Improving honey bee health: Proposed changes to managing and controlling pests and diseases

Prioritisation exercise – method and results

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Scope and objectives

1. This exercise was carried out as one of several activities informing the review of pest and disease control policy. Its objectives were to assess the relative economic importance of the principal pest and disease risks to honeybees and examine the potential impacts of three alternative policy options for the future management of bee pests and diseases. It was required to conduct the exercise within a limited time period, using expertise available from the Review Group, and to conduct and document the analysis in a systematic and transparent way, taking account of the uncertainties that are inevitably associated with an assessment of this type.

2. It was decided to focus the evaluation on the year 2020, and restrict its geographical scope to England and Wales.

3. It was decided to consider the following categories of pest and disease:

- Endemic pests and diseases
  - *Varroa*
  - *Nosema*
  - European Foulbrood (EFB)
  - American Foulbrood (AFB)
  - Other endemic pests and diseases (considered together)
- Exotic pests and diseases
  - CCD (Colony Collapse Disorder)
  - Asian hornet
  - Small Hive Beetle (SHB)
  - *Tropilaelaps*
  - Other known exotics (considered together)
  - Currently unknown exotics (considered together)

4. It was decided to assess three policy options for the management of bee pests and diseases:

- Baseline – current policies continue
- Do minimum – do the minimum consistent with EU requirements
- Preferred option – developed by the Review Group

The three options are described in detail in the main consultation document.

Methods

5. The methodology was developed and agreed in consultation with the Review Group. The principal features of the methodology were:

- A simple model for estimating the costs of bee diseases, based on the probability the disease is present, the proportion of colonies affected, and the average cost per affected colony.
- A procedure for elicitation of estimates of these parameters from the Review Group, including beekeeper representatives, bee inspectors, bee scientists and bee health policy staff, based on their expert knowledge and evidence available to them.
- Statistical methods for using the elicited estimates of the individual parameters to generate estimates of the total cost per disease, and of the difference in cost between pairs of policy options.
- Interpretation of the results by the Review Group.

Model for estimating cost of bee pests and diseases

6. The total cost for each category of bee pest and disease in the year 2020 was estimated using the following model:

$$\text{Cost} = p_{present} \times p_{infected} \times (\text{Loss}_{BK} \times \text{Value}_{BK} + \text{Loss}_{AGR} \times \text{Value}_{AGR})$$

where:

$\mathbf{p_{present}}$ = Probability of the pest or disease being present in 2020 (for endemic pests and diseases this was set to 1).

$\mathbf{p_{infected}}$ = Proportion of colonies in England and Wales infected/affected by the pest or disease in 2020, *if* it is present in that year.

Loss_{BK} = Average loss to the beekeeper[1] per colony infected with disease *d* in 2020, expressed as a proportion of the cost of total loss of the colony (averaged over destroyed colonies, treated colonies and colonies infected but not treated, including those where the disease is not detected).

$\mathbf{Value_{BK}}$ = Total cost to beekeepers in 2020 if *all* colonies in England and Wales were lost (£ at 2012 prices).

$\mathbf{Loss_{AGR}}$ = Average loss to agriculture per colony infected with disease *d* in 2020, expressed as a proportion of the cost of total loss of the colony (averaged over destroyed colonies, treated colonies and colonies infected but not treated, including those where the disease is not detected).

[1] Throughout this document, the term ‘Beekeeper’ is used in the broad sense to include all persons who keep bees, whether on an amateur or professional basis, including ‘bee farmers’.

$Value_{AGR}$ = Total cost to agriculture in 2020 if *all* colonies in England and Wales were lost (£ at 2012 prices).

7. The model was constructed with these parameters because the Review Group were able to estimate them based on their expert knowledge and evidence available to them. It was not possible within the scope of this exercise to model the factors influencing change in the model parameters, or to estimate annual changes over the period up to 2020 over time. Instead, the model parameters were estimated using the expert judgement of the Review Group. This model is not intended as a substitute for a more detailed analysis. Rather, the aim is to provide more reliable estimates, within the time and resources available, than could be obtained by a less structured approach to the use of expert judgement.

8. The cost estimated produced by the model is the 'expected value': the potential cost of each disease (if it occurs) is multiplied by the probability of that disease occurring. If a disease was not present in 2020 then its cost would be zero.

9. It is important to note that:

- costs for 2020 were estimated using 2012 prices without discounting, and represent a projected snapshot. **They should not be interpreted as a formal economic appraisal.**
- the assessment does not consider pollination services to non-agricultural plants (and some excluded crops) and also consequential costs e.g. dependence of English cider industry on pollination by honeybee, and is therefore expected to underestimate actual costs.

Elicitation of model parameters

10. A structured procedure was used to elicit estimates for the model parameters from the Review Group, based on their expert knowledge and evidence available to them. The Review Group included beekeeper representatives, bee inspectors, bee scientists, bee health policy staff, an economist and an independent scientist.(See consultation document for more details).

11. The elicitation was conducted in a series of meetings, some with the Review Group as a whole and, due to the constraints of the review timetable and availability of participants, some meetings with only the Fera members of the Review Group:

- Initial Fera meeting to discuss the approach
- One day Review Group meeting to elicit estimates for the baseline policy option (ie, no change to current policies)
- A half day Fera meeting to refine the estimates for the baseline policy option
- Two day Review Group meeting to review the revised estimates for the baseline option (circulated in advance), to discuss dependencies between the parameters, and to elicit estimates for the do minimum option and for some diseases under the preferred option
- A half day Fera meeting to complete the estimates for the preferred option

- Two small Fera sub-meetings to discuss alternative estimates for EFB and AFB under the preferred option.

12. Draft results and interpretation were presented and discussed during a further meeting of the Review Group.

13. The elicitation procedure was designed and facilitated by A Hart. The general procedure was as follows:

- For each policy option (except baseline/no change to policies):
    - Initial group discussion to ensure a common understanding of what that policy entailed, and its implications for the operations and behaviour of the parties involved in managing bee pests and diseases including beekeepers, beekeeper associations, bee inspectors, the National Bee Unit.
- For each disease:
    - Initial discussion of how the disease might develop under the policy option
- For each parameter for the disease:
    - For the baseline option (i.e., no change to current policies):
        - Discussion of historical evidence concerning that parameter in England and Wales (including numerical results from surveys and specialist knowledge of the participants)
        - Discussion of factors that would influence the value of that parameter for England and Wales in 2020 if current policies continue
        - Elicitation of initial estimates for lower (minimum plausible), upper (maximum plausible) and most likely values for that parameter
        - Discussion and adjustment of the initial estimates to arrive at a group consensus
    - For the do minimum and preferred options:
        - Review of the parameter estimates for the baseline option
        - Discussion of factors that would influence whether and how that parameter might change in the policy option being considered
        - Discussion of evidence from the past or other countries on the value of the parameter under conditions similar to the policy option being considered
        - If the group considered the parameter would change from the baseline, elicitation of initial estimates for lower (minimum plausible), upper (maximum plausible) and most likely values for that parameter
        - Discussion and adjustment of the initial estimates to arrive at a group consensus

14. The estimates elicited by this procedure are necessarily uncertain due both to limitations of current science and to the limitations of time and resources available for the prioritisation exercise. The elicitation of minimum and maximum estimates for each parameter as well as the most likely was designed to take account of this uncertainty. The facilitator encouraged the participants to identify and discuss sources of uncertainty, and to consider them when making their estimates. The facilitator explained that there is a general tendency to over-confidence in expert judgements and periodically reminded the group to consider whether their ranges were wide enough. The facilitator encouraged discussion of apparent differences of opinion between participants: this resulted in the group agreeing on a common view in all cases except with regard to the estimates for EFB and AFB under the preferred option, where two alternative sets of estimates were provided (see Results).

15. During the two-day meeting, one hour was focussed on discussing the potential for dependencies between the parameters under the baseline option, and for some parameters the group described expected dependencies in broad terms (positive, negative, independent). In addition, the potential for dependencies between the impacts of the same management option on different diseases and dependencies between impacts of different management options on the same disease were briefly discussed at other points in the meetings. There were also two brief discussions regarding the general shape of the distributions for the parameters, i.e. how the likelihood of different values varied over the range from the most likely to the minimum on one side and the maximum on the other.

16. The parameter estimates were recorded in a spreadsheet that was displayed on screen during each elicitation session, and circulated for review between sessions. The evidence and discussions relating to each estimate were recorded in 3 ways: on flip charts, by adding comment fields in the spreadsheet displayed on screen, and by taking minutes. These three sources were combined to produce an overall record of the rationale for the estimates – these are set out in Annex 1 of this document. Copies of the overall record were circulated to all members of the Review Group with an invitation to comment before the final meeting.

Statistical analysis

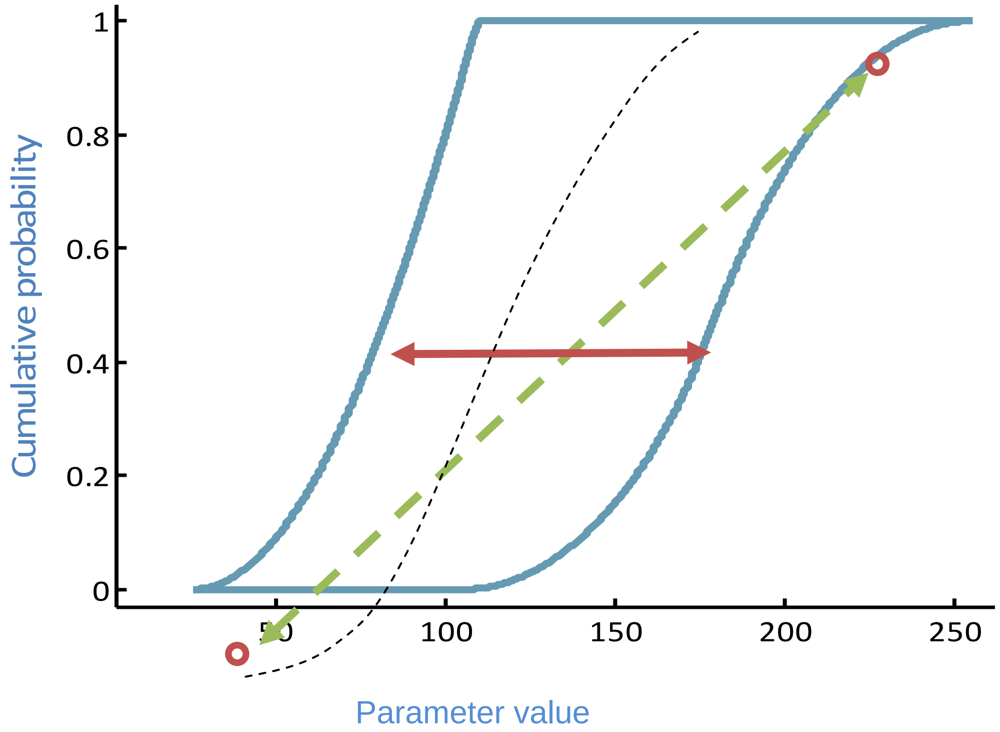
17. Simple calculations of the cost of each disease using the estimated values would be misleading. For example, using the most likely value for every parameter does not necessarily give the most likely value for the cost: this depends on the shape of the distribution for each parameter and the dependencies between parameters. If the most likely values are used to calculate differences in cost between management options, for some diseases the result lies outside the range of differences obtained when the minimum and most likely values are used. Therefore, statistical methods are needed to carry (propagate) the uncertainty represented by the minimum, maximum and most likely estimates through the model calculation to estimate the cost for each disease.

18. The statistical method chosen for the calculation uses probability boxes (p-boxes, Ferson et al. 2003, Tucker and Ferson 2003). P-boxes were chosen because they allow calculations using the estimates provided by the Review Group (minimum, maximum and

most likely values together with limited qualitative information on dependencies and distribution shapes) without the need to make additional assumptions, and hence avoid overstating the certainty of the results. An example of a p-box is shown graphically in Figure 1: a p-box encloses all cumulative probability distributions that are consistent with the information provided about a parameter.

