Economic impacts of climate change on supply and demand of food in the world

Jun Furuya, Shintaro Kobayashi (JIRCAS)
Seth D. Meyer (MU-FAPRI)
Topics

- Higher temperature and agriculture
- Estimation of yield function
- World food model
- Deterministic analyses
- Stochastic analyses
Rising temperature

0.5 to 1.0 degrees Celsius increased in the 20th century.

Cause:
- Increase of GHG (CO2)
- Sun spot activity
Increasing CO2 density

At Mauna Loa observatory, University of California
Relationship between crop production and higher temperature

- **High temperature injury**
  - Oxygen deficit in a stem
  - Deteriorates protein

- **Increase of insect damage**
  - Higher temperature increases the number of insects

- **Drought**
  - Higher temperature leads to decreasing rainfall
  - Water shortage leads to growth retardant
Climatic changes probably make large impacts on agricultural production and food market.

Climatologist and crop scientists estimate yield functions including climatic variables.

We estimated (macro) yield functions and replace them with yield functions of the world model.

We examine possible impacts of climatic change focusing on global warming and its impacts on world agricultural market by using stochastic version of world food model.
Estimation of Yield Functions

Specification

- \( \ln YH_t = a + b_1 T + b_2 \ln TMP_t + b_3 \ln PRC_t \) \hspace{1cm} (1)
  - \( YH \): Yield, \( T \): trend,
  - \( TMP \): temperature, \( PRC \): precipitation
  - (Heading Season: 1-2 months before harvest s.)
- \( d\ln YH_t = a + b_2 d\ln TMP_t + b_3 d\ln PRC_t \) \hspace{1cm} (2)
  - \( d\ln YH_t = \ln YH_t - \ln YH_{t-1} \)

Estimation

- OLS, AR \( \leftrightarrow \) serial correlation

Unit Root Test

- Augmented Dickey-Fuller Test (10%)
Data of yield functions

- **Yield**
  - FAO-STAT

- **Temperature, rainfall**
  - GHCN (Global Historical Climatology Network)

- **Flowering season (months) are selected using cropping calendar**
  - USDA

- **Cropping regions are selected in large countries such as the USA**
  - USDA
Maize planting region in the USA

This map was originally drawn by the USDA and modified.
### Elasticity of yield for temperature and rainfall

<table>
<thead>
<tr>
<th>Country</th>
<th>Elasticity of yield</th>
<th>Country</th>
<th>Elasticity of yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temp.</td>
<td></td>
<td>Temp.</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>Maize</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>-0.327</td>
<td>USA</td>
<td>-1.226</td>
</tr>
<tr>
<td>EU</td>
<td>-1.076</td>
<td>EU</td>
<td>-0.211</td>
</tr>
<tr>
<td>Ex-USSR</td>
<td>-0.454</td>
<td>E. Europe</td>
<td>-2.222</td>
</tr>
<tr>
<td>India</td>
<td>-0.333</td>
<td>Brazil</td>
<td>-0.012</td>
</tr>
<tr>
<td>China</td>
<td>-0.585</td>
<td>China</td>
<td>-0.967</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
<td></td>
<td>0.186</td>
</tr>
<tr>
<td></td>
<td>-0.117</td>
<td></td>
<td>0.136</td>
</tr>
<tr>
<td></td>
<td>0.636</td>
<td></td>
<td>0.417</td>
</tr>
<tr>
<td></td>
<td>0.050</td>
<td></td>
<td>0.054</td>
</tr>
</tbody>
</table>

If temperature increases 1 %, the yield of maize in the USA will decrease 1.226%.
### Elasticity of yield for temperature and rainfall (cont’d)

