# Supplementary Material: Short-sighted evolution constrains the efficacy of long-term bet-hedging.

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## Complement to Figure 4: higher value of disaster probability

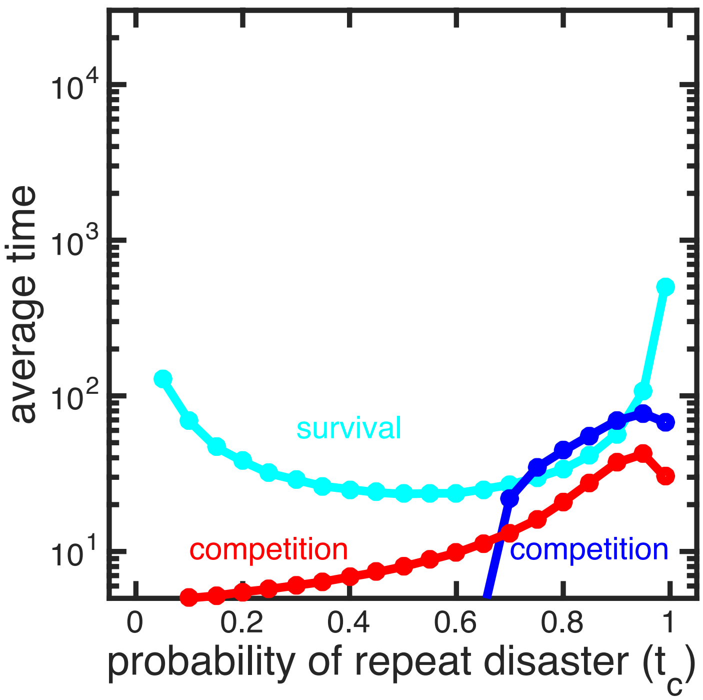


Figure S1: **Time scales for surviving an environmental challenge and demographic competition with increased disaster probability.** A higher disaster probability ($k = .65$) causes the time scale for survival to play out faster than the time scale for competition. The time for the slow switching strategy ($p = .01$) to go extinct (cyan) is shorter than the time it takes $p = .01$ (blue) to win. However, it is not shorter than the time it takes $p = 1$ (red) to win. The fast switching strategy did not go extinct and so is not plotted.

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## Complement to Figure 6: different environmental switch rates