19. The output of the model calculations is a p-box that encloses all distributions for the estimated cost that are consistent with the information provided about all the parameters and the dependencies between them. Figure 1 also illustrates how the p-box for the estimated cost was used to generate numerical results for summarising the results of the calculation: a range for the median estimate of the cost (50^{th} percentile), accompanied by lower and upper bound for the 95% probability interval.

Figure 1. Example of a probability box (p-box), the method used for calculations of disease cost using the parameter estimates elicited from the Review Group. The p-box (blue line) encloses all cumulative probability distributions that are consistent with the information provided about the parameter. The dashed curve shows one example of such a distribution. The horizontal arrow shows the range for the median (50^{th} percentile), and the diagonal arrow joins the lower and upper bound for the 95% probability interval.



20. Where more information can be provided about the distribution for a parameter, such as the distribution shape or estimates for specified quantiles, this reduces the variety of cumulative distributions that are consistent with that information and hence the p-box for the parameter will tend to be narrower. Due to the restricted time available for elicitation, the Review Group were not asked to consider the shape of distribution parameter by

parameter. Instead, they were engaged in a discussion about their general expectations regarding the distribution of values between their most likely estimates and their minimum or maximum estimates. Based on their response (see results), some of the calculations used p-boxes that enveloped uniform and triangular distributions based on the elicited values.

21. Similarly, where more information can be provided about the dependencies between parameters, this will provide narrower p-boxes for estimated cost than if no knowledge of dependencies is assumed. Simple assumptions about dependencies between some parameters were included in some of the calculations (where indicated in the results section), taking account of the limited information on dependencies provided by the Review Group. The options considered were unknown dependency (positive or negative), unknown positive dependency, perfect positive dependency, and complete independence.

22. The p-box calculations were used to generate estimates for the following outputs:

- Total of costs to beekeepers and agriculture if *all* colonies in England and Wales were lost
- Cost in 2020 under each policy option, estimated separately for each disease
- Difference in 2020 costs between policy options, estimated separately for each disease
- Total cost difference between policy options.

23. When writing the equations for the calculations, care was taken to avoid the same parameter appearing twice as this would result in its uncertainty being represented twice. When calculating differences in costs between policy options, the equations could be written in more than one way for some diseases. In such cases, the intersection between the p-boxes for the two versions of the calculation was taken, so that only distributions that satisfied them both would be included in the final p-box.

Interpretation of quantitative results

24. Results from the calculations were presented to and discussed with the Review Group. In the course of this discussion, the realism of key aspects of the results (e.g. the potential scale of impacts) was confirmed and the evidence relating to diseases showing the largest differences between policy options was reviewed, to check the robustness of the assessment. Finally, the Review Group discussed and agreed draft conclusions about the impacts of the different policy options on disease cost, while taking account of the uncertainties indicated by the assessment. It was agreed that the principal conclusions from the assessment should be expressed as qualitative statements and approximate values, and not interpreted as precise quantitative estimates.

Results

Parameter estimates elicited from the Review Group

25. Estimates elicited from the Review Group are shown in Tables 1-4. The rationale for the estimates is documented [see Annex 1 of this document].

26. For the preferred option, two sets of estimates were provided for EFB and AFB: one as shown in Table 4 and the other set the same as in the baseline (no change to policies) scenario (Table 2). The rationale for these alternative views was as follows:

- VIEW 1: If the targeting of beekeepers with a history of repeated infections is effective and if ‘trusted’ beekeepers who are given more responsibility for detecting and reporting disease in their colonies continue to do this efficiently, the preferred option is expected to maintain losses to EFB and AFB at about current levels. In this case the relevant estimates for EFB and AFB are the same as for the baseline option (as shown in Table 1).
- VIEW 2: If targeted beekeepers resort to dosing with antibiotics (which conceal but do not remove the disease), or ‘trusted’ beekeepers seek lower cost options (which may be more likely in poor years, and may include dosing with antibiotics), or resources are diverted from inspection to training, then the preferred option might result in increased losses to EFB and AFB. The estimates for this viewpoint are those shown in Table 3.

Distributions

27. The Review Group considered that, for all the parameters, values close to their most likely estimates are more likely than values closer to their minimum or maximum, and that the distributions would in general be unimodal and somewhere between uniform and triangular in form, although closer to the latter.

Dependencies

28. The Review Group described some expected dependencies between parameters in broad terms, as follows:

- Losses to beekeepers and agriculture under the same policy option are expected to be strongly positively correlated, since they are both directly related to proportion of honeybees lost.
- Losses to different diseases under the same policy option may show complex dependencies:
    - Losses to some diseases, but not all, may be positively correlated due to being influenced by the same environmental or management factors. The Review Group identified the following expected dependencies:
        - A general positive correlation between the endemic diseases due to common influence of management factors; data from the Random

Apiary Survey, a positive correlation was found between presence of *Nosema* and ‘other endemic diseases’ but no correlation between *Nosema* and Varroa.

    - The RAS data show a positive correlation between presence of *Varroa* and CCD
    - A positive correlation between Asian hornet and CCD for probability of presence and proportion of colonies affected, because the hornet has been shown to carry IAPV which is associated with CCD
    - It was thought there could be a positive correlation between *Varroa* and *Tropilaelaps*
    - A general positive correlation between similar exotic diseases (i.e. between SHB and *Tropilaelaps*, and between the Asian hornet and other known exotics, some of which are also hornets, and unknown exotics) due to common causes of entry into England and Wales via international trade and illegal import
    - If one exotic pest or disease arrived, beekeepers would learn control methods that would make them better prepared to control subsequent exotic diseases more quickly

  - There is an absolute limit to the total loss, which cannot exceed 100% (each colony can be lost only once).

- Some degree of positive correlation is expected between losses to the same disease under different management options, because much of the loss would be due to factors other than the difference in management.

Table 1. Review Group estimates for cost of total loss of honeybee colonies in England and Wales. Note the same estimates for these parameters apply to all 3 policy options.

Total cost to beekeepers in 2020 if *all* colonies in England and Wales were lost (£ at 2012 prices)	Upper (maximum) estimate	£125m
	Most likely estimate	£102m
	Lower (minimum) estimate	£90m
Total cost to agriculture in 2020 if *all* colonies in England and Wales were lost (£ at 2012 prices)	Upper (maximum) estimate	£300m
	Most likely estimate	£192m
	Lower (minimum) estimate	£170m

Table 2. Parameter estimates for the Baseline Option (no change to policies), elicited from the Review Group. All estimates relate to England & Wales.

Criteria		*Varroa*	*Nosema*	Other Diseases	EFB	AFB	CCD Syndrome	Asian Hornet	SHB	Tropilaelaps	Other Known Exotics	Currently Unknown Exotics
% probability of disease being present in 2020 (0-100 for exotics; 100 for endemics).	U[2]	100	100	100	100	100	10	100	10	5	100	100
	M	100	100	100	100	100	5	70	5	1	70	85
	L	100	100	100	100	99	0	30	0	0	30	50
% of colonies infected/affected in 2020 (if present)	U	100	95	84	3.8	1.1	1.8	40	80	10	40	100
	M	99	45	42	0.34	0.11	0.18	30	40	3	30	40
	L	99	15	25	0.34	0.1	0	0	5	1	0	0
Average % loss to the beekeeper per infected/ affected colony in 2020	U	40	5	10	85	100	100	70	50	100	70	100
	M	20	2.5	5	75	95	100	20	15	75	20	50
	L	10	1	1	40	75	100	2	1	30	2	1
Average % loss of agricultural value per infected/ affected colony in 2020	U	40	5	10	80	100	100	75	60	100	70	100
	M	20	2.5	5	70	95	100	20	15	60	20	50
	L	10	1	1	35	75	100	3	2	30	2	1

[2] U = upper (maximum) estimate, M = most likely estimate, L = lower (minimum) estimate.

Table 3. Parameter estimates for the Do Minimum Option, elicited from the Review Group. All estimates relate to England & Wales.

Criteria		*Varroa*	*Nosema*	Other Diseases	EFB	AFB	CCD Syndrome	Asian Hornet	SHB	Tropilaelaps	Other Known Exotics	Currently Unknown Exotics
% probability of disease being present in 2020 (0-100 for exotics; 100 for endemics).	U[3]	100	100	100	100	100	15	100	20	10	100	100
	M	100	100	100	100	100	7	70	10	5	70	90
	L	100	100	100	100	100	0	30	0	0	30	50
% of colonies infected/affected in 2020 (if present)	U	100	95	84	50	20	5	50	80	50	60	100
	M	99	45	42	36	17	0.20	40	50	10	40	50
	L	99	15	25	10	10	0	20	10	5	0	0
Average % loss to the beekeeper per infected/ affected colony in 2020	U	60	7	12	85	90	100	70	70	100	100	100
	M	45	2.5	7	55	85	100	40	20	75	50	60
	L	10	1	2	55	75	100	20	5	35	20	1
Average % loss of agricultural value per infected/ affected colony in 2020	U	60	7	12	85	90	100	75	70	100	100	100
	M	45	2.5	7	55	85	100	40	20	70	50	60
	L	10	1	2	55	75	100	20	5	35	20	1

[3] U = upper (maximum) estimate, M = most likely estimate, L = lower (minimum) estimate.

Table 4. Parameter estimates for the Preferred Option, elicited from the Review Group. All estimates relate to England & Wales.

Criteria		*Varroa*	*Nosema*	Other Diseases	EFB	AFB	CCD Syndrome	Asian Hornet	SHB	Tropilaelaps	Other Known Exotics	Currently Unknown Exotics
% probability of disease being present in 2020 (0-100 for exotics; 100 for endemics).	U[4]	100	100	100	100	100	10	100	10	5	100	100
	M	100	100	100	100	100	4.8	60	3	0.6	60	84
	L	100	100	100	100	99	0	20	0	0	20	48
% of colonies infected/affected in 2020 (if present)	U	100	95	84	7.6	2.2	1.8	40	70	8	40	100
	M	99	45	42	3.80	1.10	0.18	25	30	2	28	40
	L	99	15	25	0.1	0.1	0	0	1	0.8	0	0
Average % loss to the beekeeper per infected/ affected colony in 2020	U	40	5	10	75	100	100	60	40	100	60	100
	M	15	2.2	4.5	65	98	100	15	10	65	15	50
	L	5	0.5	0.7	20	75	100	2	1	35	2	1
Average % loss of agricultural value per infected/ affected colony in 2020	U	40	5	10	75	100	100	65	50	100	65	100
	M	15	2.2	4.5	60	98	100	15	10	60	15	50
	L	5	0.5	0.7	15	75	100	3	2	35	3	1

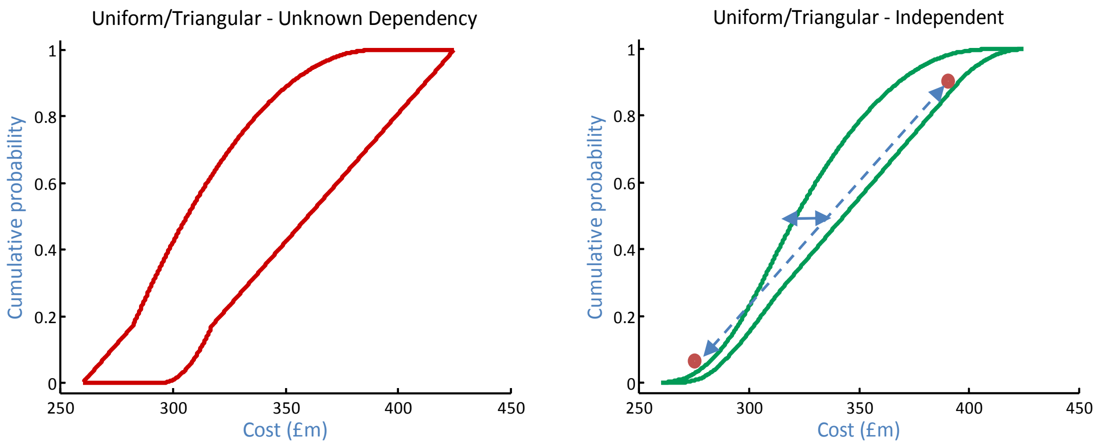
[4] U = upper (maximum) estimate, M = most likely estimate, L = lower (minimum) estimate.

