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Potential Impacts of Climate Change on Global Rice Market and Food Security in Asia

Ching-Cheng Chang
Institute of Economics, Academia Sinica
Chi-Chung Chen
Dept of Applied Economics, National Chung-Hsing University
Shih-Hsun Hsu
Dept of Agricultural Economics, National Taiwan University

Outlines

- **Climate Change and Food Security in Asia**
- **Three Empirical Studies**
  - Partial Equilibrium vs General Equilibrium
  - Deterministic vs Stochastic
  - Regional vs Global

Focus:

- How to conduct an economic impact assessment?
- How to incorporate adaptation strategies?

Climate Risk in Aisa-1
East-Asian Monsoon

- **Observations since 1950s:**
  - Weakening of summer and winter monsoon (Xu et al., 2006)
  - Moving southward where both land and sea surface temperature rise
- **Examples**
  - **Thailand** Flood, 2011 (684 death) (Thai Meteorological Department, 2011. http://www.tmd.go.th)
  - Typhoon Washi (Sendong) in **southern Philippines**, 2011 (>2000 death/missing, 70,000 families affected)

Climate Risk in Asia-2
El Niño Southern Oscillation (ENSO)

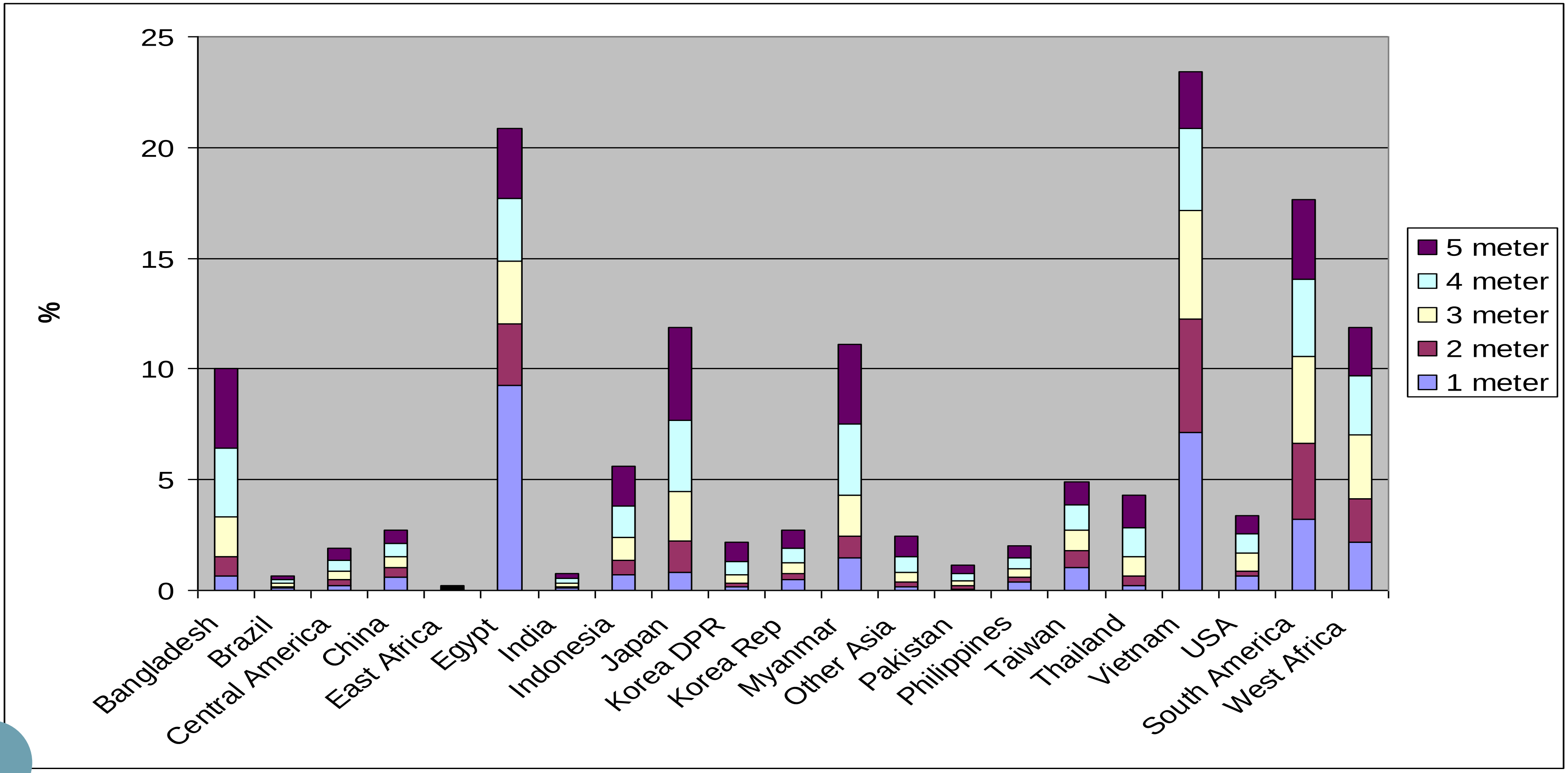
- **Risk (IPCC, 2001a,b; Rasmusson, 1989)**
  - Enhance variability of precipitation and stream flow
  - Lead to greater risk of droughts and floods
- **Examples:**
  - 1997-98 in **Indonesia**: substantial threat to rural livelihood
  - 2010-11 in **Queensland:** Flood

Climate Risk in Asia-3
Sea Level Rise (SLR)

- **Long-term threat to agriculture**
- **Recent Projections by 2100**
  - **Annual:**
    - ***Raper and Braithwaite (2006)*** *project SLR caused by melting glaciers and icecaps will fall between 0.046 and 0.051 m*
    - **Meier et al. (2007)** estimate an additional 0.1 to 0.25 m.
  - **Cumulative**
    - **Rahmstorf (2007)** projects a cumulative SLR of 0.5 to 1.4 m.
    - **Dasgupta et al. (2009)** projects 1 to 3 m of rise but indicates as much as 5 m is possible if unexpected rapid breakup of Greenland ice cover and West Antarctic ice sheet occurs.

Impacts of SLR on Agricultural Land

- Inundate 0.39% to 2.10% of global cropland
- Occurs in ag land in SE Asia, E Asia, S Asia, SE US
  - ➢ Constitutes a threat to rice

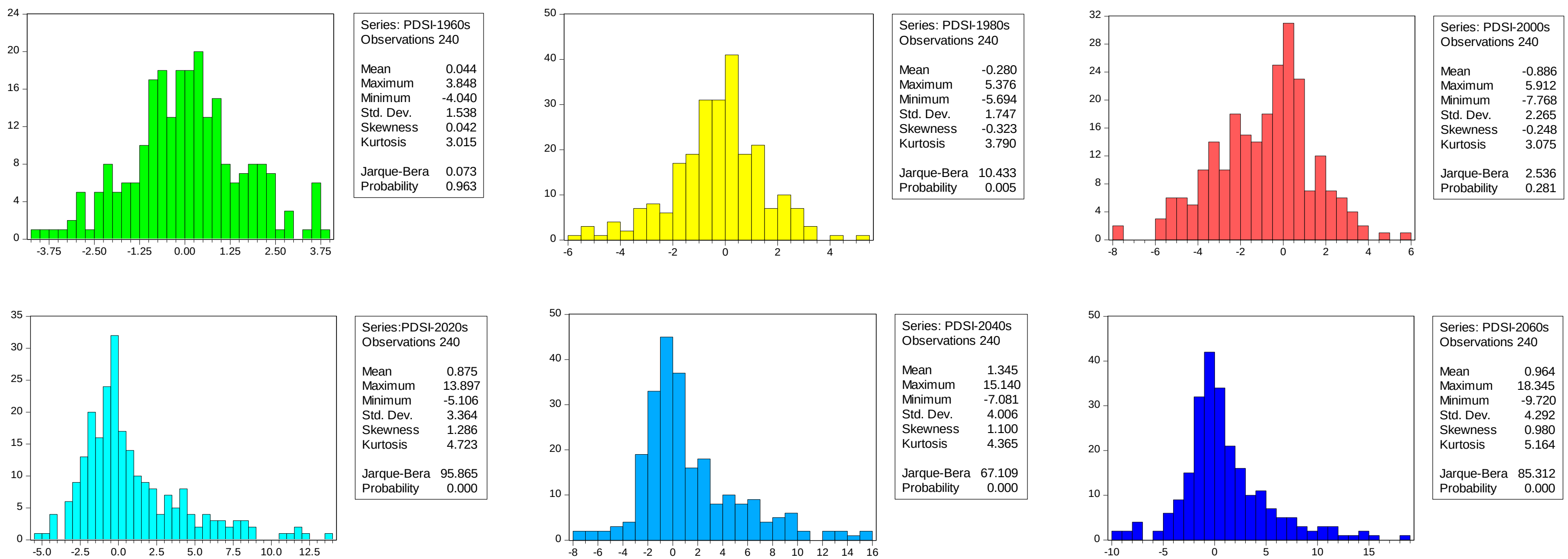


Source: Dasgupta et al. (2009).

