

Industrial Structure and COD Emission of Livestock and Poultry Breeding in Liaoning Province, NE China: Empirical Research on the Panel Threshold Model

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Abstract. Assessing waste from livestock and poultry breeding and clarifying the relationship between industrial structure and livestock and poultry pollution are of critical essence in agricultural non-point source pollution control. This paper estimated the chemical oxygen demand (COD) emissions of livestock and poultry breeding of all 14 prefecture-level cities in Liaoning Province in China. Threshold regression models were applied to analyse whether the industrial structure had the threshold effect on the COD emission of livestock and poultry breeding amongst cities varying in economic levels in Liaoning Province from 2005 to 2015. The results show that the COD emission of livestock and poultry breeding in Liaoning increased from 2.5308 million tons in 2005 to 4.5022 million tons in 2015, with an average annual growth rate of 5.929%. Jinzhou City and Chaoyang City were the main contributors of COD emissions of livestock and poultry in Liaoning Province. Moreover, the industrial structure had the double-threshold effect on the COD emission of livestock and poultry breeding in Liaoning Province, and the double threshold values of the per capita GDP were respectively $e^{10.841}(51072.425)$ yuan and $e^{11.608}(109974.082)$ yuan. In addition, with the improvement of economic development level, the marginal impacts of industrial structure on COD emissions of livestock and poultry breeding went from negative to positive and from low to high, presenting a V-pattern trend in impacts. Besides, The COD emission of livestock and poultry breeding was in positive correlation with economic density while in negative correlation with financial support in science and technology in all cities. And the preference to primary industry in workforce structure had a positive effect on the COD emissions of livestock and poultry breeding in cities of lower and medium economic development level.

1. Introduction

Livestock and poultry breeding sector is an important component of Chinese agricultural industry system. With the adjustment of industrial structure and the booming demand for animal products, the livestock and poultry breeding industry has developed rapidly. Along with it, the substantial increase in pollutants from livestock and poultry breeding causes great pressure on the environment. The livestock and poultry breeding sector has become the main source of agricultural non-point source pollution. Liaoning Province is a typical agricultural province in northeastern China. The gross output value of livestock and poultry sector in Liaoning Province increased from 63.65 billion yuan in 2005 to 156.14 billion yuan in 2015, with an average annual growth rate of 9.388%. Meanwhile, the aggravating pollution from livestock and poultry breeding severely hampered the sustainable development of agriculture in Liaoning Province.



There are complicated connections between economic factors and pollution of Livestock and poultry breeding. Wang et al estimated the amount of animal manure produced in China and evaluated the environmental effects in 2003 [1]. Zhou focused on the pollution intensity of livestock and poultry breeding in China from 2002 to 2008 and studied the relationship among industrial agglomeration, environmental regulation and half-point source pollution of livestock and poultry breeding [2]. Qiu et al calculated the magnitude of livestock manure excretion and pollution of China in 2010, and predicted development tendency of it in 2020 [3]. Pan explored the relationship between intensification of livestock production and livestock pollution based on microeconomic surveys in five provinces in China [4]. Bin et al studied the factors influencing farmers' willingness to investment in livestock breeding pollution treatment based on survey data of Hunan Province [5]. Qian et al analyzed whether the transformation of raising scale would be beneficial to the environment and assessed the latest status of livestock and poultry breeding in China [6]. The present study concentrates on estimating waste of livestock and poultry breeding at the national and provincial level, and the analyses of the economic factors of livestock and poultry pollution are still insufficient.

This research aims to explore the relationship between industrial structure and pollution of livestock and poultry breeding and tries to provide a reference for controlling pollution. On the basis of estimating the COD emissions of livestock and poultry breeding of all 14 prefecture-level cities in Liaoning Province in China, this paper constructs panel threshold models to verify the threshold effects in models and analyze the impact industrial structure having on COD emission of livestock and poultry breeding in cities at different economic development levels.

