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Macroscopic Factor Decomposition of Non-Point Source Pollution of Chemical Fertilizer: Scale, Structure and Constraint

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ABSTRACT

This paper builds a factor decomposition model of non-point source pollution of chemical fertilizer from the three dimensions of scale, structure and constraint, with using the panel data covering 31 provincial regions in China during 2007-2016, aims to reveal the action mechanism of scale effect, structure effect and effect of restraint on non-point source pollution of chemical fertilizer. The research shows that the inverted U-shaped curve relationship between economic scale and non-point source pollution of chemical fertilizer is essentially an environmental negative externality in production, as well as the evolution path of the implementation of control measures. Economic structure and resource constraint, each has positive exogenous effects on non-point source pollution of chemical fertilizer, while technical constraint has negative exogenous effects on it. Thus, the ultimate effectiveness of pollution control measures depend on the balance of the two opposing forces in reality. In addition, population size and population structure both have no exogenous effect on non-point source pollution of chemical fertilizer. Therefore, implementation of the "source control" mode of pollution control, with optimizing the internal structure of agriculture, transforming agricultural production patterns, making rational use of cultivated land resources, and vigorously promoting applicable environmental technologies, etc., are particularly important.

INTRODUCTION

Chemical fertilizer application has been an important way to increase agricultural production in China. Over the past 30 years, while the amount of chemical fertilizer being used in agricultural production continued to increase, the marginal production had fallen and there was a little room for increased production. However, as the application intensity kept increasing and the utilization level was generally low, a large amount of residual nutrients in chemical fertilizer not only lead to soil compaction and air pollution, but also lead to eutrophication of water bodies through leaching. From 2007 to 2016, the amount of chemical fertilizer applied in China increased from 51.078 million tons to 59.841 million tons, an average annual increase of 1.91 percent. In 2016, the amount of chemical fertilizer applied per unit area of cultivated land in China was 443.53 kg/hm^2, far higher than the internationally recognized safe limit of 225 kg/hm^2. It can be inferred that the non-point source pollution caused by excessive use of chemical fertilizer has been very serious.

As the micro subject of agricultural production, farmers' application of chemical fertilizer will have a direct impact on environmental quality. Therefore, most of the studies are based on the field investigation to explore the influence factors of non-point source pollution of chemical fertilizer from the perspective of farmers. In fact, the occurrence of micro-subject behaviour must be guided by the overall macroeconomic situation. At a time when industrialization was advancing rapidly, the primitive accumulation of capital had not been realized and industry was still unable to nurture agriculture. The lagging of the agricultural economic development itself is difficult to meet the growing needs of farmers for life, which has formed the idea that economic benefits precede environmental benefits, and thus agricultural production is solely dependent on the increase of inputs such as chemical fertilizers and pesticides, resulting in the increasing pollution of non-point sources. Obviously, it is the key to grasp the policy direction of environmental management accurately to analyse the internal mechanism of non-point source pollution of chemical fertilizer from the macro level.

A series of studies on the decomposition of environmental quality influencing factors were mainly carried out through IPAT model and EKC model. Ehrlich et al. (1971), based on the three aspects, population, consumption and technology, proposed the IPAT model for the relation between population and environment, believing that the combination of population and consumption will cause great environmental pressure, which must be alleviated through technological adjustment. Subsequently, the IPAT model was improved by Yorker et al. (2002) and evolved into a STIRPAT model which could incorporate various other factors. So far, these two models have been widely used, mainly devoted to the decomposition of the factors influencing on industrial energy consumption and carbon emissions (Poumanyvong & Kaneko 2010, Zhangqi 2018) and other factors affecting industrial waste gas emissions (Nan & Weiyang 2016, Ling et al. 2017), but the empirical analysis of the agricultural non-point source pollution is not much (Yuzhuo 2017).

The EKC model proposed by Grossman et al. (1991) to explain the relationship between economy and environment has always been an important tool for environmental economic analysis. However, this model has become a "black box" because it abstracts many key factors in application. For this, Grossman et al. (1995) and Islam et al. (1999) analysed the impact of economic growth on environment quality, the former revealed the economic scale effect, economic structure effect and technology progress effect; the latter revealed the scale effect, structure effect and waste reduction effect. But before that, Commoner (1972) and Angang (1993) had made a similar decomposition, and their research ideas tended to be consistent, that is, the effects of economic growth on environmental quality were analysed from three aspects: population growth effect, economic scale effect and technological progress effect. At present, although some scholars have explored the decomposition of influencing factors of agricultural non-point source pollution (Taiping et al. 2011, Liutao et al. 2013), most studies have not opened their own "black box" when applying EKC model, to further deepen their conclusions (Haipeng & Junbiao 2009, Xianghai et al. 2015).

