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Macroscopic Factors Decomposition of Methane Emissions from Livestock Based on the Empirical Analysis of 31 Provinces in China

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ABSTRACT

This paper builds a factor decomposition model of methane emissions from livestock from the three dimensions of technology, economy and population, by using the panel data covering 31 provincial regions in China during 2003-2016, and aims to reveal the macroscopic causes of methane emissions from livestock. The research shows that technical, economic and population factors of methane emissions from livestock have diminishing marginal contribution. The methane emissions from intestinal fermentation is mainly restricted by livestock's physiological structure. Following increase or decrease of livestock feeding quantity, it changes with a relatively stable parameter and has little controllability. Methane emissions from faecal management is limited little by livestock's physiological structure and it is largely controllable. The government should increase technical input to reduce methane emission factors of livestock, deal with livestock manure through resource utilization, and reduce raising scale by using a certain market mechanism in due course.

INTRODUCTION

Since the beginning of the new century, animal husbandry, as the most dynamic pillar industry in China's agricultural economy, has achieved rapid development again with increasing policy support. According to China Statistical Yearbook (2017), by 2016, the output value of animal husbandry in China (excluding Taiwan, Hong Kong and Macao) had accounted for 28.3% of the total agricultural output value and 4.2% of the total GDP. At the end of the year, the stock of cattle, goats and sheep had reached 106.679 million head, 139.769 million head and 161.351 million head respectively, and the number of pigs kept and raised had reached 435.037 million and 685.02 million respectively. However, the rapid growth of animal husbandry inevitably brought about some environmental problems, especially the emissions of carbon dioxide, methane, nitrous oxide and other greenhouse gases that cause global warming. Livestock accounts for an estimated 18 percent of global greenhouse gas emissions (Fao 2006). Methane contributes 15 percent of global warming to greenhouse gases (Dui 2003), and although it emits less overall than carbon dioxide, the greenhouse effect of the same volume is 20 to 25 times that of carbon dioxide (Shengli et al. 2010). Methane emissions from livestock mainly come from intestinal fermentation and faecal management (Chianese et al. 2009). With the substantial increase of livestock feeding quantity, methane emissions from livestock also increases year by year. According to statistics, global methane emissions were 5.5×10^8 tons, while livestock methane emissions were 8.5×10^7 tons, accounting for 15.5% (Mcginn et al. 2006), and cattle and sheep were the largest emitters. In China, methane emissions from livestock that are fermented in the gut alone account for 29.7 percent of total methane emissions, excluding those from manure management (Renhua 2010). Therefore, it is extremely urgent for China to establish low-carbon production mode of animal husbandry and promote energy conservation and emission reduction to cope up with climate change.

Carbon dioxide emissions have been paid great attention by researches on greenhouse gas emissions that cause climate change. In spite of this, still some scholars remain highly alert to persistent warming caused by methane emissions from livestock. Taking cows, sheep and other major methane emitters as research objects, many workers analysed the biological and chemical mechanism of methane emissions from intestinal fermentation and faecal management, calculated the corresponding emission factors by various methods, and finally proposed scientific methods to curb methane emissions from livestock at the micro level (Bo et al. 2009, Min et al. 2013, Zhi et al. 2017, Yunlong et al. 2018). Some scholars, like Jing et al. (2012) after subdividing the livestock categories, found that the number of pigs, cows, sheep and other livestock had a significant impact on methane emissions through regression analysis of the number of livestock raised in China in the past 20 years, so as to determine the reasonable path for the low-carbon development of animal husbandry in China. At the macro level, however, what causes methane emissions from livestock? How to combine the micro-level scientific methods to control methane emissions from livestock for effective policy regulation? To these questions, the existing literature so far has little discussion. Therefore, we used panel data of 31 provinces in China from 2003 to 2016 to construct decomposition models from three dimensions of technology, economy and population, aiming at revealing the cause of methane emissions of livestock, to supplement the strength of macro explanation in addition to micro explanation. This is of great significance for China to improve the efficiency of livestock breeding, optimize the strategy of reducing greenhouse gas emission and promote the sustainable development of animal husbandry.

