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5 Appendix: ESS

Recall that the evolutionary stable virulence level will maximize:

$$\frac{\beta(v)}{v - \frac{\ln(k\beta(v))}{T}}$$

By taking the derivative of the above with respect to v, we can find an expression for $\frac{d\beta(v^*)}{dv}$, the slope of the transmission rate as a function of the evolutionary stable virulence level v^*.

$$\frac{d\beta(v^*)}{dv} = \frac{\beta(v^*)}{v^* - \frac{1}{T}\ln(k\beta(v^*)) + \frac{1}{T}}$$

5.1 dv^*/dT

First we rewrite (10) as a function of v and T and we let this function be denoted $R(v, T)$.

$$R(v,T) = \frac{\beta(v)}{v - \frac{\ln(k\beta(v))}{T}}.$$

Let $R_v(v,T) = F(v^*,T)$

$$F(v^*,T) = \frac{\frac{d\beta(v^*)}{dv}(v^* - \frac{1}{T}\ln(k\beta(v^*))) - \beta(v^*)(1 - \frac{1}{T\beta(v^*)}\frac{d\beta(v^*)}{dv})}{(v^* - \frac{1}{T}\ln(k\beta(v^*)))^2}$$

If we differentiate $F(v^*,T)$ with respect to T and then substitute in $\frac{d\beta(v^*)}{dv}$ we get:

$$F_T(v^*,T) = -\frac{\beta(v^*)T(\ln(k\beta(v^*)) - 1)}{(-v^*T + \ln(k\beta(v^*)))^2(-v^*T + \ln(k\beta(v^*)) - 1)} < 0$$

If we differentiate $F(v^*,T)$ with respect to v and then substitute in $\frac{d\beta(v^*)}{dv}$ we get:

$$F_{v^*}(v^*,T) = -T\frac{A+B+C}{D} < 0$$

provided $\frac{d^2\beta}{dv^{*2}} < 0$.

where:

$$A = -\frac{d^2\beta(v^*)}{dv^{*2}}T^3v^{*3} + 3T^2v^{*2}\frac{d^2\beta(v^*)}{dv^{*2}}\ln(k\beta(v^*)) - 3T^2v^{*2}\frac{d^2\beta(v^*)}{dv^*} + \frac{d^2\beta(v^*)}{dv^*}(\ln(k\beta(v^*)))^3 > 0$$

$$B = 6Tv^*\frac{d^2\beta(v^*)}{dv^{*2}}(\ln(k\beta(v^*))) + \beta(v^*)T^2 > 0$$

$$C = -3\frac{d^2\beta(v^*)}{dv^{*2}}(\ln(k\beta(v^*)))^2 - 3\frac{d^2\beta(v^*)}{dv^{*2}}v^*T + 3\frac{d^2\beta(v^*)}{dv^{*2}}\ln(k\beta(v^*)) - \frac{d^2\beta(v^*)}{dv^{*2}} > 0$$

and

$$D = (-v^*T + \ln(k\beta(v^*))))^2(-v^*T + ln(k\beta(v^*)) - 1)^2 > 0$$

Finally if we implicitly differentiate $F(v^*,T) = 0$ with respect to T and treat optimal virulence, v^*, as a function of cohort duration, T, we get:

$$F_{v^*}(v^*,T)\frac{dv^*}{dT} + F_T(v^*,T) = 0$$

From which we have,

$$\frac{dv^*}{dT} = -\frac{F_T(v^*, T)}{F_{v^*}(v^*, T)} < 0$$

5.2 dv^*/dk

Next we rewrite (10) as a function of v and k and we let this function be denoted $S(v, k)$. We let $G(v^*, k) = S_v(v^*, k)$ and treat the optimal virulence level, v^*, as a function of k.

$$G(v^*, k) = S_v(v^*, k) = R_v(v^*, T) = \frac{\frac{d\beta(v^*)}{dv}(v^* - \frac{1}{T}\ln(k\beta(v^*))) - \beta(v^*)(1 - \frac{1}{T\beta(v^*)}\frac{d\beta(v^*)}{dv})}{(v^* - \frac{1}{T}\ln(k\beta(v^*)))^2}$$

and by differentiating $G(v^*, k)$ with respect to k and substituting in $\frac{d\beta(v^*)}{dv}$ we get:

$$G_k(v^*, k) = \frac{\beta(v^*)T^2(k+1)}{k(-v^*kT + k\ln(k\beta(v^*)) - 1)(-v^*T + \ln(k\beta(v^*)))^2} < 0$$

Finally if we implicitly differentiate $G(v^*, T) = 0$ with respect to k and treat optimal virulence, v^*, as a function of cohort duration, k, we get:

$$G_{v^*}(v^*, T)\frac{dv^*}{dk} + G_k(v^*, T) = 0$$

From which we have,

$$\frac{dv^*}{dk} = -\frac{G_k(v^*, k)}{G_{v^*}(v^*, k)} < 0$$