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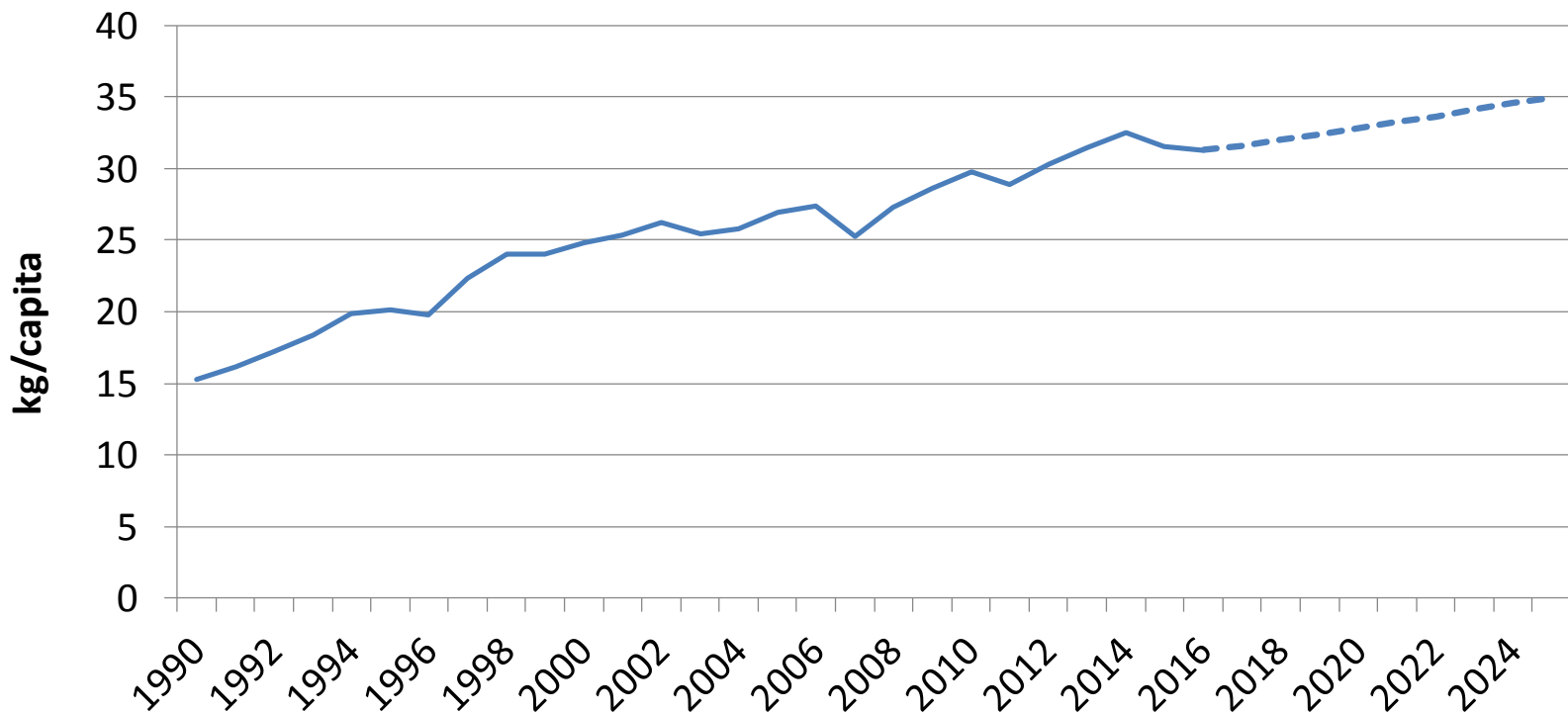# IN TRANSITION ECONOMIES

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Technical and environmental efficiency of livestock farms in China: a slacks-based DEA approach

