Understanding the economic trade-offs in resistance management

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Focal question

How much should producers spend
to
delay the build up of resistance?

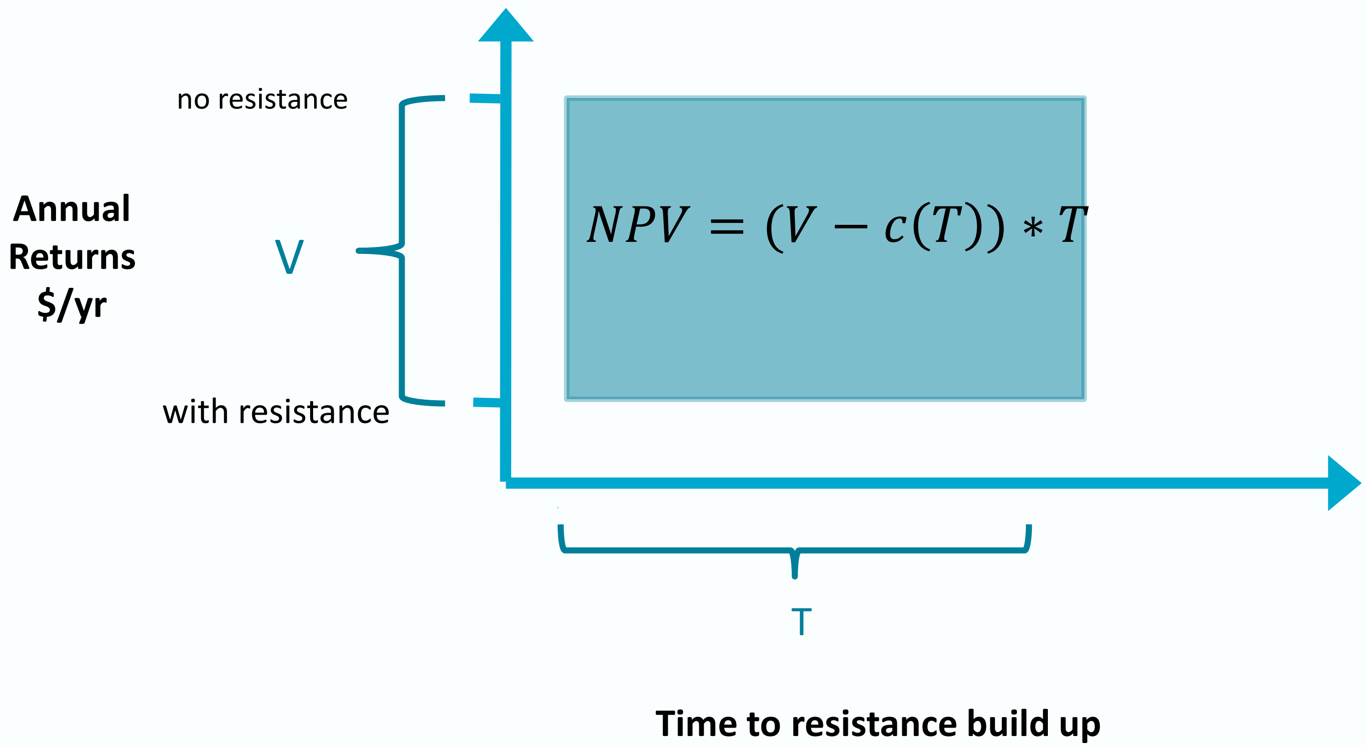
Resistance management presents complex economic trade-offs

- Economic intuition may be too simple and miss important trade-offs

- Optimisation models may mislead
  - black box complex relationships
  - include poorly understood and uncertain relationships