<table>
<thead>
<tr>
<th>Other Coarse Grains</th>
<th>Elasticity of yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td><strong>Temp.</strong></td>
</tr>
<tr>
<td>USA</td>
<td>-1.061</td>
</tr>
<tr>
<td>EU</td>
<td>-0.772</td>
</tr>
<tr>
<td>Australia</td>
<td>-0.110</td>
</tr>
<tr>
<td>E. Europe</td>
<td>-0.529</td>
</tr>
<tr>
<td>Ex-USSR</td>
<td>-2.070</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rice</th>
<th>Elasticity of yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td><strong>Temp.</strong></td>
</tr>
<tr>
<td>USA</td>
<td>-1.125</td>
</tr>
<tr>
<td>India</td>
<td>-2.023</td>
</tr>
<tr>
<td>Indonesia</td>
<td>-0.082</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.078</td>
</tr>
<tr>
<td>China</td>
<td>-0.270</td>
</tr>
</tbody>
</table>
Elasticity of yield for temperature and rainfall (cont’d)

<table>
<thead>
<tr>
<th>Country</th>
<th>Elasticity of yield</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>-0.791</td>
<td>0.220</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.141</td>
<td>0.067</td>
</tr>
<tr>
<td>Argentina</td>
<td>-1.248</td>
<td>0.067</td>
</tr>
<tr>
<td>India</td>
<td>0.115</td>
<td>0.131</td>
</tr>
<tr>
<td>China</td>
<td>0.276</td>
<td>0.131</td>
</tr>
</tbody>
</table>
Structure of the world food model

Yield function: double log form

YH = f(time trend, temperature, rainfall)

World food model (IFPSIM)

- 14 commodities
- 32 countries or regions
- Structures of IMPACT (IFPRI) and WFM (FAO) are same as that of IFPSIM
- Program: FORTRAN90
Flowchart of world food model (Crop sector)

- **Leader**
  - Temperature
  - Yield
  - Harv. area
  - Produc.
  - World Sum=0
  - Net imports
  - Stock change
  - Supply
  - World price
  - Demand
  - GDP

- **Other countries**
  - Harvested area, demand of other countries
  - Dom. price
  - Tariff

- One year later: Harvested area, demand of other countries
Crop production in the USA (Annual increase rate)
Livestock production in the USA (Annual increase rate)

Baseline Baseline Baseline Baseline Rising temp.(A2) Rising temp.(A2) Rising temp.(A2) Rising temp.(A2)

Beef Pork Poultry Poultry Egg Egg F.Milk F.Milk

(%)

-0.2 -0.2 -0.2 -0.2 0.0 0.0 0.2 0.2 0.4 0.4 0.6 0.6 0.8 0.8 1.0 1.0 1.2 1.2 1.4 1.4 1.6 1.6 1.8 1.8

Baseline Rising temp.(A2)
Impact of rising temperature on the world wheat production
Impact of rising temperature on the world maize production
Impact of rising temperature on the world other coarse grain production
Impact of rising temperature on the world rice production
Impact of rising temperature on the world soybeans production
Crop production in the world (Annual increase rate)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Baseline</th>
<th>Rising temp.(A2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Maize</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>O.C. Grains</td>
<td>1.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Rice</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>SoyBeans</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Maize</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>SoyBeans</td>
<td>1.9</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Legend:
- **Baseline**
- **Rising temp.(A2)**
Stochastic analysis

The temperature and rainfall variables entering into the yield functions are exogenous to the world food model.

To evaluate the effect of changes in temperature and rainfall during flowering or silking seasons on the world food model, these climatic variables must be endogenized in a model.
Climatic data estimation

- **Linear function**
  - \( TMP_{ijt} = a^T_{ij} + b^T_{ij}T \)
  - \( PRC_{ijt} = a^R_{ij} + b^R_{ij}T \)
  - \( i: \) country, \( j: \) crop, \( T: \) time trend

- **% error correlation coefficient**
  - 1961-2000

- **Estimation of trend for forecasting**
  - 2001-2050
Flowchart of creating random climatic data

