Irreversibility, Uncertainty, and Dynamic Pest Resistance

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Abstract

The susceptibility of pests to control agents has been viewed by economists as a non-renewable resource, and hence the appearance of pest resistance as an irreversibility. Biologists and entomologists in particular argue that susceptibility to control agents, pesticides in particular, should be viewed as a renewable resource. That is, if pests become resistant to a control agent and consequently the use of the control agent stops, pest resistance breaks down after a while and pests do become susceptible again. The important question within the context of this paper is whether or not an irreversibility effect exists, i.e. timing of using a new control strategy matters – at least at the theoretical level. This paper develops a four period discrete time, discrete model with uncertainties about the benefits of a new technology as well as uncertainty about the time pest resistance will develop and disappear. The results show the irreversibility effect decreases at a decreasing rate with respect to the length of the pest susceptibility and increases at a decreasing rate with respect to the length of pest resistance. Interestingly, the length of third period pest susceptibility can be as important as the length of first period pest susceptibility with important implications for pest management.

JEL: Q16, Q2, Q5

Keywords: irreversibility, pest-resistance dynamics, uncertainty, dynamic optimization

1 Introduction

The susceptibility of pests to control agents has been viewed by economists as a non-renewable resource, and hence the appearance of pest resistance as an irreversibility. Biologists and entomologists in particular argue that susceptibility to control agents, pesticides in particular, should be viewed as a renewable resource. That is, if pests become resistant to a control agent and consequently the use of the control agent stops, pest resistance breaks down after a while and pests do become susceptible again (Ervin et al., 2010). The important question within the context of this paper is whether or not an irreversibility effect exists, i.e. timing of using a new control strategy matters – at least at the theoretical level. To show that an irreversibility effect does indeed exist consider the following hypothetical example for Bt-corn used against damages from the European Corn Borer (ECB). The incremental benefits from adopting Bt-corn are assumed to be 200 at the beginning, year one, and due to price uncertainty increase to either 300 or 100 after one time period and remain at the level till the end of the fourth year. At the end of the fourth year the ECB becomes resistant to Bt-corn and the incremental benefits decrease to zero from year five till the end of year seven. At the end of year seven, the ECB becomes susceptible again to Bt-corn. To keep the example simple, I assume that the incremental benefits increase to 200 Euro until infinity as the ECB will also be susceptible till infinity. The example is illustrated in figure 1. The costs of developing the technology are 1600 units.