- Need simple models that guide intuition

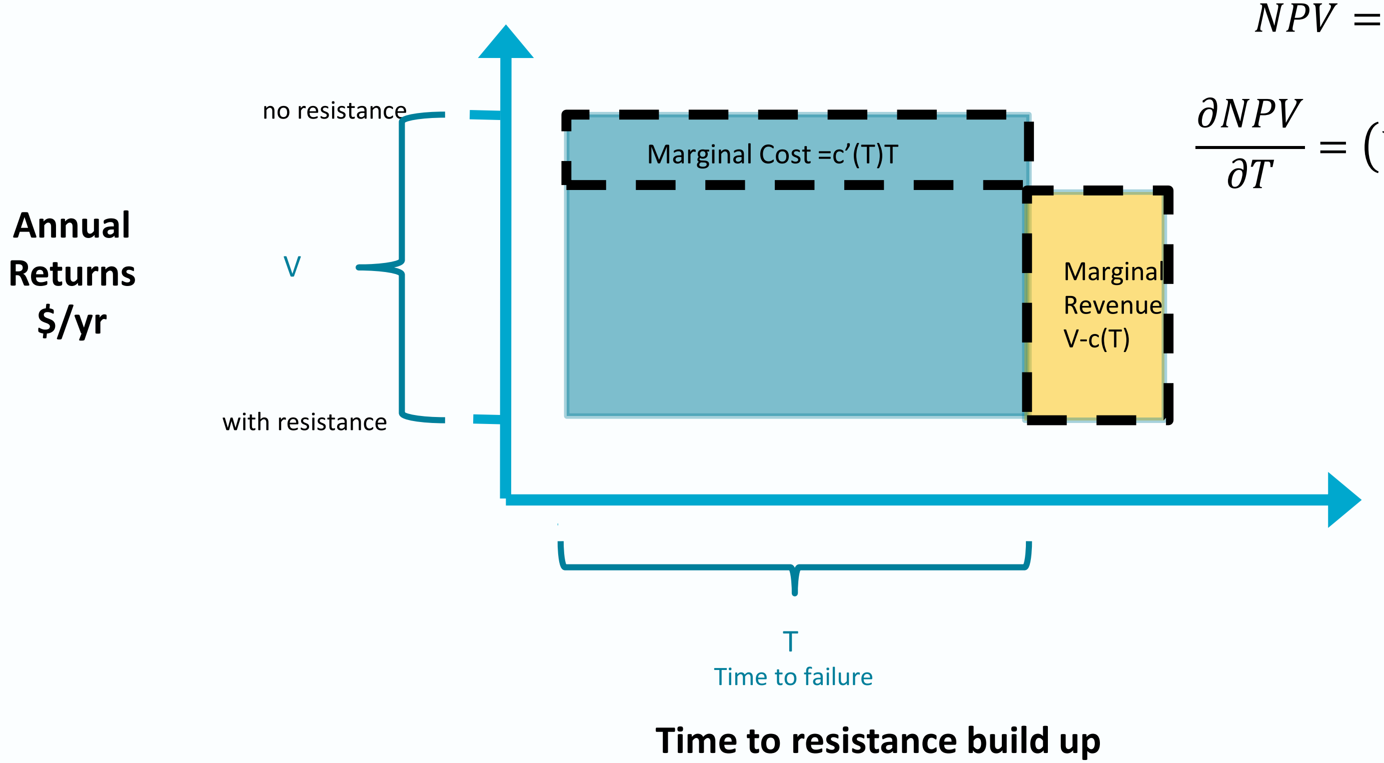
A steady state model of the benefits and costs of a resistance management (RM)