Draw lessons from existing research, with using the panel data covering 31 provincial regions in China during 2007-2016, we built the factor decomposition model of non-point source pollution of chemical fertilizer from the three dimensions of scale, structure and constraint, designed to reveal the mechanism of scale effect, structure effect and constraint effect on non-point source pollution of chemical fertilizer, so as to increase the strength of macro-explanation beyond micro-explanation.

MATERIALS AND METHODS

We argue that, scale and structure are two important dimensions to decompose the influencing factors of non-point source pollution of chemical fertilizer, and the effect of each dimension should involve economic and demographic factors. Non-point source pollution of chemical fertilizer is a negative environmental externality problem caused by excessive application of chemical fertilizer in agricultural production. In terms of scale effect, the urban and rural population scale of continuous expansion drives the whole society the general increase of agricultural product demand, pressing for faster agricultural production, or the scale of agricultural economy itself continues to expand, both of which will lead to an extensive use of chemical fertilizers. In terms of scale effect, the internal structure of agricultural economy, especially the proportion of the output value of the agricultural industry with a demand for chemical fertilizer in the whole agriculture, plays an important role in the direct input of chemical fertilizer; in population structure, with the increasing proportion of urban population and the transfer of agricultural labour force, intensification of agricultural production inevitably requires the concentrated investment of chemical fertilizers.

Technological factors have gradually tended to improve environmental quality in the process of changing from extensive mode to intensive mode in economic development. As a result, advances in agricultural technology are likely to reduce the amount of chemical fertilizer applied while increasing the level of output, thus reducing the degree of pollution. However, technology itself has certain applicability, if technological progress deviates from production mode, it will be difficult to give full play to its environmental protection effect. It can be seen that technical factors should be within the constraint dimension when the influencing factors of non-point source pollution of chemical fertilizers are decomposed. In addition, the area of cultivated land also belongs to the constraint dimension for defining the space range of chemical fertilizer application.

According to the three dimensions of scale, structure and constraint, as well as the establishment of economy, population, technology and resources, we construct a decomposition model of influencing factors of non-point source pollution of chemical fertilizers as follows:

$$CFP = f(E, H, S, U, T, C) \quad ...(1)$$

Here, the dependent variable CFP indicates non-point source pollution of chemical fertilizer, and the independent variables *E, H, S, U, T* and *C* indicate respectively, the economic scale, population scale, economic structure, population structure, technical constraint and resource constraint. We introduce a quadratic term of *E* to verify the possible *EKC* curve.

Concretely, two indicators, nitrogen pollution emission and phosphorus pollution emission, are set up to represent non-point source pollution of chemical fertilizer, for nitrogen fertilizer and phosphate fertilizer are mainly used in China's agriculture for a long time, and nitrogen, phosphorus and other elements were lost in a large number with extremely low utilization rate, resulting in water eutrophication and becoming a serious pollution source.

As chemical fertilizer application is closely related to crop production, we set two indicators, crop production value and the proportion of crop production value in total agricultural output value, respectively, to represent economic scale and economic structure. The demand for agricultural products comes from the total population of urban and rural areas in a certain period, and the proportion of urban population determines the supply structure of agricultural products, so two indicators, year-end population and urban population proportion, respectively, represent population scale and population structure. In order to show the effect of agricultural technology progress on reducing non-point source pollution of chemical fertilizer and the effective space of chemical fertilizer application, we set two indicators, crop production value per unit of chemical fertilizer (nitrogen fertilizer or phosphate fertilizer) and irrigated area, respectively represent technical constraint and resource constraint (Table 1).

