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The Value of Observations in Determination of Optimal Vaccination Timing and Threshold

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NATIONAL INSTITUTE FOR HEALTH AND WELFARE

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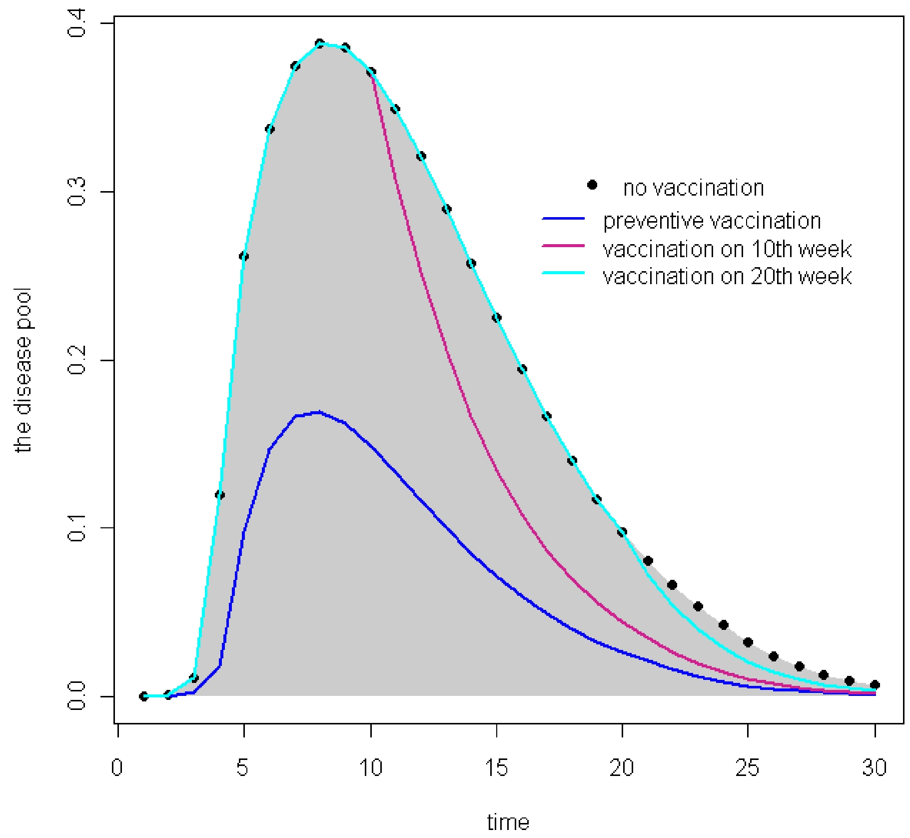
- **G**lobal **E**arth **O**bservation – **B**enefit **E**stimation: **N**ow, **N**ext and **E**merging.
  - » www.geo-bene.eu
- **Objective:** To develop methodologies and analytical tools to assess economic, social & environmental effects of improved quantitative and qualitative information delivered by GEOSS for the **nine** benefit areas of GEO.
- The benefit areas include *health*, *climate* and *weather*.

Dynamics of an epidemic



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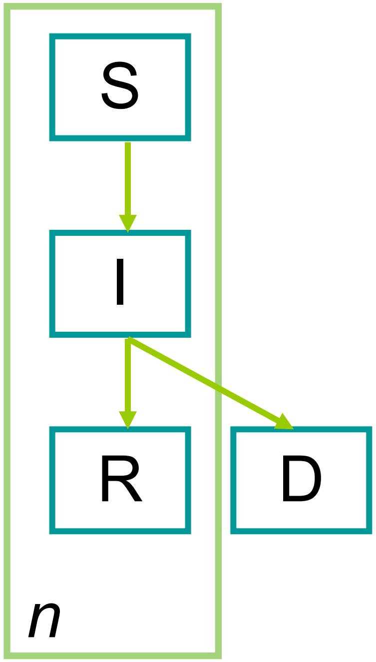
Meningococcal Meningitis

- In sub-Saharan Africa, infectious and parasitic diseases (excluding HIV/AIDS and including respiratory infections) were responsible for over 200 disease-adjusted life years per 1000 population. (Lancet, 1997)
- A polysaccharide vaccine for meningitis is available. New vaccine is being tested.
- Association of meningitis epidemics with dust storms (Science, 2008) and other environmental factors (Emerg Infect Dis 2003) has been suggested.