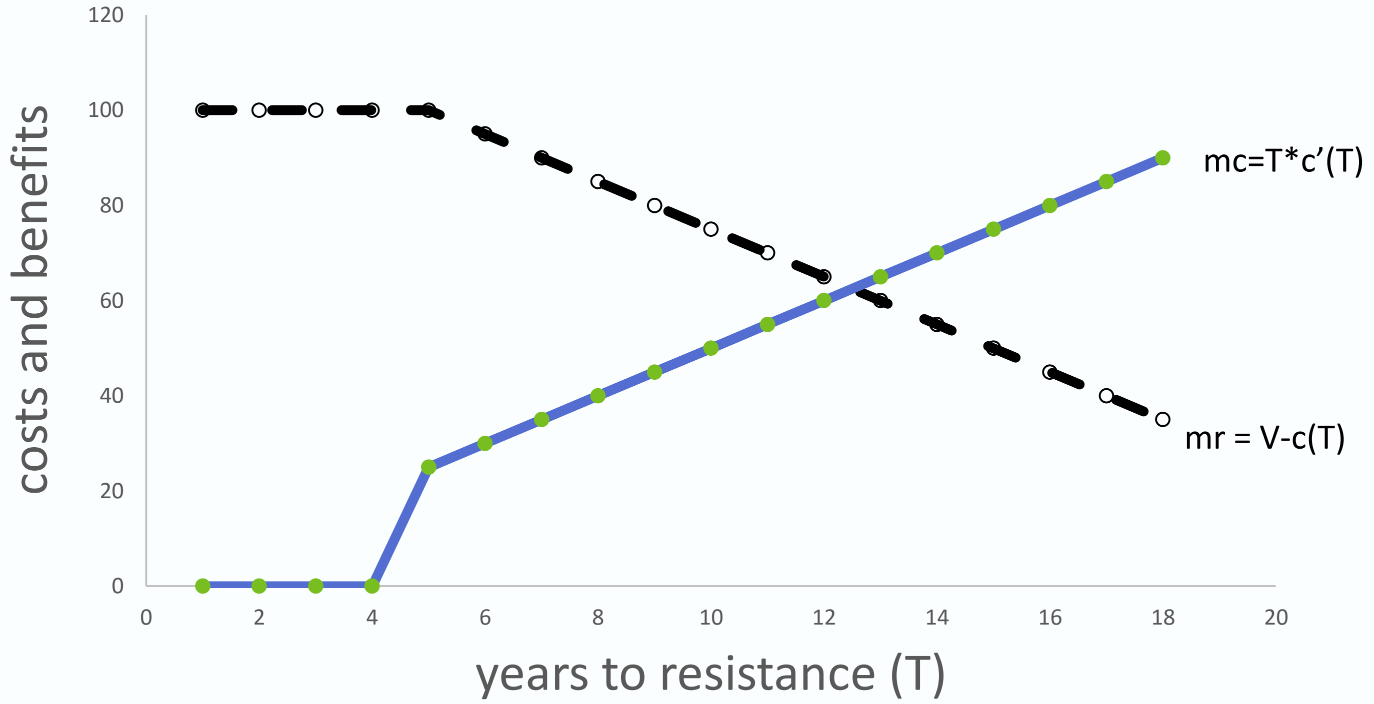
Benefits and costs of a delaying resistance one year

$$NPV = (V - c(T))T$$

$$\frac{\partial NPV}{\partial T} = \big(V - c(T)\big) - c'(T)T$$



Simple economic logic drives the optimal delay time (T)



With c'(T) = a constant (k)

$$c(T) = \left(0, k(T - to)\right)$$

Should we apply more or less RM effort?

MR = MC

$$\left(V - c(T)\right) = c'(T)T$$

Need estimates of:

- V ✓ value of the crop relative to the best option under resistance
- c(T) ✓ the annual cost of resistance management
- T ✓? the expected time to resistance build up
- c'(T) ? the annual cost of delaying resistance an extra year

How to identify all direct and indirect effects of RM on profit in 5 easy steps!

