Assessing Environmental Impacts of Chinese Livestock Policies

An Agent-Based Approach

Chaohui Zheng

Thesis Committee

Promoter

Prof.dr.ir. A.P.J. Mol
Professor of Environmental Policy
Wageningen University, the Netherlands

Co-Promoters

Dr. Y. Liu
Associate Professor, School of Environment
Tsinghua University, Beijing, China

Dr. B. Bluemling
Assistant Professor of Environmental Policy
Wageningen University, the Netherlands

Other members

Prof. dr. B. Kemp, Wageningen University

Prof.dr. W. Li, Beijing Normal University, China

Prof. dr. J.H.H. Wesseler, Technische Universität München, Germany

dr. W. Jager, University of Groningen, the Netherlands

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Chaohui Zheng

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Preface

This dissertation attempts to provide a different perspective and search a new methodology for Chinese policy assessment. Strategic environmental impact assessments, including policy assessments, have been more popular in China, reshaping the system of Chinese environmental management. Moreover, Chinese government is transferring its focus of environmental protection to rural areas. It is hence a big challenge to suit the measures of Chinese environmental management to the rural context, due to the significant differentiations between rural and urban areas and agricultural and industry sectors. In the autumn of five years ago, I left my home country for the first time, and started my doctoral study at the Environmental Policy Group (ENP) of Wageningen University. When I touched upon the discipline of environmental sociology, I was attracted and inspired by the ideas of that understanding and addressing environmental problems on the basis of microcosmic dynamics, such as personal choice behavior, interactions among individuals etc.. The theories and approaches advocated by environmental sociology are significantly different with the conventional approaches of Chinese policy assessment which are mainly constructed from the perspective of natural sciences. This research gives me an opportunity to experiment on integrating the concepts of social sciences into environmental system analysis and modeling. In the past five years, my research benefited from the supports of many people and organizations. This dissertation would not be possible without their assistance, cooperation, facilitating, advice, and even criticism.

This doctoral research has been conducted under the framework of the SURE (SUstainable Natural REsource Use in Rural China) project, which is one part of the Programme Strategic Scientific Alliances between China and the Netherlands. The project is sponsored by the Royal Netherlands Academy of Arts and Science (KNAW), as well as the China’s Ministry of Science and Technology (MoST), for which I am very grateful. I also would like to express my gratitude to Wageningen University in the Netherlands and Tsinghua University in China for enabling my study.

I own my heartfelt thanks to my promoter prof. Arthur P.J. Mol, the chair of the ENP group and the director of SURE project on the Dutch side. This work can only be accomplished under his invaluable supervision, encouragement and detailed commenting on the papers. He was always patient to guild my research and gave me confidence to overcome the difficulties, whenever the research had little progress at the initial stage and got unexpected criticisms at the final stage. It is my good luck to be his student. My sincere thanks also go to my co-promoters Dr. Yi Liu from Tsinghua University and Dr. Bettina Blumeling from ENP group. During the years of my staying in China, Dr. Yi Liu provided me the great guidance to implement the field surveys and develop the model. I felt so much comfortable and relaxed in his research group to work on my research and discuss with other students, although I was a guest student in Tsinghua. As my daily supervisor, Dr. Bettina Bluemling spent lots of time on helping me to supplement the knowledge of social sciences, and promoting my work. Her experience and insights about rural China were of great help to improve the questionnaire design and explain the findings of field surveys. She is also the coordinator of SURE project. Thanks to her careful arrangement, I can concentrate on my research, enjoyably live in the Netherlands, and smoothly accomplish field work in China. All of them influenced me a lot through their profound knowledge, rich experience, as well as their rigorousness and enthusiasm toward academic research.

I highly appreciate prof. Jining Chen, the president of Tsinghua University, for his invaluable suggestions not only on this research but also on my research career. His encouragement and recommendation gave me the opportunity and confidence to participate in SURE project and pursue my doctorate abroad. This is a challenge for myself. In spite of so many difficulties and setbacks I faced to, I have benefited a great deal from this special experience. I am particularly grateful to prof. Pengfei Du and associate prof. Siyu Zeng from Tsinghua University for their recommendation, guidance and concern.

The field surveys conducted in the research showed me the complexity of farmers' decision making which possibly decouples from the phenomenon described by statistical data. I am thankful to the officials, experts and interviewers who gave me great help during my field surveys. Special thanks to Mr. Jian Hu, the director of Environmental Protection Bureau in Deyang city, and Mr. Weiwei Dai from Rudong County.

I would like to extend my deep gratitude to all my colleagues and friends in Wageningen and Tsinghua University. My special thanks go to Ms. Corry Rothuizen, the secretary of ENP group. She was so warm-hearted to solve many problems for me, largely facilitating my living in Wageningen. I appreciate Dr. Peter Oosterveer for his special help when I injured my back in Wageningen. Thanks to all the fellow PhD students in SURE project, Jia Li, Dr. Lei Zhang, Dr. Shuqin Jin, Tie Chen, Dr. Wenling Liu, Xianlei Ma, and Yan Wu for our fighting together in these five years. I am grateful to Alexey Pristupa, Alice Miller, Carolina Toschi Maciel, Ching Kim, Dorien Korbee, Elena Degli Innocenti, Eira Carballo Cárdenas, Jennifer Lenhart, Joeri Naus, Harry Barnes Dabban, Hilde Toonen, Kari Stange, Marjanneke Vijge, Natapol Thongplew, Nguyen Dung, Sarah Stattman, Somjai Nupueng, and Thomas Nugroho, for giving me such an international and wonderful experience. Special thanks to Hilde for the Dutch translation of the summary, and Eira and Wenling to be the paranymphs. I also own many thanks to my Chinese friends in Tsinghua and I met in Wageningen, Dr. Fanxian Yu, Dr. Fu Sun, Dr. Guizhen He, Dr. Jing Lu, Dr. Jingyi Han, Jinyun Zhang, Dr. Liang Dan, Dr. Lei Zhang, Dr. Lijing Zhong, Dr. Minpeng Chen, Dr. Qin Tu, Shumin Yu, Dr. Wenjia Cai, Xiaoyun Bing, Dr. Xin Dong, Yan Feng, Yuan Zhang, for their company, encourage and helpful discussions.

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Beijing, November 2013

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Abbreviations

ABM	Agent-Based Model
ANEM	Agent-based Nutrient Emission Model
AQSIQ	Administration of Quality Supervision, Inspection and Quarantine
CHS	Collection technology and Handling pattern Selection module (in Chapter 2)
C.P.C.	Communist Party of China
CPSC	China's Pollution Source Census
EPB	Environmental Protection Bureaus
ER	Ecological Rationality (in Chapter 3)
FSD	Farm Scale Decision module (in Chapter 2)
GOSC	General Office of the State Council
MoA	Ministry of Agriculture
MoEP	Ministry of Environmental Protection
MoLR	Ministry of Land and Resources
MoST	Ministry of Science and Technology
N	Nitrogen
NBSC	National Bureau of Statistic of China
NDRC	National Development and Reform Commission
NEPA	National Environmental Protection Administration
NPSP	non-point source pollution
NGO	non-governmental organization
ODD	Overview, Design concepts, and Details protocol
OECD	Organization for Economic Co-operation and Development
P	Phosphate/phosphorous
SAC	Standardization Administration of China
SCNPCC	Standing Committee of National People's Congress Council
SEA	Strategic Environmental Assessment
SSB	State Statistical Bureau
WTO	World Trade Organization

1 Introduction

A medium scale pig farm in Zhongjiang County, Deyang City, Sichuan Province

Chapter 1. Introduction

1.1 Transitions of Chinese livestock production

China has a long tradition of livestock production. The transitions of Chinese livestock production during the last decades amazed the whole world, especially the sharp increase of the productivity and the continuous intensification progress.

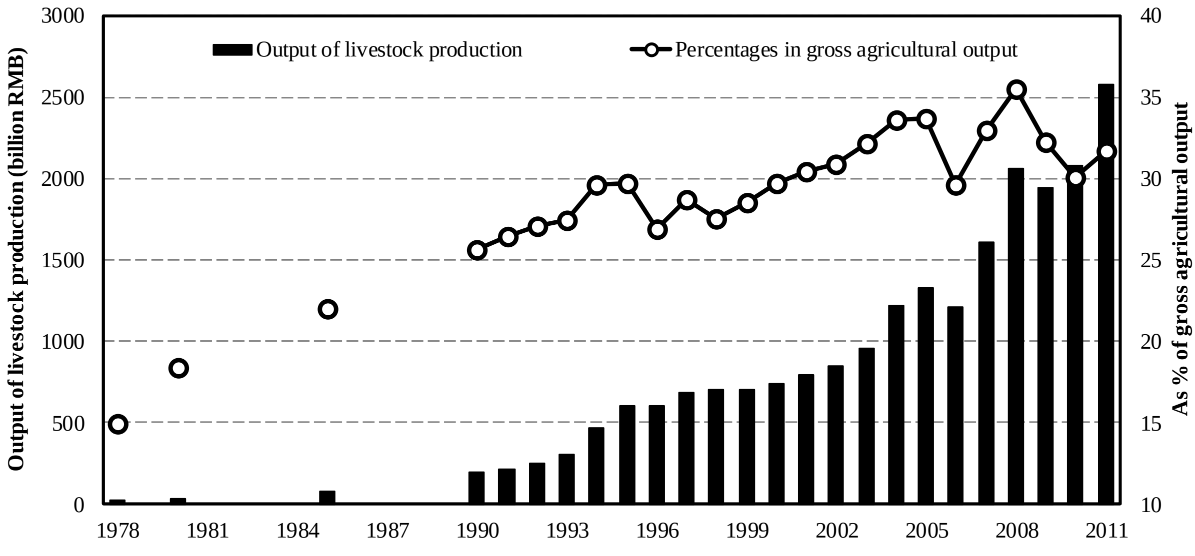
1.1.1 Increase of livestock productivity

As one of the most important livestock producers in the world, China has accelerated its livestock production since the economic reform in 1979. At pre-reform time, livestock production was not prioritized in the agricultural sector, due to the “grain production first” strategy of the Chinese central government. At the beginning of the market-oriented rural reform, a number of policies adjusted the structure of agricultural sector and put an end to the authoritative limitation on livestock production, which allowed farmers[1] to expand their animal breeding and later provided farmers access to agricultural markets. Livestock production has been seen as important as cropping for food security from the mid-1980s onwards (Li, 2009; Jin, et al., 2010). The increases of income per capita and purchasing power significantly contributed to growing demand for Chinese livestock products (Delgado, 2003; Li, et al., 2008; Bluemling and Hu, 2011). From 1990 to 2005, the Chinese per capita consumption of eggs, poultry meats, pork, beef, and milk grew at 7.8%, 8.8%, 4.4%, 14%, and 7.9%, respectively (Li, et al., 2008). In addition, Chinese farmers have more and more participated in the global agricultural market, since China became a member of World Trade Organization (WTO). For instance, the exports of meat and meat processed goods in 2012 reached 2.94 billion US dollars, 20.4% more than over 2011 (*Chinese business yearbook 2012*). Therefore, the development of Chinese livestock production is profound not only for China but also for global agricultural supply. Moreover, governments have considered livestock production an essential way to increase rural household income since 2000, when the income gap between urban and rural areas was the major problem for rural management (Tuan and Ke, 1999; Ma, 2004; Ma and Zhang, 2009). Coupled with enormous macro-economic changes, such institutional transformation triggered substantial changes in

[1] In this thesis, farmers will be always referred as him/male to make the writing less complicated. The majority of the household decision-makers in Chinese livestock production are male, although I acknowledge that there are also substantial numbers of female farmers.

production, marketing and consumption of livestock products (Fan and Pardey, 1992; Bingsheng, 2002; Daniel, et al., 2004).

Figure 1.1 shows the development of Chinese livestock production in the decades after 1978. The value of livestock production in 1985 was almost three times higher than in 1978, meanwhile its share in gross agricultural output increased from 15% to around 22%. The rapid growth of livestock output continued over the following two decades. The development speed of the livestock sector outpaced the cropping sector (Jin, et al., 2010). In the early 1990s, livestock production accounted for approximate 30% of total agricultural production, doubling its share back in 1978. The weight of livestock production in gross agricultural output reached 34% in 2005. However, the livestock sector went through a series of fluctuations during the last couple of years, regarding both its output and shares in agricultural production. Livestock output peaked with more than 400 billion US dollars in 2011, accounting for about 32% of gross agricultural output that year. Furthermore, livestock production is expected to have a share of 36% of the gross agricultural output by the end of 2015 (State Council of China, 2012).

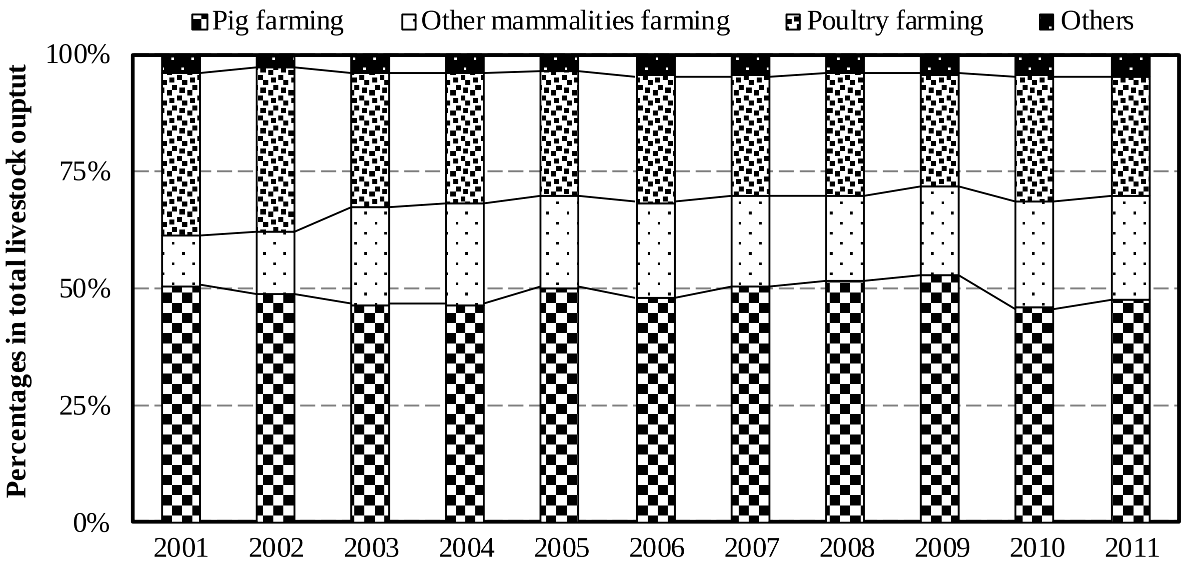


(Data source: Chinese statistical yearbooks)

Figure 1.1 Progress of Chinese livestock production (1978-2011)

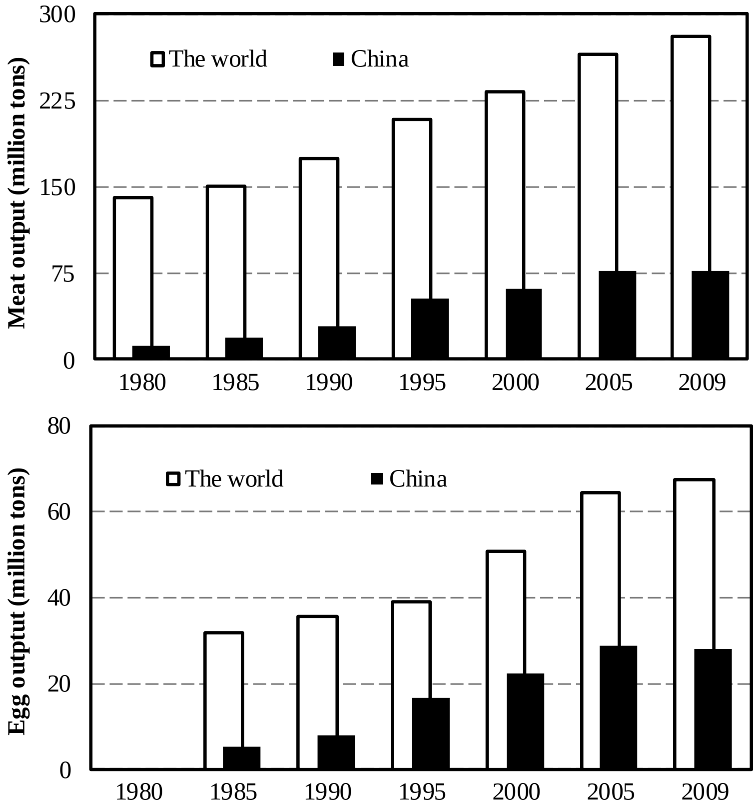
As showed in Figure 1.2, pig and poultry farming dominate Chinese livestock production. Pig farming has been the largest component of livestock production for a long time, taking about half of Chinese livestock value and 40% of global pork production. It showed an increase of 22.5% over the period 1999 to 2009, and an increase of 113.4% over the period

1989 to 2009 (Bluemling and Hu, 2011). Although the share of poultry farming in total livestock production reduced during the last decade, the production of poultry meat and eggs keeps increasing fast. The output of poultry meat has taken the second place in the world, only behind US (Li, et al., 2008). China contributed with 40% of egg production to the in global market by 2009. In recent years, the shares of large animal farming, mainly as cattle and sheep, in total livestock production increased to 22% and approximated the share of poultry farming. In sum, meat and egg outputs reveal the distinct performance of Chinese livestock production in the global market (as showed in Figure 1.3). For instance, some countries are replacing Europe, North and Central America to dominate global livestock production. Among these countries, China alone accounted for more than half of the increase of total meat supply (Windhorst, 2006; Li, et al., 2008; Kanaly, et al., 2010). According to the FAO (2006), China has been the largest producer and consumer of livestock products in Asia and is the number one global producer of pork, mutton and eggs. However, it is found that animal species are regionalized (Figure 1.4). Cattle and sheep farming are mostly located in north and west China, while pig and poultry farming are concentrated in eastern areas. The difference of dominant animal species across regions will be enhanced by governmental policies in the recent future (MoA, 2008).



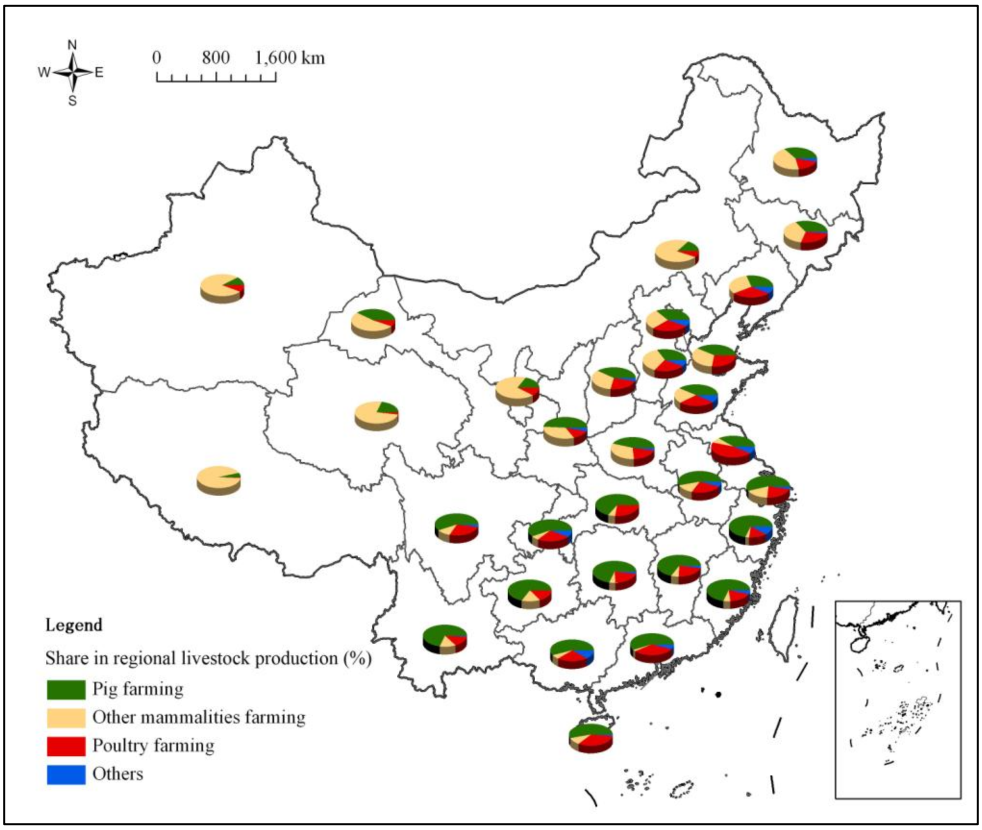
(Data source: China rural statistical yearbooks)

Figure 1.2 Shares of different components of Chinese livestock production (2001-2011)



(Data source: FAO database)

Figure 1.3 Development of meat and egg output of China and the world (1980-2009)



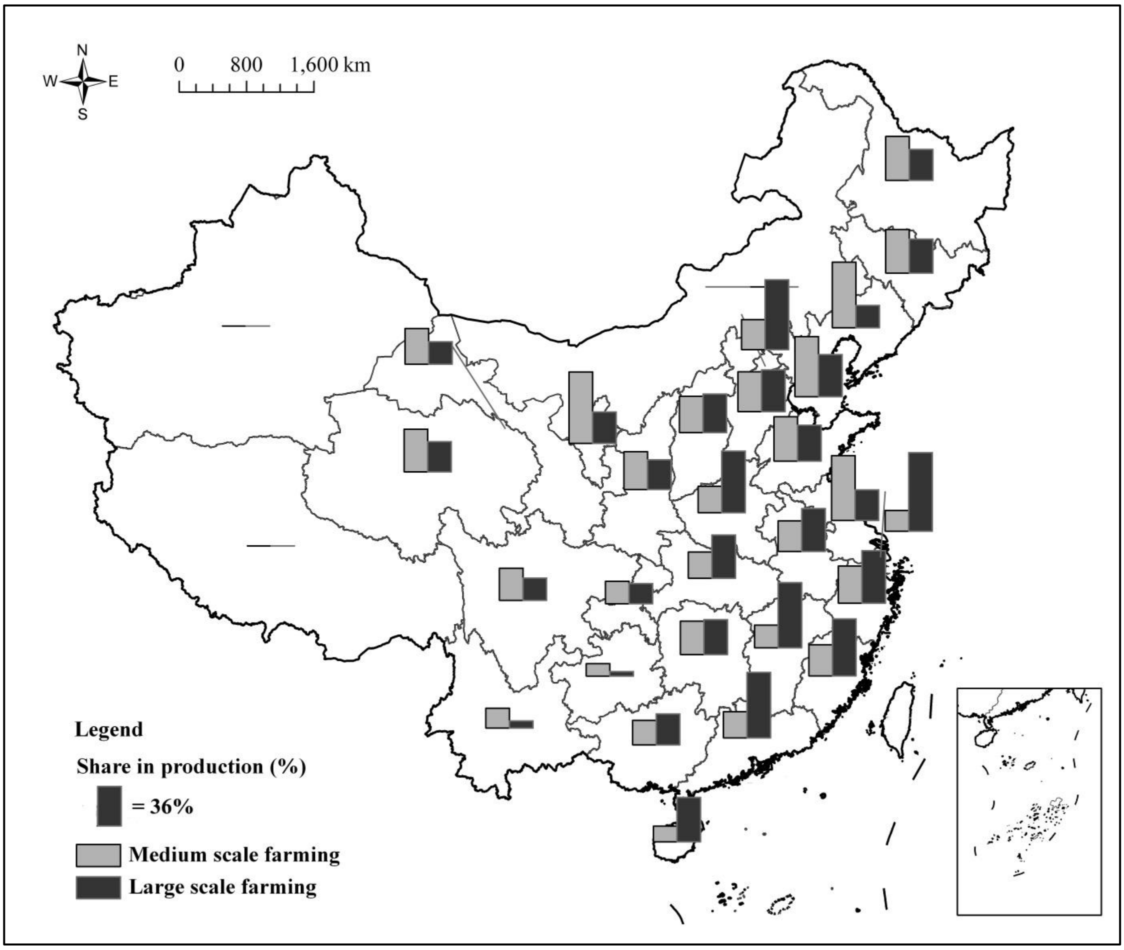
(Data source: China rural statistical yearbooks 2011)

Figure 1.4 Share of different livestock production in Chinese provinces (2011)

1.1.2 Intensification

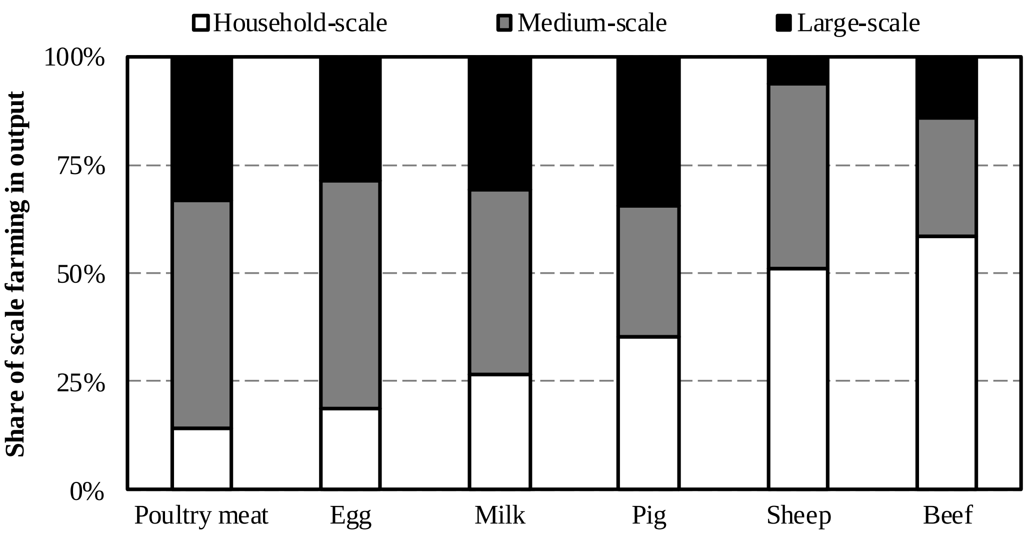
The structure of Chinese livestock production underwent a rapid evolution as well. Traditionally, households breed a few species and small numbers of animals in their backyard, for the purpose of self-consumption, draft power and organic fertilizer. In 1996 it was found that 70% rural households (around 135 million farmers) kept on average 2-3 pigs (SSB, 1996). Since 1980s, farmers have had opportunities to raise additional animals for sale in local markets. Governments encouraged farmers to specialize in one or several animal species and to adopt western intensive farming models (Li, 2009). An increasing number of households paid more attention to livestock, and increased their animal heads, for example raising dozens of pigs. Meanwhile, Chinese government has explicitly supported intensification in the sector through providing incentives for building of animal feed plants, modernizing in animal drug plants, import of foreign technologies, and so on (Li, 2009). Beside of governments, multilateral financial institutions and even large private investment firms invested to promote intensification of livestock production (Woeld Bank, 2004). Many traditional households thus have shifted to medium-scale farmers (called specialized farmers in the Chinese administration system) and, going a step further, been industrialized operators (or so called large-scale farmers). All of them are labeled intensive animal farmers.

Intensive livestock production firstly emerged and became popular near large cities as provincial capitals and eastern more developed cities, which have high population density, purchasing power and thus sharp increasing demand of animal products (Delgado, et al., 1999; Kanaly, et al., 2010). Recently, such intensification process diffuses further away from these demand centers, benefiting from better transport infrastructure and food processing technology (Li, et al., 2008). Figure 1.5 shows the intensification of provincial livestock production in 2010, using the farming of dominant animal species in the provinces as representatives. The intensive animal farms in middle and western China, however except in Inner Mongolia, Tibet and Xinjiang, have taken a share of regional livestock production, although their shares are generally lower than in eastern provinces. The intensification progress also significantly differs with animal species (Figure 1.6). On a national level, poultry farming is the most intensive sub-sector, followed by cow and pig farming. The household-scale farming of sheep and cattle (for beef) still contributes more than half to the output in the respective sub-sectors.



(Data source: Statistical yearbooks of Chinese livestock production.)

Figure 1.5 Intensification of livestock production for provinces (2010)



(Data source: Statistical yearbooks of Chinese livestock production.)

Figure 1.6 Intensification of different animal farming in China (2010)

Although the Chinese livestock sector is experiencing a rapid intensification progress, it has been characterized by its small-scaled structure compared to western developed countries (Bingsheng, 2002). As showed in Figure 1.5, the average share of intensive production in provincial livestock is around 66%, and half of it is medium-scaled. Pig and poultry farming show significant industrial consolidation in China. Medium-scale broiler farms contributed more than 50% to poultry meat in 2007. But the average productivity in 2007 was only 1380 pounds per farm, equal to the US in1992 (Walker, et al., 2005). The share of intensive farming in the pig sector jumped from 27% in 2002 to 64.5% in 2010.The average pig density in China is only 15 heads per farm, much less than 1229 pigs per farm in the US in 1999 (Gillespie and Fulton, 2001). In a word, the rapid growth of Chinese livestock production in the past decades was achieved by both intensive modern farms and the millions of traditional household farms. Moreover, the household scale farms will still remain vital suppliers of livestock products in the foreseeable future (Li, et al., 2008).

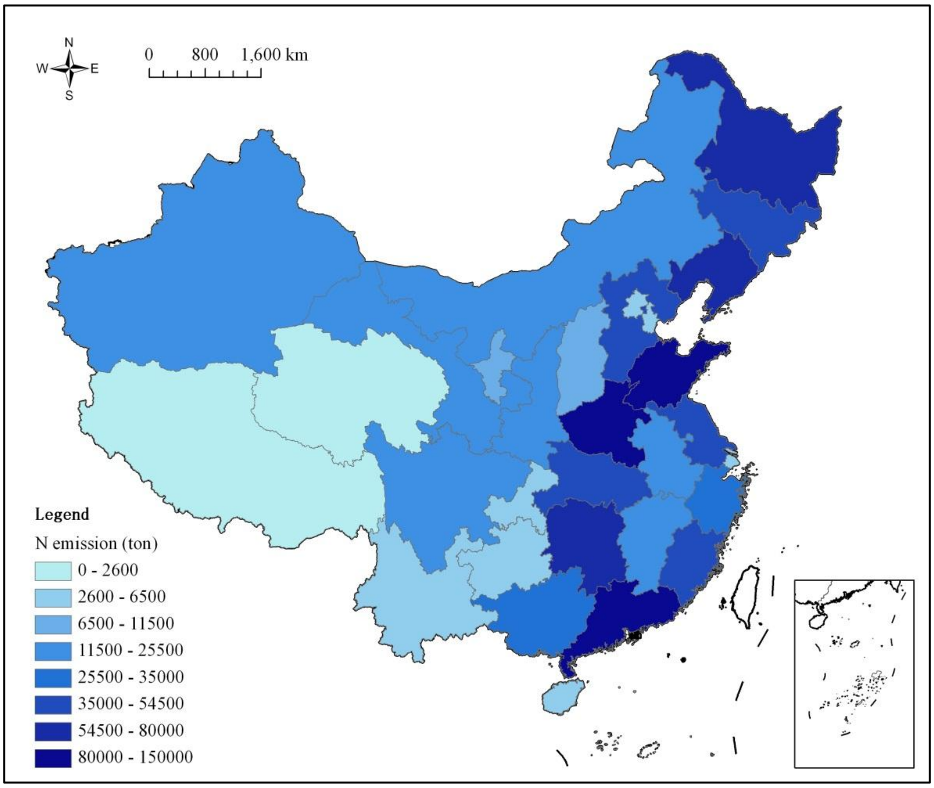
The differences across farm scales are not only in terms of animal densities, but also in terms of production practices on farm. For instance, traditional household-scale farms utilize readily available feedstuffs and maintain free-range models, while intensive farms feed more grain and protein meals and use battery cages (Li, 2009; Jin, et al., 2010). The life spans of animals in intensive farms are usually shorter than in household-scale farms. Recently, the intensive livestock is criticized due to lots of (potential) problems, such as mass epidemic outbreaks, concentrated negative impact on the environment, etc.. However, intensive livestock production is still preferred by Chinese government, since its productivity is prioritized above all other considerations in China. The seven sequential No. 1 documents of CPC Central Committee and the State Council (2004-2010), all of which took rural issues as the topics, fully revealed the national strategy to continuously promote and intensify livestock production (details are listed in Appendix 1-S1). The intensification process is continued with explicit targets of 15% and 10% higher proportions of large scale farming for pig and cow farming, respectively.

1.2 Environmental management in Chinese livestock sector

1.2.1 Ecological problems

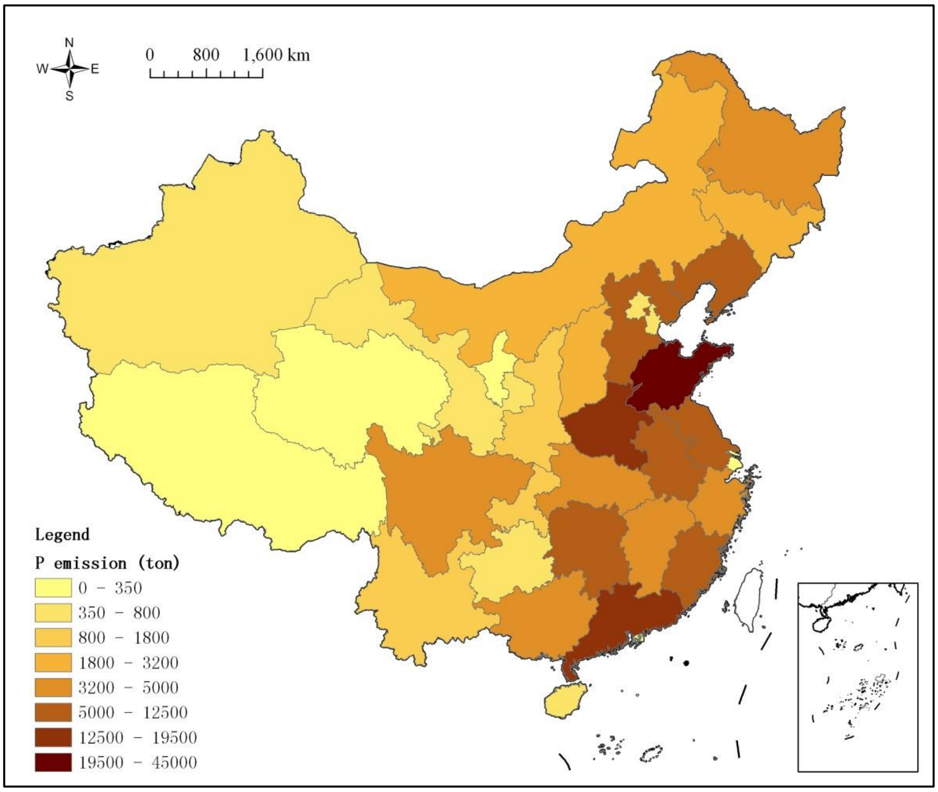
At the same time the world witnessed the rapid development of Chinese livestock production, it became evident that livestock production is responsible for a number of ecological crises. Many international institutes have studied the potential ecological challenges caused by the expansion and intensification of livestock production in developed countries, including significant groundwater and surface water contamination due to onsite nutrient release, greenhouse gas emissions released from animal manure, threats to biodiversity and so on (Adams, 2000; Jackson, et al., 2000; Kellogg, et al., 2000; Costales, et al., 2003; Kanaly, et al., 2010). However, the recognition of such ecological damages by Chinese livestock sector was lagged behind. Before 2000, Chinese governments and Chinese scholars commonly agreed that only a small number of industrialized animal farms had a potential threat to the environment, which was localized and had no marked impacts on a national level (Bingsheng, 2002).

Since 2000, the Chinese government officials and scholars have more and more discovered the negative effects of livestock production, resulting in a number of ecological disasters. Eutrophication of major watersheds proved to be closely related to agricultural non-point source pollution (NPSP). For example, livestock production in Dian Lake area ranked as the fourth pollution source of phosphorous after cropping, human bio-metabolism and wastewater treatment plants (Liu, 2005). Zhao and Zhang (2012) hold that the waste of the livestock sector was possibly the major source of threat to the health of Chinese river ecosystems. In addition, contamination accidents happened time to time, such as the dead pigs flowing in a river near Shanghai at early 2013, triggering scholars and the public to focus on the environmental degradation and health risks of expanding livestock production (Qiu and Wang, 2013). It was estimated that over 90% of animal farms in China were built without environmental impact assessment or pollution-prevention facilities (Fu and Li, 2004). According to the first China Pollution Source Census (CPSC), the Nitrogen (N) and Phosphorous (P) emissions from livestock production in 2007 accounted for 22% and 38% of overall N and P emissions, respectively. Figure 1.7 and Figure 1.8 shows the regional N and P emissions from provincial livestock production reported by CPSC.



(Data source: the first China Pollution Source Census.)

Figure 1.7 Nitrogen emissions of Chinese livestock production in 2007



(Data source: the first China Pollution Source Census.)

Figure 1.8 Phosphorus emissions of Chinese livestock production in 2007

In addition to the increasing number of animals, intensive production is considered an important reason for sharping the ecological crisis caused by livestock production. Household scale farmers usually adopt crop-livestock mixed models, which recycle most animal waste (containing nutrients) within the agricultural sector. Nevertheless, intensive livestock farms commonly decouple cropping and livestock, to specialize themselves in livestock production. Intensive livestock geographically concentrated animal production. Many studies confirmed that intensive livestock production in China indeed released massive amounts of various contaminants, compromising drinking water quality, causing eutrophication and decreasing biodiversity (Neeteson, 2000; Steinfeld, et al., 2006). When the nutrient emissions of regional livestock production in Figure 1.7 and Figure 1.8 are compared to the data of local intensification progress (Figure 1.5), higher intensification in general corresponds with more nutrient emissions (Figure 1.9). However, it is obvious that intensification cannot fully explain the differences of nutrient emissions across provinces. The way farmers manage animal waste also determines nutrient emissions. Some technologies and waste management practices can offer environmental advantages. For example, combinations of bedding and composting reduce the risk of manure to leach, volatilize or accidentally spill pollution (Richard and Choi, 1999). Manure can be processed through biogas digesters, and organic-fertilizer and feedstuff plants for maximizing agricultural reuse (Li, et al., 2008).

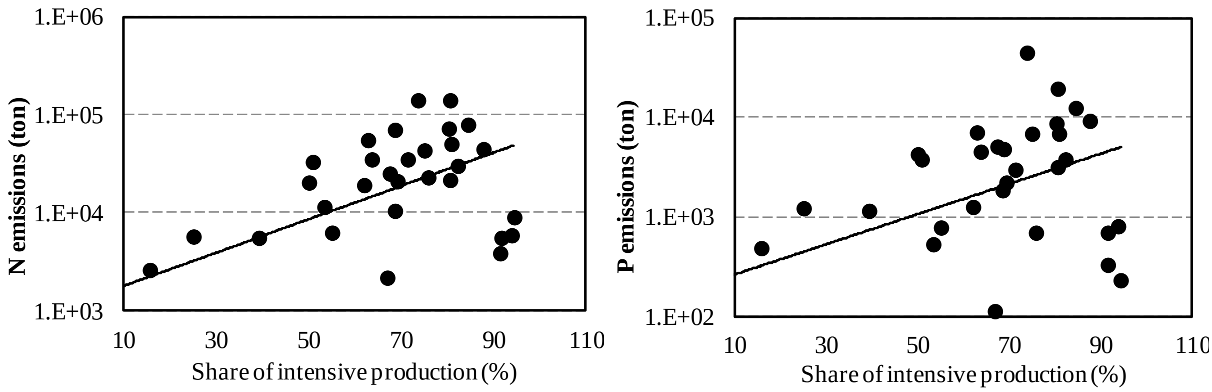


Figure 1.9 The correlations between nutrient emissions and livestock intensification

1.2.2 Governing environmental management of livestock production

The serious ecological problems have awakened the Chinese government to mitigate ecological damage and achieve sustainable development of livestock production. According to the No. 1 documents, the one-dimensional inclination of the central government to economic development is replaced by ecological development. For instance, the programme of

'Building a New Socialist Countryside' (*shehuizhuyi xin nongcun*) initiated in 2006 defined circular and environmental-friendly agriculture as one of its characteristics, as well as proposed controlling agricultural NPSP. The projects to promote rural biogas and recycle livestock waste are able to reduce livestock pollution. A pollution prevention plan for livestock production was jointly issued by Ministry of Environmental Protection (MoEP) and the Ministry of Agricultural (MoA) recently. As we known, it is the first specific national plan to manage livestock pollution. It sets ambitious targets for the next five year, including that the total emissions of COD and ammonia-nitrogen from livestock should be reduced by 8% and 10% respectively, and that the penetration rate of waste treatment facilities in large-scale farms needs to exceed 50% (MoA, 2012). Reference targets for pollution mitigation for each province are also established.