Estimates of total value

29. Figure 2 shows p-boxes for the total value (cost of total loss) of all honeybee colonies in England and Wales to beekeepers (honey production plus replacement costs) and agriculture (crop pollination). Both graphs are based on the estimates provided by the Review Group (Table 1), plus assumptions about the distribution shape for each value and the dependency between them. In both graphs, it is assumed that the shape of each distribution is uncertain but contained within the envelope of uniform and triangular distributions based on the Review Group's estimates. The left hand graph shows the result assuming that nothing is known about the dependency between the value to beekeepers and agriculture. The right hand graph shows the result assuming that the values to beekeepers and agriculture are independent. By comparing the two graphs it can be seen that assumptions regarding dependency can have a substantial impact, even when only two variables are considered. In this case, independence is considered to be the most reasonable assumption because the costs to beekeepers and agriculture are unknown fixed values that were estimated by different methods involving different considerations.

30. Based on this assessment the median of the total value of honeybees to beekeepers and agriculture lies in the range £321m - £343m and the outer bounds for the 95% probability are £274m and £410m (see arrows in right hand graph in Figure 2). Because the distributions for both costs are skewed to the right (most likely value provided by the Review Group further from their upper estimate than their lower estimate), the range for the median is higher than the sum of the most likely estimates (£294m, see Table 1). Note that the estimates exclude pollination services to some excluded crops and to non-agricultural plants. They also exclude consequential costs e.g., due to the dependence of the English cider industry on pollination by honeybees.

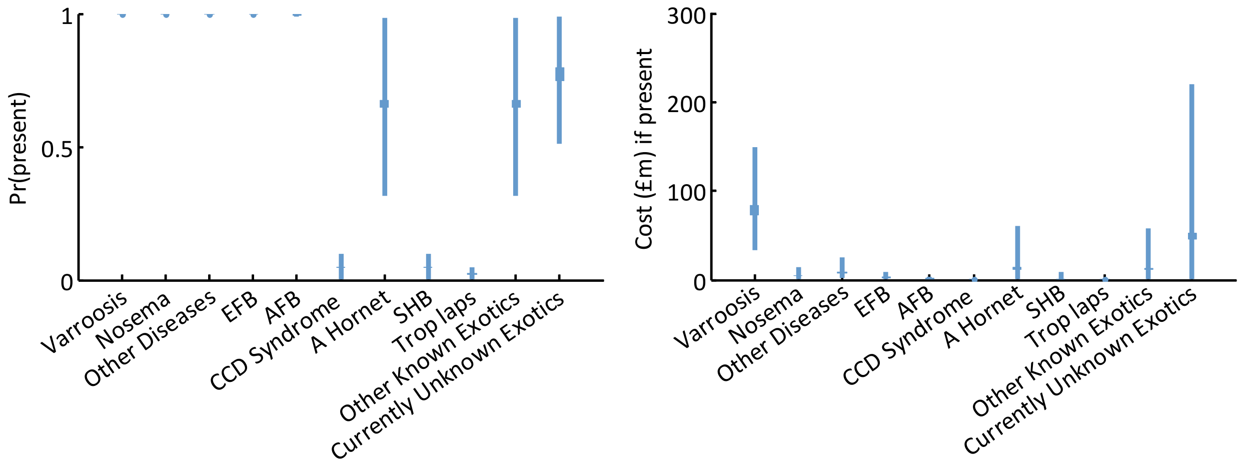
Figure 2. P-boxes for the cost of total loss, based on the estimates provided by the Review Group and alternative assumptions (indicated in the title above each graph) regarding distribution shape and dependency. Arrows on the first graph show median and outer 95% probability interval. See text for further explanation.



Baseline scenario (no change to policies)

31. In the baseline scenario it is assumed that current policies continue. Figure 3 shows estimates for the probability of each disease being present in England and Wales in 2020 under this scenario, and its cost to beekeepers and agriculture if it is present. The results are based on the estimates provided by the Review Group combined with assumptions about distribution shapes (envelope of uniform and triangular) and dependency. As above, the value of total loss to beekeepers and agriculture are considered to be independent. However, the proportions of those costs lost in 2020 are considered to be perfectly positively dependent for each disease, because both are determined by the same quantity (proportion of honeybees lost). Other variables in the calculation of cost for each disease are assumed to be independent, although it is possible to conceive of reasons why either positive or negative correlations might occur between the proportion of colonies infected and the average loss per colony.

Figure 3. Estimated probability of each disease being present in England and Wales in 2020 if current policies continue (left graph), and its cost to beekeepers and agriculture if it is present (right graph). See preceding text for assumptions regarding distributions and dependencies. Thin bar for each disease represents the outer 95% probability interval, thicker part of bar represents the range for the median. Probability of presence is 1 for endemic diseases.



32. Projecting disease levels and costs to 2020 is subject to considerable uncertainty even in the baseline scenario, as reflected by the wide ranges for the estimates in Figure 3. If no exotic diseases are present, then the majority of losses will be caused by *Varroa*, as at present. Asian hornet is considered much more likely to be present in 2020 (arriving in that year or arriving earlier and still being present in 2020) than the other specified exotics (CCD, Small hive beetle and *Tropilaelaps*), but the probability of other known exotics (including several hornets) or a currently unknown exotic being present is considered to be similar to that for Asian hornet. If an exotic disease is present, the loss it would cause is very uncertain but could exceed those for *Varroa*. As an extreme outcome, the Review Group considered it conceivable, though unlikely, that honeybees could be almost completely destroyed by a new, unknown exotic pest or disease if it spread rapidly and no effective controls were found (see upper estimates in Table 2). If more than one

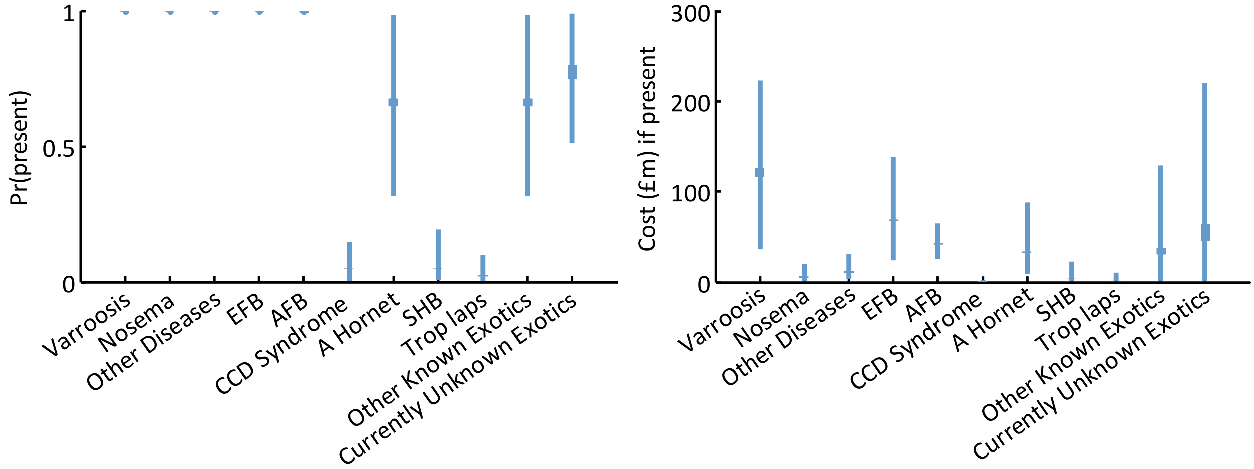
exotic is present the loss would increase. A total across diseases is not calculated because part of the range produced by summing diseases based on the present model would include outcomes where the average loss per colony exceeds 100%, which is not possible.

Assessment of Do Minimum option

33. In the Do Minimum option it is assumed that government contribution to the management of honeybee pests and diseases is reduced to the minimum required by EU legislation. Details of what this would entail are provided in the main Review document.

34. Figure 4 shows estimates for the probability of each disease being present in England and Wales in 2020 under the Do Minimum option, and the cost to beekeepers and agriculture if each disease is present. The results are based on the estimates provided by the Review Group for the Do Minimum option, combined with the same assumptions about distribution shapes and dependencies as described in the previous section for Figure 3.

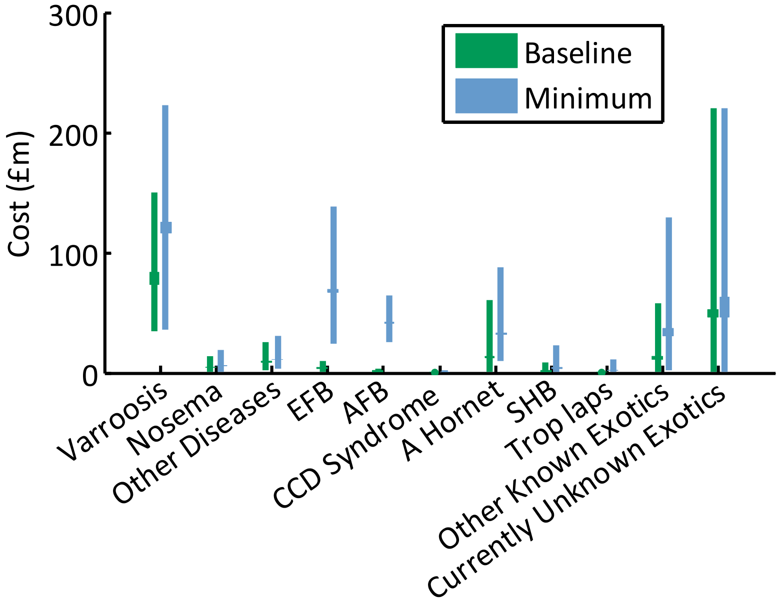
Figure 4. Estimated probability of each disease being present in England and Wales in 2020 under the 'Do Minimum' option (left graph), and its cost to beekeepers and agriculture if it is present (right graph). Assumptions regarding distributions and dependencies are the same as Figure 3. Thin bar for each disease represents the outer 95% probability interval, thicker part of bar represents the range for the median.



35. Comparing Figures 3 and 4 shows increases in probability and more markedly the cost for several diseases in the Do Minimum option, when compared to the baseline. The expected values (combining probability and cost) for disease losses in the baseline and Do Minimum scenarios are shown in Figure 5. The estimates are clearly subject to high levels of uncertainty as indicated by the wide probability bounds, but show potentially large increases in loss to *Varroa*, EFB & AFB under the Do Minimum option, together with substantial additional losses to Asian Hornet and other known & unknown exotics. If these losses were simply additive, they would result in almost total loss of the honeybee population. This provides a very approximate indication of return on investment for current policy: on the scale of 10s to 100s of £millions. However, the potentially strong but

complex dependencies between diseases, especially as losses become large, make quantitative assessment of the total loss under the Do Minimum option very uncertain.

Figure 5. Comparison of expected value of losses to different pests and diseases in the Baseline and Do Minimum options. Assumptions regarding distributions and dependencies are the same as Figure 3.