2. Materials and methods

2.1. Estimation method of the COD emission of livestock and poultry breeding

We attempted to estimate the amount of nutrients released from livestock and poultry excreta to water body by parameterizing the emission factors. The amount of chemical oxygen demand (COD) was chosen as a main environmental indicator of livestock and poultry breeding. COD discharges were estimated by using the amount of livestock and poultry combined with the corresponding pollutant discharge coefficient. Based on the pollutant discharge coefficient method of Li et al [7] and Wang [8], annual COD emissions were calculated as shown in (1).

$$P_X = \sum_i (Q_i \times \alpha_i \times T) \quad (1)$$

Where P_X denotes the annual COD emissions from livestock and poultry breeding, Q_i indicates the number of animal type i of livestock and poultry sector, α_i is the corresponding COD discharge coefficient for animal type i , and T indicates the calculation period (one year) and was adjusted for the production cycle. In this study, livestock and poultry mainly contains fattening pigs, dairy cows, beef cattle, layers, and broilers. The relevant COD discharge coefficients for different animal types were adjusted and revised according to the actual cultivation conditions in Liaoning Province. Results in Table 1 show the emission coefficients of livestock and poultry in Liaoning Province.

Table 1. Emission coefficients of livestock and poultry in Liaoning Province a .

Fattening pigs (g/head·a)		Dairy cows (g/head·a)	Beef cattle (g/head·a)		Layers (g/head·a)	Broilers (g/head·a)	
In stock	Slaughtered	In stock	In stock	Slaughtered	In stock	In stock	Slaughtered
108.91	159.57	1659.22	315.59	473.38	13.69	13.55	13.55

^a The emission coefficients were derived from the First National Survey of Pollution Sources and adjusted.

2.2. Panel threshold model

Threshold regression methods were proposed by Hansen in 1999. Threshold regression methods are developed to validate whether the significant change exists in regression function when the independent variable exceeding certain threshold value. According to Hansen, it is an econometric

technique appropriate for non-dynamic panels with individual-specific fixed effects [9]. We intended to investigate whether the industrial structure had the threshold effect on the COD emission of livestock and poultry breeding in Liaoning Province. Threshold regression models were used to estimate the differing effects of industrial structure having on COD emission among areas in different economic levels in Liaoning Province. The structural equation of COD emission of livestock and poultry breeding is as follows:

$$\ln\text{COD}_{it} = \alpha + \beta_1 \ln\text{STR}_{it} \times I(Q_{it} \leq \delta_1) + \beta_2 \ln\text{STR}_{it} \times I(\delta_1 \leq Q_{it} \leq \delta_2) + \dots + \beta_n \ln\text{STR}_{it} \times I(\delta_{n-1} \leq Q_{it} \leq \delta_n) + \beta_{n+1} \ln\text{STR}_{it} \times I(Q_{it} > \delta_n) + \gamma \ln\text{CON}_{it} + \varepsilon_{it} \quad (2)$$

where i indicates the individual prefecture-level city in Liaoning Province and t indicates time. The dependent variable COD_{it} is the COD emission of livestock and poultry breeding. The key independent variable STR_{it} is the ratio of the first industrial added value to GDP, denoting local industrial structure. The threshold variable Q_{it} is the per capita GDP of the city (PGDP), representing the regional economic development level. The observations were divided into different groups depending on the comparing result of threshold variable Q_{it} and the threshold δ_n to be estimated. $I(\cdot)$ is the indicator function. The groups were distinguished by different regression slopes, namely β_1, β_2, \dots and β_{n+1} . The control variable is CON_{it} . In this paper, we selected several indexes as the control variables, including GDP per unit of land (DE), the proportion of the primary industry employed persons in the workforce (PEF), and the proportion of the science & research expenditure in public finance expenditure (PFET). These indexes respectively represent the level of economic density, the level of preference to primary industry in workforce structure, and the level of financial support for science and technology.

2.3. Research Area and Data Sources

The samples cover all 14 prefecture-level cities in Liaoning Province from 2005 to 2015, including Shenyang, Dalian, Anshan, Fushun, Benxi, Dandong, Jinzhou, Yingkou, Fuxin, Liaoyang, Panjin, Tieling, Chaoyang, and Huludao. Emission coefficient data was derived from the First National Survey of Pollution Sources. The data of livestock and poultry breeding and agricultural economy from 2005 to 2015 were available in Liaoning Statistical Yearbooks.