MATERIALS AND METHODS

Econometric Model

The study on the decomposition of factors influencing environmental variation began with the IPAT model proposed by Ehrlich P. R. and Holdren J. P. The basic form of this model is as follows:

$$I = P \cdot A \cdot T \qquad \ldots(1)$$

Here, I, P, A and T respectively stand for environmental indicator, population indicator, economic indicator and technical indicator. The combination of population and economy will cause great environmental pressure, which must be alleviated through technical adjustment. Later, in order to facilitate empirical analysis, Yorker et al. (2002) proposed the following STIRPAT model based on IPAT model.

$$I = a \cdot P^b \cdot A^c \cdot T^d \cdot \mathrm{m} \qquad \ldots(2)$$

Here, a represents constant term, b, c, d are the exponents of P, A, T, and μ represents error term.

So far, both the models have been widely used, mainly focusing on the decomposition of the influencing factors of carbon emission (Ang et al. 1998, Zhang 2000, Poumanyvong & Kaneko 2010, Qiang et al. 2012, Xiao & Yaohui 2012, Zhangqi et al. 2018) and industrial emission (Nan & Weiyang 2016, Ling et al. 2017), but empirical analysis of agricultural non-point source pollution (Yuzhuo et al. 2017, Yigen et al. 2017) is rare. Based on the existing empirical studies, we will decompose and investigate the influencing factors of methane emissions from livestock based on the two models. Firstly, according to equation (1), the decomposition form of influencing factors of methane emissions from livestock is set as below:

$$M = \frac{M}{A_n} \cdot \frac{A_n}{A_g} \cdot \frac{A_g}{Y} \cdot \frac{Y}{P} \cdot P \qquad \ldots(3)$$

Here, M is methane emissions from livestock, A_n is animal husbandry output value, A_g is total agricultural output value, Y is total output value, and P is population. We set M (methane emissions from livestock) as an environmental indicator, $MPA = M/A_n$ (methane emissions from livestock per unit animal husbandry output value) as a technical indicator, $AAP = A_n/A_g$ (proportion of animal husbandry output value in total agricultural output value) and $AGP = A_g/Y$ (proportion of total agricultural output value in total output value) as economic structure indicators, $PGDP = Y/P$ (per capita total output value) as an economic scale indicator, and $POP = P$ (population) as a population indicator. Secondly, according to equation (2), the decomposition form of influencing factors of methane emissions from livestock can be further obtained as follows:

$$M = \mathrm{a}_0 \cdot MPA^{\mathrm{a}_1} \cdot AAP^{\mathrm{a}_2} \cdot AGP^{\mathrm{a}_3} \cdot PGDP^{\mathrm{a}_4} \cdot POP^{\mathrm{a}_5} \cdot \mathrm{d} \qquad \ldots(4)$$

Here, a_0 is a constant term, a_1, a_2, a_3, a_4, a_5 are the indices of MPA, AAP, AGP, $PGDP$, POP, respectively, and d is a random error. After taking the logarithm form of both sides of the equal sign, equation (4) is changed into as below:

$$\ln M = \ln \mathrm{a}_0 + \mathrm{a}_1 \ln MPA + \mathrm{a}_2 \ln AAP + \mathrm{a}_3 \ln AGP + \mathrm{a}_4 \ln PGDP + \mathrm{a}_5 \ln POP + \ln \mathrm{d} \qquad \ldots(5)$$

Method for Estimating Methane Emissions from Livestock

There are two main sources of methane emissions from livestock, namely, intestinal fermentation and faecal management, so a set of equations can be set as follows:

$$M = M_1 + M_2 \qquad \ldots(6)$$

$$M_1 = \sum_{i=1}^{n} \left(u_i \cdot Q_i\right) \qquad \ldots(7)$$

$$M_2 = \sum_{i=1}^{n} \left(v_i \cdot Q_i\right) \qquad \ldots(8)$$

Here M_1 and M_2 are respectively methane emissions from intestinal fermentation and methane emissions from faecal management, u_i is the intestinal fermentation methane emission factor of category i livestock, v_i is the faecal management methane emission factor of category i livestock, and Q_i is the feeding quantity of category i livestock.