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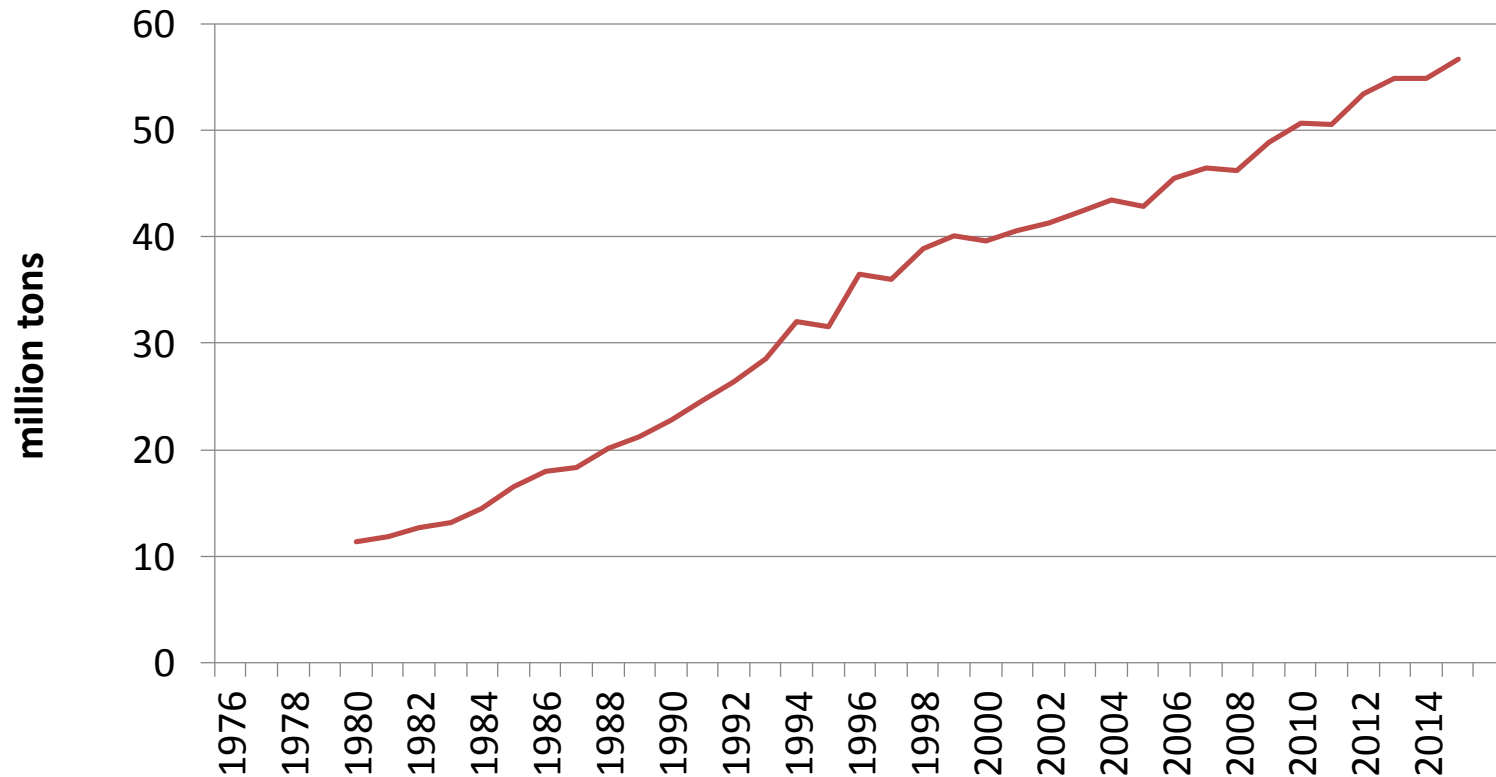
1. Introduction

Chinese annual pork consumption (kg/capita)

Source: OECD-FAO Agricultural Outlook 2016

1. Introduction

Output of pork meat (million tons)

