General ODE systems

```
In[•]:= dIsdt = R[Iw, Is, Iww] - d Is - Πs[Ds, Dw, Dww] Is - η Is;
dIwdt = (1 - p) η Is - (d + αw) Iw - Πw[Ds, Dw, Dww, βw] Iw;
dIwwdt = p η Is - (d + αww) Iww - Πww[Ds, Dw, Dww, βww] Iww;
dDsdt = B[Ds, Dw, Dww, Is, Iw, Iww] - μ Ds - (λww + λw) Ds;
dDwdt = (λw + (1 - q) λww) Ds - (μ + σw) Dw - ((1 - q) λww + λw) Dw;
dDwwdt = q λww Ds + ((1 - q) λww + λw) Dw - (μ + σww) Dww;
dWdt = fw Dw + fww Dww - δ W - η Is;

forceInf = {η → γ W, λw → h (ρ + βw) Iw, λww → h (ρ + βww) Iww};
odesRes = {dIsdt, dIwdt, dIwwdt, dDsdt, dDwdt, dDwwdt, dWdt};
varRes = {Is, Iw, Iww, Ds, Dw, Dww, W};

In[•]:= dDsdt + dDwdt + dDwwdt // FullSimplify

Out[•]= -Ds μ - Dw (μ + σw) - Dww (μ + σww) + B[Ds, Dw, Dww, Is, Iw, Iww]
```

R0 using next generation matrix

```
In[•]:= varPar = {Iw, Iww, Dw, Dww, W};
dDwdt = (λw + (1 - q) λww) Ds - (μ + σw) Dw - ((1 - q) λww + λw) Dw;
Mmatrix = {{-d - αw - Πw[Ds, Dw, Dww, βw], 0, 0, 0, (1 - p) γ Is},
   {0, -d - αww - Πww[Ds, Dw, Dww, βww], 0, 0, p γ Is},
   {h (ρ + βw) Ds, (1 - q) h (ρ + βww) Ds, - μ - σw - ((1 - q) λww + λw), 0, 0},
   {0, q h (ρ + βww) Ds, ((1 - q) λww + λw), - μ - σww, 0},
   {0, 0, fw, fww, - δ - γ Is}};
{{dIwdt, dIwwdt, dDwdt, dDwwdt, dWdt} == Mmatrix.varPar} /. forceInf //
 FullSimplify
Fmatrix = {{0, 0, 0, 0, 0}, {0, 0, 0, 0, 0},
   {0, 0, 0, 0, 0}, {0, 0, 0, 0, 0}, {0, 0, fw, fww, 0}};
Vmatrix = {{d + αw + Πw[Ds, Dw, Dww, βw], 0, 0, 0, -(1 - p) γ Is},
   {0, d + αww + Πww[Ds, Dw, Dww, βww], 0, 0, -p γ Is}, {-
      h (βw + ρ) Ds, - (1 - q) h (βww + ρ) Ds, μ + σw + ((1 - q) λww + λw), 0, 0}, {0,
    - q h (ρ + βww) Ds, -((1 - q) λww + λw), μ + σww, 0}, {0, 0, 0, 0, δ + γ Is}};
Fmatrix - Vmatrix == Mmatrix // FullSimplify

Out[•]= {True}

Out[•]= True
```

In[•]:= Mmatrix // MatrixForm

Out[•]//MatrixForm=

$$\begin{pmatrix} -d-\alpha w-\Pi w[Ds, Dw, Dww, \beta w] & 0 & 0 \\ 0 & -d-\alpha ww-\Pi ww[Ds, Dw, Dww, \beta ww] & 0 \\ Ds\, h\, (\beta w+\rho) & Ds\, h\, (1-q)\, (\beta ww+\rho) & -\lambda w-(1-q)\, \lambda ww-\mu-\sigma w \\ 0 & Ds\, h\, q\, (\beta ww+\rho) & \lambda w+(1-q)\, \lambda ww & - \\ 0 & 0 & fw \end{pmatrix}$$

In[•]:= Fmatrix // MatrixForm

Out[•]//MatrixForm=

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & fw & fww & 0 \end{pmatrix}$$