Furthermore, a series of policies have revealed the intention of governmental authorities to reduce environmental damages made by livestock production. Regulatory instruments have been the earliest environmental policies inserted for the livestock sector. As listed in Table 1.1, livestock production is being constrained by a number of environmental regulations. However, the inadequate regular monitoring systems operated by local Environmental Protection Bureaus (EPB) and poor implementation are responsible for the common ineffectiveness of regulatory policies (Carter and Mol, 2006; Liu, 2013). Until now, CPSC has been the only official database for livestock pollution. Nevertheless, the published CPSC report covered national and provincial levels, but not municipal and lower levels. Improved regulation and implementation of pollution prevention for livestock production may be issued during this Five-Year period (2011-2015), and is expected to increase the effectiveness of regulatory instruments. The annually updated CPSC database then can be an assistant to track policy effects. Environmental management in China is generally shifting away from rigid hierarchical command and control approaches, to an increasingly 'hands-off' approach (Carter and Mol, 2006). Meanwhile, the Chinese agricultural sector has largely moved toward marketization since economic reform (Rozelle, et al., 2000). In the context of market-oriented livestock production, there are more opportunities to apply market-based instruments for environmental management. A number of market-based environmental policies have been introduced to manage rural issues, such as subsidies, rewards, and tax preference, as indicated in No.1 documents. And information programmes will be strengthened to improve environmental management in rural area. For example, the plan listed in Table 1.1 requires setting up a national information platform, which aims to collect, store and publishing dynamics of pollution emission, recycling of animal waste, infrastructure construction, and policy implementation. Moreover, the extension system takes the responsibility to disseminate environmental information on technologies to the farmers. The Chinese agricultural extension system was one of the most effective in developing countries, but nearly disintegrated as the positions of extension agents in most localities were privatized after the mid-1980s (Park and Rozelle, 1998; Jin, et al., 2010). No.1 documents after 2006 restated the importance to re-build an effective agricultural extension system, and the central government attempted to assign more extension agents at the county and township levels. They have to become liaison between the farmers, supported by ties with experiment stations and demonstration sites, and facilitated by of funds and service performances.

Table 1.1Some environmental regulations relevant to livestock production

Title	**Year**	**Document catalogue**
The Law of Water Pollution Prevention of PRC (revision)	2008	SCNPCC
Administrative Method on Pollution Prevention for Livestock Production	2001	No.9 policy paper of NEPA
Technical Standard of Pollution Prevention for Livestock Production	2001	HJ/T81-2001 of NEPA
Discharge Standard of Pollution for Livestock Production	2001	GB18596-2001 of NEPA and AQSIQ
Criteria for Evaluating Environmental Quality of Livestock Farms	2004	CB/T 19525.2-2004 of AQSIQ and SAC
Technical Standard for Non-hazardous Treatment of Animal Manure	2006	NY/T1168-2006 of MoA
Technical Standard of Environmental Pollution Prevention for Livestock Farms	2006	NY/T1169-2006 of MoA
Technical Specifications for Pollution Treatment Projects of Livestock Farms	2009	HJ497-2009 of MoEP
Technical Guidelines for Agricultural Solid Wastes Pollution Control	2010	HJ588-2010 of MoEP
Technical Policy of Pollution Prevention for Livestock Production	2010	No. 151 policy paper of MoEP
Farmland Environmental Quality Evaluation Standard for Livestock Production	2010	HJ568-2010 of MoEP
The planning of pollution prevention for livestock production for ‘12th five-year’	2012	MoEP, MoA

SCNPCC Standing Committee of National People’s Congress Council; *NEPA* National Environmental Protection Administration (promoted and renamed as Ministry of Environmental Protection in 2008); *AQSIQ* Administration of Quality Supervision, Inspection and Quarantine; *SAC* Standardization Administration of China; *MoA* Ministry of Agriculture; *MoEP* Ministry of Environmental Protection.

However, it would be an overstatement to claim that environmental concerns have been sufficiently integrated into Chinese livestock production. In contemporary China, the national strategy of livestock production is set by the central government and its different ministries, while it is operationalized and implemented by local governments and their subordinate bureaus. At the national level, MoEP is mainly in charge of environmental management, but also other institutions have environmental management tasks (Wu, 2009). There is no comprehensive policy program of environmental management for livestock sector, which thus needs the cooperation of multi government ministries (Fu and Li, 2004). Some national policies even reveal that environmental management is viewed as an extra burden for livestock farming (NDRC and NEPA, 2008). For instance, the central government disapproved lower governments to limit the expansion of intensive livestock in the name of environmental protection, after the drastic fluctuation of the pork market in 2007 (MoA and MoLR, 2007). At the local level, EPBs are primarily responsible for environmental regulations enforcement, but they are financially and administratively controlled by local governments (Tang, et al., 2010). Since the central government decentralized the highly bureaucratic system, local governments now can interpret more discretion in national legislation and regulations, to suit local needs (Li, 2008; Li, et al., 2008). Some local governments implemented little or no requirements on environmental protection in order to promote development and intensification of the regional livestock sector (Li, 2009). This is especially pronounced in less-economically developed rural areas, where EPBs are exceptionally lax in regulatory enforcement due to lack of funds and power and low environmental priorities (Ma and Ortolano, 2000; Economy, 2004; Ma, 2004). Even worse, there is no specific environmental agency at township and village levels. The enforcement of environmental policies then fully depends on how the cadres perceive environmental issues and how they balance environmental protection and other considerations. But some changes seem to be another way. The central government is trying to enhance regulatory enforcement at local level in various ways. The elevation of the National Environmental Protection Administration (NEPA) to be MoEP is expected to penetrate to local levels. The new administrative leadership responsibility system adds environmental performance indicators in the annual assessment of local party/state leaders, making the entire local government responsible for overall environmental quality within its jurisdiction, rather than EPB alone (Rock, 2002; Lo and Tang, 2006).

1.3 Problem description and research questions

Global China-watchers concluded that the reform of the Chinese government's polices facilitated the stunning growth and structural changes of Chinese livestock production (Lin, 1992; Li, 2009). However, the Chinese government has put itself in a dilemma in the livestock sector: on the one hand economic priority is and will be preferential for long-term food security and increasing farmers' income; and on the other hand environmental reform is urgent as livestock production has been responsible for significant pollutant emissions (NRDC, 1994; OECD, 2009; MoEP, 2010). With all the policies mentioned in the former section, the Chinese government clearly stated their acknowledgement of and answers to the environmental problems caused by livestock production. However, there is little confidence on the effectiveness of current environmental policies to cope with the environmental impacts of rapidly expanding and intensifying livestock production in the future. The ineffectiveness of environmental policies in the past was commonly ascribed to the lack of a comprehensive policy program at the national level, the one-sided command-and-control nature of policies, the economic priority at each governmental level, and the feeble implementation on local levels. In recent years, the preferences for environmental protection have diffused form central government to local governments, which enhanced enforcement of environmental management and thus has helped a little to improve the effectiveness of environmental policies. However, there are other vital but insufficiently analyzed factors affecting policy outcomes. Do policies (either economic or environmental policies) set feasible targets for the sustainable development of Chinese livestock production? And do local governments adopt adequate instruments to motivate farmers? And how do farmers react to these policy instruments? Hence, it is necessary to assess policies and their implementation before governments attempt to modify existing or design new policies for the environmental reform of the livestock sector.

As an essential part of Strategic Environmental Assessment (SEA), policy assessment is being institutionalized at the national level in China and many other countries. However, there is no sophisticated or commonly accepted framework to operationalize policy assessment (Partidário, 2000; Sheate, et al., 2003). There are many practices of policy assessment in Western countries, which commonly tailor environmental assessment in a rationale of policy making (e.g. Tonk, et al., 1998; Bailey and Dixon, 1999; Shuttleworth and Howell, 2000). In China, policy assessments have been mainly performed by natural scientists and environmental engineers who prefer model-based approaches to quantify the effects of polices on environmental performance (Li and Li, 2008). Conventional methods (and models) of these policy assessments are based on macro-level and statistical data, without thorough insight in how policy outcomes and environmental impacts are arising. These methods are inadequate to predict policy outcomes in the livestock sector, among others because they assume universal and autonomous farmers, while in reality livestock policies are directed at huge numbers of highly scattered, heterogeneous and interdependent farmers. Since the beginning of economic reform, the Chinese government confirmed the individual household as the basic unit of agricultural production, as well as legalized the privatization of livestock production (Fan and Pardey, 1992; Zhang, et al., 2004). Such a reform from the communal system to individual households led to decentralization and liberalization of decision making on livestock production. Millions of households, involved in livestock production, could decide on how to respond to governmental policies (Li, 2009). Some studies found that Chinese farmers are very sensitive and responsive to changes of governmental policies. But other scholars found that farmers responded to policies in a very diverse way, due to the interference of many other factors. For instance, farmers' decisions may depend on personal experience, habits, neighbors' practices, and economic factors (Ouyang, et al., 2004). Xu's (2006) research illustrated the different ecological perspectives of the Chinese state and traditional farmers. In this case, Government policy influence on farmers was limited. Therefore, a modeling approach, which is able to look inside the livestock system to study diverse individual behavior, interactions, as well as reactions to policies, might be a more appropriate choice for policy assessment in the Chinese livestock sector.

Against this background, this research aims to assess the environmental consequences, focusing on nutrient emissions, of Chinese livestock policies, taking into account farmers' differences in decision making. As stated above, it is inappropriate to assume that these scattered 'decision makers' (i.e. livestock farmers) are uniform and make their decisions independently. Farmers 'shape' the effectiveness of policies through their diverse responses. Interactions among farmers, e.g. observation, learning and imitation, influence individual decision-making as well. Instead of merely testing hypotheses on outcomes of governmental policy in relation to set policy goals this research explores how and to what extent heterogeneity of and interactions among farmers play a role in changing livestock farming practices following policy interventions. Therefore, an Agent-Based Model (ABM) approach is selected (instead of other modeling methods) to investigate how farming practices are individually and as a whole changed by policies to improve the overall environmental performance of the livestock sector in China. Section 1.4.1. further provides support for the choice of an ABM approach.

Based on the research objectives mentioned above, four research questions are formulated:

- How to apply an Agent-Based modeling approach in Chinese livestock production, in order to represent the environmental impacts of policies in this sector?
- How do Chinese farmers manage animal manure in their farms?
- Which environmental policy instruments aimed at which group of farmers improve the effectiveness of pollution mitigation?
- What will be the environmental consequences of Chinese style livestock intensification focusing on medium-scale farmers?

1.4 Research approach, framework and methods

1.4.1 Why an ABM approach?

Rather than just focusing on the overall performance of a system, the principle of an ABM approach is that the system is composed of, and should be described as a collection of numerous ‘agents’, who can interact with each other and the environment they live in, and who make decisions under these interactions (Ferber, 1999). With such an ‘individualist’ notion of modeling, ABM is particularly suitable to support the definition, design and assessment of systems in which the ‘local’ behavior of agents is important in generating the overall evolution of systems (O'Sullivan and Haklay, 2000; Bandini, 2009). Topics like aggregate consequences of individual (but often interconnected) decisions thus are typical domains for ABM studies. In recent decades, ABM approaches have become increasingly popular in many different research fields (Heath et al., 2009). Regarding policy development and decision support, ABMs were applied on a wide variety of subjects, among others, spatial planning (e.g. Ligtenberg et al., 2001; Brown et al., 2005), trade (Gulden, 2013) urban management (Dia, 2002), and socio-ecological systems (An et al., 2005; Castella et al., 2005; Grimm et al., 2005). Some studies using ABM have even been carried out in agricultural and agro-policy research. For instance, Becu et al. (2003) simulated farmers’ decision making on resource management with an emphasis on negotiation among stakeholders; Courdier et al., (2002) studied collective management of animal waste using ABM; and Berger (2001) and Happe and Balmann (2006) applied ABM to evaluate outcomes of agricultural policies..

Although these previous studies addressed different issues and had their own emphases, the shared understanding in the community of ABM practitioners is that the representation of heterogeneous agents and the emergence of self-organization due to interaction are the universal and most important contributions of ABM approaches (Macal and North, 2007; Bandini, 2009). While an ABM functions as a bridge between individual and aggregate levels of socio-ecological systems, the agents in the model behave autonomously. ABM hence provides the possibility to decouple the decision-making and behavioral changes of multiple individuals from the overall behavior of the system. Hence, it is inclined to map macroscopic regularities and organizations by applying individual rules (Epstein, 1999). Some researchers, such as Brown and Robinson (2006), examined and confirmed the effects of heterogeneity in the system. The interactions among heterogeneous agents in an ABM are considered the root of complexity of the system, which makes it next to impossible to predict the emerging system patterns from simple individual rules (Alam, 2005). A series of studies were carried out to explore emergent properties by various interactions of heterogeneous agents (see Courdier et al., 2002; Janssen and Jager, 2003; Delre et al., 2010; Giabbanelli and Crutzen, 2013; Wunder et al., 2013).

Furthermore, an ABM has the capability to integrate individual behavior models defined in the social sciences into environmental system modeling, and thus represent the collective response of agents to environmental management interventions (Hare and Deadman, 2004). Since the behavior of agents in an ABM is not hidden in equations but directly observable and explainable, an ABM approach holds the promise to communicate aggregate outcomes to people who might have limited scientific background, like policy makers and stakeholders (Hazell et al., 2001; van Paassen, 2004; Berger and Schreinemachers, 2006; Gulden, 2013). The observation at aggregate level performance is necessary and desired, but normally less understood and less self-explicable. This often leads to unexpected outcomes of policy making or even policy failure. Therefore, it is reasonable to question the effects of top-down policy making approaches, which is the typical policy implementation model in China, especially in dealing with a large number of families and medium size livestock farms for which ABM can fill the information gap through studying individuals and simulating macro-performance (Bandini et al., 2009; Saqulli et al., 2010). Although ABM approaches are criticized by traditional models for their difficulties of model validation and testing assumptions (Yu, 2013), the advantages and features of ABM approaches mentioned above meet the needs of this research: to simulate the diverse and interactive decision-making processes of Chinese livestock farmers, and analyze the aggregate environmental consequences of policies that interfere in those decisions.

1.4.2 An ABM based conceptual framework

According to the research objectives and questions, a conceptual framework with consideration of the specific conditions of contemporary China is developed, which locates ABM at the center (see Figure 1.10). Normally, an ABM has four elements, including goal-oriented agents, individual behavior rules, interaction among agents, and the environment where agents are located. In this research, agents are defined as livestock farmers, who either run household-scale farms, medium-scale or large-scale farms. The farmers possibly interact with some of their neighbors (as the arrows in Figure 1.10 illustrate).

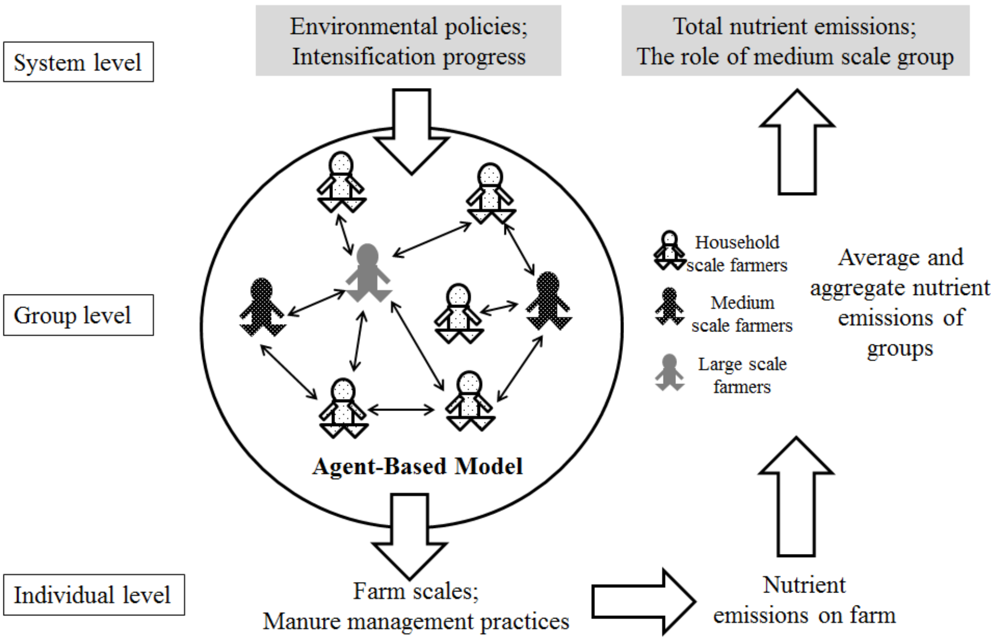


Figure 1.10 Research framework for assessing Chinese livestock policies

Policy instruments and the intensification process change the social environment that motivate and influences farmers' activities. The flexibility of ABM allows this research to examine different scenarios (see chapter 4 and 5), in order to discover the mitigation potentials of various policies and intensification processes within the Chinese livestock sector. ABM embodies the outcomes of scenarios as the collective of individual – but interdependent – decisions on farm scale and manure management practices. A series of performance indicators are used to quantitatively express policy impacts on an aggregate scale, including both economic development (e.g. animal amount in total, percentage of intensive production) and environmental impacts (e.g. penetration rate of cleaner technologies, nutrient emissions). Furthermore, special attention will be given to medium-scale farms, as the government preferred style of Chinese livestock production, by comparing the performance of this group with the whole farmer community in the model.

Apart from the environment, the goals, behavioral rules and interactions are considered in order to jointly define individual decision-making, respectively. Without exception, agents in ABMs are goal-oriented, but the notion of a goal can be defined from different perspectives. For instance, the Goal Frame Theory (Lindenberg and Steg, 2007) states that there are three kinds of goals, including hedonic, gain and normative goals. Jager and Janssen (2012) translate goals as meeting existence, social and personal needs. It is assumed in this research that the primary goal of agents is to maximize their economic/environmental benefits. Some scholars claim that it is inappropriate to use the assumption of pure economic rationality as the only goal in the context of ecological reform (Mol, 1999). Hence, our model agents would be permitted to weigh between economic and environmental benefits differently. Due to social research that found that individuals are often clustered around some similarities (Rogers, 2003; Jager and Janssen, 2012) but that these clusters also show heterogeneity.

In general, stepwise behavioral rules to achieve the goals are molded as innovation adoption under uncertainty. To address innovation adoption, there are a number of theories developed in psychological, behavioral economics, and sociological disciplines. For instance, Schwarz and Ernst (2009) integrated the theory of planned behavior into an ABM to model the diffusion of water-saving innovations. Pegoretti et al. (2012) posited the concept of social network in their ABM for analyzing the adoption of competing products. A more broad collection of innovation adoption theories included in ABM is listed by Dawid (2006). From these various theories Rogers' (2003) theory of innovation diffusion is integrated in ABM in this study. Rogers (2003) generalized his theory of innovation diffusion upon numerous empirical studies in different domains and fields of study. This theory introduces the cumulative appearance of innovation diffusion, and most notably clarifies the innovation-decision process at an individual level. It is widely used for understanding innovation diffusion and the specific choice behavior of individuals in different geographical contexts. For instance, Berger (2001) inserted part of this theory into his ABM to investigate diffusion of new technologies in rural Chile. This research applies Rogers' (2003) theory to analyze a decision-making process as successive steps of evaluating current options, learning about and judging alternatives by observation and imitation, and adopting or rejecting alternatives.

Interaction among farmers, which is an essential part of behavior rules, is induced by uncertainty of innovation adoption. When a farmer interacts with his peers, the obtained influence can be categorized into two types: informational influence and normative influence. The former influence occurs when individuals collected information as evidence, while the latter one occurs when individuals conform to the expectations of others (Delre et al., 2010; Van Eck et al, 2011). Both of them are included in this research, mostly at the step of observation. Through empirical surveys, the assumed behavior rules can be found/verified to capture the core dynamics of the specific simulated system sufficiently to support model development, although they cannot cover all the complexity and considerations valid in reality (Epstein, 2008).

Developing such an ABM cannot only depend on assumptions from social theories, but should also be based on real-world observations. Real-world observations are essential in this research to develop the ABM and subsequently to execute policy assessment. Since it is impossible in the framework of this study and with the limited time and resources to carry out a nation-wide survey, case studies are used as pilots in this research. In fact, empirical data were used in various ways, in line with other studies (see Janssen and Ostrom, 2006; Garcia and Jager, 2011). For example, ABMs can be validated qualitatively or quantitatively through empirical observation (Giabbanelli and Crutzen, 2013). Alternatively, empirical data can form input to an ABM as definitions of behavior rules, portrait of individuals and parameter settings (Brown and Robinson, 2006; Sopha et al., 2013; Yu, 2013). In particular, many researchers paid attention to the method of using empirical data for the parameterization of ABM, such as Berger and Schreinemachers (2006); Saqulli et al., (2010); Ma et al., (2013); and Jager et al. (2014). This research developed an empirically based ABM in the two latter ways. Data of the field surveys in the case study areas are used as input for parameterizing individual heterogeneity and initialization, while literature review provided references for the other parameters in the ABM. Finally, the qualitative outcome performance of ABM is to be compared to macroeconomic data and environmental census data.

Developing such an ABM-based policy assessment framework for the Chinese livestock sector is expected to contribute to methods of Chinese policy assessment in other production sectors or policy fields. The operationalization of the whole assessment process enhances insights in the usefulness of the assessment framework and advantages of using an ABM approach as a tool for policy assessment in China.

1.4.3 Case setting and data collection

Data collection is operated in two cases to trace historical decision-making on diverse populations of animal husbandry farmers by questionnaire surveys, and system dynamic of policies and regional livestock production through government interviews. The locations of two cases, Rudong and Zhongjiang County, are marked in Figure 1.11.

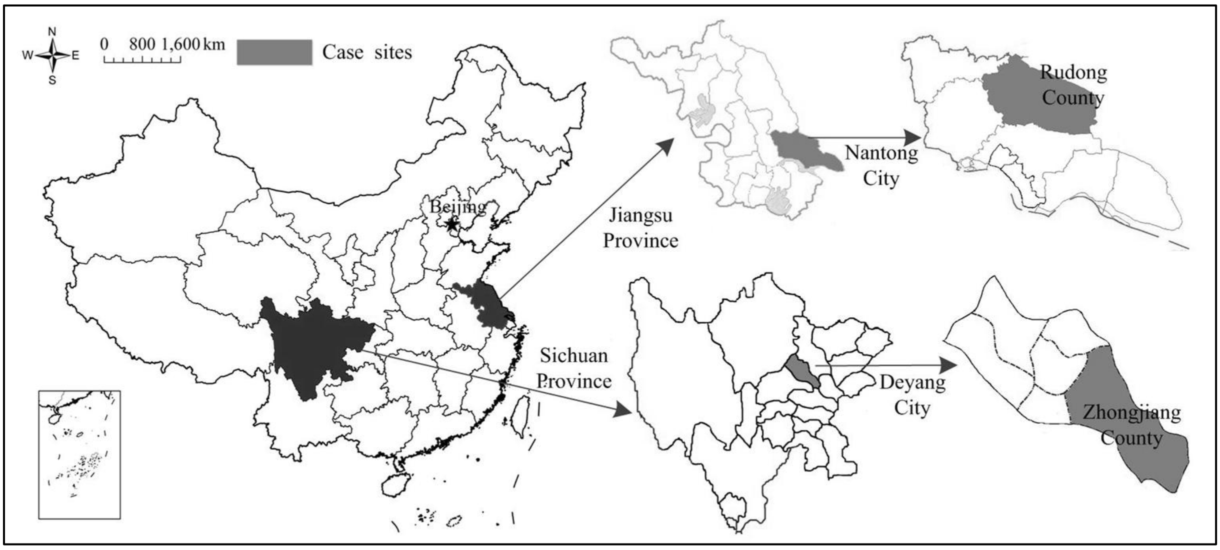


Figure 1.11 The locations of two case studies (grey areas)

There are several reasons to select these two regions as cases. In the past decade, Jiangsu and Sichuan Province are two of the top10 livestock production provinces. That means the regions where these two cases locate are traditional livestock areas. This facilitates the selection of enough samples in both cases. The farmers there possibly have better cognition of livestock dynamics, including sector development, and have been more subject to market change and policy transforms. Moreover, the two cases are located respectively in southwest (poor) and the coastal east (more developed) of China. They can represent some regional differences of livestock production. In addition, the comparison of the two cases also represents the diffusion of livestock production from demand centers to less developed areas. The productivity ranking of Jiangsu province declined 3 positions in the past 10 years, while Sichuan Province rose to number 3. Combining the two cases in one research is expected to obtain some general knowledge of practices of livestock production and associated environmental performance.

The questionnaire surveys are respectively conducted within 5 towns. The criteria to select towns are as follow: there should be relatively developed and intensified livestock production with not only household scale farmers, but also medium and large scale farmers; the transportation from villages to downtowns are convenient so that farmers can normally take part in livestock markets and communicate with governments; governments have implemented preferential policies, such as financial investment and demonstration sites, to stimulate livestock practice changes. 20-30 farmer households are sampled in each town by stratified random sampling method. Consistent with the research questions, stratification ensures the involvement of different scale farmers, while random sampling guarantees the representativeness. In face-to-face interviews, one adult member of every household answered a structured questionnaire. The questions cover personal information, regular interactions with other farmers, changes of animal number and manure management practices in the recent 5 years, and the reasons of (non-)changes. Such questionnaire survey is applied to gain in-depth insights of how farmers perceive policies, integrate diverse considerations in decision making and respond to policies changes. Besides, information and data about key policies in the case study areas and their implementation are collected at different governmental levels and among different governmental agencies through interviews. Table 1.2 summarizes the data collection in this research.

Table 1.2 Data collection methods

Data collection methods	**Tools**	**Data sources**
Household surveys	Questionnaires, face to face	130 farmers in Rudong, 128 farmers in Zhongjiang
In-depth interviews	Semi-structured, face to face	City and/or county level: environmental protection bureau, livestock bureau (or animal epidemic prevention station) Township and/or village level: the cadres
Secondary data collection	Review of governmental database and statistical yearbooks	Policy documents, statistical yearbooks (national, local ,and sectorial), monitoring data in local government agencies (non-public), government reports, literatures

1.5 Outline of the thesis

The thesis is divided into 6 chapters. The first chapter has provided general background information of Chinese livestock sector, including its production development and environmental management. Research questions have been formulated on the basis of the problem description. As well, the chapter has introduced the research methodology of this research, which has an ABM at the core of it.

After the introduction, Chapter 2 models environmental performance of Chinese livestock sector by an ABM approach. Data collected in a case area is used to validate that the developed model is adequate to capture the dynamics in reality. It provides basic knowledge of ABM, detailed description of model design, calibration and validation, and a discussion of the implications from simulation. Chapter 3 reports empirical findings of what manure management practices look like and how these affect individual decision-making of husbandry practice improvement. 'Ecological rationality' is the concept to analyze the situation under which practice transformation may take place. Chapter 4 and Chapter 5 examine and assess environmental consequences of different policies, using the ABM model built in Chapter 2. Chapter 4 focuses on the assessment of five environmental policy instruments, while Chapter 5 attempts to assess through scenario analysis the national strategy of promoting livestock intensification from an environmental perspective. Besides, effects of various policy instruments on the whole population of animal producers and on the respective farm scales are compared.

The last chapter 6 provides a discussion of and conclusion for this thesis. How useful is the ABM approach for policy assessment? What are the best policy options to promote nutrient mitigation in Chinese livestock sector? Is it possible to use the ABM-based framework for other sectors and regions? Research findings are discussed against general literature, and finally recommendations for policy making and future research are provided.

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Appendix 1-S1

Table 1-S1.1 Key notes of No. 1 documents of C.P.C. Central Committee and the State Council (2004-2010)

Year	Title	Major focus
2004	Advices on promoting income increasing in rural areas	• Income inequality is one of the major problems for rural development • Trying best to increase rural household income • Supporting rural development by the strategy of "give more, take less, loosen control" (*duoyu, shaoqu, fanghuo*) • Promoting livestock production, better using surplus crops especially in cropping-dominate areas • Improving intensification and industrialization of agricultural production • Increasing the investment for "six small-project" (*liu xiao gongcheng*), including livestock water suppling and household biogas production
2005	Advices on further strengthening rural work, and increasing overall agricultural productivity	• Keeping the strategy of "give more, take less, loosen control" (*duoyu, shaoqu, fanghuo*) • Reducing and abolishing agricultural taxes, including cancelling the specific tax of livestock products • Facilitating agricultural production with technological innovations, such as breeds improvement project (*lingzhong gongcheng*) • Livestock development is an essential part to enhance comprehensive productive capacity • Improving intensification industrialization of livestock production • Increasing governmental financial investment on construction of manure and wastewater treatment facilities in livestock areas
2006	Several advices on advancing the construction of socialism new countryside	• Building a New Socialist Countryside (*shehuizhuyi xin nongcun*) • Modernizing agricultural production • Adjusting the agricultural structure, including promoting livestock by expanding agricultural subsidies, investing the pilot study of livestock standardization • Promoting the circular agriculture (*xunhuan nongye*), with emphasis on recycling of waste, utilization of renewable energy, and prevention agricultural NPSP • Increasing the investment on biogas construction to diffuse household biogas production and encourage medium/large scale biogas projects • Requiring and helping farmers to move livestock out of living areas
2007	Several advices on developing modern agriculture, and further advancing the construction of socialism new countryside	• Modernizing agriculture is the primary task of 'Building a New Socialist Countryside' • Integrating ecological protection in agricultural production beside of supplying food • Carrying out comprehensive treatment and recycling of animal manure, testing large scale biogas production in animal farms • Encouraging circular agriculture, ecological agriculture and organic agriculture • Reducing NPSP, and preventing pollution in watersheds • Strengthening livestock production with encouraging intensive animal farming and specific livestock areas, and increasing livestock subsidies

Year	Title	Major focus
2008	Several advices on strengthening the construction of agricultural infrastructure, further advancing agricultural development, and increasing rural income	• Implementing supportive policies about pig and cow farming, and increasing rewards and subsidies for counties with high productivity • Making mayors responsive for 'basket project' (*cailanzi gongcheng*) to ensure the supply of non-staple food • Accelerating the transition of livestock production through rewards for intensive farming, defining land used for large scale animal farms as agricultural land, keeping on subsidizing livestock, improving policy-based insurance for pig and cow, and etc. • Encouraging circular agriculture, and promoting energy conservation and emission reduction in rural areas • Improving the prevention of agricultural NPSP by setting plannings, increasing investment, and defining responsibility • Increasing the investment on biogas construction to further diffuse household biogas production, organize medium/large scale biogas projects and establish service system
2009	Several advices on advancing steady agricultural development, and continue increasing rural income in 2009	• Accelerating the development of standardized livestock production, especially for pig and cow farming • Keeping the policy-based insurances and rewards for counties with high productivity • Increasing the investment and credit aid on standardized livestock farms, and exactly implementing the policy of land use • Setting a specific fund to support the prevention of rural pollution in the form of rewards
2010	Several advices on reinforcing the balance of urban and rural development, and consolidating the foundation of agriculture and rural development	• Implementing new round of 'basket project' • Accelerating the intensification of livestock production, especially for pig and cow farming • Encouraging non-pollution, green and organic agriculture • Promoting prevention of agricultural NPSP • Developing circular agriculture and ecological agriculture • Advancing household biogas and centralized biogas projects to promote recycling and cleaning of agricultural waste • Rewarding comprehensive improvement of rural environment
2013	Several advices on accelerating the development of Morden Agriculture, and further strengthening the rural developmental vitality	• Constructing an intensive, specialized, systematized, and socialized new agricultural system • Keeping the new round of 'basket project' • Increasing the total amount of agricultural subsidies with inclination to intensive farmers and cooperatives • Improving supportive policies for livestock production • Promoting the sustainable development of biogas in rural areas • Advancing ecological civilization construction (*shengtai wenming jianshe*), including improving waste, wastewater and soil treatment, and preventing pollution in rivers • Strengthening environmental monitoring of agricultural production • Improving prevention of livestock pollution

2

Modeling the Environmental Behavior and Performance of Livestock Farmers in China: an ABM approach

Abstract

The diversity of farmers is a central concern in the development of environmental policies related to livestock production. However, this diversity is largely ignored in policy making, implementation and evaluation in China. In this research, an Agent-based Nutrient Emission Model (ANEM) was developed by integrating the decision-making process of individuals into an environmental impact assessment. The agent based model facilitates an improved understanding of how farmer behavior and associated environmental consequence change according to the heterogeneity of and interactions among farmers. Decisions related to farm-scale, manure collection technologies and manure handling patterns were identified as the most relevant behavior categories when analyzing nutrient emissions. The model was applied to pig farming in Zhongjiang County in Sichuan Province of China to simulate the dynamics of local livestock production and the associated nutrient emissions during the period from 2005 to 2008. The results suggest that ANEM adequately captures real-world dynamics and can provide recommendations to policy makers.

Keywords

Agent-based model, Environmental impact, Livestock production, Nutrient emissions.

Chapter 2. Modeling the Environmental Behavior and Performance of Livestock Farmers in China: an ABM approach[2]

2.1 Introduction

Livestock production in China developed rapidly during the last decade. According to the China Statistical Yearbook 2010, the total output value of the livestock husbandry sector increased by 1.5 times from 2000 to 2009. In 2009, the monetary output of this sector contributed 32.25% to the total agricultural production, which is estimated to increase to 35% in 2015. The central government facilitated the development of livestock production through a diversity of policies, such as market construction, disease control, infrastructure construction, 'alleviation of financial burdens' and agricultural industrialization. Since the promulgation of 'Resolution of C.P.C Central Committee on the Key Issues for Agriculture and countryside Management' in 1998, the central government has attempted to guide farmers by increasing market access and developing quality standards, not by directly intervening. The central budget was used to improve infrastructure and to control animal disease in rural areas after 2000, thereby creating a better environment for livestock farmers. In addition, all agriculture taxes were abolished in China in 2006 to alleviate the financial burden on agricultural producers. For instance, the 'Circular on implementing the Demonstration of Reform of Rural Taxes and Administrative Charges' (No.7 policy paper of the general office of the C.P.C. Central Committee) banned the animal slaughter tax in 2000.

The industrialization of agriculture mainly depends on the intensification of agricultural production. Several central government policies in China, such as the 'Provisional regulation on promoting adjustment of production structure' published by the State Council in 2005, have addressed the importance of intensive livestock production. As reported by the Statistical Yearbooks of Chinese livestock production (1999-2007), the number of intensive livestock farms increased in recent years, while the proportion of household-scale livestock breeding

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operations decreased by 1.4% per year during this period. Nevertheless, intensive animal breeding is not, and will not soon become, the dominant mode of livestock production in China (Shen and Li, 2005). The continuing coexistence of intensive and household-scale livestock operations is one of the most important differences between China and many developed countries, where intensive livestock production is often dominant.

The rapid development of livestock and husbandry operations has aggravated China's environmental problems (Development, 2006). According to China’s pollution source census (CPSC) (MoEP, 2010), agricultural production accounted for 57.2% of nitrogen (N) emissions and 67.4% of phosphate (P) emissions in 2007. In that year, livestock operations discharged more than 1 billion kg of N and 160 million kg of P, accounting for 38% and 56%, respectively, of all agricultural emissions of these substances. Some researchers have claimed that livestock production is a major pollution source of eutrophication in many areas (Geng and Tong, 2007; Miao, et al., 2010; Jiang, 2011). Accordingly, the Chinese government has engaged in developing more comprehensive environmental regulatory systems to address water pollution. For instance, the ‘Discharge standard of pollutants for livestock and poultry breeding’ (GB18596-2001) and the ‘Technical standard of preventing pollution for livestock and poultry breeding’ (HJ/T 81-2001) were issued in 2001 to mitigate nutrient emissions from livestock operations. However, these efforts seem to have had a minimal impact, with considerable variations in different regions (Gao, et al., 2006; Ren, et al., 2010). As Chen (2007) predicted, livestock operations might be responsible for emissions of 3.5 billion kg of N and 330 million kg of P in 2050, which will account for respectively 42.3% and 40.4% of total N and P emissions to the water environment. To improve nutrient mitigation in Chinese livestock operations, the environmental performance of current agricultural and environmental policies must be assessed from a systemic perspective (Ren, et al., 2010).

The decision-making process of individual farmers is an important factor in the environmental performance of Chinese policies, but it is often ignored in policy assessments. Conventional policy assessments treat human behavior as an external ‘black-box’ due to the lack of observations on an individual level (Berkes, et al., 2000; Zhang, 2006; Chen, 2007). However, agricultural production is not only influenced by farm-external factors (e.g. policies), but also driven by farm-internal factors (Happe, et al., 2011). As (Komarek, et al., 2012) said, the rural households in developing economic systems are heterogeneous. Some empirical studies have shown that the diversity in the behavior of individual farmers plays an important role in the overall performance of policies in the Chinese livestock husbandry sector (Wang and Yang, 2006; Xi and Lu, 2007; Feng and Heerink, 2008). Some farmers readily follow suggestions from the government and participate in demonstration projects. Other farmers do not respond to policies as expected. For example, farmers may discharge manure in forbidden areas or reject mitigation technologies recommended by the government (Qian and Chen, 2008). The differences in individual behavior and performance are believed to arise because of the different economic and/or cognitive abilities of farmers (Rogers, 2003; Wang and Yang, 2006; Xi and Lu, 2007; Feng and Heerink, 2008). In addition, farmer behavior is often dependent on colleagues and neighbors. The heterogeneity of farmers and their interactions make the development of livestock operations and their associated environmental performances a nonlinear and complex system.

To assess the aggregate environmental performance of such a complex, heterogeneous and interacting system of livestock farmers, a new bottom-up approach is needed. Agent Based Model (ABM) is one of the most promising computational tools for this purpose (Miller and Page, 2007; Saqalli, et al., 2011). In ABM, a system is modeled as a collection of autonomous agents, each of which is capable of individually assessing its situation and making decisions on the basis of a set of rules (Bonabeau, 2002; Grimm, et al., 2005; Page, 2008). By modeling agents individually, the full effect of attribute and behavior diversity of agents, which together give rise to the behavior of a system as a whole, can be observed (Macal and North, 2010). Moreover, the interactions between diverse agents may generate emergent phenomena, which are not explicitly programmed in a model (Bonabeau, 2002; Smith and Conrey, 2007; Macal and North, 2010). The emergent phenomena are usually not obvious when agents are considered individually; rather, they only arise at a collective level (Gilbert and Terna, 2000). The emphasis on modeling the heterogeneity of agents across a population and the emergence of self-organization are two distinguishing features of ABM (Macal and North, 2007).

This article introduces an agent based model, the Agent-based Nutrient Emission Model (ANEM), which can be used to evaluate the environmental consequences of the Chinese livestock industry. The model systematically analyzes farmer heterogeneity, the interactions that arise from this heterogeneity, autonomous decision-making, the aggregate development of the livestock sector and its associated environmental performance. Differing from any general agricultural ABM, ANEM develops a more specific structure depending on understanding characteristics of Chinese livestock sector. After a detailed introduction of ANEM, the results of a simulation in Zhongjiang County, located in southwest China, are presented and discussed. ANEM is flexible to be applicable to different Chinese areas through empirical calibration, the Zhonjiang case hence provides a test whether the chosen model structure is appropriate.

