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

***David Corderi Novoa**, *J. R. Lund*#, *J. Williams*#**

* Inter-American Development Bank
#University of California - Davis

Outline

- Introduction
- Analytical Framework
- Investment Timing Analysis
- Investment Location Analysis
- Conclusions

Introduction

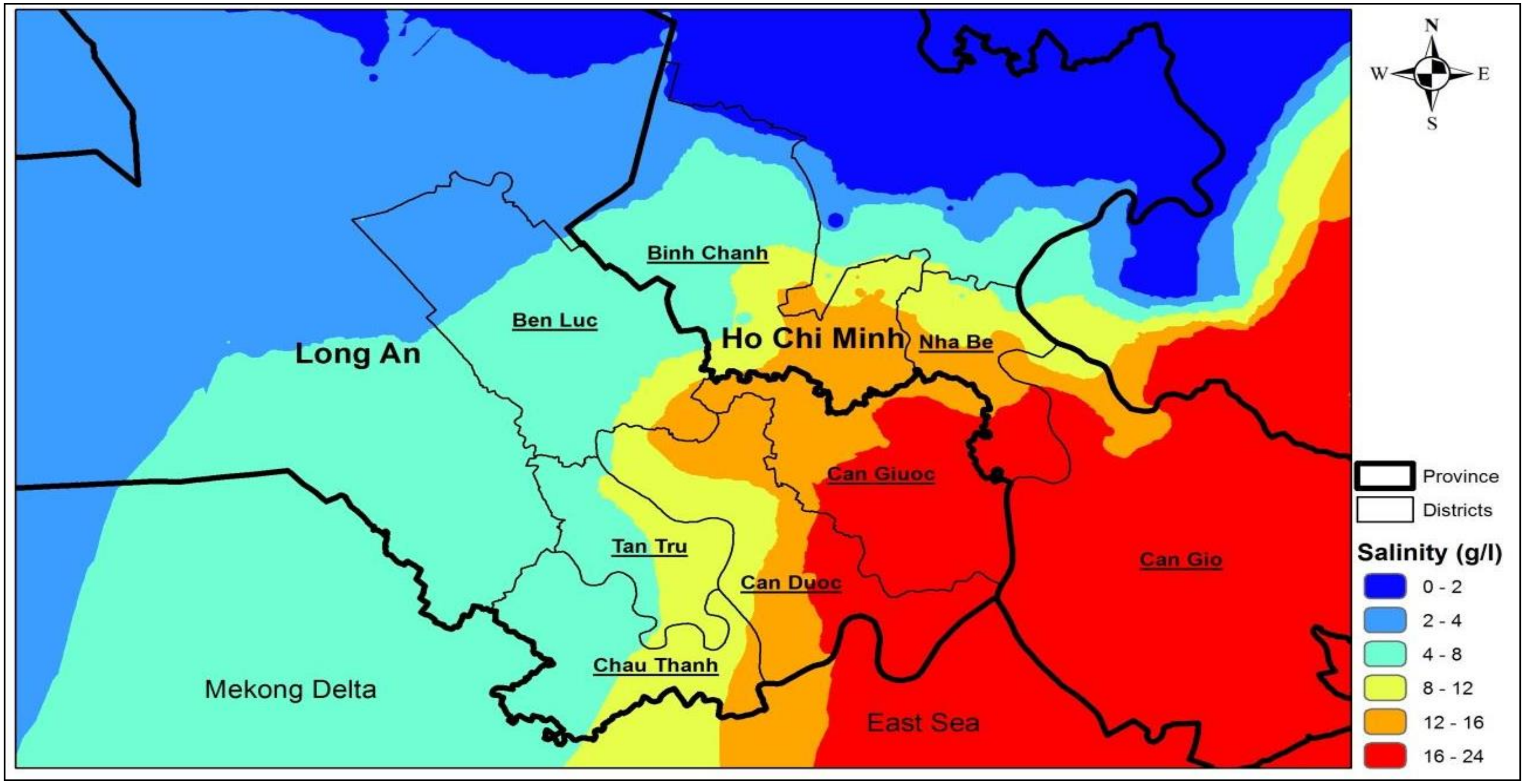
Agriculture, Salinity and Climate Change

