Balancing Water Resource Conservation and Food Security in China

Qiu Huanguang

School of Agricultural Economics and Rural Development
Renmin University of China

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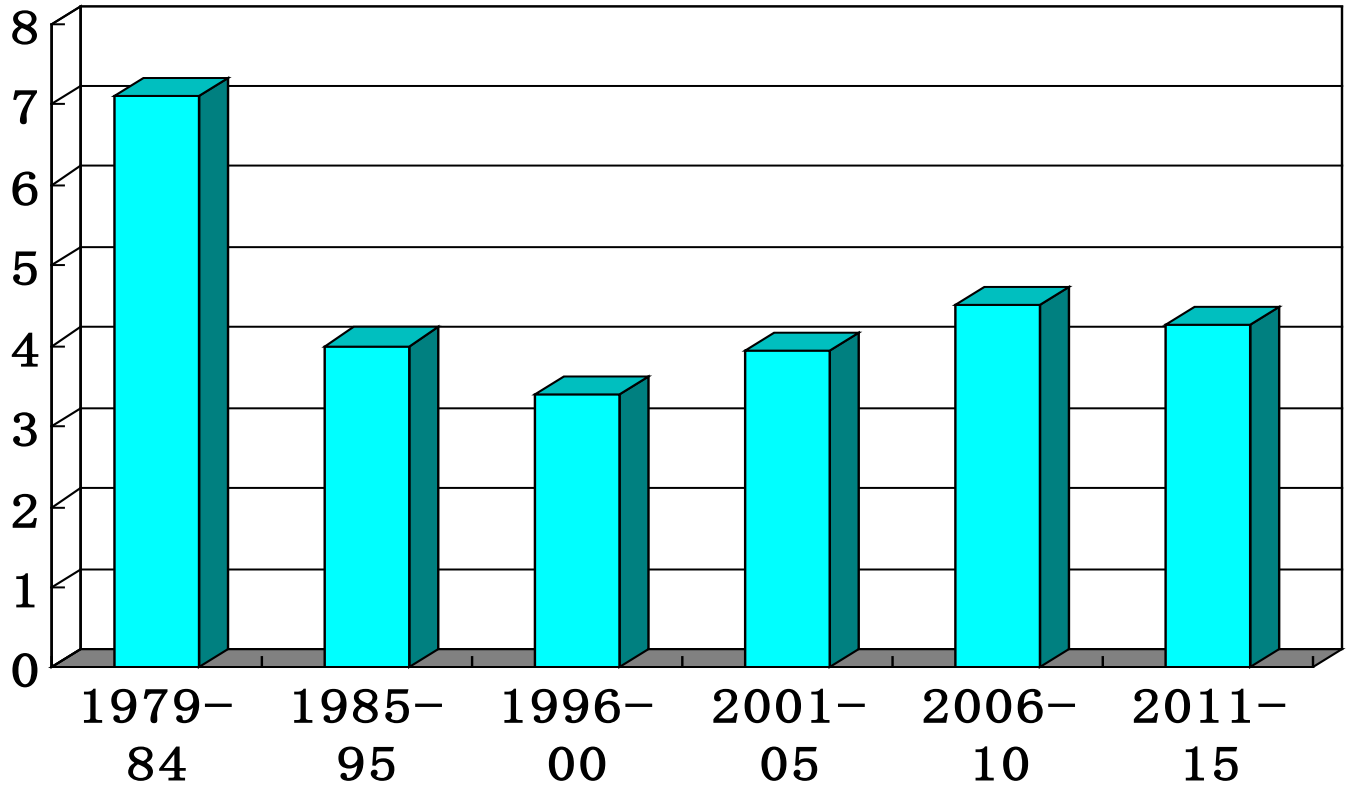
1. China’s food production in the past and challenges in future

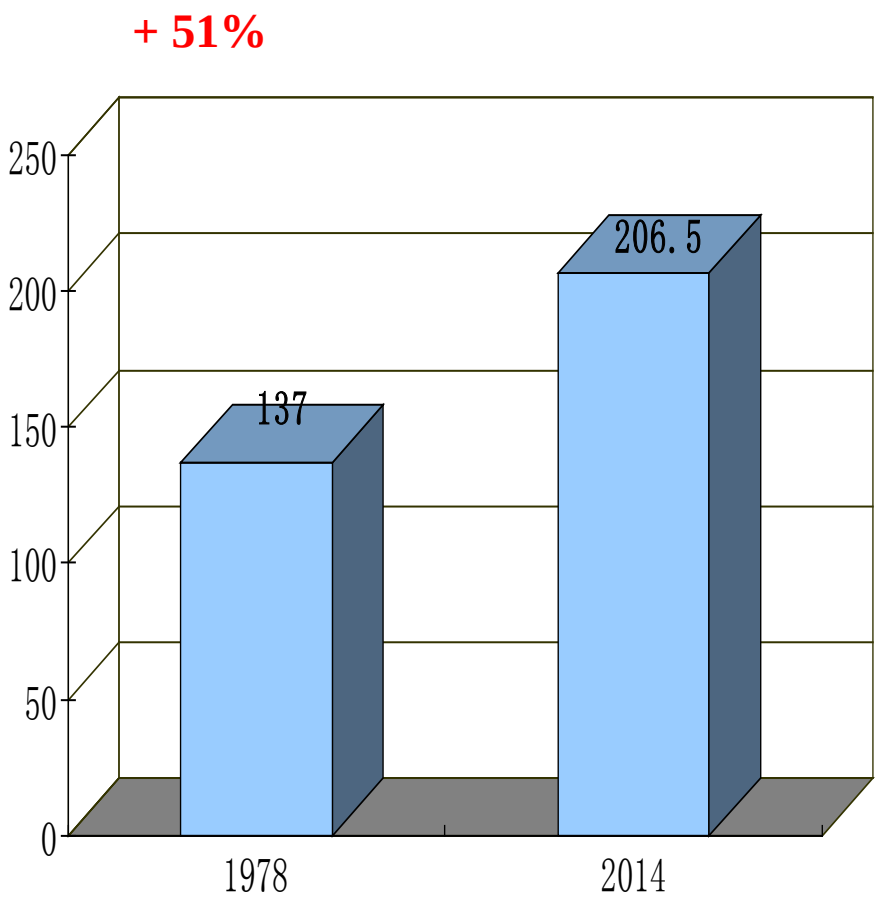
Average annual growth rate (%) of agricultural GDP



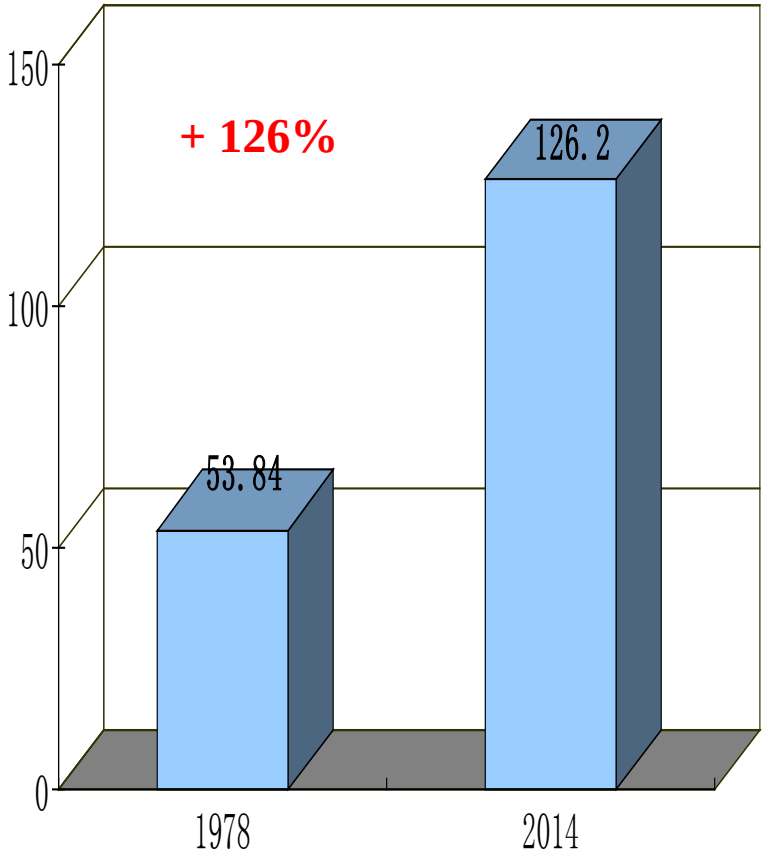
Average annual growth rate in agricultural GDP was about 4 times of population growth rates.

Rice and wheat production (million tons)

