

TB Vaccination

PDF Version available [here](#).

Data creation

```
library(data.table)
library(pomp)
library(ggplot2)
library(rstan)

rstan_options(auto_write = TRUE)
options(mc.cores = parallel::detectCores())

#everyone enters on jan 1
#results are for dec 31
newPeople <- data.table(id=1:1000,year=2000,age=1,timeNoVax=0,timeWithVax=0,vaccinated=0,ltbi=0,atbi=0,ageAtTB=0)

pomp::bake("data/peopleNoVax.RDS",{
  set.seed(4)
  peopleNoVax <- vector("list",length=17)
  peopleNoVax[[1]] <- newPeople[1,][-1,]
  for(i in 1:17){
    # NO VACCINATIONS
    if(i!=1) peopleNoVax[[i]] <- copy(peopleNoVax[[i-1]])
    peopleNoVax[[i]][,age:=age+1]
    peopleNoVax[[i]] <- rbind(peopleNoVax[[i]],newPeople)
    peopleNoVax[[i]][,year:=2000+i]

    N <- nrow(peopleNoVax[[i]])
    peopleNoVax[[i]][sample(1:N,size=round(N*0.050)),ltbi:=1]
    peopleNoVax[[i]][,timeNoVax:=timeNoVax+1]

    Nltbi <- sum(peopleNoVax[[i]]$ltbi)
    peopleNoVax[[i]][atbi==1,ageAtTB:=age]
    peopleNoVax[[i]][,atbi:=0] # people with ATBI go to the doctor and get cured last year
    peopleNoVax[[i]][sample(which(peopleNoVax[[i]]$ltbi==1 & peopleNoVax[[i]]$ageAtTB==0),size=round(Nltbi)),atbi:=1]
  }
  peopleNoVax
}) -> peopleNoVax

pomp::bake("data/peopleWithVax.RDS",{
  set.seed(4)
  peopleWithVax <- vector("list",length=17)
  peopleWithVax[[1]] <- newPeople[1,][-1,]
  for(i in 1:17){
    # WITH VACCINATIONS, BUT STOPPING THEM AFTERWARDS
    if(i!=1) peopleWithVax[[i]] <- copy(peopleWithVax[[i-1]])
    peopleWithVax[[i]][,age:=age+1]
    peopleWithVax[[i]] <- rbind(peopleWithVax[[i]],newPeople)
    peopleWithVax[[i]][,year:=2000+i]
```

```

N <- nrow(peopleWithVax[[i]])
if(i>=10){
  peopleWithVax[[i]] [sample(1:N,size=round(N*0.050)),ltbi:=1]
  peopleWithVax[[i]] [,timeNoVax:=timeNoVax+1]
} else {
  peopleWithVax[[i]] [sample(1:N,size=round(N*0.050)),ltbi:=1]
  peopleWithVax[[i]] [,timeWithVax:=timeWithVax+1]
}

Nltbi <- sum(peopleWithVax[[i]]$ltbi)
peopleWithVax[[i]] <- peopleWithVax[[i]] [atbi==0]
peopleWithVax[[i]] [atbi==1,ageAtTB:=age]
peopleWithVax[[i]] [,atbi:=0] # people with ATBI go to the doctor and get cured last year
peopleWithVax[[i]] [sample(which(peopleWithVax[[i]]$ltbi==1 & peopleWithVax[[i]]$ageAtTB==0),size=round(N*0.050)),size=round(N*0.050)]
}
peopleWithVax
}) -> peopleWithVax

```

Detecting LTBI without vaccination

Lets try an easy model, detecting LTBI in unvaccinated people.