- 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

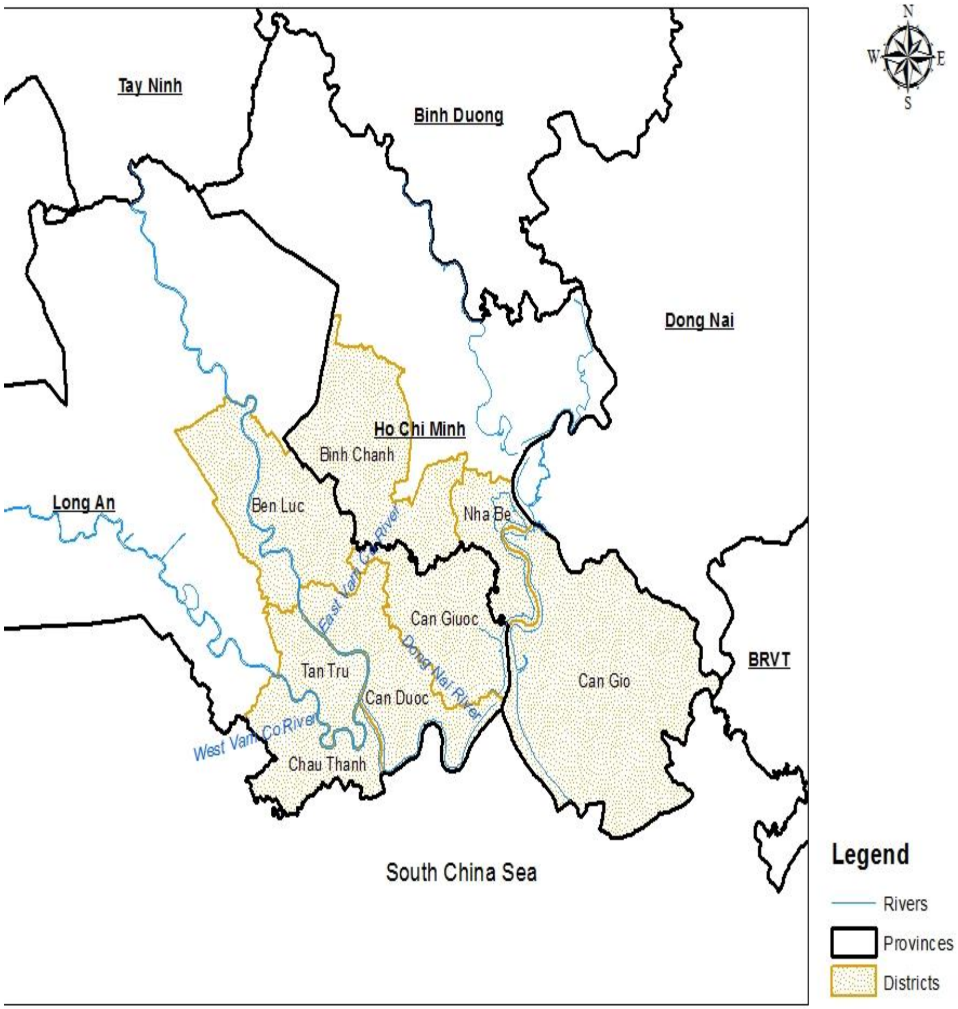
Study Area

Province	Land Area 2007	Gross Irrigated Area 2007	Population 2007	GDP 2007	Agriculture share of GDP in the province
	(ha)	(ha)	('000)	(M USD)	(%)
HCMC	209,505	72,482	6,347	6,254	4
Long An	188,153	151,246	1,430	724	54
Tay Ninh	402,812	220,635	1,053	413	46
BR-VT	190,000	30,057	947	4,456	5
TOTAL	990,470	474,420	9,777	11,847	