3. Results and Discussion

3.1. Assessment of COD emission of livestock and poultry husbandry in Liaoning Province

Results in Table 2 show the estimated amount of COD emissions of livestock and poultry husbandry in Liaoning. Based on emission estimates, the COD discharge from livestock and poultry husbandry in Liaoning increased from 2.5308 million tons in 2005 to 4.5022 million tons in 2015, showing the aggravating pollution of livestock and poultry breeding in this period. The amount of COD emission from the source of livestock and poultry breeding in Liaoning Province in 2015 increased 0.779 times that in 2005, with an average annual growth rate of 5.929%. The average annual growth rate of COD emissions was 8.872% from 2005 to 2010, and that was 1.154% from 2011 to 2015, showing the slowing downward trend in the growth rate of COD emissions. Significant differences were found in the geographical distribution of COD emissions in livestock and poultry breeding in Liaoning Province. Pollutants discharged from livestock and poultry breeding were mostly distributed in Jinzhou City and Chaoyang City. COD emissions of livestock and poultry sectors in Jinzhou City increased from 0.4983 million tons in 2005 to 0.9667 million tons in 2015, indicating that the pollution degree of livestock and poultry breeding in Jinzhou City was obviously heavier than any other city in Liaoning Province. The Chaoyang City exceeded most other cities in Liaoning Province in not only absolute amount but also the average annual growth rate, reaching 12.364% from 2005 to 2015.

Table 2. The estimated COD emissions of livestock and poultry breeding of all prefecture-level cities in Liaoning Province from 2005 to 2015 (in ten thousand tons)a.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
SY	26.18	29.41	26.2	32.59	36.94	38.7	43.71	46.76	49.98	49.44	40.84
DL	29.71	31.5	27.32	31.6	35.88	34.83	37.19	37.66	12.9	12.29	37.36
AS	23.73	24.65	20.69	23.86	27.64	28.47	29.25	30.65	29.73	28.58	31.22
FS	8.92	9	7.43	7.96	7.54	9.19	10.42	10.96	11.03	9.38	10.27
BX	11.2	12.33	10.75	11.55	14.32	14.29	14.72	15.42	14.18	12.7	15.29
DD	8.25	7.98	7.81	10.2	12.07	13.25	13.98	14.89	15.46	15.12	16.27
JZ	49.83	47.15	46.28	60.55	69.12	77.07	90.44	93.62	130.04	92.73	96.67
YK	13.67	13.63	11.59	14.55	18.87	18.22	19.92	20.54	20.72	20.66	21.75
FX	8.23	9.01	7.96	9.85	11.35	14.16	16.41	18.84	18.76	18.66	19.35
LY	12.34	11.42	9.95	14.79	18.94	25.03	22.48	17.63	15.3	13.73	12.43
PJ	5.81	6.02	6.4	8.76	13.41	12.97	15.12	16.52	18	18.22	19.53
TL	16.81	17.53	14.04	17.78	19.28	28.66	31.46	34.77	35.63	30.85	29.83
CY	26.31	37.09	28.11	36.3	54.73	56.37	67.34	70.58	62.02	76.83	84.41
HLD	12.09	12.91	10.48	12.1	14.76	15.9	17.58	17.04	17.18	16.48	15
Total	253.08	269.63	235.01	292.44	354.85	387.11	430.02	445.88	450.93	415.67	450.22

^a Full name of all prefecture-level cities in Liaoning Province: SY-Shenyang, DL-Dalian, AS-Anshan, FS-Fushun, BX-Benxi, DD-Dandong, JZ-Jinzhou, YK-Yingkou, FX-Fuxin, LY-Liaoyang, PJ-Panjin, TL-Tieling, CY-Chaoyang, HLD-Huludao.