In[•]:= Vmatrix // MatrixForm

Out[•]//MatrixForm=

$$\begin{pmatrix} d+\alpha w+\Pi w[Ds, Dw, Dww, \beta w] & 0 & 0 & 0 \\ 0 & d+\alpha ww+\Pi ww[Ds, Dw, Dww, \beta ww] & 0 & 0 \\ -Ds\, h\, (\beta w+\rho) & Ds\, h\, (-1+q)\, (\beta ww+\rho) & \lambda w+(1-q)\, \lambda ww+\mu+\sigma w & 0 \\ 0 & -Ds\, h\, q\, (\beta ww+\rho) & -\lambda w-(1-q)\, \lambda ww & \mu+\sigma w \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

In[•]:=
$$R0 = \gamma\, Is \frac{p\, q\, h\, (\beta ww + \rho)}{\alpha ww + d + \Pi ww[Ds, Dw, Dww, \beta ww]} \frac{Ds}{\mu + \sigma ww} \frac{fww}{\delta + \gamma\, Is} + \gamma\, Is \left(\frac{(1-p)\, (\beta w + \rho)\, h}{\alpha w + d + \Pi w[Ds, Dw, Dww, \beta w]} + \frac{p\, (1-q)\, (\beta ww + \rho)\, h}{\alpha ww + d + \Pi ww[Ds, Dw, Dww, \beta ww]}\right) \frac{Ds}{\mu + \sigma w} \frac{fw}{\delta + \gamma\, Is};$$

```
R0 == (Eigenvalues[Fmatrix.Inverse[Vmatrix]][[5]] /. λw → 0 /. λww → 0) //
  FullSimplify
```

Out[•]= True

Stability of the disease-free equilibrium with linear birth function

```
In[•]:= func0 = {R[Iw, Is, Iww] → r (Is + Iw + Iww), Πs[Ds, Dw, Dww] → ρ (Ds + Dw + Dww),
    Πw[Ds, Dw, Dww, βw] → (ρ + βw) (Ds + Dw + Dww),
    Πww[Ds, Dw, Dww, βww] → (βww + ρ) (Ds + Dw + Dww),
    B[Ds, Dw, Dww, Is, Iw, Iww] → ρ c (Ds + Dw + Dww) (Is + Iw + Iww)};
sysfunc0 = odesRes /. forceInf /. func0;
```

In[•]:=
```
solSusceptibleFunc0 = Solve[
    Thread[sysfunc0 == 0] /. {Iww → 0, Iw → 0, Dww → 0, Dw → 0, W → 0}, varRes][[2]]
```

••• Solve: Equations may not give solutions for all "solve" variables.

Out[•]=
$$\left\{Is \to \frac{\mu}{c\,\rho},\ Ds \to -\frac{d-r}{\rho}\right\}$$

In[•]:=
```
jacob0 = D[sysfunc0, {varRes}];
```

In[•]:=
```
jacob0 /. {Iww → 0, Iw → 0, Dww → 0, Dw → 0, W → 0, Is → μ/(c ρ), Ds → -(d - r)/ρ} //
  MatrixForm
```

Out[•]//MatrixForm=
$$\begin{pmatrix}
0 & r & r & -\frac{\mu}{c} & -\frac{\mu}{c} & -\frac{\mu}{c} & -\frac{\gamma\,\mu}{c\,\rho} \\
0 & -d-\alpha w+\frac{(d-r)\,(\beta w+\rho)}{\rho} & 0 & 0 & 0 & 0 & \frac{(1-p)\,\gamma\,\mu}{c\,\rho} \\
0 & 0 & -d-\alpha ww+\frac{(d-r)\,(\beta ww+\rho)}{\rho} & 0 & 0 & 0 & \frac{p\,\gamma\,\mu}{c\,\rho} \\
-c\,(d-r) & -c\,(d-r)+\frac{h\,(d-r)\,(\beta w+\rho)}{\rho} & -c\,(d-r)+\frac{h\,(d-r)\,(\beta ww+\rho)}{\rho} & 0 & \mu & \mu & 0 \\
0 & -\frac{h\,(d-r)\,(\beta w+\rho)}{\rho} & -\frac{h\,(1-q)\,(d-r)\,(\beta ww+\rho)}{\rho} & 0 & -\mu-\sigma w & 0 & 0 \\
0 & 0 & -\frac{h\,q\,(d-r)\,(\beta ww+\rho)}{\rho} & 0 & 0 & -\mu-\sigma ww & 0 \\
0 & 0 & 0 & 0 & fw & fww & -\delta-\frac{\gamma\,\mu}{c\,\rho}
\end{pmatrix}$$

