Accessing the impact of negative externalities from Concentrated Animal Feeding Operations in China

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Abstract

Concentrated animal feeding operations (CAFOs) have emerged as a result of the rapid industrialization of the livestock sector five decades ago, leading to positives such as increased global food security and negatives: massive point source pollution sites, potential human health effects, and questions over animal cruelty. Though much research has been published in the United States regarding these harms, this paper specifically focuses on trends and pollution from the livestock industry in China. With data gathered from the National Bureau of Statistics, the statistical database for China, and the World Bank, I analyze four geographical areas with differing outputs of meat, which I use as a proxy for the number of CAFOs in a region. The findings reveal a strong and positive correlation between the output of meat and pollutants. My results show that it is certainly plausible for livestock to be a strong contributor to the varying levels of observed pollutants.

Keywords: CAFOs, Livestock, Pollutants, Greenhouse gases, Manure, Environment, Green technology, Meat production

Introduction

In recent decades, China has emerged as the world's leading producer of livestock, overtaking the United States and Europe. Growing demand, driven by a growing population, technological innovation, and improved infrastructure has fueled the expansion of the livestock sector, resulting in impressive aggregates of total industry output (Bai et al., 2018). The gross output value of animal husbandry in China has increased by 13612.4% from 1978 to 2018 (3.23 billion USD to 442.91 billion USD).

As with many industries, the livestock sector has industrialized, from small-scale family farms into large industrial complexes. Concentrated animal feeding operations (CAFOs) are an intensive version of animal feeding operations (AFOs), where at least 1000 animal units, equivalent to one million pounds of animal weight, are confined for over 45 days per year in an area without vegetation (United States Environmental Protection Agency, 2021). Recently, the scrutiny has been placed on these operations as a result of agriculture being identified as a driving factor of climate change.

This paper focuses on negative externalities produced by CAFOs in China. Negative externalities are the costs on third-party members not included in the production costs of the agent who generates the externalities. The specific lens on pollution within negative externalities has been chosen due to the extensive harmful effects that pollution from these operations imposes on surrounding communities. The plethora of impacts created by CAFOs have been studied at length in various contexts, but the vast majority of studies focus on operations in the Midwest of the United States. Within China, research concentrates on aquatic pollution and the potential health impacts of antibiotics which are biomagnified up the food chain to affect human and animal life. Although growing emphasis has been placed on mitigation of harmful environmental impacts, to my knowledge, no comprehensive study on externalities from water and atmospheric pollution specifically in the context of China has been published.

CAFOs are the epitome of industrialization's response to traditional agriculture. When properly managed, the phenomenon generates economies of scale and efficiency. In the United States, it has allowed for milk production to double, meat production to triple, and egg production to increase fourfold since the 1960s (Delgado et al., 2003). The operation's goal is to maximize output while minimizing costs, effectively resulting in low-cost animal products and production, easier management of animals, and less resource consumption in relation to family-operated livestock farms. Animals are fed specialized feed and antibiotics to speed growth – in comparison to the 1920s, chickens can reach more than double the size in less than half the time (Pew, 2009).

Yet, this process has also led to massive tradeoffs with the environment and transformative global impacts. Total greenhouse gas emissions in China increased more than two-fold, from 233 to 520 tera-grams of carbon dioxide equivalent between 1980 and 2010 in the livestock sector (Bai et al., 2018). The amount of feces and urine resulting from the smallest CAFO is equivalent to that of 16,000 humans, which leads to continual questions regarding waste disposal and treatment. This waste is not always treated properly to rid it of possible pathogens and antibiotics present in the matter, which can lead to severe and adverse impacts on human and animal health (Hribar, 2010). Moreover, the number of nutrients contained in fecal matter, such as nitrogen and phosphorous, can lead to harmful algal blooms in nearby streams and bodies of water.

The environmental harms which result from the advent of the operations described here have been increasingly highlighted as the world becomes more aware of sustainability issues. The aim of this paper is to identify the numerous negative externalities associated with producing livestock at CAFOs. A summary of the findings is this: there are strong positive correlations between livestock production and four major pollutants in wastewater and waste gas in China. From this, it is certainly plausible to assume that livestock production, which arises from CAFOs, contributes to the concentration of pollutants in four distinctive areas: Shanghai, Jiangxi, Hunan, Shandong.

The paper is organized as follows: in section 2, I explore previous work on CAFOs and the externalities they generate; further, I highlight how my findings fill a gap in the literature. In section 3, I introduce the data and its sources; in section 4 I present the empirical findings; section 5 is the conclusion.