大米 Rice

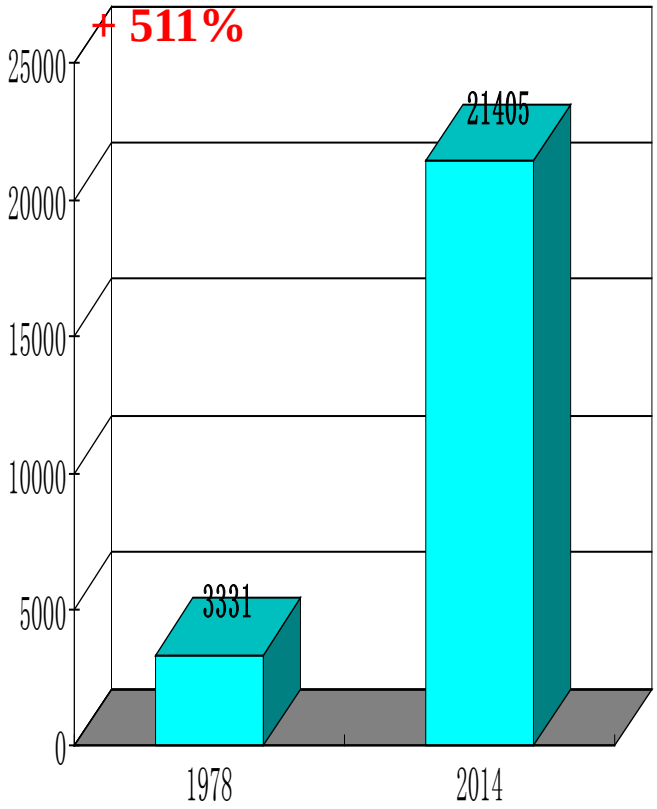


小麦 Wheat

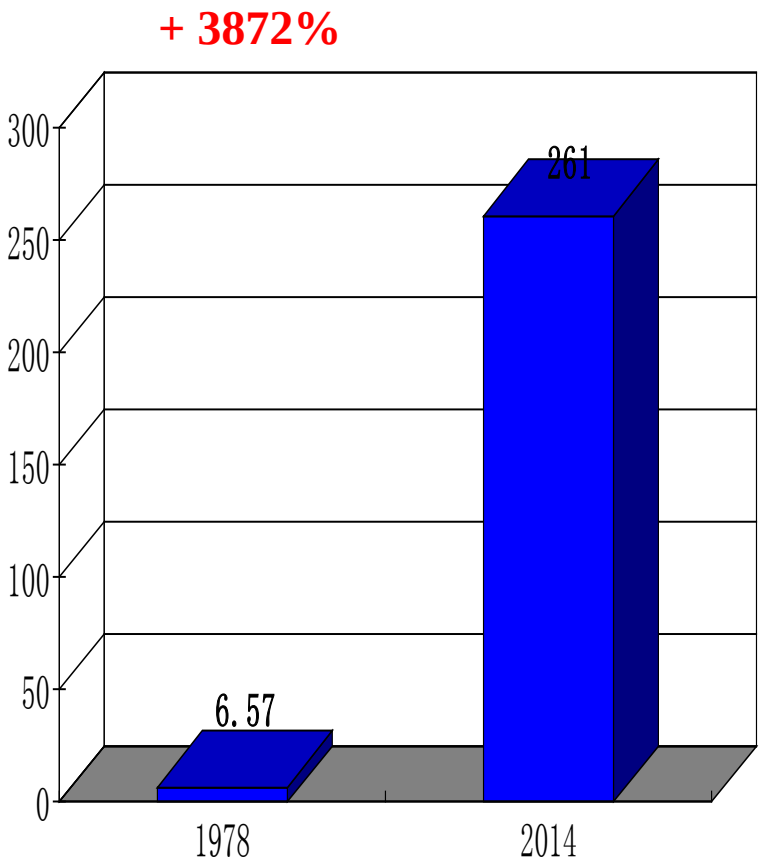


Vegetables and Fruits

Vegetable area (thousand ha)

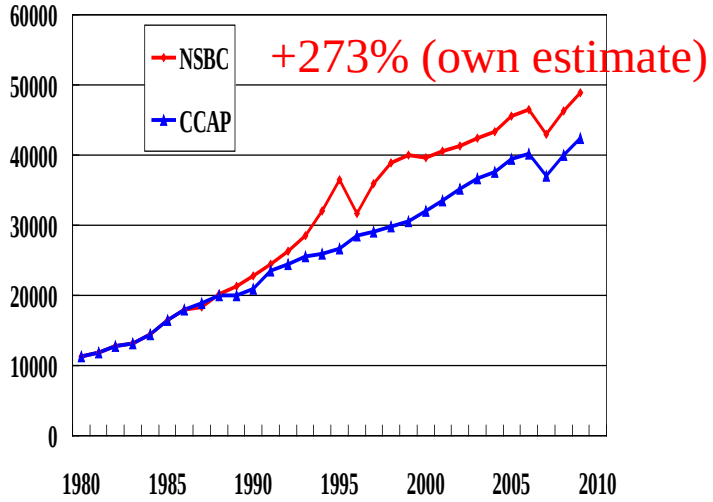


Fruit (million ton)

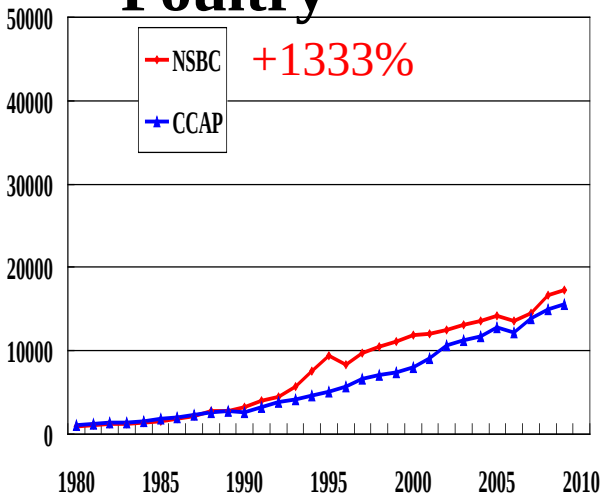


Livestock production
(1000 tons)

