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An assessment of risk compensation and spillover behavioural adaptions associated with the use of vaccines in animal disease management

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ABSTRACT

This paper analyses farmers' behavioural responses to Government attempts to reduce the risk of disease transmission from badgers to cattle through badger vaccination. Evidence for two opposing behavioural adaptions is examined in response to the vaccination of badgers to reduce the risk of transmission to farmed cattle. Risk compensation theory suggests that interventions that reduce risk, such as vaccination, are counterbalanced by negative behavioural adaptions. By contrast, the spillover effect suggests that interventions can prompt further positive behaviours. The paper uses data from a longitudinal mixed methods study of farmers' attitudes to badger vaccination to prevent the spread of bovine tuberculosis, their reports of biosecurity practices, and cattle movement data in 5 areas of England, one of which experienced badger vaccination. Analysis finds limited evidence of spillover behaviours following vaccination. Lack of spillover is attributed to farmers' beliefs in the effectiveness of biosecurity and the lack of similarity between badger vaccination and vaccination for other animal diseases. Risk compensation behaviours are associated with farmers' beliefs as to who should manage animal disease. Rather than farmers' belief in vaccine effectiveness, it is more likely that farmers' low sense of being able to do anything to prevent disease influences their apparent risk compensation behaviours. These findings address the gap in the literature relating to farmers' behavioural adaptions to vaccine use in the management of animal disease.

1. Introduction

Risk compensation theory suggests that initiatives to reduce risk are counterbalanced by greater risk taking [1,2]. Studies of post-vaccination behaviour suggest an association with risk compensation behaviours [3–5]. By contrast, concerns that Human Papillomavirus vaccination may promote increased sexual activity [6] have been shown to be false [7,8]. Vaccination may also act as a 'wedge' [9] to drive the adoption of additional risk reduction behaviours, known as the 'spillover effect' [10,11]. Behavioural spillovers are associated with pre-natal care and post-natal vaccination choices [12], and more generally, environmental practices such as purchasing organic food, recycling, waste minimisation, and transport choices [10,13,14]. However, positive behavioural spillovers may act to legitimise other negative behaviours [15] or they may be limited by low 'self-efficacy' [16]: feelings of fatalism and being unable to prevent ill-health or disease.

Whilst vaccination is connected to both these behavioural adaptions, there are no studies of risk compensation or behavioural spillovers in relation to the use of animal disease vaccines. This is surprising because the pre-conditions for risk compensation suggested by Hedlund [1] apply equally to animal keepers, such as farmers, as to the general public. These include: the intervention must be visible; have an effect on risk perception; there must be a motivation to increase risk taking (for example, economic incentives); and individuals have the ability to adapt their behaviour (as opposed to being restricted by regulation). Expected and unexpected positive, negative and neutral behavioural responses to animal disease interventions should therefore be anticipated [17].

Given the potential consequences of these behavioural adaptions to animal disease management, it is imperative to determine

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the conditions in which such behavioural adaptions occur, yet there are few studies of risk compensation and/or behavioural spillover in the animal disease management literature. The aim of this paper is therefore to examine farmers' behavioural responses to policies designed to reduce the risk of transmission of bovine tuberculosis (bTB) from wildlife to cattle. Despite the volume of epidemiological research on the transmission of bTB, there have been no studies examining the impact of wildlife interventions on farmer behaviour. The paper therefore addresses this gap in the literature by examining the extent and reasons for risk compensation and spillover behaviours amongst farmers in areas where wildlife have been vaccinated to prevent the spread of disease, with those in comparison areas.

2. Materials and methods

2.1. 1 Background: Bovine tuberculosis and the vaccination of wildlife

In the United Kingdom, bTB is recognised as the most challenging animal disease problem [18] resulting in the slaughter of approximately 56,000 cattle per annum [19,20] at an annual cost to the taxpayer of £100 million [21]. Whilst cattle can transmit the disease between themselves, or translocate the disease by moving between farms, wildlife – notably badgers – are implicated in the spread of disease [22]. As a culturally iconic species [23], the culling of badgers to reduce the risk of transmission has resulted in public opposition but is supported by farming unions [24]. Since the 1970s, successive governments have implemented policies of badger culling but a scientific trial of badger culling between 1998 and 2007 found limited benefits to disease incidence [25]. The availability of a badger vaccine and evidence that it could reduce infection transmission [26,27] led the Department for Environment, Food and Rural Affairs (Defra) to announce that badger vaccination would be delivered through the Badger Vaccine Deployment Project (BVDP) [28].[1]

Badger vaccination to reduce the risk of bTB transmission from wildlife meets the four pre-conditions for risk compensation suggested by Hedlund [1]. A perceived protective effect of vaccination may be balanced by purchasing replacement stock that carries the risk of translocating disease [29,30]. There are no regulations to prevent this, and stock from areas of high disease incidence will be cheaper to purchase than those from herds with a history of disease freedom. A lack of trust between the government and farmers [31], debate over the ownership of disease management, and increasing incidence of bTB may contribute to risk compensation behaviours by encouraging low self-efficacy and fatalistic attitudes amongst farmers [32,33]. Behavioural spillovers such as implementing additional biosecurity measures to limit contact between badgers and cattle may also be connected to vaccination. This may be for two reasons. Firstly, behavioural spillovers may be explained by cognitive dissonance theory [11] and self-perception theory [34] whereby similar behavioural routines are changed to minimise tension with the newly adopted behaviour and the identity they provide. The role of self-identity plays an important role in understanding farmer behaviour in which the cultural idea of 'good farming' [35] influences farmers' decisions. Vaccination may therefore prompt farmers to take further biosecurity precautions to display the symbolic cultural capital of 'good farmers' [36,37]. As with risk compensation, however, these responses may be limited where farmers' low self-efficacy leads them to conclude that there is nothing they can do to prevent disease [33,38]. Secondly, culling can create a perturbation effect in badger populations [39] that increases the risk of disease transmission prompting the need for additional biosecurity. Concerns about perturbation were raised by farmers in public meetings about vaccination attended by members of the research team. In response, Defra stated that observation of long-term research studies of badger populations meant that vaccination was 'very unlikely' to cause perturbation [28], this was subsequently confirmed by analysis which found no evidence of perturbation arising from badger vaccination [40].