Climate Risk in Asia-4
Drought

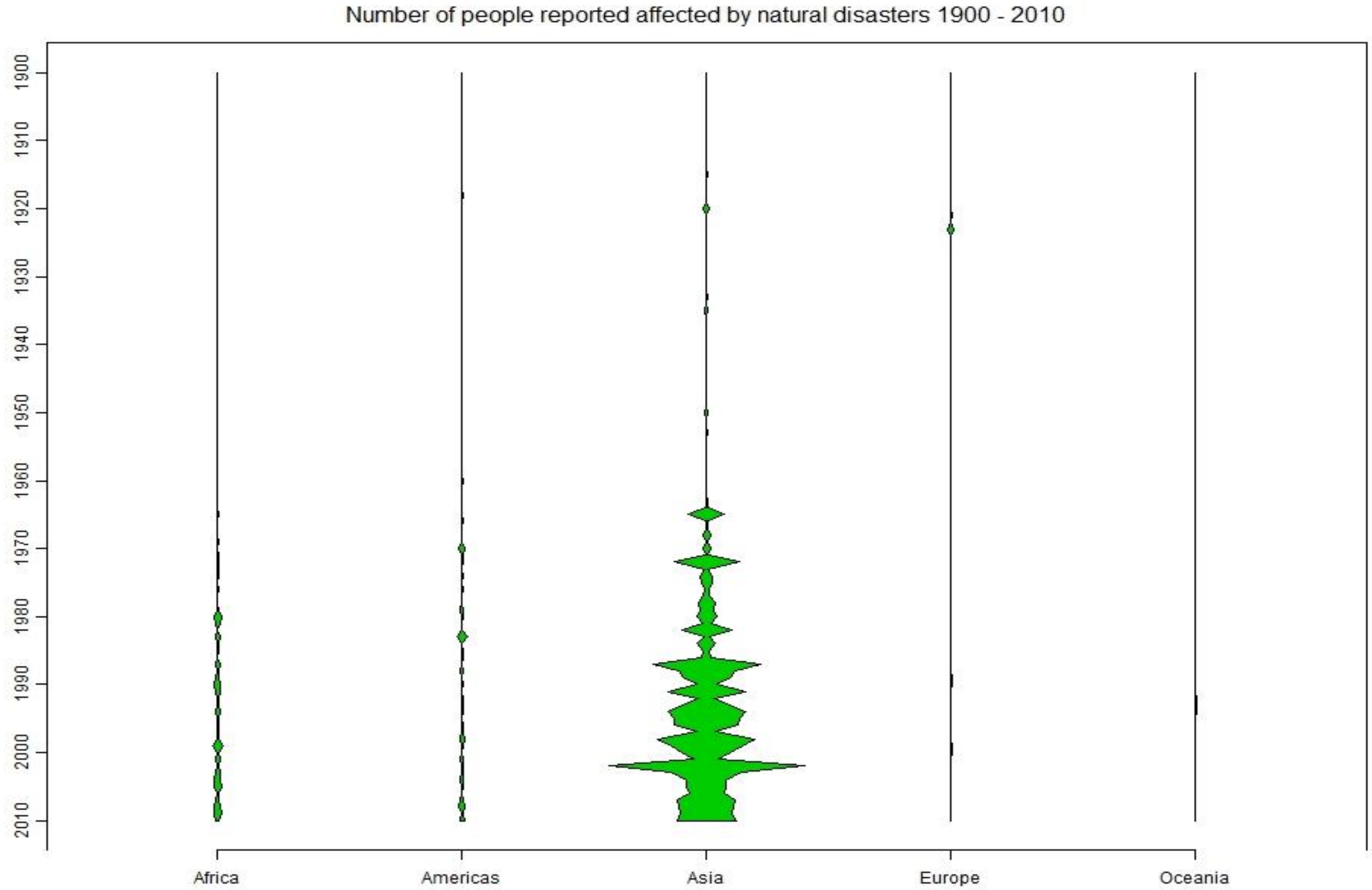
- **Pandey et al. (2007)**
  - At least 20% of Asian rice area is estimated to be effected
  - More than 50% of this area is located in China.
  - India: 1987 and 2002-03 drought affected >50% cropped area.
  - Thailand: 2004 drought affected 20% of rice area

The histogram and projection of Palmer Drought Severity Index (PDSI, Dai, 2012) for Asian rice growing season, 1960~2060



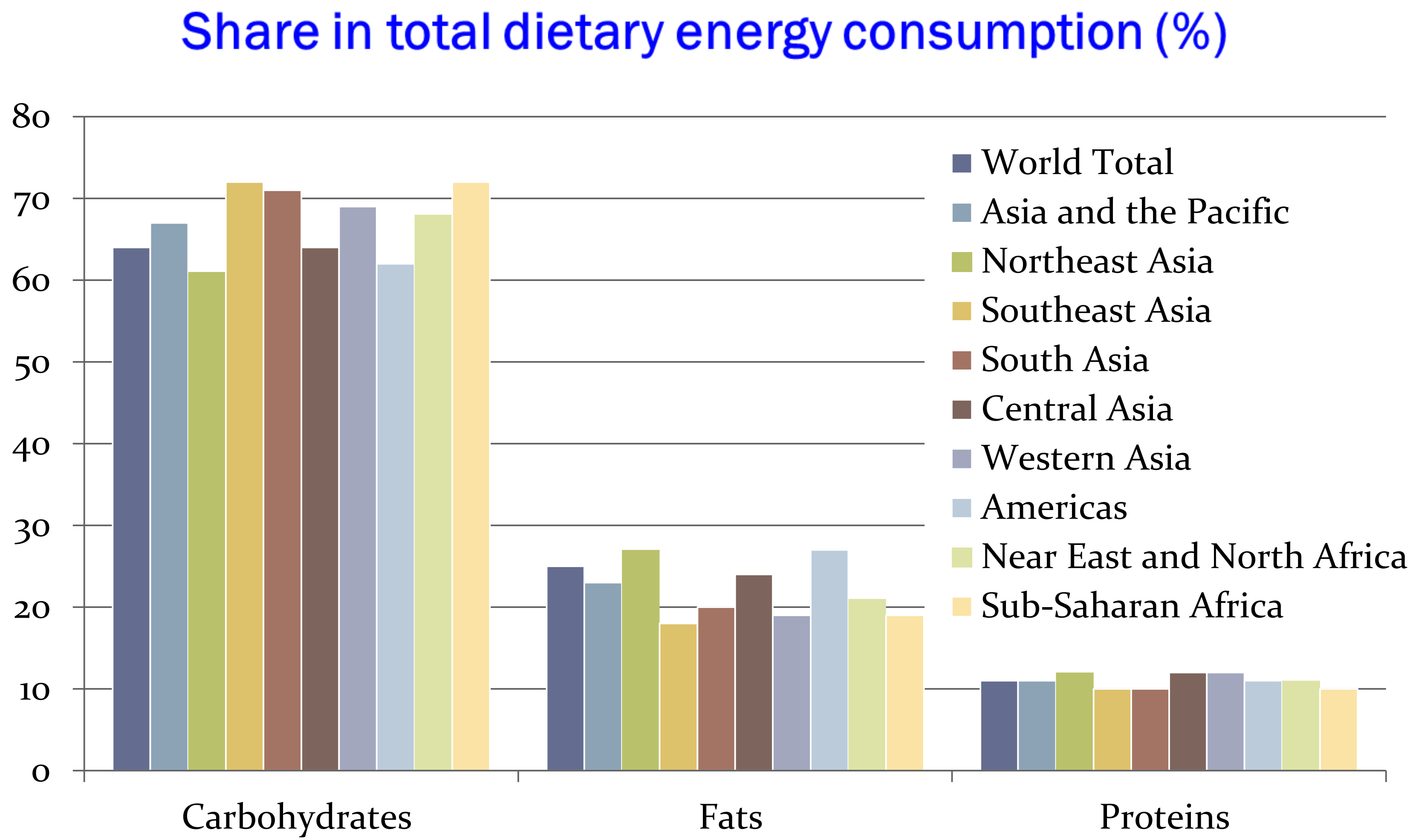
Climate Risk-5
Natural Disasters

No of people affected in Asia increases more dramatically than those in other continents since 80's.