2.2 Methods

The structure of ANEM is shown in Figure 2.1. The model is mainly composed of a large number of autonomous agents defined by a series of attributes. Every agent has a set of rules that define personal and interaction behaviors. The agents autonomously decide on the amount of animals in their farms within the Farm Scale Decision module (FSD) and choose a manure collection technology and manure handling pattern within the Collection technology and Handling pattern Selection module (CHS). The external (social and physical) environment in which agents live is considered to be an external input. Individual behavior decisions are outputs on an individual level, while the aggregate output is a synthesis of individual agents.

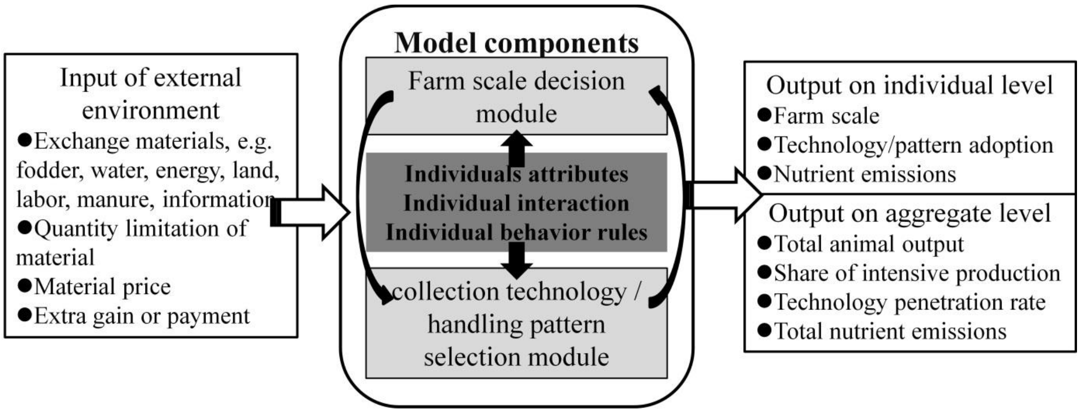


Figure 2.1 Components of the ANEM model

ANEM is built on an ABM paradigm in its concepts and coded on a Matlab platform. The major definitions in ANEM are presented below. A more detailed documentation of the model is provided in an Overview- Design concepts-Details (ODD) protocol (see appendix) as recommended by the literature of ABMs (Grimm, et al., 2010).

2.2.1 Agents and behavior

The simulation units (agents) in ANEM are defined as animal breeders. Although there is no universal agreement on the definition of an 'agent', the ability to act autonomously is the most important defining characteristic (Macal and North, 2007; 2010). Moreover, previous researchers have stated that an agent should represent a social actor with any type of independent component (Bonabeau, 2002; Gilbert, 2008). This study attempted to understand and simulate the responses of farmers who operate animal farms to inform the development of relevant policies.

The behavior of agents in ANEM is narrowed to farm-scale decisions, the adoption of manure collection technologies and the selection of manure handling patterns. Three dynamic attributes describe these decisions agents make at each point in time, which changes over time. The scale of animal farms is essential to their nutrient emissions (Petersen, et al., 2007). The concentration of nutrients in drainage water from intensive animal farms can be many times greater than that from farms with low livestock densities (per sq. m) (Kato, et al., 2009). Intensification increases the environmental impact of livestock production systems (Petersen, et al., 2007), because more manure is generated per farm, as well as manure collection and handling systems become more diverse (Happe, et al., 2011). Manure collection refers to the process of collecting feces and urine from animals and animal pens. Manure handling is defined as the way in which farmers handle the collected manure before discharging it to the environment. Various handling patterns are used in China. Examples include discretionary abandonment without any treatment, which results in all nutrients being released to the environment, partial reuse of nutrients as organic fertilizers or fermented materials, which reduces nutrient emissions, and full reuse of nutrients to achieve 'zero emission' status (Duan and Ni, 1998; Sharpley, et al., 2000; Van Evert, et al., 2003; Chen, et al., 2005; Bai, 2007; Chen, 2007). Thus, the quantity of nutrients emitted is influenced by the ways in which breeders collect and handle manure (Ogink, et al., 2000; Cederberg and Flysjö, 2004; Bai, 2007; Petersen, et al., 2007; Wang, 2007; Zhao, 2009). The definitions of farm scale, manure collection technology and manure handling pattern are listed in Table 2.1. Both medium- and large-scale farms were considered to be intensive farms in this study.

Table 2.1 Definitions of agent behavior and dynamic attributes

Behavior	Behavioral options	Description	Parameters
Farm scale decision	Maintain or change to household scale	<50 pigs per farm	Survival rate; Consumption of fodder, water and energy per animal; Production life span; Pork output; Land and labor use; coefficients of nutrient emissions.
	Maintain or change to medium scale	≥50 and <500 pigs per farm	
	Maintain or change to large scale	≥500 pigs per farm	
Manure process decision	Washing	Flushing manure from animal-pens to (septic-) tank	Water and energy consumption per animal; maintain cost; investment; coefficients of nutrient emission.
	Dry cleaning	Separating solid and liquid components of manure as soon as it is generated; and collecting separately	
	Bedding	Covering the land of animal-pens with thick straw layer to contain manure; Collecting both straw and manure regularly	
	Discharge	Discard manure to surroundings without any treatment or reuse	
	fertilization	Returning manure to farm-land as organic fertilizer	
	Treatment	Treating manure in biochemical process, especially bio-fermentation	
	Industry	Selling manure for industrial processing	

2.2.2 Model dynamics

ANEM (Figure 2.2) begins with an initialization step, in which the breeders' static attributes and the original conditions of the dynamic attributes are set and the values of coefficients and dynamics of external environment are updated. These settings and values depend on the specific case study, which is done in section 2.3.2.

In the model, agents attempt to optimize farm performance whenever they have the option to change their behavior. This dynamic individual decision-making process is considered to be equivalent to the decision-making process during the adoption of innovations under uncertainty, a process which has been described in numerous empirical studies (Geroski, 2000; Rogers, 2003; High, 2009). Innovation can relate to a technology, idea, practice, routine, or object that is perceived as new by an agent (Rogers, 2003). Hence, intensification, new manure collection technologies and new manure handling patterns are innovations in the model.

At each point in time, the decision-making process of an agent can be considered as a sequence of steps. Agents firstly evaluate current performance of animal farms based on economic profit gained from farms and negative impacts imposing on the environment. When animal breeders are introduced to an innovation ('knowledge gain' in Figure 2.2) via information channels, they learn more by observing colleagues and neighbors who are practicing the innovation (Rogers, 2003). If the introduced innovations are sufficiently adopted in observation networks, agents then evaluate the expected performance of the innovation as they engage in the decision-making process (High, 2009). Finally, the options with the perceived largest economic profits and/or the smallest emissions are adopted ('performance improvement'). Agents will further confirm an innovation after adoption, which is a 'performance evaluation' at a next time point. They reverse their decision if an innovation is not as good as expected, meaning this innovation will be excluded in the following decision-making step at a next time point. The farm-scale decision and manure-process decision have almost the same internal decision steps. And they are sequential.

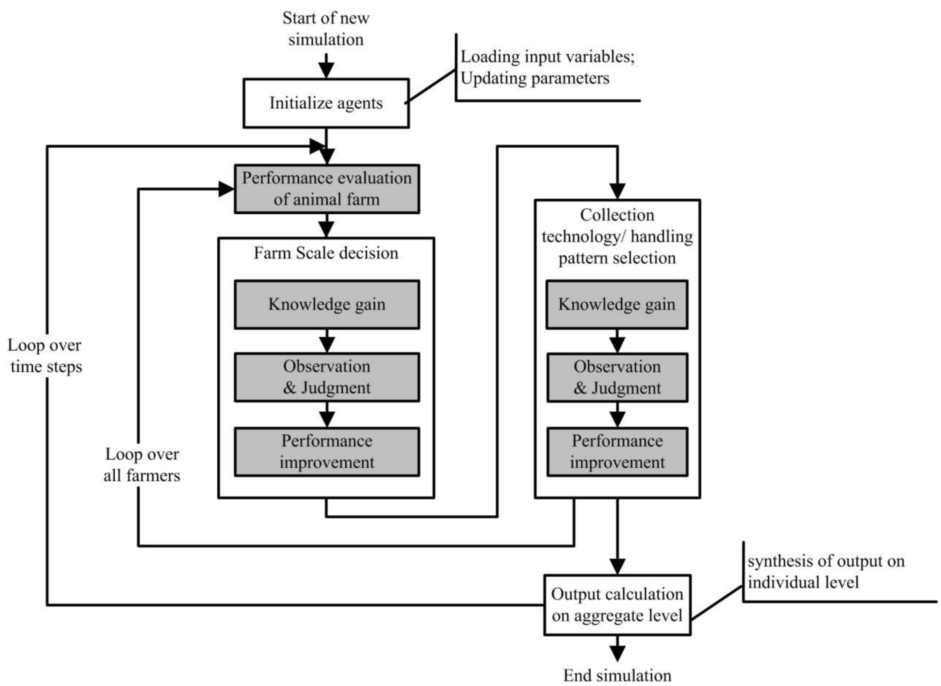


Figure 2.2 Flowchart of model simulation

Data from the external environment influence the decision-making process via 'performance evaluation', 'knowledge gain' and 'performance improvement', while interaction data influence the process mainly via 'observation'. In summary, agents synchronously make personal decisions based on environmental conditions, their historical behavior and that of others, and behavior rules.

2.2.3 Behavior rules

The behavior of animal breeders in ANEM dictates the performance of their farms. Another essential characteristic of ABM is that agents are not passively governed by external authorities, environment or other pressures; rather, they are goal-directed actors (Macal and North, 2006; Smith and Conrey, 2007; Macal and North, 2010). The model assumes that animal breeders will attempt to improve the economic and environmental performances of their farms.

Economic performance evaluations are based on the concept of cost-benefit analysis (Equation 2.1). ANEM assumes that economic performance increases with net economic profits. Agents pay for nutrient emissions and animal breeding, and they obtain income by selling livestock products and manure. ANEM adopts the coefficients of manure generation per animal per day defined in CPSC (MoEP, 2010) and the coefficients of products generation and resources consumption per animal per life span recorded in 'National Collection of Cost and Benefits for Agricultural Production'' (NDRC, 2010).

$$\begin{aligned} Profit_t &= Ben_t - Cos_t \\ &= (ProP_t \times ProCo + ManP_t \times ManGen \times Cycle) \times Ani\_Num_t \times SurR_t \\ &+ ExG_t - (\sum_{i=1} MP_{i,t} \times MCo_i \times Ani\_Num_t + Poll_{F_t} + ExP_t) \end{aligned}$$

Equation 2.1

Where $Profit_t$ is net economic profit per farm at time t; Ben_t is the benefit of animal breeding; Cos_t is the cost of animal breeding; $ProP_t$ and $ManP_t$ are the prices of products and manure, respectively; *ProCo* is coefficients that describes the products generated per animal per production life span; *ManGen* is the coefficient describes manure generated per animal per day; *Cycle* is the production life span of animals; Ani_Num_t is the number of animals; $SurR_t$ is survive rate of animals; ExG_t is extra gain such as subsidies; $MP_{i,t}$ and MCo_i are the price and consumption coefficients per animal per production life span, respectively, of breeding inputs i such as fodder, water, energy, land, labor and young animals; $Poll\_F_t$ is the pollution fee; and ExP_t is extra payment such as penalties.

The environmental performance of an animal farm is improved by reducing its nutrient emissions. The coefficients of manure generation and nutrient emissions per animal per day as defined in CPSC were used in ANEM. The nutrient emissions from each farm during a time step of animals are described by Equation 2.2. The coefficients vary by animal, collection technology and manure handling pattern.

$$\begin{aligned} Nu\_Emi_t &= Nu\_Emi_{collect} + Nu\_Emi_{handle} \\ &= [Nu\_Co_{collect} + (NuGen - Nu\_Co_{collect}) \times Nu\_Co_{handle}] \times Ani\_Num_t \times Cycle \end{aligned} \quad \text{Equation 2.2}$$

where Nu_Emi_t is nutrient emissions per farm; $Nu\_Emi_{collect}$ is nutrient emissions during manure collection; Nu_Emi_{handle} is nutrient emissions during manure handling; $Nu\_Co_{collect}$ is the coefficient of nutrient emissions per animal per day during manure collection; *NuGen* is the coefficient of nutrient generation per animal per day; and Nu_Co_{handle} is the coefficient of nutrient emissions per animal per day during manure handling.

When agents confirm an innovation ('performance evaluation' in Figure 2.2), economic performance is considered to be good enough if the net profit is comparable to the average rural household income in the simulation areas. During farm-scale decisions, ANEM assumes that agents possibly further expand their farms only after they confirm current scales. In terms of environmental performance, nutrient emissions from farms must be below governmental standards. Agents stop adopting new collection technologies and manure handling patterns if they are not able to mitigate nutrients more effectively and/or reduce economic costs. Economic and environmental performance is estimated according to Equation 2.1 at this decision-making step.

It is assumed that agents estimate expected economic and environmental performance based on the current external environment. The estimated nutrient emissions per farm are calculated in the same way as Equation 2.2, except using planned animal numbers instead of actual animal numbers. However, variables of external environment (used in Equation 2.1) possibly change unexpectedly at the next time step. Therefore, agents face risk and uncertainty due to their limited prediction ability (Janssen and van Ittersum, 2007). ANEM represents agents' considerations of this uncertainty as the perceived probabilities of objective benefits (Equation 2.3).

$$\begin{aligned} Profit_t' = Ben_t' \times P_t - Cos_t' = \\ [(ProP_t \times ProCo + ManP_t \times ManGen \times Cycle) \times Ani\_Num_t' + ExG_t] \times P_t \\ -(\textstyle\sum_{i=1} MP_{i,t} \times MCo_i \times Ani\_Num_t' + Poll_{F_t} + ExP_t) \end{aligned} \quad \text{Equation 2.3}$$

where $Profit_t'$ is perceived net economic profit per farm at time t; Ben_t' is the estimated benefit of animal breeding; Cos_t' is the estimated cost of animal breeding; P_t is the perceived probability to achieve estimated benefits; and Ani_Num_t' is the number of planned animals.

The present perceived probability can be valued simply by breeders personally in individual interviews, or more complexly measured by a series of experiments (Xi and Lu, 2007). This research uses Equation 2.4 to trace historical or predicted future perceived probability. The risk coefficient represents the relative risk and uncertainty compared to reference time point, which can be the weighted average of several components, as shown in Equation 2.5. Excessively pessimistic subjective probabilities cause breeders to underestimate possible profits and reject future farm expansions.

$$P_t = P_0 \times Risk_t$$ Equation 2.4

where P_0 is perceived probability at reference time; and $Risk_t$ is risky coefficient at time t.

$$Risk_t = \sum_{n=0}^{n} a_n r_n$$ Equation 2.5

where a_n is the weight of component n; and r_n is the nth component of risk considered by agents. As found during field work, breeders mainly considered price fluctuations and disease outbreaks as major future uncertainty. Breeders subjectively assumed that frequent and huge price fluctuations and disease outbreaks, which increase death rate of pigs, together decreased the likelihood of achieving benefits.

ANEM assumes that animal breeders prioritize economic and environmental performances differently (Equation 2.6). ANEM distinguishes agents into three categories based on their level of ‘environmentalism’. Highly profit-oriented agents in the first category give priority to economic performance. They prefer options with the largest profit. Options with less pollution will be chosen only when they have the same or larger profits than options with high pollution levels. Moderately profit-oriented agents choose the options with the least pollution among the options with the largest and second-largest economic profits. If there is no difference in pollution, the options with larger economic profits are favored. The last category of agents contains 'environmentalists', who give priority to pollution reduction.

$$Prefer_t = f(Profit_{t,j}, Nu\_Emi_{t,j}, Env)$$ Equation 2.6

where $Prefer_t$ is individual preferred option at time t; $Profit_{t,j}$ is economic profit of option j; $Nu\_Emi_{t,j}$ is nutrient emission of option j; and Env is individual awareness of negative environmental impact.

Furthermore, the ability to invest in innovations can be a constraint for agents. Agents cannot update their construction and equipment if the costs exceed their current net profits. Meanwhile, sunk investments of current options, which are depreciated over 4 years, are added to investments at the time of option transformation to avoid frequent option transformations.

2.2.4 Interactions

The interactions considered in ANEM are based on observations of others' behavior within personal networks. Agents look for examples of innovation adoption to help judge if an innovation would benefit him/herself. Since the decision-making processes of all agents in ANEM are synchronous, agents are only able to seek examples from behavior that happened before the time of decision-making. Options insufficiently adopted are considered too uncertain and not included in perceived performance evaluations. Behavior options that have been used before by the same agent are not considered to be innovations. Such familiar options are always considered.

An observation network in ANEM is assumed to be the scope of agent's active information search. Whoever is outside one's observation network is invisible and has no influence/effect. Empirical research has demonstrated that community members prefer to imitate 'opinion leaders' who may have higher socioeconomic status, have more advanced education and are more innovative (Rogers, 2003). Therefore, ANEM employs four attributes to define the observation network of each agent (as listed in Table 2.2): social status, farm scale, education level and risk aversion. Agents consider historical behavior of others who are more advanced in one or more of these four attributes. Hence, besides representing the diversity of agents, the attributes affect agents' interaction with each other. Due to the fact that farm scale is a dynamic attribute, the network of a given agent is likely to change over time.

An agent will consider an innovation after its adoption level has reached a threshold in his observation network (Berger, 2001) (see Equation 2.7). Thresholds are represented as minimum percentages of innovation adopters in the entire network, which are identified individually different in the simulation. A lower threshold means an innovation will be adopted earlier. Therefore, future behavior of agents is influenced by the historic behavior of colleagues and neighbors.

$$Con_{k,j} = \begin{cases} 1, & (Thr_k \leq Ad_j / Ob_k) \\ 0, & (Thr_k > Ad_j / Ob_k) \end{cases}$$ Equation 2.7

where $Con_{k,j}$ is a dummy variable indicating consideration of agent k whether to further evaluate option j; Thr_k is minimum percentage of innovation adoption set by agent k; Ad_j is number of option j adopters within agent k's network; Ob_k is number of observed neighbors of agent k.

Table 2.2 Agent attributes for network definition

Attributes	**Level**	**Description**
Social status	1	Either government officer or C.P.C. party member
	0	Neither government officer nor party member
Education level	1	Lower than primary school
	2	Primary school
	3	Junior high school
	4	Senior high school
	5	Higher than senior school
Risk aversion	1	Laggards to adopt innovations
	2	Late majority of adopters
	3	Early majority of adopters
	4	Early adopters
	5	Pioneers to use innovations
Location	Positive integer	

All interaction networks are established locally. In accordance with a common assumption in ABM, neighbors (that is: agents geographically located close to one another), are more likely to interact and influence one another than agents living far apart (Gilbert and Terna, 2000; Macal and North, 2010). Hence, ANEM uses 'location' to divide all agents into different spatially isolated populations, e.g. villages, without information spillover. Agents can only connect if they are located in the same spatial population.

2.2.5 External environment

In addition to the diversity of agent attributes and behavior rules, individual decisions are influenced by the condition of the external environment in which the agents live (Gilbert and Terna, 2000; Smith and Conrey, 2007). The external environment often includes non-agent resources or influencing factors, as listed in Table 2.3. All this information will play a role during the decision-making process.

The prices and quantity limitations of matters that breeders exchange with the environment and the associated extra gains or payments are used by agents during performance evaluations, as showed in Equation 2.1 and 2.3. The dynamic prices of products, manure and inputs are either guide prices set by the government, or market prices when guide prices are absent. And quantity limitations constrain the feasibility of behavioral options. Any option breaking quantity limitations cannot be considered by agents, represented as negative economic profits and infinite environmental destruction in the simulation. One typical example of quantity limitations is emission limits, which is excessive emissions followed by a huge penalty or mandatory order to close the farm. Other examples may involve limited land access and even explicit limits of animal numbers and technology adoption.

Table 2.3 Information from farmer's external environment

Variable category	**Variable description**
Knowledge information	The information of existence and functions about all behavior options in information channels
Market price	Prices, without government enforcement, of product, manure, fodder, piglet and disease control
Guide price	Minimum or maximum limitation of prices or fixed prices set by government, for products, water, energy, fodder, piglet and pollutants
Extra benefit	Extra financial benefit added by government for products, fodder, piglet, construction, technology The value is either negative (e.g. penalty), or positive (e.g. subsidy)
Limitation quota	The maximum limitation to use resources or take certain action, including contracted land, rent land and technology
Others	Other variables to describe agents' environment, such as disease outbreak, average household income

Knowledge of the economic and environmental consequences of behavioral options affects agent behavior during 'knowledge gain'. In ANEM, agents investigate innovations using different information channels, including mass media, expert consultations, government and non-governmental organization (NGO) recommendations, and interpersonal communication among peers (Rogers, 2003). However, not all innovations introduced in this research are assumed to be significantly present in every information channel. For instance, bedding technology is mainly communicated to farmers through mass media, while dry collection is communicated through all kinds of information channels. Besides, some other variables are used at various steps to help individual decision-making. For instance, agents compare current economic performance with average rural household income at 'performance evaluation'.

Since all agents are assumed to be fully exposed to the external environment, they are able to search useful information directly from the environment. All variables of the external environment are input to the simulation at each time step. Therefore, policy changes can influence the decision-making process of breeders at any time point by changing their external environment. However, the specific effects will also depend on individual attributes and interactions.

2.3 Simulation

2.3.1 Study area and data collection

ANEM was applied to the livestock sector in Zhongjiang County, located in the middle of Sichuan Province in southwest China. In Zhongjiang County in 2009, more than 90% of the population lived in rural areas. Pigs were chosen as the single animal species for simulation because they were the source of more than half of the N and P emissions in that area, according to the CPSC (2009 data).

There were three kinds of variables pre-defined based on field survey (listed in Table 2.4), including the initial condition of ANEM, heterogeneous attributes of agents and the external environment (model inputs), as well as some general coefficients. A questionnaire survey was conducted in 2011 to investigate the attributes, interactions and behavior rules of breeders (Table 2.4). In 5 towns, 128 breeder households were selected, accounting for approximately 0.9‰ of all breeder households. Interviews with governmental agricultural production and environmental management agencies provided information on the dynamics of the external environment. Some statistical data about pig breeding and related technologies were also collected from local livestock husbandry yearbooks and pollution source censuses.

Table 2.4 Data collected and variable assignment

Variable category	Variables	Variable values	Questions/ data resource	Observations
Initialization	Farm-scale;	Randomly valued as 1,2 or 3	Statistic tales of livestock and poultry production	Pig output:1.63 million pigs Intensive farms contributed 13% output
	Number of animals	Randomly valued (integer)		

Variable category	Variables	Variable values	Questions/ data resource	Observations
	Collection technology	Randomly valued as 1,2 or 3	The historical actions of technology adoption	Washing was dominant, but less used in larger-scale farms.
	Handling pattern	Randomly valued as 1,2, 3 or 4		Biogas production was the rising alternative
Individual heterogeneity	Social status	Randomly valued as 0,1	Are you party member or governmental official?	Number of either party member or officials in one village varies from 3 to 8
	Education level	Randomly valued as (integer) 1-5 in accordance with distribution in scale groups	What is your education level?	Educated 1-6 years (valued 2) and educated 6-9 years (valued 3) are two major group; Significantly correlated to scale
	Risk aversion	Randomly valued as (integer) 1-5	What-to-do in hypothesized situations	Most breeders are neutral (valued 2-4)
	Criteria to define personal interaction network	higher social status, education level, risky or larger farm	Who do you prefer to learn an innovation?	Breeders consider behavior of others who are more advanced in one or more of criteria.
Individual heterogeneity	Environmenta-lism	Randomly valued 0,1,2	What-to-do in hypothesized situations	Very small number of breeders fully prioritizes environmental to economic benefit (valued 2).
	Adoption threshold	Randomly valued [0,1] with one decimal in accordance with distribution in scale groups	What-to-do in hypothesized situations	Overall, 46.8% breeders set higher than 0.5; Larger-scale breeders prefer to lower threshold
	Tolerance capability	Randomly valued as 1,2 or 3 years	The situations to decrease farm	Normally it is 1 year; No breeders can handle losses for >3 years
	Subjective probability (reference)	Randomly valued in interval (0,0.3], [0.3,0.5], [0.5,0.8] or [0.8,1]	Which interval is your probability belongs to in current situation?	More breeders choose higher interval along with scale increase.
	Weight of risk component	Differs according to farm scale	The situations to adjust subjective probability of benefit	Large-scale breeders give70% weight to price fluctuation, when other breeders give <60%.
	Information channels	Vector with six elements random valued as 0 or 1 for each breeder;	The information channels used to search knowledge of technologies	Breeders favour interpersonal communication; 26%, 37% , 14% and 7%, used mass media, farmer organizations, the government for information and experience, respectively

Variable category	Variables	Variable values	Questions/ data resource	Observations
External environment	Knowledge information	knowledge existing in the channel=1, otherwise = 0	Government interview; Where do you get knowledge?	Not evenly distributed among channels
	Market prices		Agricultural market reports	Fluctuated a lot in 2007
	Guide prices		Government interview	No guide price
	Extra benefit	= 32000 *yuan* farms with 500 and more pigs; = 1000 *yuan* to invest biogas digsters	Government interview	Governmental subsidy for livestock production but not technologies (only biogas)
	Limitation quota	Limitation quota = infinite Limitation of land use = 50 mu	Government interview	No limitation quota expect land use;

2.3.2 Model inputs and calibration

The production life span of a pig is normally 6 months in intensive farms and 1 year in household-scale farms. Therefore, the time step of the simulation was taken as 1 year. This also facilitated a comparative analysis of the simulation results with statistical data. Based on data availability, ANEM ran for a period of 4 years from 2005 to 2008. Since the number of animal breeders in Zhongjiang County is too large to be all included in a simulation, only 20,056 artificial breeders were included in the simulation. The number of agents was enough to cover all possible collocation of attributes. To insist with average number of households per village, agents were assumed to locate at 80 isolated populations.

Farm-scale and technology adoption of agents in 2005 were initialized randomly, with constraints on total amount of pig output, percentage of pigs from intensive farms and aggregate penetration rates of technologies at that year. Heterogeneity of agents in ANEM was calibrated depending on our questionnaire survey. Similar to initialization, variables of agents were valued randomly but in accordance with the distribution observed in the survey. Due to independence of some variables, it was possible that agents in the model were different from the respondents in terms of certain attributes. Therefore, heterogeneous agents were not copies of the 128 respondents in survey.

The data of the second variable category in Table 2.4 reveals diversities of individual characteristics, behavior rules and interactions. For instance, a what-to-do question with a hypothesized situation measured ‘risk aversion’ and ‘environmentalism’, which differed person to person. As another example, large-scale farm owners generally felt more self-confident in managing risks and estimated higher ‘subjective probabilities to achieve economic benefits’. Additionally, large-scale breeders were more concerned with price dynamics than smaller-scale breeders, giving higher weight to price fluctuation. The ‘adoption threshold’ in the case study area varied from 0 to 100%. In the simulation, 46.8% of breeders set their thresholds higher than 50%, meaning that they would only adopt innovations that have been adopted by more than half of the other breeders in their interaction networks. In general, the breeders with large-scale farms had lower ‘thresholds’. Furthermore, more than half of the breeders stated that they would decrease the size of the farm as soon as they did not receive a sufficient profit for a given year. Some breeders are better able to handle business losses, but rarely can they be tolerant to such losses for more than three consecutive years. In addition, the last row in Table 2.4 helped to confirm parameters which were not individual heterogeneous, such as coefficients in Equation 2.1and 2.2.

National and local policies defined the external environment in ANEM. In recent years, the government attempted to increase the total output of pig breeding and encouraged further intensification. Hence, government did not set limitation quotas for breeders’ activities, except on land use. Respondents without enough land could easily rent land from other households. The market prices in the case study area fluctuated a lot in 2007; especially the increase of fodder price reduced economic profits of pig breeding. To cope with this crisis, a governmental subsidy was provided to pig farms. The local government was not active promoting technology improvement and nutrient mitigation within the simulation period. There was a biogas project to cover investment of infrastructure, but for the purpose of better energy use in rural area. Since information of technologies was not evenly distributed among information channels, not all respondents had access to knowledge of new technologies. According to our survey, breeders favored face-to-face communications for information exchanges. A breeder minority of 26%, 37% and 14%, used mass media, farmer organizations and the government for information, respectively. Approximately 7% of the breeders only trusted themselves and did not rely on any external source of information. Although agents were assumed to use the same information channels during the simulation period, knowledge may exist in different channels at different time point. For example, biogas production started to appear in ‘government recommendations’ only after 2006.

In a word, agents’ attributes and their behavior mechanisms and coefficients were set in ANEM as found in the survey. Individual decisions at the farm-scale resulted in phenomena at an aggregate level, including changes in the total production output and intensification. And individual decision-making processes for technologies and manure handling patterns determined technology penetration rates at an aggregate level, as represented by the percentage of adoptees in a given population. The aggregate behavior of animal breeders in the case study area changed within these four years. ANEM attempted to trace this historical dynamics for model validation to some extent.

2.3.3 Simulation results

(I) Farm-scale decisions

The ANEM simulation results for pig breeding approximate the actual data during the period from 2005 to 2008. Figure 2.3 shows the simulation results for the total amount of pig output and the percentage of pigs produced by intensive farms (medium- and large-scale farms). The pig output surged for 3 years and then slipped in 2008, while the percentage of pigs from intensive farms increased from 13% to more than 15%, with a small decrease in 2007. The relative annual deviations between the simulated results and actual data were below 2% for total output and below and 6% for the share of intensive farming.

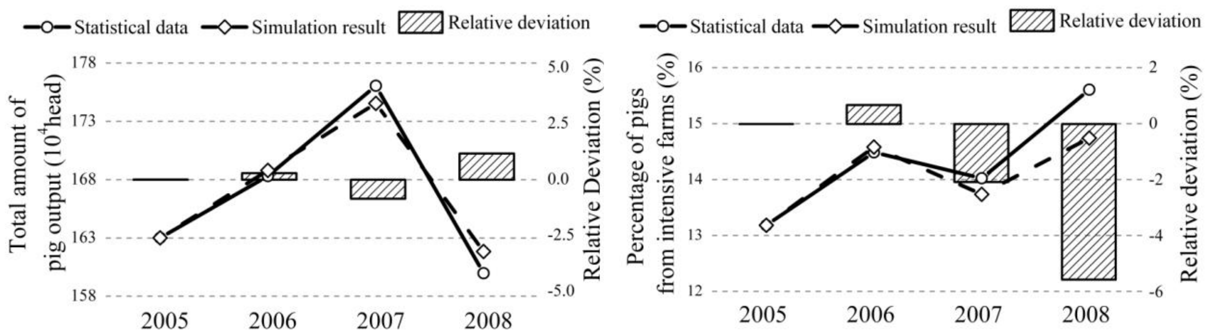


Figure 2.3 Simulation results and statistic data of total pig output and intensive rate from 2005 to 2008

(II) Selection of manure technology and handling pattern

The ability of ANEM to replicate changes in manure collection technologies and handling patterns was examined using cross-sectional data for a one-year period due to the lack of continuous observations in the case study area. The simulation result for manure collection technology was compared to the statistical information collected during the local CPSP in 2007 (Table 2.5). The simulated penetration rates for both medium- and large-scale farms were similar to the statistical data, with less than 4% deviation. According to simulation, breeders moved from ‘washing’ to ‘dry’ collection compared to 2005. The penetration rate of washing for all farms decreased from 90% in 2005 to 82% in 2008. The use of dry collection gradually increased and became dominant among intensive farms. Dry collection was adopted to serve 61% and 67% of pig in medium- and large-scale farms, respectively. Fewer farms used washing than dry collection technologies, while very few farms (less than 1%) applied bedding technologies.

The handling pattern simulation matched data from a 2008 field survey (Table 2.6). The diffusion of manure handling patterns was slower than that of collection technologies; breeders continued to prefer ‘treatment’ and ‘fertilization’ above ‘discharging’ and selling to ‘industry’. More than 95% of the farms used manure as fertilizer or for household biogas production. However, discharging manure without any treatment had not been completely eradicated; approximately 4% of farms used this handling pattern. A very small number of farms sold manure on a regular basis.

Table 2.5 Simulation results and statistical data of manure collection technology diffusion (in %) in 2007

Technology penetration rate	Medium-scale farms			Large-scale farms		
	Simulation result	Statistical data	Stdeva	Simulation result	Statistical data	Stdeva
Washing	40.24	43.82	-3.58	30	33.26	-3.26
Dry	58.96	55.46	3.50	70	66.74	3.26
Bedding	0.80	0.72	0.08	0	0	0

Table 2.6 Simulation results and statistical data of manure handling patterns diffusion (in %) in 2008

Pattern penetration rate	Simulation result	Statistical data	Stdeva
Discharge	4.08	4.32	-0.24
Fertilization	37.63	37.44	0.19
Treatment	57.69	57.58	0.11
Industry	0.59	0.65	-0.06

(III) Nutrient emissions

The simulated emissions were compared with records from local environmental agencies (Table 2.7). The local government has investigated pollution emissions from livestock operations for every year since the CPSP in 2007. The simulation captured the actual dynamics of nutrient emissions for 2007 and 2008. The relative deviations between the simulated results and actual observations were below 5%, an acceptable level. In both 2007 and 2008, medium- and large-scale pig farms discharged more than 300 ton of N and 50 ton of P.

Table 2.7 Simulation results and statistical data of nutrient emissions (in tons) for medium- and large-scale farms in 2007 and 2008

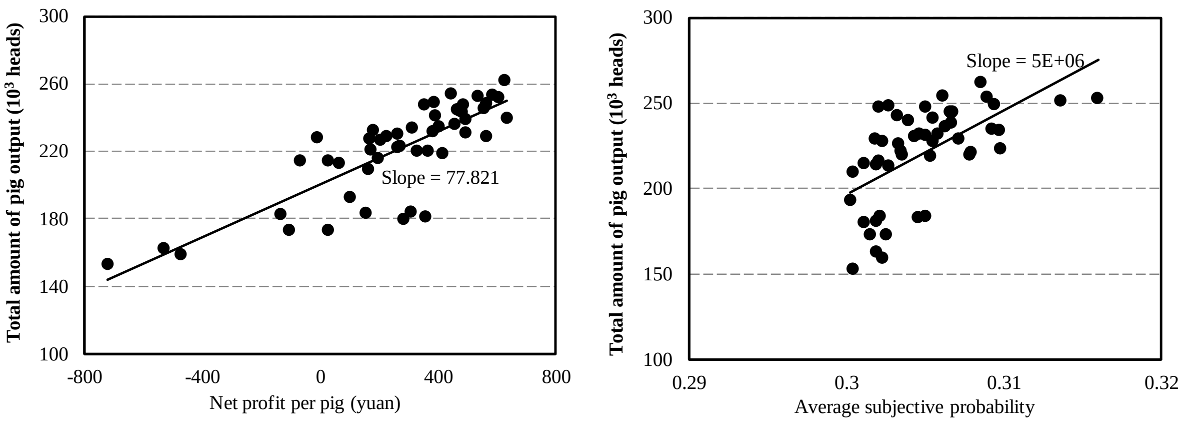
Nutrient	2007			2008		
	Simulation result	Statistical data	Relative deviation (%)	Simulation result	Statistical data	Relative deviation (%)
Nitrogen	347.44	345.18	0.66	339.49	336.29	0.95
Phosphorus	52.19	54.37	-4.00	49.66	51.92	-4.35

2.4 Discussion

The analysis of simulation runs, that generated results, identified variables in each decision-making steps that prevent breeders from changing their behavior, as well as the common features of these non-changing breeders, although the simulation results to draw these findings cannot be fully shown in details.

At the farm scale decision, the influence of net profit was obvious in 2006. The medium-scale agents had limited profits that year, with approximately 31% running at a deficit. This was one of the major reasons that 65% of the medium-scale agents reduced the number of animals in 2007, resulting in a decrease in the percentage of pigs from intensive farms. In contrast to the medium-scale agents, household- and large-scale agents showed positive net profits in 2006 and income levels higher than the average rural household income. As a result, approximately 30% of households and large-scale agents expanded their farms, which explains the increase in the total number of pigs in 2007 despite a lower intensification rate than that in 2006. Besides cost and benefit, subjective probabilities were important to form perceived net profits in the next time period. Drastic price fluctuations in 2007 resulted in more pessimistic subjective probabilities and an increase in the diversity of this variable among agents. In 2007, the maximum subjective probability was more than 95% and the minimum one was less than 10%, while all subjective probabilities in 2005 were between 80% and 90%. According to the simulation, 80% of the agents who decreased the number of pigs bred in 2008 compared to 2007 decided to destock because of worsening economic performance expectations.

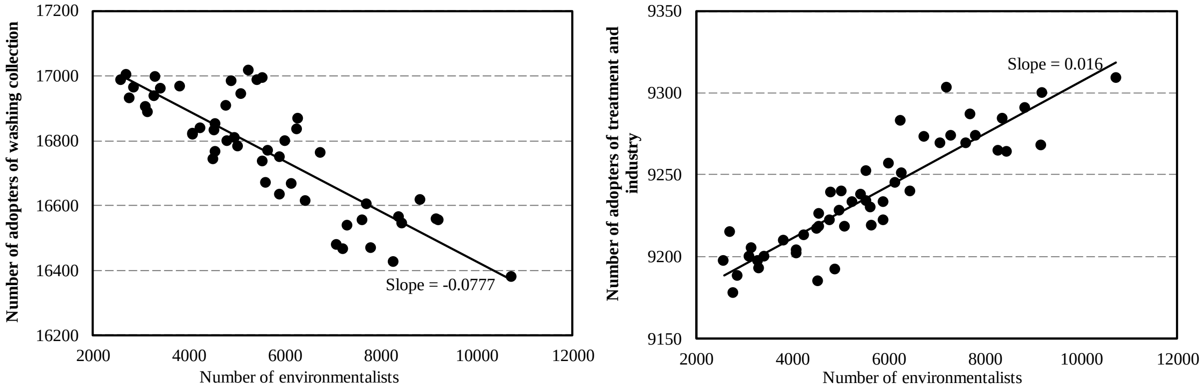
Prices of product, fodder and piglet are key factors for both net profit and subjective probability. Hence, random values in intervals of respective minimum and maximum prices in 2005-2008 were used to simply examine sensitivities of net profit and subjective probability to farm scale decision. As depicted in Figure 2.4, total pig output increases along with either larger net profit per pig or higher average subjective probability. These two correlations were significant at 0.01 level.



(a) correlation of net profit and total pig output (b) correlation of subjective probability and total pig output

Figure 2.4 Respective correlation of net profit and subjective probability with pig output

In the adoption of collection technologies and handling patterns, every decision step may be influential. First of all, economic and environmental performance and priority between these two determine individual preferences. On the one hand, ANEM demonstrated that a change in collection technology or handling pattern occurred when such a change was likely to improve economic performance by reducing maintenance cost and/or saving water and energy. An increasing number of breeders produced biogas on household-scale instead of using manure as fertilizer. Biogas production supplied an alternative energy source. Although household biogas digesters required major investments, local governments provided subsidies to help breeders construct the necessary infrastructure. Hence, breeders in this study considered ‘treatment’ to have a better economic performance than ‘fertilization’. The Chinese government effectively managed better economic performance of biogas production, resulting in 10% more adoption of this treatment technology. On the other hand, the diffusion of unconventional technologies likely exemplified the effect of “environmentalism” on decision-making. When part of the highly profit-oriented and moderately profit-oriented breeders were randomly picked up and defined as environmentalists, the number of washing collection adopters decreased and the number of breeders adopting treatment and selling to industry increased (see Figure 2.5).