Projected Salinity for 2050



Water Infrastructure Investment Plans



- Investments in Water Infrastructure to control salinity

Analytical Framework

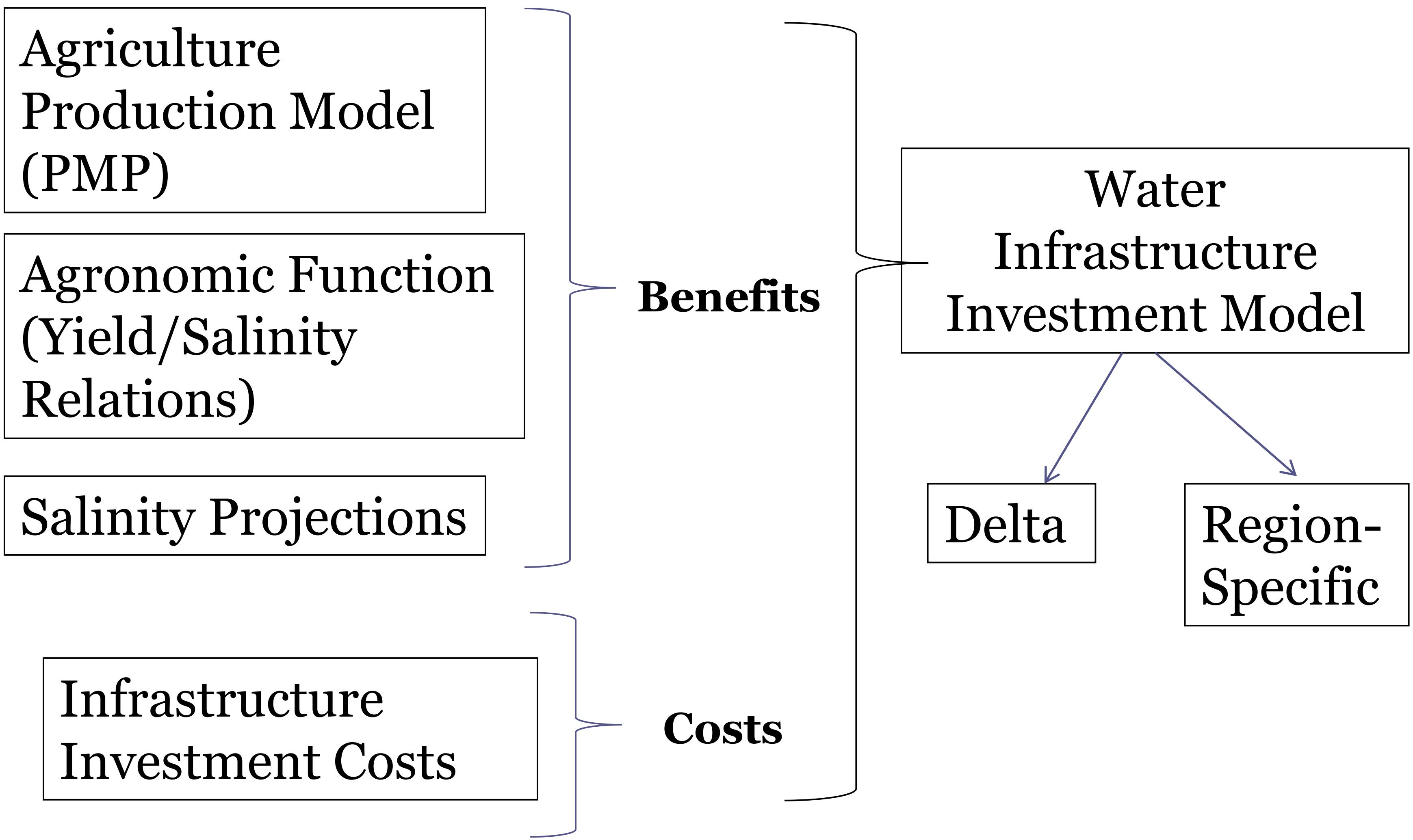
Main Research Question

- 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
  - Block and Strezepek (2007): evaluation of fixed dam construction returns.
  - Wright and Erickson (2003): theoretical framework on optimal investment timing

Analytical Approach



Investment Timing

Model Formulation I

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

Equation of Motion of Salinity

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

→ Salinity level if Infrastructure is constructed

Payoff Function

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

→ Payoff if Infrastructure is constructed

Model Formulation II

Model is solved using the Bellman Equation as follows:

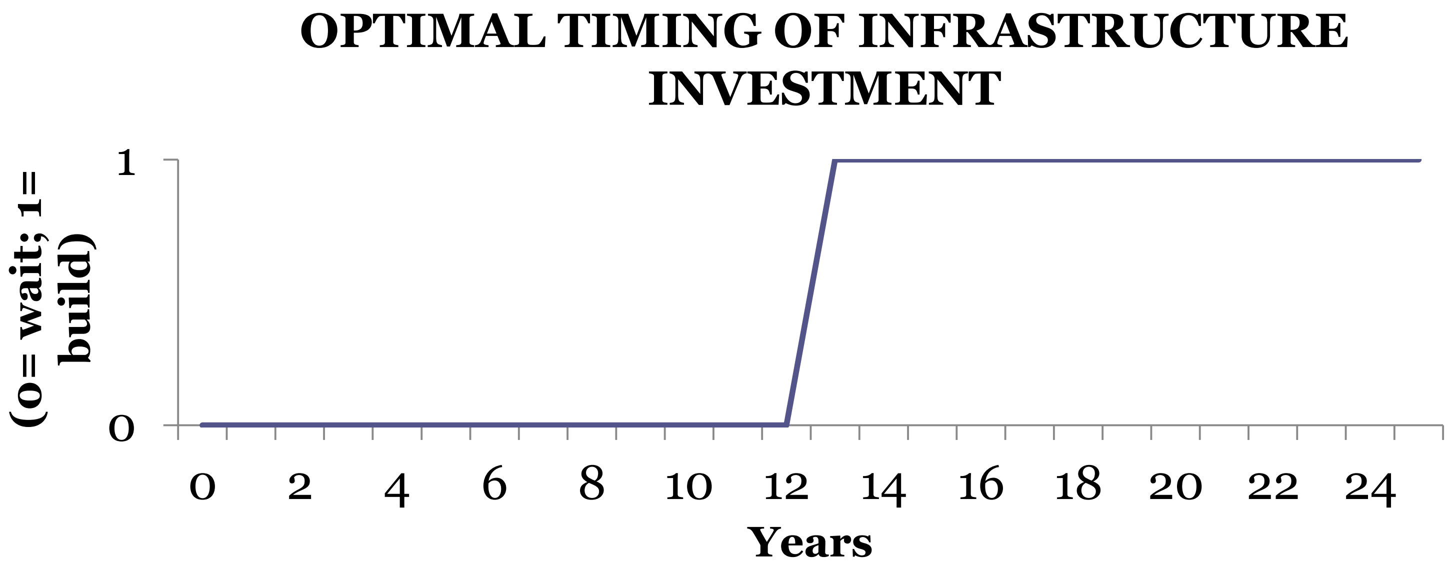
$$V(S_t) = \max_{X_t=0,1}\{f(S_t, X_t = 0) + \beta * V_{t+1}(S_{t+1}),\ f(S_t, X_t = 1) + \beta * V_{t+1}(\delta)\}$$