Table 1: Methane emission factors of intestinal fermentation of livestock [kg/(h.a)].

Feeding way	Cow	Bull	Water buffalo	Sheep	Goat	Pig	Horse	Donkey/Mule	Camel
Large-scale feeding	88.1	52.9	70.5	8.2	8.9	1	18	10	46
Cage-free feeding	89.3	67.9	87.7	8.7	9.4				
Grazing feeding	99.3	85.3	-	7.5	6.7				

Table 2: Methane emission factors of faecal management of livestock [kg/(h.a)].

District	Cow	Non-cow	Buffalo	Sheep	Goat	Pig	Horse	Donkey/Mule	Camel
North	7.46	2.82	-	0.15	0.17	3.12	1.09	0.60	1.28
Northeast	2.23	1.02	-	0.15	0.16	1.12	1.09	0.60	1.28
East	8.33	3.31	5.55	0.26	0.28	5.08	1.64	0.90	1.92
South-central	8.45	4.72	8.24	0.34	0.31	5.85	1.64	0.90	1.92
Southwest	6.51	3.21	1.53	0.48	0.53	4.18	1.64	0.90	1.92
Northwest	5.93	1.86	-	0.28	0.32	1.38	1.09	0.60	1.28

Methane emissions from livestock are estimated to involve cattle, horse, donkey, mule, camel, pig, goat and sheep in eight categories. The feeding cycle of 7 kinds of livestock other than pig is long, and the amount of livestock raised at the end of every year is small, so the amount of livestock kept at the end of every year is used to indicate the feeding quantity. The feeding cycle of pig is generally 180 days, and the feeding quantity is calculated by adding up the annual output and annual stock at the end of every year. The data of the amount of 8 categories of livestock kept and raised at the end of every year are all derived from *China Statistical Yearbook* from 2004 to 2017. The methane emission factors of intestinal fermentation and faecal management of all kinds of livestock were mostly taken from *IPCC Guidelines for National Greenhouse Gas Inventories* (2006) in existing researches. In order to better adapt to the actual situation of each province in China, we refer to *Provincial Greenhouse Gas Inventory Compilation Guide (Trial)* (China National Development and Reform Commission, 2011) compiled by the Climate Division of China National Development and Reform Commission, as given in Table 1 and Table 2.

It should be noted that the methane emission factors of intestinal fermentation of cattle or sheep in different feeding methods in Table 1 are not consistent. Because it is difficult to count the number of cattle or sheep in each province under various feeding methods, and the cattle and sheep in China are still mainly raised by grazing, we decide to adopt the methane emission factors of intestinal fermentation of cattle and sheep under grazing feeding. At the same time, still given that it is difficult to distinguish the number of cows, non-cows and buffaloes in a province, the mean value of methane emission factors of intestinal fermentation of cow, non-cow and buffalo under grazing feeding in Table 1 (excluding the default term) is unified as the methane emission factor of intestinal fermentation of cattle, and the mean value of methane emission factors of faecal management of cow, non-cow and buffalo in Table 2 (excluding the default term) is unified as the methane emission factor of faecal management of cattle. In addition, according to *Provincial Greenhouse Gas Inventory Compilation Guide (Trial)*, in Table 2, North District consists of five provinces (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia), Northeast District consists of three provinces (Liaoning, Jilin, Heilongjiang), East District consists of seven provinces (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong), South-central District consists of six provinces (Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan), Southwest District consists of five provinces (Chongqing, Sichuan, Guizhou, Yunnan, Tibet), and Northwest District consists of five provinces (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang).

Other Variables

Methane emissions from livestock per unit animal husbandry output value is calculated by dividing methane emissions of livestock by animal husbandry output value. Proportion of animal husbandry output value in total agricultural output value is calculated by dividing animal husbandry output value by total agricultural output value. The data of animal husbandry output value, total agricultural output value, proportion of total agricultural output value in total output value, per capita total output value, and population are all directly derived from *China Statistical Yearbook* from 2004 to 2017.