3.2. Industrial structure and COD emission of livestock and poultry breeding in Liaoning Province

3.2.1. *Testing for threshold effect.* Testing was conducted to determine if the threshold effect is statistically significant. Different forms of thresholds were taken into assumption, namely single, double and triple threshold. A bootstrap method was also used to assess the statistical significance of the threshold effect. F-value, P-value, and critical value of various hypothetical threshold models were calculated by bootstrap method 400 times. Results in Table 3 show that a single threshold was not statistically significant, since the corresponding F value was 9.596. Triple threshold was statistically significant at 10% significance level since the corresponding F value was 5.757. Double threshold was statistically significant at 1% significance level since the corresponding F statistic and p values are 69.910 and 0.010 respectively. It indicated that there was double-threshold for the per capita GDP as threshold variable.

Table 3. Tests for threshold effects.

Threshold forms	F-value	P-value	Bootstrap times	Critical values		
				1%	5%	10%
Single threshold	9.596	0.115	400	23.266	16.121	10.497
Double threshold	69.910***	0.010	400	71.250	35.004	17.227
Triple threshold	5.757*	0.083	400	14.938	8.245	4.670

^a ***, ** and * represent that the results are statistically significant at 1%, 5% and 10% significance level respectively.

3.2.2. *Threshold estimate and section partition.* Based on Hansen panel threshold regression method, further estimation was conducted for the threshold values of the natural logarithm of per capita GDP and their 95% confidence intervals. According to the Hansen threshold regression method, the threshold to be estimated is the value of the threshold variable when the likelihood ratio test statistic

LR is zero. In addition, the confidence interval of each threshold is the critical value of the LR value at the 5% significant level. Results in Table 4 show the double thresholds estimates of the natural logarithm of per capita GDP and confidence intervals for each threshold. The values of double thresholds were respectively $\text{e}10.841$ (51072.425) yuan and $\text{e}11.608$ (109974.082) yuan. On the basis of double threshold values of the per capita GDP, all prefecture-level cities in Liaoning Province were divided into three sections: cities of lower level of economic development [6280, 51072.425], cities of medium level of economic development (51072.425, 109974.082] and cities of higher level of economic development (109974.082, 110682].

Table 4. Threshold estimates and confidence intervalsa.

Threshold forms		Threshold estimate	95% confidence intervals
Single threshold		10.858	[9.511, 10.943]
Double threshold	Ito1	11.608	[11.608, 11.608]
	Ito2	10.841	[9.663, 10.927]
Triple threshold		11.193	[9.425, 11.296]

^a The results of 95% confidence intervals are calculated by bootstrap method 400 times.

3.2.3. Panel threshold model regression estimation. This paper aims to validate the threshold effect of industrial structure on COD emission of livestock and poultry breeding in Liaoning Province. Results in Table 5 show the regression results of the panel threshold model. On the whole, the marginal impacts of industrial structure on COD emissions of livestock and poultry breeding presented evident threshold characteristics amongst cities at different economic levels in Liaoning Province. As for cities of lower economic development level, when the per capita GDP was less than $\text{e}10.841$ (51072.425) yuan, there was significantly negative correlation between the COD emission of livestock and poultry breeding and industrial structure. It implied that the preference to primary industry in industrial structure leads to reducing the COD emission of livestock and poultry breeding in cities of lower economic development level. However, as for cities of higher economic development level, when the per capita GDP exceeded $\text{e}11.608$ (109974.082) yuan, industrial structure had a significantly positive impact on COD emission of livestock and poultry breeding. It indicated that the preference to primary industry in industrial structure resulted in increasing the COD emission of livestock and poultry breeding in cities of higher economic development level. In addition, as for cities of medium economic development level, the industrial structure had a positive effect on the COD emissions of livestock and poultry, but it was not significant. In general, with the gradual improvement of economic development level, the marginal impacts of industrial structure on COD emissions of livestock and poultry breeding went from negative to positive and from low to high. It presented a V-pattern trend in impacts the industrial structure having on COD emission of livestock and poultry breeding. For cities of lower and higher economic development level, the regression coefficients of the primary industry added value were -0.0563 and 0.332 respectively. In other words, the industrial structure caused a higher degree of change in COD emissions of livestock and poultry in cities of higher economic development level compared than cities of lower economic development level.