Number of people affected by natural disasters by Regions, 1900-2010
Source: EM-DAT: The OFDA/CRED International Disaster Database.

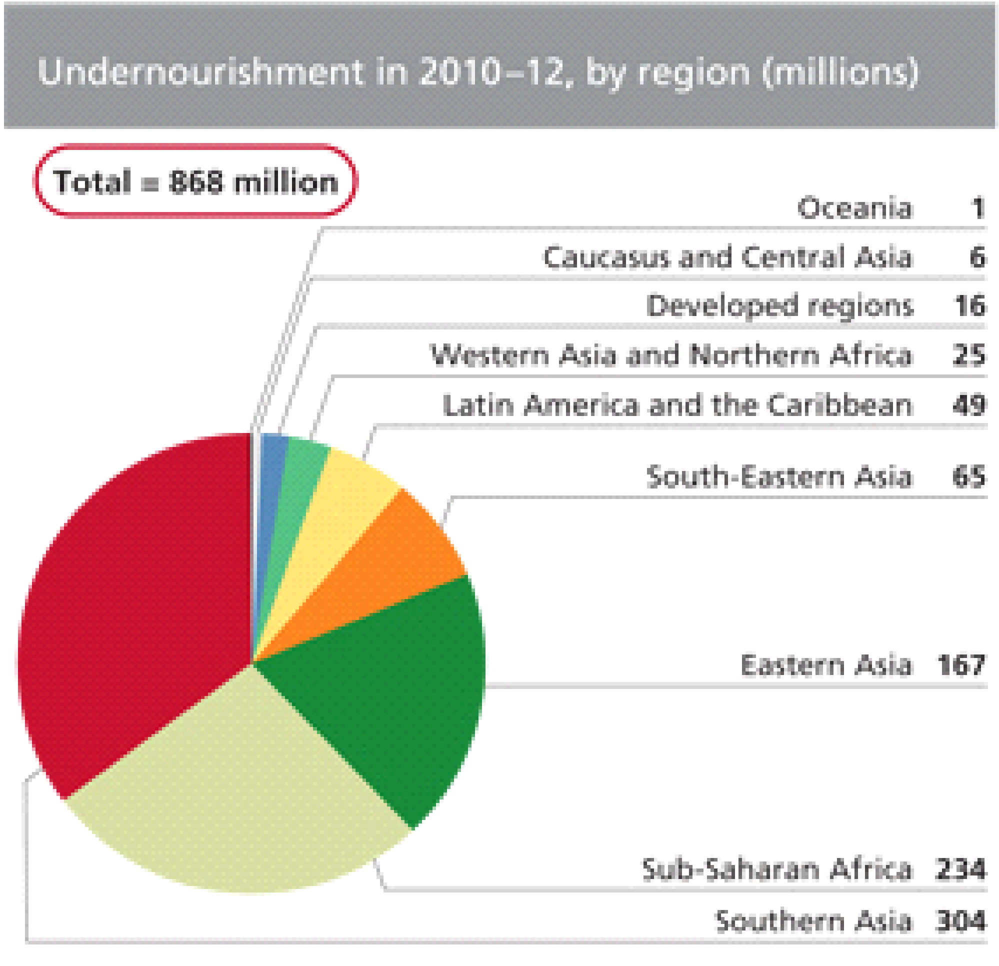
Food Security in Asia-1



Source: Chang et al. (2013), and Food Security Statistics, FAO.

Food Security in Asia-2

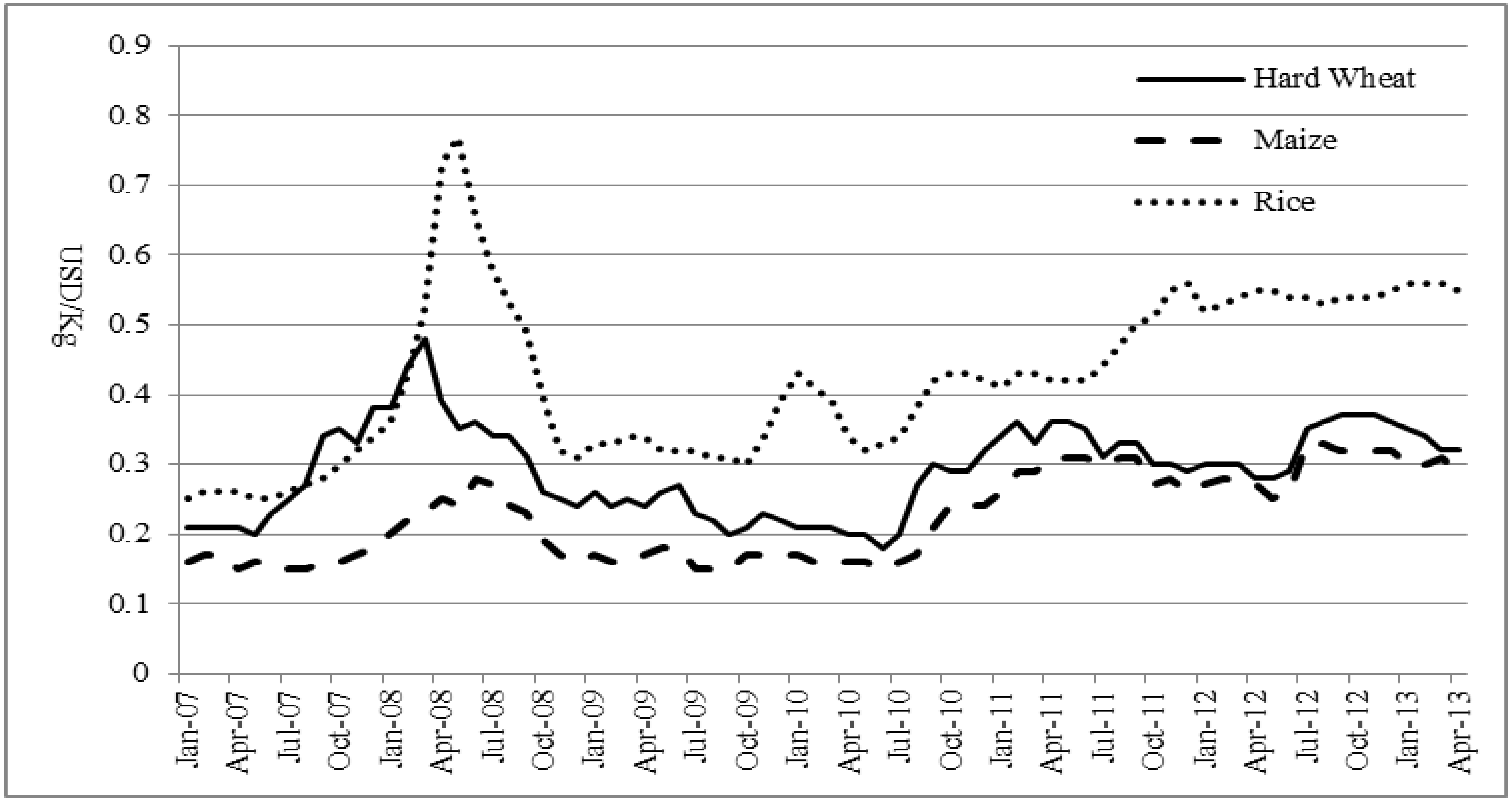
Undernourishment in 2010-12, by region (millions)



Source: *FAO Hunger Portal*. Food and Agriculture Organization (FAO), United Nations 2012 [cited December 1 2012]. Available from http://www.fao.org/hunger/en/.