In[•]:=
```
jacob0 /. {Iww → 0, Iw → 0, Dww → 0, Dw → 0, W → 0, Is → μ/(c ρ), Ds → -(d - r)/ρ} //
  Eigenvalues
```

Out[•]=
$$\Big\{-\sqrt{d-r}\,\sqrt{\mu},\ \sqrt{d-r}\,\sqrt{\mu},\ \frac{\text{Root}\left[-c^4\,d^2\,fw\,h\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+\text{⋯ 326 ⋯}+\#1^5\&,1\right]}{c\,\rho^5},$$
$$\frac{\text{Root}\left[-c^4\,d^2\,fw\,h\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+\text{⋯ 326 ⋯}+\#1^5\&,2\right]}{c\,\rho^5},$$
$$\frac{\text{Root}\left[-c^4\,d^2\,fw\,h\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+\text{⋯ 326 ⋯}+\#1^5\&,3\right]}{c\,\rho^5},\ \frac{1}{c\,\rho^5}\text{Root}\Big[$$
$$-c^4\,d^2\,fw\,h\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+c^4\,d^2\,fw\,h\,p\,q\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}-c^4\,d^2\,fww\,h\,p\,q\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+$$
$$\text{⋯ 322 ⋯}+\left(-c\,d\,\beta w\,\rho^4+c\,r\,\beta w\,\rho^4-c\,d\,\beta ww\,\rho^4+c\,r\,\beta ww\,\rho^4+\gamma\,\mu\,\rho^4+2\,c\,r\,\rho^5+c\,\alpha w\,\rho^5+\right.$$
$$\left.c\,\alpha ww\,\rho^5+c\,\delta\,\rho^5+2\,c\,\mu\,\rho^5+c\,\rho^5\,\sigma w+c\,\rho^5\,\sigma ww\right)\#1^4+\#1^5\ \&,\ 4\Big],\ \frac{1}{c\,\rho^5}\text{Root}\Big[$$
$$-c^4\,d^2\,fw\,h\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+c^4\,d^2\,fw\,h\,p\,q\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}-c^4\,d^2\,fww\,h\,p\,q\,\beta w\,\beta ww\,\gamma\,\mu^2\,\rho^{22}+$$
$$\text{⋯ 322 ⋯}+\left(-c\,d\,\beta w\,\rho^4+c\,r\,\beta w\,\rho^4-c\,d\,\beta ww\,\rho^4+c\,r\,\beta ww\,\rho^4+\gamma\,\mu\,\rho^4+2\,c\,r\,\rho^5+\right.$$
$$\left.c\,\alpha w\,\rho^5+c\,\alpha ww\,\rho^5+c\,\delta\,\rho^5+2\,c\,\mu\,\rho^5+c\,\rho^5\,\sigma w+c\,\rho^5\,\sigma ww\right)\#1^4+\#1^5\ \&,\ 5\Big]\Big\}$$

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In[•]:=
```
(R0 /. func0 /. solSusceptibleFunc0 /. {Dw → 0, Dww → 0});
R0func0cond =
  Reduce[% > 1 && fw > 0 && fww > 0 && r > 0 && d > 0 && r > d && γ > 0 &&
    μ > 0 && 0 < p < 1 && 0 < q < 1 && c > 0 && δ > 0 && βww > 0 && βw > 0 &&
    αw > 0 && αww > 0 && ρ > 0 && σw > 0 && σww > 0 && h > 0 && h ≤ 1, Reals];
```

Simplify the expressions for γ

```
γcond = R0func0cond[[14]][[1]][[5]][[2]];
```

In[∘]:=

$$\left(\frac{(c\,\delta\,\rho\,((r-d)\,\beta w+(\alpha w+r)\,\rho)\,((r-d)\,\beta ww+(\alpha ww+r)\,\rho)\,(\mu+\sigma w)\,(\mu+\sigma ww))}{\mu}\right.$$