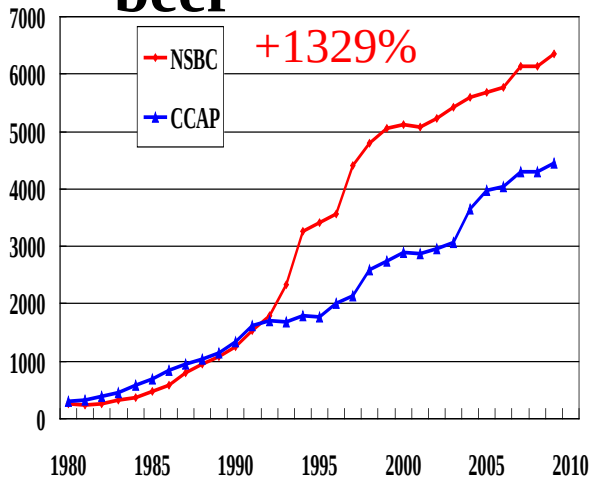
Pork



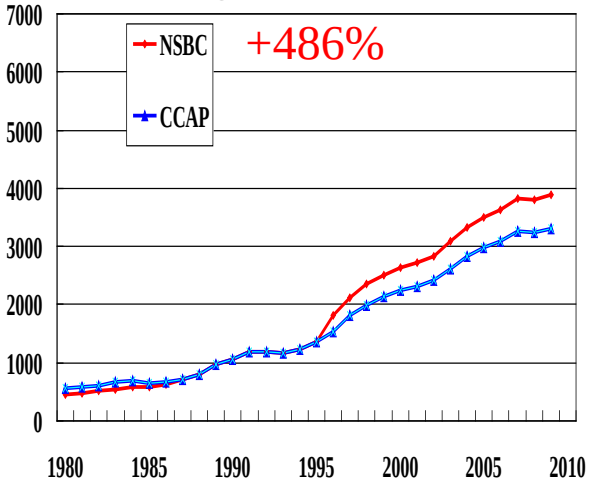
Poultry



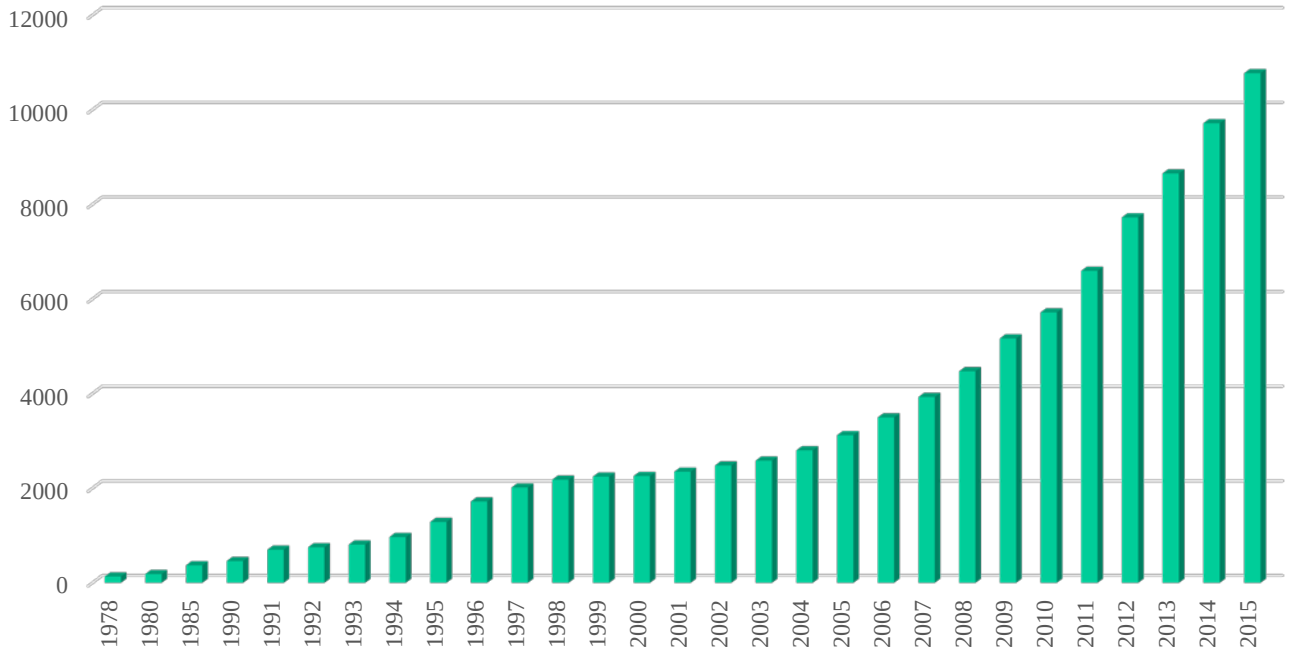
beef



mutton



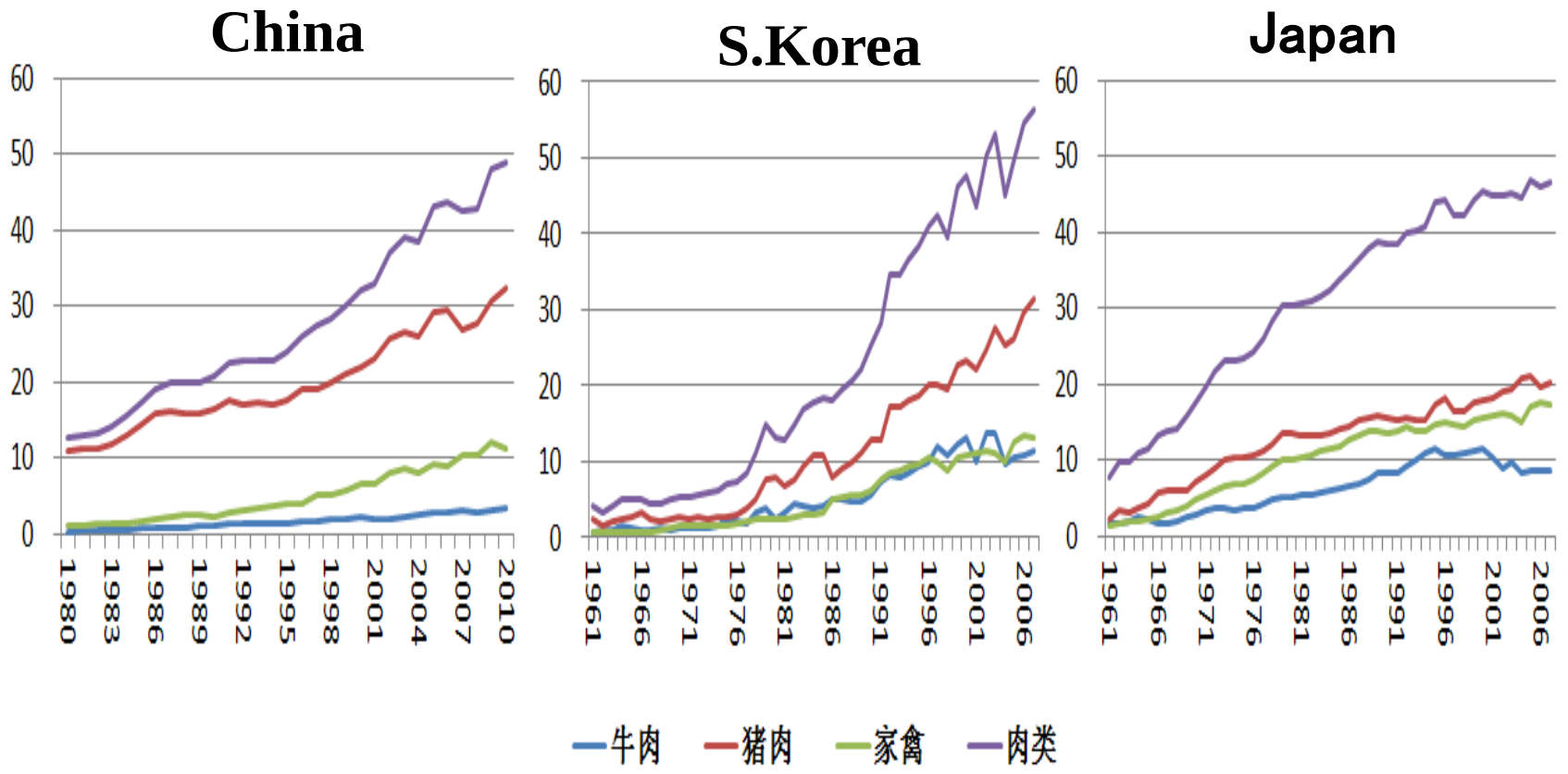
The average annual growth rate farmers' real income is about 7.6%



Nominal income increased from 133.6 yuan in 1798 to 10772 yuan in 2015

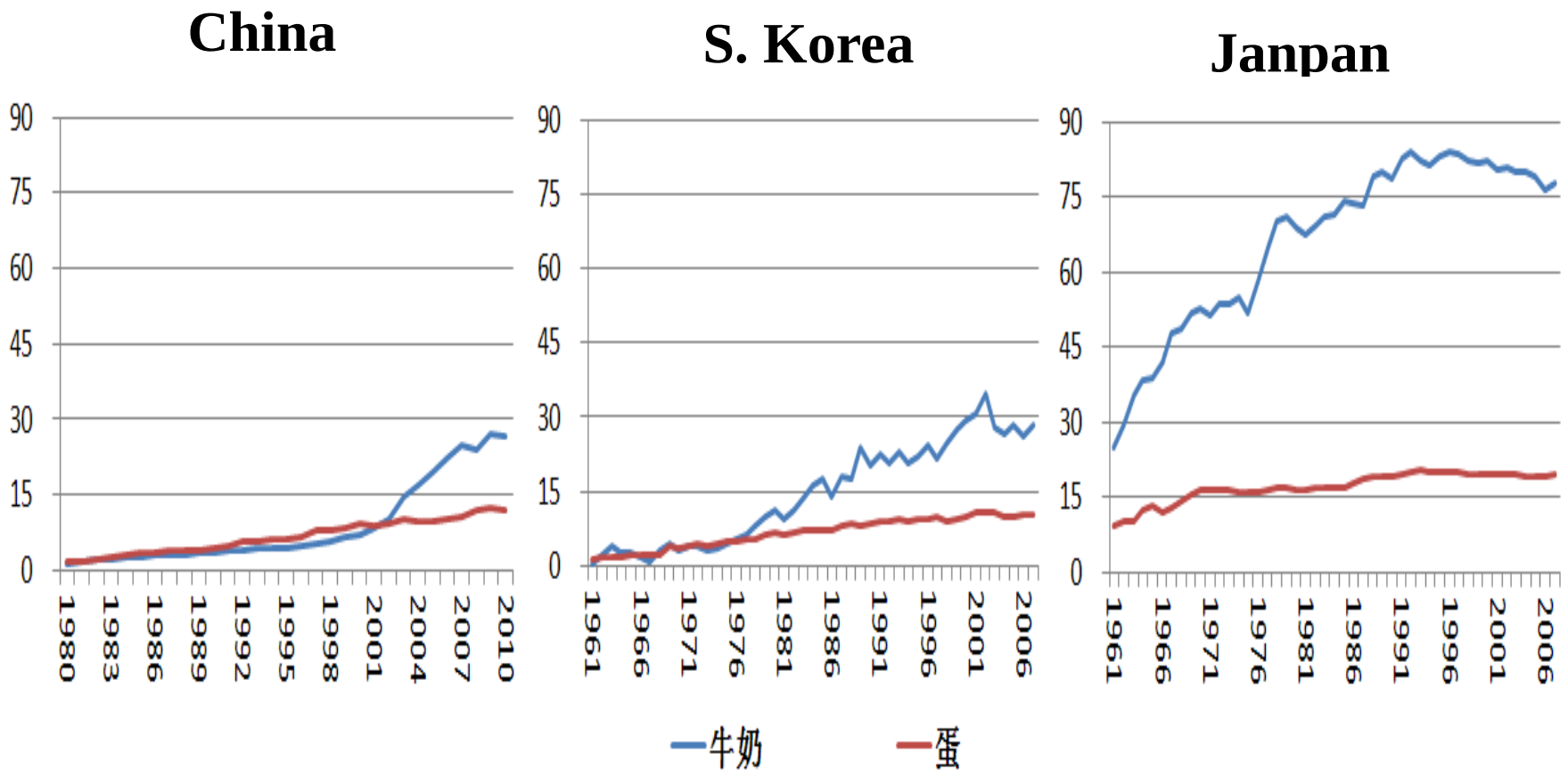
Challenges for the future

Comparison of meat consumption in China, Japan, and South Korea（kg/caput）



Data source from FAO

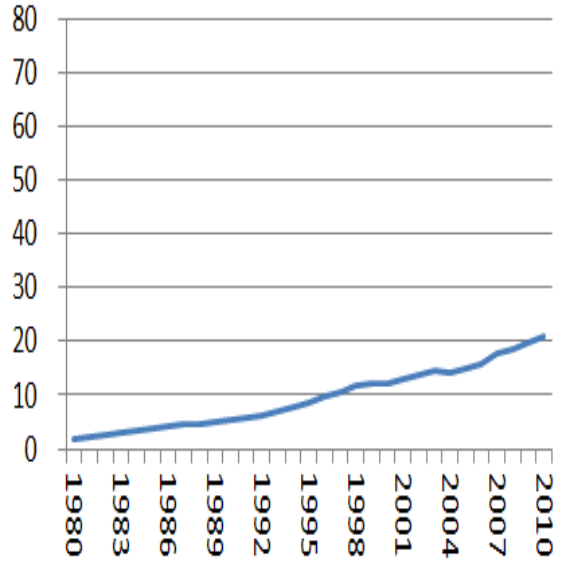
Comparison of milk consumption in China, Japan, and South Korea（kg/caput） （kg/caput）



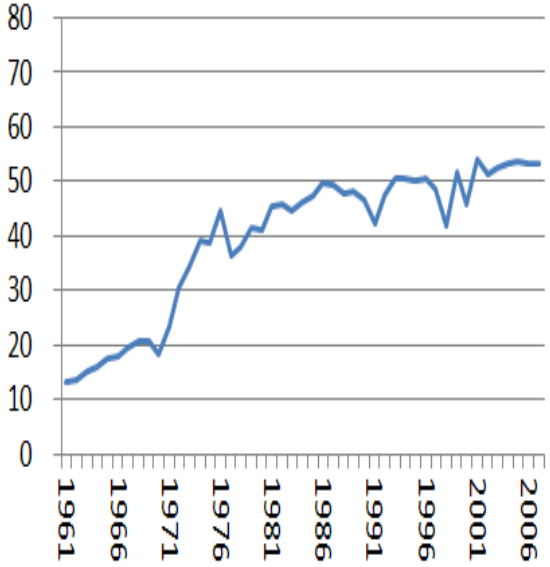
Data source from FAO

Comparison of fishery products consumption in China, Japan, and South Korea （kg/caput）