$$NPV(x_h, x_r) = [V - c(x_h, x_r, n_{sus})]T(x_h, x_r, .)$$

1. Specify detailed objective function

$$n_{sus} = n(x_h, x_r)$$

2. Specify steady state functions of intermediate variables

$$x_h = x_h^*(x_r, .)$$

3. Specify other choice variables as a function of resistance management

4. Sub 2&3 into 1 and take derivative with respect to a change in RM

$$\frac{\partial NPV(.)}{\partial x_r} = -T(.)\left[c_1 \frac{\partial x_h}{\partial x_r} + \frac{\partial c^y}{\partial x_h}\frac{\partial x_h}{\partial x_r} + c_2 + \frac{\partial c^y}{\partial x_r} + \frac{\partial c^y}{\partial n}\left(\frac{\partial n}{\partial x_r} + \frac{\partial n}{\partial x_h}\frac{\partial x_h}{\partial x_r}\right)\right]$$
$$+[V - c(.)]\left[\frac{\partial T}{\partial x_h}\frac{\partial x_h}{\partial x_r} + \frac{\partial T}{\partial x_r} + \frac{\partial T}{\partial n}\left(\frac{\partial n}{\partial x_h}\frac{\partial x_h}{\partial x_r} + \frac{\partial n}{\partial x_r}\right)\right]$$

5. This is the complete set of ways in which resistance management affects returns

Example of indirect effects

$$\frac{\partial c^y}{\partial n} \frac{\partial n}{\partial x_h} \frac{\partial x_h}{\partial x_r}$$

Change in optimal herbicide use
With a change in resistance management

Change in weed population
with the change in herbicide use

Change in revenue (yield) due to change in
weed population

Importance of different effects of resistance management on profitability

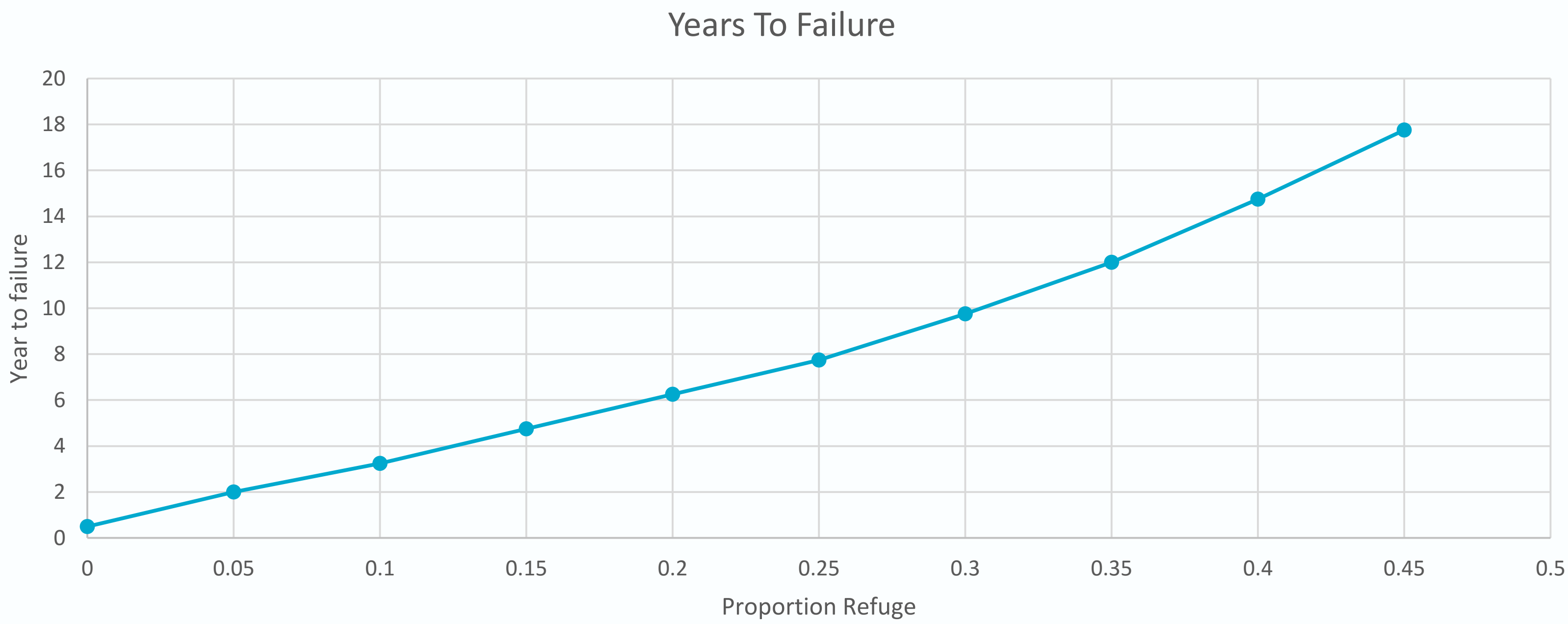
Effect of resistance management (RM)	$\frac{\partial NPV(.)}{\partial x_r} =$	Moth resistance to Bt toxins in Cotton	Ryegrass resistance to herbicides in Wheat