Susceptible-Infected-Recovered (SIR) Model



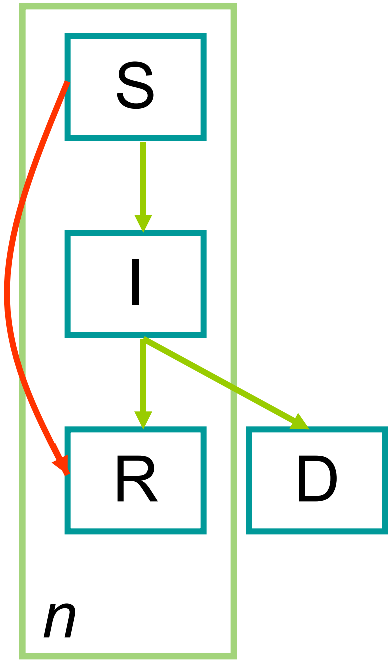
$$S(t) = S(t-1) - I.new(t-1)$$

$$I(t) = I(t-1) + I.new(t-1) - D.new(t-1) - R.new(t-1)$$

$$R(t) = R(t-1) + R.new(t-1)$$

$$n(t) = n(t-1) - D.new(t-1)$$

Susceptible-Infected-Recovered (SIR) Model



$S(t) = S(t-1) – I.new(t-1) - u(t)\alpha S(t-1)$

$I(t) = I(t-1) + I.new(t-1) – D.new(t-1) – R.new(t-1)$

$R(t) = R(t-1) + R.new(t-1) + u(t)\alpha S(t-1)$

$n(t) = n(t-1) – D.new(t-1)$

Susceptible – Infected – Recovered (SIR) Model

- Probability of becoming infected:

$$p(t) = 1 - \left(1 - \frac{\pi(t) I(t)}{n(t) - 1}\right)^N$$

- Dynamics:

I.new (t) ~ Bin (S(t),p(t))

{R.new(t), D.new(t),I(t)-R.new(t)-D.new(t)} ~ Multinomial(I(t), { γ , μ, 1- γ- μ})

Optimization:

$$\sum_{t=0}^{T} \frac{1}{(1+\rho)^t} \{ u(t)\, c^{vacc}\, \alpha\, S(t) + c^{treat}\, I(t) + c^{dead}\, D.new(t) + c^{seq}\, \delta\, R.new(t) \}$$

- cost of vaccination
- cost of treatment
- cost of death
- cost of sequelae/ disability