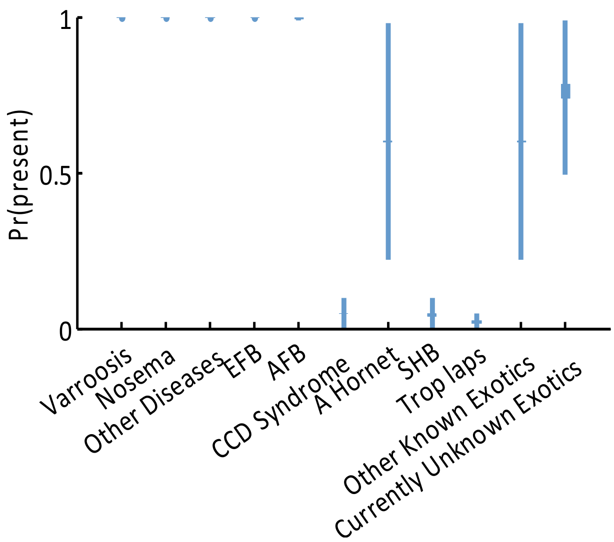


Assessment of Preferred option

36. The Preferred option comprises a number of adjustments to current policy, including an increased focus on improving the management of *Varroa*, changes in the strategy for inspections for EFB and AFB, and a general increase in collective action on pests and diseases by government, beekeepers and beekeeping associations. Details of what the policy would entail are provided in the main Review document.

37. Figure 6 shows estimates for the probability of each disease being present in England and Wales in 2020 under the Preferred option, and the cost to beekeepers and agriculture if each disease is present. The results are based on the estimates provided by the Review Group for the Preferred option, combined with the same assumptions about distribution shapes and dependencies as described earlier for Figure 3. The expected values (combining probability and cost) for disease losses in the baseline and Preferred scenarios are shown in Figure 7.

Figure 6. Estimated probability of each disease being present in England and Wales in 2020 under the 'Do Minimum' option (left graph), and its cost to beekeepers and agriculture if it is present (right graph), based on the data in Table 4. Assumptions regarding distributions and dependencies are the same as Figure 3. Thin bar for each disease represents the outer 95% probability interval, thicker part of bar represents the range for the median.



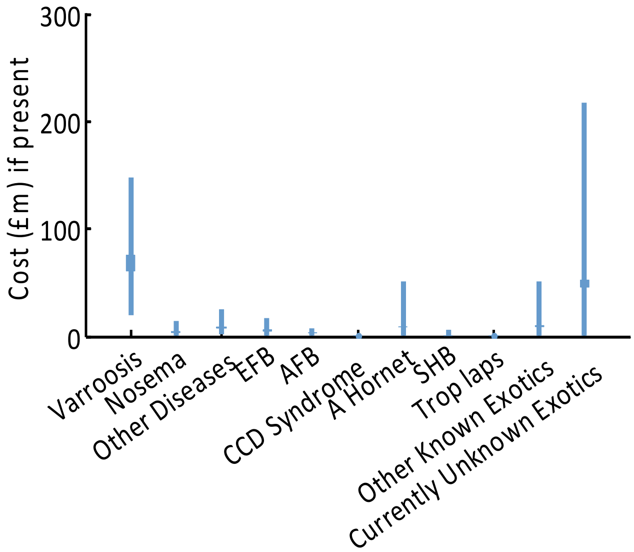
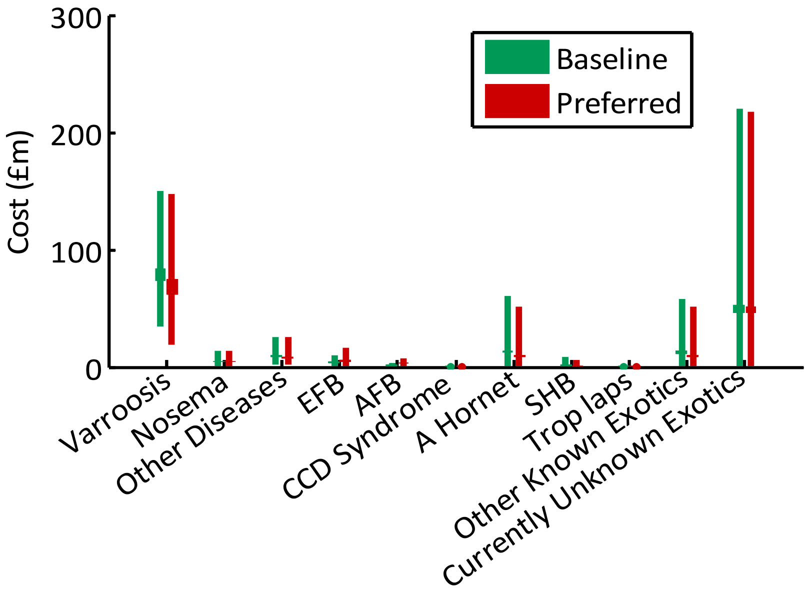


Figure 7. Comparison of expected value of losses to different pests and diseases in the Baseline and Preferred options, based on the data in Table 4. Assumptions regarding distributions and dependencies are the same as Figure 3.



38. Close examination of Figure 7 shows a small decrease in loss to *Varroa*, Asian Hornet and other known exotics, and small increases in EFB and AFB. The increases in EFB and

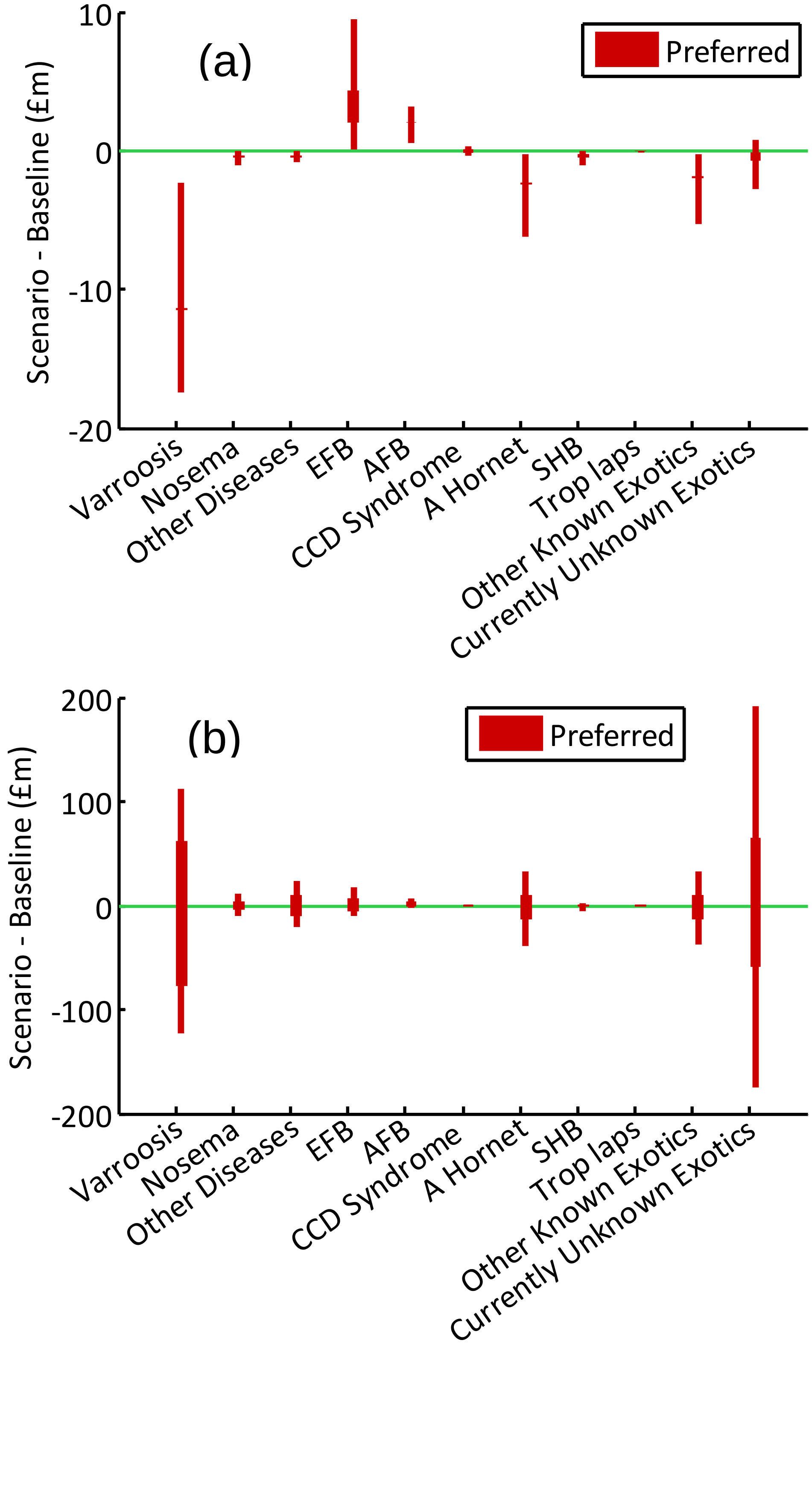
AFB reflect the parameter estimates in Table 4, based on the more pessimistic of two alternative views regarding the outcome of the Preferred option for these diseases. Under the other view, parameter estimates for these diseases would be the same as those in Table 3 and the cost difference between the two policy options for each disease would be zero.

39. All the differences between policy options in Figure 7 are small relative to the high levels of uncertainty of the estimates, as indicated by the wide probability bounds. Because the ranges overlap, differences between the policy options for each disease could be either positive or negative. For example, if the actual outcomes in 2020 for the baseline scenario were towards the top of the estimated range, and the actual outcomes for the preferred option were towards the bottom, then the costs of disease would be much lower in the Preferred option compared to the baseline. However, if the reverse pattern occurred, the costs of disease would be much higher in the Preferred option. Thus it is important to consider the dependency between losses for the same disease under each policy option in order to assess the difference between them.

40. There is some reason to consider that the dependency between losses under the two policy options will be positively correlated, because the changes between the policy options are marginal. Environmental conditions influencing bee pests and diseases are the same under both options, as are most of the activities involved in beekeeping. The Preferred option is designed to result in improvements in aspects of beekeeper behaviour that will improve the management of bee pests and diseases. These changes will result in substantial changes in management for some honeybee colonies, but little or no change for others which are already being managed well. Thus, overall, most of the factors influencing pests and diseases will be very similar for most colonies, so there will be a positive dependency between outcomes in the two scenarios. Given the marginal nature of the changes (as seen in Figure 7) this dependency is likely to be strong.

41. Based on the expectation of a strong positive dependency between outcomes under the two policy options, and the expectation that the Review Group's uncertainty about the parameter estimates are closer to triangular than uniform (see earlier), it was decided to calculate differences between the two policy options under the assumption of perfect positive dependency and triangular distributions. This should be regarded as a type of 'best case' comparison, in the sense of maximising the differentiation of the policy options. The result of this calculation is shown in Figure 8a. An alternative 'pessimistic case' calculation is shown in Figure 8b, using envelopes of uniform and triangular distributions and assuming only that the dependency between policy options is positive (any positive dependency from very weak to perfect).

Figure 8. Differences between the baseline scenario and Preferred option in the expected value of losses to bee pests and diseases. Calculated using the same assumptions as for Figure 3 (see earlier) except that (a) assumes triangular distributions for the uncertainty of parameter estimates and perfect positive dependencies between costs in the two policy options for each disease, while (b) envelopes uniform and triangular distributions and assumes any positive dependency between policy options. See text for discussion.



42. As foreseen above, assumptions regarding dependencies and distribution shapes have a very large impact on assessment of the differences between the policy options. Clear positive or negative differences are apparent with perfect dependency between policy options and triangular distributions (Figure 8a), whereas if the positive dependencies could be very weak, and the distributions could be uniform, the differences are much more uncertain and span both positive and negative changes (Figure 8b). However, as explained earlier, a reasonable view would be closer to the assumptions of Figure 8a than Figure 8b, and therefore expectations regarding cost outcomes could reasonably be closer to Figure 8a than Figure 8b.