We have a Poisson binomial distribution, where the probability of person i not having LTBI is:

$$Pr(Y_i = 0|p, T_i) = (1 - p)^{T_i}$$

And the probability of person i having LTBI is:

$$Pr(Y_i = 1|p, T_i) = 1 - Pr(Y_i = 0|p, T_i)$$

```

stanData <- copy(peopleNoVax[[17]])
stanData[ageAtTB>0,ltbi:=1]
stanData <- stanData[,.(R=.N),by=.(timeNoVax,timeWithVax,ltbi)]
data = list(N=nrow(stanData),
            R=stanData$R,
            y=stanData$ltbi*stanData$R,
            timeNoVax=stanData$timeNoVax)

stan_code = "
data {
  int<lower=0> N;
  int R[N];
  int y[N];
  vector[N] timeNoVax;
}
parameters {
  real<lower=0,upper=0.5> thetaNoVax;
}
model {
  thetaNoVax ~ beta(0.05, 1);

  for (n in 1:N){

```

```

    y[n] ~ binomial(R[n], 1 - ((1 - thetaNoVax) ^ timeNoVax[n]));
  }
}
"
pomp::bake("results/noVaxLTBI.RDS", {
  stan(model_code=stan_code,
        model_name="noVaxLTBI",
        data=data,
        iter=10000, chains=4, init=0, seed=4)
}) -> fit
summary(fit)$summary

```

```

##                mean      se_mean      sd      2.5%
## thetaNoVax  4.968032e-02  7.435445e-06  0.0006439624  4.843936e-02
## lp__        -9.876380e+03  7.590283e-03  0.7304575869 -9.878464e+03
##                25%      50%      75%      97.5%
## thetaNoVax  4.924807e-02  4.967613e-02  0.0501136  5.095891e-02
## lp__        -9.876532e+03 -9.876102e+03 -9875.9232189 -9.875873e+03
##                n_eff      Rhat
## thetaNoVax  7500.791  1.000616
## lp__        9261.345  1.000465

```

Detecting LTBI with vaccination

Lets try a harder model, detecting LTBI when vaccination originally exists, and is then phased out.

We have a Poisson binomial distribution, where the probability of person not i having LTBI is:

$$Pr(Y_i = 0 | p_w, p_n, TW_i, TN_i) = (1 - p_w)^{TW_i} \times (1 - p_n)^{TN_i}$$

And the probability of person i having LTBI is:

$$Pr(Y_i = 1 | p_w, p_n, TW_i, TN_i) = 1 - Pr(Y_i = 0 | p_w, p_n, TW_i, TN_i)$$

```

stanData <- copy(peopleWithVax[[17]])
stanData[ageAtTB>0, ltbi:=1]
stanData <- stanData[, .(R=.N), by=.(timeNoVax, timeWithVax, ltbi)]
data = list(N=nrow(stanData),
            R=stanData$R,
            y=stanData$ltbi*stanData$R,
            timeNoVax=stanData$timeNoVax,
            timeWithVax=stanData$timeWithVax
            )

stan_code = "
data {
  int<lower=0> N;
  int R[N];
  int y[N];
  vector[N] timeNoVax;
  vector[N] timeWithVax;
}

```

```

parameters {
  real<lower=0,upper=0.5> thetaNoVax;
  real<lower=0,upper=0.5> thetaWithVax;
}
model {
  thetaWithVax ~ beta(0.05, 1);
  thetaNoVax ~ beta(0.05, 1);

  for (n in 1:N){
    y[n] ~ binomial(R[n], 1-((1-thetaWithVax)^timeWithVax[n])*((1-thetaNoVax)^timeNoVax[n]));
  }
}
"

pomp::bake("results/withVaxLTBI.RDS",{
  stan(model_code=stan_code,
        model_name="withVaxLTBI",
        data=data,
        iter=10000, chains=4, init=0, seed=4)
}) -> fit
summary(fit)$summary

```

```

##                mean      se_mean      sd      2.5%
## thetaNoVax      4.023537e-02 1.193584e-05 0.0009857973 3.830165e-02
## thetaWithVax    1.068818e-02 2.480706e-05 0.0020852201 6.601235e-03
## lp__            -7.533216e+03 1.260362e-02 1.0357132482 -7.535946e+03
##                25%      50%      75%      97.5%
## thetaNoVax      3.957005e-02 4.023253e-02 4.089666e-02 4.218267e-02
## thetaWithVax    9.275577e-03 1.069942e-02 1.207870e-02 1.482700e-02
## lp__            -7.533628e+03 -7.532893e+03 -7.532477e+03 -7.532201e+03
##                n_eff      Rhat
## thetaNoVax      6821.334 1.000376
## thetaWithVax    7065.667 1.000509
## lp__            6752.873 1.000107

```

Detecting ATBI without vaccination

Lets try a hard model, detecting ATBI in unvaccinated people. ATBI is incident TB and detected in the year that it occurs.