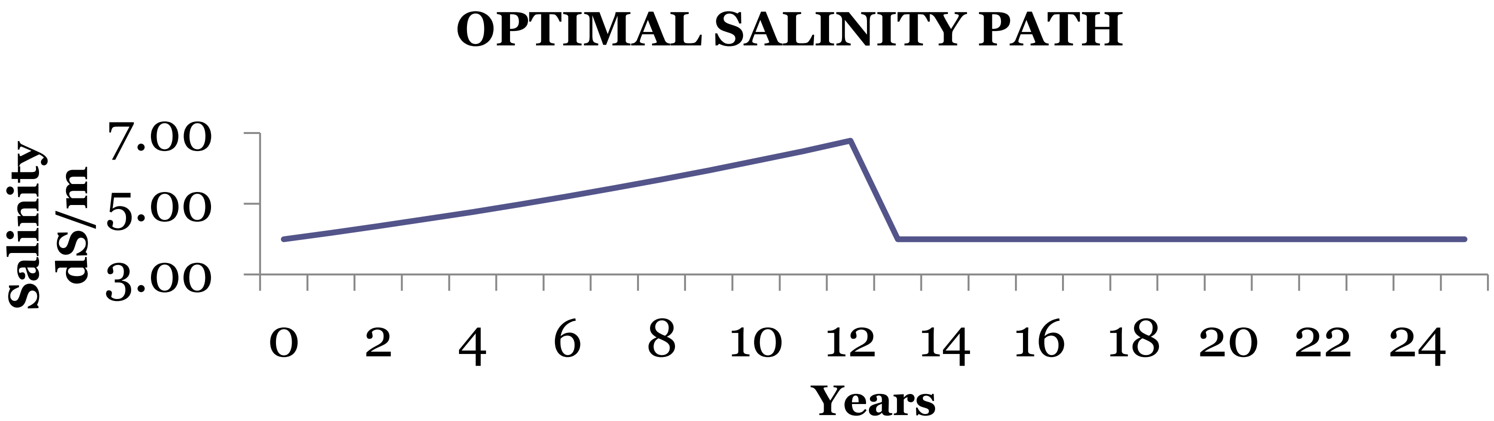
- Solved numerically in Matlab (optimal policy rule)

Base Case Simulation

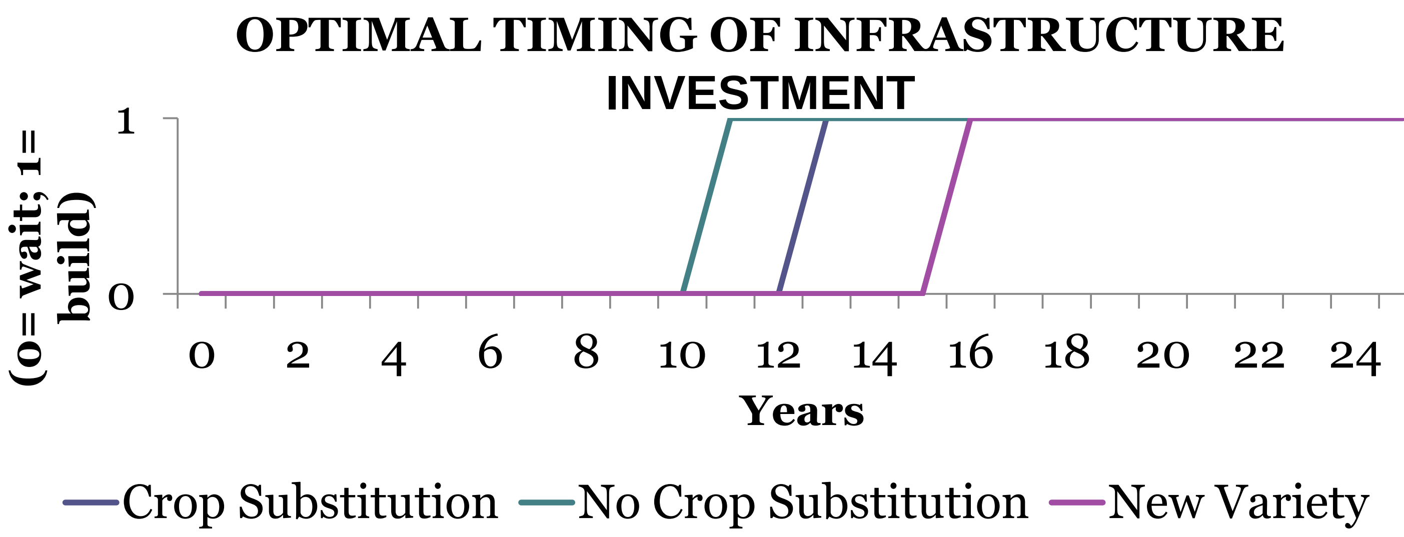
Parameter	Description	Value
ß	Discount factor	0.95
a	Intercept of agricultural profit function (billion VND)	892.8
b	Linear term of agricultural profit function	-0.1
c	Quadratic term of agricultural profit function	36.79
d	Fixed cost of sluice gate construction (billion VND)	650
μ	Salinity drift rate (percent)	4.5%
δ	Constant salinity after sluice gate is built (dS/m)	4
T	Number of years	40