43. The assumptions made for Figure 8a amplify the potential differences seen in Figure 7: a decrease in loss to *Varroa*, Asian Hornet and other known exotics, and small increases in EFB and AFB. As explained above, the increases in EFB and AFB reflect the more pessimistic of two alternative views (detailed earlier) regarding the outcome of the Preferred option for these diseases. Under the other view, the differences for EFB and AFB would be zero. This indicates the importance of the detailed design and implementation of the policy regarding these diseases, to maximise the chance that the effect of the policy change is cost neutral (or better) and minimise the risk of an increase in cost that would offset the benefits anticipated for other diseases. It also suggests a need for active monitoring during the implementation of the policy change, if that would make it possible to detect and react to early signs of adverse effects.

44. Finally, the differences in cost were summed over diseases to obtain estimates for the overall difference in the cost between the baseline and Preferred options. For this calculation additional assumptions are needed regarding dependencies between the differences for different diseases. These are very uncertain: discussion with the Review Group identified some reasons for expecting positive dependencies between diseases, but also a constraint on total loss that implies negative dependencies as losses increase (see earlier section on Dependencies). To explore the implications of this uncertainty, alternative calculations were conducted with two different assumptions regarding dependencies between diseases: one calculation assuming perfect positive dependency between the diseases, and one assuming the dependency between diseases is unknown. Each calculation was repeated with two different sets of assumptions regarding the assessment of individual diseases, corresponding to those of Figure 8a and Figure 8b. This resulted in four sets of assumptions and results, shown in Table 5. All the results in Table 5 are based on the pessimistic view of changes in EFB and AFB in the Preferred option, where the policy change unintentionally causes increases in those diseases.

45. The most reasonable set of assumptions for calculating total differences in cost would be close to the first two rows in Table 5: distributions much closer to triangular than uniform, strong (but not perfect) positive correlations between losses for the same disease under different policy options, and mainly positive but potentially complex correlations between diseases. This leads to the conclusion that, under the pessimistic view for EFB and AFB, the overall cost of disease to beekeepers and agriculture could either increase or decrease compared to the baseline, with a 95% probability interval from around £45m decrease to £20m increase. The median estimate of the change is almost certainly

negative (a decrease in cost), and is perhaps most likely to lie in the region of a £10m-15m decrease. The right hand column of Table 5 shows the probability that the total cost is lower for the preferred policy, expressed as a percentage. This probability is 83-93% under the strongest assumptions, in the top row of the table, but reduces and becomes more uncertain (31-100%) if no assumption is made about dependencies between diseases (second row).

46. Table 6 shows the results of equivalent calculations for the more optimistic view of the impact of policy on EFB and AFB, which envisaged no change in those diseases from the baseline. As expected, this improves the results for the Preferred option: larger decreases in cost, and higher probabilities that the total cost is lower than the baseline.

Table 5. Difference in costs to beekeepers and agriculture between Preferred option and baseline, summed over the different pests and diseases under 8 different sets of assumptions. The most reasonable set of assumptions would be intermediate, closer to the upper two rows than to the lower two. All calculations based on the *pessimistic* view of changes in EFB and AFB in the Preferred option. See text for discussion.

Assumptions within diseases	Assumed dependencies between diseases	Difference in 2020 pest/disease costs between Preferred option and baseline (no change to policies) (£m)[5]		
		Range for median	Bounds for 95% probability interval	Probability cost is lower for preferred option
Triangular distributions, perfect dependency between losses in baseline and Preferred option	Perfect	-14 to -11	-34 to +11	83-93%
	No Assumptions	-28 to +3	-45 to +19	31-100%
Envelopes of triangular & uniform distributions, positive dependency between losses in baseline and Preferred option	Perfect	-182 to +173	-423 to 433	0-100%
	No Assumptions	-317 to +321	-503 to +505	0-100%

[5] Calculated as Preferred option minus baseline, so negative values indicate decreased cost in Preferred option.

Table 6. Difference in costs to beekeepers and agriculture between Preferred option and baseline, summed over the different pests and diseases under 8 different sets of assumptions. As in Table 5, except that the calculations are based on the *optimistic* view of changes in EFB and AFB in the Preferred option. See text for discussion.

Assumptions within diseases	Assumed dependencies between diseases	Difference in 2020 pest/disease costs between Preferred option and baseline (no change to policies) (£m)		
		Range for median	Bounds for 95% probability interval	Probability cost is lower for preferred option
Triangular distributions, perfect dependency between losses in baseline and Preferred option	Perfect	-19 to -16	-37 to +2	96-100%
	No Assumptions	-31 to -6	-47 to +8	83-100%
Envelopes of triangular & uniform distributions, positive dependency between losses in baseline and Preferred option	Perfect	-183 to +168	-423 to +422	0-100%
	No Assumptions	-317 to +308	-503 to +491	0-100%

46. The wide variation of the estimates produced by these calculations, especially in the lower two rows of Tables 5 and 6, reflects the uncertainties that are unavoidably associated with this assessment, including:

- limitations in current understanding of bee pests and diseases,
- the limited time and resource available for this analysis,
- the difficulty of projecting pest and disease impacts to 2020,
- uncertainties concerning the impact of policy, especially on EFB and AFB,
- uncertainty about the appropriate distributional form for representing uncertainties,
- uncertainty about dependencies between the parameters involved in calculating impacts for individual diseases,
- uncertainty about dependencies between policy impacts on different diseases.

47. If more precise estimates were needed, some reduction in uncertainty could be achieved by spending more time with the Review Group to elicit more information about distribution shapes and dependencies, and about the potential impact of policy on EFB and AFB. Further improvements might be obtained by epidemiological modelling of bee pest and disease levels over time under the different policy options. However, the precision of the analysis would still be constrained by limitations in current understanding of the diseases, improving which would require further empirical research.

References

Ferson S, Kreinovich V, Ginzburg LR, Myers DS, Sentz K. Constructing Probability Boxes and Dempster-Shafer structures. Technical Report SAND2002-4015, Sandia National Laboratories, Albuquerque, New Mexico, 2003. Tucker WT and Ferson S. Probability Bounds Analysis in Environmental Risk Assessments. Technical report, Applied Biomathematics, Setauket, New York, 2003. www.ramas.com/pbawhite.pdf. Accessed on March 31, 2012.

Annex: Assumptions used to populate costs of impacts from pests and diseases projected to 2020

Varroa (Assessment includes consideration of deformed wing virus)

CRITERIA		BASELINE (NO CHANGE TO CURRENT POLICIES)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: 0-100 for exotics: 100 for endemics	**U**	**100**	**100**	**100**
	M	**100**	**100** unchanged as all at 100%	**100** Unchanged as all at 100% -still endemic
	L	**100**	**100**	**100**
% colonies infected/affected in 2020 (if present)	**U**	**100**	**100**	**100**
	M	**99** Already everywhere in England and Wales. Not found on Isle of Man and Scilly Isles. Unlikely to reduce under current policy. New treatments will only reduce severity not reduce incidence.	**99** England and Wales. Not found on Isle of Man and Scilly Isles. Unlikely to reduce under current policy. New treatments will only reduce severity not reduce incidence.	**99** No change in % colonies affected from baseline.
	L	**99**	**99**	**99**
ii. Average % loss to the beekeeper per infected/affected colony in 2020	**U**	**40**	**60**	**40**

CRITERIA		BASELINE (NO CHANGE TO CURRENT POLICIES)	DO MINIMUM	PREFERRED OPTION
	M	**20** Losses mainly overwinter, not all due to varroa. Normal overwinter loss 15% , of which varroa 10%; 'ideal' winter is 10% of which varroa 5%; higher levels in 2007-8 ca 30% (higher in some areas). This figure includes losses due to lost honey and cost of treatment for more heavily affected colonies (maybe 10% of colonies lose honey yield due not effectively treated).	**45** Assumes an increase in % losses compared with baseline due to removal of surveillance programme (and hence 1-to-1 training of beekeepers) and reductions in training activities by NBU. Colony losses would increase but not as much as those seen when Varroa first arrived in UK (colony losses of 50-60%). Assume upper estimate won't be higher than this and lower estimate could be very similar to now (baseline). Lower estimate is unchanged (as beekeepers will find advice from another source and follows this advice).	**15** Reduction in loss to beekeeper compared to baseline. Assumes shift in inspection resource to dedicated (varroa) campaigns, although high turnover of beekeepers may impact on effectiveness of training/campaigns. May need to focus effort on new beekeepers. Would be doing well to halve the losses. Telephone follow up of beekeepers who had attended Healthy Bees Plan 2009 roadshows indicated positive uptake of advice of management and treatment of Varroa. Lower estimate - in principle could reduce losses to zero but a small proportion of beekeepers will not take up advice, hence assume 5% loss. 40% upper figure assume no training impact.
	L	**10**	**10**	**5**
Average % loss	U	**40**	**60**	**40**

CRITERIA		BASELINE (NO CHANGE TO CURRENT POLICIES)	DO MINIMUM	PREFERRED OPTION
of agricultural value per infected/ affected colony in 2020	**M**	**20** Size of colony may be affected even if treated. Little effect if well treated. Colonies with DWV are smaller and less productive. Similar losses as for beekeepers.	**45** Mirrors figures seen above. Lower estimate unchanged assumes advice etc. replaced by another source and this advice is taken up.	**15** More healthy colonies and therefore mirrors above, and hence lower losses to agriculture
	L	**10**	**10**	**5**

NOSEMA (INCLUDES BOTH SPECIES)

CRITERIA		BASELINE (no change to current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100**	**100**	**100**
	M	**100**	**100** Unchanged as all at 100% - remains endemic	**100**
	L	**100**	**100**	**100**
% of colonies infected/affected in 2020 (if present)	**U**	**95** Note - These numbers relate to pathogen detection in single colony apiaries (from RAS). Only a proportion of these will have symptoms at levels implied below. Given a likely increase in prevalence from near 0% in 1992-2004 to 26% in 2009/10 (149/574) and 39% in 2010/11 (208/537), then this is likely to be very high. Levels in other countries that have had it for longer are in the 90s%.	**95**	**95**
	M	**45** If you take apiaries with single colonies from the Random Apiary Survey then you have a sample of 1111 colonies, for which 499 were positive for at least one Nosema species. One species has only been known here since at least 2004. Some evidence of increasing prevalence due to spread by beekeepers and by new imports, but only 2 years data. Some strains of bees may be resistant (Denmark).	**45** Unchanged because all at high level	**45**

CRITERIA		BASELINE (no change to current policies)	DO MINIMUM	PREFERRED OPTION
		Unlikely to reach 100% by 2020.		
	L	**15** Only registered treatment has been withdrawn. Increase in immunity in the honey bee population may occur over time; as often happen when new pathogens arrive. Breeding programme to enhance resistance is unlikely.	**15**	**15**
Average % loss to the beekeeper per infected/ affected colony in 2020	U	**5**	**7** Slightly increased compared to baseline to reflect very small increase in chance of similar losses to those experienced in Spain (thought to be due to Nosema ceranae), although losses might be up to 40% in these circumstances.	**5**
	M	**2.5** Judged to be fairly low based on current experience in the UK because husbandry can limit losses. In Spain and Portugal losses (death) of 40% have been reported (Higes et al 2007). Infection weakens colonies in Spring, and with N ceranae continues weak into summer. Probably small total loss of colonies (1-2%) but increased to include lost production from weakened colonies. Future situation is hard to predict. Latest NBU data suggest differences in pathogenicity of strains; and differences in susceptibility of honey bee races.	**2.5**	**2.2** No focussed campaign for Nosema in although likely benefits (small reduction in losses), in particular from greater beekeeper responsibility and beekeeping associations raising profile of diseases and their management, and from enhanced training activities (eg, added benefit from campaigns on Varroa). Most likely estimate reduced from baseline (from 2.5% to 2.2% due to added/spin-off benefits from

CRITERIA		BASELINE (no change to current policies)	DO MINIMUM	PREFERRED OPTION
				training and improved beekeeping standards, particularly regular checking of bees and feeding as required so that bees don't become malnourished and susceptible to infection). Same impact on optimistic (lower estimate of losses) but not upper estimate (pessimistic) due to risk of entrenched poor practice.
	L	**1**	**1**	**0.5**
Average % loss of agricultural value per infected/affected colony in 2020	**U**	**5** Similar to above	**7** Mirrors figures seen above. Lower estimate unchanged assumes advice etc. replaced by another source and this advice is taken up.	**5** Mirrors changes as above - slight reduction in losses for most likely and optimistic estimates.
	M	**2.5**	**2.5**	**2.2**
	L	**1**	**1**	**0.5**

OTHER DISEASES (acarine, chalkbrood, Chronic Bee Paralysis Virus (CBPV), sacbrood, . This table reflects 1 or more of the diseases. CPBV and Acarine may both lead to loss of colonies. Chalkbrood and sacbrood in some circumstances can have significant effects on productivity.