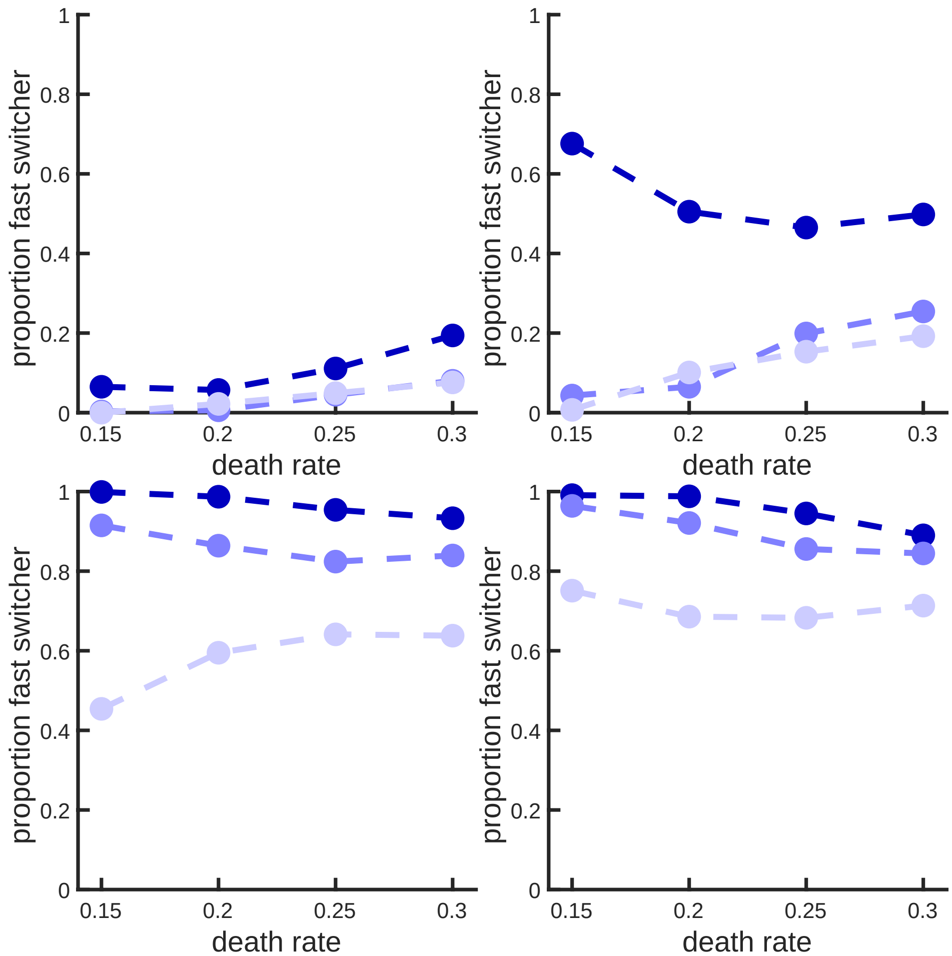


Figure S2: **Model with fluctuating environments for different parameter combinations.** These plots show an extended analysis of the fluctuating environment model for different probabilities that the environmental state switches (top left 0.005, top right 0.01, bottom left 0.05, and bottom right 0.1). In each plot the proportion of simulations (out of 1000) that the fast switcher won is shown as a function of the death rate for the maladapted phenotype ($A$ in $E_B$ and $B$ in $E_A$). The different colors of curves correspond to different death rates for the adapted phenotype ($A$ in $E_A$ and $B$ in $E_B$): dark blue 0.01, medium blue 0.025, and light blue 0.05. The reproductive rate is held fixed at 0.1. One general trend is that when the death rate for the preferred phenotype is smaller (i.e. the advantage for being the preferred phenotype is greater) then the fast switcher wins more often. Also, the faster the environment switches, the more often the fast switching strategy wins. Interestingly, increasing the death rate of the maladapted phenotype does not seem to systematically favor either switching strategy—its effect is context dependent.

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## Code for stochastic simulations

```
using StatsBase


function StochCompetition(alpha,k,p1,p2,C,tp,maxt)
   ## Inputs:
   # alpha = population turnover rate, scalar between 0 and 1
   # k = probability of a disaster, scalar between 0 and 1
   # p1 = probability of switching for organism 1, scalar between 0 and 1
   # p2 = probability of switching for organism 2, scalar between 0 and 1
   # C = carrying capacity, scalar assume it is divisible by 4
   # tp = temporal correlation between disasters, scalar between 0 and 1
   # maxt = maximum time for simulation, scalar

   vect=round(Int64,[C/4,C/4,C/4,C/4]); # tracks # of phenotypes [A1,B1,A2,B2];
   t=0; # starting time
   lastext=rand()<.5; # determines phenotype disaster targets, either 0 or 1
   win=0;cause=0; # determine which genotype wins and how
   while (t<maxt)
      t+=1
      if rand()<k
         # disaster hits
         if rand()>tp
            # switch phenotype targeted
            lastext=!lastext;
         end
         # destroy either A or B phenotypes
         vect[lastext+1]=0
         vect[lastext+3]=0
      end
      win=Extinct(vect); # check to see if a genotype is extinct
      if win>0
```

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```
            # a genotype went extinct because of a disaster
            cause=1;
            break; # stop simulation
        end
        if (alpha != 0)
            # population turnover
            DeathN!(vect,alpha);
        end
        win=Extinct(vect); # check to see if a genotype is extinct
        if win>0
            # a genotype went extinct because of population turnover
            cause=2;
            break; # stop simulation
        end
        # Regrow population
        tot=sum(vect); # living organisms
        torep=C-tot; # number of organisms to replace
        GrowBack4!(vect,tot,torep,p1,p2); # repopulate
    end
    return win,vect,t,cause
end



function Extinct(vect)
    # Determines whether or not one genotype went extinct
    win=0
    if (vect[1]+vect[2])<.5 && (vect[3]+vect[4])>.5
        win=2
    elseif (vect[3]+vect[4])<.5 && (vect[1]+vect[2])>.5
        win=1
    elseif (vect[3]+vect[4])<.5 && (vect[1]+vect[2])<.5
```