1. Actual TMP, PRC
2. Estimated TMP, PRC (DDC)
3. Errors
4. Sorted Errors
5. Empirical CDF
8. Correlated Uniform Random no.
9. Correlated Empirical Dist. Error
10. Std. Norm. CDF
11. Sample of TMP, PRC
Flowchart of simulation of stochastic model
Data of simulation

- Temperature, Rainfall (1961-2000)
  - DDC (Data Distribution Center, UEA)
- Temperature, Rainfall (2001-2050)
  - HadCM3 A2 scenario
- Data aggregation
  - 0.5° grid → country or planting region
  - Dr. Nishimori (NIAES) calculated
Forecasting of temperature

IPCC (Intergovernmental Panel on Climate Change) reports forecasts of temperature rising for some scenario

Scenarios:
- A: More economic, B: More environmental
- 1: More global, 2: More regional
- A1: Rapid growth society
- A2: Heterogeneous society
- B1: Dematerialization society
- B2: Local sustainable society
Temperature of flowering season in the USA (A2 scenario)

Correlation matrix of %error of major production countries of wheat

<table>
<thead>
<tr>
<th>Country</th>
<th>Temperature</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EU</td>
<td>Ex-USSR</td>
</tr>
<tr>
<td>USA</td>
<td>-0.26</td>
<td>0.23</td>
</tr>
<tr>
<td>EU</td>
<td>0.01</td>
<td>0.22</td>
</tr>
<tr>
<td>Ex-USSR</td>
<td>0.06</td>
<td>-0.12</td>
</tr>
<tr>
<td>India</td>
<td>-0.04</td>
<td>-0.25</td>
</tr>
<tr>
<td>China</td>
<td>-0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>USA</td>
<td>-0.02</td>
<td>-0.14</td>
</tr>
<tr>
<td>EU</td>
<td>0.21</td>
<td>-0.39</td>
</tr>
<tr>
<td>Ex-USSR</td>
<td>-0.36</td>
<td>-0.09</td>
</tr>
<tr>
<td>India</td>
<td>-0.05</td>
<td></td>
</tr>
</tbody>
</table>
Assumptions of a simulation

- Cropping calendar is fixed
- Cropping region is fixed
- Climatic variables directly affect yields
- Temperature measured in degrees Celsius and rainfall of all countries and regions follows the data of HadCM3 A2 Scenario
- All parameters are fixed
Fluctuation of production of wheat

10% up: variations of temperature and rainfall increase 10% along the forecasts

- Production of wheat in the USA will increase about 14.6 million MT between 2010 and 2030, 71.3mMT → 85.8mMT.
- Difference in P90 and P10 is 2.0 in 2010 and 4.2 in 2030.
- Production in the world: 701mMT(2010) → 983mMT(2030) [282]
- P90-P10 in the world: 29.3mMT(2010) → 46.0mMT(2030) [16.7]
Fluctuation of production of maize

Production in the USA:
263mMT(2010) → 326mMT(2030) [63]

P90-P10 in the USA:
40.7mMT(2010) → 77.5mMT(2030)[36.8]

Production in the world:
726mMT(2010) → 1020mMT(2030)[294]

P90-P10 in the world:
54.6mMT(2010) → 103.8mMT(2030)[49.2]
Fluctuation of production of rice

- Production in the USA
  - 6.1mMT(2010) → 6.4mMT(2030)
- P90-P10 in the USA
  - 0.7mMT(2010) → 0.9mMT(2030)
- Production in the world
  - 459mMT(2010) → 622mMT(2030) [163]
- P90-P10 in the world
  - 20.7mMT(2010) → 27.7mMT(2030) [7.0]

Rice production in the USA

Rice production in the world
Fluctuation of production of soybeans

- **Production in the USA**
  - 83.8mMT (2010) → 131.1mMT (2030) [47.3%
- **P90-P10 in the USA**
  - 17.7mMT (2010) → 55.7mMT (2030) [38.0%

- **Production in the world**
  - 185mMT (2010) → 307mMT (2030) [122%
- **P90-P10 in the world**
  - 29.3mMT (2010) → 121.0mMT (2030) [91.7%
Production of wheat in India