CRITERIA		BASELINE (no change to current policies	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100**	**100**	**100**
	M	**100**	**100** Unchanged as all at 100% - remain endemic	**100**
	L	**100**	**100**	**100**
% of colonies infected/affected in 2020	**U**	**84**	**84**	**84**
	M	**42**	**42** Current advice is thought to have some impact on removal/spread.	**42**
	L	**25**	**25**	**25**
Average % loss to the beekeeper per infected/affected colony in 2020	**U**	**10** In most cases, the direct effect of any one of these assorted pests and diseases on honey bee mortality is unquantified. What is known, however, is that they often occur simultaneously and all have detrimental effects on survival. In combination, colony mortality will also be affected. The 5% average loss is thus a (conservative) estimate, based on	**12**	**10**

CRITERIA		BASELINE (no change to current policies	DO MINIMUM	PREFERRED OPTION
		following reasoning: Direct effects of chalkbrood on honey bee mortality unknown in UK, however indirect effects include: chalkbrood has been associated with average 5%-37% reduction in honey crop and 49% reduction in foraging capacity. Chronic Bee Paralysis virus is believed present in 1% - 8% of honey bees in England and Wales (figures fluctuate annually). Figures from USA suggest that 32% of colony losses between 1995-1996 could be attributed to Tracheal mites (acarine). Direct effects of Sacbrood on mortality unknown - but ~30% of colonies in England and Wales may be infected at a low level (a few larvae/brood) at any one time.		
	M	**5** See comment above for upper estimate above. Severity similar to nosema combined frequency higher.	**7** Increased losses to beekeepers compared with baseline to reflect judgement that current inspections and advice have a small positive impact on these diseases.	**4.5** Small reduction from baseline estimates. Similar rationale as for Nosema for most likely and optimistic estimates (ie, spin off benefits from improvement in beekeepers' responsibility, associations' role in raising profile of diseases, and enhanced training activities) but not to same extent as Nosema because there are

CRITERIA		BASELINE (no change to current policies	DO MINIMUM	PREFERRED OPTION
				numerous other diseases and not all will benefit. Good husbandry, feeding and checking bees regularly are key to ensure bees don't become malnourished and susceptible to disease in general.
	L	1	**2** Losses of colonies to CBPV can be attributed to some beekeepers.	**0.7**
Average % loss of agricultural value per infected/affected colony in 2020	**U**	**10**	**12**	**10**
	M	**5** Mirrors above.	**7** Mirrors above losses.	**4.5** Mirrors changes above - slight reduction in losses for most likely and optimistic estimates.
	L	**1**	**2**	**0.7**

European Foul Brood

CRITERIA		BASELINE	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100**	**100**	**100**	**100**
	M	**100**	**100** Unchanged as all at 100% - remains endemic	**100**	**100**
	L	**100**	**100**	**100**	**100**
% of colonies infected/affected in 2020 (if present)	**U**	**3.8** Maximum annual % of disease colonies found using entire inspections programme since 2001	**50** Upper limit based on inspectors view/ experience that high density areas would experience significant increases. Reflects spread into North and West (where this disease is currently absent).	**6** Worse case assumes an increased % infected (compared to baseline) due to risks from giving (some) beekeepers greater autonomy for detecting and control foulbroods in their apiaries.	**7.6** Worse case assumes an increased % infected (compared to baseline) due to risks from giving (some) beekeepers greater autonomy for detecting and control foulbroods in their apiaries
	M	**0.34** Random Apiary Survey based on apiaries with single colonies (1111) - 0.34% colonies infected. Compared with inspection data over 10 year since 2001- range was 1.32 to 3.8%.	**36** % colonies infected will greatly increase compared to baseline. Latent period of EFB is quite long so high likelihood of it being spread before symptoms detected. Evidence from the Netherlands suggests up to 36% losses. Specific mitigation steps or replacement services provided by vets and/or associations might help reduce risks,	**0.34** EFB control programme continues with changes in approach. Phasing in of autonomy for skilled beekeepers to do their own disease management. More focus on dealing with recurrent outbreaks. Main focus on reducing colony losses (not incidence). 0.34% most likely to be same % infected by 2020. 0.1% lower	**3.8** EFB control programme continues with changes in approach. Phasing in of autonomy for skilled beekeepers to do their own disease management. More focus on dealing with recurrent outbreaks. Main focus on reducing colony losses (not incidence). With fewer foulbrood inspections will likely lead

CRITERIA		BASELINE	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
		Lower value might decrease a little by 2020.	assuming these would be taken up or followed by beekeepers. However, legislation providing for inspection of neighbours' bees and movement controls would no longer be in place, undermining the effectiveness of mitigation or other replacement services (unless carried out with the voluntary cooperation of the beekeeping community). This is reflected in the lower estimate.	value indicates benefits from targeting recurrent outbreaks. 6% upper value indicates risk from giving (some) beekeepers autonomy for EFB controls.	to EFB remaining undiscovered for longer and the best case scenario would be the maximum observed in the current programme since 2001 (3.8%)
	L	**0.34** Based on RAS data for apiaries with single colonies - lower than annual % of disease colonies found using inspection programme data since 2001(lower end of range was 1.32%)	**10** Based on severity of problem in South East, progression and optimistic view of other parts of the country remaining EFB free and effective mitigation in some areas with replacement resource.	**0.1**	**0.1** Indicates benefits from targeting recurrent outbreaks.
Average % loss to the beekeeper per infected/affected	**U**	**85**	**85**	**75**	**75**

CRITERIA		BASELINE	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
colony in 2020					
	M	**75** Of those cases detected in 2010, 42% were destroyed, 15% antibiotic treatment, 41% shook swarm. Lost value 10-20% for treated or shook swarm. Proportion not detected can be estimated from the RAS (approx 50% but large error). Policy options remain, so range for 2020 quite narrow, although there might be some move to more destruction and more shook swarm.	**55** Most likely figure is 55% because the control programme has stopped under 'do minimum' and 50% of infected colonies detected are no longer destroyed (and others treated) - in effect a lower % loss per beekeeper as infected colonies would continue to produce honey, and would not incur replacement costs until the colony died. Lower estimate is the same as most likely for similar reasons.	**65** Reduction in losses to beekeepers from EFB compared with baseline due to: More rigorous policy on recurrent outbreaks may lead to destruction of more infected colonies removing disease source and therefore reduce EFB infections (losses) in the area. Beekeepers who still have EFB at their apiaries may lose fewer colonies due to more awareness and training. General improvements in disease prevention practices from training including targeted training in areas with recurrent outbreaks (spot infection early leading to fewer losses). There may be some new tools and diagnostics to help beekeepers' management of disease risks. Research programs underway which may help improve understanding of losses and improve/extend management	**65** As opposite.

CRITERIA		BASELINE	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
				options. More flexible deployment of resources by NBU to address priorities (from not having to inspect beekeepers' apiaries who have autonomy to manage foulbrood).	
	L	**40** Given the drive to improve BeeBase coverage in recent years, we are likely to detect more of the current unknowns and then have a 50% loss associated rather than 100% for loss in undetected.	**55**	**20**	**20**
Average % loss of agricultural value per infected/affected colony in 2020	**U**	**80**	**85**	**75**	**75**
	M	**70** Losses slightly lower(than for beekeepers losses) because the colony will still be active and pollination should	**55** Much greater impact than baseline.	**60** Losses slightly lower (than for beekeepers losses) because colony is still active and pollination should hold up better than honey production.	**60**

CRITERIA		BASELINE	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
		hold up better than honey production.			
	L	**35**	**55**	**15**	**15**

American Foul Brood

CRITERIA		BASELINE (unchanged from current policies)	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100**	**100**	**100**	**100**
	M	**100**	**100** Unchanged as all at 100% and assumes no eradication policy.	**100** unchanged as all at 100% - still endemic.	**100**
	L	**99** This suggests progress toward eradication - it may be eradicated by 2020 with a 1% chance of it not being eradicated.	**100**	**99**	**99**
% colonies infected/affected in 2020 (if present)	**U**	**1.1** Max. annual % of disease colonies found using entire inspections programme since 2001	**20**	**4**	**2.2**
	M	**0.11** Random Apiary Survey based on apiaries with single colonies (1111) - 0.11% colonies infected. Compared with colony inspection data over 10 year since 2001- range was 0.1 - 1.09%. Lower value might decrease a little by 2020.	**17** Will greatly increase under 'do minimum' compared with baseline. On Jersey, AFB increased up to 17% within 2 years. When the inspection service started in England in the 1940s, AFB levels were about 17%. Beekeeping networks (e.g., shared facilities) are likely to share and spread the disease	**0.11** Giving autonomy to some beekeepers for AFB, so same effects likely to occur as for EFB - upper estimate increases due to risks from beekeepers who have autonomy to manage AFB. The increase in the upper estimate is higher than for EFB because the likelihood of reporting and action is reduced (because	**1.10** Same logic as for EFB, for mean - fewer foulbrood inspections (due to diverting to training) would mean AFB would conservatively reach the highest levels seen using the current inspection since 2001. Upper double of mean.

CRITERIA		BASELINE (unchanged from current policies)	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
			quite rapidly. However, the chance of disease being spread from apiary to apiary will be much slower than for EFB. AFB is easier to deal with and symptoms are more obvious than EFB. Beekeepers are now more aware of disease, so would do something about it. Lower estimate assumes some active mitigation steps by beekeepers/associations and/or vets.	only option is destruction) leading to increased risk of spread from the infected colony, as it declines. Spin off benefits from raised awareness and profile of disease control amongst beekeepers (leading to improvements in disease prevention measures such as barrier management.)	Spin off benefits from raised awareness and profile of disease control amongst beekeepers (leading to improvements in disease prevention measures such as barrier management.)
	L	**0.1** Min. annual % of disease colonies found using entire inspections programme since 2001 (which was slightly lower than the RAS data).	**10**	**0.1** Lower estimate unlikely to reduce as already low.	**0.1** Lower estimate unlikely to reduce as already low.
Average % loss to the beekeeper per infected/affected colony in 2020	**U**	**100**	**90**	**100**	**100**
	M	**95** Aim is to destroy all infected colonies, if detected/notified - hence values above are high. Some cases go undetected. Assuming we detect and	**85** Reduced loss to beekeeper compared with baseline as colonies might be left to decline and die over several years rather than being destroyed - reflected in both	**98** Increase in most likely estimate of loss to beekeeper compared with baseline - as a higher proportion of infected colonies may go undetected	**98** As opposite.