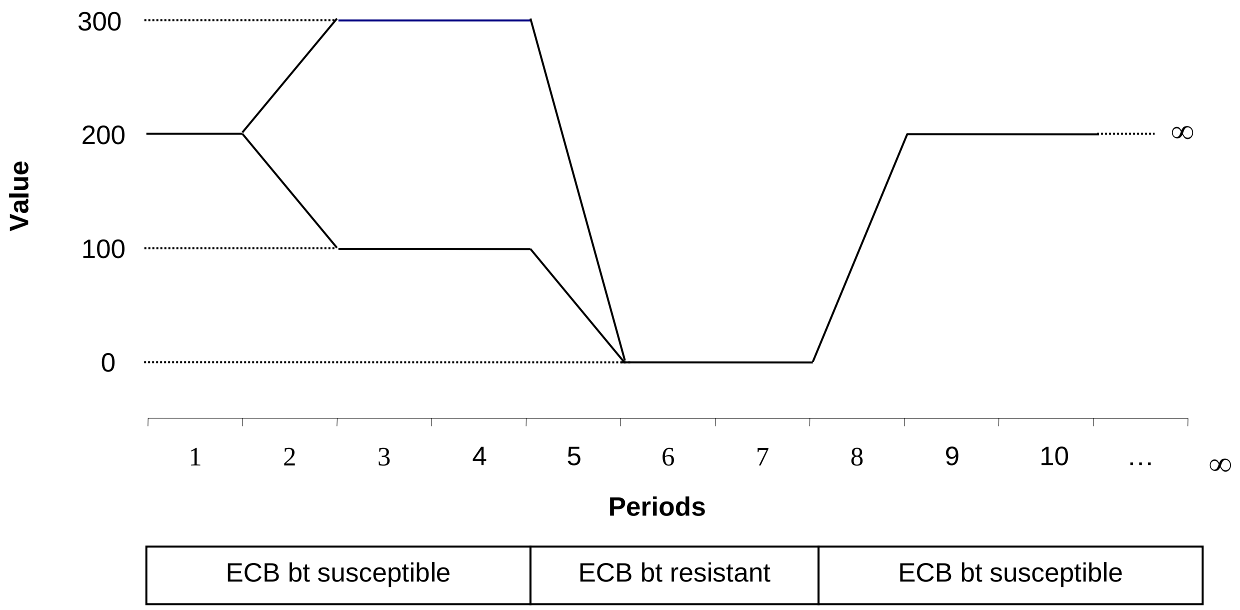

Figure 1: Example for appearance and breakdown of ECB resistance to Bt-toxin.

The value of from immediate adoption is:

$$\mathrm{E}[\mathrm{NPV}_{\mathrm{now}}] = -1600 + 200 + 0.5\sum_{\mathrm{t}=1}^{4} 300/1.1^{\mathrm{t}} + 0.5\sum_{\mathrm{t}=1}^{4} 100/1.1^{\mathrm{t}} + \sum_{\mathrm{t}=8}^{\infty} 200/1.1^{\mathrm{t}}=260.29$$

The result for a postponed adoption is:

$$E[NPV_{later}] = -\frac{1600}{1.1} + \sum_{t=1}^{4} 300/1.1^{t} \sum_{t=1}^{4} + \sum_{t=8}^{\infty} 200/1.1^{t} = 377.28$$

The above example illustrates that even though pest resistance can be reversible from a biological point of view, from an economic point of view an irreversibility effect exists. For the developer of the technology it is more economical to not introduce the new technology immediately but to postpone this by one year and wait and see and only introduce the technology if the benefits are high.

The numerical example has been used to illustrate the existence of an irreversibility effect. Such kind of effects are well known in the literature (Arrow and Fisher, 1974; Henry, 1974; Dixit and Pindyck, 1994). Obviously, the development of pest resistance follows a dynamic process (Gilligan, 2003). Pests can become resistant to specific control methods, but if the control strategy changes they may become susceptible again (Ervin et al., 2010). The time of length of pest susceptibility as well as resistance can be considered to be uncertain as well as the costs and benefits of control strategies. These dynamics and uncertainties result in two interesting questions. First, if dynamic entries and exits are present, under what conditions does an irreversibility effect exist? Second, if dynamic entries and exits are present, does the length of the period of susceptibility as well as the length of resistance matter for pest management? Or more precisely: does third period pest susceptibility matter for the management of first period susceptibility?

In this paper I develop a model that includes uncertainty about the benefits of the pest control strategy as well the points in time when resistance starts and disappears. Numerical results show that under this kind of model set-up third period pest control benefits can be economically as important as first period benefits and has some important implications for pest management.

The paper is structures as follows. In the second section the model set-up will be presented. The third section illustrates the implication of the model by using a numerical example. Section four discusses the implications of the results and concludes.

2 The Model

A new pesticide control strategy is available and generates known instantaneous net-benefits, B_S. Future annual net-benefits can be either high, $B_{u,t}$, with probability q or low, $B_{d,t}$, but positive with probability (1-

q). Future annual net-benefits will not stay positive forever. Over time the net-benefits will decline until at one point in time in the future, κ_1, which is uncertain from today's perspective, pests have become resistant and using the new control technology does not pay anymore. When pests have become resistant the control technology will be abandoned. The pest will stay resistant over an uncertain period of time until they become susceptible again at κ_2, for a period of κ_3. From there onwards the assumption is the technology would not be further used.

