Optimal Flood Protection: The Role of Economic and Climate Uncertainty

Taco Prins, Ton van den Bremer, Rick van der Ploeg

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Motivation

Since the first Delta Commission (1956), the Netherlands maintains a system of exceedance norms for each dyke ring segment

Motivation

- The CBA currently imposes a 'macroeconomic uncertainty premium' (3%) and a fixed risk premium for flood events (7,8%)
- Goal: move from pragmatic rule of thumb to a theoretically founded investment rule, based on optimal discounting of climate damages
- Key references: Pindyck and Wang (2013), Giglio et al. (2021) and Hong, Wang, and Yang (2023)

Baseline model

- Continuous-time Epstein-Zin preferences which allow for separate values of
  - ρ: pure rate of time preference
  - ψ^{-1}: intergenerational inequality aversion (IIA)
  - γ: coefficient of relative risk aversion (CRRA)

Baseline model

- Equilibrium condition

$$AK_t = C_t + I_{K,t} + E_{H,t} \tag{1}$$

- Stochastic process for output

$$dK_t = \Phi_K(I_{K,t}, K_t)\mathrm{d}t + \sigma K_t \mathrm{d}W_t - (1 - Z_e)K_t \mathrm{d}J_{e,t} - \sum_{i=1}^{i=n_c} (1 - Z_{c,i})K_t \mathrm{d}J_{c,i,t} \tag{2}$$

Baseline model

- Flood risk $\lambda_{c,i}$ (=arrival rate of $J_{c,i,t}$) is an exponential function of the the level of flood protection and sea level rise. Visually:

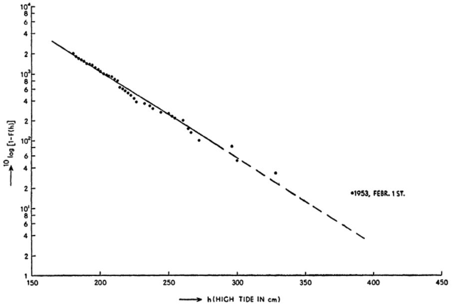


Figure 1

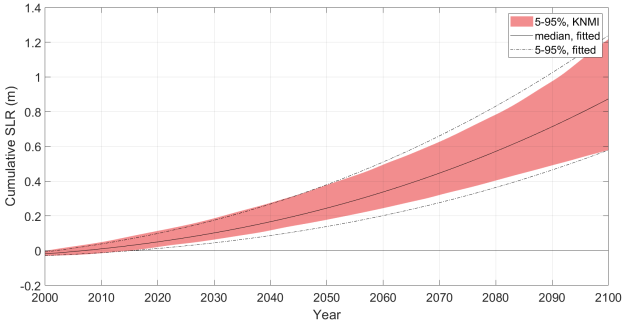
Source: Van Dantzig, Econometrica, 1956

- In symbols: $\lambda_{c,i}(H_{i,t}, h_{i,t}) = P_{0,i}e^{-\alpha_i(H_{i,t}-H_{i,0}-h_{i,t})}$

Baseline model

- Stochastic sea level rise along the North Sea Coast is approximated as a Brownian motion with trend and a skewness parameter:

$$h_t = (X_t + h_0)^{1+\theta_X} - h_0^{1+\theta_X} \tag{3}$$



Source: Climate Scenarios for the Netherlands, 2023, KNMI

Analytical solution for long-run flood protection

The optimality condition for the steady state

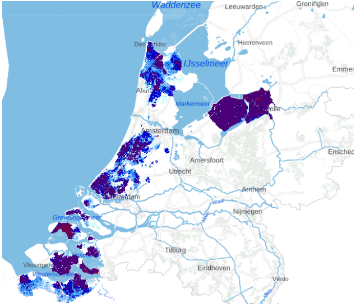
$$\sum_{i=1}^{i=n_c} \lambda_{c,i}(H)' \frac{\mathbb{E}[1 - Z_{c,i}^{1-\gamma}]}{1-\gamma} \frac{\phi_H'(i_H)}{\phi_K'(i_K)} = r^* + \delta_H \tag{4}$$

Where the discount rate adjusted for risk and growth is given by

$$r^* = \underbrace{\rho}_{\text{impatience}} + \underbrace{\psi^{-1} g_e}_{\substack{\text{rising}\\\text{affluence}}} - \underbrace{g_e}_{\substack{\text{growing}\\\text{damages}}} - \underbrace{\frac{1}{2}(1+\psi^{-1})\gamma\sigma_{total}^2}_{\text{prudence}} + \underbrace{\gamma\sigma_{total}^2}_{\text{insurance}} \tag{5}$$