Literature Review

Livestock Trends

Worldwide, the agricultural and livestock sectors have undergone significant transformations. Although it is one of the last means of production to industrialize, the livestock sector has experienced massive and standardized changes in the raising of animals. The trends indicate that despite an overall reduction in the number of total farms, there has been an overall increase in the concentration of animals and size of each farm (Copeland, 2010; Donham et al., 2007; Ikerd, 2013). This pattern points toward an industry-wide switch to large-scale factory farms. In the United States, between the years 1980 to 2008, the number of beef cattle, hog farms, and dairy farms fell by 41, 90, and 80 percent, respectively (The United States Department of Justice, 2020). However, between 1982 and 1997, the number of animals at singular feeding operations rose by 88 percent, coupled with an increase of more than 50 percent for the number of CAFOs (U.S. Department of Agriculture, 2000). Although this statistic is for the United States, it is applicable for China as both countries have undergone very similar trends in livestock production, and have nearly identical values on the livestock production index (World Bank, 2018).

Manure Management

Manure is typically beneficial for agriculture, serving as fertilizer to stimulate growth for new crops. However, the sheer amount of animal waste produced at CAFOs creates many problems, including disposal of increasingly large quantities of manure, and management of the many contaminants found in it. Typically, manure is first stored in lagoons, and then it is applied to land (Nicole, 2013). The storage process has many pitfalls — e.g., the lagoons all leach to some degree — and during storms, waste can burst or spill into surrounding fields or waterways (Nicole, 2013). As no sewage treatment process exists, there are over 150 pathogens in animal manure that may impact human health. Once the manure is applied to soil, these pathogens can survive for up to two months, creating the possibility of contaminating our food source and water (Hribar, 2010; Hu et al., 2017).

The application of manure to land creates a multitude of problems. The land cannot properly absorb the nutrients as fertilizer since the waste is typically overapplied. While there is an established threshold of 30 tons/hm^2 of animal waste loading on land to preserve land quality in China, six provinces have already overshot this guideline (Hu et al. 2017). Furthermore, the excess nutrients easily runoff into nearby bodies of water, causing pollution which severely damages aquatic life (Burkholder et al., 2007; Hu et al., 2017; Ikerd., 2013; Wing et al., 2013).

Water pollution

River contamination has been recorded during severe weather conditions, including manure spillage from lagoons or other containment methods. The impacts of such accidents are long-lasting and severe: over 35,000 miles of river have been polluted in the US, resulting in massive dead zones[1] from algal blooms, fish kills, and bacterial contamination (Burkholder et al., 2007; Gurian-Sherman, 2008; Ikerd, 2013). In 2005, a storage lagoon in upstate New York spilled, with millions of gallons of manure ending up in the Black River, resulting in an estimated 375,000 fish deaths (New York State Department of Environmental Conservation, 2007). In Jiyun River, a river in Beijing, which flows through the central meat-producing counties, research sampling has found that there are 2 to 4 times above-normal antibiotic levels in the water, which can negatively impact both aquatic and human health (Zhang et al., 2014).

Other than these specific point-source incidents, excess nutrients from the land application of manure also frequently end up in surface and underground water sources. For surface water contamination, wind and rain often move manure components into waterways; direct discharging of manure into water is also practiced. Overloading the water with nutrients and increasing water turbidity[2] can seriously impact aquatic life by changing these organisms' established environments (Copeland, 2010). Manure also has the potential to percolate

[1] Areas where the amount of dissolved oxygen in water is unable to support most marine life.

[2] A measure of the amount of suspended matter or relative clarity of water

into soils and affect groundwater quality. In China, 62 percent of wells were found to exceed the nitrate standard set by the World Health Organization (WHO), with the main identified sources of nitrate coming from manure and fertilizer (Bai et al., 2017).

Air pollution

In addition to water pollution, CAFOs also emit greenhouse gases that disrupt the atmosphere. Animal activities, from breathing to handling to feeding, and animal waste, are all sources of Volatile Organic Compounds (VOCs)[3] that can negatively impact both the environment and human health (Yuan et al., 2017). Air quality assessments around factory farms reveal concentrations of ammonia and hydrogen sulfide that are above the limits set by the US Environmental Protection Agency and can affect surrounding areas within 1km of poultry farms (Donham et al., 2006; Hu et al., 2017). Animal manure accounts for 75 percent of ammonia emissions from agriculture in the European Union (Bittman et al., 2014). As it assimilates into the atmosphere, ammonia has the potential to react with other atmospheric pollutants such as sulfur dioxide and nitrogen oxides and can spread to regions as far as 1000km (Asman et al., 1998, Fowler et al., 1998).