(a) correlation of environmentalists and manure collection (b) correlation of environmentalists and manure handling

Figure 2.5 Respective correlation of environmentalists with manure collection and manure handling

It was also found that diffusion took time, even if innovations provided better economic and/or environmental performance. Selling manure was economically and environmentally competitive, but did not diffuse effectively. Interaction between agents proved to be an important barrier. For instance, 37% of all agents were able to gain information on selling manure from NGOs, but an overwhelming majority of them (more than 90%) did not actually sell manure due to a lack of examples in their networks.

Regardless of all these simulation outcomes, it should be acknowledged that the real world is far more complex than what can be represented by simulation experiments. Several important factors have not been fully addressed, and the relationship among agents has been simplified in the model. In addition to education level, socioeconomic status and innovativeness, many other factors influence the establishment and rules of interaction networks, such as kinship and social participation. Further, variations in agent attributes over time are ignored, although static attributes in ANEM may change over time. For example, adoption thresholds may be lowered when younger generations start livestock operations. As a result, the model may be overly pessimistic in evaluating the diffusion of innovations. Therefore, an overall sensitivity analysis including all parameters and inputs is necessary to better understand and test ANEM in future research.

2.5 Conclusions

In this study, an agent based environmental model was constructed to represent individual decision-making, which is absent in conventional environmental performance assessments. A case study was performed to demonstrate the model's ability to simulate human behavior related to the number of animals raised and the adoption of manure collection technologies and manure handling patterns. These three processes are at the foundation of environmental performance assessments for individual livestock farms. The assumptions relevant to the decision-making process enable the model to capture complicated interpersonal interactions and the heterogeneity of individuals. In the model, animal breeders are assumed to interact with others based on education level, social status, economic status and risk aversion. In addition to determining interaction networks, individual attributes influence various stages in the decision-making process.

ANEM can be used by policy makers to understand livestock development and the associated environmental impacts under certain policies. The aggregate simulation results show the outcomes of certain policies in terms of the total output and structure of livestock production, the use of technologies and manure handling patterns in the livestock sector, and total nutrient emissions from animal farms. This environmental performance assessment will give great help to policy-makers to do environmental management in rural areas. The validation of ANEM using aggregate numbers confirms that the model mechanisms may be suitable to describe individual decision-making, and therefore the model allows discussing expected policy effects based on this individual-level description. Unlike conventional models, ANEM can identify the barriers related to specific policy goals and help to describe the farms and farmers who fail to respond to certain policy instruments.

There are some policy implications according to the relations of variables and model outputs. Economic instruments such as subsidies and pricing policies may promote intensification by increasing objective net profits. Other instruments designed to stabilize market prices and to control diseases are likely to improve the expected economic performance of intensification. To promote the diffusion of new technologies and handling patterns, policy makers can do afford more than providing economic incentives. A demonstration project is possibly a good way to decrease the time required to acquire knowledge and observe examples. When governmental agencies encourage influential breeders to be early adopters, information and observations of innovations can more easily reach a majority of breeders in a given population.

Acknowledgements

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Appendix 2-S1: ODD protocol of ANEM

Overview	1.purpose	Depending on understanding characteristics of Chinese livestock industry, ANEM systematically analyzes farmer heterogeneity, the interactions that arise from this heterogeneity, autonomous decision-making, the aggregate development of Chinese livestock sector and its associated environmental performance. Zhonjiang case in this paper provides a test whether the chosen model structure is appropriate.	Section1 Introductio n
	2.entities, state variables, and scales	Entities: 20056 artificial breeders State variables (unit, first-order): table 1 shows dynamic attributes, table 4 shows static attributes to characterize individuals and their behavioural strategies Entities: external environment State variables: table 3 and table 4 Scales: one time step represents 1 year and simulation was run for 4 years. The number of agents was about 1/7 all farmers in case.	Section 2.1 agents and behaviour Section 3.2 model inputs and calibration
	3.process overview and scheduling	Figure 2 shows the process as a sequence of discrete steps: Initialization; load inputs; update parameters; for time from 1 to 4 for breeders from 1 to 20056 (synchronous desicion-making) calculate net profit and nutrient emission; decide farm scale for next time step; select collection and handling technology for next time step; end for; update breeders' dynamic attributes; synthetize aggregate phenomena including total output (of each scale group), penetration rate of technologies, total nutrient emission (of each scale group); end for.	Section 2.2 model dynamics
4.Design concepts	Basic principles	Innovation adoption under uncertainty Used at the level of submodels Model validation provides insights about the usefulness of basic principle in rural China. But this is not the major purpose of this study	Section 2.3 behavior rules Section 2.4 interaction
	Emergence	Aggregate phenomena in this research all come from individuals and their interactions, so that they are considered as emergences.	
	Adaptation	Prices changes in environment influence net profits and subjective probabilities of breeders, and thus influence expected economic profits evaluations. Breeders always attempt to maximize expected economic profits (objective) in farm-scale decision. Breeders adjust their observation network and weight of risk components when their farm scale changes. Whether breeders know innovations is determined by knowledge information in environment. Breeders consider innovations after their adoption levels have reached thresholds in observation network. So the consideration is adapted by personal observation networks and number of adopters in environment.	Section 2.3 behavior rules Section 2.4 interaction Secrion 2.5 external environme nt
	Objectives	Optimize economic and environmental performance i.e. larger net profit and less nutrient emission	Section 2.3
	Learning	Behavior options that have been used before by an agent are not considered to be innovations.	
	Prediction	It is assumed that agents estimate expected economic and environmental performance based on the current external environment. ANEM represents agents' considerations of uncertainty in future as the perceived probabilities.	Section 2.3

	Sensing	Breeders sense historical behavior of local others through observation network. Breeders seek some environmental information simply, such as market prices and other information through information channel, such as knowledge of innovations (table 3).	Section 2.4 Section 2.5
	Interaction	The interactions considered in ANEM are based on observations of others' behavior within personal networks.	Section 2.4
	Stochasticity	Initialization and individual heterogeneity are modelled partly randomly (table 4).	Section 3.2
	Observation	The total amount of pig output and the percentage of pigs produced by intensive farms are collection from ANEM to approximate actual data from statistic yearbooks. The simulated penetration rate of manure collection technologies were compared to the statistical information collected during the local CPSP in 2007. And the handling pattern simulation matched data from a 2008 field survey. The simulated total emission was compared with records from local environmental agencies	Section 3.3
Details	5.initialization	Initialization is based on empirical data, and thus allowed to vary among simulations. Table 4 shows how to translate empirical data into initial model condition.	Section 3.2 model inputs & calibration
	6.input data	Inputs come from a time series of statistic data and governmental interviews (table 4).	

	7.submodels	Profit submodels at time t:
		For n from 1 to farmer number step 1
		    Extract parameters according to scale(t), collection technology(t) and handling pattern(t)
		    Equation 1, 2, 4 and 5
		End for
		Farm-scale decision submodels at time t:
		For n from 1 to farmer number step 1
		    // economic performance evaluation
		    Do
		        Year = t
		        If net profit (year)< labor (year) * average income per capita (year)
		            Unsatisfied year + 1
		            Year = year -1
		        End if
		    Until net profit (year) >= lab (year) * average income per capita (year)
		    End do
		    If unsatisfied year >= Tolerance capability
		        Willing to decrease
		    Else if profit(t) < average household income(t)
		        Willing to change within scale
		    Else
		        Willing to increase
		    End if
		    // observation and judgement
		    If willing to increase
		        Look for farmers of larger scale in network(t)
		        If examples of scale A>= threshold
		            expected scale = A
		        End if
		    Else if willing to decrease
		        expected scale = Max(scale(t-1)-1, 1)
		    Else
		        expected scale = scale(t-1)
		    End if	

		// expected performance evaluation
		Equation 4
		Do
		Equation 3
		expected animal amount decrease/increase from animal amount(t) to min/max animal amount of expected scale ,respectively
		Until expected profit $Profit_t'$ decrease
		End do
		Animal amount(t) = expected animal amount * survive rate (t)
		Scale (t) =*f*(animal amount(t))
		// scale is calculated according to number of animals as showed in Table 1
		End for
		Technology selection submodel at time t:
		For n from 1 to farmer number step 1
		//look for possible technologies
		If technology i was used before
		It is possible
		ElseIf n can learn knowledge through his information channels AND adopters in his network > threshold
		It is possible
		Else
		It is impossible
		End if
		//evaluate economic and environmental performance of possible technologies
		If investment > net profit
		Exclude it from evaluation
		End if
		Economic performance = extra benefit attached on technology – water & energy cost – maintenance cost – sunk investment
		environmental performance = emission during collection + emission during handling
		//selection
		If he is profit-oriented
		Select technology with the best Economic performance
		Else if he is moderately profit-oriented
		[technologies with the best and second-best Economic performance]
		Select technology with the best environmental performance
		Else
		Select technology with best environmental performance
		End if;
		End for.	

3

Managing Manure from China´s Pigs and Poultry – the influence of ecological rationality

Abstract

We have investigated manure management practices at three farm scales in Chinese pig and poultry production. The concept of ecological rationality was employed to explore empirically how environmental concerns drive adoption of environmental-friendly manure management technologies at different farm scales. The more developed Rudong County in Jiangsu Province and the less developed Zhongjiang County in Sichuan Province were chosen as cases for study of 258 animal breeders. On the contrary to our hypothesis, medium-scale farmers were not always found to be laggards in adoption of manure management technologies. Government ecological rationality played a key role to induce environmental friendly technology adoption on its own, but also in cooperation with ecologically rational individual or network drivers. Authorities no longer applied their efforts in a conventional command-and-control way, but more in the form of incentives, stimulation and information to farmers. Individual farmers in general showed low environmental responsibility in relation to manure handling.

Keywords:

Manure management practices, Pig farmers, poultry farmers, Nutrient emission.

Chapter 3. Managing Manure from China´s Pigs and Poultry – the influence of ecological rationality[3]

3.1 Introduction

A nationwide pollution source census was launched in China in 2007. It was the first time for the Chinese government to systemically assess pollution emissions in all provinces and from different human activities. The census showed that livestock production, which previously had largely been ignored in environmental management, was responsible for 38% and 56% of total agricultural nitrogen and phosphorus non-point source pollution, respectively (MoEP, 2010).

Livestock production has developed rapidly in China, especially after the economic reform program was launched in 1979 which allowed farmers to breed animals in their backyards (Li, 2009). Since the mid-1990s the Chinese government further has supported the expansion of livestock husbandry production resulting in considerable intensification and diversification. Pig and poultry farming all along make up major part of livestock production, but other species expanded from 14% of livestock value in 2001 to 27% in 2011 (*Statistical Yearbook of Chinese Livestock Production*, 2000-2009). Based on the number of animals on farm, three farm scales are distinguished in Chinese official statistics, i.e. household-scale, medium-scale and large-scale; the latter two are defined as intensive farms. Over the past ten years the proportion of household-scale livestock breeding has decreased by 1.4% annually, and this trend is likely to continue in the long-term (Shen and Shi, 2008). Taking pig farming as example, around half of pig output comes from household scale farms, with the other half being shared by medium and large scale farmers. The intensification in poultry farming is much higher. Medium scale farmers contribute more than half of broiler output, while household scale production reduces to 20% of broiler output (Table 3.1). The proportion of intensive layer hens farming reaches 72% of sectoral output, and large scale farms take 48%. Nevertheless, scholars believe that intensive livestock husbandry is not and won't be the only mode of production in China (Li, et al., 2007). They identify the continuing coexistence of

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three husbandry patterns as one of the most important differences between China and many developed countries.

Table 3.1 Shares of different scale production in China and cases

Animal species	Regions	Shares in total animal output (%)		
		Household scale	Medium scale	Large scale
Pigs	Average in China	51	27	22
	More developed Case	42	41	17
	Less developed Case	83	9	8
Broilers	Average in China	20	58	22
	More developed Case	5	83	12
	Less developed Case	17	77	6
Layer hens	Average in China	28	24	48
	More developed Case	3	8	89
	Less developed Case	58	6	36

Data source: Statistical Yearbook of Chinese Livestock Production; Statistic tales of local livestock and poultry production

Did the described shift in livestock scales contribute to an increase in non-point source pollution (NPSP)? Welsh and Rivers (2011) have concluded that farm scale determines farming practices. However, the literature does not provide a clear conclusion on the relation between farm size and environmental pollution. Household-scale farms can incorporate more environmentally friendly eco-agricultural farming practices (Woodhouse, 2010). In China, an increasing number of farm households follow an "eco-engineering model", where livestock faeces are used for value-adding biogas production or reused as organic manure (Bluemling and Hu, 2011). By the same token, sound disposal of especially intensive livestock manure has become an issue of environmental concern in many counties. This is due to increased livestock densities but still with the same limited availability of arable land for manure disposal, thus increasing the risk of nutrient losses (Kellogg, et al., 2000; Giller, et al., 2002; Burton and Turner, 2003; Gao and Zhang, 2010). To curb this behaviour, seasonal and limited manure application is required in many European countries (Maguire, et al., 2009). However, it was also stated that more complex and modern technologies that mitigate nutrient loads can be used more easily in industrialized production systems (Goldstein and Udry, 1999). Anaerobic digesters are more easily introduced to more specialized livestock production (Zaks, et al., 2011). There is hence no obvious straightforward conclusion which of three farm scales contributes most to non-point source pollution mitigation in China.

For explaining and mitigating nutrient emissions from livestock husbandry in China, we need to understand how the manure of different scale farms is managed, as well as what factors make farmers change their practices. The innovative concept of 'Ecological Rationality' (ER) separates environmental concerns to be “relatively autonomous from ideological, political and especially economic [...] rationalities” (Mol, 1999: 170). Institutional and behavioural changes follow ER when environmental interests and logics are the main causes, reasons and motivations for change. The movement towards distinguishing and identifying ER indicates “the growing importance of environmental interests, ideologies and logic in shaping social practices and institutions; in fact, it emphasizes the institutionalization of the environment in social practices and institutions” (Mol, 1999: 170). Empirical studies that show how ER becomes institutionalized among different actors and institutions are still limited, and this hold also for China. Zhong and Mol (2008) illustrated how urban infrastructure management became more ecologically rational though the legalization and institutionalization of public hearings. Livestock production is a good case to search for ER in rural China, because both environmental and economic interests of manure management are obvious and can be distinguished. However, in Chinese livestock husbandry an ER is not directly obvious. Governmental policies at different levels are sometimes supporting, but in other cases obstructing environmental impacts reduction and livestock husbandry environmental reform, while farmers often are not aware of the necessity to mitigate nutrient emissions. Therefore, three ways in which ecological rationalities can be incorporated in livestock husbandry in contemporary China are distinguished (Box 1). Analysing the incorporation of ER through governmental institutions, farmers and farmer networks could help to understand whether and how manure management practices change at different scales and situations of livestock husbandry. The coming together of ecological rationalities at different levels (i.e. governmental, individual and network) could have a combined influence on changing production processes within China’s livestock husbandry, which should be favourable for the environment.

When ER leads to the adoption of environmentally friendly technologies, then other factors may be crucial for improving manure management as compared to when only economic factors are taken into account. For example, education facilitates innovation adoption significantly (Fuglie and Kascak, 2001), and risk aversion levels also co-determine whether individuals are likely to adopt new practices (Rogers, 2003). Three perceived technology characteristics have been proven to be important: 'relative advantage' over other technologies or the present circumstance, 'compatibility' with the circumstances into which technologies will be adopted, and 'complexity' to learn or use the technology (Rogers, 2003). In many cases relative advantage is defined as higher profitability of a technology, which is positively associated with higher probability of adoption (Pitt and Sumodiningrat, 1991; Le, et al., 2006).

In the next section, a conceptual framework for understanding nutrient mitigation on farm level is proposed. Our research focused on two major animal species, pigs and poultry (broilers and hens) in a developed and in a less developed area. When agro-ecological household-scale farms are extended into medium-scale farms, they are expected to have neither the land, the individual environmental concerns and capacity, or the governmental attention to implement the advanced manure management technologies that large-scale farms apply. We therefore hypothesize that medium-scale farms would be the most severe polluters.

Box 1. Definitions of three articulations of ecological rationality

An ecological rationality can be adopted by individual farmers, which we might label 'individual ecological rationality'. The motivation comes from environmental awareness and a normative position against negative environmental effects of livestock production. These two motivations have been proven effective for environmental technology adoption (De Souza Filho, et al., 1999; Chen, et al., 2013). Changing farm practices may also find their roots in a network of farmers, called 'network ecological rationality'. The more farmers are embedded in (informational) networks, the more information they will receive how to realize a change in farming. Furthermore, these networks expose farmers to group norms and peer pressure to change to environmental-friendly practices. Ecological rationality can also be advanced in farming practices through governmental policies and institutions that relate to husbandry farming, called 'governmental ecological rationality'. Governmental regulation can be supportive to a change in farm practices. Extension programs can significantly facilitate voluntary adoption of technology change (Fuglie and Kascak, 2001), by supporting information, understanding, and acceptance of new technologies. It may hence exercise soft measures to push farmers towards technology adoption (De Souza Filho, et al., 1999; Karahanna, et al., 1999). Apart from these informational measures, coercive and incentive measures of governments could play an important role in technology adoption for more ecologically rational production (Bearden, et al., 1986).

3.2 Methods and materials

We studied manure management practices in Chinese pig and poultry farms of three farm scales. ER is used as our base to test our assumption about medium scale farmers, while other factors are considered as assists (Figure 3.1). Individual ER was evaluated by measuring the farmers' awareness of negative environmental effects of their manure operations. Such awareness is valued into four scales (see Table 3-S1.1). Respondents were also asked on a number of governmental driving forces and barriers to improve manure management technologies, which together were taken as a proxy for governmental ER. In addition, questions on the extent to which interactions with colleague farmers improved manure management were used to measure network ecological rationalities among farmer groups. Advantages and disadvantages of technologies could also be driving forces and barriers for their adoption respectively. Governmental and technological driving forces, barriers and interactions were valued as percentages of responding farmers who approved the importance of these items. The indicators of personal characteristics include education level and risk aversion, which were measured into five and three scales respectively (see Table 3-S1.1). An ANOV method was used to explore the differences across multi scale groups and cases.

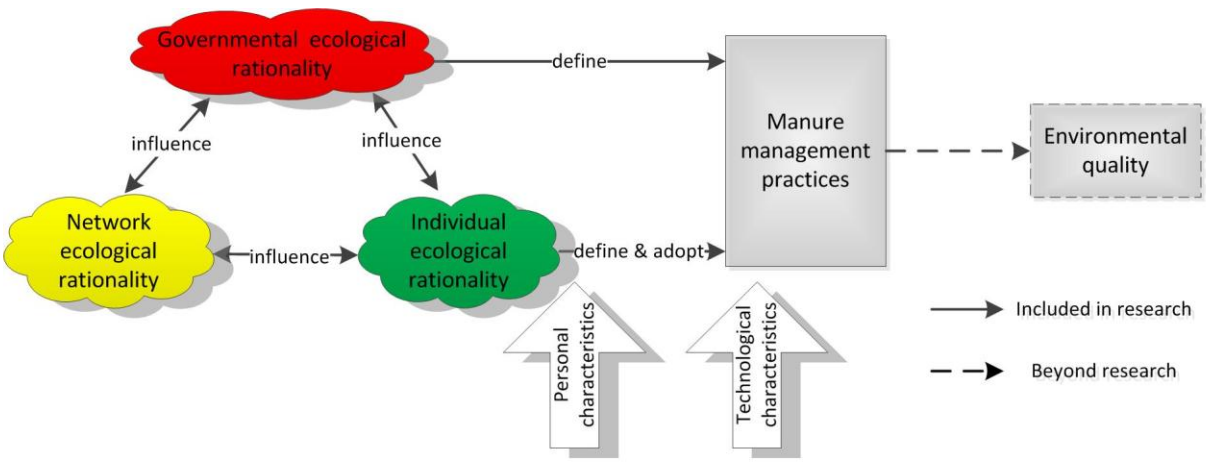

Figure 3.1 Conceptual framework of this research

3.2.1 Study area

The research covers studies in two areas with varying socioeconomic development and represented livestock production with different degrees of intensification. The more developed area was Rudong County in Jiangsu province in Eastern China (Case 1) where the demand for livestock products have increased with urbanization (Li, 2008), population density and purchasing power (Li, et al., 2008), and where there is some quite intensive livestock production (Figure 3.2). The other area Zhongjiang County in Sichuan province in Southwest China (Case 2) is a less developed region with traditional livestock production and a higher share of small-scale animal husbandry (Figure 3.2). Table 1 lists the proportion of the three farm scales in China and in the two case study counties. Surveys in Case 1 and 2 were conducted in September 2010 and July 2011, respectively. In total 258 farmers were surveyed face-to-face. The details of case introduction and data collection are shown in Appendix 3-S1.

Figure 3.2 Intensive poultry farm in Case 1 and household scale pig farm in Case 2. The photos are taken by authors in the field surveys.

3.2.2 Manure management practices

Data on manure management practices in China do not exist in official statistics, or in other regular records. The first China Pollution Source Census (CPSC) stated that non-point source pollution of livestock production in Case 1 were around 7 times as large as that of Case 2 in 2007, when the value of livestock production of Case 1 is less then Case 2. Manure nutrient loads from an animal farm were determined from the methods farmers used to collect and handle manure (Ogink, et al., 2000; Cederberg and Flysjö, 2004; Petersen, et al., 2007).

Table 3.2 lists specifications and characteristics of manure management practices involved in this research. For the different manure management practices, CPSC has reported coefficients of on-site nutrient emission per animal per day (MoEP, 2010). The environmental friendliness of manure management practices are qualitatively described according to these coefficients, and valued on a scale from 1 to 4 (see Table 3.2), where lower values mean larger emissions of nutrients into the environment. Relative economic advantages, compatibilities with farming methods and complexities of practices were analysed qualitatively, on the basis of expert consultation.

Table 3.2 Specifications and characteristics of manure management practices

	Technologies	Environmental friendliness	Relative economic advantage	Compatibility	Complexity
Manure collection technologies	Washing: *Animal pens are swilled down to clean mixture of feces and urine.*	large pollutant leakage (valued as 1)	no investment, high water use, no energy use, labor	tradition	easy
	Manually dry: *Feces and urine are separated; solid waste is collected manually, liquid waste flows along canals or pipes.*	low pollutant leakage (valued as 2)	small investment, less water use than washing; no energy use, labor	no conflict with norms; governmental recommendation	easy
	Machine dry: *Feces and urine are separated; solid waste is collected by machine, liquid waste flows along canals or pipes.*	low pollutant leakage (valued as 3)	large investment, less water use than washing, energy use, no labor	no conflict with norms; governmental recommendation; possibly bad for animal	medium
	Bedding: *Organic materials on ground (e.g. straw, rice hull) fully absorb feces and urine, with micro-biological degradation.*	almost zero emission (valued as 4)	huge investment, no water use, no energy use, less labor than washing	innovation for majority; nearly no governmental recommendation	difficult
Manure handling technologies	Discharge: *Collected manure is discharged to rivers or non-farm land without treatment.*	large pollutant leakage (valued as 1)	no investment, possible penalty	tradition	easy
	Fertilizer: *Collected manure is applied on farm land as organic fertilizer.*	some pollutant leakage (plants absorb nutrients) (valued as 2)	reduced chemical fertilizer use, requires enough farmland	tradition	easy
	Biogas: *Collected manure is stored to produce biogas; sludge is applied on farm land.*	some pollutants leakage (microbes degrade and plants absorb most nutrients) (valued as 3)	saving household energy costs, reducing chemical fertilizer use, large investments, maintenance costs	no conflict with norms; governmental recommendation in some areas	not easy to maintain and use well by farmers
	Industry: *Collected manure is sold to industrial plants to produce fertilizer or aquatic fodder.*	zero emission at farms (valued as 4)	revenues from sale of manure, transport costs (sometimes)	no conflict with norms; no governmental recommendation; no mature market	not easy to have stable buyer-supplier relationship; transport problem; difficulty to separate liquid and solid components

3.3 Results

3.3.1 Technology adoption and farm scale

The manure management practices varied according to animal species, farm scale and development level of the areas. Manure management practices diverged between pig and poultry farms, mainly due to different characteristics of respective manure. For instance, dry collection of pig manure is not convenient due to high manure moisture, while poultry manure is drier. The latter also contains more nutrients and is thus more valuable for industrial processing. We found a general trend towards more environmental-friendly manure management with increasing farming scale (Figure 3.3, also see Appendix 3-S2 for details). Manure practices of medium-scale farms did not fall between household- and large-scale farms as might be expected from their size. Instead these farms handled manure almost equally well to large-scale farms in the same area. Medium-scale farms did thus not perform as bad as we suggested in our hypothesis. Farms in the more developed county (Case 1) did not always have the most advanced manure management practices. For instance, pig farms manure collection practices in Case 1 were hardly more environmentally friendly than in Case 2, while manure handling practices in Case 1 fell behind those of Case 2.

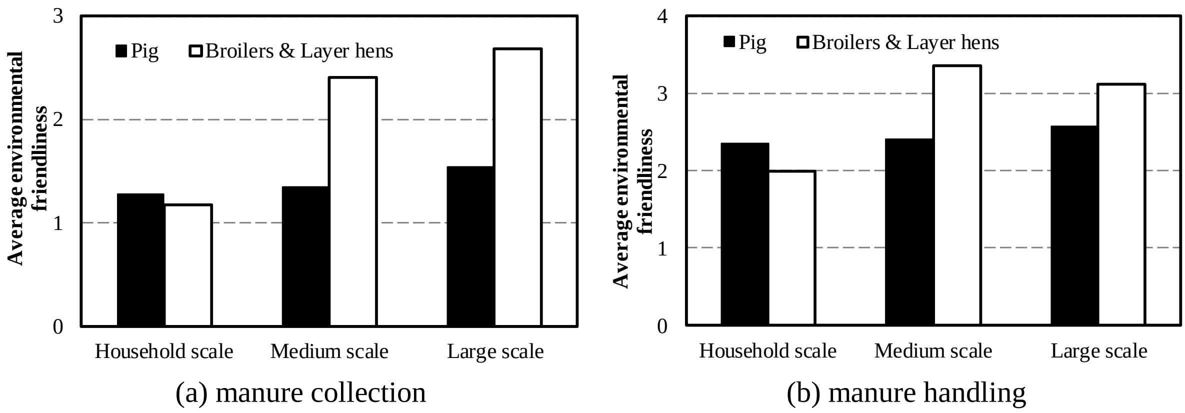

Figure 3.3 Environmental friendliness of manure management practice in different farm scales. The y-axis relates to environmental friendliness scaled from 1-4 as listed in

Table 3.2.

3.3.2 Ecological rationalities

The following analysis aimed at understanding differences in manure management from a perspective of ecological rationalities instead of a socioeconomic perspective. Table 3.3

presents differences in the variables constituting these ecological rationalities across the three farm scales and across the two case study areas, which will be explained in detail in the following three sub-sections.

Table 3.3 ANOVA analysis of ecological rationalities across scale groups and cases (pig and poultry farms)

Articulations of Ecological Rationality (ER)	Indicators	Difference between scale groups				Difference between cases		
		Household scale	Medium scale	Large scale	Diff. sig.	Case 1	Case 2	Diff. sig.
Individual ER(mean) [1]	Awareness of negative effect on environment	2.33	2.02	1.89	0.055*	1.94	2.14	0.077*
Governmental ER (%) [2]	Cost saving	31	14	10	0.105*	20	13	0.726
	Income increasing (subsidies)	15	19	10	0.983	13	18	0.408
	Regulatory requirement	38	42	30	0.762	43	36	0.980
	Limited persuasion	0	9	11	0.087*	2	13	0.001**
Network ER (%) [2]	Peers persuasion	15	14	20	0.018**	4	40	0.002**
	No awareness of alternative	40	26	27	0.080*	25	35	0.081*
	Information lack	19	15	14	0.580	16	22	0.207
	No social perceived preference	6	13	16	0.362	21	9	0.009**

** Different between cases at 5% significance level

* Different between cases at 10% significance level

[1] Individual ER is valued on a scale 1-4. 1 means no negative environmental effect of livestock production is aware of, while 4 means serious negative effect is agreed.

[2] Governmental and network ER are valued as percentages of responding farmers who approved the importance of these items.

(I) Individual ecological rationality

Around 70% of respondents perceived "nearly no" or "little" negative environmental effects from their activities, mostly limiting these effects to smell and dust. Respondents from household-scale farms were more aware of the negative environmental effects of livestock production, especially compared to large-scale intensive farms. One possible explanation for this difference is that household-scale respondents usually show environmentally friendly performance of manure handling by adopting an 'eco-agriculture' or 'eco-engineering' model. They may be more sensitive towards environmental pollution when being exposed to pollutant emissions from their neighbours. On the other hand, large-scale intensive farmers are likely to downplay the negative environmental effects from their farms in order to ensure economic profits. Medium-scale farmers seem to be in-between. Respondents of Case 2 expressed more environmental concern than those of Case 1. Thus, individual ER may explain that Case 2 farmers have equal adoption of environmentally friendly manure management technologies as Case 1 farmers, despite of the former's lower socioeconomic development.

(II) Governmental ecological rationality

In both areas ER played a clear role at governmental level to improve manure management practices. It was found to be of the same importance for all farm categories. Governmental policies played a role in changing manure management practices by altering costs and savings for different options. Progressive pricing[4] of electricity and water is a governmental ecological rational measure that 'uses' economic motives to protect environment. In Case 1, farmers adopted dry collection to reduce water costs, but due to common use of free well water this was not relevant in Case 2. Biogas production, which was believed to save household energy costs, was more common in Case 2. In both examples ER goes together with economic rationality. Cost saving was especially important for household-scale respondents. Probably due to the small proportion of manure management costs in their total production costs, the effect of cost saving on electricity and water was weaker among intensive farmers.

The question of income increase was related to governmental subsidies and not to income from manure selling. In contrast to our assumption, manure selling did not increase income in most cases, because medium- and large-scale farmers had to pay for transporting manure and could hardly cover transport costs by the price they received for manure. Biogas production is widely promoted by the Chinese government (He, et al., 2013), mostly at farm household level in rural areas. Subsidy for biogas production is mainly provided to household- and medium-scale farms. According to government interviews, this subsidy seems to be a more powerful driver in the poorer Case 2 area. Government in Case 2 considered saving energy costs by biogas valuable to improve farmer's livelihood, and applied more biogas subsidies than in Case 1. This also explains the much higher penetration rate of biogas

[4] Progressive pricing: the more electricity or water is used, the higher the price will be per unit.

production among household- and medium-scale farms in Case 2, but refutes the assumption of individual ER. Large-scale farms could obtain special funds for clean technology diffusion by central and provincial level governments. For example, the national government subsidizes large-scale livestock husbandry within its “Building the Socialist Countryside Program”.

Regulatory requirements from governmental authorities and governmental persuasion may be directed towards some manure management technologies, but levels of governmental involvement differ between livestock husbandry scales. National technology and pollution emission standards aim mainly at large-scale farms, and are directly implemented by local government at these farms. Indeed, large-scale farms were required to pre-assess environmental impacts before investing in intensive livestock constructions, mandatorily taking environmental concern into consideration. According to interviews with local governmental officials, large-scale farms are usually considered key enterprises with a demonstration character at township level (but also at county or municipal level). Hence they are strongly supported, also financially, at national, provincial or county level. Governmental support could weaken strict environmental policy implementation on livestock production, resulting in less strict monitoring and enforcement of penalties. At the same time local governments have responsibility for the “Development Plan for Modern Agriculture”. This plan specifically requires distribution of manure reutilization technology, and 'circular agriculture' (Qi, et al., 2008). The latter requires farm households to undertake waste recycling following an 'eco-engineering model'. Medium-scale farms did not encounter such favourable governmental attitudes and measures.

Persuasion can be understood as voluntary 'regulation' by government and other actors. Some farmers were persuaded to change manure management by hearsay of economic and/or environmental benefits. Others were persuaded to conform manure management practices with other farmers, or governmental preferences. However, in our research governmental persuasion was limited and only felt by intensive farms. Limited governmental persuasion worked two ways. In some cases government advised farmers to change conventional manure management technologies into more environmental-friendly ones. However, at other times governmental requests prevented demonstration farms to adopt other, even more advanced, manure management technologies. Especially large-scale farms were likely to fall victim to the latter situation. In general, governmental persuasion was more effective in Case 2 than Case 1.

(III) Network ecological rationality

Persuasion towards adoption of better manure management technologies also came from peers. Regarding adoption of technology for biogas production at household-scale farms, interviewed respondents stated strong influence from neighbouring farmers who already had adopted biogas technology. Some respondents were willing to adopt biogas production even without counting energy saving and governmental subsidy. This is a clear case of network ER. Medium-scale respondents were less driven by persuasion from other farmers. They claimed that they had less money for innovative manure investments, resources and information than large-scale ones, but confronted higher risks than household-scale farms.

Network ER can also emerge in a different way. An interview with the local governmental livestock bureau in Case 2 illustrated how the government by use of preferential policies facilitated the transfer of big livestock companies from a more developed neighbouring province to the less developed Case 2 area. This resulted in another kind of network namely a primary manure market, in turn leading to more environmentally friendly manure application. This farmer network formation explains the high level of manure selling in that Case 2 area. Low awareness of existing alternatives, a lack of information of alternatives and no social perceived preference, were all barriers for technology adoption felt by husbandry farmers of all scales, which point at a lack of network ER. Household-scale farmers perceived especially strong absence of awareness of alternatives.

3.3.3 Other factors

Other factors were also examined and compared between farm scales and cases as indicated in our research framework (Table 3.4).

Regarding education level, most respondents had six to nine years education. We found that larger-scale farmers had received significantly more education and that, on average, farmers in Case 1 received more education than those in Case 2, possibly due to the better socioeconomic development. The latter helps to explain why Case 1 farmers generally performed better in manure management practices than Case 2, as well as why more environmental-friendly collection technologies did not reach high penetration rates among medium-scale farmers. Compared to the other two scales, medium-scale farmers considered ease of use as a relatively important driver, which might explain their rejection of new but difficult to use manure collection technologies (i.e. bedding). Still, lower education levels did not prevent medium-scale poultry farms in Case 2 to practice more biogas production than other farms, though biogas production is seen as the most difficult manure technology to construct, operate and maintain among the four handling technologies. In this case, governmental ER rather than education level or ease of use determined biogas technology adoption.

Table 3.4 ANOVA analysis of other factors across scale groups and cases (pig and poultry farms)

Category	Indicators	Difference between scale groups				Difference between cases		
		Household scale	Medium scale	Large scale	Diff. sig.	Case 1	Case 2	Diff. sig.
Individual attributes (mean)	Education level[1]	2.75	3.05	3.49	0.000**	3.34	2.80	0.000**
	Risk aversion[2]	2.25	2.31	2.32	0.775	2.28	2.33	0.561
Driving forces (%)[3]	Ease of use	7.69	25.58	5	0.090*	26.67	11.11	0.224
Barriers (%)[3]	Large investment	22.64	25.84	5.41	0.012**	31.25	18.44	0.032**
	High operational cost	26.42	21.91	13.51	0.092*	21.43	24.11	0.459
	Land limitation	20.75	26.17	24.32	0.390	32.14	7.09	0.000**
	Labor requirement	3.77	6.74	2.70	0.454	13.39	1.42	0.000**

** Different between cases at 5% significance level

* Different between cases at 10% significance level

[1] Education level is valued on a scale 1-5, respectively meaning 'uneducated', '1-6 years educated', '6-9 years educated', '9-12 years educated' and '>12 years educated'.

[2] Risk aversion is valued on a scale 1-3, representing 'risk averse', 'natural' and 'risk taking' respectively.

[3] Driving forces and barriers are valued as percentages of responding farmers who approved the importance of these items.

For medium scale farmers the main barriers for technology adoption focused on economic disadvantages. Large financial investments and high operational costs were perceived as important reasons that led to rejection of manure management improvement. Financial investment, and to a lesser extent high operational costs, were hardly seen as barriers by large-scale farms. This confirms findings of earlier studies that critical success factors for adoption of environmental technologies are less of a technical, but more of an economic nature (Engle, 1995; Goldstein and Udry, 1999). In addition, large-scale farms can apply for governmental subsidy to improve farm infrastructure. Land limitation was a technology adoption barrier for all scales. In the past few years, the activities of new rural reconstruction have banned livestock production from living areas, and it is expected to be further restricted within assigned areas. Especially in the more developed Case 1 area this was felt as a constraint. Labor requirements were hardly a barrier for technology adoption in general, but cannot be ignored within the more developed Case 1 area. Here industrial development in rural areas may explain increasing constraints of land and labor. Interviews revealed the difficulty of medium-scale farms: they have insufficient capability for investing, hardly any governmental support, and too little land to apply manure directly.

3.4 Discussion

A reform in Chinese agricultural production is put on the agenda by policy-makers, where more environmentally sound manure collection and handling practices have to be introduced to diminish land and water pollution. In Chinese livestock husbandry one can witness tendencies of ecological modernization as “both the fundamental counter-positioning of economic and environmental interests as well as a complete neglect of the importance of environmental considerations, are no longer accepted as legitimate positions” (Mol and Spaargaren, 2000: 46). Our hypothesis was that, compared to household and large-scale farmers, medium-scale farmers are potentially the slowest in adopting environmentally–friendly manure management practices. If this was true, then environmental management improvement efforts should concentrate on farms of that size. This was based on the facts that conventional manure management of household-scale farmers is already quite environmentally sound, while large-scale farmers are more protected by government, have more investment capital and more human capacity to adopt environmentally friendly technologies. However, our empirical research found that medium-scale farmers sometime perform much better than expected, and sometimes not. With assistance of personal and technological characteristics, the various combinations of ER (governmental, network and individual ER) seem to explain the failure of our hypothesis.

In Case 2, governmental policies institutionalize an ER through biogas subsidies, which increases the economic advantages of biogas production. At the same time information is given to influence farmers’ perceptions of biogas production. As such, Case 2 medium-scale farmers are confronted with more governmental measures for biogas adoption than their equivalents in Case 1. Although individual ecological awareness seems to be less important and effective than economic reasons for biogas adoption in this case, the latter may promote medium-scale farmers to start information exchange and set good examples of environmental protection in their peer network, thus continuing the cooperation which started with biogas production. The combination of governmental, individual and farmer network drivers enhances the adoption of environmental-friendly technologies and practices (Figure 3.4a). However, more environmentally friendly manure *collection* technologies in Case 2 were driven by isolated individual ER, with little final spreading effect (Figure 3.4b). Neither informational, nor incentive, nor command-and-control governmental measures were reported by the interviewees regarding manure collection technology adoption. Also farmer networks were absent for learning and dissemination of such collection technologies. Farmers with environmental awareness regarding manure still could reject adoption of more environmental-friendly collection technologies, because of difficulties in learning how to use them and because they felt no governmental drive.

Manure collection practices of medium-scale farms in Case 1 exemplify the effectiveness of isolated governmental ER (Figure 3.4c), where a policy of progressive pricing of water and energy was initiated by governmental authorities (above county level). In order to reduce water costs, medium-scale farmers preferred dry collection to washing, although there is little sign of an individual ER that enhanced the adoption of this technology. Another alternative way for government to activate environmentally friendly practices is to stimulate network collaboration (Figure 3.4d). When non-governmental actors, such as companies in Case 2, are welcomed by preferential policies to participate in solving manure problems, economic benefits and environmental benefits come together, and are strengthened by convenience of use for farmers. This government-network combination explains the high rate of selling manure among medium-scale famers in Case 2. However, if these government-network driven benefits cease to exist, medium-scale farms are unlikely to be able to continue these practices.

Hence, more environmental-friendly manure management does not always have to include full ER from farmers, farmer networks and governmental authorities. In contemporary Chinese livestock husbandry governmental policy and measures seem to be a precondition for any successful mode of ER. Governmental authorities are able to induce environmentally friendly technology adoption on their own, or work together with individual or network drivers. Individual preferences and awareness did not have a strong influence on driving changes in manure management. Networks of farmers and other economic actors only drove more environmentally sound manure management practices in combination with governmental measures.