Food Security in Asia-3

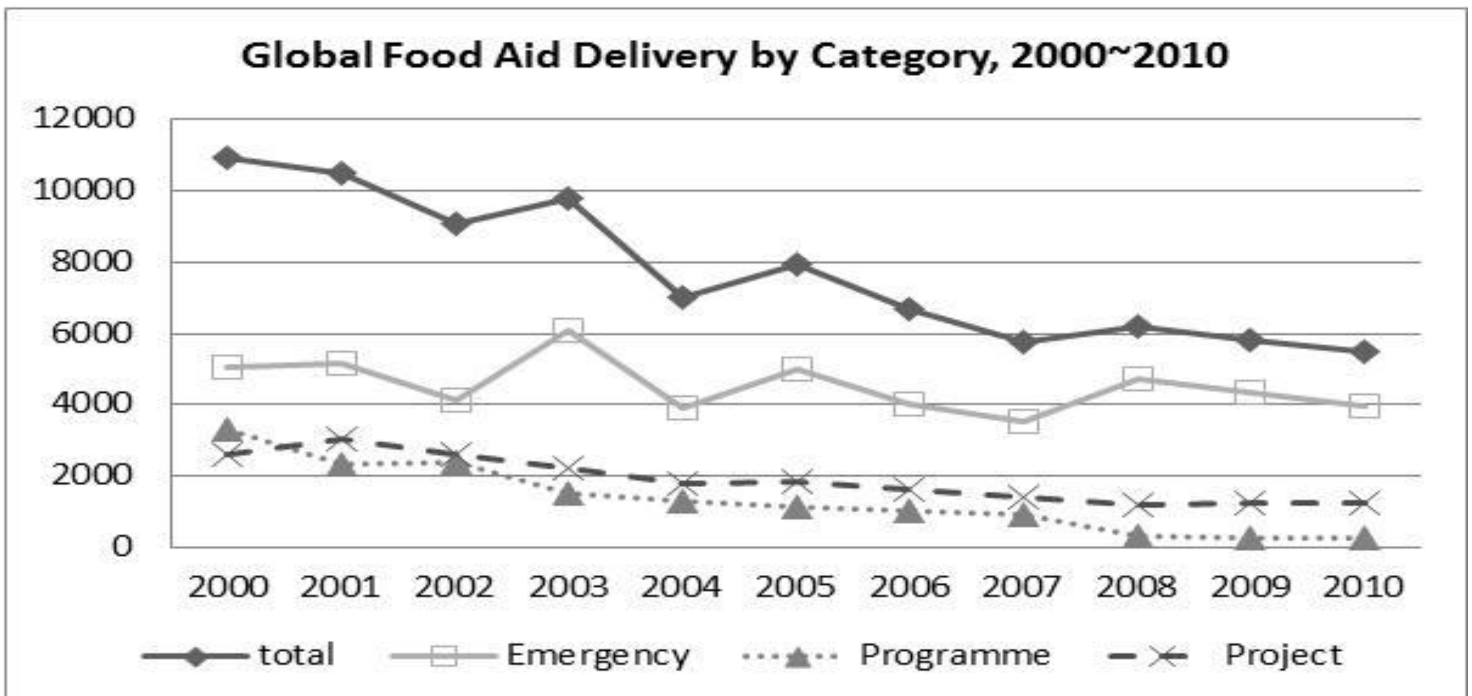
Grain prices from Jan 2007 to Apr 2013



Source: IFPRI (2013).

Food Aid Delivery Are Declining Globally

- **Main causes:** (ODI, *Food aid and food assistance in emergency and*
- *transitional contexts: A review of current thinking*, 2011)
  - Tightened food supply due to weather anomaly
  - Pressure from financial and fuel crises
  - Shift from *program/project aid* to *emergency aid* by key donors
  - Change in sourcing from *in-kind* to *in-cash local purchase*



Source: WFP, Food Aid Information System (INTERFAIS).

Rice in Asia

Rice: The Most important staple

- **Supply side**
  - More than 110 countries grow rice in the world
  - Asian countries produce 91-92% of the world total
  - China and India accounting for more than 50%

- **Demand side**
  - More than 90% of rice is consumed in Asia
  - China, India and Indonesia accounting for 75%

Climate Change and Food Security

- **Four main causes**
  - Temperature: Heat stress
  - Precipitation: Drought or Flood
  - Sea-level Rise

- **Some Recent Studies**

1. **IPCC (2007)**
   - Agricultural production in South Asia could fall by 30% by 2050 if no action is taken on rising temp and hydrologic disruption
2. **ADB-Zhai and Zhuang (2009)**
   - By 2080, global crop production would shrink 7.4%
   - Southeast Asia decline 17.3%
   - East Asia would be modest: from -0.1% in China to -5.1 in Korea.
3. **Mottaleb et al (2012)**
   - 2000-2011 NVDI data on drought in South Asia
   - Affected Area: 8.7% in SriLanka to 25.8% in Inida and 26.9 in Pakistan
   - Prob of occurrence of drought: 0.21 in Nepal to 0.46 in India
   - Drought–tolerant rice will bring USD 1.5~1.9 billion net benefit

Policy Implications- How to Measure?

Crop Yield Response

- Climate & Non-climate Factors
- Agronomy vs Statistical Model
- Mean and Variances

Global Circulation Model

- Regional Downscaling
- IPCC SRES scenarios
- Historical trend analysis

Economic Model with Adaptation Options

- Partial vs General Equilibrium
- Single vs Multiple Commodity
- Food price, Production, GDP, Social welfare

Three Empirical Models/Studies

- **Sea Level Rise**
  - Agricultural Sector Model
    - Partial Equilibrium/Single-country/Stochastic
  - Global Rice Trade Model
    - Partial Equilibrium/Multi-country/Stochastic
- **Drought**
  - GTAP
    - General Equilibrium/Multi-country/Deterministic

Methodology

- Step 1. Estimating the effects of climate change on agricultural productivity
  - Experimental Data
  - Crop Simulation Model （e.g., EPIC）
  - Econometric (Statistical) Model w/Historical Data
- Step 2. Climate Change Scenarios
- Step 3. Combinations of steps 1 and 2
- Step 4. Estimating the economic impacts
- Step 5. Evaluating the adaptation strategies

Cast Study 1—

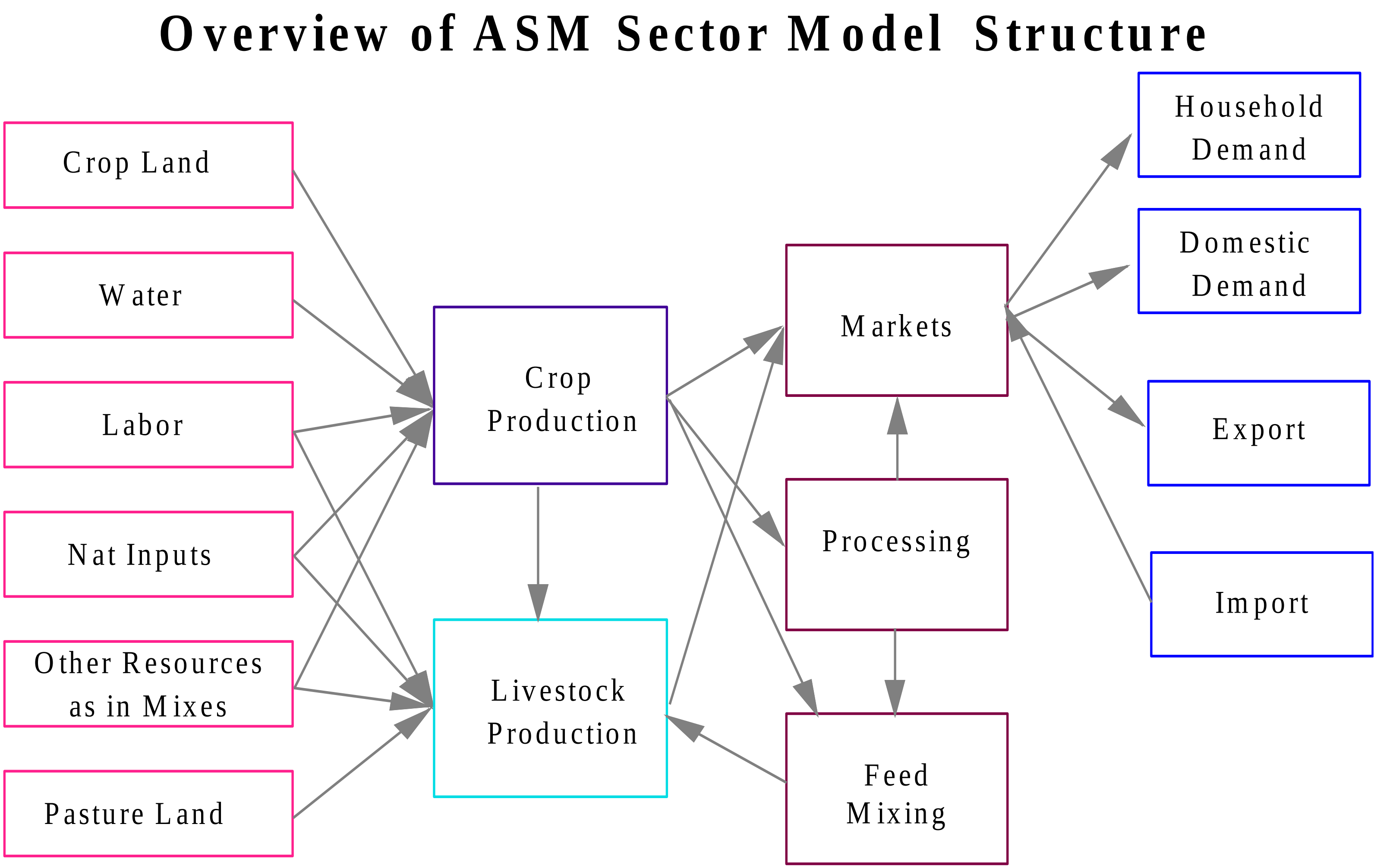
- **Evaluating the Economic Impacts of Crop Yield Change and Sea Level Rise Induced by Climate Change on Agricultural Sector in Taiwan (Chang et al., 2012)**