Table 3: Means and proportions of the methane emissions for various types of livestock in China from 2003 to 2016.

Livestock		Cattle	Horse	Donkey	Mule	Camel	Pig	Goat	Sheep
Methane emissions from intestinal fermentation	Quantity (10,000 t/a)	1,061.63	12.09	6.60	2.85	1.31	112.82	106.27	114.27
	Proportion (%)	74.88	0.85	0.47	0.20	0.09	7.96	7.49	8.06
Methane emissions from faecal management	Quantity (10,000 t/a)	54.54	0.92	0.43	0.20	0.04	509.63	5.03	3.70
	Proportion (%)	9.49	0.16	0.07	0.03	0.01	88.71	0.88	0.64

RESULTS AND ANALYSIS

Estimation of Results and Comparative Analysis of Methane Emissions from Livestock

We estimated the methane emissions from all types of livestock in China from 2003 to 2016. In order to facilitate the comparison among livestock categories, we calculated the means of methane emissions from intestinal fermentation and the means of methane emissions from faecal management of all kinds of livestock during 14 years, and the corresponding proportions, as given in Table 3.

Among the 8 types of livestock, cattle have the highest methane emissions from intestinal fermentation, about 10 times as much as pig, goat and sheep, and account for nearly 75% of all kinds of livestock. However, since the number of cattle is smaller than that of goats and sheep, and much smaller than that of pigs, obviously, high emission factor is the main reason for high emissions. Both goat and sheep are similar, and both have low emission factors, but both have a higher breeding, so their emissions are high. On the contrary, the emission factor of pig is the lowest, but the number of pigs is 9-10 times that of goats or sheep, so the emissions are almost no less than those of goat or sheep. Although the emission factors of horse, donkey, mule and camel are much higher than those of goat and sheep, the emissions of these four types of livestock are very low due to the small number of breeding, accounting for no more than 1% of all kinds of livestock.

Among the 8 types of livestock, pig has the highest methane emissions from faecal management, about 10 times as much as cattle, 100 times as much as goat, and account for nearly 90% of all kinds of livestock. Obviously, higher breeding is the main reason for high emissions, while high emission factor is the second. Cattle has the highest emission factor, and therefore has the high emissions, accounting for nearly 10% of all kinds of livestock. Both, goat and sheep are equivalent. Although both have a higher breeding, but have the lowest emission factors, so their emissions are low. On the contrary, the emission factors of horse, donkey, mule and camel are all higher than those of goat and sheep. However, due to the low breeding, the emissions of these four types of livestock are very low. Except for horse, the proportions of these four types of livestock do not exceed 0.1% of all kinds of livestock.

Given that cattle, pig, goat and sheep are the main sources of methane emissions from livestock, we calculated the proportions of methane emissions from intestinal fermentation and the proportions of methane emissions from faecal management of these four types of livestock in all districts and provinces of China in 2016, as given in Table 4 and Table 5.

The regions with the largest proportion of methane emissions from intestinal fermentation of cattle, pig, goat and sheep are southwest, south-central, southwest and north respectively and the provinces are Sichuan, Sichuan, Henan and Inner Mongolia respectively. This is determined by the breeding quantity of each major livestock under a certain animal husbandry structure. In general, southwest and south-central are the main regions for raising cattle and goat, south-central, east and southwest are the main regions for raising pig, and northwest and north are the main regions for raising sheep, each region accounting for more than 20% of the total emissions. Sichuan, Henan, Yunnan, Inner Mongolia and Tibet are the main provinces for raising cattle, Sichuan, Henan, Hunan, Shandong, Hubei, Yunnan and Guangdong are the main provinces for raising pig, Henan, Sichuan, Inner Mongolia, Shandong and Yunnan are the main provinces for raising goat, Inner Mongolia, Xinjiang, Gansu, Qinghai, Shandong, Tibet and Hebei are the main provinces for raising sheep, each province accounting for more than 5% of the total emissions.

