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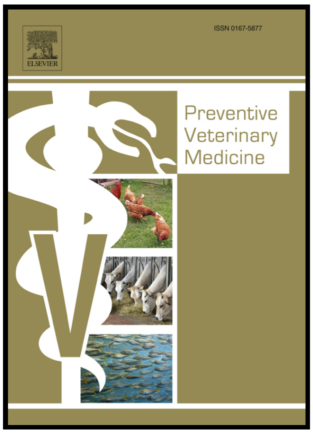

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Financial impacts of a housing order on commercial free range egg layers in response to highly pathogenic avian influenza

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Abstract

Recent annual outbreaks of Highly Pathogenic Avian Influenza (HPAI) have led to mandatory housing orders on commercial free-range flocks. Indefinite periods of housing, after poultry have had access to range, could have production and financial consequences for free range egg producers. The impact of these housing orders on performance of commercial flocks is seldom explored at a business level, predominantly due to the paucity of commercially sensitive data. The aim of this paper is to assess the financial and production impacts of a housing order on commercial free-range egg layers. We use a unique data set showing weekly performance of layers gathered from 9 UK based farms over the period 2020-2022. These data cover an average of 100,000 laying hens and include two imposed housing orders, in 2020/2021 and in 2021/22. We applied a random intercept linear regression to assess impacts on physical outputs and inputs, bird mortality and the impacts on revenue, feed costs and margin over feed cost. Feed use and feed costs per bird increased during the housing order which is a consequence of increased control over diet intake in housed compared to ranged birds. An increase in revenue was also found, ostensibly due to a higher proportion of large eggs produced, leading to a higher margin over feed cost. Overall, these large commercial poultry sheds were able to mitigate some of the potential adverse economic effects of housing orders. Potential negative impacts may occur dependant on the duration of the housing order and those farms with less control over their input costs.

Keywords

Free Range Egg Layers; Highly Pathogenic Avian Influenza; animal health economics; Multilevel Models

1.0 Introduction

Avian Influenza (AI) has been present in birds for at least 100 years (Fouchier et al., 2013; Capua and Alexander, 2009). Highly pathogenic variants of AI (HPAI) are the result of the evolution of these strains and result in broad transmission pathways across wild and domestic species (Olsen et al., 2006; Smith et al., 2009). HPAI is zoonotic and the H5N1 variant has caused some concern that infection has led to a number of deaths in humans (WHO, 2021; Gashaw, 2020). HPAI's zoonotic potential makes it a particularly pertinent example of a vector for a future pandemic (Avian Influenza Working Group, 2008). Whilst the current risk is low to humans there are significant environmental and social impacts of HPAI. These include the loss of wild bird species (Calienco et al., 2020), potential spread to other mammals (Floyd et al., 2021), as well as the economic impacts of closure of coastal and wild bird habitats (Subadra, 2021). Moreover, there is a high public expenditure burden on clean-up of sites, and concerns over transmission to mammals (Mahase 2023).

Zilberman *et al*. (2012) proposed that ex-ante prevention over an indefinite time horizon may be a more costly exercise than ex-post control. HPAI's evolution and transmission leads to such an indefinite time horizon and current ex-ante solutions to HPAI tend to revolve around hypothetical breeding schemes using genetic modification (Looi et al., 2018) or breeding for selective traits (Drobik-Czwarno et al., 2019) which do not offer solutions in the short-run. Those solutions that are available include pre-emptive culling as an emergency measure within a set radius of an outbreak (Backer et al., 2015). An alternative that has been explored in more detail is vaccination, either ex-ante for all flocks, or ex-post for those infected. An ideal vaccine has the advantage of allowing chickens to continue to roam and, thus, maintain welfare conditions, whilst also minimising disruption in the production cycle for producers.

Most economic studies have tended to explore either ex-ante or ex-post control costs at a multinational, country or regional level. The bulk of economic work on HPAI model a range of interventions to identify the financial impacts of an AI outbreak on the sector as a whole (Paarlberg et al.,2007; Boni et al., 2013; Ramos et al., 2017; Wieck et al., 2012). These studies tend to ignore the distinction between free range and caged birds, and some do not consider the economic implications of housing as part of the intervention strategy, but instead focus on vaccination (Roy, 2008; Liu et al., 2019; Egbendewe-Mondzozo *et al*., 2013). These studies find benefits exceed the costs both in the high and low income contexts. Whilst Mo et al (2023) find a strong efficacy in potential vaccine strains for avian influenza they do not guarantee zero transmission between birds. As such Governments are reluctant to implement vaccination due to, amongst others, the impact on international trade. The UK government sees development of an effective vaccine as a priority and has established a task force to consider this as a strategy[1]. Therefore, we can assume that the current cycle of imposing housing orders will continue as a means to control HPAI in UK flocks.