2.2. Data

2.2.1. Study areas

Research was conducted between 2010 and 14 in five 100 km^2 areas: one with badger vaccination (the BVDP) [41] and four comparison areas with no vaccination[2]. The BVDP was based in an area of Gloucestershire in which 50% of herds had previously experienced a bTB incident. These herds were compared with those in four similar-sized non-vaccination areas. Three areas with long-standing endemic bTB in cattle were chosen: Great Torrington (Devon), Cheltenham and Tetbury (both Gloucestershire). The final area – Congleton (Cheshire) – was chosen because it had lower bTB incidence in cattle.

2.2.2. Farmer telephone survey

As no official longitudinal records of farmers' biosecurity practices exist, self-reported biosecurity practices and attitudinal data were collected using two telephone surveys. The first survey ran between August-October in 2010 following the commencement of the BVDP. The second was completed three months prior to its completion during October and November 2014. Respondents (farmers) were selected using a stratified sample of 1227 cattle herds across the five areas, drawn from the Animal and Plant Health Agency's (APHA) bTB database.

For each survey area, herds were organised by herd type and size, and every fourth herd listed was selected to be included in the survey. Reserve herds were selected using the same process which were used when a farmer refused to take part in the study (78 in total). Replacement cattle herds were similar to the herd they replaced in terms of farm type and farm size. Sampling was proportional to the number of farms in each area and farm type (beef and dairy) but included more dairy farms than proportionally necessary to enable comparisons between farm types and to allow for longitudinal attrition (see Table 1).

Self-reported data were collected for five biosecurity activities designed to reduce cattle-badger interactions. Attitudinal data on badger vaccination were collected by asking farmers to rate statements along a scale of 1 (strongly disagree) to 5 (strongly agree). Survey items addressed respondents' overall feelings towards badger vaccination, known as their 'general affective evaluation' [42], and their perceptions of effectiveness and acceptability. Farmers were asked to assess their herd's susceptibility to bTB, the extent to which they felt able to prevent bTB ('self-efficacy'), and the role of social norms in disease prevention. Finally, farmers were asked who should pay for vaccination, and to score two dimensions of trust in government: competence and commitment [43].

2.2.3. Observed farmer behaviour – Data on cattle movements

To account for risk compensation behaviour, data from the UK Government's Cattle Tracing System (CTS) were used to identify the number of on-farm cattle movements prior to the survey period (2008–10) and during the final year of vaccination within the

[1] Following a change in government policy in 2013, badger culls funded by farmers have been approved. By 2019, there were 43 farmer-led badger culls across England (see: https://www.gov.uk/government/collections/bovine-tb-controlling-the-risk-of-bovine-tb-from-badgers#licences-and-authorisations).

[2] The BVDP was based only in Stroud. Plans for other vaccination areas were scaled back following a change in government in 2010. Voluntary vaccination projects are funded by government grants, but these were not considered for this study.

Table 1
Characteristics of surveyed farms in comparison to the total population of farms.

	Total herds surveyed/total population						Herd characteristics																	
							Dairy			Beef			Mixed			Dairy			Beef			Mixed		
	Survey N 2010	Survey N 2014	2010 Total Pop.	%	2014 Total Pop.	%	2010 Survey	Total Pop.	%	2010 Survey	Total Pop.	%	2010 Survey	Total Pop.	%	2014 Survey	Total Pop.	%	2014 Survey	Total Pop.	%	2014 Survey	Total Pop.	%
Vaccination area																								
Stroud	79	55	258	30.62	250	22.00	20	67	29.85	22	158	13.92	12	33	36.36	23	66	34.85	25	180	13.89	6	4	150.00*
Non-vaccination areas																								
Cheltenham	48	36	114	42.11	105	34.29	5	10	33.33	13	92	14.13	18	12	150.00*	6	11	54.55	28	86	32.56	2	92	2.17
Tetbury	61	33	148	41.21	135	24.44	9	34	25.71	15	95	15.79	9	19	47.37	8	28	28.57	19	101	18.81	1	6	16.67
Congelton	75	47	426	17.61	420	11.19	20	148	13.42	19	227	8.37	8	51	15.69	23	140	16.43	19	273	6.96	5	7	71.43
Great Torrington	75	49	281	26.69	249	19.68	13	66	19.70	14	189	7.41	22	26	84.62	13	68	19.12	36	177	20.34	0	4	0.00
Total	338	220	1227	27.54	1157	19.01	67	325	20.62	83	761	10.91	69	141	48.94	73	313	23.32	127	823	15.43	14	21	66.67

Notes:
*Reflects differences in herd type classification between official and farmer self-reports.

BVDP (2014). Data were extracted from CTS and matched to surveyed herds using each herd's County, Parish, Holding, Herd (CPHH) unique identification code.

2.2.4. Herd bTB history data

Data on each herd's bTB history were extracted from the APHA's bTB database and matched to surveyed farmers using their CPHH. Data included the number of cattle lost as a result of bTB (known as 'reactors'); and the number of confirmed bTB incidents[3] between 2010 and 14.

2.2.5. Qualitative interviews

Between the two surveys, three annual rounds of face-to-face interviews were carried out with a sub-sample of farmers selected from the baseline survey. In the first round, 65 cattle farmers were interviewed during October and November 2011 in the vaccination area and two non-vaccination areas (Congleton and Great Torrington). Farmers were selected based on their willingness to participate in further research, and their levels of trust in the government and confidence in vaccination identified from responses to the telephone survey. Farmers selected for interview were distributed evenly across four categories representing different levels of confidence in badger vaccination [44] (see Table 2). In the second round of interviews in November-December 2012, 56 farmers were interviewed, and 50 in November-December 2013. Interviews focused on farmers' experience of bTB, their perceptions of the causes of bTB, its management and their confidence in badger vaccination.

2.3. Analysis

Qualitative interviews were fully transcribed and analysed in Nvivo. Analysis sought to identify explanatory themes for farmers' behavioural reactions to vaccination. Responses to the telephone survey were analysed in SPSS. Analysis of spillover behaviour focussed on the five self-reported biosecurity activities relating to badger-cattle interactions. Longitudinal measures of biosecurity practices were calculated from farmers' self-reports in each survey year. Analysis of risk compensation was assessed by examining cattle movement data for each herd.