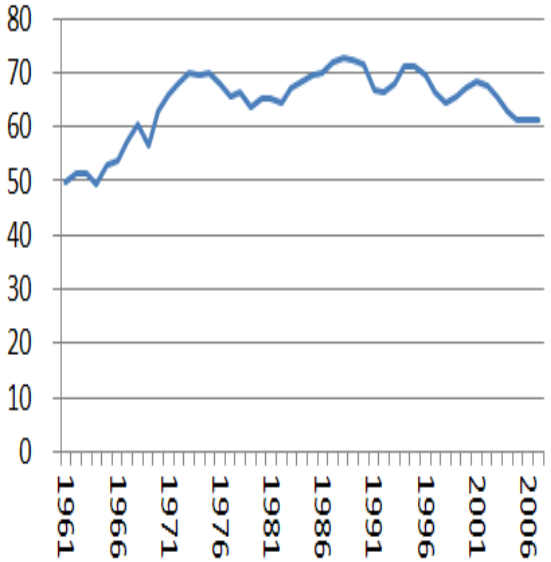
China



S.Korea

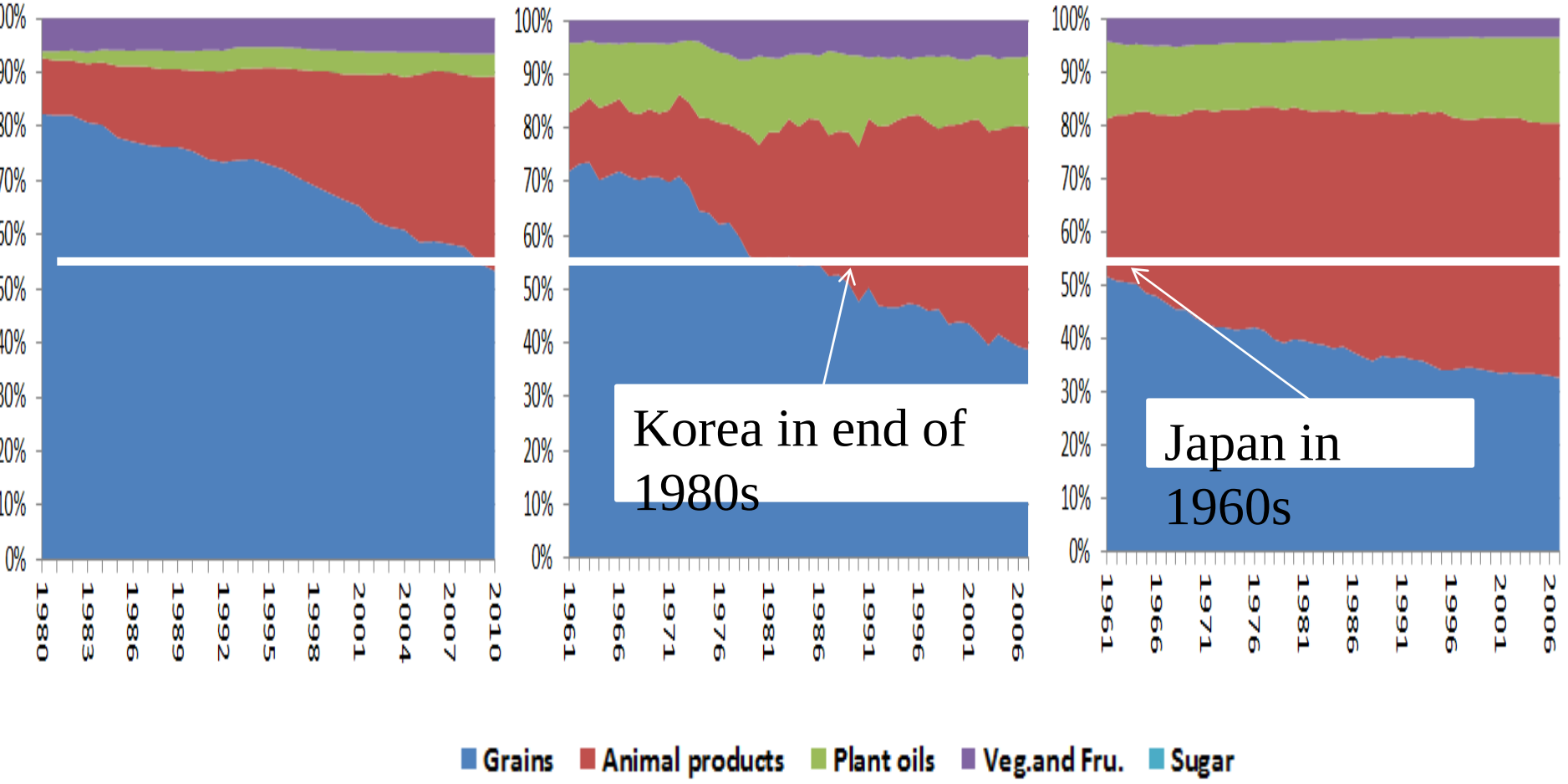


Japan

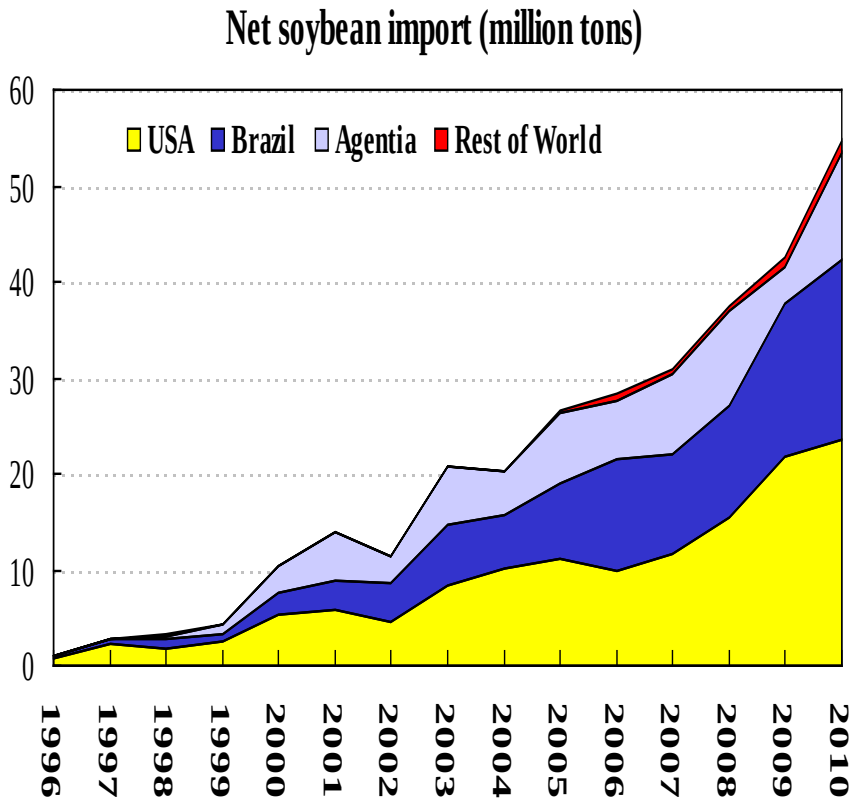


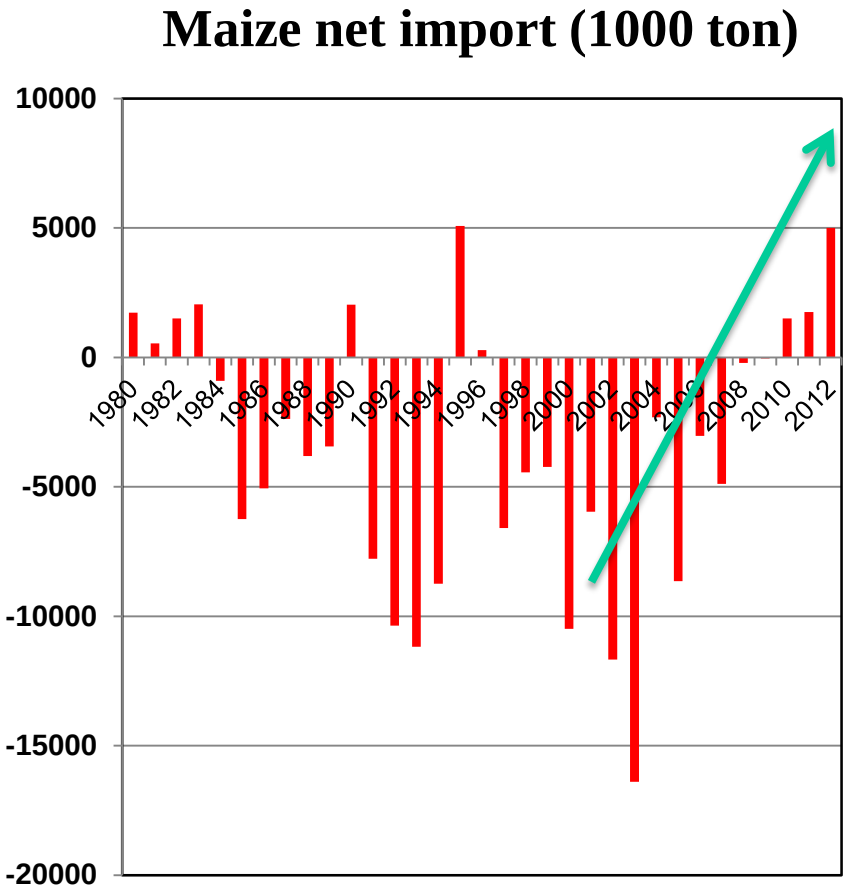
Food demand will continue to increase

Structure of Protein intake, comparison between China, Japan, and S. Korea



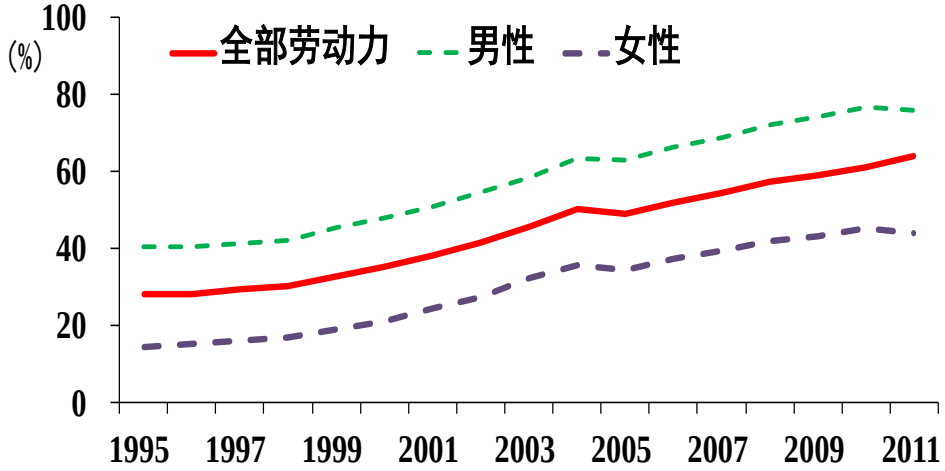
Mounting pressure for Food Security





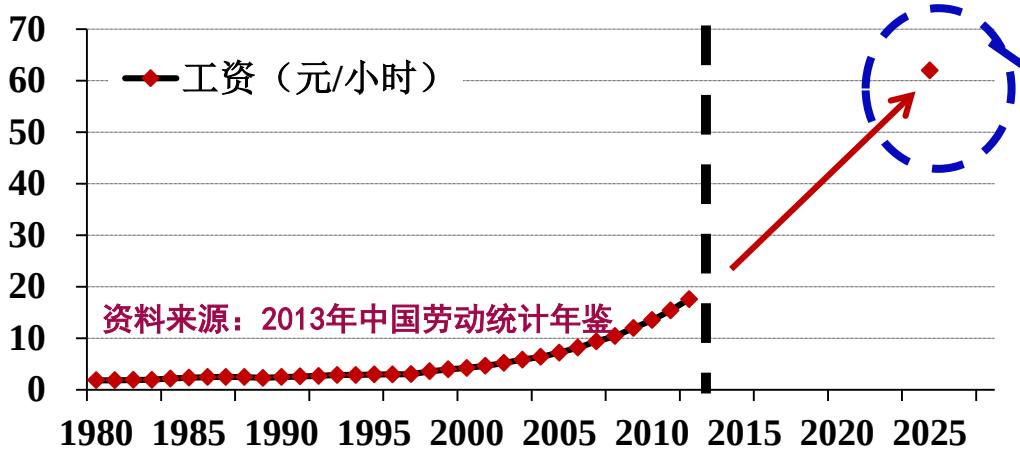
China's grain self-sufficient rate has drop below the government target (95%), and by 2012 dropped below 90%