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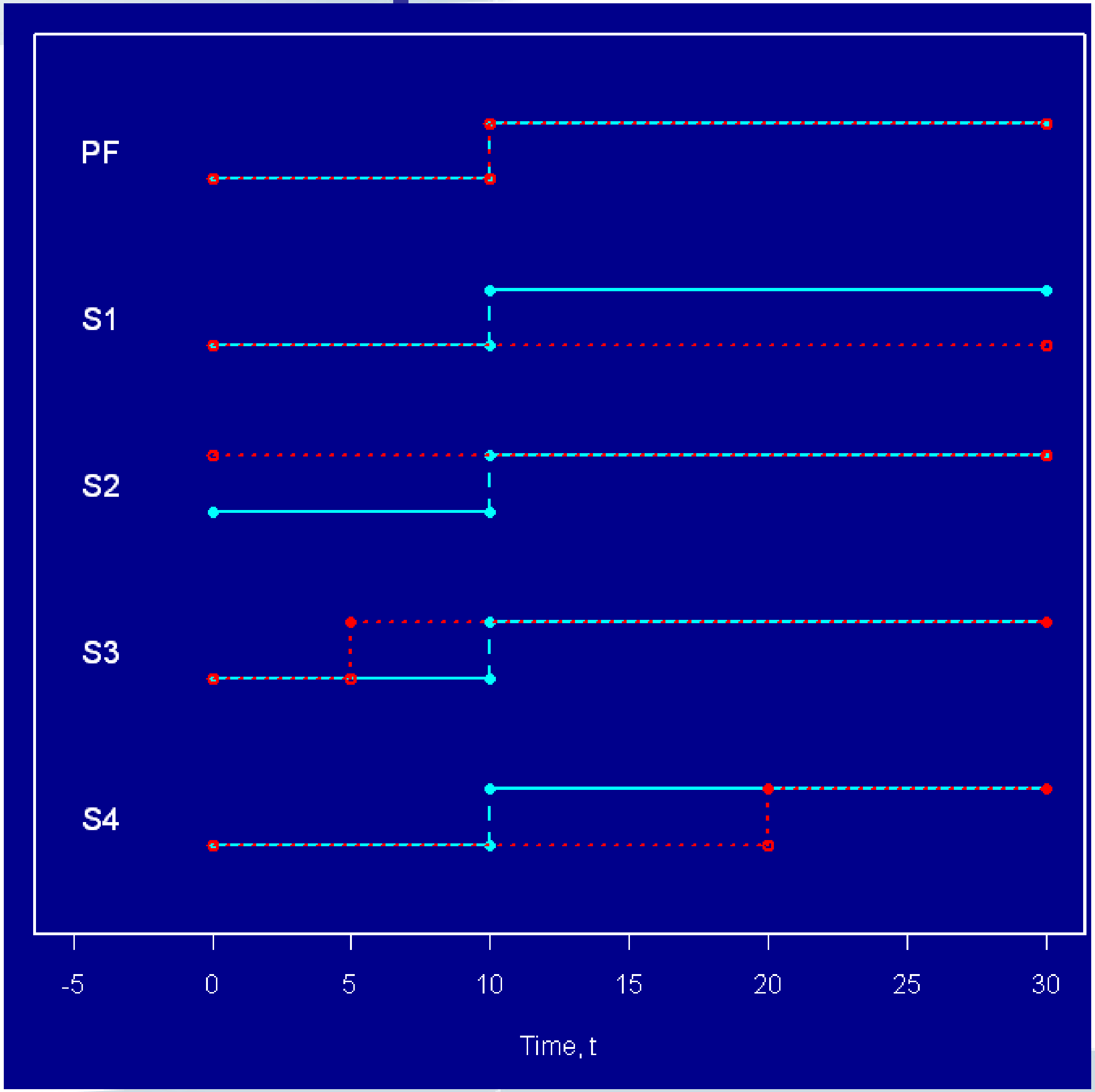
Parametrization