Source: China National Bureau of Statistics 2017

1. Introduction

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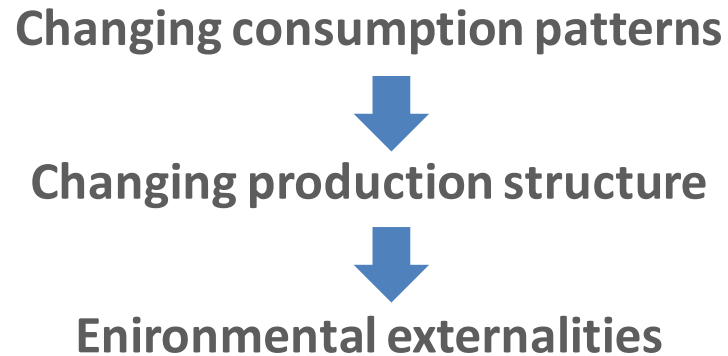

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1. Introduction

Waste management

Leakage of pollutants into soil and water:

- **antibiotics** (Zhao et al. 2010; Chen et al. 2012)
- **heavy metals** like copper, zinc and cadmium (Li et al. 2010; Xiong et al. 2010; Shi et al. 2011; Wang et al. 2013).
- **phosphorus and nitrates** (i.e. Fang et al. 2006; Ju et al. 2006; Chen et al. 2010; Bai et al. 2016).

1.1 Research questions

Changing consumption patterns

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Changing production structure

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Enironmental externalities

A) How does farm size affect both production and waste management?
B) What policy options to reduce the emission of pollutants?

2. Data
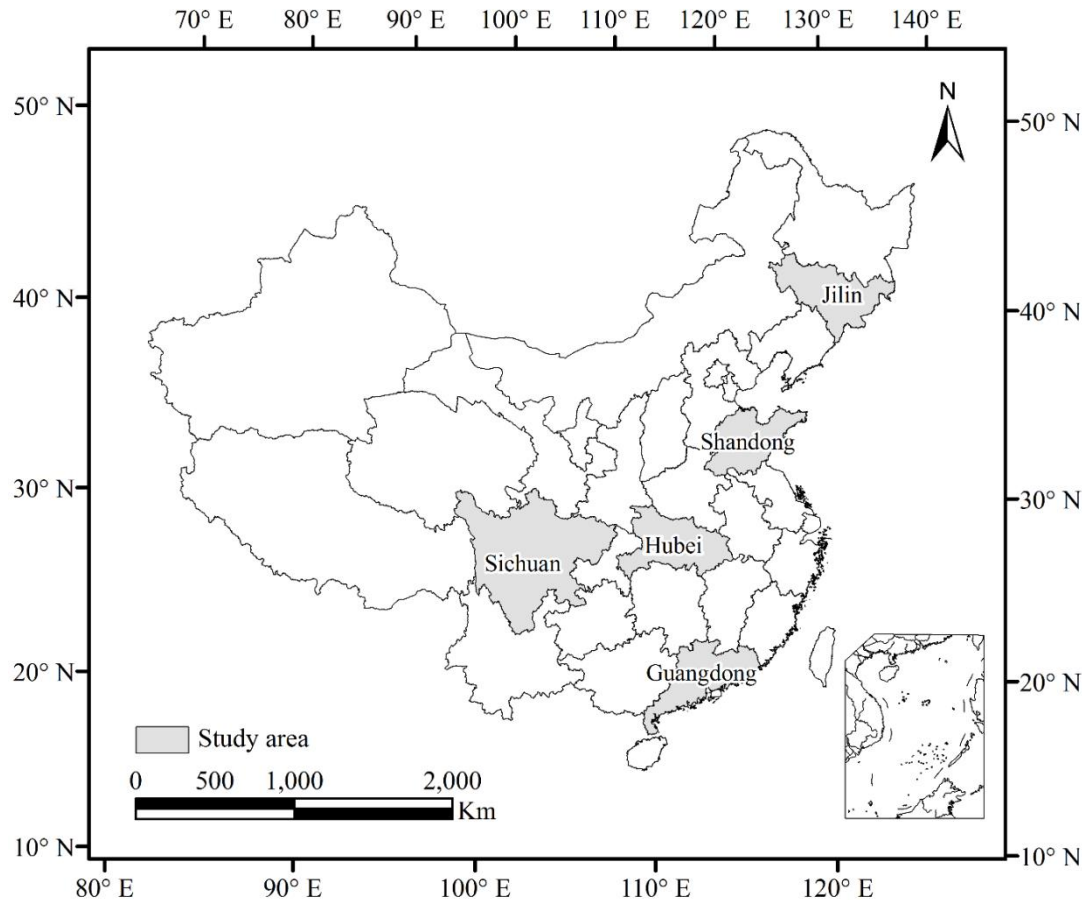
2013 Farm Survey
- Center for Chinese Agricultural Policy (CAS), U.S. Grains Council and Asian Agribusiness Consulting
- 405 hog farms
- Questions: Waste management, hog production, farm characteristics, village policies

