The Economics of Water Infrastructure Investment: Timing and Location under Climate Change

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Outline

• Introduction

• Analytical Framework

• Investment Timing Analysis

• Investment Location Analysis

• Conclusions
Introduction
Agriculture, Salinity and Climate Change

- Agricultural production is important in the Dong Nai Delta.

- Salinity is main limiting factor to agriculture in the delta.

- Climate change will increase salinity gradually over time.
# Study Area

<table>
<thead>
<tr>
<th>Province</th>
<th>Land Area 2007 (ha)</th>
<th>Gross Irrigated Area 2007 (ha)</th>
<th>Population 2007 (‘000)</th>
<th>GDP 2007 (M USD)</th>
<th>Agriculture share of GDP in the province (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCMC</td>
<td>209,505</td>
<td>72,482</td>
<td>6,347</td>
<td>6,254</td>
<td>4</td>
</tr>
<tr>
<td>Long An</td>
<td>188,153</td>
<td>151,246</td>
<td>1,430</td>
<td>724</td>
<td>54</td>
</tr>
<tr>
<td>Tay Ninh</td>
<td>402,812</td>
<td>220,635</td>
<td>1,053</td>
<td>413</td>
<td>46</td>
</tr>
<tr>
<td>BR-VT</td>
<td>190,000</td>
<td>30,057</td>
<td>947</td>
<td>4,456</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>990,470</td>
<td>474,420</td>
<td>9,777</td>
<td>11,847</td>
<td></td>
</tr>
</tbody>
</table>
Projected Salinity for 2050
Water Infrastructure Investment Plans

Investments in Water Infrastructure to control salinity
Analytical Framework
Main Research Question

• How do investment decisions of water infrastructure affect its value:

  ▫ What is the optimal timing of investment given gradual increase in salinity (when)?

  ▫ What is the optimal location of investment given the characteristics of the delta (where)?
Previous Approaches

• Salinity Control Investments:
  ▫ Lee and Howitt (1995): static problem (agriculture PMP combined with pre-defined investment portfolio)
  ▫ Characklis (2005): investment returns for a given trend in salinity increase

• Climate Change and Infrastructure:
  ▫ Callaway et al. (2007): optimal sizing of reservoir
  ▫ Wright and Erickson (2003): theoretical framework on optimal investment timing
Analytical Approach

Agriculture Production Model (PMP)
Agronomic Function (Yield/Salinity Relations)
Salinity Projections
Infrastructure Investment Costs

Benefits

Water Infrastructure Investment Model
Delta
Region-Specific

Costs
Investment Timing
Model Formulation I

- Dynamic Programming Model
  - State Variable: Salinity level (St)
  - Control Variable: Decision to Invest (Xt)

\[
g(S_t, X_t) = \begin{cases} 
  g(S_t, 0) = (1 + \mu)^t \cdot S_{t-1} \\
  g(S_t, 1) = \delta 
\end{cases}
\]

**Equation of Motion of Salinity**

- Salinity level if Infrastructure is constructed

\[
f(S_t, X_t) = \begin{cases} 
  f(S_t, 0) = a - b \cdot S_t - c \cdot S_t^2 \\
  f(S_t, 1) = a - b \cdot \delta - c \cdot \delta^2 - d 
\end{cases}
\]

**Payoff Function**

- Payoff if Infrastructure is constructed
Model is solved using the Bellman Equation as follows:

\[
V(S_t) = \max_{X_t = 0, 1} \{ f(S_t, X_t = 0) + \beta \cdot V_{t+1}(S_{t+1}), f(S_t, X_t = 1) + \beta \cdot V_{t+1}(\delta) \}
\]

- Solved numerically in Matlab (optimal policy rule)
# Base Case Simulation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.95</td>
</tr>
<tr>
<td>a</td>
<td>Intercept of agricultural profit function (billion VND)</td>
<td>892.8</td>
</tr>
<tr>
<td>b</td>
<td>Linear term of agricultural profit function</td>
<td>-0.1</td>
</tr>
<tr>
<td>c</td>
<td>Quadratic term of agricultural profit function</td>
<td>36.79</td>
</tr>
<tr>
<td>d</td>
<td>Fixed cost of sluice gate construction (billion VND)</td>
<td>650</td>
</tr>
<tr>
<td>$\mu$</td>
<td>Salinity drift rate (percent)</td>
<td>4.5%</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Constant salinity after sluice gate is built (dS/m)</td>
<td>4</td>
</tr>
<tr>
<td>T</td>
<td>Number of years</td>
<td>40</td>
</tr>
</tbody>
</table>
Results

OPTIMAL TIMING OF INFRASTRUCTURE INVESTMENT

(O = wait; 1 = build)

Years

OPTIMAL SALINITY PATH

Salinity dS/m

Years
Sensitivity Analysis I

**OPTIMAL TIMING OF INFRASTRUCTURE INVESTMENT**

- $0 = \text{wait; } 1 = \text{build}$
- Years

- Crop Substitution
- No Crop Substitution
- New Variety

**OPTIMAL SALINITY PATH**

- Salinity $\text{dS/m}$
- Years

- Crop Substitution
- No Crop Substitution
- New Variety
## Sensitivity Analysis II