The cost of change in purchases of RM inputs.	$-T(.)c_r$	★★★	★★★
The cost to production from change in RM	$-T(.)\frac{\partial c^y}{\partial x_r}$	★★★	★★
The cost of change in purchases of pest control input with a change in RM	$-T(.)p_1\frac{\partial x_h}{\partial x_r}$		★
The costs to production due to change in pest control inputs with a change in RM	$-T(.)\frac{\partial c^y}{\partial x_h}\frac{\partial x_h}{\partial x_r}$		★
The cost to production due to changes in pest population due to changes in RM	$-T(.)\frac{\partial c^y}{\partial n}\frac{\partial n}{\partial x_r}$		
The cost to production with changes in pest populations due to changes in pest control use made in response to changes in RM	$-T(.)\frac{\partial c^y}{\partial n}\frac{\partial n}{\partial x_h}\frac{\partial x_h}{\partial x_r}$		
The value of delay in time to resistance due to the change in pest control use with RM.	$[1-c(.)]\left[\frac{\partial T}{\partial x_h}\frac{\partial x_h}{\partial x_r}\right]$		
The value of delay in time to resistance due to the direct effect of RM	$[1-c(.)]\left[\frac{\partial T}{\partial x_r}\right]$	★★★	★★★
The value of delay in time to resistance due to RM influencing pest control and therefore pest populations	$[1-c(.)]\left[\frac{\partial T}{\partial n}\frac{\partial n}{\partial x_h}\frac{\partial x_h}{\partial x_r}\right]$		
The value of delay in time to resistance due to the effect of RM on susceptible pest populations	$[1-c(.)]\left[\frac{\partial T}{\partial n}\frac{\partial n}{\partial x_r}\right]$	★	