In terms of control variables, the regression coefficients of the variables of economic density were significantly positive in all sections. It indicated that the higher the economic density of the prefecture-level city, the heavier the COD pollution of livestock and poultry in Liaoning Province. There were differences in regression coefficients of the proportion of the primary industry employed persons in the workforce among cities at different economic development levels. In cities of lower and medium economic development level, the regression coefficients were relatively significant while that was not significant in cities of higher economic development level. In cities of which the per capita GDP was not higher than 109974.082 yuan, the proportion of the primary industry employed persons in the workforce had a significant positive effect on the COD emissions of livestock and poultry at 5% significance level. The regression coefficients of the proportion of the Science & Research expenditure

in public finance expenditure were significantly negative among all sections, indicating that enhancing financial support in science and technology contributes to reduction in COD pollution of livestock and poultry. Results in Table 5 also showed that F-values of three regression models were 97.64, 73.82, and 134.53, respectively, and they were all statistically significant at 1% significance level, confirming that these nonlinear panel threshold models were well-fitted.

Table 5. Regression estimation of panel threshold models^{a,b}.

Economic development level	Lower	Medium	Higher
Threshold variable (lnPGDP)	≤ 10.841	(10.841, 11.608]	> 11.608
lnSTR	-0.0563*** (-2.78)	0.0646 (0.26)	0.332*** (7.58)
lnDE	0.702*** (10.90)	0.637*** (10.05)	0.629*** (12.29)
lnPEF	0.582** (2.42)	0.522** (2.05)	0.111 (0.52)
lnFET	-0.0757** (-2.29)	-0.0798** (-2.27)	-0.0927*** (-3.26)
_cons	4.875*** (12.64)	4.863*** (7.00)	4.177*** (12.43)
Fixed region effect	controlled	controlled	controlled
Time trend effect	controlled	controlled	controlled
F Stat	97.64	73.82	134.53
Prob. F Stat.	0.0000	0.0000	0.0000

^a ***, ** and * represent that the results are statistically significant at 1%, 5% and 10% significance level respectively.

^b Results in brackets are standard errors.

4. Conclusions

This paper has estimated the COD emissions of livestock and poultry breeding of all 14 prefecture-level cities in Liaoning Province in China and constructed threshold regression models with individual-specific effects to analyze empirically whether the industrial structure had the threshold effect on the COD emission of livestock and poultry breeding in Liaoning Province. Panel threshold models were applied to a panel of socio-economic and environmental data covering all 14 prefecture-level cities in Liaoning Province in China for the period 2005-2015. Main conclusions of the study are as follows:

(1) The amount of COD emission from livestock and poultry husbandry in Liaoning increased from 2.5308 million tons in 2005 to 4.5022 million tons in 2015, with an average annual growth rate of 5.929%. The total amount of COD emission from livestock and poultry breeding was increasing while its growth rate was slowing down. Jinzhou City and Chaoyang City were the main contributors of COD emissions of livestock and poultry in Liaoning Province.

(2) The industrial structure had the double-threshold effect on the COD emission of livestock and poultry breeding in Liaoning Province, and the double threshold values of the per capita GDP were respectively e10.841 (51072.425) yuan and e11.608 (109974.082) yuan.

(3) With the improvement of economic development level, the marginal impacts of industrial structure on COD emissions of livestock and poultry breeding went from negative to positive and from low to high, presenting a V-pattern trend in impacts. The preference to primary industry in industrial structure would result in increasing the COD emission of livestock and poultry breeding in cities of higher economic development level while decreasing in cities of lower economic development level.

(4) The COD emission of livestock and poultry breeding was in positive correlation with economic density while in negative correlation with financial support in science and technology in Liaoning

Province. The preference to primary industry in workforce structure had a significant positive effect on the COD emissions of livestock and poultry breeding in cities of lower and medium economic development level.

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