The regions with the largest proportion of methane emissions from faecal management of cattle, pig, goat and sheep are south-central, south-central, southwest and northwest respectively, and the provinces are Henan, Henan, Sichuan and Xinjiang respectively. This is determined by the different emission factors in different regions in addition to the breeding quantity of each major livestock under a certain livestock husbandry structure. Overall, the top three regions with the highest cattle emission factor are in turn south-central [7.14kg/(h.a)], east [5.73kg/(h.a)] and north [5.14kg/(h.a)], with the highest pig emission factor are in turn south-central, east and southwest, with the highest goat emission factor are in turn southwest, northwest and south-central, and with the highest sheep emission factor are in turn southwest, south-central and northwest. Thus, it can be seen that the large number of breeding mainly determines the high emissions of cattle breeding in south-west, goat breeding in south-central, and sheep breeding in northwest and north, the high emission factors mainly determine the high emissions of cattle and goat breeding in south-central, and both the large number of breeding and the high emission factors determine the high emissions of pig in south-central, east and southwest and those of goat in southwest, each region accounting for more than 20% of the total emissions. Further, at the provincial level, the higher breeding mainly determines the high emissions of cattle breeding in Sichuan, Yunnan and other provinces, those of pig breeding in Sichuan, Shandong and other provinces, those of goat breeding in Henan, Shandong and other provinces, those of sheep breeding in Inner Mongolia, Gansu, Qinghai,

Table 4: Proportions of the methane emissions from intestinal fermentation from major types of livestock in the regions of China in 2016 (%).

District	Province	Methane emissions from intestinal fermentation							
		Cattle		Pig		Goat		Sheep	
North	Beijing	0.15	11.28	0.39	8.04	0.13	16.95	0.26	34.34
	Tianjin	0.28		0.50		0.04		0.26	
	Hebei	3.71		4.69		3.36		5.68	
	Shanxi	1.00		1.07		2.60		3.39	
	Inner Mongolia	6.14		1.38		10.82		24.75	
Northeast	Liaoning	3.75	12.39	3.58	8.66	3.37	5.08	2.59	9.19
	Jilin	4.01		2.29		0.38		2.39	
	Heilongjiang	4.63		2.79		1.33		4.20	
East	Shanghai	0.05	10.14	0.24	22.99	0.18	17.73	0.01	6.87
	Jiangsu	0.28		4.05		2.82		0.06	
	Zhejiang	0.14		1.56		0.29		0.45	
	Anhui	1.57		3.88		4.69		0.01	
	Fujian	0.62		2.41		0.92		0.00	
	Jiangxi	2.83		4.21		0.44		0.00	
	Shandong	4.65		6.63		8.40		6.35	
South-central	Henan	8.32	22.77	9.19	34.66	12.46	21.86	0.73	0.73
	Hubei	3.33		5.94		3.37		0.00	
	Hunan	4.28		8.80		3.79		0.00	
	Guangdong	2.19		5.01		0.31		0.00	
	Guangxi	3.92		4.91		1.46		0.00	
	Hainan	0.72		0.82		0.48		0.00	
Southwest	Chongqing	1.36	28.43	3.07	21.71	1.55	25.75	0.00	7.50
	Sichuan	9.09		10.36		11.24		1.18	
	Guizhou	4.86		2.91		2.36		0.12	
	Yunnan	7.40		5.32		6.93		0.47	
	Tibet	5.72		0.05		3.67		5.73	
Northwest	Shaanxi	1.39	14.99	1.76	3.94	3.97	12.64	0.76	41.38
	Gansu	4.19		1.12		2.91		9.11	
	Qinhai	4.53		0.23		1.31		7.49	
	Ningxia	1.06		0.15		0.80		2.91	
	Xinjiang	3.83		0.69		3.64		21.11	

Table 5: Proportions of the methane emissions from faecal management from major types of livestock in the regions of China in 2016 (%).