- **Production**
  - 85.3mMT (2010) →
  - 133.1mMT (2030)
  - 47.8mMT increase

- **P90-P10**
  - 10.9mMT (2010) →
  - 16.7mMT (2030)
  - 5.8mMT increase

- **P90-P10, 10% dev.up**
  - 12.0mMT (2010) →
  - 18.3mMT (2030)
  - 6.3mMT increase
Production of wheat in Pakistan

- **Production**
  - 23.9mMT (2010) →
  - 39.2mMT (2030)
  - 15.3mMT increase

- **P90-P10**
  - 4.2mMT (2010) →
  - 6.7mMT (2030)
  - 2.5mMT increase

- **P90-P10, 10% dev.up**
  - 4.7mMT (2010) →
  - 7.6mMT (2030)
  - 2.9mMT increase
Production of wheat in Bangladesh

- Production
  - 1.25mMT(2010) →
  - 1.41mMT(2030)
  - 0.16mMT increase

- P90-P10
  - 0.27mMT(2010) →
  - 0.34mMT(2030)
  - 0.07mMT increase

- P90-P10, 10% dev.up
  - 0.30mMT(2010) →
  - 0.38mMT(2030)
  - 0.08mMT increase
Production of maize in India

- Production
  - 13.3mMT (2010) →
  - 19.5mMT (2030)
  - 6.2mMT increase

- P90-P10
  - 1.3mMT (2010) →
  - 3.0mMT (2030)
  - 1.7mMT increase

- P90-P10, 10% dev.up
  - 1.4mMT (2010) →
  - 3.2mMT (2030)
  - 1.8mMT increase
Production of other coarse grains in India

- Production
  - 15.5mMT (2010) → 22.6mMT (2030)
  - 7.1mMT increase

- P90-P10
  - 5.3mMT (2010) → 8.5mMT (2030)
  - 3.2mMT increase

- P90-P10, 10% dev.up
  - 5.8mMT (2010) → 9.3mMT (2030)
  - 3.5mMT increase

Other coarse grains include barley, rye, oats, millet and sorghum.
Production of rice in India

Production
- 109.4mMT (2010) →
- 167.2mMT (2030)
- 57.8mMT increase

P90-P10
- 19.7mMT (2010) →
- 28.0mMT (2030)
- 8.3mMT increase

P90-P10, 10% dev. up
- 22.1mMT (2010) →
- 30.7mMT (2030)
- 8.6mMT increase
Production of soybeans in India

- **Production**
  - 10.9mMT (2010) →
  - 23.7mMT (2030)
  - 12.8mMT increase

- **P90-P10**
  - 1.1mMT (2010) →
  - 6.3mMT (2030)
  - 5.2mMT increase

- **P90-P10, 10% dev.up**
  - 1.2mMT (2010) →
  - 6.9mMT (2030)
  - 5.7mMT increase
## Changes in fluctuation of farm price of wheat in the U.S.A.

<table>
<thead>
<tr>
<th></th>
<th>Item</th>
<th>Unit</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>Ave.</td>
<td>$/MT</td>
<td>140.7</td>
<td>148.8</td>
<td>159.2</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>5.2</td>
<td>6.0</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>3.69</td>
<td>4.06</td>
<td>4.98</td>
</tr>
<tr>
<td><strong>10% dev. increase</strong></td>
<td>Ave.</td>
<td>$/MT</td>
<td>140.6</td>
<td>148.8</td>
<td>159.2</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>5.7</td>
<td>6.7</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>4.07</td>
<td>4.49</td>
<td>5.53</td>
</tr>
</tbody>
</table>

S.D.: Standard Deviation  
C.V.: Coefficient of Variation (Average/S.D.)
Changes in fluctuation of farm price of maize in the U.S.A.