Rising agricultural Labour Cost



Share of non-farm employment of Ag labour（1995-2011）

- By 2011, nearly 70%of agricultural labour fully or partially worked in non-ag sector （Zhang, et al., 2013）



Agricultural Labor price（using 2012 constant price）

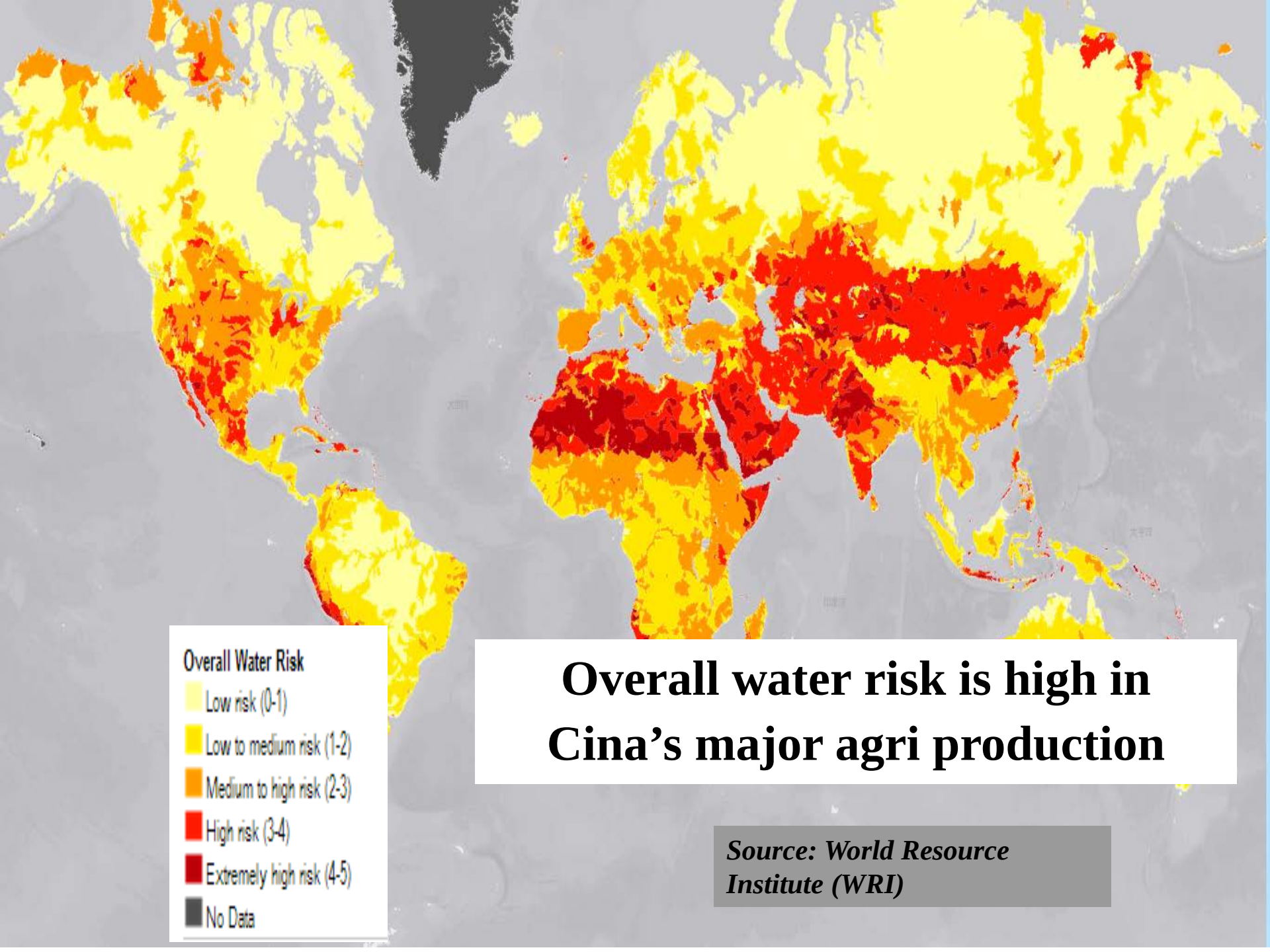
2030年，agricultural labor cost is expected to about 10USD/hour。（Scott et al., 2014）

Water shortage and pollution: Groundwater Levels are Falling

Change in Average Water Level in North China

- Increased: 8%
- No Change: 17%
- Decreased: 75%
  - Decreasing < ¼ m/year: 15%
  - Decreasing > 3 m/year: 26%

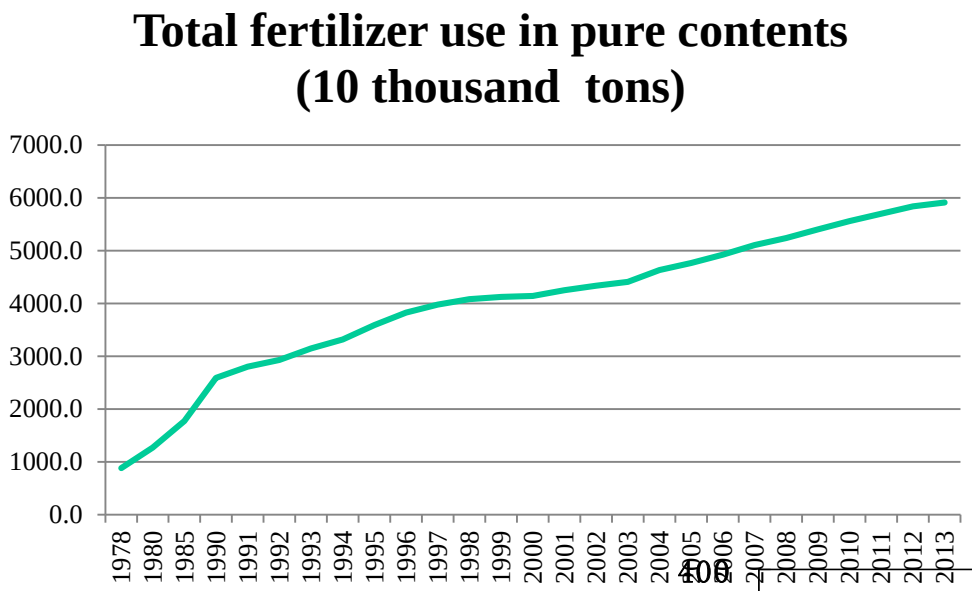
Wang et al., 2005



Overall water risk is high in Cina's major agri production

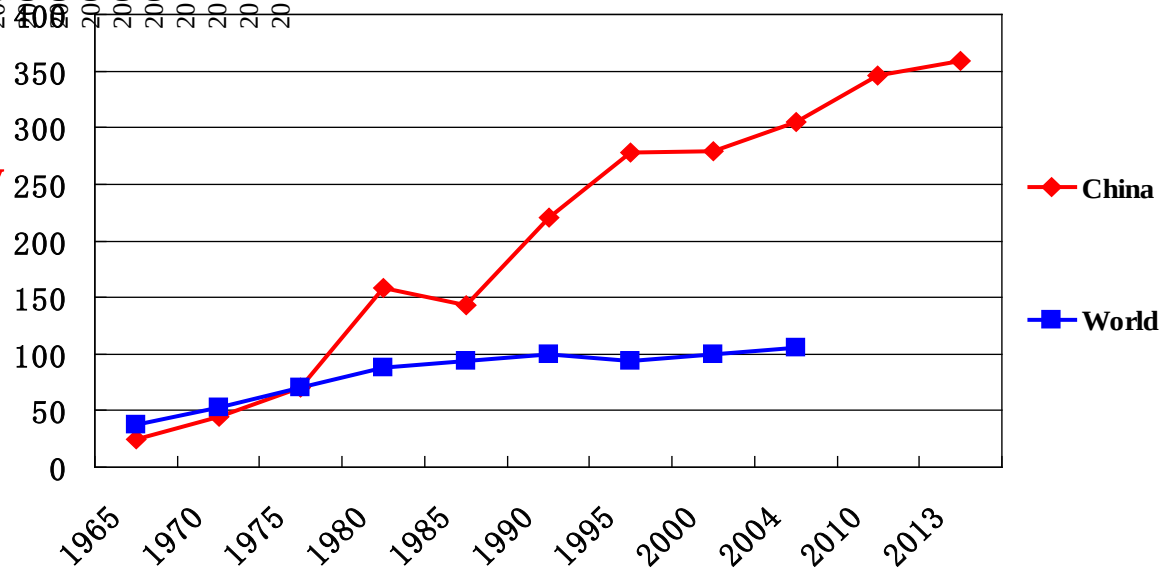
Source: World Resource Institute (WRI)

Chemical fertilizer use in China (kg/ha, sown area)