Quantitative analysis involved, firstly, a descriptive analysis of variables in each survey year and cross-tabulations between key statements and herd characteristics. Secondly, bivariate analysis tested for statistically significant differences between vaccination and non-vaccination areas, bTB status and herd characteristics and variables relating to risk compensation and spillover behaviour. Bivariate analysis used parametric (Pearson correlation, independent and paired samples *t*-test) and non-parametric (Chi-square, Mann-Whitney U and Wilcoxon) tests. Thirdly, multivariable analysis was conducted using a negative binomial log-linear regression. On-farm cattle movements during 2014 acted as the dependent variable. The selection of independent variables was informed by analysis of interview data relating to badger vaccination and disease control; and bivariate correlations to identify similar variables with the weakest relationship with the dependent variable eliminated. The final list of independent variables is shown in Tables 3–5. Count variables were log transformed in SPSS using natural logarithm, with 0.5 added to zero values prior to transformation. Longitudinal change values were calculated by subtracting 2010 values from 2014 values.

[3] Classified as evidence of lesions or culture of *M. bovis* at post-mortem.

2.4. Research ethics

Ethical approval was given by the social research ethics committees at the universities of Gloucestershire and Cardiff. Consent was gained from all research participants: they were provided with information on the project, reminded that their participation was voluntary, and that they could withdraw at any time. Farmers who completed both surveys were entered into a prize draw (£100, £50 and £25 shopping vouchers). Farmers participating in the annual interviews received a bottle of wine after the final interview.

3. Results

3.1. Survey response

The response rate for the baseline survey was 80%, eliciting 338 usable responses and representing 27% of the total population of herds in the case study areas. The repeat survey in 2014 achieved 220 responses, a response rate of 65%, representing 19% of the cattle farmer population in the study areas. Longitudinal attrition varied from 25% (North East of Cheltenham) to 45% (Tetbury. See Table 1). Fifteen farmers dropped out of the longitudinal interviews. Attrition was evenly distributed between the three study areas.

3.2. Descriptive analysis

3.2.1. Herd characteristics

In 2010 the mean herd size was 160, and 167 in 2014 (see Tables 6 and 7). Dairy herds were significantly larger ($p < 0.001$), with 73% of dairy herds having over 100 cattle. Herd sizes in 2010 were highly correlated with those in 2014 ($r = 0.880$, $p < 0.001$). The proportion of herds under bTB restrictions at the time of the survey was similar in both years (16.9% compared to 20.0%). The vaccination area had the largest proportion of herds with bTB at the time of the 2014 survey (22.2%).

3.2.2. On-farm cattle movements

Prior to the survey and deployment of badger vaccination, 85.5% of surveyed farms had on-farm cattle movements. During the survey/vaccination period, this fell to 75.5%. Taking both periods together, 7.3% farms had no on-farm cattle movements. Amongst dairy herds, 94.5% had on-farm cattle movements, and 86.1% of herds that experienced a bTB incident had on-farm cattle movements. Prior to the start of the BVDP in 2010, 69.1% of herds in the vaccination area had on-farm movements compared to 90.9% of farms in non-vaccination areas ($p < 0.001$). Herds that had experienced a bTB incident during the survey period were more likely to have on-farm cattle movements in 2014 ($p < 0.001$).

3.2.3. Biosecurity activities

Farmers' self-reported biosecurity activities were low in both survey years (see Tables 8 and 9). The most common activity was badger-proofing feed stores in 2010 (69.1%) and 2014 (57.1%). Implementation of new activities during the survey period was also low: between 12% (fencing setts and latrines) to 17% (raising feed and water troughs) of farmers reported adopting a new biosecurity activity between 2010 and 14. Farmers in the vaccination area were more likely to fence off badger latrines in 2010 ($p = 0.011$) and 2014 ($p = 0.004$) and fence off badger setts (2010, $p = 0.016$; 2014, $p = 0.002$). Similarly, farmers in the vaccination area were also more likely to start fencing off badger latrines ($p = 0.001$) and setts ($p = 0.001$) between 2010 and 14.

3.2.4. Attitudes to badger vaccination

Farmers' attitudes to vaccination were generally negative in 2010 and became more negative in 2014 (Table 9). By 2014, fewer farmers thought vaccination was acceptable ($p < 0.001$), was a good thing to do ($p = 0.003$), or gave them confidence about avoiding bTB ($p = 0.002$). Farmers' general affective evaluation of vaccination was higher in the vaccination area in 2010 and 2014 ($p < 0.001$). However, these farmers also became more negative over time: fewer thought vaccination was acceptable ($p = 0.032$), had confidence in vaccination ($p = 0.023$), or believed it would reduce their chances of getting bTB ($p < 0.001$) in 2014 than in 2010. Farmers with herds that had suffered a bTB incident between 2010 and 14 were more likely to believe that the government should pay for badger vaccination ($p = 0.008$) and that their herds were susceptible to bTB ($p < 0.001$ both survey years).

3.3. Generalised linear model

Thirteen variables were statistically significant ($p < 0.05$) (see Table 10). The model shows evidence of risk compensation amongst surveyed farmers: those in the vaccination area had more on-farm cattle movements ($p = 0.021$) even when adjusting for a large number of other independent variables. Dairy herds had more on-farm cattle movements ($p < 0.001$) as were larger herds ($p < 0.001$ both years). Herds with bTB reactors in 2014 were not associated with more on-farm movements, but they were in 2010 ($p < 0.001$). Prior cattle movement practices (in 2008–10) were also related to those in 2014 ($p = 0.007$).

Farms that had always fenced off badger setts had the lowest number of on-farm cattle movements. However, only in non-vaccination areas was the relationship between new biosecurity activities and lower cattle movements significant ($p = 0.035$).

Four of the nine longitudinal attitudinal variables were significantly related to cattle movements. Farmers with lower cattle movements were more likely to have a positive general affective evaluation of vaccination ($p = 0.001$) and increasing levels of self-efficacy ($p = 0.006$). Farmers who believed they had become more susceptible to bTB moved on fewer cattle ($p = 0.041$), as did those who increasingly thought that the government should pay for vaccination ($p < 0.001$). On-farm cattle movements were not connected to trust in government or social norms.