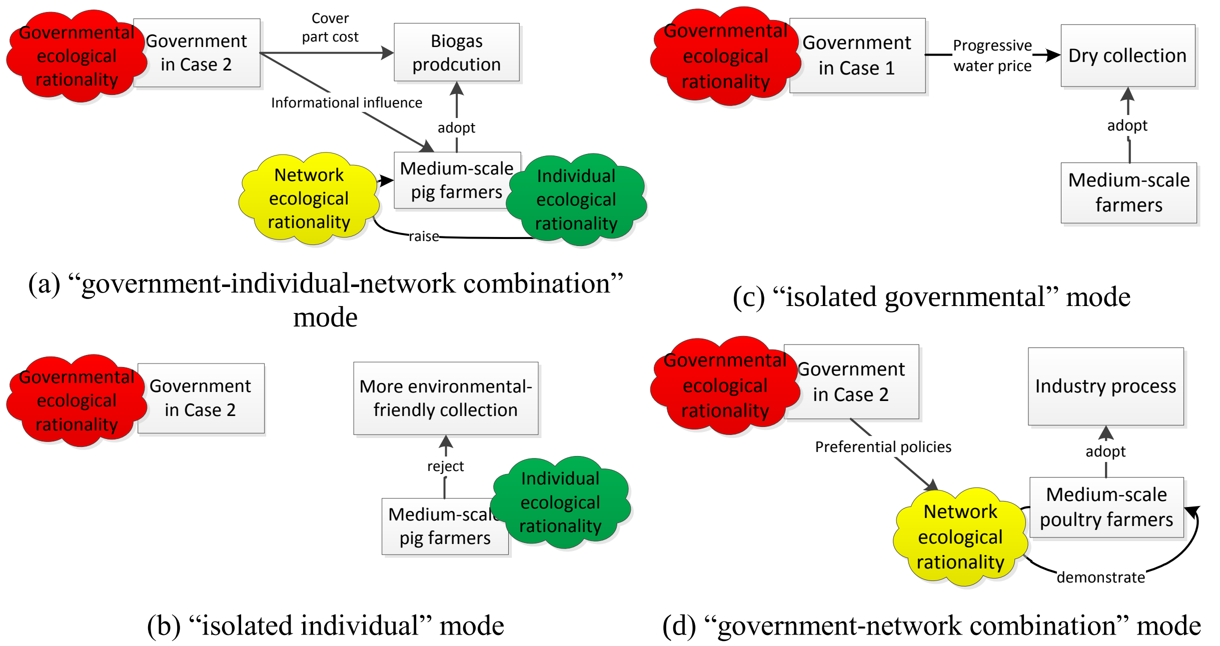

Figure 3.4 Four modes of ER combinations

Still, this does not mean that environmental transformations are just “enforced” through conventional government steering. First, conventional command-and-control regulations have shifted to incentivizing, stimulating and informing farms to improve environmentally (e.g. progressive water pricing, providing information). Taking isolated governmental ER mode as an example, the government can create economic incentives to ensure that farmers that are not ecologically motivated still manage manure in a more environmental-friendly way. Second, non-governmental private actors can take over part of the 'responsibility' for environmental management from the government through their networks. Such transformations, which are part of a wider change in China's environmental management, are often referred to as political modernization (Liang and Mol, 2013).

Though governmental policy and measures are generally the same between the two areas investigated, the four modes also revealed that they differ between the two with respect to specific technologies. The less developed and more strongly government-directed Zhongjiang case was able to compete with the more developed and market-oriented Rudong case. A regional socioeconomic development is likely to promote more intensive livestock production, but this does not automatically parallel manure management improvement. This should balance the idea of a market driven environmental change among livestock farmers in contemporary rural China: adequate government intervention remains necessary for direct environmental improvement and for facilitating the introduction and functioning of market instruments. Different ways of local policy implementation are due to different weighing of the value of livestock production in the local economy, which varies with overall socioeconomic development. In turn this aspect directs priorities set by local governments for implementation and enforcement of environmental management. The leading cadres of each government level prefer to support major economic sectors, in order to get more revenues and a better personal performance evaluation (Edin, 2003; He, et al., 2012). Livestock production in the less developed area (Case 2) counts for nearly half of the agricultural output. Therefore, county and lower level governmental officials pay more attention to livestock production in that county and, following central and provincial policies, make their policies and measures more environmentally sound than those of Case 1.

It is should be emphasized, though, that these modes are empirically found among medium-scale farms, and hence do not have to be the only modes when investigating other agricultural sectors in other counties. For instance, agricultural product labelling and voluntary standards (pollution-free, green and organic product) are measures that could be classified as a kind of market-based ER. Although livestock farms in our case studies were not involved in product labelling and market-based environmental standards, farmers do realize the future importance of these labels. In addition, environmental preferences are emerging and articulated, not only or primarily among agricultural producers and governmental authorities, but also increasingly among citizen-consumers and other civil society communities (Wang, et al., 2011). This might result in a kind of civil society ER. It can be expected that in a future market-based civil society ecological rationalities will play a more important role in China, next to the ecological rationalities revealed in this research.

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Appendix 3-S1

Pig and poultry production prevail in both cases, with 50% and 40% of total livestock production output respectively. Rudong is located in the Eastern coastal area of China, and has a high level of socioeconomic development. In 2009 the per capita incomes in urban and rural areas of Rudong reached 2679 USD and 1177 USD respectively. Zhongjiang County is located in a less developed area, where urban and rural per capita incomes in 2009 were 2140 USD and 843 USD, respectively. Its livestock production output is 1.8 times that of Rudong, while total regional output is only 48% that of Rudong.

Table 3-S1.1 Demographic profile of respondents in two cases

Division	Values	Groups	Percent in Case 1 %	Percent in Case 2: %
Age		<40	10	41
		40~50	55	39
		50~60	16	13
		>60	19	7
Gender		Male	83	69
		Female	17	31
Animal species		Pigs	51	61
		Poultry	49	39
Farm scale		Household scale	12	27
		Medium scale	66	60
		Large scale	22	13
Awareness of negative effect on environment	1	No effect	55	21
	2	A little	14	55
	3	Less serious	20	15
	4	Serious	11	9
Education level	1	Uneducated	1	6
	2	1-6 years	11	18
	3	6-9 years	48	51
	4	9-12 years	32	15
	5	>12 years	8	10
Risk aversion	1	Risk averse	21	4
	2	Neutral	26	59
	3	Risk-taking	53	37

Surveys in Case 1 and 2 were conducted in September 2010 and July 2011, respectively. In each county farmers running animal farms were selected from five towns following stratified random sampling with kind of animal and farm scale as criteria. A survey was carried out face-to-face with a structured questionnaire. Prior to the surveys, structured interviews based on an interview guideline with item points were held with environment and agriculture bureaus on county level. The survey contained questions on individuals, number of animals, technology adoption over the last five years, and perceived motives and barriers for technology adoption. Out of 267 surveyed farmers a total number of 258 respondents could be used in the analysis, 130 of which came from Case 1 and the others from Case 2 (non-response of 3.7% in Case 1 and 3.1% in Case 2). Respondents in both cases included farms of all scales. Due to the proportional differences in two cases, it was difficult to create respondent groups with a similar distribution among farm scales. Case 1 respondents came significantly less from household scale farms than those in Case 2, while Case 2 contained few layer hens breeders. The demographic profile of respondents is showed in Table 3-S1.1.

Appendix 3-S2

Table 3-S2.1 lists manure collection in two cases. Traditional washing was the main technology applied for pig manure collection, but is less present in larger-scale farms. Manual dry collection gradually became popular after being introduced to Chinese farmers in the 1980s. The other two technologies were barely applied in pig farms. Collection technologies adopted in poultry farms were more diverse. Bedding competed with manual dry collection in large-scale farms. Medium-scale farms in Case 2 were in transition between household- and large-scale farms. Medium-scale farms in Case 1 were a special situation, as they seemed to largely give up conventional routines but did not apply the newest technology. Pig farms of Case 1 use more advanced technologies in all scale groups compared to Case 2.

The distribution of manure handling technologies in the two cases is expressed in Table 3-S2.1 and Table 3-S2.2. Although direct discharge of manure to the environment was banned, it was not completely absent in reality. Environmentally sound fertilizer application was unsuitable for most medium- and large-scale farms in both cases. Manure of one pig or fifteen broilers/hens requires one mu land (0.067 ha) to adequately absorb nutrients[5], but arable land per household was quite limited, about five mu (0.33 ha) on average. Biogas production was the rising manure handling technology in pig farms, while in poultry farms sending manure to industrial plants was dominant. Pig farms practices varied distinctly in both cases: fertilizer application was dominant among farms in Case 1, while biogas was dominant in Case 2, regardless of scale. Poultry farms in Case 1 and Case 2 showed fewer differences in manure handling technologies, except for large scale farms.

Table 3-S2.1 Manure collection technologies

	Penetration rate: %	Case 1			Case 2		
		Household scale	**Medium scale**	**Large scale**	**Household scale**	**Medium scale**	**Large scale**
Pigs	Washing	57	58	55.5	78	71	50
	Manually dry	43	42	39	22	29	50
	Machine dry	0	0	0	0	0	0
	Bedding	0	0	5.5	0	0	0
Broilers & Layer hens	Washing	75	14	25	100	22	9
	Manually dry	25	46	25	0	50	46
	Machine dry	0	20	12.5	0	0	9
	Bedding	0	20	37.5	0	28	36

Table 3-S2.2 Manure handling technologies

	Penetration rate: %	Case 1			Case 2		
		Household scale	**Medium scale**	**Large scale**	**Household scale**	**Medium scale**	**Large scale**
Pigs	Discharge	0	0	5.5	6	7	10
	Fertilizer	88	91	39	48	32	40
	Biogas	0	3	39	46	59	50
	Industry	12	6	16.5	0	2	0
Broilers & Layer hens	Discharge	0	3	10	0	0	0
	Fertilizer	100	36	60	100	18	0
	Biogas	0	2	0	0	4	0
	Industry	0	59	30	0	78	100

[5] Li, G. 1999. Environmental Pollution Problems and Implementation of Environmental Standards in Chinese Large-scale Livestock and Poultry Industry. *The Prceeding of Sino-Canadian Seminar on Environmental and Soil Nutrient Management* (in Chinese).

4

Mitigation Potentials of Environmental Policy Instruments in Chinese Livestock Production

Abstract

To minimize negative environmental impact of livestock production, policy-makers face a challenge to design and implement more effective policy instruments for livestock farmers at different scales. This research builds an assessment framework on the basis of an agent-based model (named ANEM) to explore nutrient mitigation potentials of five policy instruments, using pig production in Zhongjiang county, southwest China, as the empirical filling. The effects of different policy scenarios are simulated and compared using four indicators and differentiating between small, medium and large scale pig farms. Technology standards, biogas subsidies and information provisioning prove to be the most effective policies, while pollution fees and manure markets fail to environmentally improve manure management in pig livestock farming. Medium-scale farms are the more relevant scale category for a more environmentally sound development of Chinese livestock production. A number of policy recommendations are formulated as conclusion, as well as some limitations and prospects of the simulations are discussed.

Keywords:

Policy assessment, Agent-based analysis, Nutrient mitigation potential, Chinese livestock production.

Chapter 4. Mitigation Potentials of Environmental Policy Instruments in Chinese Livestock Production[6]

4.1 Introduction

The negative effects of modern agricultural production, especially eutrophication of water bodies, are a world-wide environmental problem, which has been well documented in research of both developed countries and developing countries such as China (Foy, et al., 2003; Ulén, et al., 2007; MoEP, 2010; Jarvie, et al., 2013). Agricultural nutrient emissions, mainly in the form of non-point source pollution (NPSP), can be the result of runoff from either livestock farms, or from farmlands after manure or chemical fertilizer application. The need to mitigate nutrient losses has been the focus and subject of policy-making in certain countries over some decades. Some of these policies target the national or international level, e.g. the EU Water Framework Directive and the Clean Water Act in the US, whereas others work on regional or lower levels. A surplus of manure from increasing and more intensive animal production is considered a major cause of agricultural nutrient pollution (Maguire, et al., 2009). Therefore, environmental management practices in these countries aim at better manure management by such means as manure recycling through anaerobic digestion, restricting animal density on agricultural land, or setting limitations on manure application (Maguire, et al., 2009; Zaks, et al., 2011).

China has been one of the most important producers of livestock products in the world since its economic reform (FAO, 2006). Due to the government's priority of increasing agricultural productivity and output as well as the steep rise in meat consumption, China significantly increased meat production over the past 30 years at a rate twice as fast as the world average (Li, 2009; Ortega, et al., 2009). Thus, it is no surprise to find that livestock production is a major source of nutrient pollution, which almost equals that from crop production (MoEP, 2010). As a consequence of increasing pollution, Chinese livestock policies have gradually shifted from a one-sided objective of economic development to a more integrative objective that also includes environmental considerations. This process dates

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back to 2001, when management measures for pollution control and pollutant discharge and technology standards were issued, although these measures only attempted to govern large-scale industrialized animal producers. However, environmental policies so far have performed a poorly in rural China, because of the limited voice of environmental agencies, the insufficient environmental interest of local governments, and no market demand for 'ecological' livestock products, among other issues (Swanson, et al., 2001).

When confronted with the problem of how to enhance the effectiveness of environmental policies for Chinese livestock production, policy-makers face two essential questions. The first question concerns the policy instruments to implement. There are few studies that explore the effectiveness of environmental policy instruments in Chinese livestock production. However, such research is deemed crucial because theoretically optimal policy instruments, such as environmental taxes, may have quite different effects depending on the sector and issue (Mickwitz, et al., 2008). A second question confronting policy-makers concerns the appropriate definition of the producer group that should be targeted by environmental policies. Actors in one economic sector can be heterogeneous; some are large-scale producers, whereas others are small or micro-producers; and some may act as promoters and supporters of strict environmental management, others may not (Oye and Maxwell, 1994). Since the mid-1980s, Chinese farmers have been permitted to keep more animals than needed for self-consumption, i.e. farmers can undertake animal production as a means of revenue generation. Consequently, livestock production in China has undergone considerable intensification and diversification. This change also implies that depending on production scale, livestock producers may have distinct environmental considerations, show distinct responses to policies and differ in their contributions to nutrient emissions (Zheng, et al., 2013-a). As a consequence, environmental management of rural livestock production in China has become rather complex. Chinese policy-makers need to find effective policy instruments for the different categories of livestock producers to achieve better nutrient mitigation.

This research takes into consideration the complexity of rural livestock production in China and explores the potential of Chinese livestock policies to mitigate nutrient emissions using an agent-based analysis. An Agent-based Model (ABM) simulates the behavior of a system based on autonomous agents who individually but interdependently make their decisions according to a set of rules (Page, 2008; Macal and North, 2010). ABMs can thus cope with the heterogeneity of individuals and capture emergent phenomena generated by heterogeneity and interactions among agents (Grimm and Railsback, 2005; Macal and North, 2007). In this way, ABMs can incorporate the diversity of livestock producers in rural China, their different responses to policies, and the aggregate effects of their decisions, i.e., policy implementation effectiveness.

4.2 Methods

4.2.1 Research framework

A framework to assess the mitigation potentials of policies can be divided into two levels: the individual level of farmers and the system level, as shown in Figure 4.1.

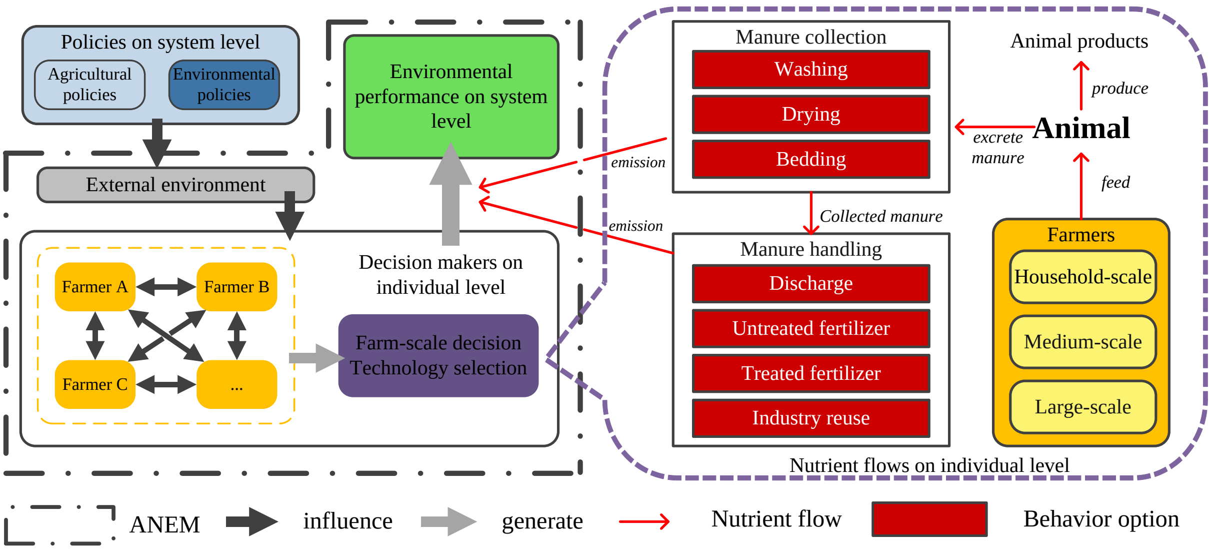


Figure 4.1 Conceptual framework and model structure

National policies from governmental agencies function at the system level, attempting to constrain and direct livestock producers in operating their farms. Two types of national policies exist for Chinese livestock production. Most national policies are implemented for non-environmental purposes, such as food security, livelihood improvement and poverty reduction. For instance, government-financed insurance attempts to expand overall animal production, while subsidies for constructing industrial farms aim to promote intensive livestock production (GOSC, 2011). A second type of policy aims to reduce the environmental effects of livestock production by improving manure management practices. Although there is no comprehensive policy program in China to improve manure management or control pollution from livestock production, the central government integrates environmental concerns into a number of other policies. For instance, the promotion of household biogas digesters also contributes to improving environmental management in livestock production

(China, 2012; He, et al., 2013). Policies addressing environmental concerns will be summarized under “environmental policies” in this research; the aforementioned policies will be summarized as “agricultural policies” (Figure 4.1). Apart from national policies, aggregate livestock production and its associated environmental performance are also measured at the system level. At an individual level, farmers make a diversity of decisions in response to policies. An Agent-based Nutrient Emission Model (ANEM) was used to predict farmers’ decision-making, as well as the economic and environmental performance of livestock production, whereas policies were considered exogenous forces (Zheng, et al., 2013-b).

The assessment of the effects of environmental policies is conducted as scenario analysis. The scenarios for different policy instruments are based on current Chinese policies and hypotheses concerning policy implementation. One common problem of policy studies is the difficulty decoupling the effects of policy instruments from those of parallel policies and exogenous factors (Guedes Vaz, et al., 2001). Because an ABM analyses a complex system as composed of ‘‘behavioral’’ entities (i.e., individual agents), it is able to identify their responses with a single policy in an integrated policy package (Bonabeau, 2002). It thus identifies the effects of the single policy from other parallel policies. The model results show the potential of nutrient mitigation in livestock production. This potential is defined as the reduction in nutrient emissions due to policy intervention compared with a reference scenario without intervention.

4.2.2 ANEM model

As delineated in Figure 4.1 by black dash-dotted lines, the ANEM comprises the external environment, the individual animal producers who make decisions and interact, and the resulting aggregate performance. Through empirical calibration, the ANEM is flexible in simulating livestock production and associated environmental performance in different areas of China.

The simulation unit, i.e., one artificial farmer, autonomously performs “farm-scale decision” and “technology selection” on his farm (see Figure 4.1) under the co-influence of the external environment, personal factors, and interactions with other farmers. The number of animals on a farm determines the quantity of manure generated, while manure management practices determine the proportion of nutrient emissions from manure to the environment. Although this research only focuses on environmental policies, the potential for nutrient mitigation possibly derives from both the reduction of the number of animals and the ecologizing of manure management practices. The ANEM distinguishes among household-, medium-, and large-scale farmers. This categorization helps to identify mitigation potentials that are dependent on the farming scale and captures the dynamics within livestock production, as agents can change from one scale to another. Manure management practices in China mainly comprise the adoption of manure collection and handling technologies. Three manure collection and four manure handling technologies are involved in the ANEM, as shown in Figure 4.1. A conventional method of manure management in China is to wash animal pens to collect the manure and then to either handle the slurry as fertilizer without treatment, or to directly discharge the slurry to the environment (Chen, 2007). Alternative technologies are more environmentally friendly because these alternatives reduce nutrient emissions to the environment.

Farmers' decision-making is conceptualized as innovation adoption processes. Larger-scale production and new, less environmentally disturbing manure management technologies are considered as innovations. Innovation diffusion theory, which is built on many empirical studies, is employed to formulate decision-making sequences in the ANEM (Rogers, 2003). It is assumed that a farmer passes through various stages, first gaining "knowledge" concerning innovations, then learning from nearby examples, followed by evaluating expected economic and environmental benefits, adopting or rejecting innovations, and finally seeking confirmation of the decision. Accordingly, interactions among farmers are defined as observing neighbors to learn about innovations and then assessing the economic and environmental performance of the innovations (High, 2009). The external environment of farmers consists of non-agent resources and certain influential factors, such as the prices of meat, feed and manure and the information provided by authorities. The external environment is affected by exogenous policies and then provides input and conditions for an individual farmer's decision-making. The variables and parameters of individual decision-making are available in Appendix (Table 4-S1.1); more details on the ANEM are given in (Zheng, et al., 2013-b).

Four indicators are calculated to represent the aggregate performance of the ANEM. The first one is nutrient emissions measured in tons per year, representing a negative effect on the environment. The second indicator shows how much improved environmental management affects economic performance and is measured in total animal numbers. The last two indicators are relevant for understanding the extent to which livestock farms have integrated pollution mitigation into their production process. One indicator is the overall improvement in manure management practices and is measured as the penetration rate (%) of different collection and handling technologies. The other indicator is pollutant nutrient emissions per animal.

4.3 Simulation

This section first introduces how the agent-based assessment framework is applied to a case study, which is pig production in Zhongjiang County, Southwest China. Then, the methodology for designing policy scenarios is presented.

4.3.1 Case study

Zhongjiang County is a traditional and important livestock-producing region. Pig production contributes more than 60% to the total monetary output of local livestock production. However, the share of intensive pig production (medium- and large-scale farms) is much lower than China's average. This lower average means that farmers in Zhongjiang are more scattered, smaller and more heterogeneous, which highlights the importance of evaluating livestock production with an agent-based analysis.

A survey was carried out in 2010 among animal producers. The collected data, which consisted of individual farmer's characteristics and behavioral rules, was entered into a database. To collect information on policies and on environmental and economic performance at the system level, interviews with governmental officials were conducted, and statistical data from yearbooks and governmental files were collected. The ANEM was programmed on the Matlab platform and simulated the dynamics in the case area from 2005 to 2008. When the simulation results were compared with the aggregate historical dynamics of livestock production, the results approximated the real-world observations in terms of livestock product output, technology change and nutrient emissions (Zheng, et al., 2013-b). This comparison demonstrated the capability of the ANEM to replicate the real-world characteristics and behavioral rules of Chinese farmers.

In this research, the ANEM simulates pig production at the survey site and its associated nutrient emissions for the next 10 years. The number of farmers in the simulation is 1/7 the actual number of livestock producers in Zhongjiang County. The simulation is initialized in 2010 and takes one year as the time step. The parameters customized in the empirical research of Zhongjiang are used in the scenario simulations. Diverse policy alternatives are introduced into the model as abrupt interventions just after the initial year. Because the ANEM does not consider the time delay of policy implementation, the policy interventions are expected to take effect immediately. Other inputs apart from the policy alternatives are set as constant for all the scenarios, available in Appendix (Table 4-S2.1).

4.3.2 Policy scenarios

To improve manure management practices, policies can utilize various instruments, including regulatory, market-based, and communicative instruments (Norberg-Bohm, 1999). Five policy instruments are assessed in this research. These policies address at different farmer groups, kinds of technologies, and decision-making sequences (details are available in Appendix 4-S3). The reference scenario is benchmarked with all five policy instruments mentioned above.

Regulatory instruments are the oldest environmental policy instruments. These tools are often believed to lack incentives for technology change, but still are considered important because they guarantee a baseline for safeguarding public and ecosystem health (OTA, 1995; Mickwitz, et al., 2008). The Chinese technology standard (HJ/T 81-2001) prescribes "dry collection" for intensive (medium- and large-scale) animal farms as the standard manure handling practice and bans the direct discharge of manure into areas such as rivers or lakes. Additionally, the technology standard encourages the utilization of manure as an energy source. Although the standard is weakly implemented in reality, it is assumed to be strictly implemented in the "technology standard" scenario.

A shift from conventional command-and-control regulations to instruments, that use incentives, forms part of a general change in China's environmental management (He, et al., 2012; Liang and Mol, 2013). Market-based mechanisms are commonly believed to be superior for promoting technology change, because they make nutrient mitigation profitable, and, if well-designed, motivate both ecologically and economically rational producers (Requate, 2005). Our scenarios represent different kinds of economic incentives. One incentive involves pollution fees, i.e., pollution fees are not levied if a livestock producer reduces emission costs through abiding by a pollution standard. Another incentive is an increase in income through subsidies or the sale of manure.

Pollution fees have been widely applied in China since the 1980s. According to Mol (2006), pollution fees provide an important source of income for local environmental agencies and significantly elicit the implementation of environmental measures. However, several studies found that the current fees are so low that most polluters prefer paying the fees instead of responding to the incentive, e.g., investing in improved technologies to reduce emissions (Taylor and Xie, 2000; Zheng, et al., 2013-b). The "pollution fee" scenario is designed to examine the effect of doubling the pollution fee.

Subsidies are also an especially widespread instrument in current Chinese agricultural policies. Biogas subsidies from the central government started in 2005 and are one of the major instruments to promote household biogas production in rural China (Chen, et al., 2010; Bluemling and Hu, 2011; Qu, et al., 2013). Biogas digesters are important for manure management because they hold livestock manure and thereby avoid manure emission into the natural environment. Furthermore, the nutrients in manure are mineralized during the digestion process, and the processed manure can be better applied to fields as "treated fertilizer". Additionally, digester tanks permit the flexible scheduling of manure applications according to crop requirements. However, the goals of the biogas subsidies contrast with the general condition of livestock breeding in China, where tanks for collecting manure hardly exist. The "biogas subsidy" scenario accordingly analyses the extent to which the subsidy is able to promote the diffusion of biogas infrastructure and the mitigation of total nutrient emissions.

As an additional instrument for providing positive economic incentives to mitigate manure emissions, the effects of a "manure market" are explored. In our empirical research, manure markets proved to be an increasingly important local solution to cope with the imbalance between manure supply and demand. Some food companies purchase livestock products as well as manure, making manure profitable for livestock producers. Unlike pollution fees and subsidies, a manure market provides direct incentives to farmers to handle manure properly without the necessity of government involvement, e.g., government subsidies or the monitoring of emissions. Given these advantages, the effects of a "manure market" are examined in a further scenario using the farmers' expected manure prices obtained in our household survey.

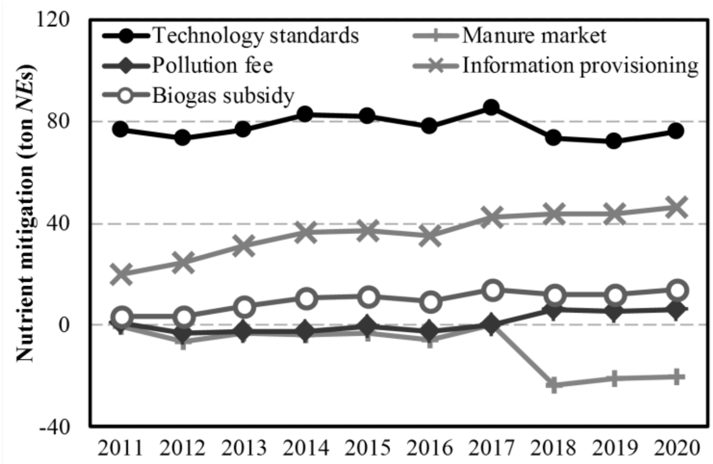
The last policy instrument, whose effects will be assessed in a scenario, is "information provisioning". According to some studies, the perception of technologies is a crucial barrier to their adoption because the payoff from environmental technologies occurs only in the long term and is associated with high uncertainty (Norberg-Bohm, 1999; Berger, 2001). To provide more information to farmers, the Chinese government decided to establish more local service offices (at township and village levels) and government-financed training programs. The "information provisioning" scenario assumes that farmers are able to obtain knowledge on all technologies via governmental consultation.

4.4 Results

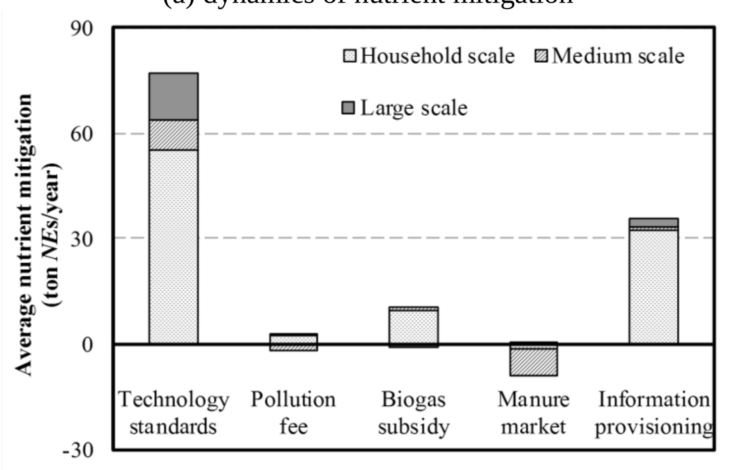
In this section, the effects of the above outlined policy instruments are analyzed using the four indicators of nutrient emissions, animal output, the penetration rate of different technologies, and pollutant nutrient emissions per animal. To understand the marginal effects of the policy instruments, we compare the policy scenarios with the reference scenario. First, nutrient mitigation is assessed through time and by the scale of the groups. Subsequently, we analyze how environmental policy instruments affect total animal output as well as output changes across the farm scales. We finally focus on the extent to which pollution mitigation is incorporated into livestock production after the implementation of the above outlined policy instruments. To cope with the random nature of ABM, multiple simulations of each scenario are carried out until stabilization of mean results occur, and these mean results are used for further analysis (see for details Appendix III). In addition, a sensitivity analysis has been carried out to assess whether the outcomes are meaningful (see also Appendix III).

4.4.1 Mitigation of negative environmental effects

Figure 4.2 illustrates the performance of all the policy instruments on the mitigation of nutrient emissions. The nutrient equivalents (*NEs*) shown in this figure are calculated as the weighted sum of nitrogen and phosphorus. The policy instruments "technology standard", "biogas subsidy" and "information provisioning" successfully reduce total emissions compared to the reference scenario. The introduction of a technology standard mitigates nutrient emissions most strongly and by more than 70 tons out of 1,391 tons of *NEs* per year. Household-scale farms contribute approximately 72% of the nutrient mitigation in this scenario, whereas medium- and large-scale farms contribute 11% and 17%, respectively (see Figure 4.2b). The time curve for the "technology standards" scenario is almost horizontal (see Figure 4.2a), which indicates a lack of continuous improvement as a result of the standards. Surprisingly, the scenario "information provisioning" reaches an average mitigation of 35 tons per year compared with the reference scenario. This policy produces most of its positive effects during the first half of the simulation and then remains relatively constant. Similar to the introduction of a technology standard, it is the household-scale farmers who contribute the most to overall mitigation under the "information provisioning" policy instrument, while medium- and large-scale farmers equally contribute a minor share (see Figure 4.2b). According to the results, biogas subsidies would also mitigate nutrient emissions from no emission reductions during the first year to a peak of approximately 14 tons of *NEs* (compared to the reference scenario). Nutrient mitigation through biogas subsidies comes only from household- and medium-scale farms. The increased pollution fee apparently has no significant effect on the mitigation of nutrient emissions. Furthermore, the introduction of a manure market leads to an increase in emissions, with medium-scale farms primarily responsible for the mitigation failure.



(a) dynamics of nutrient mitigation

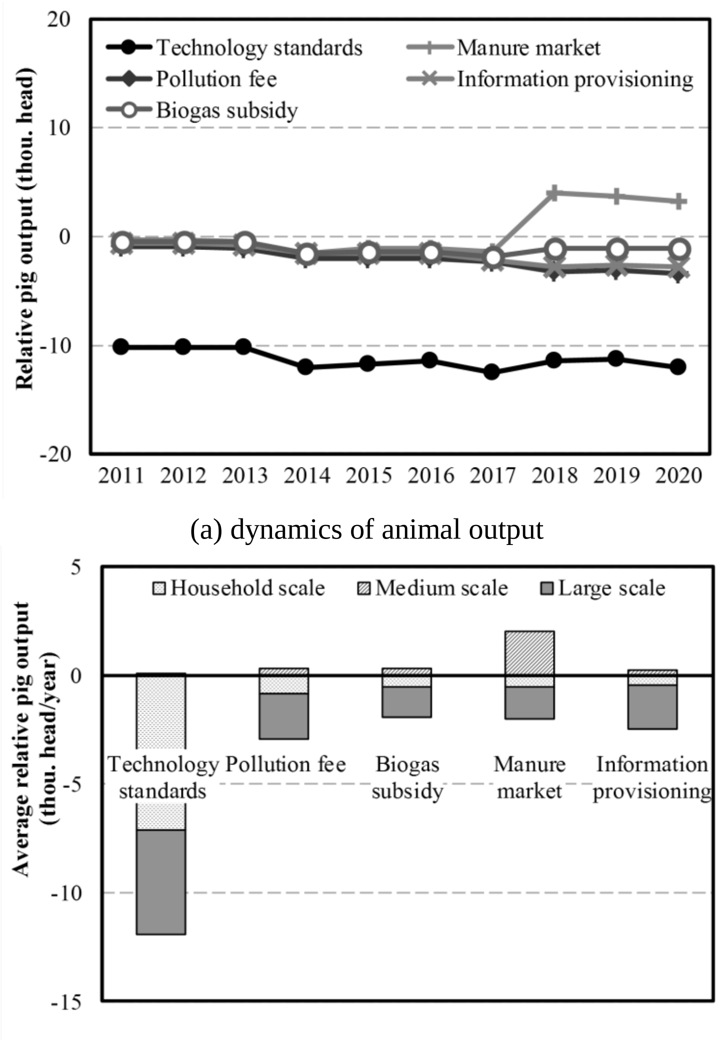


(b) average annual nutrient mitigation per scale group

Figure 4.2 Nutrient mitigation for five scenarios over 10 years (a) and on annual average (b)

4.4.2 Total animal output

Different environmental policies have different effects on the development of animal production. The changes in animal outputs as a result of the implementation of the different policies are shown for the scenarios over 10 years in Figure 4.3a. Figure 4.3b shows the average annual animal output per scale group for the whole period. Figure 4.3a indicates that stricter environmental management obstructs farm expansion, represented as negative relative pig outputs, to a greater or lesser degree. The only exception is the manure market policy, which boosts animal outputs in the last three years, with approximately 4,000 pigs per year more than the benchmark of 276,000 pigs from the reference scenario. Accordingly, in Figure 4.3b, the average annual relative output is positive for the manure market scenario. Medium-scale farmers benefit the most from the manure market, apparently the increase in the average output only occurring in this farm category. Contrary to the manure market, the introduction of a technology standard causes the largest and most immediate reduction in animal output compared to the reference scenario. Unlike the other scenarios, the technology standard significantly slows the development of animal production from the first year of intervention by nearly 9,400 out of 265,000 pigs. Such a negative effect continues and strengthens later. Thus, the average annual output gap compared to the reference scenario is more than 11,000 out of 270,000 pigs. However, medium-scale farms are hardly affected, and surprisingly, the largest output limitation (60%) occurs with household-scale farms. The other policy instruments show less influence on animal output compared with the reference scenario. On average, their output reduction per year is no more than 2,000 out of 274,000 pigs. With increased pollution fee, biogas subsidies and information provisioning, medium-scale farmers are slightly motivated to expand, whereas the other two groups are negatively affected and decrease their stock.



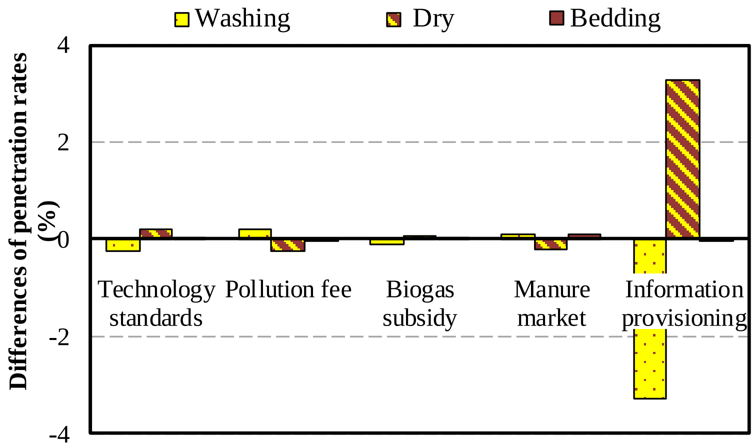
(a) dynamics of animal output

(b) average annual animal output per scale-groups

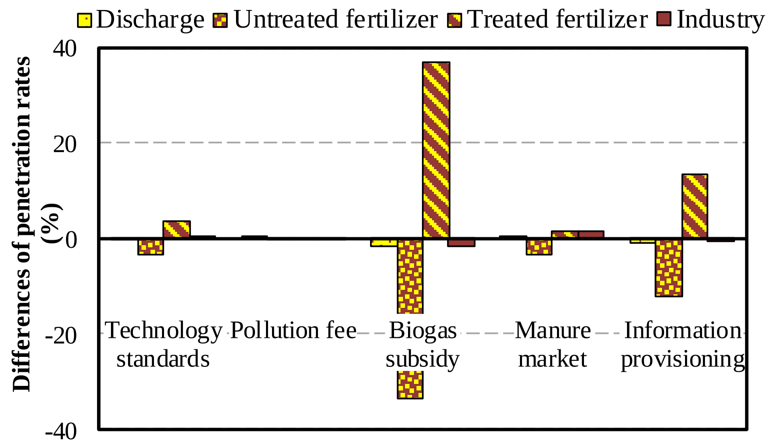
Figure 4.3 Total animal output for five scenarios over 10 years (a) and on annual average (b)

4.4.3 Technology diffusion

The simulations reveal that alternative technologies diffuse rapidly in the first year, and then the diffusion process stabilizes. For manure collection, “washing manure” shifts mainly to “dry collection” and little to “bedding”. This shift is considered as more environmentally sound because dry collection saves water and prevents nutrients from leaking into the environment. The newest collection technology, which is “bedding”, remains at a low saturation level (< 1%) in every scenario. If a typical S-shaped cumulative curve were to be used to describe system-specific technology diffusion, bedding would not have entered the rapid diffusion stage (Rogers, 2003). The application of “treated fertilizer” is the dominant alternative manure handling technology, with the application of "untreated fertilizer" in second place. Selling the manure to “Industry” does not occur at a high level in the different policy scenarios. However, no technology completely disappears by 2020. The diffusion of technologies reaches a ceiling within five years and shows no remarkable further penetration between 2016 and 2020. The detail of diffusion of manure management practices among all farms for selected years, and over the total period of ten years is available in Supporting Information.



(a) manure collection technologies



(b) manure handling technologies

Figure 4.4 Different penetrations of manure management practices for five policy scenarios

The cross-sectional data of 2020 are used to represent the cumulative effects of the policy instruments on technology diffusion. Figure 4.4 depicts the differences in technology penetration rates with and without policy interventions in 2020. The environmental policies generally are more consequential for manure handling than for manure collection. The simulation results show that providing information is the most effective way to improve collection practices. This policy instrument encourages 3.3% more farmers to adopt dry collection (at the cost of washing) than occurs with the reference scenario, which is ten times more than the effects of the other instruments. Because neither biogas subsidies nor the manure market aim to improve manure collection, their low efficacy is predictable.