Criteria for optimal refuge for insect resistance management

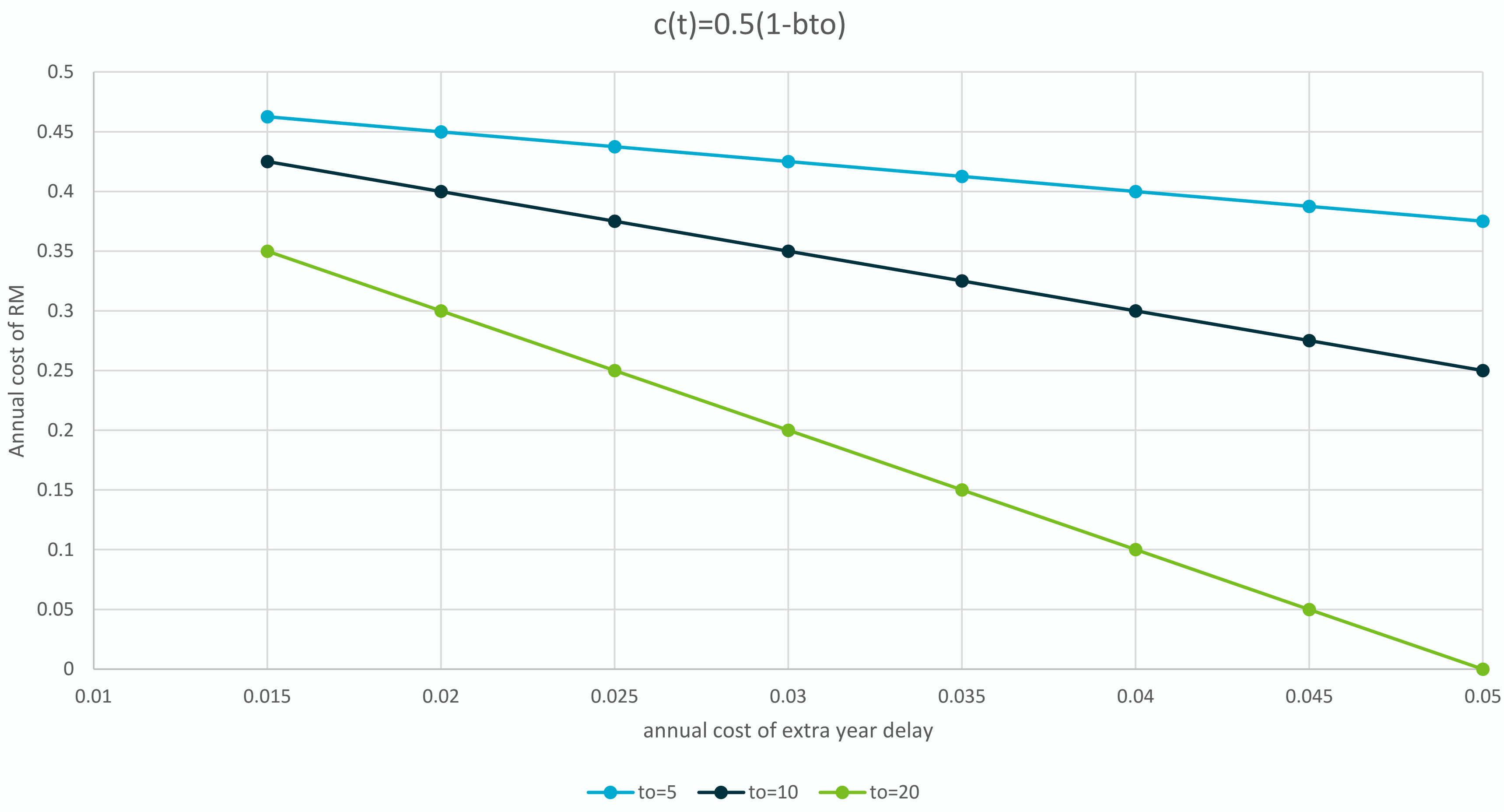
$$[1 - ax] = aT(x)\Delta\bar{x}$$

a	relative cost of refuge
x	proportion of land in refuge
$\Delta\bar{x}$	increase in refuge required to delay resistance one year
T	time to resistance build up

The marginal increase in refuge to delay resistance one year is relatively constant



Optimal annual expenditure on resistance management with linear annual costs c(T)