$$1\Big/\Big(fw\,h\,r\,((1-p)\,\alpha ww\,\rho\,(\beta w+\rho)+p\,(1-q)\,\alpha w\,\rho\,(\beta ww+\rho)+(1-p\,q)\,r\,(\beta w+\rho)\,(\beta ww+\rho))\,(\mu+\sigma ww)-(\alpha w\,\rho+r\,(\beta w+\rho))\,(\mu+\sigma w)\,((-fww\,h\,p\,q+\mu+\sigma ww)\,(\beta ww+\rho)\,r+\alpha ww\,\rho\,(\mu+\sigma ww))+d^2\,(fw\,h\,((1-p\,q)\,\beta w\,\beta ww+p\,(1-q)\,\beta w\,\rho+(1-p)\,\beta ww\,\rho)\,(\mu+\sigma ww)-\beta w\,(\mu+\sigma w)\,(-fww\,h\,p\,q\,(\beta ww+\rho)+\beta ww\,(\mu+\sigma ww)))+d\,(fw\,h\,(-2\times(1-p\,q)\,r\,\beta w\,\beta ww+(-1+p\,(-1+2\,q))\,r\,\beta w\,\rho-(1-p)\,\alpha ww\,\rho\,(\beta w+\rho)-p\,(1-q)\,\alpha w\,\rho\,(\beta ww+\rho)+r\,\rho\,((-2+p+p\,q)\,\beta ww+(-1+p\,q)\,\rho))\,(\mu+\sigma ww)+(\mu+\sigma w)\,(-fww\,h\,p\,q\,(\beta ww+\rho)\,(2\,r\,\beta w+(r+\alpha w)\,\rho)+(2\,r\,\beta w\,\beta ww+(r+\alpha ww)\,\beta w\,\rho+(r+\alpha w)\,\beta ww\,\rho)\,(\mu+\sigma ww)))\Big)\Bigg)==\gamma cond\ //\ FullSimplify$$

Out[∘]= True

```
In[∘]:= R0func0cond[[14]][[1]][[2]];
fwcond = R0func0cond[[14]][[1]][[2]][[2]];
```

```
In[∘]:= fwcond // FullSimplify
```

Out[∘]=

$$-(((d\,\beta w-\alpha w\,\rho-r\,(\beta w+\rho))\,(\mu+\sigma w)\,(-fww\,h\,p\,q\,r\,(\beta ww+\rho)+(r\,\beta ww+(r+\alpha ww)\,\rho)\,(\mu+\sigma ww)+d\,(fww\,h\,p\,q\,(\beta ww+\rho)-\beta ww\,(\mu+\sigma ww))))\,/\,(h\,(d-r)\,((-1+p)\,\alpha ww\,\rho\,(\beta w+\rho)+p\,(-1+q)\,\alpha w\,\rho\,(\beta ww+\rho)+(-1+p\,q)\,r\,(\beta w+\rho)\,(\beta ww+\rho)-d\,((-1+p\,q)\,\beta w\,\beta ww+p\,(-1+q)\,\beta w\,\rho+(-1+p)\,\beta ww\,\rho))\,(\mu+\sigma ww)))$$

In[∘]:=

$$fwcond==\frac{(d\,\beta w-\alpha w\,\rho-r\,(\beta w+\rho))\,(\mu+\sigma w)}{h\,(d-r)\,(\mu+\sigma ww)}\,(((-fww\,h\,p\,q\,(\beta ww+\rho)+\beta ww\,(\mu+\sigma ww))\,(r-d)+(\alpha ww+r)\,\rho\,(\mu+\sigma ww))\,/\,((1-p)\,\alpha ww\,\rho\,(\beta w+\rho)+p\,(1-q)\,\alpha w\,\rho\,(\beta ww+\rho)+(1-p\,q)\,(r-d)\,(\beta w+\rho)\,(\beta ww+\rho)+d\,\rho\,((1-p)\,\beta w+\rho+p\,((1-q)\,\beta ww-q\,\rho))))\ //\ FullSimplify$$

Out[∘]= True

```
In[∘]:= R0func0cond[[14]][[1]][[1]][[5]] == R0func0cond[[14]][[2]][[1]][[2]]
```

Out[∘]= True

```
In[∘]:= fwwcond = R0func0cond[[14]][[1]][[1]][[5]] // FullSimplify
```

Out[∘]=

$$\frac{(d\,\beta ww-\alpha ww\,\rho-r\,(\beta ww+\rho))\,(\mu+\sigma ww)}{h\,p\,q\,(d-r)\,(\beta ww+\rho)}$$

In[∘]:=

Nonlinear birth function for intermediate host

In[•]:=
```
func1 = {R[Iw, Is, Iww] → r (1 - k (Is + Iw + Iww)) (Is + Iw + Iww),
   Πs[Ds, Dw, Dww] → ρ (Ds + Dw + Dww), Πw[Ds, Dw, Dww, βw] →
    (ρ + βw) (Ds + Dw + Dww), Πww[Ds, Dw, Dww, βww] → (ρ + βww) (Ds + Dw + Dww),
   B[Ds, Dw, Dww, Is, Iw, Iww] → ρ c (Ds + Dw + Dww) (Is + Iw + Iww)};

sysfunc1 = odesRes /. forceInf /. func1;
jacob1 = D[sysfunc1, {varRes}];

solSusceptibleFunc1 = Solve[
   Thread[sysfunc1 == 0] /. {Iww → 0, Iw → 0, Dww → 0, Dw → 0, W → 0}, varRes][[3]]
```

Solve: Equations may not give solutions for all "solve" variables.