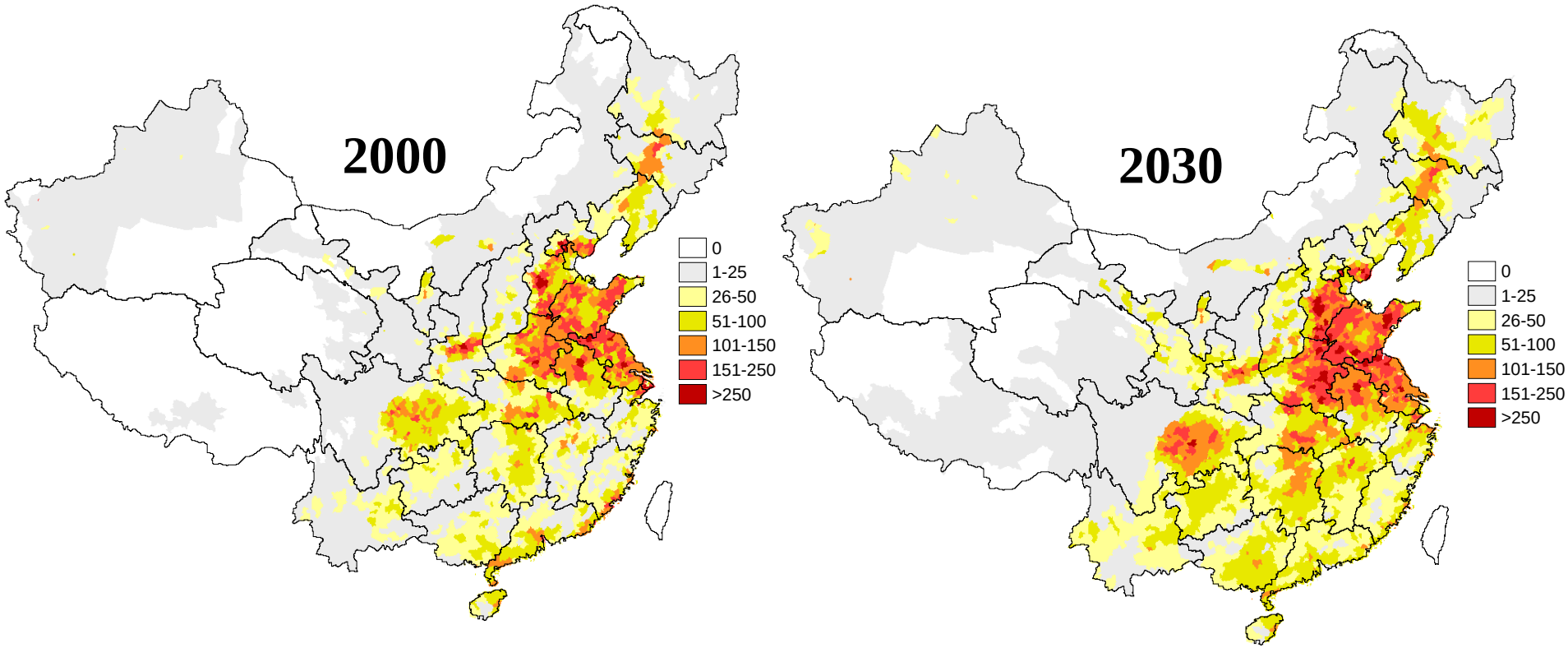


In the last 3 decades, total fertilizer use increased about 5.7 times

The fertilizer use intensity is about 4 time of that of world average, and only about 30% were used by crops



Overuse of Chemical Fertilizer (Nitrogen kg /ha land)



Fisher, Qiu et al., *Agriculture, ecosystems, and Environment*, 2010

2. Balancing water resource conservation and food security in China

Background

- Agriculture utilizes 65% of freshwater withdrawal in China
- Population growth and economic development reinforce pressure on water resources
- China's geographic mismatch between its arable land and water
- Major associated environmental issues
  - soil degradation
  - water resource overexploitation and pollution
  - land subsidence from groundwater overdraft

- **Current solutions to water scarcity are focused on sustaining existing activities, i.e., SNWT, and water saving technologies, water pricing**
- **However to what extent those activities can solve China's water pressure is questionable, let alone the high costs**

the South to North Water Transfer (SNWT) Project

Key Question

- **In contrast with previous works focusing on the effect of water shortages on food production, our key question is:**
  - **To what extent can targeted reductions in irrigated area decrease agricultural water use while maintaining grain self sufficiency?**
  - **Trade-offs between water security and food security: How would these strategies affect China's domestic and international Virtual Water Trade (VWT) flows and trade-induced Water Saving (WS)?**

Concepts and methods

Virtual Water Definition

- The water(rainfall or irrigation) embodied in the production of agricultural and industrial commodities
- Concept introduced in 1993 by Allan
- Can be thought of as the water footprint of a good

Hoekstra, 2009

Virtual Water Content
(From H08 hydrological model)

$$Kg_{water} / Kg_{crop} \rightarrow VWC_{i,c,s} = \frac{ET_{i,c,s}}{Y_{i,c}} \quad \begin{matrix} \leftarrow Kg_{water}/m^2 \\ \leftarrow Kg_{crop}/m^2 \end{matrix}$$

- i : producing (exporting) province
- c : crop or livestock commodity
- s : source of water

H08 hydrological model

- **0.5° spatial resolution: 50km x 50km=2500km^2 grid cell**
  - **Grid cell smaller than provinces (except HK & MC)**
  - **Data aggregated at the province-level for this study**
- **Yearly estimates (due to yield change)**
- **Distinction between blue (reservoirs, rivers, groundwater) and green (rainfall) sources of water**
- **7 major crops & livestock products: wheat, rice, soy, corn, beef/mutton, pork, poultry**

Virtual Water Trade

- Combine Virtual Water Content estimates with Food Trade simulations:

$$Virtual\ Water\ Trade\left(kg_{water}\right) =$$

$$Ag\ products'\ Virtual\ Water\ Content\ \left(kg_{water} / kg_{crop}\right)$$

$$\times Commodity\ Trade\ Volume\left(kg_{crop}\right)$$

China's agricultural trade

(from **CHINAGRO** model)

- General equilibrium model representing consumer and producer behavior, government policies and markets
- Spatial detail: agricultural supply by county (2885), because of:
- Commodity detail: 17 tradable commodities
- In every county 8 farm types/production activities
- Treatment of demand more aggregated
  - 8 regions with 3 rural and 3 urban classes

The most detailed model of Chinese agriculture

Theoretical Structure of CHINAGRO

$$V^* = \max_{v_{rr'} \geq 0;\, e_c, m_r^-, m_r^+, q_c, x_c^v, x_r^u \geq 0;\, z_c^-, z_c^+ \geq 0, g_r} \sum_r \alpha_r^u u_r^u(x_r^u) + \sum_r \sum_{c \in C_r} \alpha_c^v u_c^v(x_c^v)$$

subject to

$$x_r^u + \sum_{r'} v_{rr'} + \sum_{c \in C_r} z_c^+ + g_r \delta^n + m_r^-$$

$$= \sum_{r'} \frac{1}{1+\rho_{r'}} v_{r'r} + \sum_{c \in C_r} z_c^- + m_r^+ + \omega_r^u \qquad (p_r)$$

$$g_r = \sum_{r'} \theta_{rr'}' v_{rr'} + \sum_{c \in C_r} (\tau_c^+{}' z_c^+ + \tau_c^-{}' z_c^-) + \zeta_r^+{}' m_r^+ + \zeta_r^-{}' m_r^-$$

$$\sum_r (\bar{p}_r^+{}' m_r^+ - \bar{p}_r^-{}' m_r^-) \leq \bar{B}$$

$$x_c^v + e_c + z_c^- = q_c + \omega_c^v + z_c^+ \qquad (p_c)$$

$$F_c(q_c, e_c) \leq 0, \qquad c \in C_r .$$

Optimization model to downscale food trade

Optimization goal: minimize the cost TC of inter-provincial trade t, for each commodity c. t^l and t^f for *local* and *foreign* commodities.

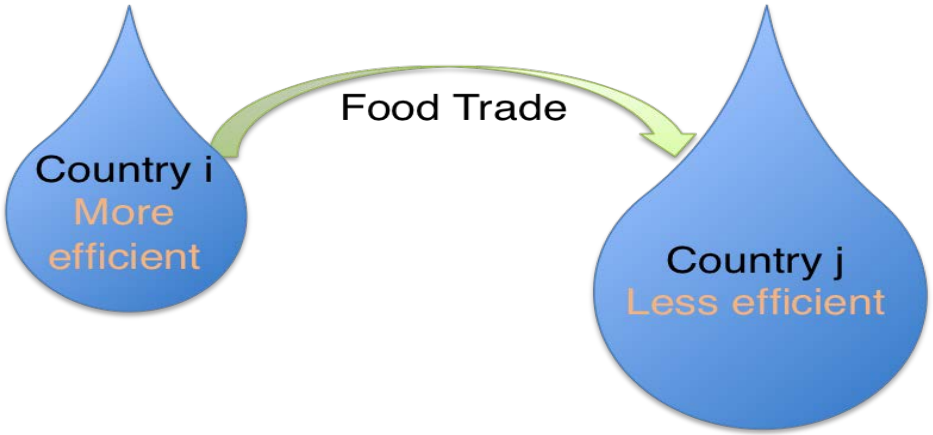
$$\min_t TC_c = \min_t \sum_{i,j} (t^l_{i,j,c} + t^f_{i,j,c}) \cdot tc_{i,j,c}$$

Constraints:

- Positive inter-provincial trade $\forall (i,j) : t_{i,j,c} \geq 0$ and $\forall i : t_{i,i,c} = 0$
- Balance supply and demand in each province$\forall i \in [1:31]$:
  $NE = \sum_j (t^l_{i,j,c} + t^f_{i,j,c} - t^l_{j,i,c} - t^f_{j,i,c}) = P_{i,c} + FI_{i,c} - D_{i,c}$
  $NE^l = \sum_j (t^l_{i,j,c} - t^l_{j,i,c}) <= P_{i,c}$
  $NE^f = \sum_j (t^f_{i,j,c} - t^f_{j,i,c}) <= max(0, FI_{i,c})$
- Compatibility with inter-regional trade $\forall (I,J) \in [1:8]^2$:
  $\sum_{i \in I, j \in J} t^l_{i,j,c} + t^f_{i,j,c} = T_{I,J,c}$