Calibration

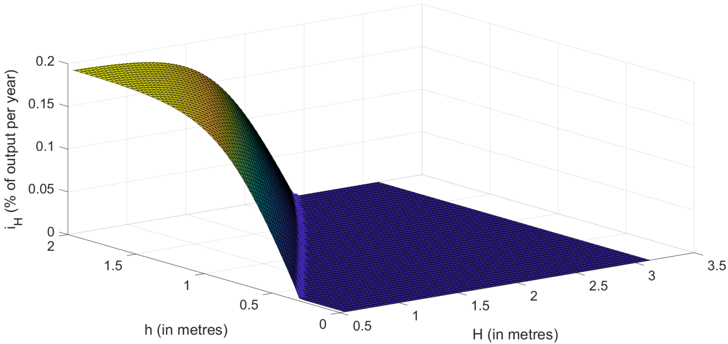
- We calibrate the flooding arrival rate and associated damages to match simulated damages in the applied flood protection literature (Kolen and Wouters 2007)
- We calibrate flood protection investment costs from a set of official studies (KP ZSS, 2023)



Source: LIWO

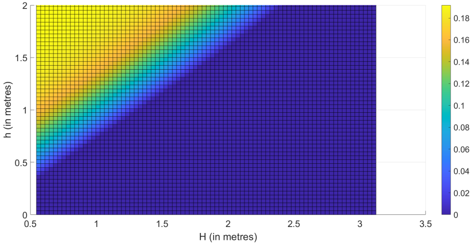
Quantitative result

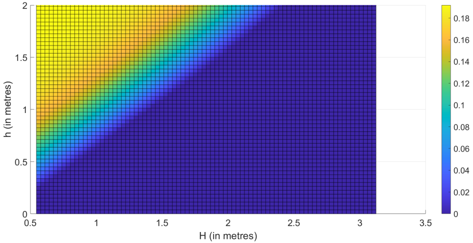
- Flood protection moves almost one-to-one with sea level rise; optimal investment quickly closes any shortfall.



$\rho = 0.0498$, $\psi = 1.5$, $\gamma = 3.066$

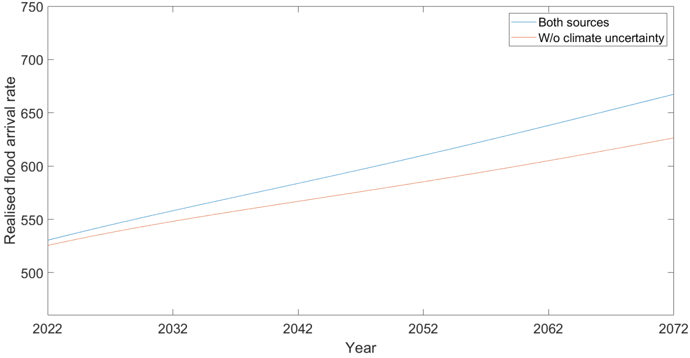
Economic uncertainty





Sea level rise uncertainty

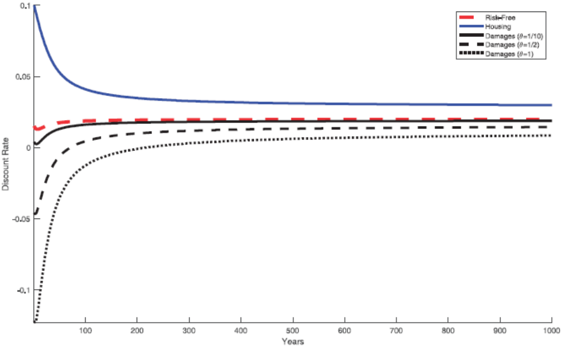
- Sea level rise uncertainty matters to exceedance norms over a fifty-year horizon, depending on preference parameters



$\rho = 0.01,\ \psi = 0.5,\ \gamma = 3.066$

Transitory shocks

- We have an economic process with only permanent shocks. However, important theoretical work finds a term structure for the discount rate of climate damages



Source: Giglio et al., 2021

Conclusion

What have we done

- Developed a tractable framework with stochastic flooding events and within-model uncertainty about economic growth
- Sketched the application of the model to the Netherlands

To do

- Find discount rate including climate uncertainty; match with existing CBA
- Transitory shocks giving rise to a term structure of discount rates

- Flood risk λ_2 (=arrival rate of $J_{2,t}$) is an exponential function of the the level of flood protection

$$\lambda_2(H_t^{'}, t) = P_0 e^{-\alpha(H_t^{'} - H_0 - \xi t)} \tag{6}$$

- By subtracting the time trend from the level of flood protection, we eliminate time as a state variable

$$H_t \equiv H_t^{'} - \xi t \tag{7}$$

- If there is an optimal 'net' flood protection level, then $\lambda_2(H_t^*)$ can be interpreted as the optimal exceedance norm at time t
- Model implication: cost of maintaining exceedance norms roughly linear in extent of long-term sea level rise

- From Pindyck and Wang (2013)