Out[•]= $\left\{Is \to \frac{\mu}{c\,\rho},\ Ds \to -\frac{k\,r\,\mu + c\,d\,\rho - c\,r\,\rho}{c\,\rho^2}\right\}$

In[•]:=

In[•]:=
```
Reduce[(Ds /. solSusceptibleFunc1) > 0 &&
  k > 0 && r > 0 && c > 0 && μ > 0 && d > 0 && ρ > 0]
```

Out[•]= $r > 0\ \&\&\ 0 < d < r\ \&\&\ \rho > 0\ \&\&\ \mu > 0\ \&\&\ k > 0\ \&\&\ c > \frac{k\,r\,\mu}{-d\,\rho + r\,\rho}$

In[•]:=
```
jacob1 /. {Iww → 0, Iw → 0, Dww → 0, Dw → 0, W → 0, Is → 0, Ds → 0} // Eigenvalues
```

Out[•]= $\{-d + r,\ -d - \alpha w,\ -d - \alpha ww,\ -\delta,\ -\mu,\ -\mu - \sigma w,\ -\mu - \sigma ww\}$

Stability of the equilibrium

In[•]:=
```
eigval = Eigenvalues[jacob1 /. {Iww → 0, Iw → 0, Dww → 0, Dw → 0, W → 0, Is → μ/(c ρ),
     Ds → (-k r μ + c (-d + r) ρ)/(c ρ^2), σw → σ, σww → σ, αw → α, αww → α, fww → ϵ fw}];
```

Coefficients

Out[•]= $A3 == c^2\,\rho^7\,(\gamma\,\mu\,\rho - k\,r\,\mu\,(\beta w + \beta ww + 2\,\rho) + c\,\rho\,(-d\,(\beta w + \beta ww) + r\,(\beta w + \beta ww + 2\,\rho) + \rho\,(2\,\alpha + \delta + \mu + \sigma)))$

Out[•]= $A2 == c^4\,\rho^{14}\,\Big(k^2\,r^2\,\mu^2\,(\beta w + \rho)\,(\beta ww + \rho) - k\,r\,\mu\,\rho\,(\gamma\,\mu\,(\beta w + \beta ww + 2\,\rho) + c\,(2\,r\,(\beta w + \rho)\,(\beta ww + \rho) - d\,(\beta ww\,\rho + \beta w\,(2\,\beta ww + \rho)) + \rho\,(\beta w + \beta ww + 2\,\rho)\,(\alpha + \delta + \mu + \sigma))) + c\,\rho^2\,\Big(\gamma\,\mu\,(-d\,(\beta w + \beta ww) + r\,(\beta w + \beta ww + 2\,\rho) + \rho\,(2\,\alpha + \mu + \sigma)) + c\,\Big(d^2\,\beta w\,\beta ww + r^2\,(\beta w + \rho)\,(\beta ww + \rho) + r\,\rho\,(\beta w + \beta ww + 2\,\rho)\,(\alpha + \delta + \mu + \sigma) + \rho^2\,\big(\alpha^2 + \delta\,(\mu + \sigma) + 2\,\alpha\,(\delta + \mu + \sigma)\big) - d\,(r\,\beta ww\,\rho + r\,\beta w\,(2\,\beta ww + \rho) + (\beta w + \beta ww)\,\rho\,(\alpha + \delta + \mu + \sigma))\Big)\Big)\Big)$

In[•]:=
```
Dsfoo = c ρ (r - d) - k r μ;

B4 == 1
```

Out[•]= 1

In[•]:=
```
B3 == ρ^7 (Dsfoo (βw + βww + 2 ρ) + γ μ ρ + c ρ^2 (2 d + 2 α + δ + μ + σ)) // FullSimplify
```