Information provisioning is the second strongest driving force for diffusing manure handling technologies, after biogas subsidies. There are 14% more farmers (than in the reference scenario) who adopt biogas production as a consequence of information provisioning. Biogas subsidies increase the penetration rate of biogas infrastructure by 37% compared to the reference scenario. The simulated manure market appears to indicate manure profitability and thus to most promote more innovative technologies, i.e., selling manure and bedding. The stricter implementation of a technology standard stimulates some adoption of dry collection and biogas infrastructure. A higher pollution fee proves to play no significant role in improving manure management practices.

4.4.4 Pollutant emissions per animal

The coefficients of nutrient emissions per animal are assumed to vary by farm scale and respective manure management practices. Therefore, the effects of the different policies will be presented as the change in pollutant nutrient emissions per pig (change here is relative to the reference scenario) for a certain farm scale group (as shown in Figure 4.5). The results indicate that only a stricter technology standard reduces the emissions per pig in all three scale groups. The relative reductions that are brought about by the application of the technology standard grow almost linear as the scale increases (R^2=0.98). This scenario shows the largest relative reduction in Figure 4.5. The effect of biogas subsidy and information provisioning are weaker; however, except on large scale farms, the emission reductions are still noticeable and meaningful. Developing a manure market has an opposite effect, represented in Figure 4.5 by the negative column for large scale and no effects for the other two scales. In four scenarios, but not in the one on stricter standards, large-scale farmers perform worse than in the reference scenario (9%, 10%, 8% and 2.3%, respectively) and their performance change is opposite to those of the other two scale groups. When compared with the reference scenario, medium-scale farmers are the forerunners of better manure management in most policies.

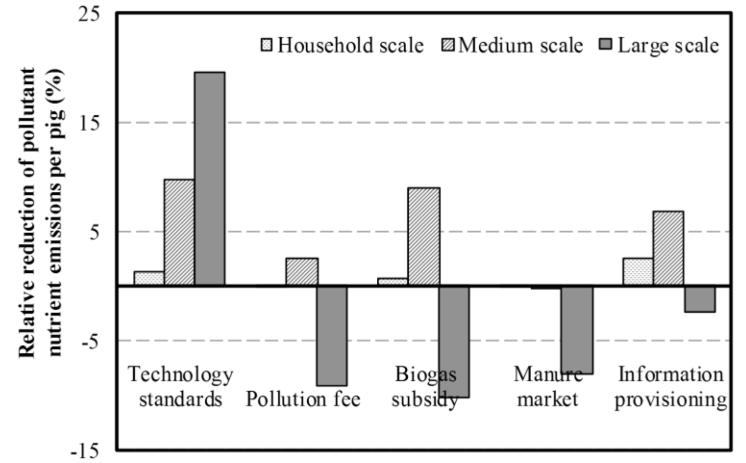


Figure 4.5 Pollutant emissions per animal of scale groups for five scenarios

4.5 Discussion

Many previous studies compared the effects of policy instruments on technological changes using theoretical models or empirical research. With these approaches, it proved difficult to draw conclusions on the effectiveness of a policy instrument (Requate, 2005). Our research attempted to fill this information gap by outlining the effectiveness of different policy instruments in mitigating the nutrient emissions of different kinds of livestock farms. To this end, our research used an empirically sustained ABM and employed different indicators to assess policy performance. The policies were assumed to be effective if both emissions are reduced (per animal and in total) and the development of production is not negatively affected. Sensitivity analyses (see Appendix III) proved that the results of the policy scenarios are robust and meaningful.

There are notable differences among the five analyzed policy interventions, including their policy designs (see Table 4-S3.1) and consequences (see Figure 4.2 to 4.5). Three policies are effective in reducing nutrient pollution, but no win-win scenario exists in which both environmental and economic benefits occur. A stricter technology standard attempts to stimulate the adoption of mitigation technologies and especially addresses intensive livestock farms. Although obviously mitigating nutrient emissions in the simulations, the constraints of a stricter standard on production development are stronger than for other policy interventions. Our findings show that such regulatory intervention as a standard does not necessarily stimulate radical technology changes, which is consistent with earlier research (Ashford, 1985). Given the decrease in production, it can be assumed that such a regulatory mechanism is not likely to be favored by the Chinese government, which is pursuing steady economic growth. Biogas subsidies focus on a single technology, and the scenarios show that these subsidies can effectively achieve emission reduction. However, large-scale farms are excluded from biogas subsidies, resulting in an average emission increase per pig. Our findings thus contradict research that considers market-based instruments to be superior in promoting low-cost environmental improvements (Kemp and Pontoglio, 2011). Instead, a preferred policy intervention for the mitigation of pollution from livestock production is likely to be information provisioning, which slightly affects production development and promotes technology improvement across two major scales (i.e. household and medium scales), thus reducing total emissions.

Responding to our two research questions, this research has shown that differences across scale groups play an important role in determining the effectiveness of policy instruments for mitigating nutrient emissions from livestock production. Until 2020, aggregate pollution from household-scale farmers is the largest source and is responsible for more than 90% of the nutrient discharge by the pig sector. However, this group is also the largest contributor to nutrient mitigation. Since household-scale farms show little change in manure management practices, their contribution to nutrient mitigation mostly comes from decreasing the number of animals. Large-scale farms reduce pollutant emissions per pig under the scenario of technology standards but neither under the three market-based policies nor under information provisioning. For medium-scale farms, many policy instruments are effective, but not the installation of a manure market. These farms are capable of mitigating negative effects through a further increase in animal production. Governing medium-scale farms is likely to be extremely critical for environmental management in rural areas. Because the Chinese government insists on the continuous intensification of animal production, more and more household-scale farms will expand to medium-scale farms (rather than reduce farm size). Therefore, ecologizing medium-scale farms becomes critical in achieving increased production and environmental protection. Our simulations show that biogas subsidies and information provisioning are the policies that work best for medium-scale farms.

Last but not the least, examining the policy interventions with an ABM allowed the study of policy effects by incorporating farmers' heterogeneity and interactions. The perspective of individualization possibly provides new knowledge concerning policy effects. This becomes clear in, for instance, the distinct performance of interventions using information diffusion. The force of such instruments is amplified through autonomous observations, learning and imitation among farmers. The ANEM captures such technology diffusion through interactions among individuals, which is usually ignored in approaches that function on the aggregate level. However, in current local policies, information provisioning is more an additional instrument, attached to subsidies or antiepidemic services. The simulation shows that instruments that increase information on pollution mitigation technologies should be given considerably more attention in environmental management in rural China. A second policy implication follows from manure markets. In this simulation, “selling manure” is assumed to be the best choice for individuals aiming to maximize economic profitability and/or environmental benefits. This assumption is made because selling manure results in economic profit without investment (e.g., in technologies) and emission reduction on the farm; therefore, pollution fees are avoided. Manure pricing can stimulate the expansion of animal production, which does not show effects in the simulation on the individual level because of high heterogeneity within the model. The simulation results at an aggregate level, however, reveal high nutrient emissions and thus make the manure market much more problematic. There are other options commonly used worldwide for mitigating livestock nutrient emissions. For instance, livestock diet adjustment to decrease manure nutrients is practiced in Northern Ireland and the US, among others (CBC, 2004; Ferris, et al., 2006). In many European countries, seasonal and quantity standards for manure application to arable areas and grassland are established to reduce nutrient losses from farmland (De Clercq, 2001). Furthermore, consumer choices can to some extent contribute to a reduction in nutrient flows within rural China and can also do so, last but not least, by a moderate or reduced consumption of meat. Although excluded from this research, our simulation can be applied to examine the effects of such policy interventions.

The ANEM has some limitations. This model simplifies the implementation of policy intervention by local governments. In the model, biogas production is easily adopted by farmers due to governmental subsidies; however, biogas digesters in reality can be too difficult for Chinese farmers to operate well for long periods without governmental service (Bluemling, et al., 2012). Therefore, the nutrient emission mitigation performance of biogas subsidies may be overestimated. Second, although we valued the parameters of the model with literature review and empirical research, many social and economic trends cannot be modeled far into the future with sufficient certainty. For example, price fluctuation is a major exogenous factor that is unknown. Third, the policy instruments in the ANEM do not “learn”. All the policy scenarios show maximum penetration rates for new technologies, and over the ten years that were simulated in the scenarios, no policy instrument provides more efficacy than that initially achieved with the intervention. Thus, "learning" policy intervention may be necessary, possibly in the form of transforming either farmer groups or kinds of technologies it aims to, in order to overcome the adherence to current practices and enable alternatives to diffuse further. These shortcomings and concerns should be part of a future research agenda. Furthermore, the policy instruments of this research are dealing with a redirection of manure flows, not with their diminution. The collection of manure in biogas digesters makes it better available and suitable for fertilization of the land; manure markets make manure better available where it is needed. The overall nutrient load remains the same, although better distributed across space and time. Whether such redistribution will be adequate to prevent environmental pollution remains to be seen.

Acknowledgement

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Appendix 4-S1

Table 4-S1.1 Major elements of the ANEM model

Decision sequence	**Input variables**	**Individual attributes**	**Relevant parameters**	**Output**
Performance evaluation	Market and guide prices of products, inputs and technologies; extra benefits; limitations to use resources or take certain action; average household income	Capability to tolerate business losses	Survival rate; consumption of inputs per animal; production life span; productivity; coefficients of nutrient emission of technologies	Current economic and environmental benefits; willingness to change behaviors
Knowledge gain	Knowledge and information of innovations	Information channels		Whether an innovation is known
Observation		Social status; education level; risk aversion; adoption threshold	Historical behavior in personal network	Whether an innovation is considerable
Performance improvement	Market and guide prices of products and inputs; extra benefits; limitations to use resources or take certain action; disease outbreak	Environmentalism; subjective probability; weight of risk component	Survival rate; consumption of inputs per animal; production life span; productivity; coefficients of nutrient emission of technologies	Animal amount; Technology adoption; nutrient emission

Appendix 4-S2

Table 4-S2.1 Constant inputs for five policy scenarios

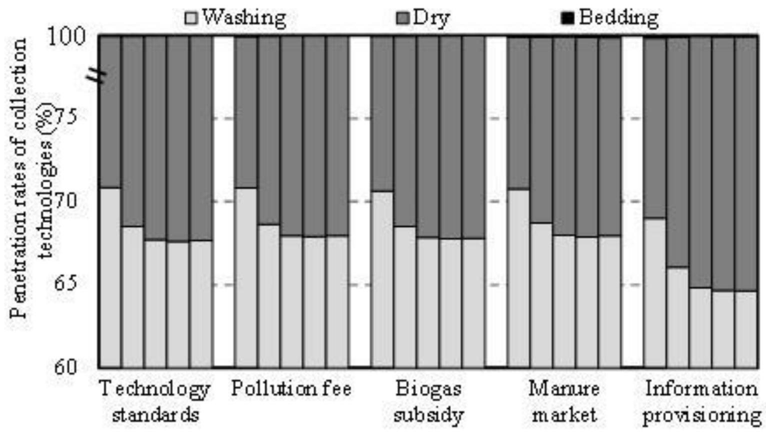
Variables	**Values**	**Data source**
Prices of livestock inputs and products	Periodic fluctuations similar to previous 10 years	Historical market monitoring; Findings in previous literatures
Extra financial benefits beside of selling products	170,000 *yuan* for large-scale farms	Estimation based on national government investments and rewards for intensive pig farms (GOSC, 2011)
Maximum of available land	4.07 *mu* for free; 50 *mu* for 850 *yuan/mu*	Local average of contracted land; Local household average of cultivated land
Average household income	Trend extrapolation	Historical statistical data
Disease outbreak	0= no disease outbreak	Authors' assumption

Appendix 4-S3

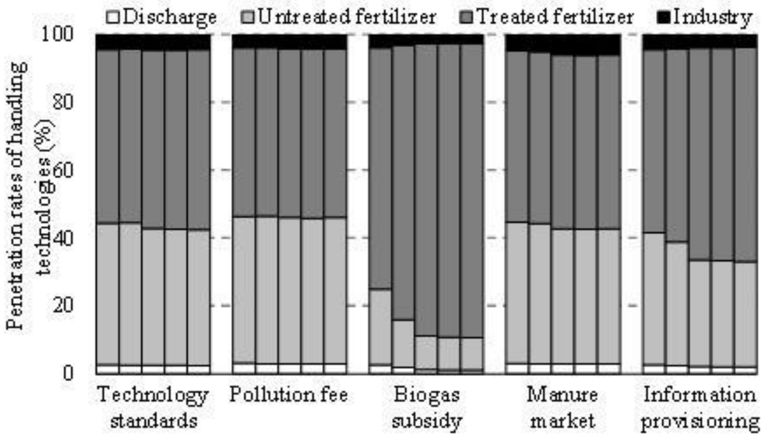
Table 4-S3.1 Heterogeneous inputs for five policy scenarios

Scenarios	**Assumed inputs**	**Targeted technologies**	**Targeted farmer groups**	**Assumed value**	**Data sources**
Technology standards	Maximum number of animals to adopt technologies	Collection = dry	New or expanded medium- and large-scale farms;	50 pigs	Technical standard of preventing pollution for livestock and poultry breeding (HJ/T 81-2001)
		Handling ≠ discharge	All farms	1 pigs	
Pollution fee	Fixed price for pollution	No specific technology	All farms	1.4 *yuan*/head (2.8 *yuan*/head after exceeding pollution standards)	Measures for the administration of the pollutant discharge fee collection standards (No.31 policy paper of SDPC in 2003)
Biogas subsidy	Extra financial benefits beside of selling products	Treated fertilizer	Household- and medium-scale farmers	1000 *yuan*/ household to cover investment for biogas infrastructure	Literature[33]
Manure market	Market price of manure	No specific technology	All farms	100 *yuan*/ton (with minimum 0.04 ton)	Household survey in case area
Information provisioning	Information in channel of governmental consultation	All technologies	All farms	Information of existence and functions about all technologies provided (=1) in governmental consultation	Research assumption

Appendix 4-S4



(a) manure collection technologies



(b) manure handling technologies

Figure 4-S4.1 Technology diffusion in collection (a) and handling (b) for the five policy scenarios.

(For every policy scenario: column 1 = 2011; column 2 = 2012; column 3 = 2014; column 4 = 2016; column 5 = 2020.)

5

Is Intensification of Livestock Production a Solution for Nutrient Mitigation in Rural China?

Abstract

Expanding intensive production is one of the most important national strategies for the livestock sector in China. A limited number of studies have quantified the environmental consequence of Chinese-style intensification processes. Applying the agent-based nutrient emission model (ANEM), we explore the dynamics of nutrient emissions under different intensification scenarios in Chinese livestock production. The intensification of livestock production is able to mitigate negative environmental impacts of livestock production to some extent. The annual decrease rates of nutrient emissions in the scenarios with limited growth of total animal output are more than 1.5%. When pig output annually increases by 6%, intensification fails to alleviate total nutrient emissions. This research also examines environmental performance of medium and large scale livestock farms in nutrient mitigation in rural China, which enhances slowly. It is concluded that intensification of livestock production facilitates some nutrient mitigation, but this will not be enough for the necessary reduction of total nutrient emissions in Chinese livestock production.

Keywords:

Nutrient mitigation, Intensification, Livestock production, China.

Chapter 5. Is Intensification of Livestock Production a Solution for Nutrient Mitigation in Rural China?

5.1 Introduction

The intensification of livestock production is a process that expands animal stocks in household backyards to raise animals in special confinement at high stocking density (Ilea, 2009). Different from the traditional backyard production, intensive livestock production uses economies of scale and modern technologies, and requires a considerable amount of resource inputs. It is predicted that most future demands for livestock products will be met through intensification (FAO, 2007). Intensification first originated in Western developed countries before taking off in developing countries. To date, most livestock production in developed countries is operated in industrialized animal farms. The average density of pig production in the United States, for example, reached 1229 heads per farm in 1999 (Gillespie and Fulton, 2001). The average productivity of US broiler farms in 1992 was 1380 pounds per farm, equal to that of China in 2007 (Walker, et al.). The stagnant demand for livestock products in developed countries redirected their livestock sectors from intensification to efficiency enhancement and environmental sustainability, among others (Thornton, 2010). Many developing countries, especially in Asia, have recently started their intensification of livestock production.

China is one of the most important producers and consumers of livestock products in the world (FAO, 2006). With the country-wide economic reform starting in 1979, China's central government abolished the restrictions on private livestock production. Since the 1980s, farmers have been encouraged to adopt Western intensive models. In the recently published national strategic plan, intensive production is preferred for developing Chinese livestock as it largely contributes to improvement of the rural economy and guarantees long-term food security (State Countil of China, 2012). However, intensification in China is still progressing slowly and is significantly different from how it developed in Western developing countries. Chinese livestock farmers are officially categorized into three groups based on annual animal output: household-, medium-, and large-scale. In pig production, farms producing less than 50 pigs per year are household-scale farms, those with more than 500 are large-scale farms, and those in between are considered medium-scale farms. Medium- and large-scale farms together are categorized as intensive livestock producers. The share of intensive production in China varies with animal species and regions but is generally low. As the major components of Chinese livestock production, household-scale pig and poultry farming still account for approximately 35% and 10% of the total national production output in tons, respectively (NBSC, 2010). Unlike in the highly industrialized Western developed countries, medium-scale farms, as a transition between household- and large-scale production, dominates China's intensive livestock production currently (NBSC, 2010).

Based on the experience of Western countries and the first China Pollution Source Census (CPSC), Chinese livestock production has been recognized to be significantly responsible for environmental degradation. Particularly, China's government has given additional attention to livestock nutrient emissions, which are a major components of agricultural non-point source pollution (NPSP). The plan for pollution prevention for livestock production in the 12th Five-year Plan issued in 2012 is one of the efforts to further mitigate the negative environmental effects of livestock production (MoEP and MoA, 2012). Although intensification of livestock production is one of the most effective ways to alleviate poverty, it has been frequently cited as harmful to the environment (Bingsheng, 2002). Many studies showed that intensive livestock production aggravates environmental threats because of, among others, the centralization of animal waste, nutrient leakage, and airborne emissions (Abdalla, 2002; Ilea, 2009; Melse, et al., 2009). When traditional animal farmers keep animals in higher density in their backyard or on contracted farmland, they adopt some Western practices, such as providing additional protein diet and battery cages. Nevertheless, there is a large gap between the practices in Chinese expanded animal farms and the mechanization and standardization of industrialized Western farms, not the least because all kind of protective measures are insufficiently included in the intensification process (Li, 2009). Therefore, intensive farmers are at greater risk of disease outbreaks and severe environmental pollution than farmers from other scales. However, our field survey found that the performance of intensive farmers, particularly medium-scale farms, to adopt environment-friendly technologies sometimes exceeds that of other farms (Zheng, et al., 2013-a). There is limited literature available that quantitatively show the relationship between environmental pollution and the special intensification process of livestock production in China. This partial cognition of the effects of livestock intensification on environmental management and performance hinders more science-based (environmental) policy-making for China's livestock sector.

Should Chinese livestock production keep following the current intensification process? Can the Chinese government consider intensification as a (partial) solution for nutrient mitigation in the livestock sector?

This research explores the development of pollutant emissions from livestock production in rural China, when the latter undergoes different growth and intensification processes. Farmers in the three scale groups are expected to have different environmental performances within and across a series of simulation experiments. This study focuses on the role of intensive farming, which is preferred by the Chinese government, in mitigating nutrient pollution from Chinese livestock production. Hence the study assesses the national strategy of livestock intensification from the perspective of (total) environmental pollution control.

5.2 Research methods

This study uses the Agent-based Nutrient Emission Model (ANEM) (Zheng, et al., 2013-b) to test a series of simulation experiments in livestock development to quantify the nutrient emissions from farms from the three scale groups under different intensification processes. ANEM is specifically based on the heterogeneity of and interactions, particularly information exchanges, among Chinese animal farmers. As a kind of agent-based model, ANEM is composed of numerous entities (farmers) in a certain region, which can autonomously assess their own situation and make a decision, possibly under conditions of limited knowledge and information-processing capacities (Berger, 2001; Page, 2008). The agents in ANEM are interdependent. They interact with either the “physical" environment or the “social” neighbors in a decentralized manner; thus, their decisions rely not only on themselves but on other agents as well (Berger, 2001; Smith and Conrey, 2007). Taking one year as the time step, the agents in ANEM synchronously decide on the farm scale, that is, the number of animals on the farm, in the “farm-scale decision module”; and they decide on the manure management practices, consisting of manure collection and handling technology adoption, in the “technology selection module” (Figure 5.1). Modeling the farmers individually helps to identify the diverse performance of farmers between the three scale groups, as well as the differentiation within scale groups, such as different education levels and risk aversion, among others.

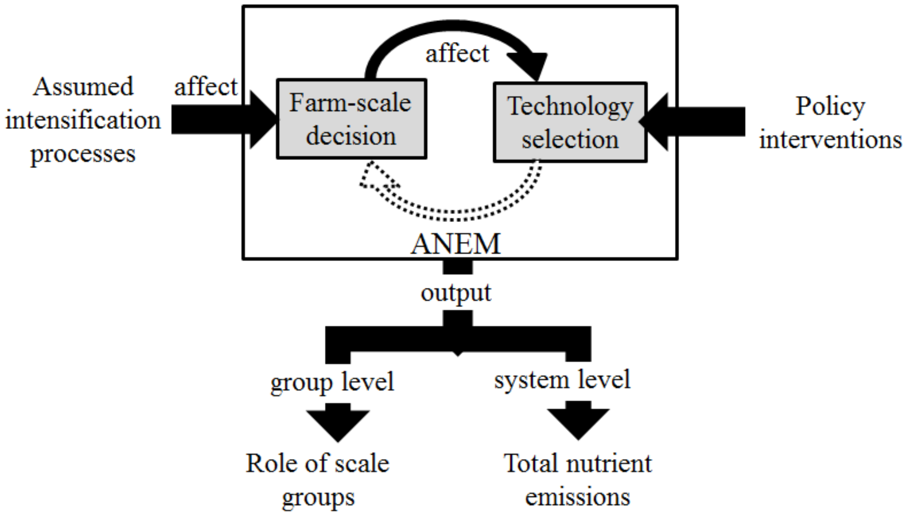


Figure 5.1 Research framework using ANEM. In ANEM, technology selection affects farm-scale decision, but is excluded in this research (indicated by the dotted arrow).

The Zhongjiang County, in Deyang City, Sichuan Province of China, is taken as the case area for this study. As a traditional and typical pig producing region, Zhongjiang County is expected to display the environmental consequences of the national livestock strategy. ANEM was applied to pig production in this case study area (Zheng, et al., 2013-b). The simulation traced the dynamics of local pig production and the associated nutrient emissions from 2005 to 2008. The attributes of individual farmers and their decision-making rules were defined on the basis of a questionnaire survey in Zhongjiang County. Parameters of ANEM were valued based on literature review and actual observation. ANEM successfully captured the actual dynamics based on individual simulation. In this research, ANEM annually simulates the dynamics of farmers' practices and nutrient emissions of livestock production in the 12th 'Five-Year Plan' (2011-2015) period. Around 1/7 of the local livestock production in 2010, including the number of farms and pig output from the three scale groups, is taken as initialization. The tailored individual attributes, behavior rules, and parameters are adopted in this research for all scenarios, thus enhancing the comparability among scenarios. Most inputs are assumed as static variables with a constant 2010 value; only a few inputs vary with assumptions of environmental policies.

For the signal farm in the simulation, the number of animals on the farms categorizes farmers into certain scales, i.e. household-, medium- and large-scale, as well as determines the amount of nutrient pollution generated on site. To highlight the effects of livestock intensification on the environment, the "farm-scale decisions" are pre-designed by the development scenarios (Figure 5.1). Significantly different intensification processes were assumed in the scenarios, to be able to observe distinct results of these scenarios in terms of nutrient pollution. There are three scenarios designed in this research to indicate three feasible development paths of regional livestock production. The differences across the scenarios are defined by various growth rates of pig output, and different shares of intensive production (Table 5.1).

Table 5.1 Development path of regional pig production for three scenarios

Scenarios	**Total pig output**	**Shares of medium- and large-scale production in output in 2015**	**Proportions of medium- and large-scale producers in 2015**
nG&sIn	Keep constant at 2010 level	Linearly increase to 22.4% and 14.8%, respectively	Linearly increase to 2.32% and 0.11%, respectively
sG&sIn	Annually increase by 1.4%	Linearly increase to 22.4% and 14.8%, respectively	Linearly increase to 2.32% and 0.11%, respectively
fG&fIn	Annually increase by 6%	Linearly increase to 30% and 34.5%, respectively	Linearly increase to 3.94% and 0.36%, respectively

Data sources: China Livestock Husbandry Yearbook (2010).

As a baseline, the first scenario assumes that pig output in the case study area would remain as it was in 2010, and intensification would slowly grow over the next five years. In 2010, both medium- and large-scale pig farming in Zhongjiang had shares of less than 10% of regional pig output. These shares were around half of the average intensification level in Deyang City, which had been much lower than China’s average. In this so called “no growth and slow intensification” (nG&sIn) scenario, assumed intensification of pig production attempts to catch up to the average level of Deyang City in 2010, which was that medium- and large-scale farms contributed with 22.4% and 14.8% to pig output. The three scale groups are assumed to keep their current densities of animal breeding (accounted as average number of pigs per farm in each scale group). The second scenario is defined as “slow growth and slow intensification” (sG&sIn). This scenario assumes a 1.4% annual increase in pig production, referring to the requirement of meat production increase in the national livestock plan, while it would undergo a similar intensification progress as in “nG&sIn”. Comparison of the first two scenarios intents to highlight the effect of productivity growth without further intensification. The shares of medium- and large-scale pig outputs and the breeding densities of the three scales at the end of simulation in the third scenario are assumed to achieve the 2010 national average. The historical increase of pig output in both the whole country and in the case study area suggests that a 6% annual increase is feasible and thus assumed in the third scenario as the highest growth rate of this research. The third scenario is hence labeled "fast growth and fast intensification" (fG&fIn). Depending on the number of famers and pig output in each scale group, the number of pigs in a single farm is randomly allocated. The development paths of the three scenarios are listed in Table 5.1 and Appendix 5-S1.

Manure management practices on farms determine the proportion of nutrient from manure that leaks to the environment. Manure management indicates to what extent the farmers integrate environmental concerns into their production. Considering data availability, three collection and four handling technologies are involved in ANEM (introduced in Appendix 5-S2). ANEM adopts Rogers' theory of innovation diffusion (Rogers, 2003) to capture the individual selection and the total diffusion of manure management technologies (Hare, et al., 2002). After the farmers are introduced to new technologies through various information channels, they learn by observing them in their personal networks. When the number of adoption examples is sufficient, farmers evaluate the expected environmental and economic benefits of all acceptable technologies and adopt the ones that can maximize their benefits. Intensification processes may affect such individual decision-making of manure management in several ways. For example, different income of livestock production across scales may result in different possibilities for farmers to invest new technologies. The personal networks are constructed based on a few criteria, one of which is farm scale. These networks thus vary in different development scenarios because of diverse distributions of farmers across scale groups.

The agent-based approach is superior in bridging the assumptions of individual decision making with the emergence of the aggregated outcome (Smith and Conrey, 2007). At the individual level, every farmer in ANEM selects applicable manure collection and handling technologies under the co-influence of external inputs, individual attributes, and interactions. The original differences of inputs in the scenarios may either enhance or weaken at the later decision stages, making the results unpredictable. By summarizing the manure management practices and nutrient emissions on farms, ANEM captures the aggregate response of the whole livestock sector to the assumed changes. Moreover, the nutrient emissions and technology adoption of each scale groups are accounted, based on the collection of farms in the same scale group. Therefore, the role of scale groups in rural environmental management is expressed by comparing the performance of each group to the environmental performance on system level.

To represent the nutrient emissions simply but comprehensively, the indicator of nutrient equivalent is defined as the weighted sum of nitrogen and phosphorus emissions (as Equation 5.1). According to studies on wastewater treatment systems, the weight of phosphorus is five times that of nitrogen (Vanrolleghem, et al., 1996; Benedetti, et al., 2008).

$$NE = \beta_1 N + \beta_2 P \qquad \text{Equation 5.8}$$

where *NE* is the nutrient equivalent, β_1 is the weight of nitrogen, *N* is the nitrogen emission, β_2 is the weight of phosphorus, and *P* is the emission of phosphorous.

5.3 Result analysis

In order to reduce the effect of randomness of ABM, the stabilized mean of multiple simulations for each scenarios is used for result analysis. (see for details Appendix III). Sensitivity analyses have been carried out to assess whether the results are meaningful 9see also Appendix III). Figure 5.2 shows the time series of total emission of *NE*s in the three development scenarios. The scenarios undergo divergent tendencies: emissions in nG&sIn and sG&sIn continuously decline throughout the simulation period, while fG&fIn continues to increase (see lines in Figure 5.2). Compared with the nutrient emissions in the baseline nG&sIn scenario, which incurs the minimum nutrient emissions, the divergences between scenarios are enlarged year by year (see bars in Figure 5.2). The minimum total emissions of nG&sIn and sG&sIn are to be found in 2015 (1200 and 1280 tons *NEs*, respectively). Since the shares of intensive production in pig output and breeding densities in each year are the same in these two scenarios, the 1.4% annual increase of pig output causes nutrient emissions in sG&sIn to be higher than in nG&sIn. In 2015, the difference in emission decline between the two scenarios is 12.7% versus 6.9%. The nutrient emissions of fG&fIn scenario accelerate their increase in the last two years, reaching a total of 1500 tons in 2015. However, the average annual increase rates of total emissions in this scenario is still much lower than the increase rates of pig production (6%). The emissions at the end of simulation are about 1.09 times higher than in 2010, while the pig output increases to 1.79 times its 2010 level. Therefore, intensive livestock production does contribute to environmental management in rural China. Though the government has a limited focus on nutrient mitigation, the intensification of livestock production does decreases environmental pollution, *ceteris paribus*. However, the positive effects of intensification likely do not work sufficiently under conditions of ambitious targets of productivity increase.

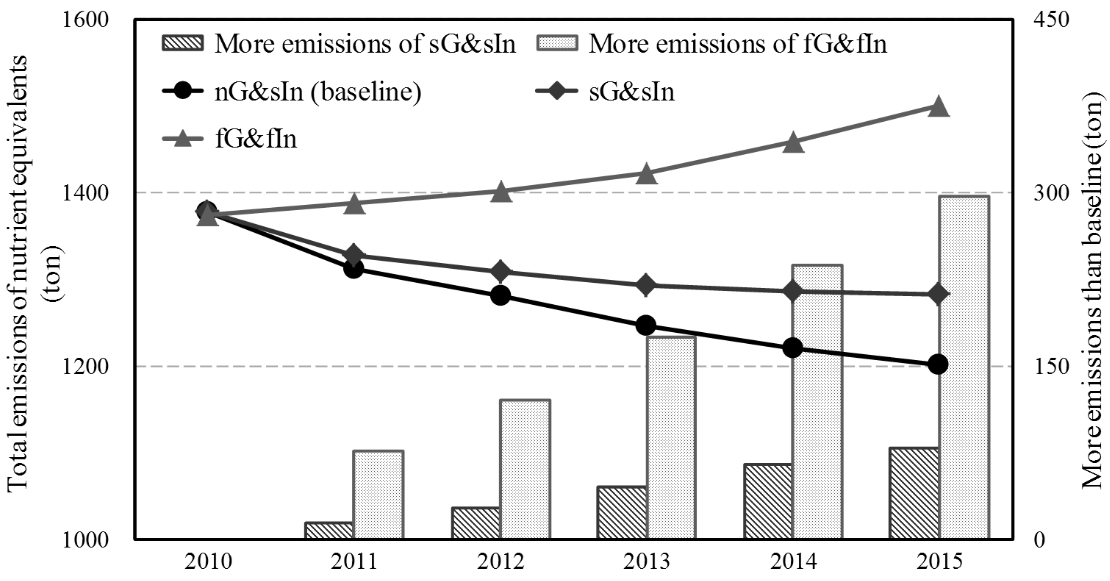


Figure 5.2 Nutrient emissions (*NEs*) in the three development scenarios

To better understand the divergence of nutrient emissions across scenarios, performance of scale groups are analyzed. The segments of medium-scale and large-scale farms in nutrient emissions increase with time in each scenario, along with their increasing shares in pig production across scenarios. This phenomenon is likely due to the growth of pig output from medium- and large-scale farms. As assumed in ANEM, the emission per pig varies per farm scales and according to the manure collection and handling technologies used on the farms. Figure 5.3 shows the emission per pig of medium- and large-scale farms to reveal the transformation of their manure management practices.

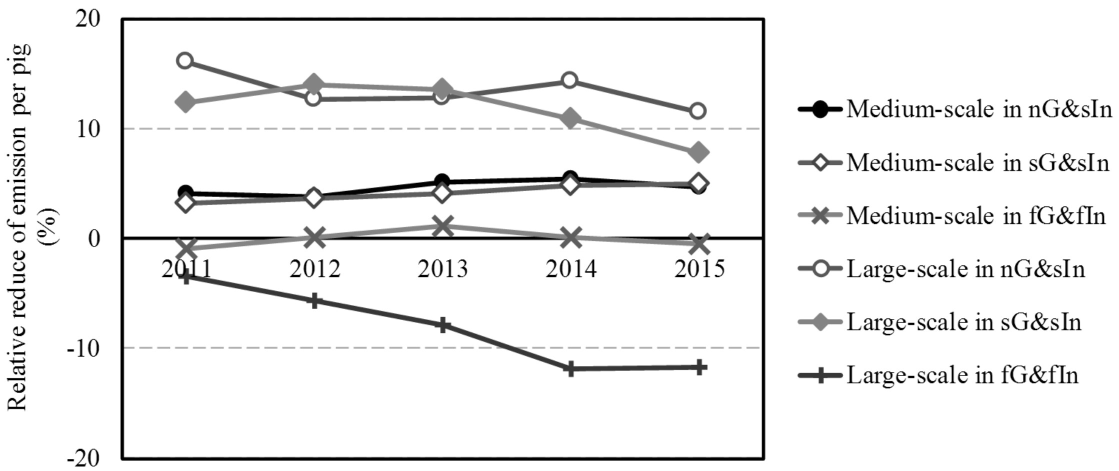


Figure 5.3 Relative reduction of nutrient emission per pig in medium- and large-scale groups for three scenarios (compared to 2010 levels)

In the both slow development scenarios, i.e. nG&sIn and sG&sIn scenario, emission per pig of medium- and large-scale farms reduces compared to that in 2010. It seems that the increasing number of intensive producers is accompanied by the adoption of more environmentally friendly technologies, which can better address the negative effect of livestock production on the environment. In general, large-scale farmers are more active to reform their manure management practices, since the curves of large-scale farms stay above that of medium-scale farms. For both scenarios the reduction of emission per pig in the medium-scale group is relatively constant, with a few differences between the two scenarios. The averages of these two lines are around 0.21 kg *EN* /head less emission compared to 2010, The curve of the large-scale group in sG&sIn scenario shows an inverted U-shape with a peak in 2012 (around 13.9%), while that in nG&sIn scenario stepwise declines from 16.0% to 11.4%. The sG&sIn scenario shows 1.73 kg *EN*/head more emission mitigation than the nG&sIn scenarios, which is possibly due to the larger number of intensive farmers that comes with higher speed of technology diffusion. However, the trends in mitigation per pig do not parallel similar dynamics of total mitigation, as showed in Figure 5.2. As a result, the gradual enhancement of total mitigation in the nG&sIn and sG&sIn scenarios should be explained by the increasing shares of intensive production but not in the improvement of manure management practices within intensive farmer groups. According to the Ministry of Environmental Protection (MoEP, 2010), more intensive production generally result in less pollution emissions, possibly due to, among others, the shorter life span and different fodder diets, besides the manure management practices. Therefore, the average of emission per pig in the whole farmer community decreases, along with a larger share of pig output produced in intensive modes.

However, neither total emission decline nor emission decline per pig emerges in the fG&fIn scenario. The emission per pig in the medium-scale group moves up and down to end around its initial level. The curve of large-scale group significantly declines during most of the years in the simulation period. It means that technology diffusion through interactions among farmers is limited. The number of medium- and large-scale farmers at the end of simulation in this scenario is 2-3 times higher than that in the other two scenarios. The diffusion of more environmental sound technologies thus is too slow to ‘cover’ all new intensive farms. At aggregate level, the emission per pig in this scenario slightly reduces with time, but is significantly higher than that in the nG&sIn and sG&sIn scenarios. Hence, it is unable to alleviate the severe environmental threats of fast growth in pig production, resulting in the rising line in Figure 5.2.

5.4 Discussion

Using the theory of innovation diffusion (Rogers 2003) as the principle basis of spreading of individual decision making, we estimated the dynamics of nutrient emissions of regional livestock production under different development processes with the agent-based environmental model ANEM. The role of intensive farms in these dynamics is separately analyzed. Nutrient emissions in the three scenarios are mitigated to some extent, not only through the shift in production mode (i.e. traditional or intensive) but also through the use of more environmentally sound manure emission mitigation technologies. The two scenarios with lower growth of pig output achieve absolute levels of decline of total nutrient emissions. The expansion of intensive production does not linearly facilitate technology adoption. Our simulation reveals that intensification has diverse effects on different technologies. Taking the sG&sIn scenario as example, the penetration rate of dry collection, which releases fewer nutrients into the environment than conventional washing collection, in 2015 is slightly higher (around 6.5%) than that in 2010. The newest technologies, such as bedding collection, have been diffused a little, especially in the medium-scale group (from zero to 0.76%). This phenomenon confirms that the adoption of more complex and modern technologies can be promoted in intensive farms (Goldstein and Udry, 1999). In contrast, a higher proportion of medium-scale farmers directly fertilize manure on farmland, approximately 10.7% more than that in 2010, rather than treating manure using biogas digesters. In addition, the advantage of intensification for emission mitigation becomes ineffective when the shift of farms toward intensive production is extensive and fast. This simulation results correspond with those of previous studies. The intensification of livestock production primarily emphasizes efficiency but not necessarily highlights environmental interests (Hinrichs and Welsh, 2003). Pig farms may not take the initiative to adopt environment-friendly technologies when they expand to intensive farms. Therefore, technological improvement in intensive farms in the fG&fIn scenario is too minimal to reduce the environmental stress of expanding livestock production. The sensitivity analysis (Appendix III) showed that these results are meaningful.

This study has some implications for the future development of intensification policies on Chinese livestock production. To date, the national strategy on livestock production highlights economic development for the whole sector and intensification of production. There is also a general target for pollution mitigation of livestock production, which is a reduction of 8% of COD and 10% of ammonia nitrogen within five years. However, this environmental target does not involve explicit criteria for promoting technology transformation. As shown in our simulation results, the livestock sector has a significant risk of causing major environmental damage. Intensification plays a positive role in diffusion of environmental sound technologies and thus in nutrient mitigation. Nevertheless, the effects of intensification may not compensate for the emission increases due to the growth of pig output. It would be over-optimistic for governments to put nutrient mitigation in livestock sector fully in the hand of autonomous improvement of farmers' manure management practices that parallel intensification. The difference of nutrient emissions between 'slow growth coupled with slow intensification' and 'fast growth coupled with fast intensification' shows the possible deviation of aggregate phenomena from the observation of behavior changes on individual level. From the perspective of mitigating environmental threats of livestock production, setting an appropriate growth rate should be prioritized above other considerations, while the intensification process has to be coordinated with the increasing productivity.

Encouraging traditional farmers to become medium-scale ones is a preferential mean to achieve the economic target, especially for less developed areas. This research criticizes this strategy as harmful to environment management. The simulation confirms that the autonomous technological improvement in a huge group of medium-scale farms is relatively slow, possibly because of limited investment capability, resource access, and risk resistance (Zheng, et al., 2013-a). To achieve a certain share of intensive production, the process towards fewer farms and higher breeding density likely results in better environmental performance than one with more farms but lower breeding density. Therefore, increase of intensive farms is good for intensification and sectoral development, but possibly not for the environment. This finding is in line with the concept of 'moderate intensification' recently stated by Chinese governmental authorities and scholars. It emphasizes the balance between productivity growth, increasing share of intensive production as well as rising the number of intensive farms in a certain area (Lu, et al., 2009; Jiang and Jiang, 2012). In a word, the Chinese government should prioritize integrating environmental concerns when deciding over livestock production.