In the non-vaccination areas, farmers who believed that the government should pay for vaccination had higher on-farm cattle movements ($p = 0.005$). In the vaccination area, farmers moved on fewer cattle if they believed badgers posed a risk to their bTB status ($p = 0.004$).

3.4. Qualitative interviews with farmers

Analysis of qualitative interviews revealed that vaccination failed to fit with farmers' cultural understandings of disease. This stemmed, firstly, from farmers' beliefs that the spread of bTB was due to a rise in the badger population. Farmers therefore believed the most effective disease control measures would be to reduce the badger population. These arguments were connected to farmers' broader cultural understandings of nature that emphasised the need for a "natural balance". In distinguishing between 'healthy' and 'diseased' badgers, farmers argued that healthy badgers needed to be protected to ward off diseased badgers, whilst those that were diseased needed to be euthanised.

Secondly, badger vaccination proved unpopular because it lacked 'practice similarity' – in that its practicalities were dissimilar to other vaccination practices that farmers employed. Explaining their opposition to badger vaccination, farmers consistently drew on their own experiences of vaccinating cattle against other diseases. Farmers argued that vaccinating badgers that were

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Table 2
Interviewees by type of and category of vaccination confidence.

	Vaccination area			Non-vaccination areas						Total		
				Congleton			Great Torrington					
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Acceptance	9	9	9	6	5	5	4	3	2	19	17	16
Distrust	4	2	2	3	3	2	7	6	6	14	11	10
Critical Acceptance	3	3	3	5	4	3	5	4	4	13	11	10
Critical Trust	4	4	3	8	6	6	7	7	5	19	17	14
Total	20	18	17	22	18	16	23	20	17	65	56	50

Table 3
Herd characteristic variables used in the Generalised Linear Model.

Concept	Dimension	Variable name	Variable type	Data type	Source
Herd management characteristics	Movements 2010–2014	2014Movements	Dependent	Count	CTS
	Movements 2008–2010	movementslog200810	Independent	Count, log transformed using natural logarithm	
Herd characteristics	Herd Size 2010	herdsizelog2010	Independent	Count, log transformed using natural logarithm	APHA bTB Dataset
	Herd Size 2014	herdsizelog2014	Independent		
Herd disease characteristics	Number of bTB Reactors 2008–2010	reactors2010log	Independent		
	Number of bTB Reactors 2010–2014	reactors2014log	Independent		
Vaccination	In the BVDP area	In bvdp (2010)	Independent	Dummy variable (vaccination/not vaccination)	
Herd type	Dairy herd	Dairy Herd in 2014	Independent	Dummy variable (dairy/not dairy)	APHA bTB Dataset / Survey

Table 4
Survey variables used in the Generalised Linear Model.

Concept	Dimension	Survey question	Variable type	Data type
Longitudinal attitudes to vaccination 2010–2014	Vaccine acceptability	Badger vaccination is an acceptable way of dealing with bTB	Independent	1–5 Scale (strongly disagree – strongly agree) Calculated scale (2014 minus 2010 value): −4 (more negative) to + 4 (more positive)
	Vaccine general affective evaluation	think vaccinating badgers is a good thing to do	Independent	
	Vaccine effectiveness	Badger vaccination will help me feel more confident about avoiding TB restrictions	Independent	
	Vaccine responsibility	Paying for badger vaccination should be the Government's responsibility	Independent	
	Vaccine self-efficacy	It's a matter of luck if my herd goes down with bTB*	Independent	
	Vaccine social norms	My chances of getting TB are lower if I follow what other farmers in the area do	Independent	
	Disease susceptibility	My herd is susceptible because of badgers on or near my farm	Independent	
	Trust in government: commitment	The Government is committed to reducing bTB	Independent	
	Trust in government: competency	The Government is doing a good job in relation to bTB	Independent	
Longitudinal biosecurity spillover activities	Fence off badger setts	Which of the following activities have you undertaken on your farm: Fencing off Badger Setts	Independent	Yes/no Longitudinal categories calculated from 2010 and 2014 responses: Never; Adopted by 2014; Always had; Stopped by 2014**

Notes:
* Reversed scale.
** Converted to dummy variables for analysis in GLM.

already infected was pointless, and just like their own approach to herd-health, badgers would need to be tested to see which ones were infected (and culled) whilst the remainder were vaccinated. Equally, farmers' experiences of vaccinating all cattle against diseases other than bTB, meant that in their view, badger vaccination would work only if 100% of badgers were vaccinated. Farmers thought this was impractical at the scale at which the vaccine needed to be administered.

Practicality was also a key reason in dismissing potential spillover behaviours such as biosecurity. Farmers suggested these would involve significant cost or disruptive changes to farm management. The challenges of effectively separating cattle from badgers at pasture was frequently cited as one reason for not implementing biosecurity, which was matched by widespread concern that farmers were unable to control bTB and that it was simply a matter of bad luck. These fatalistic attitudes towards

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Table 5
Descriptive statistics of variables used in the Generalised Linear Model.

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Percent
No. on-farm cattle movements 2014	198	0.00	6064.00	301.32	662.80	–
Herd size 2010 (Log)[1]	198	−0.69	7.31	4.11	1.80	–
Herd size 2014 (Log)[1]	198	−0.69	7.38	4.11	1.88	–
On-farm cattle movements 2008–10 (Log)[1]	198	−0.69	8.96	3.88	2.32	–
No. reactors 2010 (Log)[1]	198	−0.69	5.72	1.12	1.86	–
No. reactors 2014 (Log)[1]	198	−0.69	4.32	0.28	1.34	–
In vaccination area	198	0.00	1.00	0.26	0.44	–
Dairy Herd	198	0.00	1.00	0.33	0.47	–
Vaccine acceptability	198	−3.00	3.00	−0.37	1.28	–
Vaccine general affective evaluation	198	−4.00	3.00	−0.26	1.26	–
Vaccine effectiveness	198	−4.00	3.00	−0.36	1.29	–
Vaccine responsibility	198	−4.00	3.00	0.09	0.98	–
Vaccine self-efficacy	198	−4.00	4.00	0.16	1.29	–
Vaccine social norms	198	−3.00	3.00	0.02	1.20	–
Disease susceptibility	198	−4.00	3.00	0.08	1.16	–
Trust in government: commitment	198	−3.00	3.00	−0.01	1.28	–
Trust in government: competency	198	−3.00	3.00	−0.30	1.37	–
Never fenced badger setts	135.00	0	1	–	–	68.20%
Fenced badger setts in 2014	26.00	0	1	–	–	13.10%
Always have fenced badger setts	17.00	0	1	–	–	8.60%
Stopped fencing badger setts by 2014	20.00	0	1	–	–	10.10%

Notes
[1] Natural log transformation applied to variables.