We have a Poisson binomial distribution, where the probability of person i not having ATBI is:

$$\begin{aligned}
 Pr(ATBI_i = 0 | p_{atbi}, p_{ltbi}, T_i) &= Pr(LTBI_i = 0 | p_{atbi}, p_{ltbi}, T_i) + Pr(LTBI_i = 1 \text{ without activation} | p_{atbi}, p_{ltbi}, T_i) \\
 &= (1 - p_{ltbi})^{T_i} + \sum_{t=1}^{T_i} Pr(\text{Incident LTBI infection at time } t, \text{ no activation}) \\
 &= (1 - p_{ltbi})^{T_i} + \sum_{t=1}^{T_i} (1 - p_{ltbi})^{t-1} \times p_{ltbi} \times (1 - p_{atbi})^{T_i - t + 1}
 \end{aligned}$$

And the probability of person i having LTBI is:

$$Pr(ATBI_i = 1 | p_{atbi}, p_{ltbi}, T_i) = 1 - Pr(ATBI_i = 0 | p_{atbi}, p_{ltbi}, T_i)$$

```

cases <- list()
for(i in 1:14){
  cases[[i]] <- peopleNoVax[[i]][atbi==1]
}
cases <- rbindlist(cases)
controls <- peopleNoVax[[17]][atbi==0 & ageAtTB==0]

cases[,ageAtTB:=0]
controls[,ageAtTB:=0]

stanData <- rbind(controls[,.(R=.N),by=.(timeNoVax,timeWithVax,atbi)],cases[,.(R=.N),by=.(timeNoVax,timeWithVax,atbi)])
data = list(N=nrow(stanData),
            R=stanData$R,
            y=stanData$atbi*stanData$R,
            timeNoVax=stanData$timeNoVax)

stan_code = "
data {
  int<lower=0> N;
  int timeNoVax[N];
  int R[N];
  int y[N];
}
parameters {
  real<lower=0,upper=0.5> ltbiNoVax;
  real<lower=0,upper=0.5> atbiNoVax;
}
model {
  real ps;
  ltbiNoVax ~ beta(0.05, 1);
  atbiNoVax ~ beta(0.05, 1);

  {
    int replicates;
    int personTime;
    real prob_ltbi_no_tb;

    for (n in 1:N){
      prob_ltbi_no_tb = (1-ltbiNoVax)^timeNoVax[n];
      personTime = timeNoVax[n];
      replicates = R[n];

      for(t in 1:personTime){
        prob_ltbi_no_tb = prob_ltbi_no_tb + ((1-ltbiNoVax)^(t-1))*ltbiNoVax*((1-atbiNoVax)^(personTime-t));
      }

      y[n] ~ binomial(R[n], 1-prob_ltbi_no_tb);
    }
  }
}
"

```

```

pomp::bake("results/noVaxATBI.RDS",{
  stan(model_code=stan_code,
        model_name="noVaxATBI",
        data=data,
        iter=10000, chains=4, init=0, seed=4)
}) -> fit
summary(fit)$summary

```

```

##              mean      se_mean      sd      2.5%
## ltbiNoVax  2.361843e-02  4.658234e-06  0.0004846839  2.267644e-02
## atbiNoVax  4.987242e-01  1.018985e-05  0.0012657909  4.953213e-01
## lp__       -7.620051e+03  1.289117e-02  1.0590936326 -7.622892e+03
##              25%      50%      75%      97.5%
## ltbiNoVax  2.328883e-02  2.361434e-02  2.394616e-02  2.457647e-02
## atbiNoVax  4.982311e-01  4.991188e-01  4.996231e-01  4.999623e-01
## lp__       -7.620484e+03 -7.619730e+03 -7.619287e+03 -7.619005e+03
##              n_eff      Rhat
## ltbiNoVax 10826.163 1.0000781
## atbiNoVax 15430.801 0.9999273
## lp__      6749.695 1.0003734

```