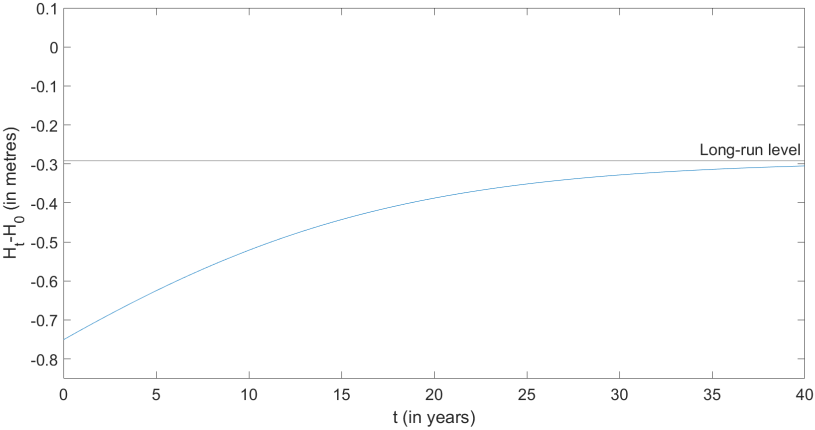
$$\Phi(I_{K,t}, K_t) = \phi_K(i_{K,t})K_t - \delta_K K_t \tag{8}$$

- For calibration, we will use $\phi_K(i_{K,t}) = i_{K,t} - \theta_K i_{K,t}^2$

- We write

$$\Phi_H(I_{H,t}, K_t, H_t) = \phi_H(i_{H,t}, K_t) - \delta_H H_t \tag{9}$$

- For calibration, we will use $\phi_H(i_{H,t}, K_t) = \frac{1}{\nu}(i_{H,t} - \theta_H i_{H,t}^2)$



0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
H_t-H_0 (in metres)
Long-run level
0
5
10
15
20
25
30
35
40
t (in years)

Parameter	Unit	Symbol	Value	Source
EIS		ψ	1.5	Pindyck and Wang (2013)
CRRA		γ	3.066	Pindyck and Wang (2013)
Diffusion volatility	$year^{-0.5}$	σ	0.1355	Pindyck and Wang (2013)
Output-capital ratio	$year^{-1}$	A	0.113	Pindyck and Wang (2013)
Initial flood risk	$year^{-1}$	P_0	$1.37 * 10^{-3}$	Den Hertog and Roos (2008)
Flood risk curvature	m^{-1}	α	5.02	Eijgenraam et al. (2017)
Flood protection cost	m^{-1}	ν	$3.53 * 10^{-3}$	Official figures for budgeted and projected spending
Sea level rise	$cm/year$	ξ	1.4	IPCC (2019)

- Using the FOCs, the HJB, and the associated envelope condition, we can characterise the long-run flood protection level H^* and exceedance norm $\lambda_2(H^*)$ analytically.
- The solution turns out to resemble a Ramsey rule for stochastic economic growth
- Standard Ramsey rule: $r = \rho + \psi^{-1} g$
- Our risk- and growth-adjusted discount rate

$$r^* = \underbrace{\rho}_{\text{impatience}} + \underbrace{\psi^{-1} g_{exp}}_{\substack{\text{rising} \\ \text{affluence}}} - \underbrace{g_{exp}}_{\substack{\text{growing} \\ \text{damages}}} - \underbrace{\frac{1}{2}(1+\psi^{-1})\gamma\sigma^2_{total}}_{\text{prudence}} + \underbrace{\gamma\sigma^2_{total}}_{\text{insurance}}$$

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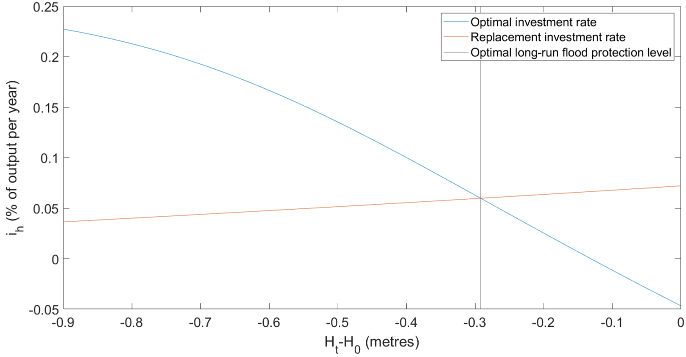
where

$$g_e \equiv \phi_K(i_K) - \delta_K - \lambda_e \mathbb{E}[1 - Z_e] - \sum_{i=1}^{i=n_c} \lambda_{c,i}(H)\mathbb{E}[1 - Z_{c,i}]$$

and

$$\sigma^2_{total} \equiv \sigma^2 + 2\lambda_e \mathbb{E}[1 - Z_e]\mathbb{E}[1 - Z_e^{1-\gamma}] + \\ 2\sum_{i=1}^{i=n_c} \lambda_{c,i}(H)\mathbb{E}[1 - Z_{c,i}]\mathbb{E}[1 - Z_{c,i}^{1-\gamma}]$$

- Starting from any H, the flood protection level converges to constant value H^*



- Heterogeneity on the cost side