Table 6
Characteristics of all herds in the research areas.

		No Herds (n)	Under bTB Restrictions at time of 2010 survey		Confirmed bTB incidents(mean)	Days under bTB restriction (mean)	Number of reactors (mean)	Movements 2008–10 (mean)	Herd size (mean)
			n	**%**					
Vaccination area									
Stroud	Dairy	67	12	17.91	2.57	827.93	34.94	295.59	214.69
	Beef	158	12	7.59	2.32	330.45	8.6	355.7	83.49
	Mixed	33	3	9.09	1.67	215.73	3.33	307.27	51.32
	Total	258	27	10.47	2.35	444.97	14.77	333.75	116.35
Non-vaccination area									
Cheltenham	Dairy	10	4	40.00	2.78	1232.0	97.60	329.22	238.6
	Beef	92	16	17.39	2.52	534.55	17.78	155.07	88.3
	Mixed	12	0	0.00	1.67	125.58	2.0	63.25	46.17
	Total	114	20	17.54	2.52	552.68	23.12	163.48	100.32
Tetbury	Dairy	34	5	14.71	2.37	760.0	27.65	474.69	305.7
	Beef	95	12	12.63	1.80	202.66	4.62	145.34	68.75
	Mixed	19	3	15.79	1.88	156.58	3.95	317.87	71.94
	Total	148	20	13.51	2.01	324.78	9.82	241.86	123.45
Congleton	Dairy	148	14	9.46	1.89	267.22	17.76	271.89	164.35
	Beef	227	7	3.08	1.24	66.11	1.49	97.03	40.23
	Mixed	51	1	1.96	1.38	54.9	1.53	132.16	55.65
	Total	426	22	5.16	1.63	134.64	7.15	164.81	87.34
Great Torrington	Dairy	66	16	24.24	2.20	1047.5	41.77	395.7	330.52
	Beef	189	15	7.94	1.86	309.25	6.28	163.66	83.19
	Mixed	26	1	3.85	1.25	211.58	3.46	166.72	72.72
	Total	281	32	11.39	1.96	473.61	14.36	222.18	141.81
Total	Dairy	325	51	15.69	2.24	622.51	29.67	324.37	225.3
	Beef	761	62	8.15	2.01	255.06	6.52	181.78	69.38
	Mixed	141	8	5.67	1.57	141.15	2.67	200.06	60.52
	Total	1227	121	9.86	2.07	339.3	12.21	223.47	111.76

biosecurity were reinforced by a belief – particularly amongst dairy farmers – that these activities did not benefit their own social or economic status.

In the vaccination area, the visibility of vaccination itself was also limited. Farmers' contact with the team delivering vaccination varied markedly. Some farmers knew the number of badgers that had been vaccinated but others raised concerns about the level of communication they had received from scientists running the project. Some farmers claimed they had "no idea" when the last or next time badgers would be vaccinated on their farm. Those that had a bTB outbreak during the BVDP questioned whether vaccination had contributed to the incident. In short, the lack of visibility of the very intervention that could prompt spillover behaviours is likely to have negatively impacted upon farmers' perceptions of the need for other complementary biosecurity behaviours.

The politics of badger vaccination and disease control were also of significance to farmers. Interviews revealed a lack of trust in the government to deal effectively with bTB. Farmers suggested the

Table 7
Characteristics of surveyed herds.

		Herd size (mean)		Confirmed bTB incidents (mean)		Cattle movement (mean)		Days under bTB restriction (mean)		Number of bTB Reactors (mean)		Herds under bTB restriction (%)	
		2010	2014	2010	2014	2008–10	2014	2010	2014	2010	2014	2010	2014
Vaccination area													
Stroud	Dairy	260.5	247.61	2.32	1.09	290.55	908.52	939.2	156.87	35.84	4.83	40.0	26.09
	Beef	161.32	151.36	1.33	0.44	457.59	107.32	380.1	99.48	6.57	3.08	27.27	20.0
	Mixed	61.92	91.67	0.33	–	33.0	20.17	101.33	29.67	3.17	–	–	16.67
	All	175.96	185.72	1.46	0.67	301.37	438.89	527.96	116.17	16.48	3.48	25.93	22.22
Non-vaccination areas													
Cheltenham	Dairy	147.8	153.33	2.80	0.50	237.0	252.67	1406.6	217.17	152.4	1.33	20.0	66.67
	Beef	211.0	131.75	1.54	0.93	604.23	132.14	499.00	118.96	20.31	4.64	15.38	10.71
	Mixed	94.89	15.5	2.06	1.00	145.22	40.0	555.18	123.5	19.17	4.0	22.22	–
	All	144.17	128.89	1.97	0.86	323.72	147.11	655.94	135.58	38.08	4.06	19.44	19.44
Tetbury	Dairy	373.33	453.75	2.11	1.13	434.22	1442.13	848.56	250.63	17.11	15.63	22.22	50.0
	Beef	56.40	58.0	1.14	0.58	109.33	91.47	171.14	90.84	4.86	2.74	–	5.26
	Mixed	49.78	150.0	0.89	–	71.78	25.0	203.22	–	3.89	–	11.11	–
	All	141.03	174.36	1.34	0.71	187.7	475.0	370.69	133.25	8.03	6.32	9.09	17.86
Congelton	Dairy	260.0	212.48	1.37	0.57	318.25	417.43	307.8	63.22	14.0	4.04	10.0	9.09
	Beef	72.63	73.11	0.47	0.32	112.79	38.89	119.63	44.0	3.16	3.11	10.53	5.26
	Mixed	30.71	147.2	0.25	0.40	84.5	366.4	60.38	5.4	0.88	4.20	–	20.0
	All	145.22	149.19	0.80	0.45	195.4	258.98	189.62	49.3	7.24	3.68	8.51	8.7
Great torrington	Dairy	316.0	351.15	2.67	1.15	399.23	874.46	1334.08	219.62	57.5	7.77	53.85	15.38
	Beef	180.43	132.28	0.86	0.33	329.71	72.94	394.79	144.22	7.43	1.31	35.71	13.89
	Mixed	111.73	–	0.73	–	114.73	–	283.05	–	4.45	–	18.18	–
	All	185.55	190.35	1.25	0.55	251.63	285.59	578.4	164.22	18.58	3.02	32.65	14.29
Total	Dairy	278.14	269.82	2.11	0.89	335.21	752.3	842.71	153.77	39.89	6.0	29.85	25.0
	Beef	133.06	115.95	1.05	0.52	317.12	90.44	304.51	106.87	7.83	2.87	18.07	11.81
	Mixed	81.94	104.79	0.97	0.29	99.36	147.0	282.25	32.29	7.58	2.07	13.04	14.29
	All	161.17	167.71	1.34	0.63	254.05	319.92	462.68	117.99	17.34	3.89	20.09	16.43