This study has several limitations. The assumption of constant external inputs is ideal, but perhaps not realistic. The static prices of agricultural inputs and outputs ensure that farmers obtain economic profits from pig production in each year of our simulation. In fact, prices increase and frequently fluctuate in the Chinese agricultural market (Yang, 2011). As farmers are economic sensitive, their decisions may be affected by the risk of deficit. Therefore, the adoption of more environment-friendly technologies may be overestimated in our simulations. Some technologies existing in other regions or other countries are excluded in this study. For example, centralized anaerobic digesters are widely adopted in the United States to produce electricity through combined heat-power installations, to prevent methane release, and to reduce air and water pollution (Zaks, et al., 2011). Therefore, simulation should be carried out in future research using other technologies. However, the feasibility of practicing new technologies and policies should be carefully considered, depending on the specific (livestock) situation in rural China.

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Appendix 5-S1

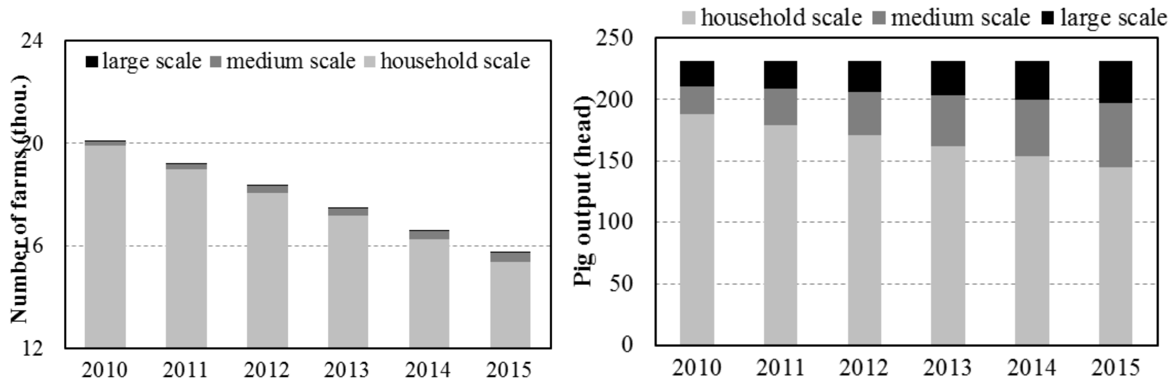

Figure 5-S1.1 Distribution of pig output and farmers across scale groups in nG&sIn scenario

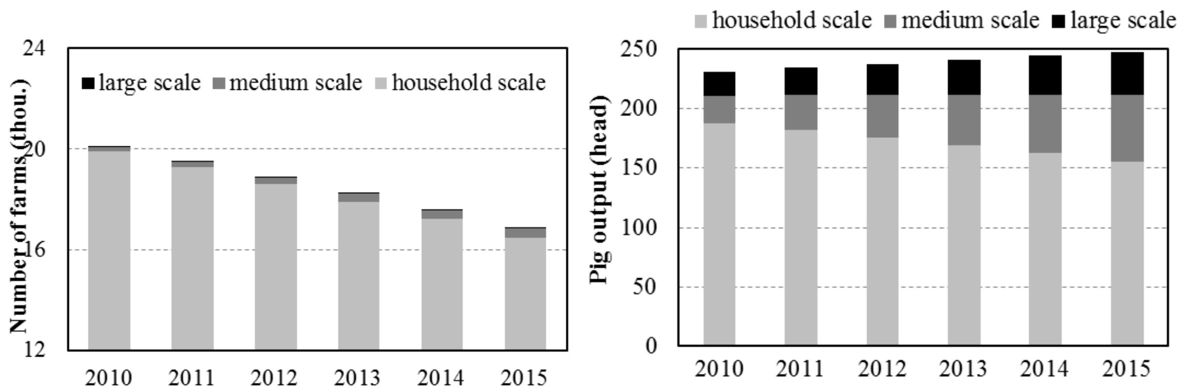

Figure 5-S1.2 Distribution of pig output and farmers across scale groups in sG&sIn scenario

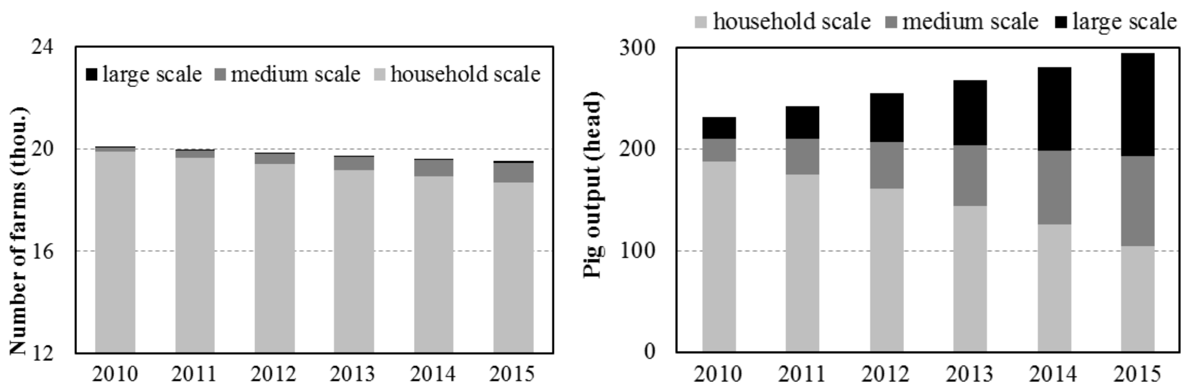

Figure 5-S1.3 Distribution of pig output and farmers across scale groups in fG&fIn scenario

Appendix 5-S2

Table 5-S2.1 The manure collection and handling technologies in ANEM

Technologies		Description	Nutrients emission
Manure collection	Washing	Animal pens are swilled down to clean mixture of feces and urine.	large pollutant leakage
	Dry	Feces and urine are separated; solid waste is collected manually or by machine, liquid waste flows along canals or pipes.	low pollutant leakage
	Bedding	Organic materials on ground (e.g. straw, rice hull) fully absorb feces and urine, with micro-biological degradation.	almost zero emission
Manure handling	Discharge	Collected manure is discharged to rivers or non-farm land without treatment.	large pollutant leakage
	Untreated fertilizer	Collected manure is applied on farm land as organic fertilizer without treatment.	some pollutant leakage (plants absorb nutrients)
	Treated fertilizer	Collected manure is stored to produce biogas; sludge is applied on farm land then	some pollutants leakage (microbes degrade and plants absorb most nutrients)
	Industry	Collected manure is sold to industrial plants to produce fertilizer or aquatic fodder.	zero emission on farms

Data source: (Zheng, et al., 2013-a)

6 Conclusion

The author and her team were in Zhongjiang County for the field survey in 2011.

Chapter 6. Conclusion

6.1 Introduction

Policy assessment is a "formalized, systematic and comprehensive process of evaluating the environmental impacts of policies" (Therivel, et al., 1992). It is hence advocated to be a means to achieve sustainable development in developing countries (Alshuwaikhat, 2005). Although policy assessment was institutionalized in China by the Law of Environmental Impact Assessment, there have been few practices up till now of a comprehensive assessment of sectoral policies on their environmental consequences.

Livestock production occupies an important place in China's economy and global agricultural production. Its rapid growth is a consequence of the sharp rising demand of non-crop agricultural products, domestically and world-wide. Expanding livestock production is valuable for farmers as it increases rural household income in China. From a global point of view, the increasing rate of livestock output in China far surpasses the average increase in the world. China has become one of the main producers for some livestock products, such as pork, eggs, and poultry meat (Li, et al., 2008). Meanwhile, Chinese livestock production is approaching the Western mode of intensive livestock production. These structural changes through intensification are—and will be in the near future—one of the major features of Chinese livestock production. Along with the prosperous development of livestock production, however, come severe environmental problems, particularly of animal manure, resulting in air pollution and ground and surface water pollution.

How to improve environmental management is a complicated policy problem in contemporary China (Mol and Carter, 2006). In the case of livestock production, governments have to guarantee the economic interests of the (especially small) farmers who are relatively poor and vulnerable. The shift of livestock production to a more market-oriented sector brings farmers better access to the market and more liberties in operational decision making. But it also provides further difficulties for central and local governments to monitor, and environmentally manage the sector, which already has been complex with numerous scattered small farmers in a large rural area. Moreover, governments lack the understanding of farmer responses to environmental and other policies, and they often do not even aim to predict overall policy impacts.

To appropriately understand and assess the environmental performance of livestock policies, this research adopted an Agent-Based Model (ABM) approach to systemically study how policies change individual behavior, as well as result in change at the macro-level through the sum of behavioral changes of all interacting and interdependent individual farmers. By modeling a system on the basis of the simulation of individuals (in my case: farmers), the ABM approach is especially appropriate (and widely applied) to analyze complex and nonlinear economic activities and social phenomena (Grimm and Railsback, 2005). As far as I know, this approach has been little used in the field of Chinese agriculture, nor for analyzing environmental policy outcomes of multiple interdependent agents.

Against this background, this research aimed to assess the environmental impacts of Chinese livestock policies, particularly by using the ABM approach. With the help of a research framework, four central research questions were defined:

- How to apply an Agent-Based modeling approach in Chinese livestock production, in order to represent the environmental impacts of policies in this sector?
- How do Chinese farmers manage animal manure in their farms?
- Which environmental policy instruments aimed at which group of farmers improve the effectiveness of pollution mitigation?
- What will be the environmental consequences of Chinese style livestock intensification focusing on medium-scale farmers?

These research questions have been answered in the previous four chapters. This chapter summarizes, compares and condenses the findings for all the research questions. The next section (Section 6.2) summarizes the experience and reflections of applying an ABM approach in policy assessments of Chinese livestock production. Section 6.3 collects the main empirical and simulation findings and conclusions of this research. Subsequently, some recommendations are provided for Chinese livestock policy-making (Section 6.4). In the last section (Section 6.5), the findings are put in a wider perspective of methodological discussions of policy assessment, finalizing with implications for future research.

6.2 A new approach for policy assessment

While the need of implementing environmental assessment for policies is widely recognized, there is a growing literature and there are increasingly new insights on the methodology of practicing policy assessment (Brown and Thérivel, 2000; Noble, et al., 2012). The major challenge is not a lack of alternative methodologies, but to make a “right choice” for the specific context of an assessment. This research developed and made operational an environmental ABM, named Agent-Based Nutrient Emission Model (ANEM), for analyzing the environmental consequences of Chinese livestock policies. The first subsection summarizes how crucial features of the simulated system were adequately represented by ABM. The second subsection then attempts to provide some feedback to the specialties of ABM which were stated in literature.

6.2.1 Applying an ABM approach in policy assessment

In order to deal with the first research question, this research (mainly in Chapter 2) constructed the ANEM model to represent the dynamics of an animal farming community, with the indicators of animal output, manure management practices (manure collection and manure handling) and nutrient emissions. Animal producers were represented as numerous agents in ANEM, who pursued the goal of maximizing their economic and/or environmental benefits. Based on social theories of behavioral change and technology diffusion, the agents were assumed to pass from initial knowledge of an innovation (i.e. more intensive mode of animal breeding and new technology), to being persuaded by the value of the innovation via observing neighbors, to putting it to implementation, and finally to confirmation of the adoption decision made. These multiple stages constituted the process of individual decision-making, and were operationalized in a sequence of mathematical equations. Although artificial farmers made their decisions following a similar process, they were sufficiently heterogeneous in terms of personal characteristics and the rules to trigger behavioral change set by themselves. By the means of information exchange, the interactions among farmers played a vital role in the decision-making process, particularly at the stage of observation. Livestock policies were not formulated within ANEM, but they respectively assigned a number of independent variables in equations. For example, water pricing policies defined the variable ‘prices of natural resources’; environmental subsidies were presented as ‘extra benefits’; and pollution permits may change the value of ‘limitation quota of pollutants’. In this way, ANEM indirectly bridged the national policies and responding individual behavioral changes.

A four-year (2005-2008) simulation of pig production in a case study area demonstrated the ability of ANEM to approximate the real world dynamics, to a major extent (Chapter 2).

Regarding the total pig output and the shares of intensive production, the annual deviations of the simulation from statistical data were always less than 2% and 6% respectively. A comparison of cross-sectional data of manure management practices showed that deviations of penetration rates for every technology were all below 10%. Finally, fairly corresponding results of nutrient emissions were achieved (δ <5%). Therefore, it could be concluded that ANEM provided an adequate description of the livestock production sector and thus was competent to assess the environmental impacts of livestock policies.

In a word, the success of applying ANEM for policy assessment as an innovative approach owes to the fact that the model appropriately replicated all the following three features of Chinese livestock production:

(I) Nonlinear response to policy dynamics

In this research, the response of farmers to policies proved to be complex and nonlinear. The deviation between policy measure and related targets on the one side and farmers' decisions, behavior and thus policy outcomes on the other side commonly appear in the reality of China. Such policy failure can be explained from different perspectives. From the perspective of individual decision-making, farmers possibly refuse to follow the policy intentions to change their behaviors, since they integrate various considerations, beyond the policies, into their decisions. On the one hand, behavioral change can be induced without policy intervention. For example, farmers may learn new technologies from their peers with no governmental persuasion, and then decide to test it. On the other hand, policies possibly conflict with characteristics of farmers. A highly risk averse farmer would reject the governmental-disseminated technology due to the uncertainty of how to use it well.

ANEM embodied the complex co-influence of these considerations by the adequate means of many conjunctions during the individual decision-making process. The considerations involved in this research are in line with many findings from previous studies. As Edwards-Jones (2006) concluded, farmers' decisions on innovation adoption are influenced by a range of factors which may be grouped as the characteristics of the farmers (households), such as education level (Zhou, et al., 2010; Liu, et al., 2013a) and cumulative effects of earlier experiences (Berger, 2001); psychological 'make-up' of the farmers, such as their risk preference (as examined by Gong, et al. (2012); the structure of the farm business, such as the land area per farmer (Zhou, et al., 2010); the social environment, which includes experiences of neighbors (Berger, 2001) and the farmers personal status in their network (Weber and Bergmann, 2010); and the features of their innovations (Rogers, 2003). The influences of policies, neighborhood, farmers themselves, and features of technologies are intermeshing, rather than paralleled. For instance, the network a farmer uses to seek examples of adopters for a technology is determined by the characteristics of both the farmer and his neighborhood, while the number of examples within the network in turn determines the farmer's preference of a certain technology. It is difficult for approaches that attempt to analyze policy outcomes only at an aggregate level, such as regression analysis, to have an insight into the interactions across the influencing factors. In contrast, ANEM is capable to incorporate social theories into environmental system modeling, It makes ANEM advanced to represent the effects of individual considerations on behavior changes.

As illustrated in Table 6.1, ANEM takes into account influential factors that make farmers respond in a nonlinear way to policies (i.e. government, neighborhood, farmers themselves, and technologies/innovations), and also takes into account different process stages via a fragmentation of individual decision-making (i.e. knowledge gain, observation & judgment, performance improvement and confirmation). Every influence source has a few measures to interpose different decision-making stages, while each stage is possibly affected by more than one influence sources.

Table 6.1 Considerations for nonlinear responses of farmers to national policies

	Knowledge gain	**Observation & judgment**	**Performance improvement**	**Performance confirmation**
Governments (policies)	Persuasion; Information dissemination		Prices; Regulatory requirements; subsidies and fines	Prices; Regulatory requirements; subsidies and fines
Neighborhood	Peers persuasion;	Examples of adoption;	—	—
Farmers themselves	Historical experiences; Information seeking	Example seeking	Expectation estimation; Priority between economics and environment;	Historical experiences;
Innovations	—	—	Economic and environmental features	Economics and environmental features

(II) Individualization of diversity

Secondly, involving the factors listed in Table 6.1 in this research implies an abundant diversity among individuals. In other words, the relevance of the influences from the government, the neighborhood and farmers themselves for their individual decision-making (i.e., on either animal output or adoption of manure management technologies) can differ from farmer to farmer. For example, household farmers who prioritize negative environmental impacts of livestock production perhaps give priority to environmental benefits over economic ones. But the negative impacts were downplayed by large scale farmers (Chapter 3). Heterogeneity between frontrunners and laggards with respect to uptake of technologies has been proven, in terms of diverse demographic, psychological and social characteristics of farmers, as well as different attributes of their business (Diederen, et al., 2003). Furthermore, enforcement activities of governmental agencies with respect to environmental policies are not equally distributed across all farmers. The government takes large scale farmers as the main target group for the implementation of technology diffusion and pollution discharge standards. In contrast, biogas subsidies are only provided to household scale farmers.

The individualization in ANEM modeling allows the inclusion of sufficient diversification of various factors at individual level. This research did not attempt to exhaust all the diversity, as suggested in literature, possible to generate divergent decisions. Instead, this research identified and quantified some significant diversity of model variables for the assumed process of individual decision making. Since ANEM decomposed the livestock production into a collection of individual farmers, the values of relevant variables varied with individuals. Some differences in variables appeared across farm scales, such as ‘extra benefits’ (coming from subsidies) and ‘limitation quota of pollution’ (defined by environmental standards). Other kind of diversity were not dependent on farm scales but on individual farmers, such as different estimation of expected performance of livestock production. Depending on such individualized diversity in ANEM, it is no surprise that the waste mitigation potential of policies differ among different farmers within ANEM. For instance, biogas subsidies were sufficient to increase medium-scale farmers’ mitigation by around 10% of emission per animal, but failed to motivate other farmers (Chapter 4). With current policies, farmers who were more environmentalist or confident of the future would, adopt new technologies or keep more pigs on their farms, respectively (Chapter 2).

(III) Interactions among individuals

Last but not least, farmers were found to interact with neighbors by learning from their experiences of adopting innovations. More than half of the respondents in the field survey agreed that, in one way or the other, their practices of manure management were affected by such interactions (Chapter 3). This is consistent with other research. For example, a randomized experiment in Jiangxi Province, middle China found that farmers who had no opportunities to participate in training programs (labeled as ‘untreated farmers’) autonomously learned innovation from their ‘treated friends’ (Cai, 2012). And Ting (2008) indicated that individual experiences and imitation among farmers mainly composed the knowledge base of farmers about innovations. These kinds of mechanisms for innovation diffusion, i.e. the preference of observation and imitation, were stated to be more influential for Chinese farmers than for their counterparts in other countries (Qian, et al., 1999; Schmit and Rounsevell, 2006).

ANEM defined the interactions among farmers through two equations. With a series of criteria, a farmer firstly identified a few neighbors to interact with. And then the farmer accounted the adopters of an innovation, in order to evaluate the uncertainty to adopt it by himself. As stated above, the interactions were important components of both (I) ‘nonlinear responses’ and (II) ‘individual diversity’. Furthermore, the interactions in ANEM implicitly transformed along with individual behavioral changes, since they were established on individual attributes. Unlike the externally assumed changes of policy interventions and behavioral changes that explicitly showed by output variables, the evolution of interactions was endogenous in the model (Chapter 2). The significance of such evolution was visible sometimes. For instance, experiments of information provisioning policy showed that the transforming interactions brought about innovative technologies to more farmers, beyond the effects of direct informing and imitation in the first two years (Chapter 4).

6.2.2 Reflections on ABM approach

The principle of an ABM approach is to model a system from its individual components to the aggregate level (or called bottom-up). It facilitates researchers to represent three crucial features of livestock production: nonlinear responses to policies, diversity on the individual level and interactions among individuals, as accounted for in section 6.2.1. Besides, the practice of using ABM in policy assessment reflects two specialties of ABM.

(I) ABM describes a system in a 'natural' way

Instead of merely looking at a system as a whole, ABM provides the description of the system through simulating "behavioral" entities whose behavioral changes are the cornerstone of system dynamics. Since ABM is able to reveal the 'bottom-up' nature of a simulated system, it makes the model seem to closer reflect reality in many cases (Holland and Miller, 1991; Bonabeau, 2002). As Parunak, et al. (1998) stated, ABM better fits either information-oriented systems or systems with scattered decision makers. This research is a good illustration for both cases. Information seeking has proven to be essential for individual decision-making in the empirical study (Chapter 3) and ANEM validation (Chapter 2). Moreover, the primary dynamic in altering the environmental performance of the livestock sector is that a group of farmers change their decisions of how many animals to keep and/or which manure management technology to adopt. The dispersal of decision-making hence can be whether the decisions would be changed and/or which kind of behaviors would be changed. In addition, the scattered farmers are not stimulated with uniform motivations. The behavioral changes of individuals can come from farmers themselves. For example, the goal which farmers set to orient their activities can vary, such as "need satisfaction" (Xu, et al., 2009), and maximize benefits (this research). Individuals may also change their behaviors due to some external drivers, for example, fluctuant prices or adjusted government permits, among others.

ANEM rejects to take "averages" as behalf of a whole, but advocates (dynamic or static) diversity on the individual level and has the capability to present the effects of individual diversity on aggregate environmental performance (Matthews, et al., 2007). It provides great help to look inside livestock production to find out maybe not better but definitely more specific and tailor-made solutions for environmental problems. For instance, it is possible to test the effectiveness of policies when they aim to change practices of certain kind of farmers (as is done in Chapter 4). Such insight is particularly important for developing countries, such as China, where consistent aggregate data hardly exist (Berger, 2001).

(II) ABM captures emergency on system level

It is found in this research that some phenomena on the system level are impossible to be predicted intuitively by relying on the rules of individual behavior. Such unpredicted or counterintuitive outcomes, called "emergent phenomena", were commonly found in ABM studies (Kauffman, 1996; Wilensky and Resnick, 1999). Emergent phenomena potentially result from nonlinear relationships between stimulations and responses of agents, especially the effects of interactions among agents (Bonabeau, 2002). The example of technology diffusion under the policy of information provisioning, as explained in the previous section, demonstrates the phenomenon that “the whole is more than the sum of its parts because of the interactions between the parts” (Bonabeau, 2002: 7280). Increasing the number of intensive farmers and share of intensive production possibly reverses nutrient mitigation to pollution aggravation, even if farmers do diffuse environmentally friendly technologies (Chapter 5). Therefore, the properties of emergent phenomena sometimes can decouple from the properties of the system’s individual agents. Since ANEM captures emergent phenomena by tracing the transition of individual agents, it implies an underlying explanation for emergency, e.g. which kind of agents and what behaviors are responsible for such phenomena, and when are the possible emergent phenomena occurring (Chapter 4 and 5). This specialty is connected to the last one *(I)*, to some extent.

In short, the practice of using ABM as the key methodology for policy assessment contributes to improved understanding of both Chinese livestock production and the advantages of the ABM approach. Furthermore, it facilitates to answer the other three research questions.

6.3 Assessment of Chinese livestock policies

6.3.1 Exploring environmental reform in livestock production

Ecologically modernizing the agricultural sector, by the means of introducing more environmentally friendly technologies to mitigate water, land and air pollution, has been on the policy agenda of the Chinese central government over the last two decades. In the case of livestock production, manure collection and handling (collectively called manure management) are two of the most crucial practices related to nutrient emissions to air and water. Therefore, the transformation of these two practices is included in the ecological modernization of the livestock sector.

Based on the investigation of pig and poultry farms in two case study areas, it was found that environmental reform relevant to manure management had taken place for a couple of years. The conventional ways to collect manure by washing animal pens and to handle manure by either immediate discharging it to the environment or applying it on farmland were more or less replaced by other technologies, which leak fewer nutrients to the water and air. Compared with other farms, medium-scale farms did not perform as bad as might be expected from their relative vulnerability, like being short of land and governmental favor. Furthermore, the less developed county sometimes had more advanced manure management practices.

A rationality based on environmental concern, which is independent from political and especially economic rationalities, is believed to be important for the ecological modernization of any sector (Mol, 1997). As shown in this research (Chapter 3), an ecological rationality (ER) had emerged in government policies, individual farmers and their networks. Environmental regulation, biogas subsidies and progressive water pricing were examples of environmental concern embedded in government decision making. The farmers declared their awareness of negative environmental impacts of livestock production. This was used as an indicator of individual ER. The common adoption and approval of household biogas digesters illustrated ER in networks.

The effectiveness of three forms of ER, with respect to promoting the adoption of more environmentally sound technologies, was significantly different. The determining role of governments in processes of environmental reform was highlighted in this research, while the other two forms of ecological rationality proved to play positive roles as well. Four modes, with various combinations of ER forms, were distinguished. Governmental ER was involved in three effective modes to ecologize manure management, while isolated individual ER had little effect. This finding is in line with other research. For example, Liu, et al. (2013b) found that environmental concern of rural households does not seem to guide a low carbon transition of daily energy use. A possible explanation is that environmental management in rural China is still highly government-oriented, though agriculture production has already switched to a more market-oriented development model. Nevertheless, the government started to reform its strategy towards rural environmental management. Conventional government steering has shifted to leveraging self-organization of the market and increasing participation of non-governmental actors. Such transformation can be referred to as part of a wider process of political modernization that has been found in a broad area of environmental management in China (Zhong, 2007; Liang, 2012).

6.3.2 Comparing the effectiveness of environmental policy instruments

Since the 1980s, a series of environmental policies has been issued to transform China to sustainable development and to a green governance approach. The transformation gradually covers more and more fields of economy and society. The 12th Five-Year Plan (2011-2015) indicated that the agricultural sector should be subject to the same strict and intensive environmental management as urban and industrial sectors. However, there has not been sufficient understanding of how to enhance the effectiveness of environmental management in livestock production until now. This research examined the effectiveness of five environmental policies, covering standard-based, market-based and information instruments.

Similar to other sectors or countries, in the past China's environmental management towards agriculture can be labeled as following a regulative model (Liu, et al., 2010). The farmers generally stated that regulatory requirements were still the most important factor that enforces changes of their manure management practices (Chapter 3). When a strictly implemented technology standard was assumed in scenario analysis, it was revealed to be much more effective than other (market-based and information) instruments. However, this standard-based policy fell short of providing continued incentives for behavioral change of livestock farmers. And it resulted in more severe negative effects on livestock (economic) development than market-based and information instruments.

More and more economic incentives, such as green taxation and green trade, have been initiated, and will be further promoted in the 12th Five-Year Plan (Wang and Ge, 2006). Market-based instruments were praised by both farmers and local governments in empirical research. Through subsidies, progressive water pricing and preferential policy for manure markets, governmental authorities seem to effectively promote environmental sound manure management (Chapter 3). Pollution fees which are borrowed from the industrial sector, biogas subsidies which have been implemented in rural China for several years now, and manure markets competed to mitigate pollution emissions in the scenario analysis. Among market-based instruments, only the biogas subsidy was found to carry out emission mitigation, ranking after technology standards and information provisioning. Although the mitigation of emissions through biogas subsidies may be not attractive for total nutrient emissions, it showed the potential to improve rural environmental quality, in concert with many other studies (Jiang, et al., 2011). Charging pollution fees, currently applied to mainly enterprises and urban infrastructure, is one of the major strategies and instruments applied by local environmental agencies. Zhang and Wen (2008) claimed in their study that pollution fee policy was implemented in the frame of ‘The Transcentury Green Engineering Program’, but with little positive results regarding environmental improvement. This is also what was found in this study’s scenario analysis on pollution fees for livestock farmers. Its ineffectiveness may result from that it is too low to motivate polluters to amend their practices (Taylor and Xie, 2000). Manure markets restore the crop-animal system, which was fragmented because concentrated livestock production did not have enough land for the application of manure at short distance. In restoring this crop-animal system through a manure market, on-farm nutrient release is reduced (Parker, 2004). In the assumed manure markets, farmers invested the extra income from selling manure in expanding their farms, but less in environmentally sound manure management technologies. This made “manure markets” to be the only scenario generating more emissions than the reference scenario. In practice, the manure markets in Western countries are mature and vast (Oenema, 2004), while the ones in developing countries are usually localized, limited and not well-organized, also in China and India (Ghosh, 2004). The number of farmers to participate in the manure markets was possibly overestimated.

Information instruments were another alternative assessed for environmental management. Governments can provide technological information to polluters to induce technology diffusion. A well-known example is the Energy Star Program in the US (Norberg-Bohm, 1999). In the current empirical study at hand, “no awareness of alternative technologies” was mostly indicated (by 40% of household scale farmers, 26% of medium scale farmers and 27% of large scale farmers) as a barrier to improve manure management practices (Chapter 3). The assumed information provisioning policy intended to break this information barrier through governmental consultation. It had the second largest mitigation potential in the simulations, experiencing a gradual increase of nutrient mitigation during the first half of the simulation and a relatively steady state during the second half. It was surprising to discover such large potential of this instrument in scenario analysis, which stood in sharp contrast with its absence in reality. In fact, information on technologies in governmental extension for a long time focuses more on increasing productivity than on environmental protection (Lv and Ding, 2005). The underlying assumption of ANEM rests on information diffusion and thus contributes to highlight the effectiveness of information instruments. The simulation results are sufficient to alert governmental policy makers that information instruments should be given more consideration regarding both environmental policy making and implementation. As exemplified in section 6.2, the mitigation enhancement of this policy draws on farmers' observation and imitation in their networks. The indicators of "peers persuasion" and "social perceived preference" assist this explanation (Chapter 3).

6.3.3 Environmental impacts of livestock intensification

The intensification of livestock production often results in a rapid increase of productivity of animal husbandry, making it a preferred strategy in many countries. China has launched intensive livestock production for a few decades. Different from Western developed countries, the livestock intensification in China has a number of Chinese characteristics, including the continuing co-existence of household and intensive livestock farming in the foreseeable future; the domination of medium-scale production in intensive production and even in the whole livestock sector; behavior of medium-scale producers being rather similar to household-scale farmers than to industrialized operators; and different policies for different scale groups in livestock production, such as harboring large scale, and subsidizing household- and medium-scale farmers.

This research explored the environmental consequences of Chinese style livestock intensification (Chapter 5). Taking the current case as the starting point, livestock production in the case study area was assumed to be intensified either at planned speed, or to linearly approach the regional or national average trend in three scenarios respectively. Absolute nutrient mitigation occurred and kept increasing with time in two scenarios, including the one that underwent intensification at the regional average rate, to achieve either no growth or slow growth (annually 1.4%) of livestock production. It was found that these two scenarios had almost the same dynamic of distribution of farmers across the three scale groups. As well, scale groups performed similar processes of technology diffusion, indicated by the penetration rates of technology at each scale group, in the two scenarios. Hence, the scenario with lower animal output had correspondingly less nutrient mitigation. However, the assumed rapid development scenario, including 6% annual increase of animal output and tripling the share of intensive production after five years, resulted in higher nutrient emissions than at the starting year, though nutrient emissions increased at a rate of less than 6% annually.

The differences in nutrient emission per animal across the three scale groups revealed their diverse roles in technology improvement and nutrient mitigation. In general, household-scale farmers largely reduced nutrient emissions from their farms by reducing animal output rather than via technology improvement. This finding corresponded to similar conclusions in Chapter 4. In the two scenarios which successfully mitigated nutrient emissions, large-scale farmers were more active than medium-scale farmers to promote the adoption of environmentally friendly technologies in their group. Chapter 4 proved that medium scale farmers are sensitive to environmental policy intervention, while Chapter 5 explored their relative not absolute inertness to autonomously improve environmental performance during the intensification process. However, there was little sustaining improvement of technology adoption, neither in medium- nor large-scale groups. Simulation results hence suggested that the enhancement of nutrient mitigation in the two scenarios was derived from the rising share of intensive production at the aggregate level, rather than the decline of mitigation per animal at group level. In the rapidly developing scenario, technology diffusion within scale groups relatively lagged behind compared to the growing number of medium- and large-scale farmers. The emission per animal of intensive groups thus did not reduce emissions to a similar degree as in the other two scenarios. Although this scenario had the largest share of intensive production, its trend of nutrient emissions at aggregate level deviated from that of other scenarios. Some studies proved that intensive animal farming has less environmental impacts per unit, and hence declared it is the best way to reduce livestock emissions (De Vries and De Boer, 2010). In contrast, this research indicated that mitigation per unit of intensive production was assessed on individual level, which possibly cannot raise corresponding absolute mitigation on system level.

In sum, intensification is not always an adequate solution to reduce the negative environmental impacts of livestock production, although it does contribute to pollution mitigation to some extent. It would be an essential policy issue how to adjust environmental policies following intensification process (Chakravorty, et al., 2007). Very recently, the government is trying to balance intensification of livestock production with the aim to enhance production, and environmental management in rural China. Setting up specific breeding zones (*yangzhi xiaoqu*), which concentrate numbers of small-scale animal farms, and crop-livestock integrated family farms (*jiating nongchang*) are recommended by governments (see No.1 documents of C.P.C. Central Committee and the State Council). This research inclines to support these polices, since they seem to be effective in promoting technology transformation in household- and medium-scale farms.

6.4 Policy implications for Chinese livestock production

The poor effectiveness of Chinese environmental management in the livestock sector in the past was caused by the dominance of economic policies over environmental ones, which is not unfamiliar across the globe. The struggle between economic and environmental interests would be fiercer in poor rural areas with a decentralized authority. The livestock production in Western developed countries seems to have largely finished its intensification process and is now turning to more environmentally sound and sustainable forms of production (Thornton, 2010). So, what should be strategies for a more environmentally sound future livestock sector for China? Which mode should livestock production take: an intensive or an extensive? And what kind of environmental management instruments should be applied to effectively regulate and stimulate livestock farmers towards an ecologically modernized form of production: regulatory, market-based or information instruments? What has become clear from the empirical and simulation findings of this study is that the national policies should be tailored to the specific characteristics of livestock production, in order to advance ecological development in this sector.

More and more studies prove that the statement that intensive livestock production always causes sharper environmental damage is incorrect. Such conclusion may depend on what indicators are used to represent environmental damage. For example, nutrient emissions are possibly reduced significantly in large-scale farming, but then the use of medicines and hormones is highly needed in industrialized farms (Matthiessen, et al., 2006). But there is growing agreement that the nutrient environmental impact of livestock is not so much determined by animal density or scale but by the way farmers manage the waste in their farms, such as the manure management practices involved in this research (Bank, 2012). As Gerber, et al. (2005) stated, environmental damages of livestock production are mainly related to mismanagement of manure and waste water. This enables Chinese livestock production to insist on its process of further intensification, as long as it initiates a paralleling “ecological reform”. There are a host of technical options available for either intensive or extensive farms to mitigate environmental impacts (FAO, 2007). However, it was found that environmental management in the current Chinese livestock sector is autonomously improved via self-regulation through the market, but not to a sufficient extent. Innovative technologies, as described in this research, have been operated in China over more than ten years, but are still not diffused significantly over the livestock sector. Hence, the Chinese government still should be a direct—and obviously much stronger—intervener in promoting environmental management. There is a phase of attaining a ‘crucial mass’ in innovation diffusion, after which the diffusion will be significantly accelerated (Rogers, 2003). Consequently, the government should create opportunities for farmers to get over the tipping point of ‘crucial mass’, by applying various instruments. For instance, it is important for the government to overcome the barriers of farmers’ limited capability in seeking information and economic investment for environmental reform.

In addition, this research shows the inappropriateness of making and implementing policies without considering the specific characteristics of Chinese livestock actors. Even in developed countries where livestock production has been industrially advanced, the environmental management of livestock sector is far from perfect. Developing countries are facing more complex problems, such as co-concentration of human populations and livestock production, a weak regulatory system, among others (Chakravorty, et al., 2007). In this research, some unexpected insights regarding policy effectiveness differ from governmental claims or theoretical statements and should alarm policy makers. For instance, the governments and scholars expect to reduce negative environmental externalities of livestock production with the aid of the market (FAO, 2007; Kaufman and Kalaitzandonakes, 2011; Dikshit and Birthal, 2013). The performance of market-based instruments for environmental protection, however, is not always superior compared to regulatory instruments, but dependent on the relative significance of incentives in cost-benefit evaluations. This finding is in line with some other studies (Ackerman and Gallagher, 2000; Casillas, et al., 2002). Chinese farmers are very sensitive to uncertainty of adopting innovations. Information instruments are hence more attractive than others. But Anderson and Feder (2004) stated that information provisioning had good intentions but was difficulty to be well implemented. To include environmental information in the current extension system seems to be a good strategy for governmental actors. Whichever policy instrument the governments would like to use, it should be modified according to its target group and hence might differ in final operationalization between household, medium and large scale farmers. There are hardly permanently and universally effective strategies to ecologically develop Chinese livestock production. When the intensification of livestock production is inevitable, government has to adjust policy making on the basis of different phases of intensification, various targeted farmers and adoption of diverse measures.

6.5 Implications for policy assessment and future research

Contemporary China is and will be in transition for quite some time. Over the last decades, the rapid development of the Chinese economy amazed observers throughout the world. But it came along with a number of ecological crises all over the country, which shocked the world. Recently, especially following the 12th Five-Year Plan, China seems to put priority on accelerating the shift to a sustainable development model. For the government, policy assessment is a widely used tool to integrate environmental concern into decision making as early as possible. However, doing policy assessment in the context of transitional China, no matter in which sector or region, faces a big challenge to capture the dynamics of the assessed system. The partial transformations which constitute the system dynamics are found to come from multiple horizontal aspects and multiple vertical levels. From the horizontal perspective, the dynamics can be coupled with political, social, technological, and ideological changes (Chunling, 2003; Holbig, 2006; Guthrie, 2012). Taking this research as an example, there was political modernization (represented as the transformation of state-market relationship), technological improvement, and paradigm shift to a more ecological rationality. It is common for developing countries that existing policy measures are hardly adapted to a quickly changing livestock sector (Gerber, 2005). More importantly, the changes of policy measures and targets would pass down to individual decision making, and then to individual behavioral changes, and finally back to aggregate policy outcomes and environmental performance. The ABM approach, with its special bottom-up principle of modeling, is maybe not the sole way to accommodate all these partial transformations, but is proves superior to more 'top-down' aggregate approaches, as has been emphasized many times in this research, ABM has sufficient flexibility to adjust its elements (i.e. agents, behavioral rules, interactions and external environment) according to different cases. A large amount of research has applied ABM for policy studies in different context (Berger, 2001; Downing, et al., 2001; Lempert, 2002; Happe, 2004; Happe, et al., 2006). Therefore, a methodology with a core of ABM approach is a promising choice for policy assessment of not only Chinese livestock production, but also of other sectors, other regions and even other transition countries.

In sum, this study on the livestock sector significantly exposed the value of an ABM approach for policy assessment. The experience of developing and implementing ANEM suggests some necessary improvement for future research. For instance, ANEM is based on cross-section data of a case study, due to limits in time. Panel or time series data in the same area would have been of great help to calibrate and validate ANEM in a more profound way, such as Brown, et al. (2005) did in their research. More case study investigation and interviews, not necessarily in the form of large sampling questionnaire-surveys, would make a better confirmation possible of the generalizability of assumptions in our model or discover other possibilities of farmers' decision-making processes. The market-oriented agricultural sector gives a chance for new actors to participate in animal production and manure management. Some enterprises and crop farmers purchase manure from animal farmers. They can be new agents in the model to involve the entire manure market. There is rising preference of consumers and retailers to eco-labeled agricultural products (Xu, et al., 2012). It may drive farmers to perform more environmentally friendly, and thus shape new kinds of interactions. In some regions, more and more agricultural cooperatives are established, which can tighten the relationships among farmers. As a result, networks in the model should be modified. Hence, it is possible in future research to assess the country-wide environmental impacts of livestock polices, although there remains often a lack of well-organized data collection in China (Chakravorty, et al., 2007).

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Appendix I Questionnaire for household survey

This questionnaire is only used for academic purposes. We will keep your response private. Thanks for your cooperation!

Reviewed by ____________________, on the date of ____________________

Part 1. Basic information

Location:_________Village_________Town_________County_______Province

Name:_________ Gender : ☐ male ☐ female; Age:____ Tel:_ ________________

1.1. Who are decision makers of livestock practices in your family?

A. His/her education level is ☐ lower than primary school; ☐ graduate from primary school (1-6 years); ☐ graduate from junior high school (6-9 years); ☐ graduate from senior high school (9-12 years); ☐ higher than senior high school (>12 years).