District	Province	Methane emissions from faecal management							
		Cattle		Pig		Goat		Sheep	
North	Beijing	0.17	12.50	0.27	5.57	0.07	8.70	0.16	21.69
	Tianjin	0.31		0.35		0.02		0.16	
	Hebei	4.11		3.25		1.73		3.59	
	Shanxi	1.11		0.74		1.34		2.14	
	Inner Mongolia	6.80		0.96		5.55		15.64	
Northeast	Liaoning	1.31	4.34	0.89	2.15	1.63	2.45	1.64	5.80
	Jilin	1.40		0.57		0.18		1.51	
	Heilong-jiang	1.62		0.69		0.64		2.66	
East	Shanghai	0.06	12.53	0.27	25.92	0.15	14.98	0.01	7.52
	Jiangsu	0.35		4.57		2.39		0.06	
	Zhejiang	0.17		1.75		0.24		0.50	
	Anhui	1.94		4.37		3.96		0.01	
	Fujian	0.77		2.72		0.77		0.00	
	Jiangxi	3.49		4.75		0.37		0.00	
	Shandong	5.74		7.48		7.10		6.95	
South-central	Henan	12.80	35.04	11.93	45.01	11.66	20.45	1.04	1.04
	Hubei	5.12		7.72		3.15		0.00	
	Hunan	6.59		11.43		3.54		0.00	
	Guangdong	3.38		6.50		0.29		0.00	
	Guangxi	6.04		6.37		1.36		0.00	
	Hainan	1.10		1.06		0.45		0.00	
Southwest	Chongqing	1.10	22.99	2.85	20.14	2.48	41.20	0.00	15.16
	Sichuan	7.35		9.61		17.99		2.38	
	Guizhou	3.93		2.70		3.78		0.24	
	Yunnan	5.99		4.93		11.08		0.95	
	Tibet	4.62		0.05		5.87		11.58	
Northwest	Shaanxi	1.17	12.59	0.54	1.21	3.84	12.21	0.90	48.79
	Gansu	3.52		0.34		2.82		10.74	
	Qinhai	3.81		0.07		1.26		8.83	
	Ningxia	0.89		0.05		0.77		3.43	
	Xinjiang	3.21		0.21		3.52		24.89	

Shandong and other provinces. The high emission factors mainly determine the high emissions of cattle breeding in Henan, Inner Mongolia, Hunan, Guangxi, Shandong, Hubei and other provinces, those of pig breeding in Henan, Hunan, Hubei, Guangdong, Guangxi and other provinces, those of goat breeding in Sichuan, Yunnan, Tibet, Inner Mongolia and other provinces, those of sheep breeding in Xinjiang, Tibet and other provinces; each province accounting for more than 5% of the total emissions.

General Regression Results and Analysis

We made a general regression of the factors affecting methane emissions from livestock. Before the regression estimation, the variance inflation factor (VIF) was used to verify that the VIF values of all explanatory variables in the model were within the interval [1.00 4.50], far less than 10, and there was no multicollinearity. LSDV test showed that the individual effect of the panel data was obvious, indicating that mixed OLS regression should not be used. According to Hausman test, compared with fixed effect regression, random effect regression was more consistent with the statistical characteristics of the panel data. Therefore, we used the random effect regression results of clustering robust standard deviation, as provided in Table 6.

The results of Regression 1 show that the model fits well. The influence coefficient of each explanatory variable on methane emissions from livestock is within the range (0.8, 1), that is, the marginal contribution of technical, economic and population factors to environmental variation is decreasing, and higher the influence coefficient is, the smaller the rate of diminishing marginal contribution is. In fact, except for proportion of total agricultural output value in total output value, the influence coefficients of other explanatory variables on methane emissions of livestock are all close to 1, with a very small rate of diminishing marginal contribution. Specifically, the impact coefficient of population on methane emissions from livestock is the highest, indicating that expansion of consumption demand for livestock caused by increase of population is the most important reason for high methane emissions from livestock. The impact coefficient of methane emissions from livestock per unit animal husbandry output value on methane emissions from livestock is second only to population, and poor technology is not conducive to controlling methane emissions from livestock. The impact coefficient of per capita total output value on methane emissions from livestock is high, meaning that greater economic size drives livestock production growth and increases methane emissions from them. Proportion of animal husbandry output value in total agricultural output value and proportion of total agricultural output value in total output value are two economic structural factors, the former undoubtedly has a higher influence coefficient on methane emissions of livestock than the latter, and the larger the proportion of livestock production value is, the larger the relative economic scale of livestock will be, and the higher the methane emissions of livestock will be.