Health effects

Studies have shown that workers at CAFOs are subject to adverse health effects – 25 percent reported developing respiratory illnesses such as asthma and organic dust toxic syndrome; spending six or more years at facilities results in a risk of contracting chronic illnesses (Cole et al., 2000; Donham et al., 2007). On a larger scale, CAFOs affect its surrounding communities by similarly increasing the risk of developing respiratory illnesses, but also increasing the prevalence of blue baby syndrome and miscarriages for pregnant women through excess nitrate in water (Gregor et al., 2010). In addition to physical health, community members also suffer psychologically through experiencing a decreased quality of life—e.g. normal social activities impaired by noxious odors — resulting in a heightened prevalence of depression, fatigue, anger, and other related illness (Schiffman et al., 1995).

[3] A variety of particles that can react to form ozone

Although this paper is one of many existing works written on the broader environmental impacts of CAFOs, as far as I can tell, it is the first that specifically concentrates on China. Many researchers have analyzed the health impacts of CAFOs on humans. Others have considered particular pollutants present in waterways, but the main focus of this paper is through a wider lens. This paper looks at overall trends within the Chinese livestock sector and seeks to explore whether there is an association between the concentration of pollutants and the amount of livestock production in a given geographical area. This paper adds to the existing body of research on this topic and focuses on very specific variables, such as the total amount of nitrogen and phosphorus in wastewater and the livestock production index compiled by the World Bank.

Empirical Methodology

To evaluate the externalities caused by CAFOs, the method of combining sets of external secondary data published by the National Bureau of Statistics of China (NBS) and the World Bank (WB) was utilized. Both of these databases are publicly available and show an array of indices under different categories which serve as indicators of national wellbeing.

The National Bureau of Statistics of China offers different types of data: monthly, quarterly, annual, census, and other. Annual data was chosen because it is the easiest to manage and can be utilized to illustrate trends across the livestock industry; further, seasonal variations are easier to remove. Data was obtained from section 6: People's Living Conditions; section 8: Resources and Environment; and section 12: Agriculture. These sections were selected as they focus on the indicators most relevant to this study. Additionally, they show national comparisons across provinces and time.

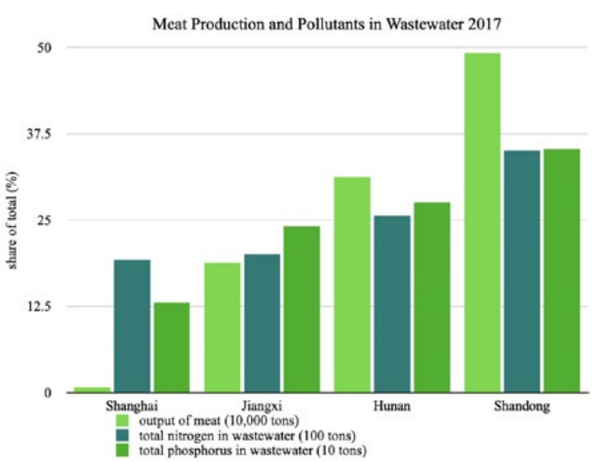
The WB offers data across countries and compiles them from official international organizations as well as national databases. The data used focuses on China and specifically on pollutant emissions relating to the agricultural industry. Unlike NBS, the WB does not provide regional data but does offer access to a longer time frame (1970 to 2018). Therefore, this database was utilized more to illustrate long-term trends between specific indicators and their correlation.

Since data from NBS shows regional differences, the NBS database was utilized to show the correlation between pollutants in different regions as related to the prevalence of livestock produced.

Data and results

As an introduction to the empirical findings, Figure 1 and Table 1 present differences in meat production for four geographical regions: Shanghai, Jiangxi, Hunan, and Shandong. These regions were chosen as Shanghai produces the least amount of meat in China, and Shandong produces among the most. Differences in meat production in the four regions are analyzed to see the relationship between the amount of meat production and the amount of nutrients present. Table 1 presents data on the production of meat and nitrogen and phosphorous emissions for the four regions in the year 2017.

Figure 1
Meat production and pollutants in wastewater in selected regions, 2017



Note. Data obtained from the National Bureau of Statistics, http://data.stats.gov.cn/index.

Table 1
Meat production and pollutants in wastewater, 2017

Baseline indicators	Shanghai	Jiangxi	Hunan	Shandong
Output of meat (10,000 tons)	17.4	330.9	529.8	777.5
Total nitrogen in waste water (10,000 tons)	7.76	8.08	10.33	14.14
Total phosphorus in waste water (10,000 tons)	0.27	0.50	0.57	0.73

Note. Data obtained from the National Bureau of Statistics, http://data.stats.gov.cn/index.