Table 8
Longitudinal changes to biosecurity activities.

		Never had	Adopted in 2014 but not 2010	Always had	Used in 2010 but not in 2014	x^2
Non-vaccination area	Fence Latrines	86.6%	10.4%	1.2%	1.8%	0.001
	Fence Setts	76.8%	8.5%	7.3%	7.3%	0.001
	Secure Buildings	46.6%	14.1%	28.8%	10.4%	0.791
	Badger proofing	12.9%	15.3%	42.3%	29.4%	0.100
	Raising Troughs	23.2%	18.3%	31.7%	26.8%	0.126
Vaccination area	Fence Latrines	66.7%	16.7%	13.0%	3.7%	0.001
	Fence Setts	48.1%	22.2%	13.0%	16.7%	0.001
	Secure Buildings	48.1%	18.5%	25.9%	7.4%	0.819
	Badger proofing	25.9%	13.0%	42.6%	18.5%	0.107
	Raising Troughs	25.9%	13.0%	46.3%	14.8%	0.124

ownership of the problem lay with the government and policy initiatives for encourage farmers to 'take ownership' of bTB [45] were viewed suspiciously. It was common for farmers to suggest that ideas of responsibility had been pushed onto the agricultural industry because of government failings. Farmers therefore perceived the government to be handing over their 'dirty work'. The government's failure to implement a badger cull policy in 2011 also contributed to the belief that they could not be trusted to manage bTB effectively.

4. Discussion

The strongest predictors of cattle movements were herd-level characteristics, such as herd size and type, prior disease incidence and management methods. Whilst the analysis shows these to be related to on-farm cattle movements, they are also well established risk factors for bTB [32]. The analysis therefore suggests the presence of a cycle of infection: movements in 2008–10 are related to disease incidence in subsequent years, which are further related to subsequent cattle movements. As highlighted by the qualitative research, these herd management practices can be difficult to change, reflecting what Sutherland et al. [46] refer to as 'path-dependent' behaviours. Path-dependency may depend on social, economic and environmental factors, but disrupting these embedded behaviours requires specific triggers to prompt change. Potential triggers include disease outbreaks, and potentially government interventions and/or significant policy changes. In this case, however, disease incidence seems to be an insufficient disruption to existing deeply embedded farming practices. This may lead not only to an embedded cycle of disease, but also reinforces existing behaviours and may explain the limited adoption of biosecurity activities.

This explanation also applies to the relative lack of spillover activities. There is only limited evidence of spillover in the vaccination area and adoption was only significantly higher in the vaccination area for two of the five biosecurity activities. For those farmers that did report new biosecurity activities, the outstanding question is why? It could be these increases represent a form of social desirability bias [47] in which farmers have become more aware of the conduct expected of them by government. There is little evidence though that implementing new biosecurity activities is related to 'good farming' cultural identities [35]. Being seen to be a 'good farmer' and practice 'good farming' can be relevant in the adoption

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Table 9
Descriptive statistics and bivariate analysis of vaccine attitudes and biosecurity activities.

	Survey Year	All herds Mean/%	Dairy herds Mean/%	Vaccination area Mean/%	TB free herds Mean/%	Herds with on-movements (2014) Mean/%
Badger vaccination is an acceptable way of dealing with bTB	2010	2.93	2.81	3.07	3.02	2.91
	2014	2.56***	2.36	2.67	2.70	2.56
Paying for badger vaccination should be the Government's responsibility	2010	4.17	4.33++	4.31	4.15	4.15
	2014	4.26	4.25	4.29	4.10+++	4.28
I think vaccinating badgers is a good thing to do	2010	3.13	3.13	3.53+++	3.19	3.13
	2014	2.87***	2.95	3.24+++	2.94	2.90
Badger vaccination will help me feel more confident about avoiding TB restrictions	2010	2.95	2.85	3.04	3.03	2.98
	2014	2.61**	2.47	2.60	2.69	2.60
Badger vaccination will reduce the chances of my herd going under bTB restrictions	2010	3.19	3.16	3.35	3.19	3.19
	2014	2.91***	2.90	2.69	2.89	2.86
The Government is doing a good job in relation to bTB	2010	2.53	2.39	2.11−−−	2.73+++	2.48
	2014	2.24***	2.21	2.45	2.30	2.25
The Government takes its commitments to reducing bTB seriously	2010	3.19	3.05	2.95-	3.30	3.14
	2014	3.23	3.18	3.20	3.27	3.21
The Government cares about reducing bTB	2010	3.72	3.61	3.52	3.75	3.68
	2014	2.74***	2.67	2.67	2.77	2.77
My herd is susceptible because of badgers on or near my farm	2010	4.02	4.34+++	3.83	3.78+++	4.10+
	2014	4.07	4.19	3.78	3.79+++	4.09
It is a matter of luck if my herd goes down with bTB (reversed scale)	2010	2.22	2.29	2.28	2.15	2.26
	2014	2.33	2.56	2.73+++	2.39	2.31
My chances of getting TB are lower if I follow what other farmers in the area do	2010	2.73	2.90	2.57	2.78	2.69
	2014	2.84	2.83	2.73	2.87	2.77
Without fence off badger latrines	2010	91.8%	90.4%	83.6%−	93.9%	92.1%
	2014	83.0%**	79.5%	70.4%−−	86.0%	81.7%
Without fence off badger setts	2010	81.7%	72.6%−−	70.9%−	85.2%	80.0%
	2014	79.4%	75.3%	64.8%−−	83.3%	81.1%
Without secure buildings from badgers	2010	62.1%	57.5%	67.3%	62.3%	59.0%
	2014	56.7%	56.2%	55.6%	57.9%	54.6%
Without badger proof feed stores	2010	30.9%	30.1%	40.0%	34.8%	28.3%
	2014	42.9%**	43.8%	44.4%	44.7%	41.7%
Without raised feed and water troughs	2010	40.6%	36.1%	40.0%	44.3%	38.2%
	2014	47.7%	41.1%	40.7%	56.1%−−	43.9%