Optimal control of resistance in weeds

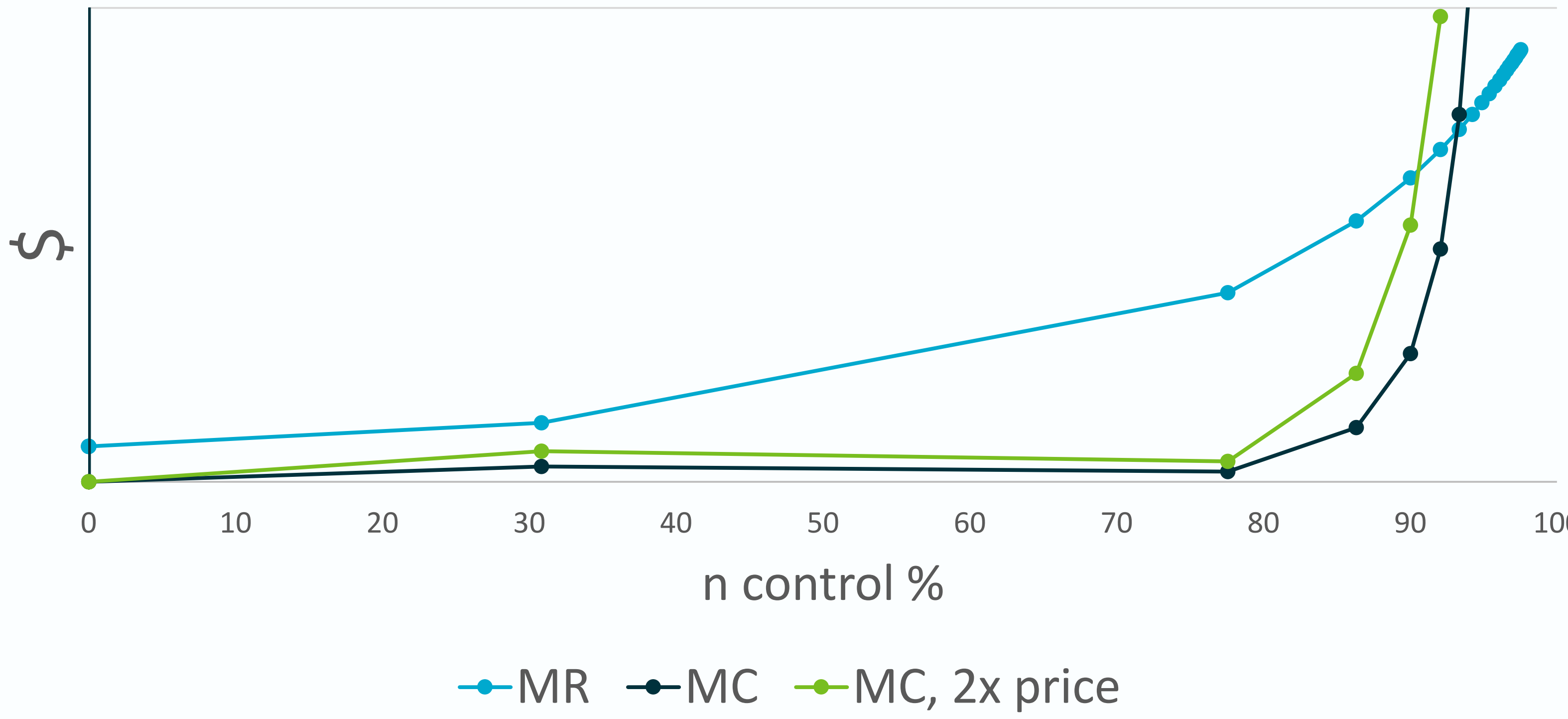
MR = MC

$$[V - c(.)]\left[\frac{\partial T}{\partial x_r}\right] = T(.)\left[c_r + \frac{\partial c^y}{\partial x_r} + \left(c_h + \frac{\partial c^y}{\partial x_h}\right)\frac{\partial x_h}{\partial x_r}\right]$$

Need estimates of:

V	value of the crop relative to the best option under resistance
c(T)	the annual cost of resistance management
$\partial T / \partial x_r$	change in T with an increase in resistance management
T	the expected time to resistance build up
c_r	cost of extra resistance management
c_h	savings from reduced herbicide use
$\frac{\partial c^y}{\partial x_r}, \frac{\partial c^y}{\partial x_h}$	cost of direct yield losses from RM / herbicide
$\frac{\partial x_h}{\partial x_r}$	decrease in herbicide use with increase in RM

Marginal costs and benefits of increasing steady state weed control (no resistance)



Summary

- Modelling the pre-resistance crop as a steady state reduces complexity and revels the economic trade-offs in RM
- Basic economic logic drive an interior solution
- The analysis can be simplified on a case by case basis as appropriate
- The method can be generalised to consider more complexities
  - effect of spray on insect predators or other beneficial insects
- Simplicity enables incorporation into integrated analysis of rotations

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