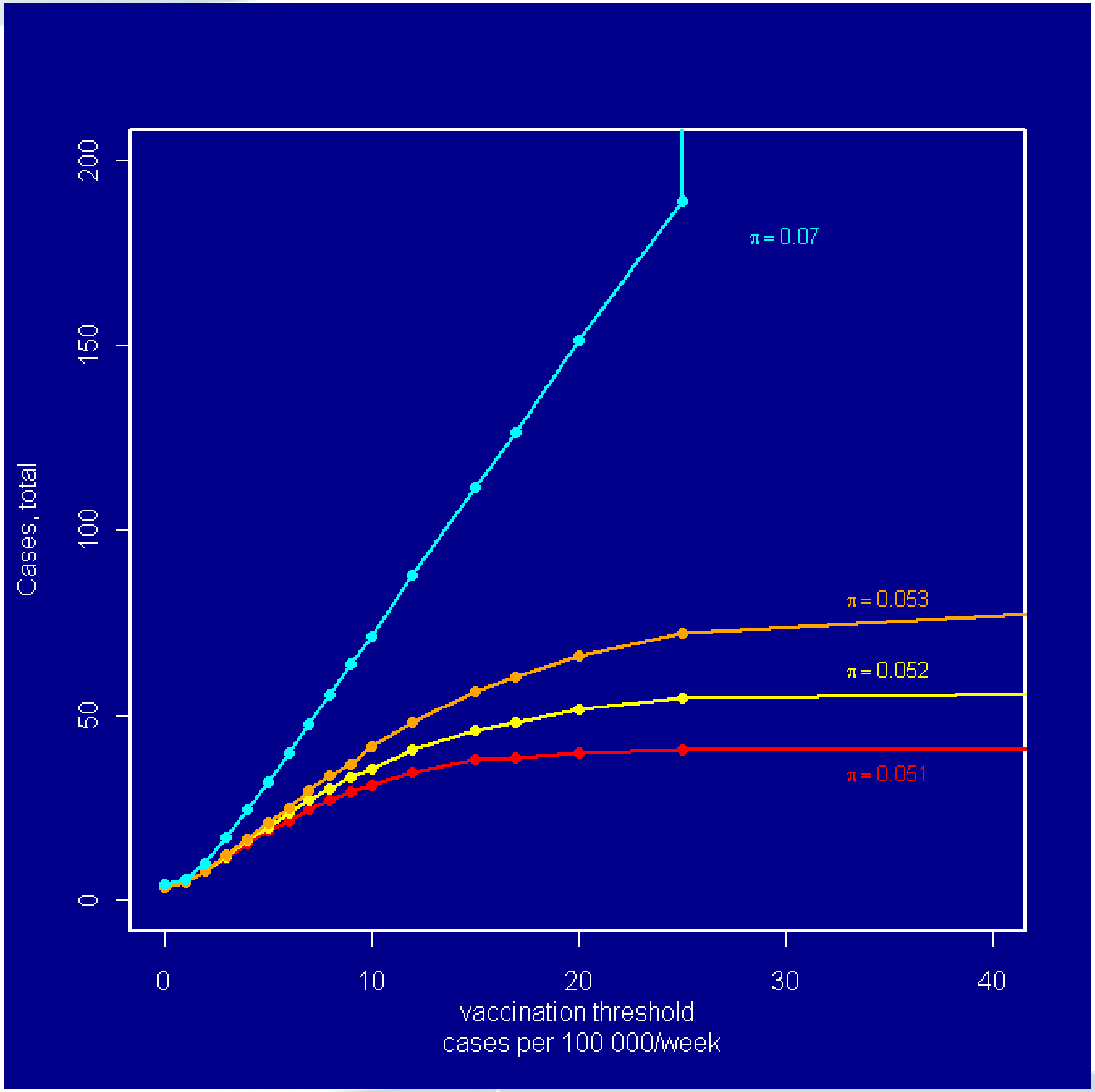
- 10% case-fatality within a week
- 2.5 weeks of recovery per infected person

  $\Rightarrow \mu = .0265$ and $\gamma = .2382$
- attack rate: 250-1000 per 100000
- duration: 30 weeks