Notes:
Within-year comparisons (Independent samples *t*-test/Mann-Whitney *U* test).
−/+ sig. $p < 0.05$.
−−/++ $p < 0.01$.
−−−/+++ $p < 0.001$.
2010–2014 Comparisons (Paired samples *t*-test/Wilcoxon sign test).
*sig. $p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

of some biosecurity management practices [36,37]. Likewise, studies of spillover suggest that the visibility of new behaviours can help to reinforce and publicly affirm positive subjectivities such as the 'responsible citizen' [48]. In this case however, the low-level adoption of biosecurity may instead reflect the activities of 'niche' identities that are yet to become mainstream [46]. Helping these cultural identities to become established is a challenge facing policy makers. New methods to make the benefits of biosecurity publicly visible and disrupt existing social norms amongst farmers could help. This could include, for example, the mandatory use of bTB herd risk ratings to regulate cattle purchasing [38]. As well as potentially contributing to spillover, these methods could also limit risk compensation behaviour in wildlife control areas.

Further research is therefore required to establish the reasons why a minority of farmers adopt new biosecurity measures, and the extent to which they count as spillover from badger vaccination or other initiatives. In general, however, the failure to implement new forms of biosecurity is more readily explained by the attitudes held by farmers displayed in both the surveys and the qualitative research. The consistency of these attitudes, showing little change between 2010 and 14, suggests that triggers like disease outbreaks or new disease control policies (such as vaccination) have little impact upon existing attitudes or behaviours.

In terms of risk compensation, the analysis finds conflicting evidence. On the one hand, the evidence suggests an association between risk compensation behaviours and badger vaccination. Separate analysis of farms in the vaccination area shows reduced on-farm cattle movements for farmers who increasingly thought vaccination was a good thing to do, that bTB was not down to luck, and with perceptions of increasing bTB risk. Potentially, changes in these attitudes may reflect a form of educational spillover from vaccination that modifies farmer behaviour. In general, however, attitudes towards vaccination were negative and the government was distrusted to manage bTB. Moreover, whilst farmers were aware they were in a vaccination area, frequently they were unaware of whether their badgers had been vaccinated and felt distanced from the practice of vaccination. Further research is therefore required to unpack how interventions such as vaccination encourage new behaviours and farming practices. For example, to what extent do factors specific to the vaccination area, not accounted for in the model, explain farmers' behaviour? One possibility might be the role of social networks and the significance of influential advisers such as local veterinarians.

Of particular importance to policy makers is the relationship between cattle movement practices and self-efficacy, and attitudes to the ownership of disease management. Firstly, low levels of self-efficacy – such as the fatalistic views of bTB transmission and the role of luck – replicate earlier qualitative research on farmers' understandings of bTB [33]. Results presented here show for the first time how these low levels of self-efficacy can impact upon

Table 10
Results – negative binomial with log link Generalised Linear Model for 2014 on-farm movements, p-values < 0.05 are shown in bold.

Parameter	All respondents				Not in vaccination area				In vaccination area			
			95% Wald Confidence Interval for Exp (B)				95% Wald Confidence Interval for Exp (B)				95% Wald Confidence Interval for Exp (B)	
	Sig.	Exp(B)	Lower	Upper	Sig.	Exp(B)	Lower	Upper	Sig.	Exp(B)	Lower	Upper
(Intercept)	**<0.001**	6.232	3.011	12.897	**<0.001**	6.023	2.318	15.646	0.169	0.167	0.013	2.139
Never fenced setts	**0.039**	0.569	0.333	0.972	0.108	0.545	0.260	1.142	0.751	1.236	0.334	4.581
Fenced setts in 2014 but not 2010	**0.010**	0.415	0.213	0.809	**0.022**	0.320	0.121	0.850	0.726	1.234	0.381	3.994
Always fenced setts	**<0.001**	0.279	0.138	0.563	**0.035**	0.336	0.122	0.924	0.110	0.304	0.071	1.308
Stopped fencing setts in 2014[a]	.	1.000	.	.	.	1.000	.	.	.	1.000	.	.
Herd size 2010	**<0.001**	1.267	1.133	1.417	**0.021**	1.171	1.024	1.339	**<0.001**	3.003	1.654	5.453
Herd size 2014	**<0.001**	1.329	1.170	1.510	**<0.001**	1.411	1.193	1.669	0.486	1.136	0.793	1.628
No. reactors 2010	0.464	1.046	0.927	1.180	0.084	1.136	0.983	1.311	0.374	0.847	0.588	1.220
No. reactors 2014	**<0.001**	1.392	1.231	1.574	**<0.001**	1.336	1.143	1.562	0.732	1.066	0.740	1.535
No. on-farm cattle movements 2008–10	**0.007**	1.152	1.040	1.277	**0.006**	1.192	1.051	1.353	0.118	1.227	0.949	1.587
In vaccination area	**0.021**	1.580	1.070	2.334	.	1.000	.	.	.	1.000	.	.
Dairy herd	**<0.001**	3.539	2.443	5.125	**<0.001**	2.639	1.668	4.173	**0.015**	3.347	1.261	8.882
Vaccine Acceptability	0.157	1.131	0.954	1.341	0.213	1.140	0.928	1.401	0.678	0.910	0.582	1.422
Vaccine general affective Evaluation	**0.001**	0.728	0.600	0.884	0.133	0.839	0.667	1.055	0.072	0.620	0.368	1.044
Vaccine effectiveness	0.162	1.126	0.953	1.330	0.446	1.086	0.879	1.342	0.621	1.122	0.712	1.767
Vaccine responsibility	**<0.001**	1.332	1.138	1.558	**0.005**	1.291	1.079	1.546	0.099	1.418	0.937	2.147
Vaccine self-efficacy	**0.006**	0.841	0.744	0.951	0.624	0.960	0.814	1.131	0.089	0.788	0.598	1.037
Vaccine social norms	0.405	1.054	0.931	1.195	0.355	1.068	0.929	1.229	0.774	0.938	0.606	1.453
Disease susceptibility	**0.041**	0.875	0.769	0.994	0.743	1.030	0.863	1.229	**0.004**	0.668	0.509	0.877
Trust in government: Commitment	0.977	1.002	0.875	1.147	0.800	0.979	0.829	1.155	0.189	1.258	0.893	1.772
Trust in government: Competency	0.471	1.053	0.916	1.210	0.447	1.068	0.901	1.266	0.819	0.947	0.595	1.508