Model features

1. Market competition
   Many producers and consumers
   Competitive for both **product** and **input** markets
2. Price endogeneity
   Social welfare will be maximized at the interception of demand and supply curves
   Prices are determined by supply-demand balance conditions
3. Embody adaptation possibilities

Agricultural Sector Model (ASM)

Based on McCarl and Spreen (1980), Chang et al. (1992), Adams et al (1995) 's earlier work in Texas A&M on farm policy and climate change



Stochastic ASM Mathematical Forms

Subscript *s* denoting the state of nature from climate conditions

$$MAX \quad \sum_{s} \rho(s) * \{ \sum_{i} \int \psi(Q_{is}) dQ_{is} - \sum_{k} \int \alpha_k(L_k) dL_k - \sum_{k} \int \beta(R_k) dR_k - \sum_{i} \sum_{k} C_{ik} X_{ik}$$

$$+ \sum_{i} \sum_{i} \int ED(Q_{is}^{M}) dQ_{is}^{M} + \sum_{i} \int EXED(TRQ_{si}) dTRQ_{is} - \sum_{i} \int ES(Q_i^{X}) dQ_i^{X}$$

$$+ \sum_{i} [tax_i * Q_{is}^{M} + outtax_i * TRQ_{is}]\} + \sum_{i} P_i^{G} * Q_i^{G} + \sum_{k} P^{L} * AL_k \ ,$$

Subject to:

$$Q_{is} + Q_{is}^{X} + Q_i^{G} - \sum_{k} Y_{iks} * (1 + CCYIELD_i) * X_{ik} - (Q_{is}^{M} + TRQ_{is}) \le 0 \qquad \forall\, i, s\,,$$

$$\sum_{i} X_{ik} + AL_k - L_k * (1 - SLR) \quad \le \quad 0 \qquad \forall\, k\,,$$

$$\sum_{i} f_{ik} X_{ik} - R_k \quad \le \quad 0 \qquad \forall\, k \quad ,$$

Chang's Estimates of Crop Yield Response to Temperature and Precipitation in Taiwan

	Temperature				Precipitation			
Season	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
Rice	0.08	0.00	-0.20	-0.05	-0.01	-0.08	0.03	0.01
Peanuts	-0.17	0.40	0.10	-0.13	-0.01	-0.08	0.00	0.06
Adzuki bean	-0.34	-0.54	0.73	-1.34	0.00	0.07	-0.27	0.08
Sweet-Potatoes	0.16	0.20	-0.67	0.26	0.00	-0.03	-0.21	-0.01
Tea	0.02	0.59	-1.18	0.64	0.02	-0.24	0.02	0.01
Cane for Process	-0.10	-0.23	0.04	-0.33	0.03	0.35	-0.26	0.06

Change in 2055 Climate under Various Climate Model Projections

GCMS	CGCM		HADCM		ECHAM	
Scenarios	A2	B2	A2	B2	A2	B2
Temperature	18%	-3%	+1%	+6%	+6%	+7%
Precipitation	-3%	-3%	+9%	+10%	-4%	-14%

- HADCM fall in the middle between CGCM and ECHAM
  - 1% increase in temperature with 6% increase in precipitation
  - 6% increase in temperature with 9% increase in precipitation

Possible Adaptation Strategies

- Crop Yield Improvement
- Free Trade and Storage

Adaptions:
Crop Yield Improvement and Free Trade

	Combinations of Sea Level Rise and Crop Yield Effects on Welfare in NT$ Million				
	1 meter & B2	2 meters & B2	3 meters & B2	4 meters & B2	5 meters & B2
	Without Adaptation Strategy				
	-2666	-3246	-3971	-4896	-5772
	Crop Yield Improvement in terms of % increase in all yields				
1%	-1235	-1822	-2537	-3455	-4334
2%	199	-384	-1095	-2000	-2867
3%	1546	990	295	-607	-1461
4%	2847	2310	1634	746	-111
5%	4140	3612	2961	2089	1265
	Trade Liberalization in form of Import Tariff Reduction				
5% Cut	-535	-1135	-1863	-2792	-3676
10% Cut	518	-71	-791	-1718	-2597
15% Cut	1860	1269	549	-372	-1247
20% Cut	2873	2285	1568	642	-233
25% Cut	3846	3259	2542	1620	745

Cast Study 2—
Impact of Sea Level Rise on Global Rice Market (Chen et al., 2011)

- **Model Fearures**
  - Based on Samuelson (1952) and Takayama and Judge (1971) **Spatial Equilibrium** Model
  - The deterministic model is modified into **stochastic version**
  - **Imperfect competitive** market in a global rice market is assumed

Stochastic Rice Trade Model

—Mathematical Forms

$$MaxCSPS = \sum_s \rho(s) \times [\begin{array}{l} \sum_i (\int f_i(QD_{is})dQD_{is} - \int g_i((QS_i + Y_{is})*(1+\text{Yieldper}_i))dQS_i) \\ - \sum_i \sum_{i'} t_{i,i'} TRE_{i,i',s} + \sum_i stoc_i(STOA_{is}) \\ - \sum_i \sum_{i'} tar_{i'} - exs_{i'}) TRE_{i,i',s} - \sum_i prs_i QS_i \end{array}]$$