3. Method

Step 1: Estimation of Environmental Efficiency

DEA approach: Comparison of productive units in terms of their efficiency of processes (Charnes et al. 1978). Environmental externalities as **undesired outputs** (Faere et al. 1989)

Slack-based DEA model: Non-radial DEA **model** that deals with both input excesses and output shortfalls simultaneously. Tone 2001). Extended to account for undesirable outputs (Zhou et al. 2006, Cooper et al. 2007, Faere & Grosskopf, 2009).

Weak disposability: Under constant inputs, reductions of all outputs by the same proportion are always feasible (Färe & Grosskopf 2004, Choi et al. 2012, Wei et al. 2012).

3. Method

Descriptive statistics of the key variables in SBM model

Variable	Type of variable	Mean	Std. Dev.	Min	Max
Weight gain (tons per farm)	Good output	25.8	52.7	0.1	452.0
COD (tons per farm)	Bad output 1	6.4	12.9	0.0	124.9
Ammonia (kg per farm)	Bad output 2	124.6	347.5	0.2	4998.8
Labor (including both family and hired labor, days per farm)	Input 1	249.6	671.4	2.3	8376.0
Feed (including complete, concentrate, premix feed and other feed, tons per farm)	Input 2	79.7	162.2	0.23	1596.8
Other cost (including vaccine fee, and electricity and water fees, etc., 1000 yuan per farm)	Input 3	86.4	235.1	0.0	2096.9

Waste management practices by farm size, village types and provinces (%)

	Manure	Biogas	Discharge	Sale	Fish Feed	other
Sample average	44.6	23.3	15.4	4.5	8.9	3.3
Farm size (marketed hogs per year)						
Backyard (1-9)	67.3	28.7	3.8	0.0	0.1	0.0
Small (10-49)	59.6	22.4	13.6	1.4	2.4	0.6
Specialized (50-499)	38.2	21.3	18.0	5.3	12.4	4.8
Commercial (>=500)	19.7	28.3	18.5	11.5	16.0	6.0
Province						
Jilin	64.0	2.2	29.2	1.4	0.0	3.2
Shandong	63.0	4.8	20.5	10.9	0.0	0.9
Hubei	44.0	34.1	7.4	4.8	5.6	4.2
Sichuan	20.6	67.0	3.4	0.6	1.0	7.4
Guangdong	26.2	13.1	14.5	3.6	41.2	1.4
Whether a village has an environmental project						
1=yes	38.9	34.4	13.2	3.5	6.7	3.3
0=no	52.7	7.7	18.4	5.9	11.9	3.4

Source: authors' survey

4.2 Results – Pollutant emission

Pollutant emissions in hog production (kg per head of pig)

	COD	TN	TP	Ammonia
Sample average	31.1	3.0	0.43	0.49
Farm size (marketed hogs per year)				
Backyard (1-9)	29.5	2.4	0.39	0.36
Small (10-49)	31.9	3.3	0.43	0.45
Specialized (50-499)	32.2	3.1	0.45	0.52
Commercial (>=500)	26.8	2.6	0.38	0.57
Whether a village has an environmental project				
1=yes	28.1	2.6	0.37	0.37
0=no	35.4	3.7	0.51	0.51
Province				
Jilin	51.7	4.1	0.75	0.55
Shandong	36.9	4.9	0.54	0.41
Hubei	22.6	1.7	0.21	0.26
Sichuan	18.6	0.9	0.22	0.33
Guangdong	22.9	2.9	0.38	0.92