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>No Crop Substitution</th>
<th>New Rice Variety</th>
<th>Linear Trend</th>
<th>Higher Sluice Cost (+20%)</th>
<th>Lower Discount Factor (β=0.86, r=15%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salinity Threshold (dS/m)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.09</td>
<td>6.21</td>
<td>8.08</td>
<td>7.09</td>
<td>7.74</td>
<td>7.40</td>
</tr>
<tr>
<td><strong>Investment timing (year)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>10</td>
<td>15</td>
<td>8</td>
<td>15</td>
<td>14</td>
</tr>
</tbody>
</table>
Investment Location
Location Tradeoffs

Salinity Control Benefits

Salinity Control Costs

<table>
<thead>
<tr>
<th>Sluice Name</th>
<th>Gate Width</th>
<th>Bottom Altitude (depth)</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can Long</td>
<td>30</td>
<td>-4.5</td>
<td>150</td>
</tr>
<tr>
<td>Na Tho</td>
<td>5</td>
<td>-3</td>
<td>15</td>
</tr>
</tbody>
</table>
Model Formulation I

- **Dynamic Programming Model**
  - **State Variable**: Salinity level in each region (Sit)
  - **Control Variable**: Decision to Invest in specific region (Xit)

\[
g(S_{it}, X_{it}) = \begin{cases} 
  g(S_{it}; X_t = 0) \Rightarrow S_{it} = (r_i \ast S_t) \ast (1 + \mu)^t \\
  g(S_{it}; X_t = 1) \Rightarrow S_{it} = r_i \ast \delta \\
  g(S_{it}; X_t = 2) \Rightarrow S_{1t} = (r_1 \ast S_t) \ast (1 + \mu)^t; S_{it} = r_i \ast \delta \forall i = 2,3 \\
  g(S_{it}; X_t = 3) \Rightarrow S_{it} = (r_i \ast S_t) \ast (1 + \mu)^t \forall i = 1,2; S_{3t} = r_3 \ast \delta 
\end{cases}
\]

Equation of Motion of Salinity
Model Formulation II

Payoff Function

\[
F(S_{it}, X_t) = \begin{cases} 
F(S_{it}; X_t = 0) &= f_1(S_{1t}) + f_2(S_{2t}) + f_3(S_{3t}) \\
F(S_{it}; X_t = 1) &= f_1(\delta) + f_2(\delta) + f_3(\delta) - d_1 \\
F(S_{it}; X_t = 2) &= f_1(S_{1t}) + f_2(\delta) + f_3(\delta) - d_2 \\
F(S_{it}; X_t = 3) &= f_1(S_{1t}) + f_2(S_{2t}) + f_3(\delta) - d_3 
\end{cases}
\]

\[
f_i(S_{it}) = a_i - b_i * r_i * S_{it} - c_i * (r_i * S_{it})^2 \\
f_i(\delta) = a_i - b_i * r_i * \delta - c_i * (r_i * \delta)^2 \\
f_i(S_{it}) = \max\{f_i(S_{it}), 0\}
\]
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<td>number of years</td>
<td>40</td>
</tr>
</tbody>
</table>

### Region-Specific Parameters

<table>
<thead>
<tr>
<th>Region</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reg. 1: Can Giuoc South</td>
<td>148.45</td>
<td>-7.58</td>
<td>0.02</td>
<td>650</td>
<td>1.3</td>
</tr>
<tr>
<td>Reg. 2: Can Giuoc North</td>
<td>520</td>
<td>-26.5</td>
<td>0.07</td>
<td>520</td>
<td>1</td>
</tr>
<tr>
<td>Reg. 3: Binh Chanh North</td>
<td>391.7</td>
<td>-5.48</td>
<td>-0.18</td>
<td>430</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Results

OPTIMAL TIMING & LOCATION OF INFRASTRUCTURE INVESTMENT

Sluice Gate Location (0=no protection, 1=Can Giuoc S, 2=Can Giuoc N, 3=Binh Chanh)

OPTIMAL SALINITY PATH

Salinity (dS/m)

Can Giuoc South  Can Giuoc North  Binh Chanh South
Conclusions
Water Infrastructure Investment

- Value of investment depends on design decisions (when, where to construct)

- Given the gradual increase in salinity and the cost of the infrastructure, other less expensive options to adapt are more optimal in the short-term

- Given the spatial characteristics of the delta, it is not economical to protect all regions
Thank You for Your Attention!
Agricultural Production Model

Profit in Million VND

Salinity (dS/m)

- Binh Chanh
- Can Giuoc
- Ben Luc
- Tan Tru
- Can Duoc

Profit in million VND

Salinity (dS/m)

- New Variety
- Crop Substitution
- No crop substitution