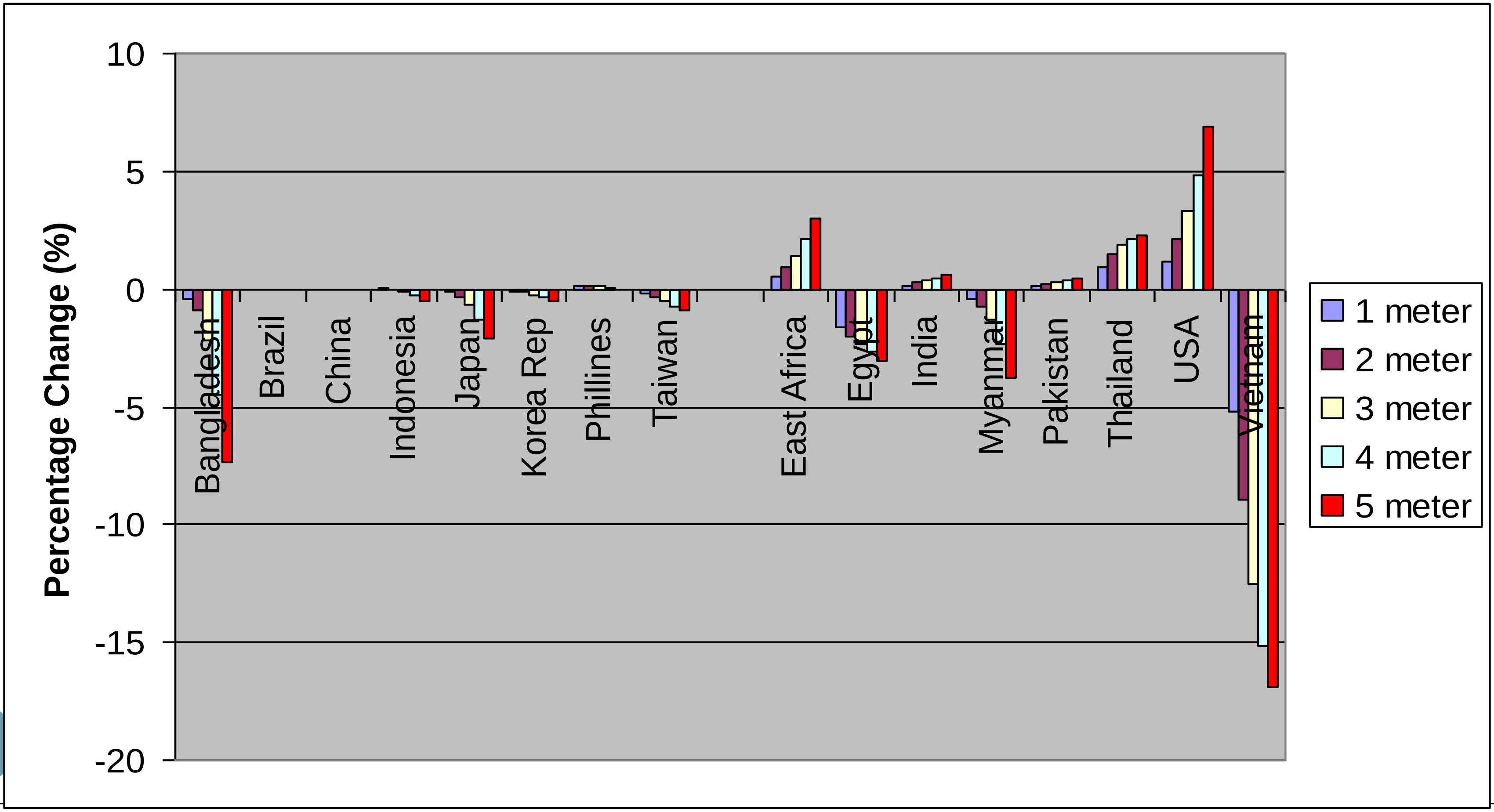
s.t.

$$+\sum_{i'}(TRE_{i,i',s} - TRE_{i',i,s}) - (QS_i + Y_{is})*(1+Yieldper_i) - STOW_{is} + STOA_{is} + QD_{is} \leq 0 \quad \forall i,$$

$$\sum_s \rho(s)*[STOA_{is} - STOW_{is}] = 0 \quad \forall i$$

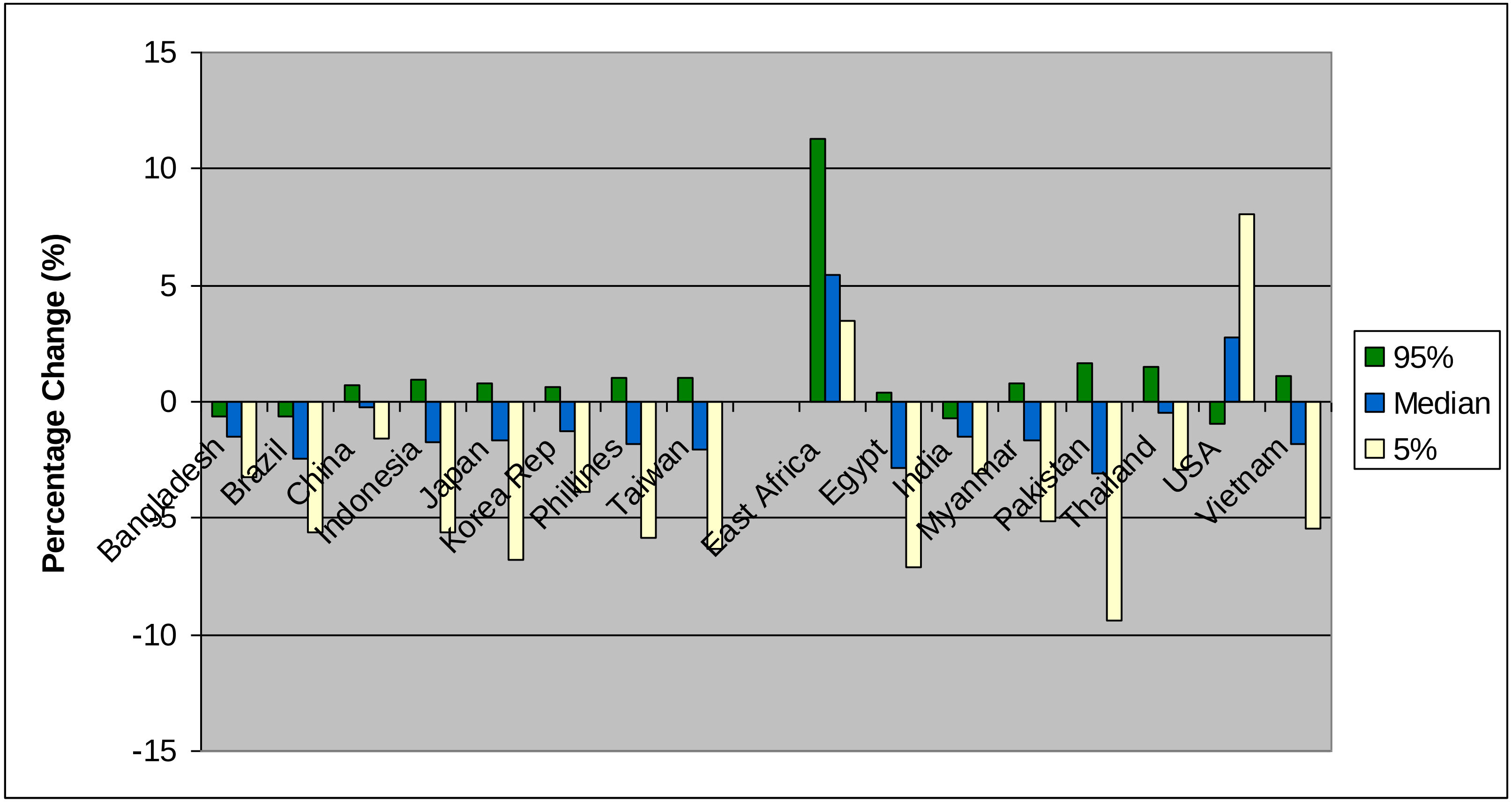
Rice Production Reduction due to Sea Level Rise

To estimate rice planted acreage affects, the ratio of rice acreage divided by total cropland is applied to the land loss scenarios.



Rice Yield Change due to 2030 Climate Change

- Lobell et al. (2008) provided the probability distribution of estimated yield across random draws based on 20 GCM models and SRES scenarios.
- We used their median, 5th, and 95th percentile impacts for 2030 case



Impacts of Sea Level Rise on Global Rice Market

	BASE	1 meter	2 meters	3 meters	4 meters	5 meters
Total Production (metric tons)	504476	-1121 (-0.22)	-2005 (-0.40)	-3154 (-0.63)	-4513 (-0.89)	-5852 (-1.16)
Total Trade (metric tons)	22416	876 -3.91	1634 -7.29	2428 -10.83	3255 -14.52	4185 -18.67
Average Price (US$/ton)	220.83	0.46 -0.21	4.64 -2.1	9.52 -4.31	14.99 -6.79	21.11 -9.56
Total Social Welfare (US$ Million)	2308525	-1453 (-0.06)	-2513 (-0.11)	-4327 (-0.19)	-7245 (-0.31)	-10593 (-0.46)

Social welfare will be lost by US$ 1.45 billion to 10.59 billion.