B. Do or did he/she work for government? ☐ yes; ☐ no

C. Is he/she a member of the communist party of china? ☐ yes; ☐ no

1.2. Do you agree with this hypothesis?

If you hear of an innovation, like a new technology, you would like to be the first adopter in your village.

☐ very agree; ☐ possibly agree; ☐ neutral; ☐ possibly disagree; ☐ very disagree;

1.3. Do you think there is severe environmental damage of livestock production？

A. Yes, the damage is too severe to threaten human health;

B. There is significant damage, but not affect human beings;

C. There is some but not significant damage;

D. No, I don’t think livestock production is polluting

1.4. If you agree with the negative environmental impacts of livestock production, which kind of pollution do you find?

☐ water pollution from animal waste; ☐ air pollution, particularly GHG emissions; ☐ bad smell; ☐ raise dust; ☐ others:

1.5. Which one of the two options mentioned below you would like to use?

A. When they have very different environmental and economic advantages, I would like to choose ☐ more environmental but expensive one or ☐ less environmental but more economic one;

B. When they have very different economic advantages and little different environmental advantage, I would like to choose ☐ more environmental but expensive one or ☐ less environmental but more economic one

Part 2. Practices of animal breeding

2.1. What is a normal process of breeding animals in your farm?

A. For pigs: production span is ___months; breed animal from ____kg to ____kg; last production span output ________head pigs; ____% animals survive for the whole production span;

B. For boiler: production span is ___months; breed animal from ____kg to ____kg; last production span output _________ boilers; ____% animals survive for the whole production span;

C. For layer hens: production span is ___months; breed animal from ____kg to ____kg; last production span keep________layer hens and _______kg eggs; ___% animals survive for the whole production span;

2.2. Cost of animal farming in last finished production span:

A. Land rent is_______*yuan* for ______mu;

B. Construction of animal pens is ______*yuan* for ______m^2;

C. Price of young animal (piglet or poult) is ______*yuan*/capita;

D. Water cost is ____*yuan*/month for ____(in summer)____(in winter) ton water;

E. Electricity cost is_____*yuan*/month for ____(in summer)____(in winter) kWh;

F. Cost of other energy is _____*yuan*/month for _____ton;

G. Fodder cost is _______*yuan* for ______ ton;

H. Labor cost is_______*yuan* for ______ persons;

I. Environmental cost is _______*yuan* in the name of_________;

J. Others: ____________________________.

2.3. How does your family manage land for agricultural production?

The area of land for cropping is ___________ mu.

The area of land for livestock is_______ mu. Resources of the livestock land is:

A. Own contracted farmland (for free);

B. Own house stand (for fee);

C. Additional land (wasteland) renting from government or village collectives with cost of_____*yuan*/year;

D. Farmland renting from neighbors with cost of_____*yuan*/year;

Others:____

2.4. Benefit of animal farming in last finished production span:

A. Selling animal products ______kg with the price of _____*yuan*/kg;

B. Selling manure______kg with the price of _____*yuan*/kg;

C. Others:____

2.5. How do you sell your products?

A. Retailing at local market;

B. Sending to collection spots nearby;

C. Selling to buyers who visit my house unregularly;

D. Signing a contract with food-process companies;

E. Self-consumption;

F. Others:____

Part 3. Farm-scale decision

3.1. As you know, where is the largest scale pig (poultry) farm in your city?

☐ in this village; ☐ in another village of my town;

☐ in another town of my county; ☐ in another county; ☐ I don't know

The number of animals in that farm is around ___________.

3.2. The last scale shift of your farm is: (multi-choice question)

A. Increasing number of animals from _____ to ____ in the year ____;

B. Decreasing number of animals from _____ to ____ in the year ____;

C. No change in the past five years.

3.3. The major reasons for the scale increase are:

A. Appearance of additional benefit, which was ____________;

B. Expiration of additional cost, which was ______________;

C. Feasibility to sell products at higher prices, due to ☐ governmental guide price, ☐ shift of way to sell product, and ☐ others__________;

D. Feasibility to buy inputs at lower prices, due to ☐ governmental guide price, and ☐ others__________;

E. Increase of ☐ land or ☐ labor;

F. Expectation of profit increase, due to other factors beyond that mentioned above;

G. Successful experience of other farmers;

H. Others: ______________________________________

3.4. The major reasons for the scale decrease are:

A. Deficit of animal production, which arose for consecutive ____ years;

B. No deficit in the past, but possibly deficit in the future (farmer's prediction);

C. Disease outbreaks in the year ____;

D. Decrease of available land, due to _________________;

E. Decrease of available labor, due to_________________;

F. Expiration of additional benefit, which was ___________;

G. Appearance of additional cost, which was ____________;

H. Mandatory requirement made by governments in the name of __________;

I. Others: ______________________________________

3.5. The major reasons for keeping the scale (no expansion) are:

A. No found of larger scale farms round me;

B. No sufficient number of examples to affirm net profits of larger scale operation;

C. Expectation of that profits will not significant increase;

D. Limited capability to expand, respect to ☐ land, ☐ labor for breeding, ☐ labor for manure management, ☐ investment of construction and equipment, ☐ government permits, and ☐ others_______________________________________

E. No reason;

F. Others: ______________________________________

3.6. If your farm is expanded, you would like to recover the investment in ____years.

3.7. How do you consider the uncertainty to achieve profitableness of animal breeding in future?

In current situation, the probability to get net profit is:

☐ < 30%; ☐ 30-50%; ☐ 50-80%; ☐ > 80%; ☐ I don't know

The major components of risk are:

A. Price fluctuation of inputs;

B. Price fluctuation of products;

C. Fluctuation of quantity of sale;

D. Possible disease outbreak;

E. Short of ability to well manage the farm;

F. Policy transition

G. Others: ____________________________________

Part 4. Manure management practices and decisions

4.1. What is the current manure collection technology in your farm?

☐ washing; ☐ manually dry; ☐ machine dry; ☐ bedding; ☐ others

4.2. What is the current manure handling pattern in your farm?

☐ discharge; ☐ untreated fertilization; ☐ treated fertilization; ☐ selling to industry; ☐ others

4.3. You learn the technology/pattern that you are using via:

A. Mass medium, such as TV, radio, newspaper, etc.;

B. Expert consultation;

C. Government agencies, such as village leaders, extent agencies, epidemic station;

D. Non-government organizations, like companies, cooperatives, association, etc.;

E. Interpersonal communication;

F. Own experience;

G. Others: ____________________________________

4.4. Is there any other technologies/patterns do you know? Via which channel?

manure collection technology	washing;	manually dry	machine dry	bedding	others
manure handling pattern	discharge	untreated fertilization	treated fertilization	selling to industry	others

A. mass medium; B. expert consultation; C. government agencies; D. non-government organizations; E. interpersonal communication; F. own experience; G. others

4.5. As you know, where is the nearest demonstration site set by government in your city, regarding to manure management practices?

☐ in this village; ☐ in another village of my town;

☐ in another town of my county; ☐ in another county; ☐ I don't know

The demonstration site is relevant to __________.technology/pattern.

4.6. Did you transform your manure management practices?

A. Yes, I changes collection technology from ________ to _________, with investing *yuan* and _____mu land;

B. Yes, I changes handling pattern from _________ to ___________, with investing *yuan* and _____mu land;

C. No, I changed neither technology nor pattern in the past five years

4.7. The major reasons of your transformation are:

A. Regulatory requirement, as you know, according to ☐ technology standard; ☐ pollution discharge standard; ☐ environment impact assessment; ☐ others:

B. Recommendation from government officials;

C. Persuasion of nearby peers;

D. Cost saving, in terms of ________________;

E. To get more benefits, in the form of ☐ subsidies, ☐ rewards, ☐ price increase, ☐ increasing quantity of products, and ☐ others: _____;

F. Relative ease of use of current technology/pattern;

G. Reduce of environmental damage;

H. Others: _____________________________________

4.8. The major reasons of maintaining manure management practices are:

A. Governmental requirement;

B. Unawareness' of alternatives;

C. No sufficient information of alternatives, although they have been first learned;

D. No sufficient number of adopters to affirm the usefulness of alternatives;

E. Ease of use of current technology/pattern;

F. Minimal cost of current technology/pattern;

G. Too large investment of alternatives;

H. Limited land or labors;

I. Others: _____________________________________

4.9. How many examples do you think are sufficient to judge the benefits of alternatives?

_____% of farmers nearby me.

4.10. Which kind of farmers nearby affect your decision of technology/pattern adoption?

A. Farmers have higher social status, such as governmental officials, C.P.C. members;

B. Operators of ☐ larger scale farms or ☐ similar scale farms to my farm;

C. Farmers who received ☐ higher education or ☐ almost the same education with me;

D. Farmers who are more risk-taking than me;

E. No special citation;

4.11. Do you actively introduce your experience of manure management to other farmers?

☐Yes; ☐ No, unless others ask about my experience; ☐ No, never;

Part 5. Open ended questions

5.1. What's your opinion of livestock policies? Which kind of policies do you think is helpful? Is there any suggestions to policy makers?

5.2. What the governments can do to improve environmental management in rural areas?

Appraising this review (filled by interviewers):

	Very good	Good	Acceptable	Unacceptable	Remarks
Willingness to answer					
Accuracy of answers					

Appendix II Initial settings in ANEM

A. Initialization

Parameter	Categories and Values		Distribution	
Farm scale	Household scale	1	99.23	% of all the farmers
	Medium scale	2	0.73	
	Large scale	3	0.04	
Number of pigs	Household scale	1-49	86.8	% of all the pig output
	Medium scale	50-100	7.5	
	Large scale	>501	5.7	
Collection technology	Washing	1	91	% of household scale farmers
	Dry cleaning	2	9	
	Bedding	3	0	
	Washing	1	75	% of medium scale farmers
	Dry cleaning	2	24	
	Bedding	3	1	
	Washing	1	50	% of large scale farmers
	Dry cleaning	2	50	
	Bedding	3	0	
Handling pattern	Discharge	1	5.6	% of all the farmers
	fertilization	2	49.8	
	Treatment	3	44.6	
	Industry	4	0	

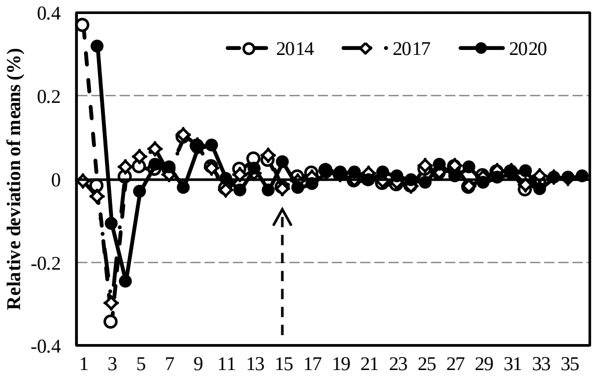
B. Individual heterogeneity

Parameter	Categories and Values		Distribution	
Social status	Neither a part member nor an official	0	equal-probability to value	
	Either a party member or an official	1		
Education level	Uneducated	1	6.3	% of all the farmers
	1~6 years	2	18.1	
	6~9 years	3	51.2	
	9~12 years	4	14.1	
	>12 years	5	10.3	
Risk aversion	Laggards	1	37	% of all the farmers
	Late majority	2	36	
	Early majority	3	21	
	Early adopters	4	2	
	Innovators	5	4	

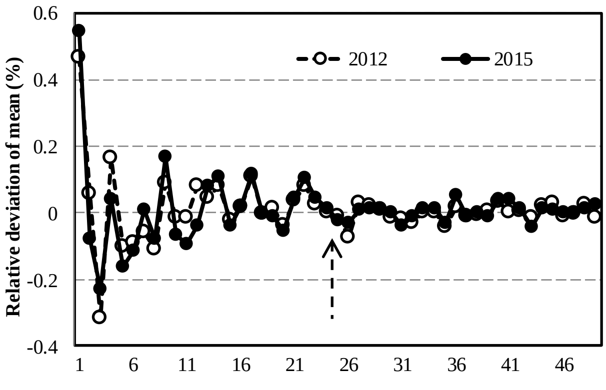
Criteria to define personal interaction network	Social status	1/0	0.41	possibility to be considered as a criteria
	Farm scale	1/0	0.44	
	Education level	1/0	0.32	
	Risk aversion	1/0	0.27	
Environmentalism	Highly profit-oriented	0	47.4	% of all the farmers
	Moderately profit-oriented	1	44.0	
	Environmentalists	2	8.6	
Adoption threshold		<20%	24	% of household scale farmers
		20%-50%	29	
		>50%	47	
		<20%	69	% of medium scale farmers
		20%-50%	22	
		>50%	9	
		<20%	100	% of large scale farmers
		20%-50%	0	
		>50%	0	
Tolerance capability	Years of running under deficit	1	55	% of all the farmers
		2	20	
		3	25	
Perceived probability of achieving benefits (reference)		<0.3	13	% of household scale farmers
		0.3-0.5	30	
		0.5-0.8	13	
		0.8-1	27	
		unknown	17	
		<0.3	12	% of medium scale farmers
		0.3-0.5	34	
		0.5-0.8	15	
		0.8-1	27	
		unknown	12	
		<0.3	0	% of large scale farmers
		0.3-0.5	0	
		0.5-0.8	29	
		0.8-1	57	
		unknown	14	
Weight of risk component	Price fluctuation versus disease outbreak	0.6 versus 0.4	for household and medium scale groups	
		0.7 versus 0.3	for large scale group	
Information channels	Mass media		26	% of all the farmers using the channel
	Agricultural organization		37	
	Government		14	
	Experience		7	
	Interpersonal communication		75	

Appendix III Robustness analysis of simulation results

ABM is commonly stated to have a nature of randomness, due to the huge number of decentralized decision makers (agents), complex interactions among the agents, and possibly dozens of random sub-processes in it (Chu, 2004). When an ABM predicts the system performance under certain conditions, it is of little certainty that the results of a signal run approximate ‘real results’ rather than just a coincidental or random outcome. A common way to reduce the error of such randomness is to use the mean results of multiple runs under the same situation. Previous research suggested that 10-30 iterations are adequate to reduce errors (see Polhill et al., 2001; Downing et al, 2003; Brown and Robinson, 2006; Saqulli et al., 2010). In this study 35-50 runs for each scenario have been made to observe the change of means along with every additional iteration. Taking one environmental policy scenario (from the five policy scenarios mentioned in Chapter 4) as an example, it is found that the means of annual nutrient emissions tend to stabilize after more than 15 iterations (with less than 0.1% deviations; see Figure S-III.1(a)). The critical point for stabilization of one of the three development scenarios as mentioned in Chapter 5 is found to be around 25 iterations (see Figure S-III.1(b). Therefore, the means of 15 and 25 simulations of each policy scenario and development scenario, respectively, are used for result analysis in the respective chapters.



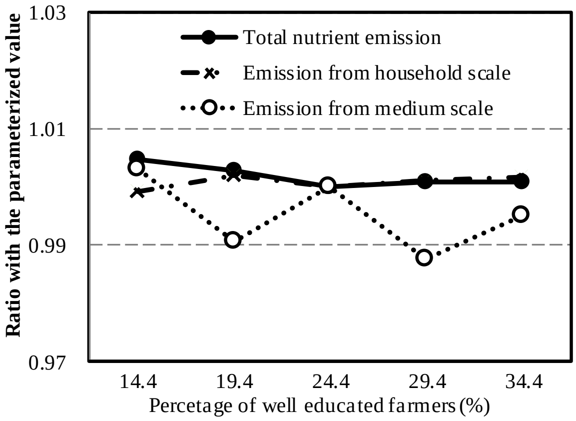
(a) one policy scenario from Chapter 4



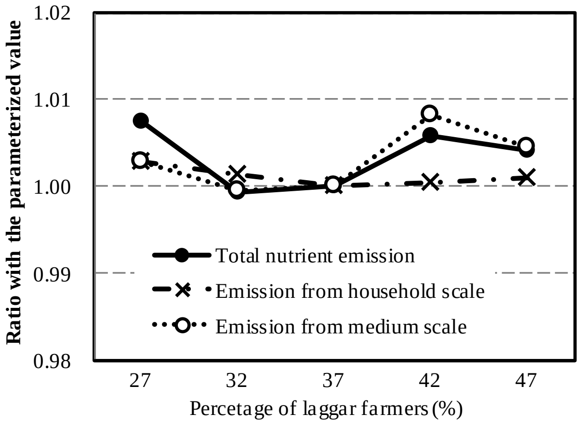
(b) one development scenario from Chapter 5

Figure S-III.1 Dynamics of mean results of annual nutrient emissions in two example scenarios (policy scenario (a) and development scenarios (b))

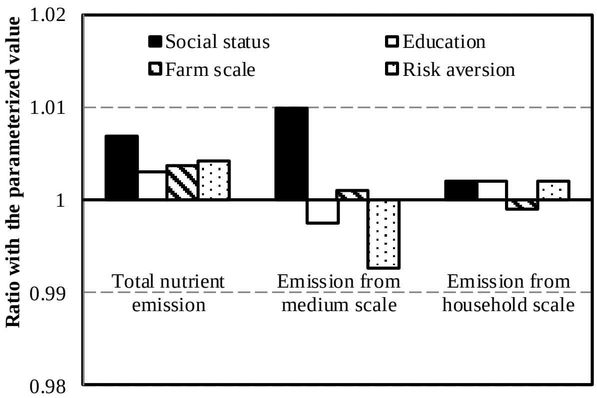
As the second step of analyzing the robustness of ANEM, a sensitivity analysis on initial settings was performed (for the list of all initial settings, see Chapter 2). Four examples of initial settings have been used in this sensitivity analysis (education level, risk aversion, criteria that define observation network, and technology adoption threshold), and the results are shown in Figure S-III.2. The first three are related to the construction of interactions among agents. Education level and risk aversion partly determine whether a certain agent would be an opinion leader, while the four criteria define who an agent prefers to observe (i.e. the farmer who has higher social status, and/or larger scale farm, and/or is better educated, and/or more risk taking). The fourth initial setting that is included in the sensitivity analysis – the adoption threshold value – reflects an agent's cognition of uncertainty to adopt certain innovations. The parameterized values of them are listed in Appendix II.



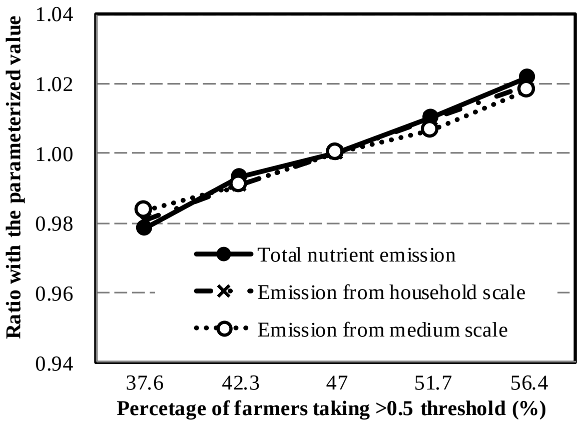
(a) impact of education level



(b) impact of risk aversion



(c) impact of criteria for observation network



(d) impact of adoption threshold

Figure S-III.2 Results of the sensitivity analysis on several initial settings

The vector variable of 'criteria for observation network' gives the probabilities of each single criterion to be considered by a certain agent. In the sensitivity analysis 10% increases of such probabilities are assumed for each of the four criteria, respectively (showed as x-axis in Figure S-III.2(c)). For education level, the initial setting of well-educated farmers (24.4%) across the whole farmer community was changed to deform toward both more well-educated farmers and towards less well-educated farmers (Figure S-III.2(a)). Similar tests are carried out for risk aversion (changing the initial setting of 37% of farmers that are considered laggards to both sides; Figure S-III.2(b)) and for the adoption threshold value (changing the initial setting of 47% of all farmers taking a threshold value of >5%; S-III.2(d)). The sensitivity analysis found that total nutrient emissions and emissions in groups vary with the changes in these initial settings, however, to a very small extent. The variation of the initial settings is more than ten times as large as the variation of simulation outcomes. Changing the setting of adoption threshold and probabilities of criteria are more sensitive than the other two variables. In short, the sensitivity analysis provides clear indications that the model is sufficiently robust for simulations. The comparisons between scenarios can thus be considered meaningful.

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Summary

Over the recent decades, environmental management has been promoted in China, and has gradually transferred from urban areas and industrial sectors to rural areas and the agricultural sector. Livestock production is extremely important for China, for increasing rural household income and guaranteeing long-term food security. At the same time of that the Chinese livestock sector amazed the world by its rapid development and intensification, it was criticized for its significant environmental damages. Policy assessment, which has played an important role in improving environmental management in many countries, offers an opportunity to improve livestock environmental management and to mitigate pollutant emissions. However, no sophisticated or commonly accepted methodology has been developed and implemented for policy assessment yet. Therefore, the central objectives of this research are to explore an adequate methodology for comprehensive assessment of sectoral policies for Chinese livestock production, and to design improved environmental management for the livestock sector. This done through empirically studying factors that change farmers' practices, comparing the effectiveness of various environmental policies and examining the environmental consequences of different sectoral development paths.

Agent-Based Modeling (ABM) is used as a core methodology for this research. On the basis of some social theories, a specific environmental ABM, named Agent-Based Nutrient Emission Model (ANEM), is developed and operationalized for Chinese livestock sector in chapter 2. Through describing individual decision-making of heterogeneous farmers at different scale regarding manure management practices, ANEM sufficiently represents the complex, nonlinear and interdependent responses of farmers to policies. These features represented by ANEM significantly affect policy outcomes and associated environmental consequences, but were largely ignored in policy making, implementation and evaluation in China up until today. A four-year (2005-2008) simulation of pig production and the associated nutrient emissions in the two case study areas of this research by ANEM, proves ANEM's ability to adequately capture real-world dynamics.

Manure management practices influence the flows of animal waste, and thus determine on-farm nutrient emissions. To understand the current status of manure management practices in China, an investigation is conducted in pig and poultry production—two major components of Chinese livestock production—by means of questionnaire surveys in two case areas. The

hypothesis that medium-scale farmers have the least capability for environmentally sound technology uptake is refuted in the investigation. The comparison of the two cases proves that less developed areas are not always laggards in adopting environmentally advanced technologies.

Furthermore, in chapter 3 the concept of ecological rationality is employed to explain differences of farming practices and investigate which governance arrangements are most successful in ecologizing Chinese livestock production. The Chinese government has integrated environmental concerns into a number of policies, not only through regulatory instruments but also by financial incentives, stimulation and information dissemination to farmers. These policies significantly motivate farmers to adopt environmental sound technologies. The vital role of governments in bringing about improved environmental management is confirmed, while the role of individual famers and networks of farmers are not major contribution to introduce ecological rationalities in farming practices.

To enhance the effectiveness of environmental policies in livestock production, policy-makers face an essential question: Which environmental policy instruments aimed at which group of farmers improve best the effectiveness of pollution mitigation? Using ANEM as a key tool, chapter 4 examines and compares the environmental consequence of five environmental policy instruments, covering regulatory standards, market-based instruments and information instruments. A stricter technology standard mitigates nutrient emissions to the largest extent. However, it strongly constrains production development, making it less favorable by Chinese governmental authorities. Biogas subsides achieve emission reduction in household- and medium-scale farms, but not in large-scale farms. Charging pollution fee and setting up a manure market seem to be little effective for nutrient mitigation. Information provisioning significantly promotes technology improvement across all scales, with slight negative impacts on production development. Governing medium-scale farms is likely to be most consequential for environmental improvement in rural China, since they better perform in adopting environmental technologies and in avoiding reduction of animal production.

Promoting intensification is a major strategy for the Chinese livestock sector. However, there have been few studies that quantitatively explored the environmental consequence of such a structural transformation. Based on scenario simulation and using ANEM, the strategy of intensifying livestock production has been assessed from the perspective of environmental management in chapter 5. The nutrient emissions of three feasible development scenarios, which involve different growth of animal output and intensification processes, are simulated in regional livestock production. The simulation results prove that intensification can play a positive role in nutrient mitigation. However, intensification fails to achieve absolute nutrient mitigation when it copes with an ambitious growth of production. Therefore, Chinese livestock production can insist on its intensification process, but needs an accelerated environmental reform to guarantee minimal environmental damages.

In sum, this research is the first in-depth assessment of the environmental impacts of Chinese livestock policies. ABM is used as an innovative approach to describe the dynamics of livestock sector based on individual but interdependent farmer behaviors, in order to capture emergency on system level. A number of policy recommendations could be formulated based on this research. Generally, Chinese livestock production can continue rapid growth and intensification, as long as it parallels stringent “ecological reform”. To advance ecological modernization in Chinese livestock production, national policies should be tailored to the specific characteristics of this sector. In addition, this research concludes that a ABM based methodology is appropriate for policy assessment, a conclusion that also holds beyond Chinese livestock production towards other sectors and even other transitional societies.

Samenvatting

In de afgelopen decennia is er in China een toenemende aandacht voor het stimuleren van milieumanagement, een trend die geleidelijk vanuit stedelijke gebieden en industriële sectoren is doorgedrongen naar het platteland en de agrarische sector. Dierlijke productie is bijzonder belangrijk voor China, aangezien het is gerelateerd aan inkomensstijging voor huishoudens op het platteland en om op lange termijn de voedselzekerheid te kunnen garanderen. De Chinese veehouderij heeft de wereld versteld doen staan door snelle ontwikkelingen en intensivering, maar is tegelijkertijd bekritiseerd vanwege de aanzienlijke druk op het milieu. Beleidsevaluaties, welke in veel landen een belangrijke rol spelen in het verbeteren van het milieumanagement, bieden de mogelijkheid om milieumanagement te verbeteren en de uitstoot van verontreinigende stoffen te beperken. Echter, er is tot nu toe nog geen geavanceerde of algemeen aanvaarde methode ontwikkeld en geïmplementeerd. Daarom is de doelstelling van dit onderzoek om te komen tot een bruikbare methodologie voor het uitvoeren van een uitgebreide evaluatie van het sectorale beleid voor de Chinese veehouderij, alsook een beter milieumanagementsysteem voor de veehouderij te ontwerpen. Om dit te bereiken zijn de factoren die de praktijken van boeren veranderen in een empirische studie onderzocht, is de effectiviteit van verschillende milieubeleidsinstrumenten met elkaar vergeleken en zijn de milieugevolgen van verschillende mogelijke ontwikkelingsrichtingen van de veehouderij bestudeerd.

In dit onderzoek is *Agent-Based Modeling* (ABM) gebruikt als centrale methodiek. Hoofdstuk 2 laat zien hoe, aan de hand van een aantal sociale theorieën, een milieuspecifieke ABM is ontwikkeld. Dit model, genaamd *Agent-Based Nutrient Emission Model* (ANEM), is geoperationaliseerd voor de Chinese veehouderij. Het brengt de individuele besluitvorming van heterogene boeren over hun mestbeheerpraktijken in kaart en houdt rekening met de verschillende schaalniveaus. Hierdoor is het mogelijk dat ANEM in voldoende mate de complexe, niet-lineaire en onderling afhankelijke reacties van boeren op het beleid laat zien. De kenmerken welke worden gerepresenteerd door ANEM hebben een significante invloed op de resultaten van beleid en de bijbehorende gevolgen voor het milieu, maar werden tot nu toe grotendeels genegeerd in de Chinese beleidsvorming, -uitvoering en -evaluatie. Aan de hand van een vier jaar simulatie (2005-2008) van varkenshouderij en de bijbehorende nutriëntenemissies in twee studiegebieden wordt aangetoond aan dat ANEM op adequate wijze de dynamiek van de realiteit weet weer te geven.

Mestbeheerpraktijken beïnvloeden de stromen van dierlijk afval en bepalen daarmee de nutriëntenemissies op een boerderij. Om de huidige situatie van mestbeheerpraktijken in China te begrijpen is er een studie uitgevoerd in de varkens- en pluimveehouderij, twee belangrijke sub-sectoren in de Chinese veehouderij. In dit onderzoek is voor de dataverzameling gebruik gemaakt van enquêtes in twee studiegebieden. De hypothese dat middelgrote boeren de minste mogelijkheden hebben om over te stappen op milieuvriendelijke technologieën wordt weerlegd. De vergelijking van de twee sub-sectoren bewijst dat minder ontwikkelde gebieden niet altijd achterblijven als het gaat om het toepassen van geavanceerde milieuvriendelijke technologieën.

In hoofdstuk 3 wordt het concept "ecologische rationaliteit" gebruikt om verschillen tussen landbouwpraktijken uit te leggen en te onderzoeken welke sturingsarrangementen het meest succesvol zijn in het verduurzamen van de Chinese veehouderij. De Chinese regering heeft milieuoverwegingen geïntegreerd in een aantal beleidsmaatregelen, niet alleen via wet- en regelgeving, maar ook door middel van financiële instrumenten, en het stimuleren en informeren van boeren. Door dit beleid worden boeren in aanzienlijke mate gemotiveerd om milieuvriendelijke technologieën toe te passen. Deze studie bevestigt dat de overheid een belangrijke rol speelt in de totstandkoming van een beter milieumanagementsysteem, terwijl de rol van individuele boeren en de netwerken tussen boeren geen belangrijke bijdrage hebben in het ontwikkelen van een ecologische rationaliteit in de landbouwpraktijk.

Om de effectiviteit van het milieumanagement in de veehouderij te verbeteren worden beleidsmakers geconfronteerd met een essentiële vraag: Welke milieubeleidsinstrumenten, gericht op welke boeren, zijn het meest effectief voor het terugdringen van vervuiling? Met behulp van ANEM wordt in hoofdstuk 4 de gevolgen van vijf milieubeleidsinstrumenten onderzocht en vergeleken. Deze instrumenten variëren van wet- en regelgeving, economische instrumenten tot informatie-gerelateerde sturingsmiddelen. Het grootste effect in het terugbrengen van nutriëntenemissies wordt bereikt door het toepassen van een striktere technologiestandaard. Echter, deze maatregel belemmert de productieontwikkeling, en wordt daardoor door Chinese overheidsinstanties minder gunstig geacht. Subsidies ten aanzien van biogasproductie leiden tot een emissiereductie in huishoudens en middelgrote bedrijven, maar dit geldt niet voor grootschalige landbouwbedrijven. Het vragen van een vervuilingsvergoeding en het opzetten van een mestmarkt lijkt weinig effectief om nutriëntenemissies terug te brengen. Op alle schaalniveaus werkt informatievoorziening bevorderlijk voor technologische verbetering, al zijn er – zij het in beperkte mate – negatieve effecten op productieontwikkeling. Het sturen op verbeterd milieumanagement in middelgrote landbouwbedrijven is waarschijnlijk het meest effectief in de verduurzaming van het Chinese platteland, omdat deze beter presteren als het gaat om het aanpassen aan milieutechnologieën en het in stand houden van dierlijke productie.

Voor de Chinese veehouderij is het bevorderen van intensivering een belangrijke strategie. Er zijn echter weinig studies bekend waarin kwantitatief onderzoek is gedaan naar de milieueffecten van een dergelijke structurele verandering. In hoofdstuk 5 is de strategie van de intensivering van de dierlijke productie beoordeeld vanuit het oogpunt van milieumanagement. Hierbij is gebruik gemaakt van scenariosimulaties en ANEM. De nutriëntenemissies zijn gesimuleerd in drie mogelijke ontwikkelingsscenario's voor een regio, die gebaseerd zijn op een verschillende groei van de omvang van de dierlijke productie en van de intensivering van de veehouderij. Resultaten van de simulatie tonen aan dat intensivering een positieve rol kan hebben in de mitigatie van nutriënten. Maar intensivering is niet in staat om in absolute zin een terugdringing van nutriënten teweeg te brengen, wanneer deze samen gaat met een ambitieuze groei in productie. Daarom kan de Chinese veehouderij het intensiveringproces stimuleren, maar moet het ook een versnelde ecologische hervorming inzetten om zeker te zijn dat er sprake is van een minimale druk op het milieu bij voortaagnde groei van de dierlijke productie.

Kortom, dit onderzoek is de eerste diepgaande evaluatie van de milieueffecten van het Chinese veehouderijbeleid. ABM is gebruikt als een innovatieve benadering om de dynamiek van de veehouderij te beschrijven, gebaseerd op basis van het individuele gedrag van boeren alsook de onderlinge afhankelijkheden tussen boeren, om op die manier geaggregeerde effecten op systeemniveau te duiden. Op basis van dit onderzoek kan een aantal beleidsaanbevelingen worden geformuleerd. In het algemeen kan worden gesteld dat de Chinese veehouderij snel kan blijven groeien en intensiveren, zolang dit samengaat met een duidelijke ecologische hervorming. Om ecologische modernisering in de Chinese veehouderij te bevorderen, moet het nationale beleid worden afgestemd op de specifieke kenmerken van deze sector. Daarnaast wordt in dit onderzoek geconcludeerd dat een op ABM gebaseerde methodologie geschikt is voor beleidsevaluaties, een conclusie die ook geldt buiten het domein van de Chinese veehouderij, en kan worden vertaald naar andere sectoren en zelfs andere samenlevingen in transitie.

摘　要

近几十年来，中国的环境管理有了长足的进步，并且已经逐渐从城市地区和工业行业推广到了农村和农业生产中。畜禽养殖是中国经济的重要部分，对于提高农民收入和保障长远的粮食安全都有重要的意义。中国的养殖业以其快速的发展和集约化震惊了世界，但同时也因其带来的显著环境破坏而饱受争议。政策环评（Policy Assessment）曾在许多国家的环境管理实践中扮演重要的角色，也为改善养殖业环境管理、减少养殖污染物排放提供了契机。然而到目前为止，政策环评还没有一套成熟的或被普遍接受的方法学框架。因此，本研究的核心目的是探索适合中国养殖行业政策综合评价的方法学，并为养殖业环境管理做出改进性的设计。研究内容包括针对影响农民行为变化因素的实证研究、多种环境政策效果的对比和不同行业发展路径环境影响的检测等。

基于主体的建模方法（Agent-Based Modeling），即 ABM，在本研究中被用作方法学的核心。以一些社会学理论为基础，第二章开发了一个命名为 ANEM 的基于主体的环境模型，并将之运用于中国的养殖行业。通过描述多样化的、不同生产规模的养殖户们对养殖粪便管理做出个体决策的过程，ANEM 充分表达出了农户个体所做政策响应的复杂性、非线性和个体间相互依赖性。ANEM 所表现出来的这些特征能够显著地影响政策结果以及相应的环境影响，但是迄今为止在中国的政策制定、执行和评价中仍被忽视。以 ANEM 模型在案例地区进行了四年（2005-2008）的生猪养殖和相应营养物质排放的模拟测试，结果表明该模型具有恰当地扑捉现实动态变化的能力。

粪便管理行为影响着养殖废弃物的物质流，并以此决定了养殖场内营养物质的排放。为了研究中国养殖业粪便管理行为的现状，本研究针对中国畜禽养殖业最主要的两个生产部分——生猪和禽类生产，以问卷调查的形式在两个案例地区进行了入户调查。研究假设中等规模养殖场（专业户养殖）最不具备使用环保型技术的能力。但调查结果推翻了这一假设。两个案例的对比证实了欠发达地区在使用先进环保技术方面

并不总是落后于更发达的地区。

第三章使用了生态理性的概念以解释养殖行为之间的差异，并调查了最能推动中国养殖业生态化发展的管理安排。中国政府已经将对环境保护的关注纳入到一些政策中，这其中不仅包括控制型的手段，也包括一些经济性的激励、鼓励性的措施和对农户的信息宣传。这些政策显著地刺激了农户对环保型技术的使用。研究确认了政府在推动环境管理中扮演着至关重要的角色，而农户个体和他们之间形成的交流网络并不是将生态理性融入农户行为的主要贡献者。

为了提高养殖业环境政策的有效性，政策制定者们面临着一个关键问题：哪种政策手段，在针对哪类农户人群时能够最好地改进污染物减排的效果？利用 ANEM 模型作为核心工具，第四章测试和对比了五种环境政策手段的环境绩效，包括控制性规范、基于市场的措施和信息手段。一个更严格的技术标准最大程度低削减了营养物质的排放。但是此政策严重地约束了生产发展，这也使得该政策不受中国政府当局的欢迎。沼气补贴在家庭养殖（散户）和中等养殖场中实现了排放减量，但是没能在大型养殖场中推动减排。收取排污费和建立粪便交易市场对营养物质减排的作用比较微弱。向农户提供信息显著地在所有规模的养殖场中推动了技术的改进，并只对生产发展产生较轻的负面影响。中等规模的养殖场应当成为是改善中国农村地区环境最重要的管理对象，因为中等规模养殖场在使用环保型技术和避免缩减养殖生产两方面都有最佳的表现。

推动集约化生产是中国养殖行业的主要发展战略之一。然而，很少有研究定量地探讨这种行业结构变化可能带来的环境影响。基于情景分析和 ANEM 模型的使用，第五章从环境管理的角度评价了养殖生产集约化这一策略。研究模拟了地区养殖业在三种可能的发展情景下的营养物质排放情况。发展情景的差异包括不同的产量增长率和不同的集约化率。模拟结果证实集约化可以在营养物质减排中发挥正面作用。但是在生产增长过快的情况下，集约化进程已无法实现营养物质排放的绝对量减少。因此，中国的养殖业可以坚持其集约化的进程，但同时也需要加速行业的环境改革以确保将

环境破坏最小化。

总之，本研究第一次深入地评价了中国养殖业政策的环境影响。作为一种创新性的方法，基于主体的建模方法以个体化的、但相互依赖的农户行为为基础来描绘养殖业的行业动态，以扑捉系统层面所涌现的现象。研究还形成了一些政策建议。总的来说，中国养殖业可以继续其快速发展和集约化的趋势，但必须并行以严格的“生态化改革”。为推动中国养殖业的生态现代化，政府必须按照行业特点量身定制国家性的政策。另外，本研究总结发现以基于主体的建模方法为基础的方法学是适宜于政策环评的。这一结论不仅适用于中国的养殖行业，也可拓展到其他行业甚至是其他处于转型期的社会。

About the author

Chaohui Zheng was born on 12 May 1984 in Zhoushan, Zhejiang Province, China. She obtained her Bachelor degree in Water Supply and Sewer System Engineering from Tsinghua University in 2006, and her Master degree in Environmental Engineering from Tsinghua University in 2008. In October 2008, she started to pursue her Dectoral Degree in Wageningen University, the Netherlands.

Major publications:

Zheng C., Liu, Y., Bluemling B., Chen, J. and Mol, A.P.J., Modeling the Environmental Behavior and Performance of Livestock Farmers in China: an ABM approach. *Agricultural Systems*, 2013, 122, 60-72.

Zheng C., Bluemling B., Liu, Y., Mol, A.P.J. and Chen, J., Managing manure from China ́s pigs and poultry – the influence of ecological rationality, *AMBIO*, doi:10.1007/s13280-013-0438-y.

Chaohui Zheng
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the course	Department/ Institute	Year	ECTS (=28 hrs)
Project related competences			
Techniques for literature search and argumentation building for SURE PhD students	WUR, ENP	2008	1.8
Sure course on institutional theories	WUR, ENP	2009	4.3
Writing research proposal	WASS	2008	6
General research related competences			
Qualitative data analysis: procedures and strategies , YRM 60806	WUR	2008	6
Introduction course	WASS	2009	1.5
Interdisciplinary and transdisciplinary research: intervision and communication skills	WGS, WASS	2009	1.1
From topic to proposal	WASS	2009	4
Career related competences/personal development			
Summerschool (STEP 2011)	SOE, Tsinghua University	2011	4
"The study on quantitative linkage from land use changes to agriculture non-point pollution in China"	SURE workshop, Wageningen	2009	1
"Assessing environmental impacts of Chinese livestock husbandry policies: integrating livestock practices into environmental modeling"	SURE workshop, Nanjing, China	2010	1
"Assessing environmental impacts of Chinese livestock & husbandry policies"	SURE workshop, Nanjing, China	2011	1
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