<table>
<thead>
<tr>
<th></th>
<th>Item</th>
<th>Unit</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Ave.</td>
<td>$/MT</td>
<td>96.0</td>
<td>103.5</td>
<td>109.7</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>7.2</td>
<td>9.2</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>7.50</td>
<td>8.92</td>
<td>11.38</td>
</tr>
<tr>
<td>10% dev. increase</td>
<td>Ave.</td>
<td>$/MT</td>
<td>95.9</td>
<td>103.6</td>
<td>110.1</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>7.9</td>
<td>10.2</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>8.27</td>
<td>9.84</td>
<td>12.47</td>
</tr>
</tbody>
</table>

S.D.: Standard Deviation  
C.V.: Coefficient of Variation (Average/S.D.)
## Changes in fluctuation of farm price of rice in the U.S.A.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Ave.</td>
<td>$/MT</td>
<td>148.6</td>
<td>155.2</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>1.9</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>1.30</td>
<td>1.71</td>
</tr>
<tr>
<td>10% dev. increase</td>
<td>Ave.</td>
<td>$/MT</td>
<td>148.5</td>
<td>155.2</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>2.1</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>1.42</td>
<td>1.65</td>
</tr>
</tbody>
</table>

S.D.: Standard Deviation  
C.V.: Coefficient of Variation (Average/S.D.)
## Changes in fluctuation of farm price of soybeans in the U.S.A.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>Ave.</td>
<td>$/MT</td>
<td>215.3</td>
<td>228.7</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>36.1</td>
<td>54.4</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>16.76</td>
<td>23.78</td>
</tr>
<tr>
<td><strong>10% dev. increase</strong></td>
<td>Ave.</td>
<td>$/MT</td>
<td>216.2</td>
<td>229.7</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>$/MT</td>
<td>39.9</td>
<td>59.7</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>%</td>
<td>18.47</td>
<td>26.01</td>
</tr>
</tbody>
</table>

S.D.: Standard Deviation
C.V.: Coefficient of Variation (Average/S.D.)
Changes in C.V. of farm price of crops in the U.S.A.

If variations of temperature and rainfall increase 10% along the forecasts, C.V. of farm prices of crops increase as following numbers.

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>%</td>
<td>0.38</td>
<td>0.43</td>
<td>0.55</td>
</tr>
<tr>
<td>Maize</td>
<td>%</td>
<td>0.77</td>
<td>0.92</td>
<td>1.09</td>
</tr>
<tr>
<td>Rice</td>
<td>%</td>
<td>0.12</td>
<td>-0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Soybeans</td>
<td>%</td>
<td>1.71</td>
<td>2.23</td>
<td>2.71</td>
</tr>
</tbody>
</table>

C.V.: Coefficient of Variation (Average/S.D.)
If variations of temperature and rainfall increase 10% along the forecasts, C.V. of farm prices of crops increase as following numbers.

<table>
<thead>
<tr>
<th>Crops</th>
<th>Unit</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>%</td>
<td>0.35</td>
<td>0.41</td>
<td>0.53</td>
</tr>
<tr>
<td>Maize</td>
<td>%</td>
<td>0.63</td>
<td>0.77</td>
<td>0.92</td>
</tr>
<tr>
<td>Rice</td>
<td>%</td>
<td>-0.29</td>
<td>0.23</td>
<td>0.14</td>
</tr>
<tr>
<td>Soybeans</td>
<td>%</td>
<td>1.33</td>
<td>1.76</td>
<td>2.27</td>
</tr>
</tbody>
</table>

C.V.: Coefficient of Variation (Average/S.D.)
Conclusions

Crop production in some countries or regions will be affected greatly by rising temperatures with increased fluctuation.

Crop production by the USA and south Asian countries could suffer severe damage from global warming.

The changes in production resulting from variations of temperature are quite different for each crop in each country.

World total production for most crops other than soybeans is not severely affected.

The countries which suffer higher price risk by temperature variations may need to consider changes in cropping patterns and practices.
Thank you very much!