The points in time when critical values of resistance and susceptibility will be reached as already mentioned are uncertain and follow an exponential failure distribution: $f(\kappa) = he^{-h\kappa}$, $F(\kappa) = \int_0^{\kappa} he^{-h\kappa}\, d\kappa = 1 - e^{-h\kappa}$ and $E(\kappa) = {}^{1}/_{h}$, $Var(\kappa) = {}^{1}/_{h^2}$, $m(\kappa) = \frac{ln(2)}{h}$, $StdD = |E[\kappa] - m[\kappa]| = \frac{1-ln(2)}{h} < \frac{1}{h}$.

The assumptions about future benefits are simplifying assumption to keep the model tractable, but they are not as restrictive as they might appear as they can be interpreted as the average annual benefits (e.g. Wesseler et al., 2017 for more details). One might also consider to model the annual benefits as a Brownian bridge, but this would not allow to derive analytical solutions and would complicate the interpretations of the results. I leave such kind of model modification for future research.

Using this specification the present-value of the new control technology $V(I, B_i, \kappa_j, q, \mu)$ using the discount rate μ, the subscript $i = s, u, d$, subscript $j = 1,2,3$, and I for the irreversible investment costs:

$V(I, B_i, \kappa_j, q, \mu) = -I + B_s +$

$$q\left(\int_0^\infty\left[\int_0^\infty\left[\int_0^\infty\left(\int_0^{\kappa_1}(B_{u,t})e^{-\mu t}dt+\int_{\kappa_1+\kappa_2}^{\kappa_1+\kappa_2+\kappa_3}(B_{u,t})e^{-\mu t}dt\right)f(\kappa_1)d\kappa_1\right]f(\kappa_2)d\kappa_2\right]f(\kappa_3)d\kappa_3\right)e^{-\mu}+$$

$$(1-q)\left(\int_0^\infty\left[\int_0^\infty\left[\int_0^\infty\left(\int_0^{\kappa_1}(B_{d,t})e^{-\mu t}dt+\int_{\kappa_1+\kappa_2}^{\kappa_1+\kappa_2+\kappa_3}(B_{d,t})e^{-\mu t}dt\right)f(\kappa_1)d\kappa_1\right]f(\kappa_2)d\kappa_2\right]f(\kappa_3)d\kappa_3\right)e^{-\mu}$$

(1)

This can be simplified:

$$V(I,B_i,\kappa_j,q)=-I+B_s+(q(B_u-B_d)+B_d)He^{-\mu} \quad (2)$$

with $H=\left(\frac{(\mu+h_2)(\mu+h_3)+h_1h_2}{(\mu+h_1)(\mu+h_2)(\mu+h_3)}\right)$

Postponing the introduction by one year and assuming that $V_P\left(I,B_s,\ B_d,\kappa_j,(1-q)\right)<0$ as otherwise it would always be optimal to introduce the new technology immediately, yields:

$V_P(I,B_i,\kappa_j,q)=$

$$q\left[-Ie^{-\mu}+\left(\int_0^\infty\left[\int_0^\infty\left[\int_0^\infty\left(\int_0^{\kappa_1}(B_{u,t})e^{-\mu t}dt\right.\right.\right.\right.\right.$$

$$\left.\left.\left.\left.\left.+\int_{\kappa_1+\kappa_2}^{\kappa_1+\kappa_2+\kappa_3}(B_{u,t})e^{-\mu t}dt\right)f(\kappa_1)d\kappa_1\right]f(\kappa_2)d\kappa_2\right]f(\kappa_3)d\kappa_3\right)e^{-\mu}\right]$$

(3)

and can be simplified to

$$V_P(I,B_i,\kappa_j,q)=q(-I+B_uH)e^{-\mu}. \quad (4)$$

An irreversibility effect will be present, if

$$V_P(I, B_i, \kappa_j, q) - V(I, B_i, \kappa_j, q) = q(-I + B_u H)e^{-\mu} - (-I + B_s + (q(B_u - B_d) + B_d)He^{-\mu}) > 0$$

$$=> I > \frac{B_s + (1-q)B_d He^{-\mu}}{1 - qe^{-\mu}} = \frac{B_s + (1-q)B_d H}{1 - qe^{-\mu}}$$