Source: authors' estimation

Efficiency scores from SBM model across farm size, village type and province [a]

	Hog output	COD	Ammonia	Labor	Feed	Other cost	Overall
All sample	0.99	0.53	0.48	0.61	0.90	0.52	0.54
Farm size (marketed hogs per year)							
Backyard (1-9)	0.88	0.71	0.67	0.67	0.93	0.59	0.61
Small (10-49)	1.00	0.40	0.38	0.48	0.83	0.46	0.44
Specialized (50-499)	1.00	0.49	0.44	0.60	0.92	0.49	0.53
Commercial (>=500)	1.00	0.76	0.71	0.85	0.96	0.73	0.76
Environmental project in village							
1=yes	0.99	0.56	0.51	0.63	0.91	0.54	0.56
0=no	0.98	0.48	0.44	0.58	0.89	0.50	0.51
Province							
Jilin	0.97	0.48	0.53	0.68	0.92	0.54	0.57
Shandong	1.00	0.34	0.38	0.51	0.85	0.47	0.45
Hubei	0.99	0.62	0.66	0.64	0.92	0.63	0.62
Sichuan	0.97	0.65	0.53	0.66	0.91	0.52	0.57
Guangdong	1.00	0.60	0.36	0.58	0.91	0.49	0.52

[a] 1=full efficiency and 0 =the least efficiency

4.2 Results – Shadow prices

Estimated shadow prices of undesirable outputs

	COD (yuan/kg)	Ammonia (yuan/kg)
Farm size (marketed hogs per year)		
Backyard (1-9)	22.8	1695
Small (10-49)	16.6	1151
Specialized (50-499)	21.0	1395
Commercial (>=500)	24.0	1539
Whether a village has an environmental project		
1=yes	21.7	1470
0=no	18.5	1251
Province		
Jilin	6.6	622
Shandong	19.0	1657
Hubei	34.1	2817
Guangdong	20.7	528
Sichuan	23.0	1275
Average	20.4	1379

5. Discussion

State of affairs?

- Low environmental efficiency

- Increasing problem of low **manure-land ratio**

Can the environmental efficiency be improved?

- Potential to increase environmental efficiencies in regions with low shadow price

- Where abatement cost of manure pollutants is high, monitoring and raising the awareness of farmers may not be sufficient

Outlook

- Government support for improving the participation of small- to medium farm size in existent manure **markets** (i.e. subsidization of transport and storage facilities)

- The use of manure for **biogas** as alternative (i.e. rural biogas project, which was firstly proposed in 2007 and now recently seized again by the Ministry of Agriculture's rural waste treatment pilot)

4.4 Results – Tobit regression

Regression results of factors affecting technical and environmental efficiency

	overall	COD	ammonia	labor	feed	other
Village Environment programs (0/1)	0.063*	0.050	0.057	0.074*	0.030	0.079
	(0.033)	(0.041)	(0.040)	(-0.041)	(0.031)	(0.059)
Farm size (sold hogs per year, control: small farms)						
Backyard (1-9)	0.139**	0.281***	0.241***	0.241***	0.184***	0.114
	(0.066)	(0.076)	(0.068)	(0.068)	(0.056)	(0.110)
Specialized (50-499)	0.095***	0.090**	0.095**	0.095**	0.136***	0.033
	(0.036)	(0.044)	(0.041)	(0.041)	(0.033)	(0.065)
Commercial (>=500)	0.405***	0.439***	0.504***	0.504***	0.255***	0.394***
	(0.070)	(0.082)	(0.085)	(0.085)	(0.062)	(0.113)
Distance feed shop (km)	-0.002	0.001	-0.000	-0.000	-0.010**	0.003
	(0.006)	(0.008)	(0.007)	(0.007)	(0.005)	(0.011)
Husbandy experience (yrs)	0.005**	0.006**	0.007***	0.007***	0.000	0.007*
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.004)
Education of hh (yrs)	0.008	0.009	0.008	0.008	0.002	0.015
	(0.006)	(0.008)	(0.008)	(0.008)	(0.006)	(0.012)
Age of hh (yrs)	0.002	0.002	0.002	0.002	-0.001	0.004
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
Off-farm job (1/0)	0.059*	0.047	0.043	0.043	0.017	0.098
	(0.035)	(0.043)	(0.041)	(0.041)	(0.031)	(0.067)
Household consumption (1000 RMB/ per capita)	0.001	0.000	0.001	0.001	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Cultivated land (ha)	-0.003	-0.003	-0.003	-0.003	-0.005	-0.008
	(0.008)	(0.010)	(0.009)	(0.009)	(0.005)	(0.013)