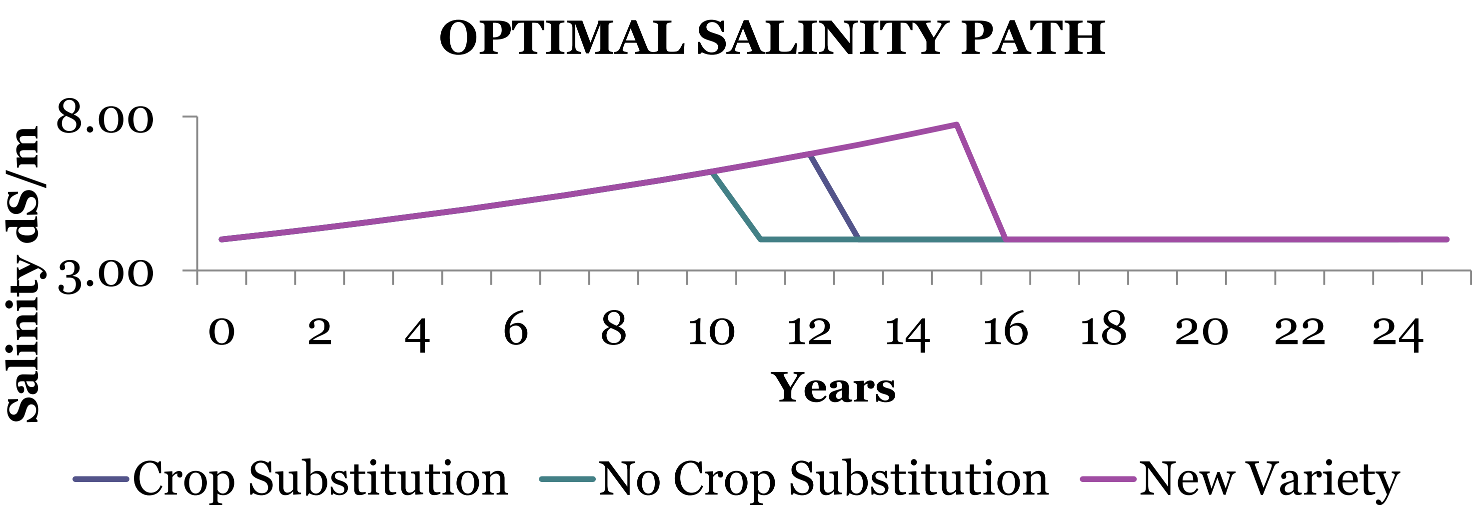
Results


OPTIMAL TIMING OF INFRASTRUCTURE INVESTMENT
(0= wait; 1= build)
1
0
0 2 4 6 8 10 12 14 16 18 20 22 24
Years


OPTIMAL SALINITY PATH
Salinity dS/m
7.00
5.00
3.00
0 2 4 6 8 10 12 14 16 18 20 22 24
Years