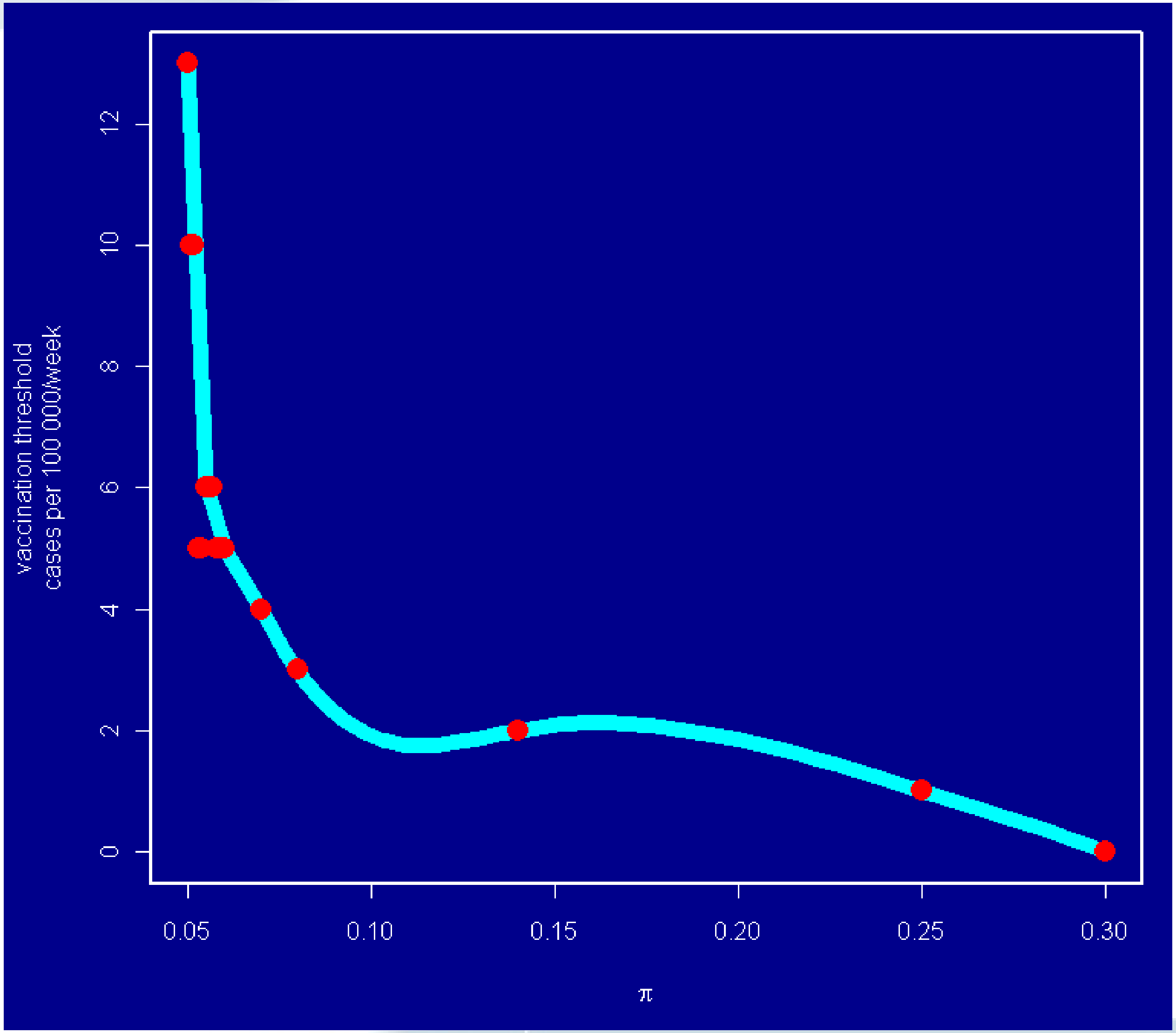
  => $N\pi \cong 0.26$
- number of contacts (const.) N=5
- $n_0 = 100'000$, $\pi \cong 0.05$, $\alpha = 80\%$, $\rho = 3\%$

Response Scenarios





Cases, total
0
50
100
150
200
π = 0.07
π = 0.053
π = 0.052
π = 0.051
0
10
20
30
40
vaccination threshold
cases per 100 000/week


vaccination threshold
cases per 100 000/week
0
2
4
6
8
10
12
0.05
0.10
0.15
0.20
0.25
0.30
π