CRITERIA		BASELINE (unchanged from current policies)	DO MINIMUM	PREFERRED OPTION (optimistic)	PREFERRED OPTION (pessimistic)
		destroy perhaps 85%, the remainder will likely die anyway within the year.	most likely and in upper (pessimistic) estimate.	as more reliance on autonomous beekeepers to detect it. (in comparison to EFB) recurrent offenders not an issue and not expecting new management tools or diagnostics.	
	L	**75** assuming low detection/destruction (ca 50%) and lose rest over 2 years.	**75** no change from baseline	**75** Remains unchanged from baseline - assumes that autonomous beekeepers are able to detect and report as effectively as bee inspectors. In addition, raised awareness across beekeeping community to detect and report foulbroods.	**75** As opposite.
Average % loss of agricultural value per infected/affected colony in 2020	**U**	**100**	**90**	**100**	**10**
	M	**95** close to numbers above, because if not destroyed will decline quickly.	**85** Losses mirror those seen above - Agricultural losses in proportion to beekeepers losses.	**98** small increase in losses mirroring above.	**98** As opposite.
	L	**75**	**75**	**75**	**75**

Colony Collapse Disorder (CCD) Syndrome A condition observed in the USA (but not in the UK or EU): large-scale, unexplained losses of colonies. Main trait is sudden or rapid loss of adult worker bees. The queen and brood remain plus abundant honey and pollen stores. But hives cannot sustain themselves without worker bees and would eventually die. Assumed to occur only if risk factors such as Kashmir Bee Virus (KBV) or Israel Acute Paralysis Virus (IAPV) are present although the cause is unknown and multifactoral.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**10**	**15**	**10** Remains the same reflecting limited opportunities for NBU to monitor and limited benefit from early detection.
	M	**5** IAPV and KBV are present at very low levels in England and Wales. The probability of this occurring by 2020 are very low based on current understanding of risk factors.	**7** Currently have no surveillance for two viruses and no international legislation to prevent movement - suggesting no change under 'do minimum'. However, various factors could increase levels of viruses and associated possible risk of CCD syndrome being present in 2020: 1. If beekeepers adopted more risky behaviours following deregulation 'do minimum' (such as increased risks of illegal bee imports, and wax which also carries these viruses) 2. If Asian hornet arrived (it can transmit IAPV). Uncertainty about these factors is reflected in range.	**4.8** Small reduction in probability of syndrome being present from raised level of responsibility in the beekeeping community to monitor own colonies and NBU looking for opportunities as part of the surveillance programmes to monitor for CCD risk factors (IAPV and KBV). However, since complete list of risk factors is unknown, the benefits of early detection (of any increase in IAPV and KBV) are uncertain.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
	L	**0**	**0**	**0**
% colonies infected/affected in 2020 (if present)	**U**	**1.8** KBV has been resident in the UK for at least 8 years, yet incidence remains very low. Unless something changes, prevalence is unlikely to become 10 times higher over the next 7 years.	**5** High reflecting possibility of rapid spread and associated losses.	**1.8**
	M	**0.18** RAS **-** Based on known incidence of only 2 risk factors (IAPV & KBV) - **KBV** 0.29% year 1, 0.035 year 2. **IAPV** 0.047% year 2, not detected in year 1. Assumed level of syndrome in 2020 will be equal to the level of the viruses now. Levels of syndrome could increase due to the arrival of additional risk factor(s) currently unknown and unmonitored.	**0.20** Same factors as 'A' above will tend to increase levels of viruses and potential risk of CCD syndrome in colonies. Evidence from RAS which tested 16000 colonies found 1 colony with IAPV. Subsequent monitoring (within 2 years of the RAS) showed 4 colonies with IAPV in that same apiary. No effective controls apart from Varroa control to keep down levels of viruses. A new treatment for IAPV is being developed in the USA based on techniques which interfere with virus genetics, although uncertain whether/when will be available. Most likely estimate suggests a small increase in losses. Note: assessment of this risk is based on viruses which is not the same as presence of the CCD syndrome. (IAPV and KBV are risk factors associated with CCD which is recognised as multifactorial and not fully	**0.18** This is based on known incidence of only 2 risk factors (IAPV & KBV). Assumed level of syndrome in 2020 will be equal to the level of the viruses now. Incidence unlikely to alter as although preferred option includes intention to develop a response policy (as required and if possible given complexity and the unknown risk factor of syndrome). However, is unlikely to have an impact by 2020 (note **-** CCD is not fully understood or controlled in USA). Levels of syndrome could increase due to the arrival of additional risk factor(s) currently unknown and unmonitored.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
			understood).	
	L	**0** Equally, KBV has been around for many years and is unlikely to suddenly disappear or necessarily reduce in prevalence but the other risk factor may not arrive or be detected hence lower value is 0.	**0**	**0**
Average % loss to the beekeeper per infected/affected colony in 2020	**U**	**100**	**100**	**100**
	M	**100**	**100**	**100**
	L	**100**	**100**	**100**
Average % loss of agricultural value per infected/affected colony in 2020	**U**	**100**	**100**	**100**
	M	**100**	**100**	**100**
	L	**100**	**100**	**100**

ASIAN HORNET

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100**	**100**	**100**
	M	**70** Established in France including Channel ports. Also Belgium and Spain. Increased risk of arrival to southern England due to proximity in France. Response plan in place to seek to prevent establishment or longer term management. Establishment and spread will depend on success of this response.	**70** 'do minimum' is unlikely to lead to any change compared with baseline as current response plan would remain in place as this is a shared response plan with Defra's non-native species responsibilities. Response may be more effective if only one government department involved. Education activities may reduce under this scenario (due to reduced role of NBU), although some should continue as part of Defra's non-native species remit. Others, in addition to beekeepers, are involved in possible entry routes and aware of risks.	**60** Strategy is very early detection and eradication with some benefit from sentinel apiary increase (in AH risk areas) and increased awareness (including involvement of other organisations such as possible synergies with public health concern and actions). Leading to reduction in probability of AH being present in 2020. Traps are being developed and sent out to sentinel apiaries and to vulnerable coastal areas. Reproductive capacity of these hornets is far greater than European hornets. Most effective control is dealing with nests early in season. Fera and other organisations are involved in eradication measures.
	L	**30**	**30**	**20**
% colonies infected/ affected in	**U**	**40**	**50** Higher than baseline on assumption that no further advice from NBU on how to limit spread	**40**

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
2020 (if present)	**M**	**30** Potential range would be similar to European hornet, but will prefer southern counties. May move as far north as Yorkshire. About 30-50% of European hornet are in south and east. Likely will have tried and failed to eradicate, maybe following a series of entry events over years. But also possible that eradication has succeeded.	**40** Increased % colonies affected compared with baseline for all three estimates. Entry risk points all over England, not only just across the Channel e.g. shipping into Humber, although unlikely to establish in northern areas. Response plan would still be in place but interception would be less effective as NBU inspectors would have lower presence in the field, and hence fewer nests would be found and then destroyed (unless others, such as local authorities stepped in to respond in view of potential public nuisance risks and complaints from the public). However, first nests may not be detected by public.	**25** Impact of policy mostly on early detection and management and new traps and awareness. Slight reduction in %age colonies affected. Very difficult to manage.
	L	**0**	**20**	**0**
Average % loss to the beekeeper per infected/ affected colony in 2020	**U**	**70** Assumes that losses will be high after the new pest or disease has arrived (although 40% of colonies would be affected).	**70**	**60**
	M	**20** Hornets prey on bees and can sometimes consume the whole colony. In response to the attack, bees stop foraging, get stressed and hungry and	**40** Increased losses to beekeepers - most likely estimate and lower value because no further advice from NBU on effective trapping, design of traps and sharing of lessons learned from other countries on	**15** Impact of policy to improve beekeepers' awareness and better preparedness. Reducing the upper and most likely assessments for beekeeper losses.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
		succumb to other pests and pathogens. Beekeepers would set traps to reduce impacts of hornets on their colonies which are lost rather than damaged – either lost immediately or weakened so much they die in winter. In France, unprepared beekeepers lost 70% of their colonies, but losses are now lower in response to awareness raising.	how to deal with this pest. Private sector may offer advice but may not be as trusted as the NBU. Other bodies e.g. Non Native Species Secretariat may step in to provide advice and help mitigate losses.	
	L	**2**	**20**	**2**
Average % loss of agricultural value per infected/ affected colony in 2020	**U**	**75**	**75**	**65**
	M	**20** Similar to numbers above because many affected colonies are completely lost. Increase in upper value compared to loss to the beekeeper reflects the fact that they eat other insect pollinators.	**40** Same factors as above. More colonies affected so less active in pollination. A. hornet may also predate other pollinators - or their predators.	**15** Similar to above, although additional losses from predation on bumble bees and other insect pollinators could increase upper estimate.
	L	**3**	**20**	**3**

SMALL HIVE BEETLE

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**10**	**20** Many possible routes of entry and ways to detect suggesting a moderate increase as exotic pest surveys would no longer carried out by NBU. Possible reduction in (EU) import checks too.	**10**
	M	**5** Native of S Africa. Spread to Australia (from where UK import honey bees) and USA (no imports). As long as absent from EU, the risk of import to UK is relatively low (but much higher than for Tropilaelaps). Possible entry by eggs which survive well, either associated with bee packaging or on fruits (adult beetles feed on fruit so not necessary for bees to be present for the eggs/beetles to be imported). Harder to detect than Tropilaelaps.	**10** Increased probability of being present compared with baseline	**3** Increased and expanded ways to improve early detection (through more sentinel apiaries, increased coverage in high risk areas, regular debris samples and a random element in expanded exotic pest survey) will help spot arrivals in high risk areas/entry points. Early detection will reduce probability of SHB being present in 2020 (as better chance of eradication) and improved availability of treatment/ management options will also help.
	L	**0**	**0** No change from baseline as it may not arrive.	**0**
% colonies	**U**	**80**	**80**	**70**

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
infected/affected in 2020 (if present)	**M**	**40** Can fly several km. Doesn't mind overwintering as can burrow when cold or remain in hive. Expect high rate of spread. Policy is eradication by destruction, and if this fails then longer term management. Varroa took 3years to move from Devon to Yorkshire and 3 more years to move to Scotland. Most likely % will be higher than Asian hornet, due to limited management options.	**50** If found, EU safeguard measures would apply requiring the competent authority to act to eradicate/control it. 'do minimum' would decrease chance of early detection and eradication. Lower (optimistic) value of 5% in baseline suggests that eradication is not possible but limited further spread due to UK climate being less favourable for SHB compared to other countries. 'Most likely' and 'lower' values would both increase (from baseline) due to limited/less advice and limited if any control or rapid response. Eradication would no longer be a realistic option and beekeepers would manage and contain outbreaks, supported by their associations.	**30** Reduction in % colonies affected assuming improved chance of catching early, particularly with increased sentinel apiaries for earlier detection, and reduced spread. If policy changes to containment (from eradication) beekeepers would apply treatment options which requires off- label approvals etc. SHB- specific pesticide is unlikely to be available (by 2020) although this is uncertain and cost may be an issue for beekeepers. May damage other bees leading to potential for Natural England to become involved with control policies.
	L	**5**	**10**	**1**
Average % loss to the beekeeper per infected/affected colony in 2020	**U**	**50** Based on literature reviews for the 2010 SHB PRA, the impact of SHB on first arrival in a new region/ country can be very high. This impact may reduce over time as beekeepers become more effective at	**70** Based on literature reviews for the 2010 SHB PRA, the impact of SHB on first arrival in a new region/ country can be very high. This impact may reduce over time as beekeepers become more effective at dealing with/ managing the problem. The likelihood that SHB would arrive and be effectively contained by	**40**