Sensitivity Analysis I





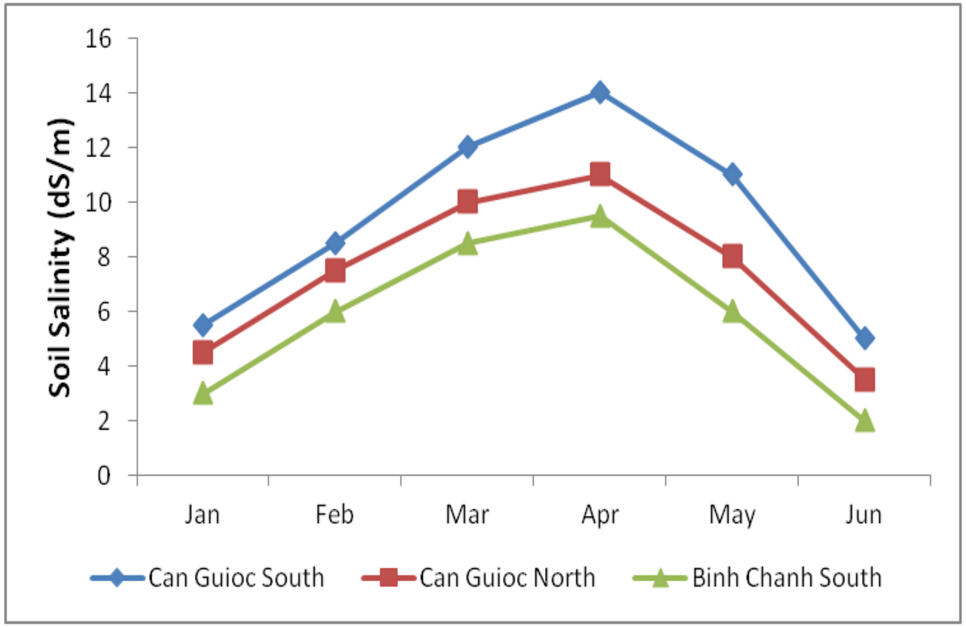
Sensitivity Analysis II

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

Investment Location

Location Tradeoffs

Salinity Control Benefits



Salinity Control Costs

Sluice Name	Gate Width	Bottom Altitude (depth)	Area
Can Long	30	-4.5	150
Na Tho	5	-3	15

Model Formulation I

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

Equation of Motion of Salinity

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

Model Formulation II

Payoff Function

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

$$f_i(S_{it}) = a_i - b_i * r_i * S_{it} - \ c_i * (r_i * S_{it})^2$$

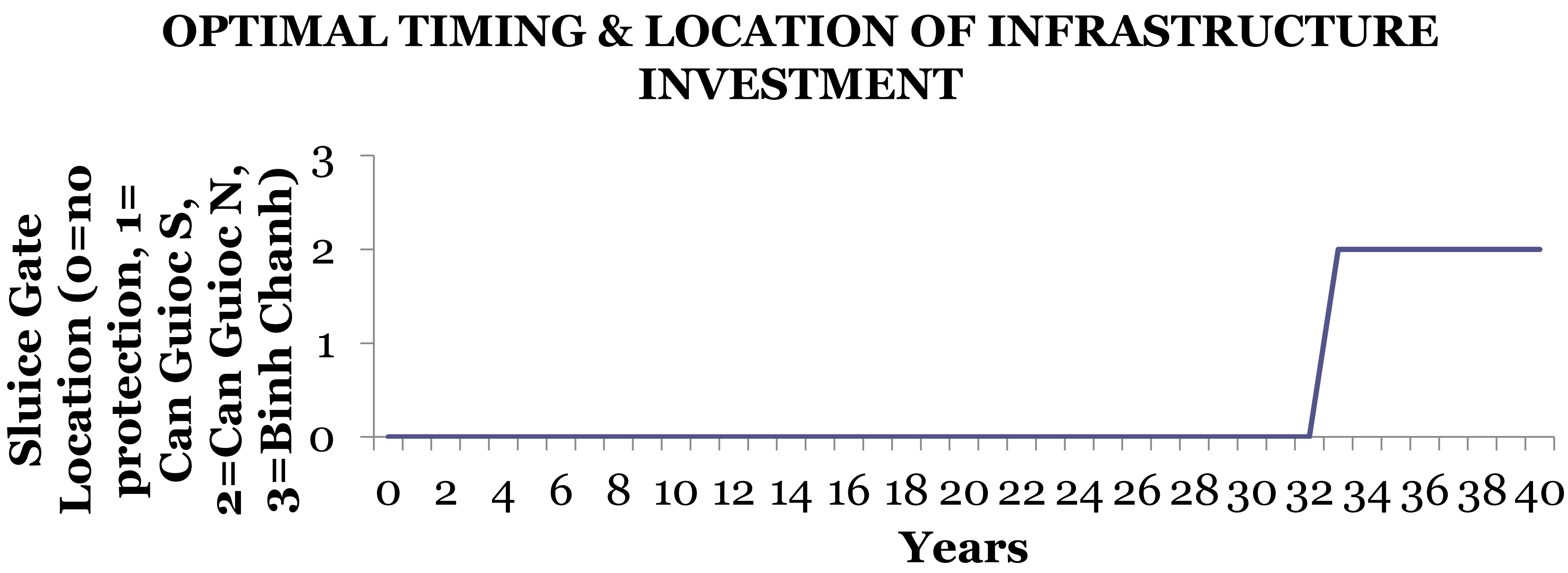
$$f_i(\delta) = a_i - b_i * r_i * \delta - \ c_i * (r_i * \delta)^2$$