Out[•]= True

In[•]:=
```
B2/ρ^14 == (c ρ^2 (α + δ + μ + σ + d) + γ μ ρ) (βw + βww + 2 ρ) Dsfoo +
   Dsfoo^2 (βw + ρ) (βww + ρ) + c ρ^3 (d γ μ + (d c ρ + γ μ) (2 α + μ + σ + d) +
      d c ρ (2 δ + μ + σ) + ρ c (α^2 + δ (μ + σ) + 2 α (δ + μ + σ))) // FullSimplify
```

Out[•]= True

In[•]:=
```
foo1 = α ρ^2 (α γ μ + 2 (γ μ + c δ ρ) (μ + σ) + c α ρ (δ + μ + σ));
foo2 =
  c ρ^2 (α γ μ + (γ μ + c δ ρ) (μ + σ) + c α ρ (δ + μ + σ)) (Dsfoo (βw + βww + 2 ρ) + d 2 ρ c ρ) +
   (βw + ρ) (βww + ρ) Dsfoo^2 (γ μ + c ρ (δ + μ + σ)) +
   ((βw + βww + 2 ρ) Dsfoo (γ μ + c ρ (δ + μ + σ)) + d c ρ^2 (γ μ + c ρ (δ + μ + σ))) d c ρ^2;
foo3 = ((1 - p) βw + ρ + p (βww + q (ϵ - 1) (βww + ρ)));

B1/ρ^22 == -fw γ μ h c ρ^2 Dsfoo foo3 + c^2 ρ^2 foo1 + foo2 // Simplify
```

Out[•]= True

In[•]:=
```
(1 - p) βw + ρ (1 - p q) + p βww (1 - q) == foo3 /. ϵ → 0 // Simplify
```

Out[•]= True

In[•]:=
```
foo4 = Dsfoo (Dsfoo (1 + p q (ϵ - 1)) (βw + ρ) (βww + ρ) + c ρ^2 (d + α) foo3);
foo5 = (γ μ + c δ ρ) (Dsfoo^2 (βw + ρ) (βww + ρ) +
     c ρ^2 (d + α) Dsfoo (βww + ρ) + Dsfoo (βw + ρ) c ρ^2 (d + α) + c^2 ρ^4 (d + α)^2) (μ + σ);

B0/(c^9 ρ^31) == -fw h γ μ foo4 + foo5 // Simplify
```

Out[•]= True

Condition for basic reproduction

In[•]:=
```
R0 /. func1 /. solSusceptibleFunc1 /. {Iww → 0, Iw → 0, Dww → 0,
    Dw → 0, W → 0, σw → σ, σww → σ, αw → α, αww → α, fww → ϵ fw};
R0func1cond = Reduce[% > 1 && fw > 0 && ϵ > 0 && βw > 0 && βww > 0 && 0 < q < 1 &&
    0 < p < 1 && r > d && r > 0 && d > 0 && c > 0 && ρ > 0 && μ > 0 && γ > 0 &&
    σ > 0 && δ > 0 && α > 0 && k > 0 && c > k r μ/(-d ρ + r ρ) && h > 0 && h ≤ 1];
```

In[•]:= `R0func1cond[[17]][[2]] // FullSimplify`

Out[•]= $$((\gamma\,\mu + c\,\delta\,\rho)\,(k\,r\,\mu\,(\beta w + \rho) - c\,\rho\,(-d\,\beta w + r\,\beta w + (r + \alpha)\,\rho))\,(k\,r\,\mu\,(\beta ww + \rho) - c\,\rho\,(-d\,\beta ww + r\,\beta ww + (r + \alpha)\,\rho))\,(\mu + \sigma))\,/\,(h\,\gamma\,\mu\,(k\,r\,\mu + c\,(d - r)\,\rho)\,(k\,r\,(1 + p\,q\,(-1 + \epsilon))\,\mu\,(\beta w + \rho)\,(\beta ww + \rho) - c\,\rho\,(d\,(-1 + p)\,\beta ww\,\rho + r\,(1 + p\,q\,(-1 + \epsilon))\,(\beta w + \rho)\,(\beta ww + \rho) - d\,\beta w\,(\beta ww + p\,q\,\beta ww\,(-1 + \epsilon) + p\,(1 + q\,(-1 + \epsilon))\,\rho) + \alpha\,\rho\,(\beta w - p\,\beta w + \rho + p\,(\beta ww + q\,\beta ww\,(-1 + \epsilon) + q\,(-1 + \epsilon)\,\rho)))))$$