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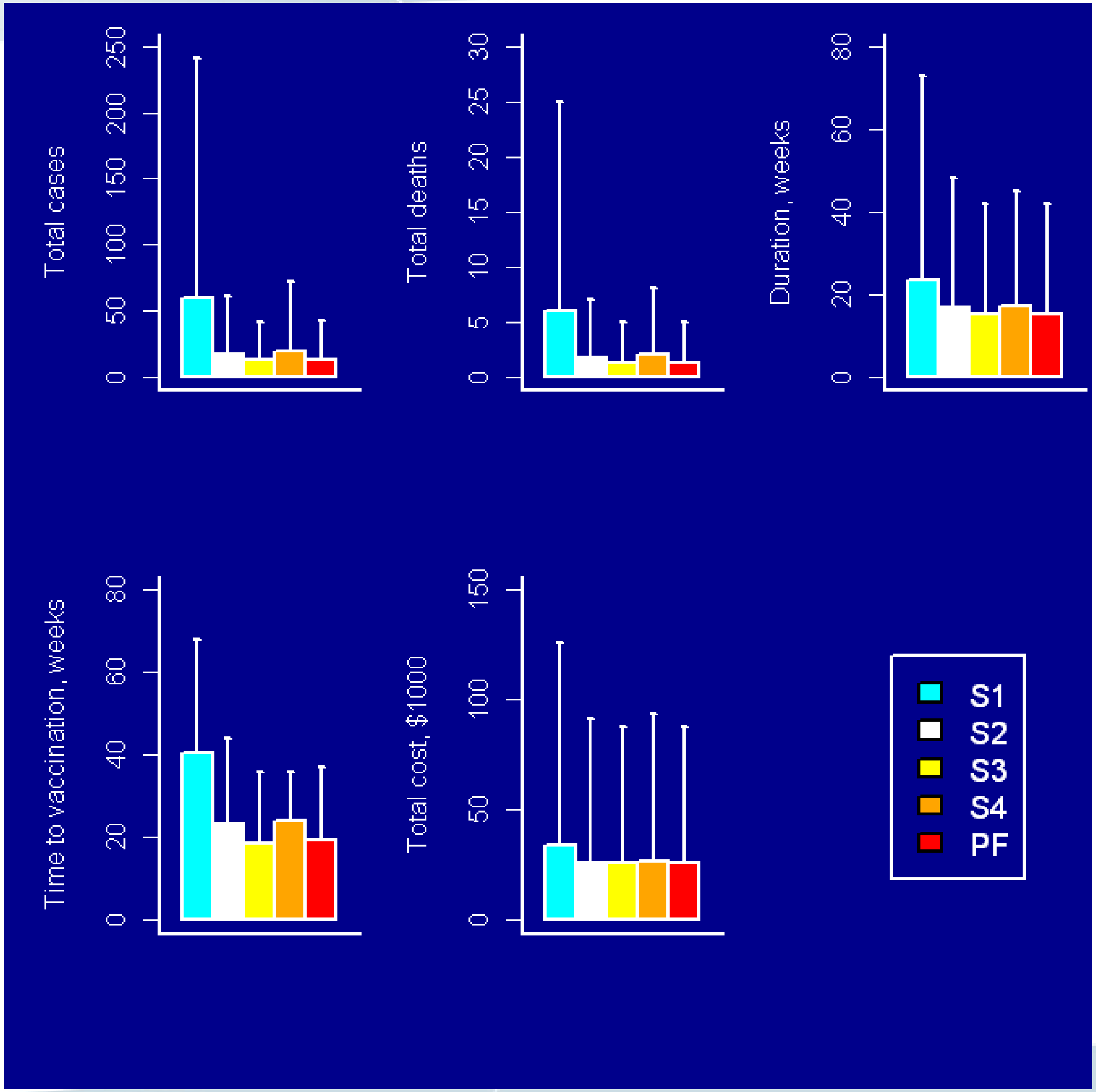

Total cases
0
50
100
150
200
250
Total deaths
0
5
10
15
20
25
30
Duration, weeks
0
20
40
60
80
Time to vaccination, weeks
0
20
40
60
80
Total cost, $1000
0
50
100
150
S1
S2
S3
S4
PF

Some Insights:

- The outcome of an epidemic is apparently highly sensitive to the values of the individual contagion probability π
- The vaccination time is determined by the response strategy chosen: the less contagious the disease is assumed to be, the higher the optimal threshold and, consequently, the later the vaccination time.
- Setting the vaccination rules without reliable information on contagious probability increases the expected total costs
- Information on timing of the weather event is a major factor in the determination of the optimal vaccination response

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Discussion

- Carriage is not explicitly considered
- Homogeneous population is an oversimplification
- Dollars vs. Lives
- Endogeneous decision rules vs. Dynamic decision-making with a learning mechanism.