In order to test the robustness of the regression model, we combine the two economic structure factors of proportion of animal husbandry output value in total agricultural output value (*AAP*) and proportion of total agricultural output value in total output value (*AGP*) into one, that is, proportion of animal husbandry output value in total output value (*AAGP*), and the calculation method is $AAGP = A_n/Y$. After testing, we used the random effect regression results of clustering robust standard deviation, as given in Table 6. The results of Regression 2 show that the sign and significance of the influence coefficient of each explanatory variable on methane emissions from livestock are consistent with the results of Regression 1, and the values of each coefficient are only slightly changed, indicating that the results of Regression 1 are robust.

CLASSIFICATION REGRESSION RESULTS AND ANALYSIS

Furthermore, we made two separate regressions of the factors affecting methane emissions from livestock from intestinal fermentation and faecal management. For each regression, LSDV test showed that the individual effects of the panel data were obvious, indicating that mixed OLS regression should not be used. According to Hausman test, compared with random effect regression, fixed effect regression was

Table 6: Regression results for the methane emissions from livestock.

Influencing factors	Regression 1		Regression 2	
	Coefficient	Z-value	Coefficient	Z-value
ln*MPA*	$0.985\,6^{***}$	45.89	$0.981\,1^{***}$	43.55
ln*AAP*	$0.959\,0^{***}$	30.02	-	-
ln*AGP*	$0.870\,6^{***}$	25.40	-	-
ln*AAGP*	-	-	$0.893\,0^{***}$	25.88
ln*PGDP*	$0.966\,6^{***}$	50.01	$0.963\,9^{***}$	42.77
ln*POP*	$0.998\,9^{***}$	44.47	$0.992\,9^{***}$	39.47
Intercept	$-17.122\,5^{***}$	-53.12	$-12.769\,1^{***}$	-38.85
Wald-Statistic	$4\,810.22^{***}$		$2\,956.27^{***}$	
Adj-R^2	0.945 5		0.944 2	
VIF	2.54		2.88	
Observations	434		434	

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

Table 7: Regression results for the methane emissions from intestinal fermentation and faecal management.

Influencing factors	Methane emissions from intestinal fermentation		Methane emissions from faecal management	
	Coefficient	T-value	Coefficient	T-value
ln*MPA*	1.107 3***	16.95	0.600 0***	5.90
ln*AAP*	0.995 9***	11.28	0.786 6***	6.65
ln*AGP*	0.989 0***	9.05	0.615 1***	8.47
ln*PGDP*	1.032 1***	13.85	0.711 0***	7.21
ln*POP*	1.117 8***	5.40	0.526 5***	2.89
Intercept	-19.288 8***	-7.82	-11.908 2***	-4.85
F-Statistic	69.35***		33.38***	
Adj-R^2	0.875 7		0.610 2	
Observations	434		434	

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

more consistent with the statistical characteristics of the panel data. Therefore, we used the fixed effect regression results of clustering robust standard deviation, as provided in Table 7.

The results of each regression show that the model fits well. Each explanatory variable has a significant positive effect on methane emissions both from intestinal fermentation and from faecal management. Differently, on the one hand, the influence coefficient of each explanatory variable on methane emissions from intestinal fermentation is close to 1, which indicates that methane emissions from intestinal fermentation is mainly restricted by livestock's physiological structure. Following increase or decrease of livestock feeding quantity determined by each explanatory variable, it changes with a relatively stable parameter and has little controllability. On the other hand, the influence coefficient of each explanatory variable on methane emissions from faecal management is within the range (0.5, 0.8), lower than the influence coefficient of each explanatory variable on methane emissions from livestock in the results of Regression 1, and technical, economic and population factors all have diminishing marginal contribution, which indicates that methane emissions from faecal management is limited little by livestock's physiological structure, and it is largely controllable. In fact, whether and to what extent methane emissions, both from intestinal fermentation and from faecal management, are constrained by livestock's physiological structure can be reflected in methane emission factors of livestock. Table 1 and Table 2 show that the methane emission factors of intestinal fermentation are relatively stable, while those of faecal management have large regional differences.