(5)

The result in Eq. 5 shows that if the irreversible investment costs for developing the new technology are larger the right-hand-side postponing the introduction of the new technology is economical. The larger the right-hand-side will be the larger the irreversible investment costs need to be for a delay to be economical. In the context of the paper I call this the irreversibility effect. The irreversibility effect increases if the right-hand-side decreases as a decreasing amount of investment costs justifies immediate investment.

Numerical Example

Assessing the economic properties Eq. 5 will be done by using a numerical example. The parameter values are chosen to be in line with recent experiences related to the introduction of pest resistant crops such as maize resistant to lepidopteran pests.

Table 1. Parameter Values Used for the Numerical Example.

Parameter	Value
B_s	200
B_d	100
q	0.5
Discount rate (μ)	0.10
h_1, h_2, h_3 (one to twenty years)	1.0 to 0.05

Scenario 1. The first scenario illustrates the effect of different length of time of pest resistance on the irreversibility effect depending on the length of pest susceptibility in the first period. For this scenario the third period length of pest susceptibility has been set to an expected value of ten years. The results presented in Fig. 1 show that the threshold level increases with an increase in the time length at a decreasing rate. This result can be easily verified by deriving the first and second derivative of equation 5with respect to h_1. What the results in Fig. 1 also show is that the length of pest resistance matters less and less the longer the first time period of pest resistance.

