural carrying capacity, agriculture distribution and policy effects could have some influences on environmental change. Moreover, the EKC results may initially show the same pattern as the inverted U-shaped curve and only a short-run phenomenon, but beyond a certain income level, return to exhibiting a positive relationship between growth and the environment [15,55]. This inverted U relationship is not meant that environmental degradation is only a temporary phenomenon associated with some stage of economic growth and environmental degradation will naturally decrease to a certain stage of economic growth. The government should actively give farmers more guidelines and motivation mechanism on the rational use of agrochemicals, and meanwhile enforce efficient pollution reduction efforts, especially in main agriculture area. All in all agricultural pollution abatement is much more difficult than normal industrial pollution. Further evidence of technology, regulation and others is still required to answer this question. More significantly, the crux of the matter is to deal with China's serious urban-rural dualistic structure. Although further theoretical and empirical investigation is clearly needed before any unquestionable conclusion can be drawn, for the EKC on agriculture-related environmental issues, deriving the quantitative estimates of the likely environmental impacts of growth is helpful to advance decision debate. In the future, environmental poverty and environmental equity should become the focus of the policy debate.

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Appendixes: Agrichemicals and economic growth

Figure A shows observations for agrichemicals and GDP per capita, where simple plots are provided for year 1989, 1999 and 2009. The EKC pattern might come from either the changes over time or between provinces. The data for a given year shows the cases of inverted U shape more than the data for a given province.

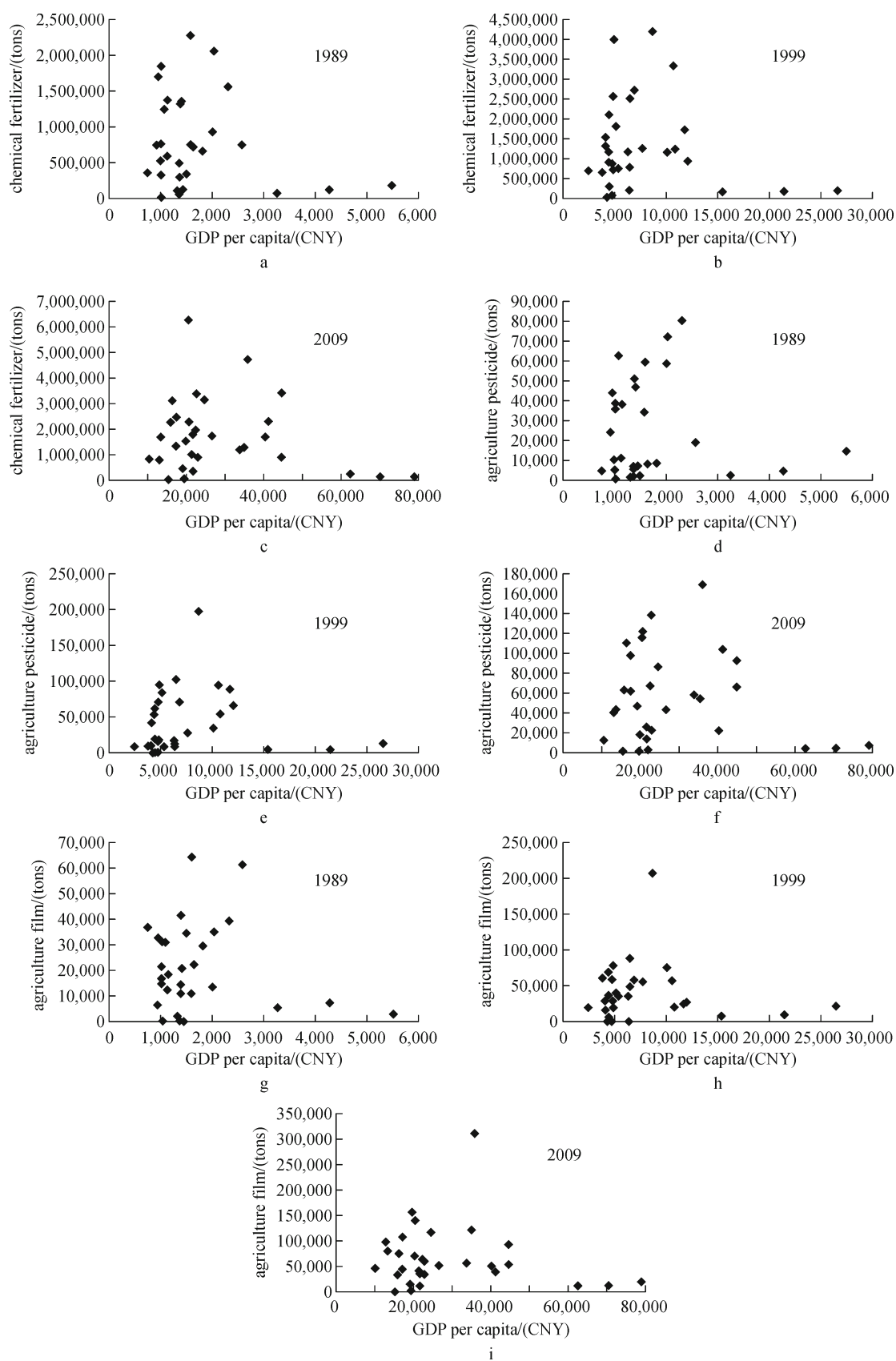


Fig. A The agricchemicals and economy relationship by year, such as chemical fertilizer (a- 1989, b- 1999, c- 2009), pesticide (d- 1989, e- 1999, f- 2009) and film (g- 1989, h- 1999, i- 2009)
Source: China Rural Statistical Yearbooks, various years