```
      win=3
   end
   return win
end



function GrowBack4!(vect,tot,torep,p1,p2)
   # Regrows population from vect to the carrying capacity
   inds=[1,2,3,4]
   for i=1:torep
      k=sample(inds,WeightVec(vect))
      if k==1
         if rand()<p1
            vect[2]+=1
         else
            vect[1]+=1
         end
      elseif k==2
         if rand()<p1
            vect[1]+=1
         else
            vect[2]+=1
         end
      elseif k==3
         if rand()<p2
            vect[4]+=1
         else
            vect[3]+=1
         end
      elseif k==4
         if rand()<p2
```

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```
            vect[3]+=1
         else
            vect[4]+=1
         end
      end
      tot+=1
   end
end

function DeathN!(vect,alpha)
   # Population turnover
   for i=1:length(vect)
      if vect[i] != 0
         vect[i]-=FastBinN(vect[i],alpha)
      end
   end
end


function FastBinN(n,p)
   # Samples binomial quickly
   cutoff=10
   if (n*p>cutoff) && (n*(1-p)>cutoff)
      done2=0
      while done2<1
         y=round(randn()*sqrt(n*p*(1-p))+n*p);
         if y>=0
            done2=2
         end
      end
   else
```

```
      y=0
      for i=1:n
         if rand()<p
            y+=1
         end
      end
   end
   return y
end
```

## Code for evolving switching rates

```
function EvoModel(alpha,k,p1,mutrat,C,tp,maxt)
   vect=[C/2,C/2]; #[As,Bs,Ad,Bd];
   vect=int(vect);
   pvect=[p1]
   t=0;
   lastext=rand()<.5; # for tp, boolean but used as number
   vecthistory=zeros(3,maxt);
      notdone=true;
   while notdone
      t+=1
      if rand()<k
         if rand()>tp
            lastext=!lastext;
         end
         vect[lastext+1:2:end]=0
      end
      if (alpha != 0)
         DeathNEvo!(vect,alpha);
      end
```

```
      tot=sum(vect);
      torep=C-tot;
      if (tot<.5)
          notdone=false;
          break
      end
      GrowEvo!(vect,tot,torep,pvect,mutrat)
      temp=vect[1:2:end]+vect[2:2:end];
         k1=indmax(temp);
         k2=pvect[k1];
         k3=temp[k1]/C;
         k4=sum(pvect.*temp)/C;
      println([t k4])
      vecthistory[:,t]=[k2,k3,k4];
      if (t>=maxt)
          notdone=false;
      end
   end
   return t,vect,pvect,vecthistory[:,1:t]
end


function DeathNEvo!(vect,alpha)
   for i=1:length(vect)
      if vect[i] != 0
         vect[i]-=FastBinN(vect[i],alpha)
      end
   end
end
```

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```
function FastBinN(n,p)
   cutoff=10
   if (n*p>cutoff) && (n*(1-p)>cutoff)
      done2=0
      while done2<1
         y=round(randn()*sqrt(n*p*(1-p))+n*p);
         if y>=0
            done2=2
         end
      end
   else
      y=0
      for i=1:n
         if rand()<p
            y+=1
         end
      end
   end
   return y
end
```

```
function GrowEvo!(vect,tot,torep,pvect,mutrat)
   done=0;
   temp=vect[1:2:end]+vect[2:2:end];
   while done<1
       inds=findfirst(temp.<.5);
       if inds>.5
           splice!(vect,2*inds-1:2*inds)
```

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```
        splice!(pvect,inds)
        splice!(temp,inds)
    else
        done=2
    end
end
probs=zeros(length(pvect));
sprobsB=zeros(length(probs));
for i=1:length(probs)
    probs[i]=vect[2*i-1]+vect[2*i];
    sprobsB[i]=vect[2*i-1]*pvect[i]+(1-pvect[i])*vect[2*i];
    sprobsB[i]=sprobsB[i]/probs[i];
end
probs=probs./sum(probs);
probs=cumsum(probs);
for i=1:torep
    if rand()<mutrat
        if rand()<.5
            push!(vect,1)
            push!(vect,0)
        else
         push!(vect,0)
            push!(vect,1)
        end
        push!(pvect,10.0^(-6*rand()));
    else
        ind=sum(rand().>probs)+1;
         if rand()<sprobsB[ind]
             vect[2*ind]+=1
         else
             vect[2*ind-1]+=1
```

```
            end
        end
   end
end
```