As is evident in Figure 1, Shanghai produces the least amount of meat and Shandong produces the most. Jiangxi and Hunan are somewhere in between. The variables highlighted in the figure are output of meat, total nitrogen in wastewater, and total phosphorus in wastewater. The latter two variables represent the main pollutants in water associated with meat production. Though Shanghai produces the least meat, its wastewater pollution levels remain relatively high. This is due to the comparatively smaller surface area of the region, which leads to a concentration of the nutrients accumulating in bodies of water.

Figure 1 and Table 1 illustrate the output of meat in four regions along with two of the most common pollutants resulting from animal manure and fertilizer application: nitrogen and phosphorous. The data in Figure 1 is represented as a share of total output and total emissions, while Table 1 provides the actual total values. As can be observed, there is a positive correlation between the output of meat and the number of pollutants emitted. It is shown that in these four regions in 2017, regions with a higher output of meat also had higher total nitrogen and total phosphorus in wastewater.

Nitrogen ends up in the atmosphere mainly due to agricultural processes, such as soil erosion and manure management. However, there could also be other factors that influence its presence, such as fossil fuel emissions from vehicles. The correlation between the output of meat with total nitrogen and output of meat with total phosphorus is very high, 0.936 and 0.989 respectively. Despite this, Shanghai is an anomaly. Even though its output of meat is significantly lower than the other three provinces, the concentration of total nitrogen and phosphorus in wastewater remains relatively high due to its small surface area.

Table 2
Population in four regions, 2017

Baseline indicators	Shanghai	Jiangxi	Hunan	Shandong
Population (10,000 persons)	2418	4622	6860	10006
Population Density (inhabitants per square kilometer)	3814	276.9	323.8	634.5

Note. Data obtained from the National Bureau of

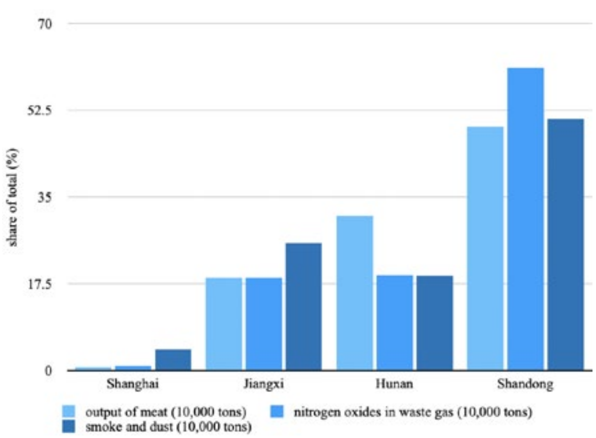
Statistics, http://data.stats.gov.cn/index, and Statista, https://www.statista.com/.

Table 2 introduces another factor that may explain the different levels of pollutants present: is population density. Both nitrogen and phosphorus have a negative correlation coefficient with it, -0.447 for nitrogen in wastewater, and -0.814 for phosphorus in wastewater, which may indicate that population density may not be the only factor generating these pollutants.

Additionally, the correlation between total nitrogen and total phosphorus in all the regions is +0.88, showing that in 2017, regions with higher total nitrogen in wastewater also had higher total phosphorus. This would make sense as both pollutants are present in livestock production from fertilizer and animal manure. The high correlation could indicate that livestock production is one of the main sources of both pollutants, as this industry is one of the only ones that emit both.

Figure 2 and Table 3 illustrate the output of meat in the same four regions along with nitrogen oxides (released during the treatment and storing of livestock manure), and smoke and dust (released through ventilation of animal houses).

Figure 2
Meat production and pollutants in waste gas in selected regions, 2017



Note. Data obtained from the National Bureau of Statistics, http://data.stats.gov.cn/index.

Table 3
Meat production and pollutants in waste gas, 2017

Baseline indicators	Shanghai	Jiangxi	Hunan	Shandong
Output of meat (10,000 tons)	17.4	330.9	529.8	777.5
Nitrogen oxides in waste gas (10,000 tons)	19.39	35.54	36.47	115.86
Smoke and dust in waste gas (10,000 tons)	4.70	27.95	20.71	54.96

Note. Data obtained from the National Bureau of Statistics, http://data.stats.gov.cn/index.