Combination Effects on Global Rice Market

	Scenarios	Sea Level Rise in meters					
	Economic Items	BASE	1	2	3	4	5
No Yield effect	Total Production (1000 mt)	504,476	-0.22%	-0.40%	-0.63%	-0.89%	-1.16%
	Total Trade (1000 mt)	22,416	3.91%	7.29%	10.83%	14.52%	18.67%
	World Price ($/mt)	361.43	0.90%	1.67%	2.67%	3.88%	5.13%
	Social Welfare ($ billion)	2,309	-1.45	-2.51	-4.33	-7.25	-10.59
95% Yield Effect	Total Production (1000 mt)	0.39%	0.16%	-0.01%	-0.01%	-0.50%	-0.76%
	Total Trade (1000 mt)	1.68%	4.34%	7.78%	7.78%	15.19%	19.23%
	World Price ($/mt)	-2.24%	-1.35%	-0.59%	-0.59%	1.54%	2.72%
	Social Welfare ($ billion)	2.99	1.56	0.52	-1.26	-4.14	-7.45
Median Yield Effect	Total Production (1000 mt)	-1.01%	-1.23%	-1.40%	-1.62%	-1.88%	-2.13%
	Total Trade (1000 mt)	0.69%	5.83%	9.11%	12.63%	16.50%	20.83%
	World Price ($/mt)	4.68%	5.60%	6.39%	7.41%	8.62%	9.89%
	Tocial Welfare ($ billion)	-6.91	-8.41	-9.51	-11.39	-14.38	-17.77

Amount of Adaptation Needed

(…): % change in yield improvement to overcome welfare losses to zero

[…] : % trade barriers cut (i.e. trade liberalization) to overcome welfare losses

	Sea Level Rise in meters					
	BASE	1	2	3	4	5
No Yield Effect		(1%) [14%]	(2%) [18%]	(2%) [22%]	(4%) [28%]	(5%) [33%]
Upper 95% Yield Effect	(0%) [0%]	(0%) [0%]	(0%) [0%]	(1%) [15%]	(2%) [24%]	(4%) [28%]
Median Yield Effect	(3%) [28%]	(4%) [32%]	(4%) [33%]	(5%) [35%]	(7%) [38%]	(8%) [40%]
Lower 5% Yield Effect	(10%) [45%]	(10%) [46%]	(11%) [46%]	(12%) [48%]	(13%) [49%]	(15%) [51%]

Cast Study 3—

Potential Impact of Drought on Food Security in Asia (Chen et al., 2013)

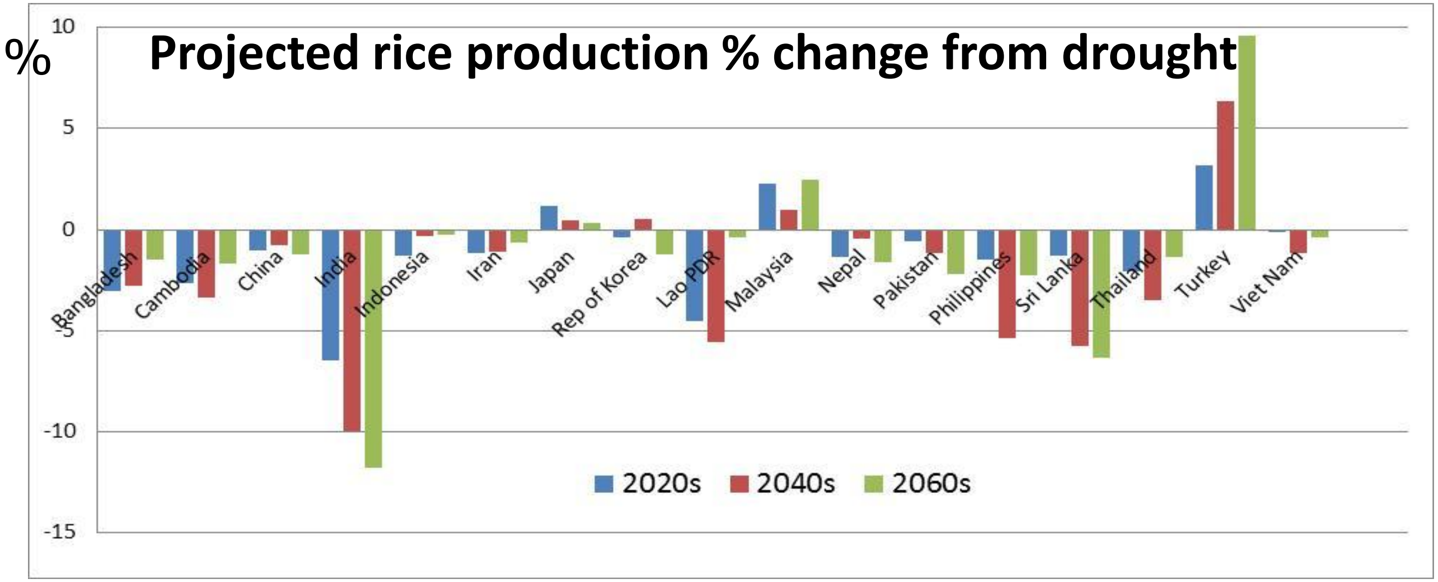
STEP 1: Examine monthly SC-PDSI data (Tunalioglu and Duedu, 2012) for 24 Asian countries from Dai (2012) at a grid resolution of 2.5˚ by 2.5˚.

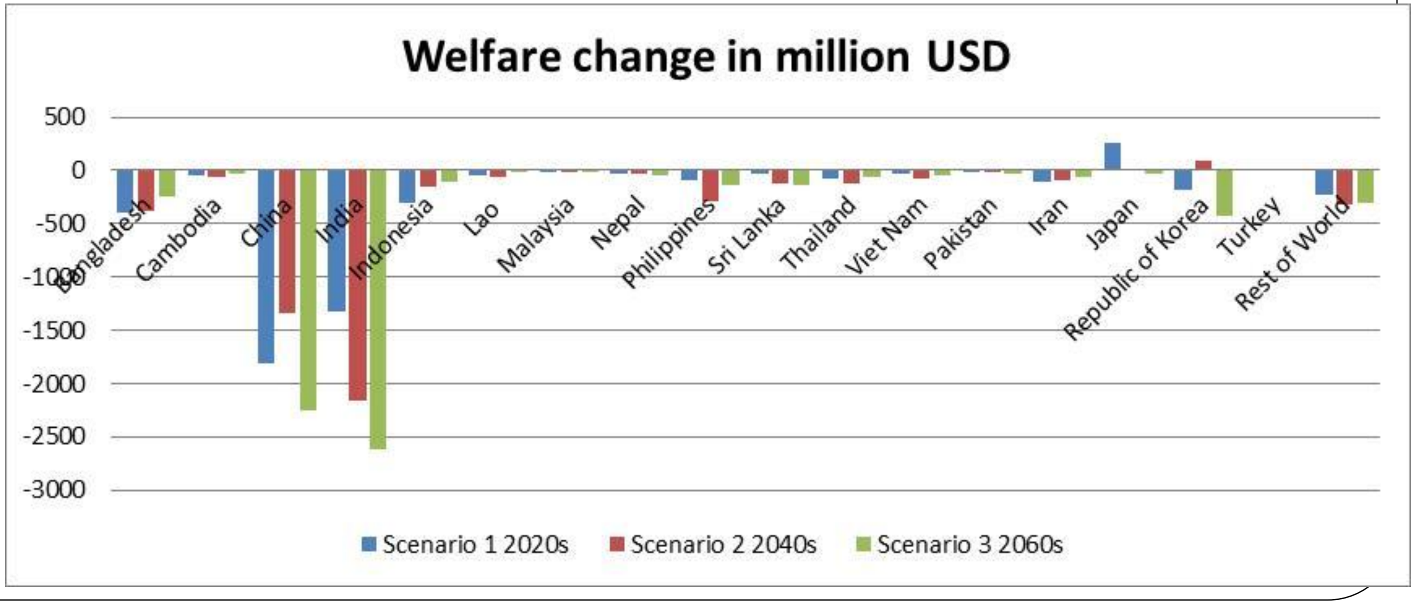
● = selected grid point

Step 2: Use Just and Pope (1978) stochastic production function to find marginal effect of PSDI on rice production: Panel of 18 Indica and 6 Japonica rice zone, 1961-2010