Notes:
a This category is the baseline against which "Never fenced setts", "Fences setts in 2014 but not 2010" and "Always fenced setts" are compared.

the transmission of bTB by being significantly related to on-farm cattle movements. This shows the importance to policy makers of taking farmers' self-efficacy seriously when managing disease: when farmers lose faith in disease management and their ability to do anything about disease, their actions may increase disease risks. This may explain the apparent conflict between risk compensation and farmers' sceptical attitudes towards vaccination effectiveness. Rather than beliefs in vaccination effectiveness driving risk compensation, as Hedlund's conditions would suggest, higher levels of on-farm cattle movements in vaccination areas may be attributable to farmers' perceived lack of alternative options or their belief that any risk reduction measures they take will be ineffective.

Secondly, both qualitative and quantitative data revealed how farmers believed that it was the government's responsibility to deal with bTB, and where they did they were more likely to engage in risky behaviour and eschew risk reduction measures. This is significant for two reasons. Firstly, the governance of disease and its 'ownership' by the farming industry has been cited as a key factor in successful disease eradication programmes [49,50]. These results suggest that attempts to encourage a greater sense of ownership of bTB amongst English farmers is required if they are not to undermine the efforts of disease management policy. This could include allowing farmers greater say in the governance of disease and/or the use of financial levies to both fund disease control and help develop a collective sense of responsibility [38]. These findings also suggest that perceptions of 'ownership' need to be added to Hedlund's preconditions of risk compensation. In this sense, it is not enough to simply have confidence in a disease control intervention, such as vaccination, to reduce the perception of risk. Rather, interventions need to be delivered by and paid for by the people or agencies perceived to be the most appropriate: those that are not are unlikely to succeed. It is not clear, however, whether ownership is more or less relevant to all interventions, or whether those that fit cultural understandings of disease management (in this case, badger culling) means it is less significant. Further research is therefore required to assess the extent of risk compensation and its relationship with other wildlife control measures.

These findings also confirm wider concerns in the spillover literature. Analysis confirms that farmers appear to be consistent in their risk-taking: either adopting biosecurity and reducing cattle movements, or vice-versa. Given concerns about the ownership of disease, this may not be surprising: there was no cost of vaccination to farmers and as such they are likely to have placed little value on it. Moreover, previous studies suggest that spillover occurs when new practices are functionally and culturally similar to those that are already used [11]. This research confirms this in two ways. Spillover behaviours depend on the similarity between related but different practices – referred to as 'practice similarity'. In this case, badger vaccination was not perceived to be similar to farmers' existing herd health management practices. Badger vaccination was also inconsistent with farmers' cultural beliefs on disease transmission and the management of wildlife. Other social research of veterinary vaccines finds similar results. For example, Heffernan, Thomson [51] shows how the use of vaccines for Foot and Mouth Disease in Bolivia did not relate to factors such as efficacy, but to a match between cultural beliefs of disease aetiology and lay beliefs about how vaccines work.

The study has a number of limitations that should be addressed by further research. Firstly, there was only one vaccination area and it was not large. External validity would be improved with comparative data from vaccination areas in other parts of England and Wales with different farming characteristics and bTB infection risk. Secondly, using the number of on-farm cattle movements as an example of risk compensation does not take into account their degree of risk. Taking into account the disease histories of purchased cattle in further analysis would help to inform policy decisions over the need to introduce risk-based trading schemes to limit cattle movements [21]. The contextual nature of farming decisions highlights the importance of on-going detailed social research. In particular, research targeted at understanding the

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decision making process in cattle purchasing decisions [52] would provide a greater level of understanding to risk compensation behaviour. Finally, risk compensation (or spillover) following vaccination may be encountered in different disease contexts (exotic and endemic diseases) and for different animals (farmed and companion). Further research in all these different contexts can help provide a broader understanding of how and why behavioural adaptions to animal health interventions occur.

5. Conclusion

Integral to an understanding of how animal disease control interventions work is an appreciation of what behavioural changes they provoke. This paper has investigated for the first time whether risk compensation and/or spillover behaviours are associated with the vaccination of wildlife to control the spread of animal disease. Evidence of these behavioural reactions is important for policy makers in order to effectively plan disease control interventions. In focusing on the behavioural impacts amongst farmers of badger vaccination, this paper finds limited evidence of spillover behaviour whilst apparent risk compensation behaviour may be better explained as a reaction to low self-efficacy and a poor match between vaccination and farmers' cultural understandings of disease management. Crucially, perceptions of the ownership of disease management appear to be linked to farmers' disease management practices that may also contribute to a reinforcement of existing behaviours. The results provide important lessons for policy makers seeking to manage the spread of animal disease. Given their importance, further research should be directed to analyses of risk compensation and spillover behaviours in relation to other disease control measures and uses of vaccination for other animal diseases.

Declaration of Competing Interest

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Author contributions

GE, DM, and RF designed the research project and collected data. Analysis was led by GE and CAD with assistance from LB and SHD. The manuscript was drafted by GE in association with all other authors.

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