As the data in Figure 2 and Table 3 shows, out of the four regions in 2017, regions with a higher output of meat also have higher nitrogen oxides. The same is true for smoke and dust in three of the four regions, with Hunan being the exception. It is interesting to note that the correlation between the output of meat with smoke and dust (+0.913) is higher than the correlation between the output of meat with nitrogen oxides (+0.881). This remains the case even after taking into consideration the dip in Hunan.

In Hunan, the differences in the composition of gross domestic product (GDP) may account for the departure from the direct positive association between the output of meat and smoke and dust. Although both pollutants, nitrogen oxides and smoke and dust, are emitted through the livestock sector, the main contributors to nitrogen oxides and particular matter are combustion processes from automobiles and other industries (ScienceDirect, 2021). GDP is made up of primary, secondary, and tertiary industries. Primary industry concerns harvesting raw materials, which includes agriculture, mining, and forestry. Secondary industry, also known as the manufacturing sector, converts the materials obtained from primary industry into consumer products. Out of the four regions, Jiangxi has the highest concentration on the secondary industry, 46.6 percent, compared to Shandong's 39.8 percent, Hunan's 37.6 percent, and Shanghai's 27 percent. Therefore, Hunan's comparatively lower focus on the secondary industry may explain the smaller amount of pollutants in the waste gas, as the secondary industry is the main contributor to the prevalence of these pollutants.

Additionally, the amount of pollutants emitted in Shanghai is unusually low compared with the other three regions, which could be explained by this city's more developed state. As China's main metropolis, it has more access to innovative and greener technology and is more conscientious of the air quality that its citizens breathe. Therefore, it is unsurprising that it also has the least amount of pollutants.

When the data is compared to population density in Table 2, there is a negative correlation between the presence of pollutants in waste gas and population density: -0.416 for nitrogen oxides and -0.646 for smoke and dust. This may indicate that the amount of inhabitants per square kilometer is not necessarily the only factor that explains the presence of pollutants. As data regarding meat production and water-gas pollutants indicates, when the output of meat increases in 2017, so does nitrogen oxides and smoke and dust in waste gas.

Table 4
Livestock production index and greenhouse gas emissions

Baseline indicators	2006	2007	2008	2009	2010	2011	2012
Livestock production index (2014-2016=100)	84.07	84.14	88.23	91.3	93.59	94.05	97.38
Total greenhouse gas emissions (% change from 1990)	120.24	134.39	157.46	172.75	187.30	209.92	219.95

Note. Data obtained from the World Bank, data.worldbank.org.

Table 4 displays data compiled from the World Bank's livestock production index and total greenhouse gas emissions as a percentage change from 1990 in China. The livestock production index is an aggregate of livestock production compared to the base period 2014-2016. It is calculated through the Laspeyres formula and compiled by the Food and Agricultural Organization of the United Nations (FAO).

When examined, the correlation coefficient between the two variables, livestock production index and total greenhouse gas emissions, is nearly perfect, +0.98 (p-value = 0.00012). The correlation is statistically significant, showing that from 2006-2012, as livestock production increased, the amount of total greenhouse gas emissions also increased. This conclusion is further supported in earlier findings (figure 2, table 3) where the prevalence of nitrogen oxides and smoke and dust exhibit a high positive correlation with the output of meat. Other greenhouse gases emitted from livestock production would include methane, primarily from cattle digestive processes (Grossi et al., 2019). In all, the strong positive correlation between the livestock production index and greenhouse gas emissions, which encompasses nitrogen oxides and smoke and dust, indicates that livestock processes might be one of the main contributors to rising greenhouse gas emissions.

Conclusions and policy recommendations

To analyze the negative externalities arising from CAFO production in China, I compared four geographical regions differing in the output of meat with pollutants: nitrogen in wastewater, phosphorus in wastewater, nitrogen oxides in the waste gas, and smoke and dust in waste gas. All four pollutants showed a high positive correlation with the output of meat. Additionally, there is a strong positive correlation between the livestock production index and the amount of greenhouse gas emissions.

The trend of converting to large-scale factory farms in China in the last few decades has been well documented. Therefore, it is reasonable to assume that the high output of meat is an indication of the existence of CAFO factories in different geographical areas. Though it may not be the only reason, it is certainly plausible to assume that livestock, and effectively, CAFOs, contribute to the varying pollutant levels found throughout the country.

A policy recommendation that emanates from my findings is that access to greener technology may help dampen pollution levels. This is most apparent in Shanghai, which is by far, the least polluted region out of the four regions analyzed here. As the most technologically advanced city, it makes sense that there is greater emphasis placed on environmental standards, and more research to improve living conditions. With this added innovation, it can be assumed that greener technology is one of the facets leading to its overall less polluted climate.