Limitation

- Causal effect of policies requires
  - More information about regional regulatory frameworks
  - Time series data
- Finer weights for usage of manure in fields (discharge of pollutants depends on absorption capacity of specific plant, irrigation, type of soil etc.)

3. Method

Excursion: Estimation of pig waste

a) Transform the default produced pollutant coefficients of hogs to the farm specific ones:

$$C_{i,s} = C_{i,d} \frac{W_s^{0.75}}{W_d^{0.75}}$$

$C_{i,s}$ produced pollutant coefficient for the i*th* pollutant in the s*th* farm
$C_{i,d}$ default coefficient for the i*th* pollutant in the manual
W_s hog weight gain in kg for the s*th* farm (subtracting the starting weight from the selling weight)
W_d reference hog weight given in the manual.

b) Estimate the *produced* pollutant for each specific farm:

$$P_{i,s} = W_s \cdot C_{i,s} \cdot D_s$$

$P_{i,s}$ amount of the i*th* pollutant produced in the s*th* farm
D_s average raising days for the s*th* farm

c) Estimate the *discharged* pollutant for each specific farm.

$$PD_{i,s} = P_{i,s} \cdot \sum_{j=1}^{n} k_j \cdot M_j$$

$PD_{i,s}$ is the amount of the i*th* discharged pollutant for the s*th* farm
M_j is the percentage of pollutants dealt with the j*th* waste management practice
k_j weight capturing the rate of pollutants leaking into the environment for the j*th* waste management practice.

Source: Chinese Environmental Handbook

3. Method

Step 2: Estimation of confounding factors

Tobit model

$$ES_i = f(CLEAN_v, Size_i, X_i, e_i; \beta_s),$$

ES_i technical or environmental efficiency score of the i-th hog farm,

$CLEAN_v$ village has an environmental project (1 = yes, 0 = no)

$Size_i$ set of dummy variables representing the farm size,

X_i set of farm characteristics and farmers' socio-economic information (see Table A2),

e_i the error term

β_s are the coefficients to be estimated.

Descriptive statistics of the key variables in the regression analysis

Variable	Mean	Std. Dev.	Min	Max
Village environmental project related with livestock production (1=yes, 0=no)	0.59	0.49	0	1
Farm size (marketed hogs per year)				
Backyard (1=yes, 0=no)	0.11	0.31	0	1
Small (1=yes, 0=no)	0.26	0.44	0	1
Specialized (1=yes, 0=no)	0.48	0.50	0	1
Commercial (1=yes, 0=no)	0.15	0.36	0	1
Distance to the **feed shop** (km)	3.35	3.04	0	17
Livestock production **experience** of hh head (yrs)	12.01	7.36	0	42
Education of the head (yrs)	7.29	2.53	0	15
Age of the head	47.41	9.28	21	71
Household member with **off-farm job** (0/1)	0.25	0.43	0	1
Consumption expenditure per capita (1000 RMB)	19.92	35.97	1.2	300
Cultivated land (ha)	1.29	3.39	0	50

Source: authors' survey