## Code for fluctuating environment simulations

```
function [win,t,mat,swc,pop,swct]=fluctenvmodel_par(switchprob,pdA,pdB,pr)
p1=1;p2=.01;
K=1000;
mat=[K/4 K/4 K/4 K/4];
maxnum=100000;
t=0;
pd=[pdA pdB pdA pdB];
swc=0;
win=-1;
pop=zeros(maxnum,4);
;
while t<maxnum
    if rand()<switchprob
        %switch
        temp=pd(1);
        pd(1)=pd(2);
        pd(3)=pd(4);
        pd(2)=temp;
        pd(4)=temp;
        swc=swc+1;
        swct(swc)=t;
    end
    for i1=1:4
        temp=rand(mat(i1),1);
```

```
        mat(i1)=mat(i1)-sum(temp<pd(i1));
        repro(i1)=sum(temp>1-pr);
    end
    if sum(mat)+sum(repro)>K
        num=K-sum(mat);
        newrepro=zeros(1,4);
        for i1=1:num
            ind=sum(rand()>cumsum([0;repro'])/sum(repro));
            newrepro(ind)=newrepro(ind)+1;
            repro(ind)=repro(ind)-1;
        end
        repro=newrepro;
    end

    t=t+1;
    pop(t,:)=mat;
    temp=sum(rand(repro(1),1)<p1)+sum(rand(repro(2),1)<(1-p1));
    mat(2)=mat(2)+temp;
    mat(1)=mat(1)+repro(1)+repro(2)-temp;
    temp=sum(rand(repro(3),1)<p2)+sum(rand(repro(4),1)<(1-p2));
    mat(4)=mat(4)+temp;
    mat(3)=mat(3)+repro(3)+repro(4)-temp;


    if sum(mat)<.5
        break
    elseif ((mat(1)+mat(2)<.5)) && ((mat(3)+mat(4)>.5))
        win=2;
    elseif ((mat(1)+mat(2)>.5)) && ((mat(3)+mat(4)<.5))
        win=1;
    end
```

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```
end

pop=pop(1:t,:);
```

## Code for metapopulation model

```
N=10;

migprob=.00001;

popcell=cell(N,1);

ps=10.^linspace(-3,0,10);;

for i1=1:N;

    popcell{i1}=zeros(length(ps),2); %initial matrix with # of A and B types of each p

    ind1=i1;

    ind2=round(rand())+1;

    popcell{i1}(ind1,ind2)=1000;

    lastdisast(i1)=2-ind2;

    extinct(i1)=0;

end

t=0;

probdisast=.1;

probtc=.99*ones(N,1);

probmut=0.0001;

probdeath=.1;

carrycap=1000;

maxt=100000;

extct=zeros(maxt,1);

totpop=extct;

curlead=zeros(maxt,length(ps));

while t<maxt

    t=t+1;