Based on the decomposition model of influencing factors of non-point source pollution of chemical fertilizer, two regression equations are established as follows:

$$N=\alpha_0+\alpha_1 e+\alpha_2 e^2+\alpha_3 h+\alpha_4 s+\alpha_5 u+\alpha_6 t_n+\alpha_7 c+\varepsilon \quad ...(2)$$

$$P=\beta_0+\beta_1 e+\beta_2 e^2+\beta_3 h+\beta_4 s+\beta_5 u+\beta_6 t_p+\beta_7 c+\eta \quad ...(3)$$

Here, N and P are respectively nitrogen pollution emission (ten thousand tons) and phosphorus pollution emission (ten thousand tons), e is crop production value (100 million RMB yuan) and e^2 is a quadratic term of e, h is year-end population (ten thousand people), s is the proportion of crop production value in total agricultural output value (%), u is urban population proportion (%), t_n and t_p are respectively crop production value per unit of nitrogen fertilizer (ten thousand RMB yuan) and crop production value per unit of phosphate fertilizer (ten thousand RMB yuan), c is irrigated area (thousands of hectares), α_i and β_i (i=0, 1, 2, …, 7) denote the corresponding coefficient, and ε and η are the random perturbation terms.

Nitrogen pollution emission and phosphorus pollution emission are calculated by multiplying the amount of fertilizer applied (ten thousand tons) by the fertilizer loss rate (%). The fertilizer loss rate of 31 provinces in China was measured by Feng (2011). The application amount of nitrogen fertilizer and phosphate fertilizer and the relevant panel data required for each explanatory variable are related to 31 provinces in China from 2007 to 2016, all of which are from China Statistical Yearbook from 2008 to 2017.

RESULTS AND DISCUSSION

We use mixed OLS, fixed effect and random effect for regression. First, LSDV test showed that most individual virtual variables are significant at 5% level, that means, there is an individual effect, and mixed OLS regression should not be used; then Hausmann test showed that the two equations are significant at 5% level and the regression of random effect is rejected; finally, we choose the fixed effect regression estimation result of cluster robust standard deviation.

Table 2 shows the estimation results. There are significant quadratic function relationships between crop production value and nitrogen pollution emission, and between crop production value and phosphorus pollution emission, and the corresponding inverted U-shaped EKC curves are formed. The crop production values at the inflection points are respectively 491.803 billion RMB yuan and 519.931 billion RMB yuan. There are significant positive correlations between the proportion of crop production value in total agricultural output value and nitrogen pollution emission, and between the proportion of crop production value in total agricultural output value and phosphorus pollution emission, which means an increase in the proportion of 1% of crop production value would increase nitrogen pollution emission and phosphorus pollution emission by 1,040 tons and 92 tons respectively. There are significant negative correlations between crop production value per unit of nitrogen fertilizer and nitrogen pollution emission, and between crop production value per unit of phosphate fertilizer and phosphorus pollution emission, which means an increase of 10,000 RMB yuan of crop production value per unit of nitrogen fertilizer would reduce nitrogen pollution emission by 1,268 tons and an increase of 10,000 RMB

Table 1: Decomposition of the influencing factors of non-point source pollution of chemical fertilizer.

Factors	Scale	Structure	Constraint
Economic factors	Crop production value	The proportion of crop production value in total agricultural output value	-
Demographic factors	Year-end population	Urban population proportion	-
Technical factors	-	-	Crop production value per unit of chemical fertilizer
Resources factors	-	-	Irrigated area

Note: -represents default.

Table 2: Estimation results of panel model regression.

Influencing factors	N		P	
	Coefficient	*t*-Statistic	Coefficient	*t*-Statistic
E	0.003 6***	3.71	0.000 3***	3.91
E^2	-7.32e-07***	-3.98	-5.77e-08**	-2.41
H	0.000 7	0.65	0.000 0	0.20
S	0.104 0**	2.29	0.009 2*	1.70
U	0.033 7	0.59	-0.008 5	-1.65
T	-0.126 8***	-3.29	-0.001 6*	-1.87
C	0.000 8*	1.96	0.000 2**	2.56
Intercept	1.448 5	0.26	0.573 9	0.72
F-Statistic	8.38***		20.22***	
within-R^2	0.438 7		0.386 8	
VIF	6.46		6.12	

Note: ***, ** and * respectively indicate that the estimated results are significant at the levels of 1%, 5% and 10%, respectively.

yuan of crop production value per unit of phosphate fertilizer would reduce phosphorus pollution emission by 16 tons. There are significant positive correlations between irrigated area and nitrogen pollution emission, and between irrigated area and phosphorus pollution emission, which means an increase of 1,000 hectares of irrigated area would increase nitrogen pollution emission and phosphorus pollution emission by 8 tons and 2 tons respectively. However, there are no correlations between the year-end population and chemical fertilizer pollution emission, and between urban population proportion and chemical fertilizer pollution emission.