DISCUSSION

Due to different degrees of constraints by livestock's physiological structure, it is necessary to distinguish methane emissions between from intestinal fermentation and from faecal management to control methane emissions from livestock at the macro level. To control methane emissions from intestinal fermentation, which is more restricted by livestock's physiological structure, the primary task is to increase technical input to reduce methane emission factors of intestinal fermentation, and then reduce methane emissions from livestock per unit animal husbandry output value. First, through breeding and improvement, the level of yield per unit can be improved, and the number of livestock breeding can be reduced under the premise of meeting the established demand for livestock products. Second, the quantity and quality of food intake should be standardized, and the specific measures include promotion of straw silage and ammonification, rational preparation of fine/coarse ration of daily food, and appropriate use of nutritional additives. Third, the production of methane in the rumen can be inhibited by inhibiting methanogenic bacilli. In addition, to adjust economic structure in order to reduce proportion of animal husbandry output value in total agricultural output value, in turn, reduce proportion of total agricultural output value in total output value, or to shrink economic scale in order to reduce per capita total output value, or to control population size to reduce population, will have a negative impact on the overall economic quality, and thus is not desirable. For the areas with a large stock of livestock, reducing scale of breeding may be the most direct and effective measure, but the policy of prohibition and restriction should be avoided, and it can be solved through a certain market mechanism, that is, taxes can be levied on the ruminant animal (cattle, goat or sheep) husbandry industry, on the one hand, to promote industrial substitution from the supply side, and on the other hand, to encourage reduction of meat consumption from the demand side.

The diminishing marginal contribution of technological level, economic structure, economic scale and population scale essentially reflects the effective role of some external forces in controlling methane emissions from faecal management. Due to small degree of restriction by livestock's physiological structure, in the exogenous factors of controlling methane emissions from manure management, it is very important to deal with livestock manure through resource utilization, and using biogas project to recover methane is particularly effective. Enterprises or farmers should be given a certain subsidy for purchase and construction of biogas facilities according to livestock type and breeding scale, at the same time, fines should be imposed for illegal discharge and release of livestock waste. Of course, methane emissions from livestock per unit animal husbandry output value could still be reduced by investing more in technology to reduce methane emission factors of faecal management. There are two specific ways: first, to reduce faecal production through scientific selection of feed, precise control of food, the use of feed additives and other methods; second, to realize updating and upgrading of the technology for cleaning up faeces by changing water flushing and blisters into dry cleaning or adopting automatic dry and wet separation to clean.

CONCLUSION

Finally, we came to five conclusions. Firstly, the methane emissions of four main types of livestock are different in categories. Large number of breeding is the main reason for high emissions of pig, goat and sheep, and high emission factor is the main reason for high emissions of cattle. Secondly, the methane emissions of four main types of livestock are different in regions. Methane emissions from intestinal fermentation is determined by breeding quantity of each major livestock under a certain animal husbandry structure, and methane emissions from faecal management is determined by different emission factors in different regions in addition to breeding quantity of each major livestock under a certain livestock husbandry structure. Thirdly, in general, technical, economic and population factors of methane emissions from livestock have diminishing marginal contribution. Fourthly, methane emissions from intestinal fermentation are mainly restricted by livestock's physiological structure. Following, increase or decrease of livestock feeding quantity, it changes with a relatively stable parameter and has little controllability. Methane emissions from faecal management is limited little by livestock's physiological structure, and it is largely controllable. Fifthly, in order to control methane emissions from intestinal fermentation, technical investment should be increased to reduce methane emission factors of intestinal fermentation and a certain market mechanism should be used in due course to reduce raising scale. In order to control methane emissions from faecal management, it is very important to deal with livestock manure through resource utilization, but technical input should still be increased to reduce methane emission factors of faecal management.

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