    for i1=1:N
```

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```
        % check
        if extinct(i1)==1;continue;end
        % disaster
        if rand()<probdisast
            if rand()>probtc(i1)
                lastdisast(i1)=1-lastdisast(i1); % switch
            end
            popcell{i1}(:,lastdisast(i1)+1)=0;
        end
        if sum(sum(popcell{i1}))<1;
            extinct(i1)=1;
            continue;
        end

        % random death
        for i2=1:length(ps)
            if popcell{i1}(i2,1)>0
                popcell{i1}(i2,1)=popcell{i1}(i2,1)-sum(rand(popcell{i1}(i2,1),1)<probdeath);
            end
            if popcell{i1}(i2,2)>0
                popcell{i1}(i2,2)=popcell{i1}(i2,2)-sum(rand(popcell{i1}(i2,2),1)<probdeath);
            end
        end
        if sum(sum(popcell{i1}))<1
            extinct(i1)=1;continue
        end

        % regrowth
        [popmat,tot]=regrow(popcell{i1},carrycap,probmut,ps);
        popcell{i1}=popmat;
    end
```

```
oldpopcell=popcell;
oldextinct=extinct;
if N>1
    for i1=1:N
        if oldextinct(i1)==0
            temp=[oldpopcell{i1}(:,1);oldpopcell{i1}(:,2)];
            for j2=1:length(temp);
                nummig=zeros(1,N);
                temp2=sum(rand(temp(j2),1)<migprob);
                temp3=randsample([1:N-1],temp2,'true');
                nummig=nummig+histc(temp3,[1:N]);
                nummig(N)=nummig(i1);
                nummig(i1)=0;
                if j2>length(ps)
                    for j3=1:N
                        popcell{j3}(j2-length(ps),2)=popcell{j3}(j2-length(ps),2)+nummig(j3);
                        popcell{i1}(j2-length(ps),2)=popcell{i1}(j2-length(ps),2)-nummig(j3);
                    end
                else
                    for j3=1:N
                        popcell{j3}(j2,1)=popcell{j3}(j2,1)+nummig(j3);
                        popcell{i1}(j2,1)=popcell{i1}(j2,1)-nummig(j3);
                    end
                end
            end
        end
    end
end

succ=zeros(size(ps));
```

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```
    for i1=1:N
        % record
        temp=popcell{i1}(:,1)+popcell{i1}(:,2);
        tot=sum(temp);
        if tot < 1
            extinct(i1)=1;
        else
            extinct(i1)=0;
            [u,v]=max(temp);
            succ(v)=succ(v)+1;
        end
        totpop(t)=totpop(t)+tot;
    end
    curlead(t,:)=succ;
    extct(t)=sum(extinct);
    if extct(t)==N
        break
    end
    if any(succ==N)
        break
    end
    [t/maxt extct(t) curlead(t,:)]
end
```

```
function [mat,tot]=regrow(mat,carrycap,probmut,ps)

tot=sum(sum(mat));
while tot<carrycap
```

```
if 2*tot<=carrycap
    muts=zeros(length(ps),2);
    for i2=1:length(ps)
        nummutA=sum(rand(mat(i2,1),1)<probmut);
        nummutB=sum(rand(mat(i2,2),1)<probmut);
        numswitchA2B=sum(rand(mat(i2,1)-nummutA,1)<ps(i2));
        numswitchB2A=sum(rand(mat(i2,2)-nummutB,1)<ps(i2));
        mat(i2,1)=2*mat(i2,1)-numswitchA2B-nummutA+numswitchB2A;
        mat(i2,2)=2*mat(i2,2)+numswitchA2B-nummutB-numswitchB2A;
        % determine mutants
        prob=ones(size(ps));
        prob(i2)=0;
        prob=prob/sum(prob);
        mutA=randsample([1:length(ps)],nummutA,true,prob);
        temp=histc(mutA,[1:length(ps)]);
        muts(:,1)=muts(:,1)+temp(:);
        mutB=randsample([1:length(ps)],nummutB,true,prob);
        temp=histc(mutB,[1:length(ps)]);
        muts(:,2)=muts(:,2)+temp(:);
    end
    mat=mat+muts;
else
    temp=[mat(:,1);mat(:,2)];
    for i2=1:carrycap-tot
        v=randsample([1:2*length(ps)],1,true,temp/(tot+i2-1));
        if rand()<probmut
            prob=ones(2*length(ps),1);
            prob(v)=0;
            if v>length(ps)
                prob(v-length(ps))=0;
            else
```

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```
                prob(v+length(ps))=0;
            end
            prob=prob/sum(prob);
            v=randsample([1:2*length(ps)],1,true,prob);
        end
        if v>length(ps)
            ind1=v-length(ps);ind2=2;
        else
            ind1=v;ind2=1;
        end
        if rand()<ps(ind1)
            ind2=3-ind2;
        end
        mat(ind1,ind2)=mat(ind1,ind2)+1;
        temp(v)=temp(v)+1;
    end
end
tot=sum(sum(mat));
end
```

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