In terms of scale effect, the inverted U-shaped curve relationship between the economic scale and non-point source pollution of chemical fertilizer is essentially an environmental negative externality in production, as well as the evolution path of the implementation of control measures. Over the years, the application of chemical fertilizer has been subject to a variety of direct or indirect subsidy incentives, which inevitably aggravate the degree of pollution. During 2011-2015, after clearly put forward agricultural non-point source pollution control target at the policy level, measured soil fertilizer technology had been used more widely, and chemical fertilizer use efficiency had also improved, which makes the degree of non-point source pollution reduced. In terms of structural effect, economic structure has a significant positive influence on non-point source pollution of chemical fertilizer, which indicates that the increase of relative value of crop industry in agriculture is mainly caused by the increase of its absolute value. Nevertheless, we can judge that an increase in the number of urban and rural population expanded the demand of agricultural products, at the same time an increase in the proportion of urban population made the transfer of agricultural labour force to cities, reducing the supply of agricultural products, and the demand gap generated cannot be met with by the agricultural production (including crop production), which relied more on imports. This is undoubtedly an important reason that both population size and population structure have no significant influence on non-point source pollution of chemical fertilizer. In terms of constraint effect, technical constraint has a significant negative effect on non-point source pollution of chemical fertilizer, which is consistent with the research results of Taiping et al. (2011) and Liutao et al. (2013). Due to the different calculation methods of indicators, in fact, the improvement effect of technical constraint on environmental quality is limited to the way of substitution or consumption reduction. For example, use of slow-release fertilizers instead of conventional fertilizers not only reduces dosage by 10% to 20%, but also extends fertilizer effect by 30 days. In addition, resource constraint has a significant positive effect on non-point source pollution of chemical fertilizer. The larger irrigated area, the more effective cultivated land is put into use, which means the more extensive space for pollution spread.

It is important to note that under the inverted U-shaped curve relationship between economic scale and non-point source pollution of chemical fertilizer, economic structure, technical constraint and resource constraint have exogenous effects on non-point source pollution of chemical fertilizer. Specifically, positive changes in economic structure and resource constraint will cause the entire inverted U-shaped curve to shift upward, further weakening the effect of pollution control; the positive change of technical constraint will cause the entire inverted U-shaped curve to shift downward and further enhance the effect of pollution control. The ultimate effectiveness of pollution control measures depends on the balance of the two opposing forces in reality.

CONCLUSION

Based on the existing literature, this paper builds a factor decomposition model of non-point source pollution of chemical fertilizer from the three dimensions of scale, structure and constraint, with using the panel data covering 31 provincial regions in China during 2007-2016, aims to investigate the effects of economic scale, population size, economic structure, population structure, technical constraint and resource constraint on non-point source pollution of chemical fertilizer.

The results show that the influencing factors of non-point source pollution of chemical fertilizer come from scale effect, structure effect and constraint effect. Economic size rather than population size leads to scale effect, economic structure rather than population structure leads to structure effect, and technical constraint and resource constraint jointly lead to constraint effect. The inverted U-shaped curve relationship between economic scale and non-point source pollution of chemical fertilizer is essentially an environmental negative externality in production, as well as the evolution path of the implementation of control measures. Economic structure and resource constraint have positive exogenous effects on non-point source pollution of chemical fertilizer, and technical constraint has a negative exogenous effect on non-point source pollution of chemical fertilizer. The ultimate effectiveness of pollution control measures depends on the balance of the two opposing forces in reality.

Although there are also environmental negative externalities of economic size, in terms of non-point source pollution of chemical fertilizer, the industrial point source pollution control model of "attaching importance to end management and neglecting source control" is no longer applicable, for that the high dispersion and concealment of pollution sources, and the randomness and heterogeneity of pollution emission makes it difficult to define the subject and the share of environmental responsibility, combined with the difficulty of process monitoring and the lag in end governance. It is urgent to promote the pollution control mode of "source control". Due to the formulation and implementation of environmental control policies, there is a possibility of coordination between the scale of agricultural economy and non-point source pollution of chemical fertilizer. Therefore, we should spare no effort to optimize agricultural structure, transform agricultural production mode and make rational use of cultivated land resources, at the same time, we should vigorously promote applicable environmental technologies, especially continue to increase the popularization of soil testing formula fertilization technology.

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