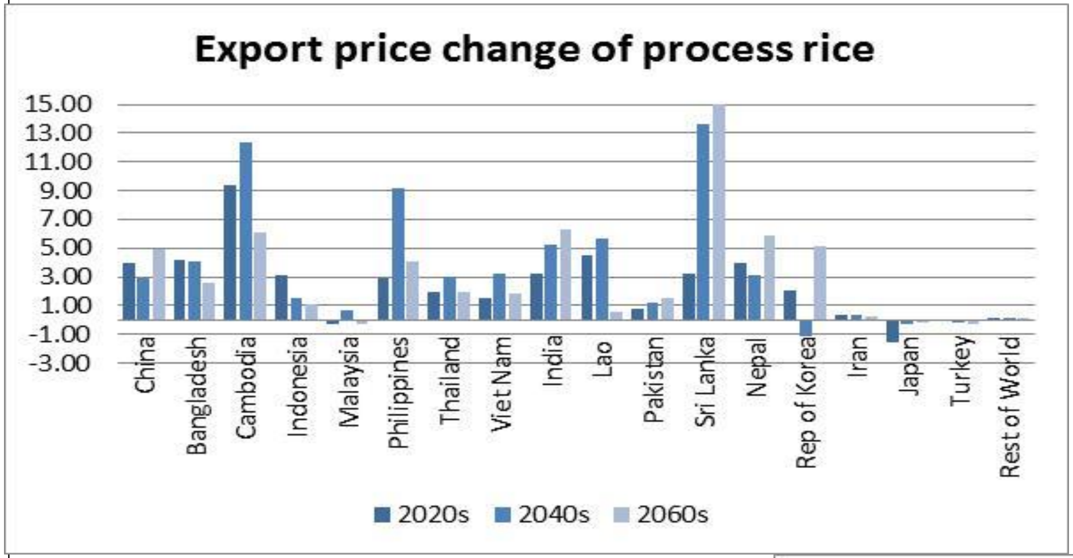
	Japonica rice			Indica rice		
Baseline PDSI	-0.6889			-0.3705		
Marginal effect of PDSI on rice						
Mean equation	-0.4030			-0.1602		
Variability equation	7.3285			-1.2807		
Skewness equation	1.3232			0.1703		
	2020s	**2040s**	**2060s**	**2020s**	**2040s**	**2060s**
Projection of PDSI	-1.3664	-1.7294	-2.3278	-1.3249	-1.3752	-1.7679
Marginal effect of future PDSI on rice production distribution						
Mean	-0.2730	-0.4193	-0.6605	-0.1528	-0.1609	-0.2238
Variability	4.9647	7.6247	12.0103	-1.2222	-1.2871	-1.7895
Skewness	0.8964	1.3767	2.1686	0.1625	0.1711	0.2379
Marginal effect of future PDSI on rice production distribution in %						
Mean	-8.7934	-13.5058	-21.2749	-5.8695	-6.1806	-8.5968
Variability	2.1222	3.2592	5.1339	-2.4256	-2.5544	-3.5515
Skewness	14.3550	22.0462	34.7270	15.0009	15.7966	21.9634
	2020s		**2040s**		**2060s**	
Changes in total rice production						
-in absolute volume (mil ton)	-42.01		-53.54		-79.93	
-in percentage(%)*	-6.93		-8.83		-13.18	

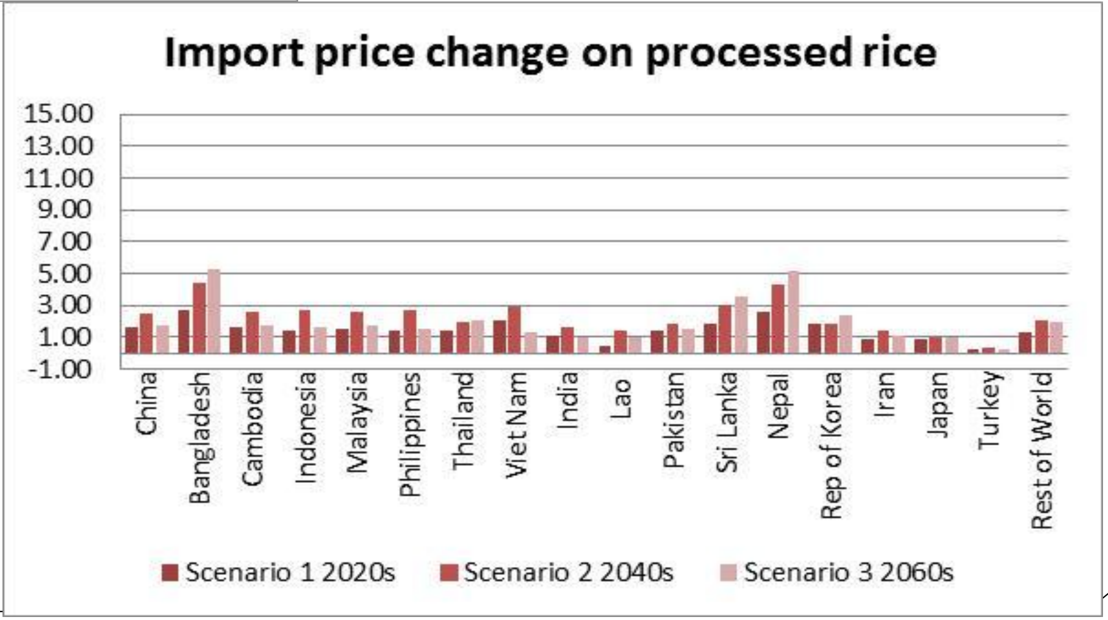
Step 3. social economic impact assessment is based on the GTAP model





Trade implication:
Import and export price change





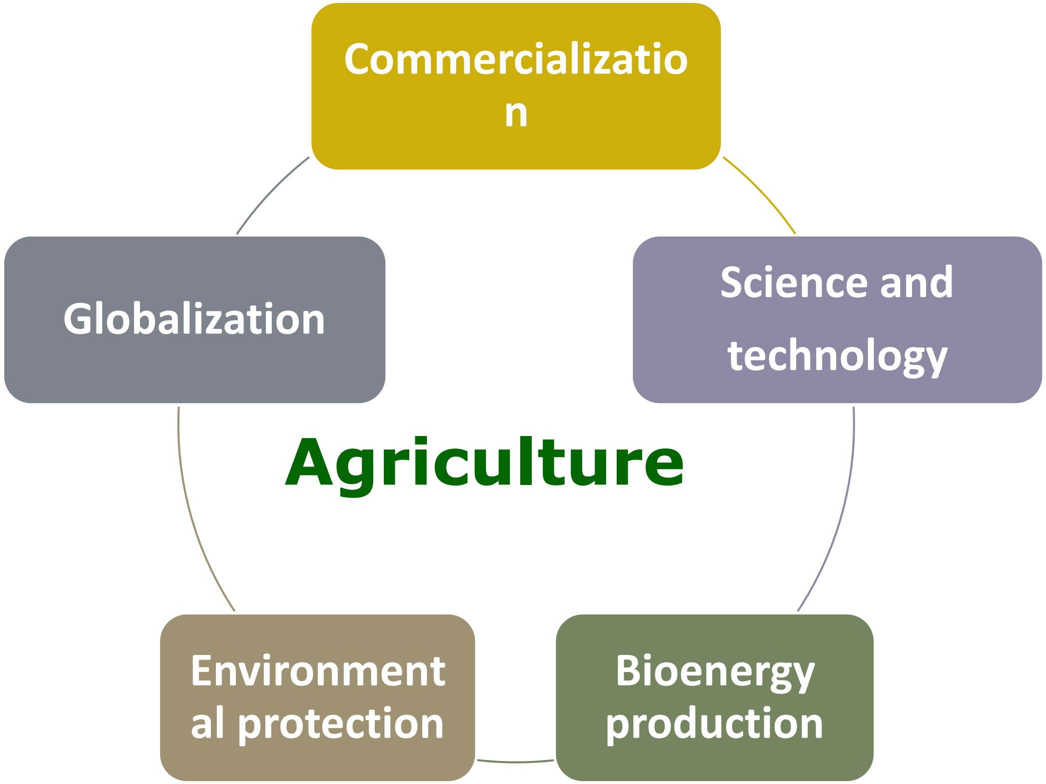
Agenda for Further Research-1

- Our study has not yet considered
  - Possible expansion/shrinkage of land use under the influence of climate change
  - Consequent change in the crop suitability of land
  - Climate change driven plant pest and diseases
  - Adoption of heat/drought-resistant varieties of crops

➔Collaboration with experts of agronomy and biogeography will help fill the gap.

Agenda for Further Research-2

- Agriculture: Rapid transformation in the global context
- Climate Change: A challenge or an opportunity?



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