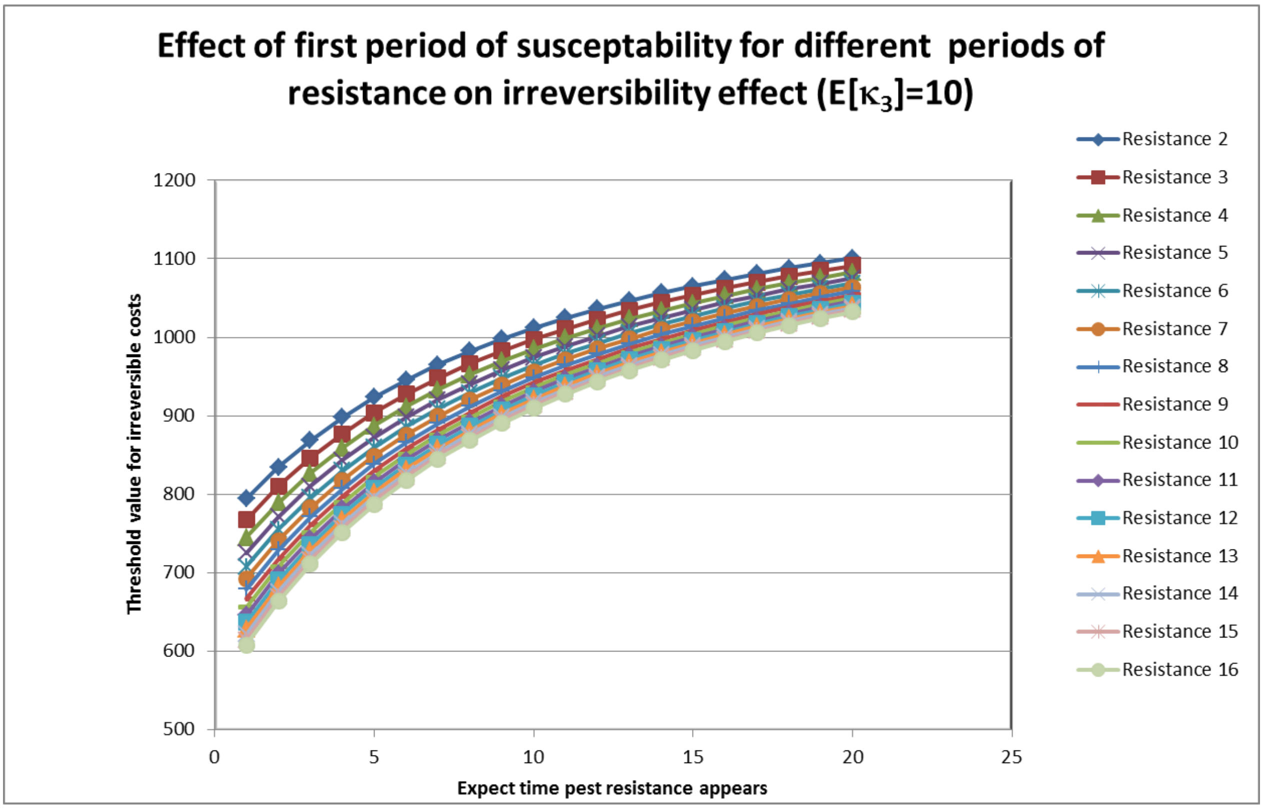

Figure 1. Effect of first period of susceptability for different periods of resistance on irreversibility effect (E[κ_3]=10)

Scenario 2. In the second scenario the effect of differences in length of pest resistance for different first period length of pest susceptibility has been modelled. The result are presented in Fig. 2. They show that the irreversibility effect increases at a decreasing rate with an increase in the time length of pest resistance. The effect is stronger the longer the first period length of pest susceptibility and the marginal effect of a one year difference also decreases.