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
		dealing with/ managing the problem. The likelihood that SHB would arrive and be effectively contained by 2020 is considered minimal. Also there are no treatment options for SHB.	2020 is considered minimal. Also there are no treatment options for SHB**.**	
	M	**15** Distinctive impact on colony and would not be mistaken for other pests and diseases. Therefore it should be detected and would have lower impact than Tropilaelaps. If detected, beekeeper should destroy colony quickly. Currently no treatments registered, but by 2020 may have improved. 1% is based on losses in the US. Figures on living with SHB suggest no increase in losses when compared to Varroa (Schafer et al 2010).	**20** Assumes increased beekeeper losses compared with baseline across all 3 values. Even under 'do minimum' government action to eradicate would continue to meet to EU requirements. Destruction of infested colonies/apiaries would be a priority and losses should be similar to baseline, although assumes that (standing) staff resources are in place to be deployed to implement the response. If alternative resources need to be deployed (eg, vets or associations), could lead to a delay in the response and greater risk of spread possibly undermining efforts to eradicate, and increased losses. Delays in the government's response may also arise due loss of BeeBase data on beekeepers and apiaries. Increase in losses could also arise due to limited containment options for beekeepers to use, particularly if eradication is unfeasible.	**10** Training management options would help reduce beekeeper losses - most likely estimate and upper estimate.
	L	**1**	**5**	**1**
Average %loss	**U**	**60**	**70**	**50**

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
of agricultural value per infected/affected colony in 2020	**M**	**15** Similar to above because colony rapidly destroyed if not cured. Upper agricultural loss figure is higher due to potential impacts on/loss of bumble bees from predation by SHB.	**20** Same factors as above for increase.	**10** Upper agricultural loss figure is higher due to potential impacts on/loss of bumble bees from predation.
	L	**2**	**5**	**2**

TROPILAELAPS

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**5**	**10**	**5**
	M	**1** Quite low overall risk of arrival. Not present in EU and has to be imported on a living bee on a journey that lasts no more than 5 days. UK doesn't import living bees from Asia where it is naturally present. Risk would increase if it entered EU and not detected in time to stop exports to other Member States. Biggest concern is nucleus colonies as this mite feeds on bee grubs. However, as we only import nucleus colonies from other EU Member States and New Zealand. It is unlikely to arrive in the UK via any legal route unless it's in another EU country. Possible alternative hosts could lead to arrival through different (unknown) pathways.	**5** Increased probability of being present compared with baseline as: - NBU's checks on EU member state imports would stop (currently 30% physical, 50 % document checks); - less likely to detect entry to UK as NBU's exotic pest survey would cease; - difficult for untrained people to detect it but also less likely to arrive (in comparison to SHB).	**0.6** Small reduction in probability of being present in 2020 from: Increasing and expanding ways to improve early detection (through more sentinel apiaries, increased coverage in high risk areas, regular debris samples and a random element in expanded exotic pest survey) will help spot arrivals in high risk areas/entry points. Early detection will reduce probability of Tropilaelaps being present in 2020 (as better chance of eradication).
	L	**0**	**0**	**0**
% colonies infected/affected	**U**	**10**	**50**	**8**
	M	**3** Does not spread easily itself and	**10** Increase in % colonies affected	**2** Small reductions in % colonies

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
in 2020 (if present)		would rely on beekeepers to spread it e.g., by sharing equipment or moving colonies for pollination purposes. But if it arrives in UK, it could spread silently as it is less likely to be noticed than A hornet or varroa and can only be spotted by looking at brood (uncapping). Or it could be noticed but unrecognised. Would have to overwinter in brood to establish so is more likely in southern UK or mild winters. Policy is eradication by destruction followed by movement restrictions. Should be successful if/when detected but might remain chronic at low level.	(compared with baseline): - no surveillance or exotic pest survey by NBU. - unlikely to be detected by beekeepers so levels and spread may increase. - unless EU safeguard measures are specified, only current requirement is to notify Commission. - (as for SHB) possible delay in deployment of resources if specific measures are required. - movement of colonies and sharing equipment would continue leading to increased risk of spread (some parallels with Varroa spread) - Delays in the government's response may also arise due loss of BeeBase as an updated list of beekeepers and apiaries.	affected. Better chance of catching early, particularly with increased sentinel apiaries for earlier detection and reduced spread. If policy changes to containment (from eradication) beekeepers would apply treatment options e.g. varroacides.
	L	**1**	**5**	**0.8**
Average % loss to the beekeeper per infected/affected colony in 2020	**U**	**100** Assuming destruction or treatment policy	**100**	**100** Reflects destruction policy which is likely to be maintained in the longer term.
	M	**75** Destroyed if detected and reported.	**75** Most likely and upper values stay	**65** Destroyed if detected and

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
		If not detected will kill colony within about 3 years. About half infected colonies might be detected and destroyed, other half partial loss.	same as pest can be controlled with varroacides, although would need off-label approval. Other management options include brood interruption for a few days. New options may emerge. EU response uncertain.	reported. If not detected will kill colony within about 3 years. With improved detection more than half infected colonies might be detected and destroyed, remainder partial loss.
	L	**30** Reflects undetected colonies that continue for some years before dying.	**35** Slight increase but uncertain.	**35** Increase from baseline due to improved early detection followed by destruction.
Average % loss of agricultural value per infected/affected colony in 2020	U	**100**	**100**	**100**
	M	**60** Lower than beekeeper loss because in first year of infection (if not destroyed) colony will still provide nearly normal pollination service.	**70** Small increase in losses compared with baseline due to: - reduced education and training role of government (NBU); - more rapid decline of colonies when infected; - uncertainties about EU response although EC might act to provide advice to beekeepers to fill knowledge gap.	**60** Increase above is not fully reflected because undetected infected bees will forage near normally.
	L	**30**	**35**	**35**

KNOWN EXOTICS These include:

1) Other Asian hornets (e.g. Vespa mandarinia, V. orientalis) both of which pose similar risks of import from Asian to that posed by V. velutina (confirmed present and spreading in mainland EU). Both of these could have significant negative impact on European honey bees (equal to/worse than risks posed by V. velutina); Hornets also pose public health/nuisance threat;

2) Africanised honey bees - these pose a threat to gene pool of UK A. mellifera stocks and a risk to public health;

3) Cape bees (capensis) - these pose a threat to colony survival of UK A. mellifera stocks.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100**	**100**	**100**
	M	**70** Similar to Asian Hornet	**70** No change compared with baseline as: - bearing in mind A. hornet already in EU; - 'other known' reflects aggregation of a number of different exotics. Currently no EU action on these exotics.	**60** More sentinel apiaries and exotic pest surveillance increases earlier detection. Will not affect rate of arrival but may act more quickly to remove them and may be more successful in removing by 2020. increasing and expanding ways to improve early detection (through more sentinel apiaries, increased coverage in high risk areas, regular debris samples and a random element in expanded exotic pest survey) wiill help spot arrivals in high risk areas/entry points. Early detection will reduce probability of Tropilaelaps being present in 2020 (as better chance of eradication). Also see comments for Asian hornet.
	L	**30**	**30**	**20**

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% colonies infected/ affected in 2020 (if present)	**U**	**40**	**60** Increase in % colonies affected for most likely and upper values (compared with baseline) as no inspections and surveillance and hence no incidental detection. Loss of BeeBase would also impact on ability to control.	**40**
	M	**30** assumed to have similar impacts to Asian Hornet.	**40** Ideally would aim to destroy Cape bees if found, but currently no powers within EU to do so although policies could still be introduced from non-native species perspective but there might be difficulties in detecting new species. May be very highly mobile species.	**28** Slight reduction from baseline. Impact of policy mostly on early detection and management and new traps and awareness used for Asian hornet could be effective against other flying insects. Slight reduction in % colonies affected. Very difficult to predict or manage.
	L	**0**	**0** Value same as baseline as none may arrive.	**0**
Average % loss to the beekeeper per infected/ affected colony in 2020	**U**	**70**	**100**	**60**
	M	**20**	**50** Increased losses compared with baseline: - lack of awareness in beekeeping community; reduced detection and advice in the field; and delays in alternative	**15** Impact of policy to improve beekeepers' awareness and better preparedness. Reducing the upper and most likely assessments for beekeeper losses.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
			resource and lack of BeeBase would reduce effectiveness of any official response. All suggested pests in this category are at least as damaging as Asian hornet, and some eg, capensis lead to 100% loss of colonies.	
	L	**2**	**20**	**2**
Average % loss of agricultural value per infected/ affected colony in 2020	**U**	**70**	**100**	**65**
	M	**20**	**50** Mirrors loss to beekeepers above. (However, possibility of improved pollination services from Africanised honey bees which are resistant to Varroa. However beekeepers may not want to keep them and stop keeping bees - counterbalance any possible gains from being Varroa-resistant).	**15** Similar to above. Additional losses from predation on bumble bees and other insect pollinators could increase upper estimate.
	L		**20**	**3**

CURRENTLY UNKNOWN EXOTICS

Currently unknown exotics: This takes into account currently unknown risks to honey bee health. NB. SHB, Asian hornet, Nosema ceranae IAPV have all emerged as risks in the last 16 years - equivalent to 1 emergent risk every 5 years - so could reasonably anticipate a further 2 emerging from now until 2020. Africanised bees, capensis, other mites, unknown unknowns (potential risks not yet identified i.e. SHB, Asian hornet, Nosema ceranae weren't known at the time and have all emerged as risks in the last 16 years). 1 every 5 years so could reasonably anticipate a further 2 emerging from now until 2020.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
% probability of disease being present in 2020: (0-100 for exotics; 100 for endemics)	**U**	**100** Based on historical evidence, likely at least 1 if not 2-3 will arrive by 2020 and once present are likely to remain.	**100**	**100**
	M	**85** Based on likelihood of arrival and control/ eradication of them. Unknowns assumed to be higher probability of arrival compared with known exotics as they are unknown and not looked for! 85% probability of arrival based on: - 4 previously unknown exotics in 15 years; - probability of new exotic in any one year = 4/15 - probability of no new exotic in any one year= 11/15 = 0.733 - chance of no new exotic in any	**90** Slight increase in probability of arrival due to reduced/lost inspection and surveillance by government, although nature of disease/ pest unknown so estimates are difficult to judge. Possibility that any new exotic would have been responsive to other policies which are now removed in the 'do minimum' option. If the new exotic affected other species, control measures might be taken as part of non-native species policy.	**84** Small reduction from baseline. Some unknown exotics may be similarly detectable to known exotics (and control methods may be available) but also may not be. May not be detected and we may not have appropriate control mechanisms. For those that are detected there may be action taken under other policy remits i.e. toxic plant food source, contaminated water courses.

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
		of the next 7 years = (11/15) to power of 7 = 0.11405 - chance of any new exotic in any of the next 7 years= 1 - 0.11405 = approx 0.89 - likelihood of arrival 89%, rounded to 85%		
	L	**50**	**50**	**48** Optimistic scenario = unknown more likely to be detected and controlled.
% colonies infected/affected in 2020 (if present)	U	**100** Taken from exotics to reflect the range of characteristics that incoming species might have e.g.. SHB, Asian hornet, tropilaelaps. % colonies affected could be 0-100%	**100**	**100**
	M	**40**	**50** Assume small increase in % colonies affected compared with baseline as the new unknown exotic might be one which would have responded to policies which are removed in 'do minimum' option.	**40** No change from baseline. No reason to expect preferred option policy to alter this.
	L	**0**	**0**	**0**
Average % loss to the beekeeper per	U	**100** Same rationale as applied above for currently unknown exotics.	**100** Same rationale as applied above for currently unknown exotics	**100**

CRITERIA		BASELINE (no change from current policies)	DO MINIMUM	PREFERRED OPTION
infected/affected colony in 2020				
	M	**50**	**60** Assumes increase in losses to beekeepers compared with baseline as policies might have had an impact on some exotic species but have been removed in the 'do minimum' option.	**50** No change. No reason to expect preferred option policy to alter this.
	L	**1**	**1**	**1**
Average % loss of agricultural value per infected/affected colony in 2020	**U**	**100**	**100**	**100**
	M	**50**	**60** Mirrors losses above **-** for same reasons.	**50** No change. No reason to expect preferred option policy to alter this.
	L	**1**	**1**	**1**

U = upper (maximum) estimate, M = most likely estimate, L = lower (minimum) estimate