$$f_i(S_{it}) = \max\{f_i(S_{it}), 0\}$$

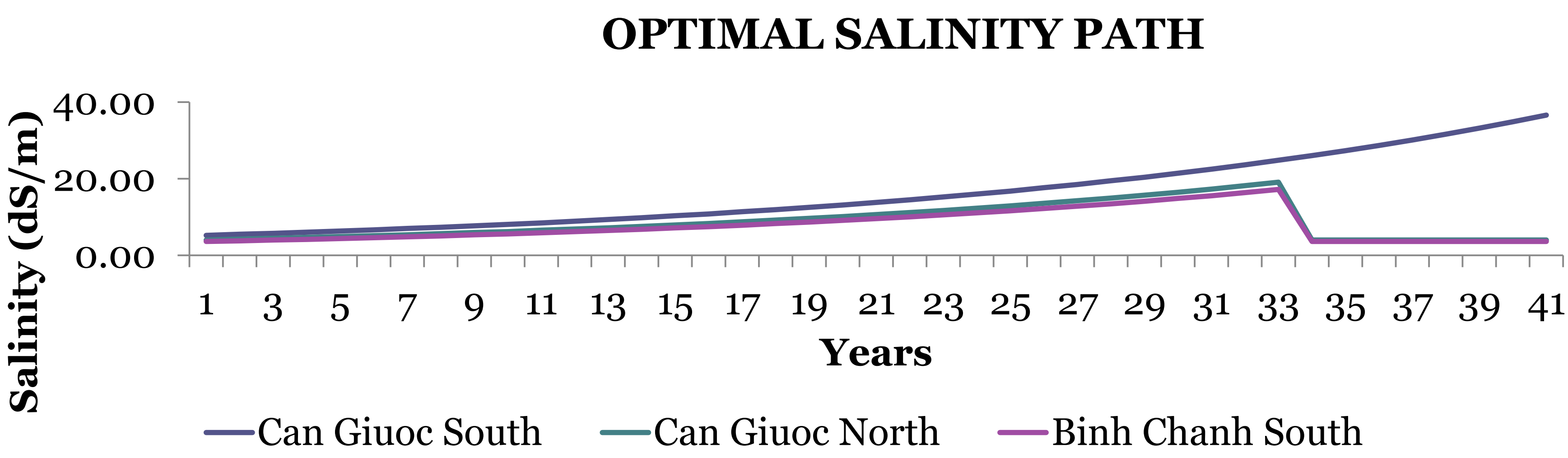
Base Case Simulation

<table>
<tr><td>Parameter</td><td colspan="4">Description</td><td>Value</td></tr>
<tr><td>β</td><td colspan="4">discount factor</td><td>0.95</td></tr>
<tr><td>μ</td><td colspan="4">salinity drift rate (percent)</td><td>5%</td></tr>
<tr><td>δ</td><td colspan="4">constant salinity after sluice gate is built (dS/m)</td><td>4</td></tr>
<tr><td>T</td><td colspan="4">number of years</td><td>40</td></tr>
<tr><td colspan="6">Region-Specific Parameters</td></tr>
<tr><td></td><td>a</td><td>b</td><td>c</td><td>d</td><td>r</td></tr>
<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>
</table>

Results



OPTIMAL TIMING & LOCATION OF INFRASTRUCTURE INVESTMENT
Sluice Gate Location (0=no protection, 1= Can Guioc S, 2=Can Guioc N, 3=Binh Chanh)
3
2
1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Years



OPTIMAL SALINITY PATH
Salinity (dS/m)
40.00
20.00
0.00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
Years
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!

David Corderi Novoa

Agricultural Production Model