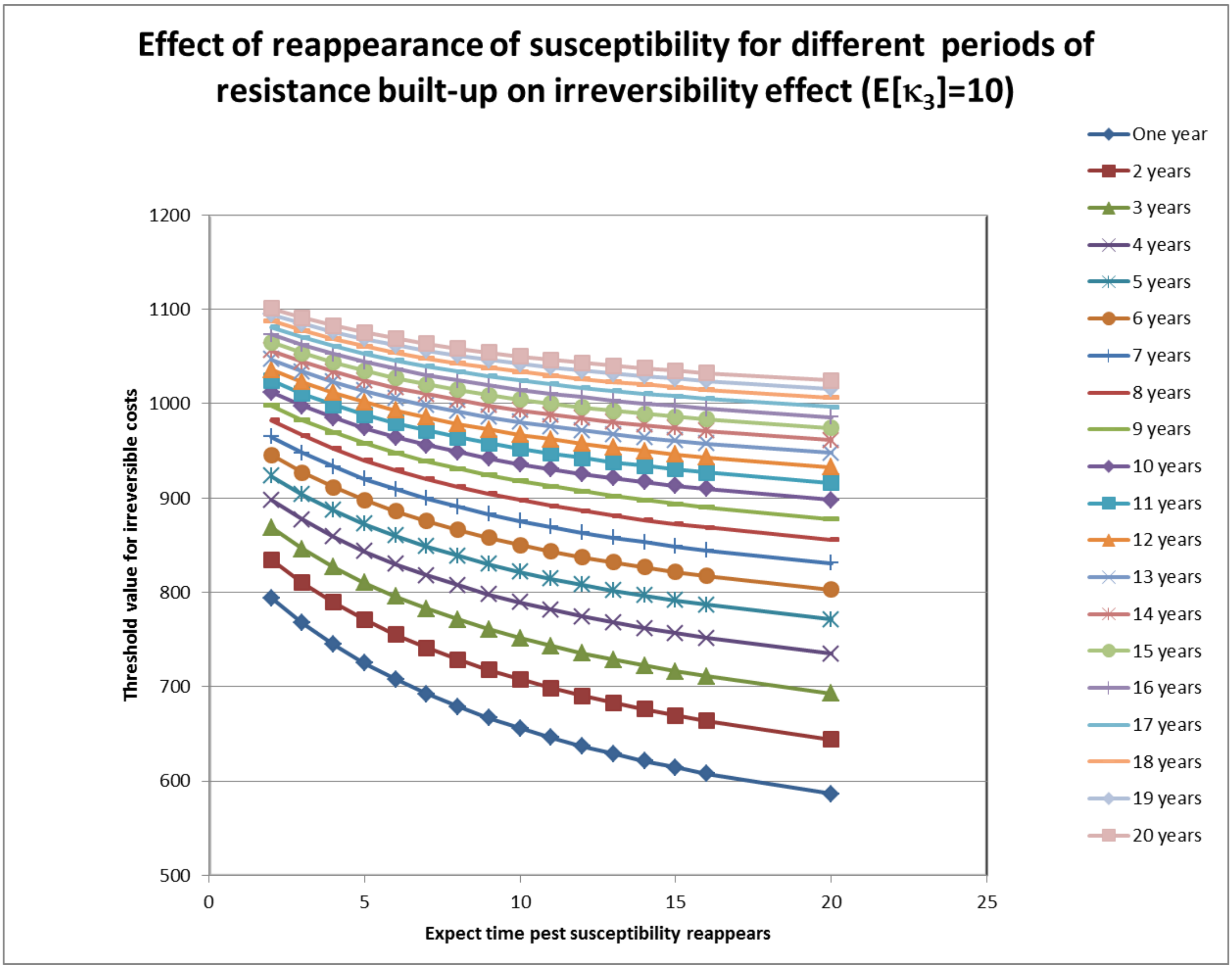

Figure 2. Effect of reappearance of susceptibility for different periods of resistance built-up on irreversibility effect (E[κ_3]=10)

Scenario 3. In the third scenario the effects of changes in the length of the third period susceptibility on the irreversibility effect are modelled for different lengths of pest resistance are modelled. In his scenario the expected length of first period susceptibility is fixed to ten years. The results are presented in Fig. 3. They show that the irreversibility effect decreases at a decreasing rate with an increase in the length of third period pest susceptibility . Further, the effect decreases with an increase in the length of second period pest resistance.