Water Savings through Trade

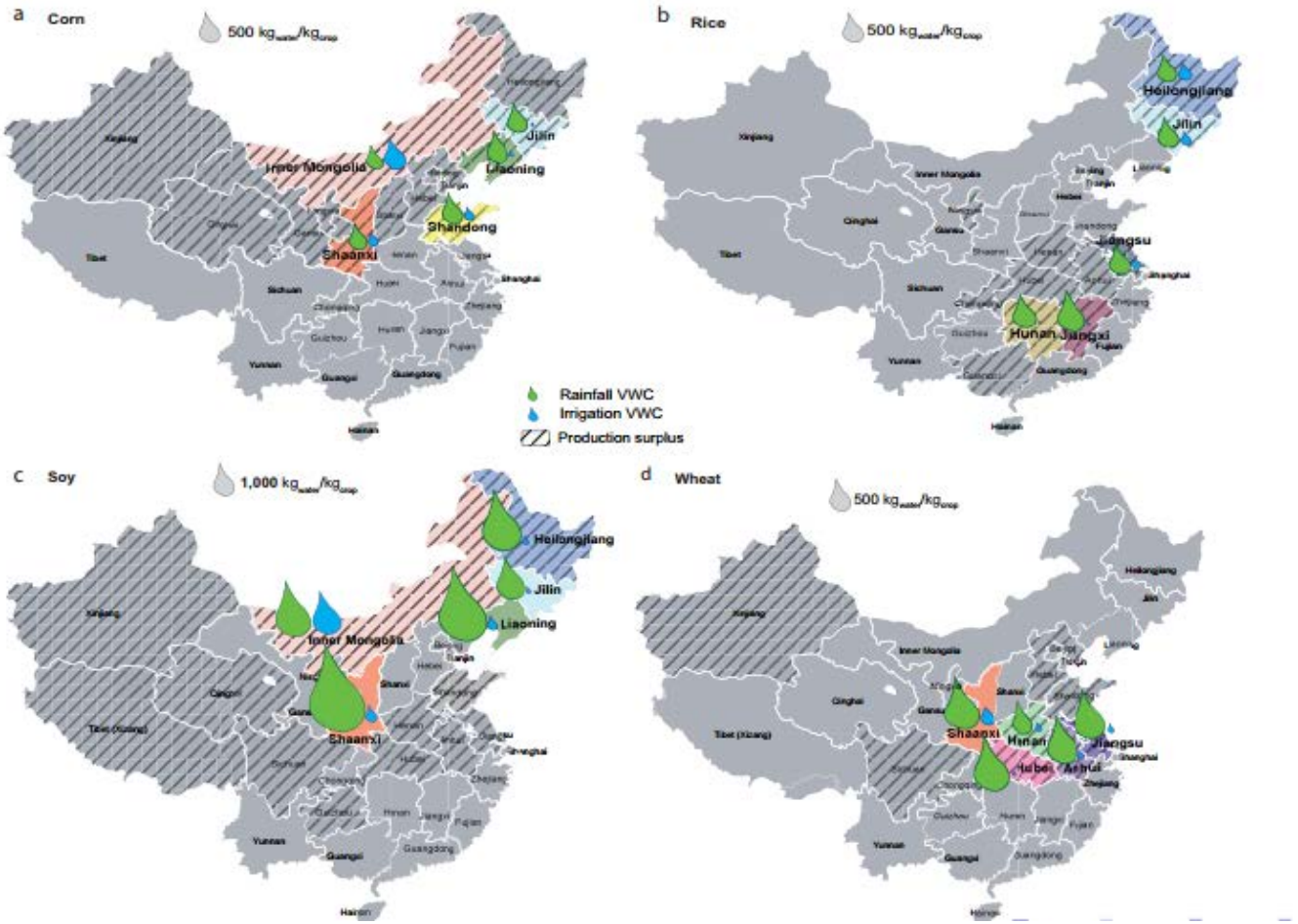
- **Differences in VWC can lead to water savings (loss) from trade:**
- $WS_{i,j,c}\ (kg_{water}) = T_{i,j,c}\ (kg_{crop}) \cdot (VWC_{j,c} - VWC_{i,c})$ (kg_{water}/kg_{crop})



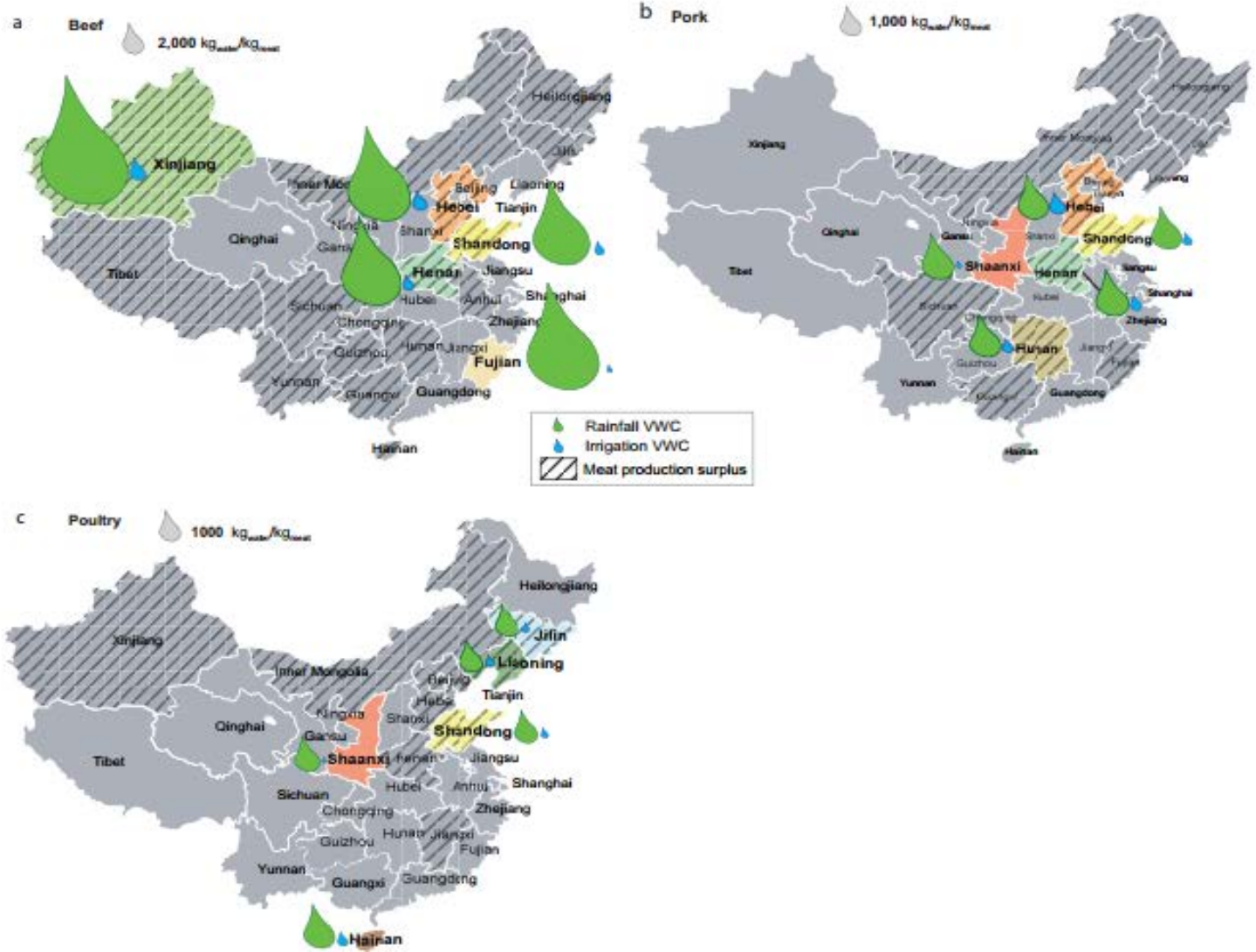
"water-efficient" trade: water savings

China’s VWT in 2005

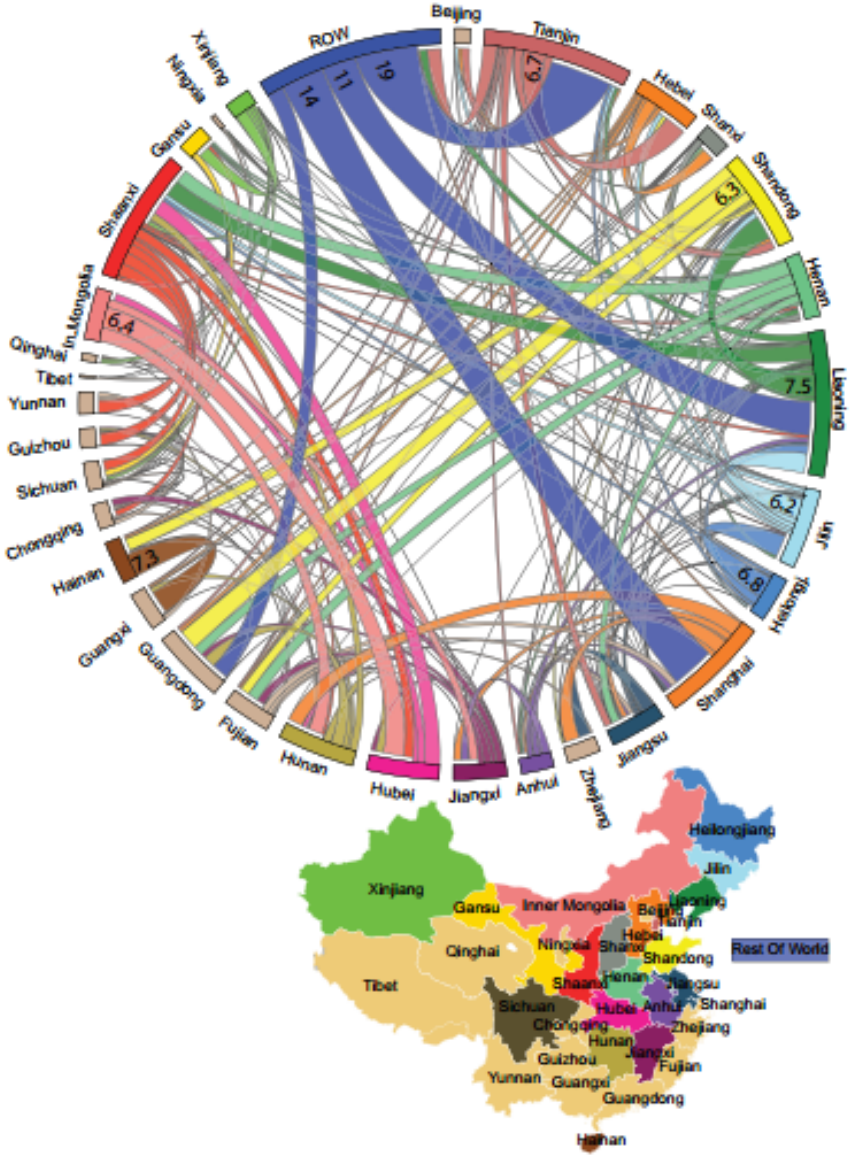
Crops VWC in major exporting provinces



Livestock VWC in major exporting provinces

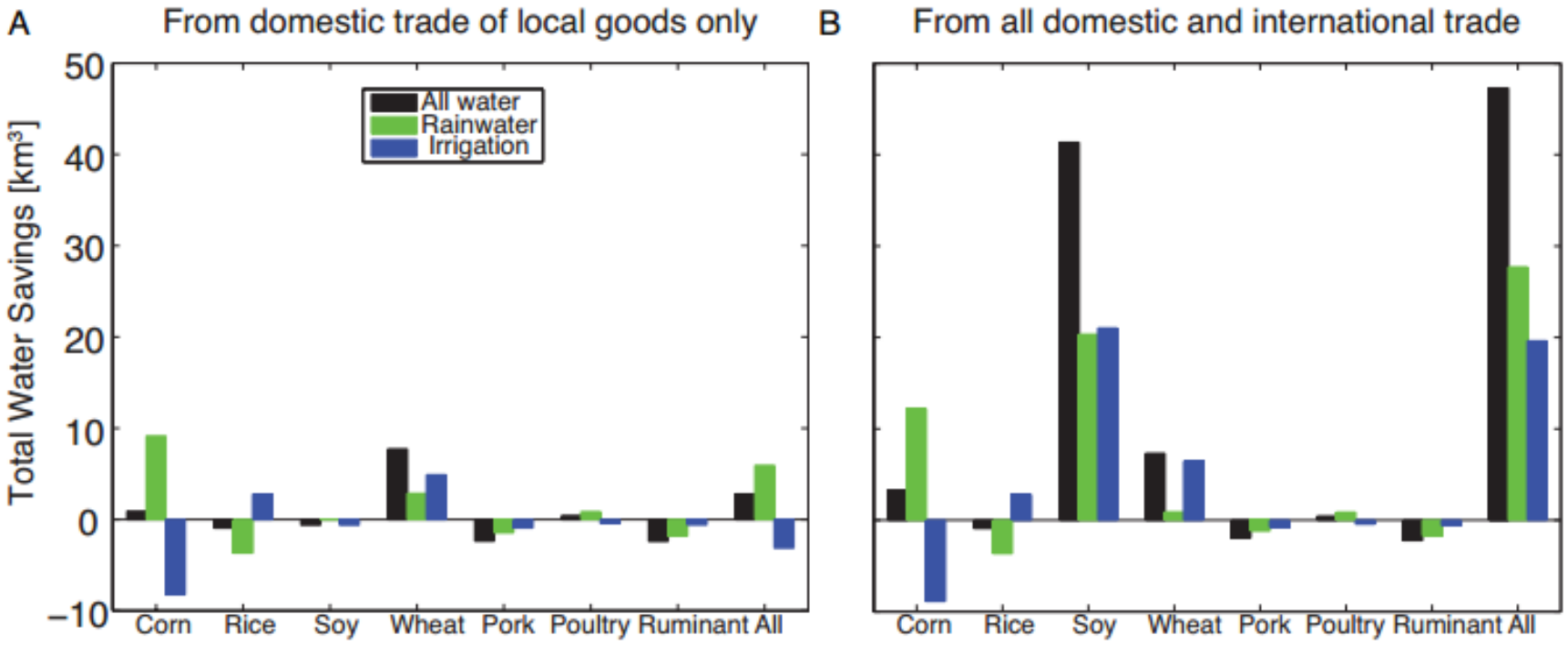


China's Virtual Water Trade Flows



- Undirected node strength range is less than two orders of magnitude $[7.4 \cdot 10^8; 5.6 \cdot 10^{10} m^3]$ (vs. $[10^5; 10^{11} m^3]$ for the global VWT network)
- Top exporting provinces: Shaanxi, Shangdong and Henan (including foreign goods or not).
- Major importers: Shaanxi, Guangdong and Guangxi.
- Largest domestic link: from Liaoning to Shandong 7.5 km^3, total $239 km^3$ (U.S. export $115 km^3$ globally, intn'l volume $567 km^3$)

Total Water Savings



- Domestic corn trade is inefficient for blue water resources
- Domestic wheat trade is efficient, saving both blue and green water
- Soy imports from abroad contribute to 87% of the total water savings associated with China's food trade. Shift from loss (domestic) to saving (foreign)

China's water savings through agricultural trade

- **We find that China's domestic and international food trade leads to global water savings of 47 km^3, representing about 13% of Chinese irrigation water use in 2005**
- **In particular, the water savings associated with trade of soy products (41 km^3) largely dominate water savings from Chinese domestic and international VWT**
- **Domestic trade of local goods alone leads to a net loss of blue water sources: 3.1 km^3 (vs. 5.9 km^3 of green water savings)**

Trade-offs between food security and water conservation

Baseline scenario(to 2030)

- **(Relatively) high non-agricultural growth sustained at 6 - 7% annually**
- **Moderate population growth to 1,436 million by 2030**
- **Urbanization moves on to about 70% by 2030**
- **Loss of crop land of 6.5 million ha by 2030, especially for rainfed land**
- **Further intensification of livestock sector**
  - **Higher feed efficiency but less based on residuals**
- **Continued improvement of input efficiency and yields in cropping**
- **Constraint of water resource (share of irrigated land)**

Scenarios of targeted reduction of irrigated area (in 2030)

- **IM scenario: On top of BL, assuming that, in 2030, 50% if irrigated land in Inner Mongolia province will be shifted to rainfed land**

- **IM+B: On top of BL, assuming that, in 2030, 50% if irrigated land in Inner Mongolia and Greater Beijing area (Beijing, Tianjin, and Hebei)will be shifted to rainfed land**

Major Results (1)

- Effects of Targeted Irrigation Reductions on Water Resources and Food Self-Sufficiency

Table 1. Differences in irrigation water consumption (all products combined), by area, and in China's self-sufficiency ratios for three major crops, for IM and IM+B scenario, relative to BL (year 2030)

Scenario and area	Δ Irrigation water consumption, km^3	Δ Corn self-sufficiency ratio, percentage points	Δ Wheat self-sufficiency ratio, percentage points	Δ Soy self-sufficiency ratio, percentage points
IM				
Inner Mongolia	–5.2			
China	**–7.7**	–1.8 [84.3%]	–0.3 [97.9%]	–0.2 [21.4%]
IM+B				
Inner Mongolia	–5.2			
Beijing	–0.2			
Tianjin	–0.3			
Hebei	–5.7			
China	**–14.8**	–3.6 [82.4%]	–3.0 [95.2%]	–0.7 [20.9%]

Numbers in brackets indicate the self-sufficiency ratio in each scenario, and those in bold font highlight national changes in irrigation water consumption. Note that in the IM+B scenario, about 15 km^3 of freshwater are saved (14% decrease in irrigation water consumption) without significantly altering China's food self-sufficiency (by 4.2% for corn, the largest relative decrease).

Major Results (2)

Avoided water consumption (WC, in km^3) in IM and IM+B scenarios relative to BL, by area and water source in 2030. Negative values indicate increased water consumption.

Scenario	Area \Avoided WC	Total	Green	Blue
IM	In. Mongolia	6.4	1.2	5.2
	Other provinces	2.0	-0.5	2.5
	China	8.5	0.8	**7.7**
IM+B	In. Mongolia	6.4	1.9	5.2
	Beijing	0.2	0.01	0.2
	Tianjin	0.2	-0.09	0.3
	Hebei	7.8	2.1	5.7
	Other provinces	1.8	-1.6	3.5
	China	16.3	1.6	**14.8**

Major Results (3)

Avoided blue water consumption (in km^3) relative to BL, in IM and IM+B scenarios (2030)

Scenario	Area	Corn	Rice	Soy	Wheat	Beef	Pork	Poultry
IM	In. Mon.	3.4	0.2	0.8	0.4	0.2	0.2	0.08
	Other prov	-0.06	-0.008	0.02	0.01	0.1	2.0	0.4
	China	**3.4**	0.2	0.8	0.4	0.3	**2.3**	0.5
IM+B	In. Mon.	3.5	0.2	0.8	0.4	0.2	0.2	0.07
	Beijing	0.1	0.0005	0.01	0.03	0.01	0.002	0.004
	Tianjin	0.1	0.01	0.01	0.04	0.01	0.06	0.007
	Hebei	2.8	0.1	0.2	1.1	0.5	0.9	0.2
	Other prov	-0.008	-0.01	0.1	-0.1	0.2	2.8	0.5
	China	**6.5**	0.3	1.0	1.4	0.8	**4.0**	0.8

Discussions

- **China is facing mounting pressures from food security and water scarcity**
- **While it's important improve agricultural water productivity through technological measures, other measures to reduce agricultural water should also be explored**
- **Our results show that targeted reduction of irrigation area can significantly reduce agricultural water use while have relatively small negative impacts on food security (14% water use reduction, with about 3% decline in cereal production).**

Discussions (cont.)

- **The total transfer projected through the SNWT scheme by 2050 (45 km3/y) is about three times the volume saved in the IM+B scenario relative to BL.**
- **However, providing more water to these regions with both scarce resources and inefficient use may encourage the development of wasteful water-intensive activities in dry areas, thus failing at improving environmental sustainability.**
- **Long-distance water transfers have serious socioeconomic and environmental costs, such as population displacement, in addition to important benefits.**
- **Reducing irrigation would likely come at a small financial cost, mostly devoted to farmer support (e.g., by government transfers, such as ecological compensation) and additional foreign food imports.**

Relative shifts in national food supply and demand (in %)

Scenario	Variable	Area	Corn	Rice	Soy	Wheat	Beef	Pork	Poultry
IM	P (% national)	In. Mon.	-2.5	-0.2	-0.3	-0.3	0.005	0.04	0.02
	P	China	-2.2	-0.07	-0.4	-0.3	0.05	-0.05	-0.09
	C	”	-0.1	-0.08	-0.9	-0.02	-0.003	-0.05	-0.03
	FI	”	12.6	0	0.8	17	-0.5	0	0.5
	SSR	”	-2.1	0	-0.9	-0.3	0.05	0	-0.06
IM+B	P (% national)	In. Mg	-2.6	-0.2	-0.4	-0.3	0.05	0.04	0.02
	”	Beijing	-0.05	-0.0007	0.003	-0.1	0.0009	0.0002	0.001
	”	Tianjin	-0.04	-0.02	-0.01	-0.1	-0.002	0.01	0.007
	”	Hebei	-1.8	-0.1	-0.2	-4.9	0.02	0.2	0.2
	P	China	-4.3	-0.2	-1.5	-4.5	0.06	-0.05	-0.2
	C	”	-0.1	-0.3	2	-1.5	0.001	-0.05	-0.08
	FI	”	25.7	0	2.6	167	-900	0	3,900
	SSR	”	-4.2	0	-3.2	-3.0	0.06	0	-0.2

One is tempted by one’s own desire, being lured and enticed by it; then, when that desire has conceived, it birth to sin, and that sin, when it is fully grown, gives birth to death.

中國人民大學
RENMIN UNIVERSITY OF CHINA

Thank you

Huanguang QIU, Renmin University of China

hgqiu@ruc.educ.cn