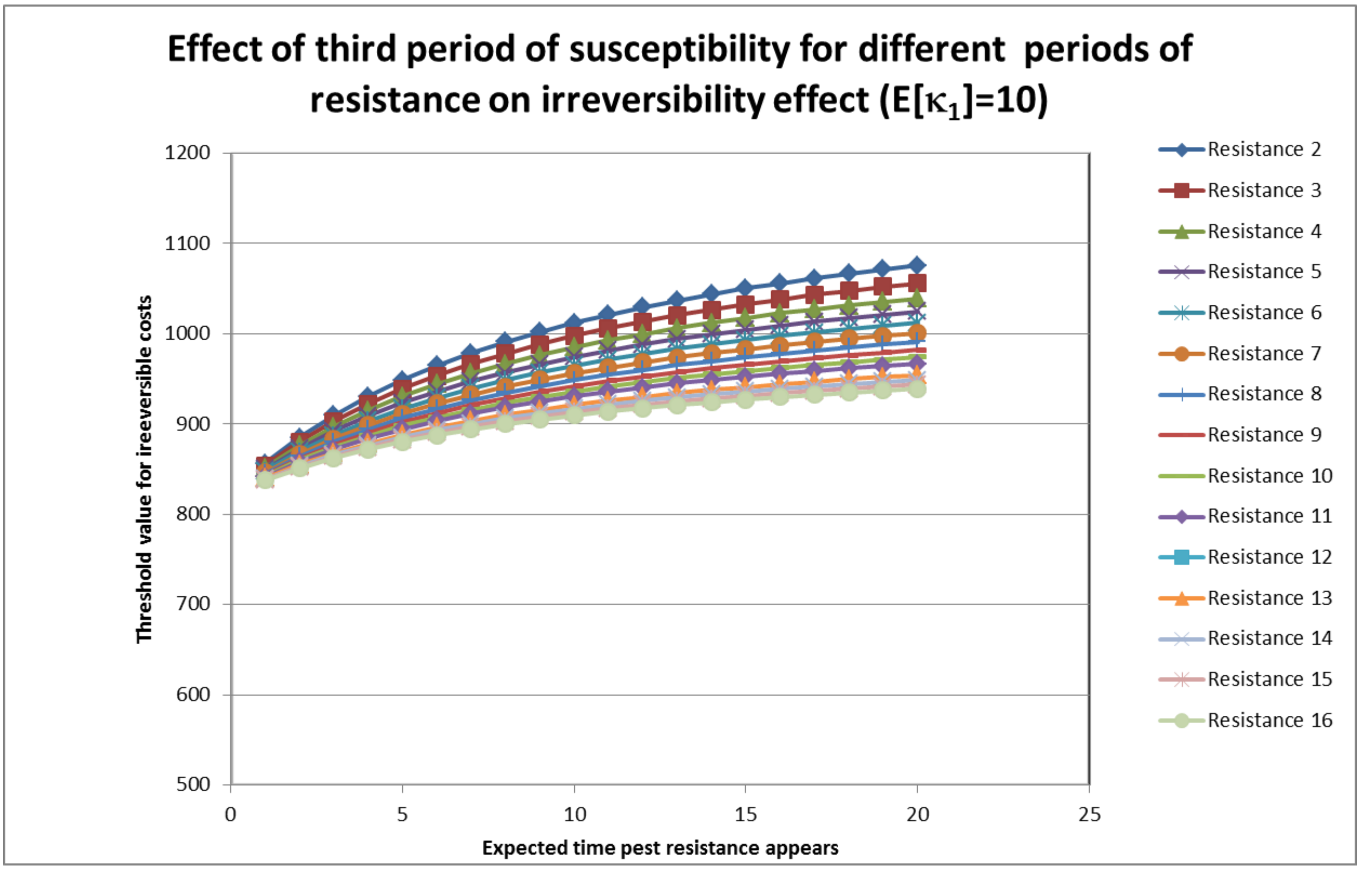

Figure 3. Effect of third period of susceptibility for different periods of resistance on irreversibility effect (E[κ_1]=10)

The results presented in Fig. 1 to Fig. 2 provide already some interesting insights into the irreversibility effect. The most interesting is to compare the results presented in Fig. 1 and Fig. 3. They allow to compare the effect of the length of the first period and the third period susceptibility for different lengths of pest resistance on the irreversibility effect. The results are presented in Fig. 4.

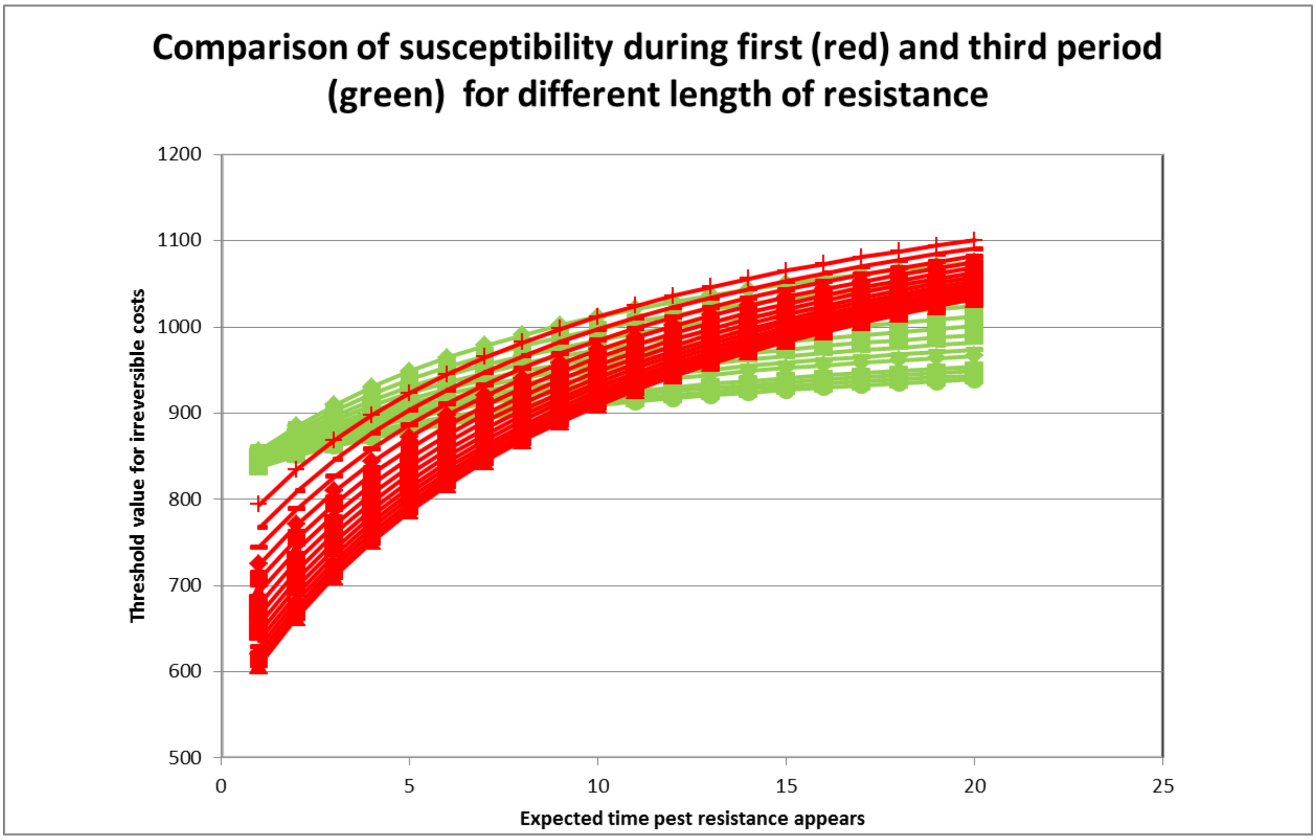

Figure 4. Comparison of susceptibility during first (red) and third period (green) for different length of resistance

The surprising result presented in Fig. 4 is that there is a substantial overlap between scenario 1 and scenario 3.

4 Discussion and Conclusions

The results of the mathematical model as well as the numerical example show that an irreversibility effect is present, but that the magnitude of the effect depends on the downside risk. The larger the net-benefits are in case they are lower the less the irreversibility effect will be. This is not surprising and has be shown in the literature on real options. The implications with respect to new technologies for pest management are that technologies for crops where this effect is smaller, ceteris paribus, will receive more attention than other strategies.

The irreversibility effect increases at a decreasing rate with respect to κ_1 and κ_3. Technologies where the development of pest resistance is less likely to happen soon provide stronger economic incentives to be developed than others. Pest management strategies that delay the appearance of pest resistance built-up and are not born by the provider of the technology provide stronger incentives for developing new pest management strategies. Further, private sector companies that develop new pest control technologies have an economic incentive to delay the appearance of pest resistance and delaying resistance development by one more year pays more if resistance is expected to build-up quickly.

The reappearance of susceptibility and its length matters and can be as important as first period susceptibility from an economic point of view. This implies pest control technologies that have been successful are still of value in the case pest resistance disappears. The length of resistance increases the irreversibility effect at a decreasing rate. Hence, reducing pest resistance built -up as well as reducing the length of susceptibility built-up pays and has an effect on the investment in pest control technologies. Similarly, pest resistance built-up as well as well pest susceptibility built-up are both economically important and require almost the same amount of attention if the time length is similar. In specific cases one (resistance built-up) or the other (susceptibility built-up) may be more important and depends on the biology of pest resistance and its control possibilities. The model presented allows to assess these effects and would be worth to apply on case study level to get more information about the magnitude of the effects (economic relevance).

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