At the farm level, Beech et al (2007) built a hypothetical model on the farm level impacts of avian influenza to determine the socially optimal level of investment for public and private sectors during a hypothetical outbreak. Meuwissen et al (2016) coupled an epidemiological model with a model of financial impacts to estimate the uncertainties around a HPAI infection in the Netherlands. Nevertheless, Shockley *et al.* (2020) point out the paucity of empirical studies focused on farm-level impacts in more commercial systems. They explore a financial model of two typical commercial US broiler farms built from a set of empirically derived estimates and model the long-term

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[1] https://www.gov.uk/government/groups/bird-flu-avian-influenza-vaccination-task-force

financial impact of an AI outbreak. They found the impact was most severe for new (referred to as ‘beginner’) farmers, but impacts were more severe due to the timing and length of the outbreak. These studies do not focus on egg layers, nor provide estimates of housing impacts on these units.

The few studies that consider both free-range production and HPAI outbreaks do not examine economic impacts (Gonzales et al., 2021; Glass et al., 2019). In our review of studies only one unpublished study has focused on the financial effects of restricting the movement of free-range egg layers at the farm level (Poultry World, 2017). This explored the 2016/2017 outbreak through a survey of free-range producers in Northern Ireland and failed to find any discernible changes in production after the initial shock of housing. The authors found fewer abnormal eggs than expected in free-range, and an overall increase in egg size due to higher and more controlled feed intake. More pertinently this study found a negative economic impact as feed consumption increased without a significant increase in mass of output[2].

Direct costs are incurred by commercial poultry keepers and a range of measures have been proposed for managing HPAI in commercial flocks, including mass vaccination, pre-emptive culling and heightened biosecurity (Sims, 2007; Liu et al., 2020). For free-ranging flocks housing orders, coupled with heightened biosecurity, have been the main preventative measure (Kaleta et al., 2007; Verhagen et al., 2021; EFSA, 2021;2022;2023). The housing order requires all poultry to be kept indoors and maintenance of heightened biosecurity measures, such as changing clothes and footwear when entering poultry sheds. The aim of a housing order is to separate domestic and commercial poultry from wild birds and other potential sources of HPAI by imposing a set period in which poultry remain housed and restricted from ranging. Housing reduces the risk of incursion should the flock become infected with HPAI (Tammes, 2024). The recent HPAI outbreaks in 2020/21 and 2021/22 have led to extended periods of imposed housing for free-range flocks in the UK and other countries.

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[2] https://poultry.network/4680-4-key-things-to-know-about-a-free-range-poultry-housing-order/

Commercial free-range egg producers are affected in a number of ways by housing during a production cycle, on supply and changes to point of sale eggs, e.g., costs of re-labelling and potentially the loss of the free-range marketing status if the housing period is prolonged beyond 16 weeks. In addition, behaviours are modified as birds previously allowed to range remain indoors, leading to potential welfare effects around boredom related behaviours, such as feather pecking, aggression, and smothering (Zimmerman et al., 2006; Fortomaris et al., 2007; Campbell et al., 2020).

The UK has the highest proportion of free-range egg production across Europe (AgraCEAS, 2017). It is estimated that the UK produces approximately 10.4 billion eggs annually with a value of £1.3bn. Free range eggs represent around 65% of the market (British Egg Industry Council, 2023). A housing order could therefore have a significant impact on the industry. In the absence of feasible alternatives, housing orders will be increasingly regular intervention for mitigating some of the consequences of AI incursions. The firm level consequences of a housing order are an underexplored facet and to date as far as these authors are aware there are no peer-reviewed published studies on the financial effects of a housing order on free-range flocks, and certainly none pertaining to recent outbreaks and recent bird flu strains.

We add to the literature on avian influenza by providing empirical estimates of the farm level impact of a housing order on commercial free-range egg producers. Our aim is to present the impact on various key indicators within free range egg production and, as such, provide a basis for understanding the commercial consequences of the housing order as an intervention in mitigating HPAI. We do so by employing a rarely available commercial data set of UK poultry sheds that provide weekly cost, revenue and production dynamics over two production cycles and which span two recent epidemics in 2020/2021 and 2021/2022.

3.0 Materials and Methods

Production data were collected from a range of commercial poultry sheds from individual farms with the intention to capture diversity in terms of experience of the housing orders. These data cover two production cycles over the 2020-2022 period. Within this time two housing orders were officially imposed, between 14th December 2020 - 23rd February 2021 and 29th November 2021 - 18th April 2022.

Summary data by each shed is shown in Table 1. These are presented as means showing the average weekly number of birds over both production cycles after 20 weeks when production begins. These show the housing system used per farm, namely a flat or multi deck, the latter are usually reflective of higher stocking densities (AgraCEAS, 2020[3]). High performance breeds were used across all farms with the majority using Lohmann Browns, though several used Hyline Brown Plus.

Table 1. Average number of birds per shed, weekly means from 20 weeks onwards

Farm	N	Mean	SD	Min	Max	Deck	Breed
1	120	8,697	192	8,308	9,030	Multi	Hyline Brown Plus
2	119	5,698	178	5,281	5,998	Flat	Lohmann Brown
3	119	5,695	155	5,407	5,996	Flat	Lohmann Brown
4	176	13,457	322	12,776	13,983	Flat	Lohmann Brown
5	137	15,710	242	14,885	16,013	Multi	Lohmann Brown
6	123	15,795	166	15,242	15,996	Multi	Hyline Brown Plus
7	126	15,737	147	15,378	15,994	Multi	Hyline Brown Plus
8	119	11,384	368	10,550	11,934	Flat	Lohmann Brown
9	123	8,485	340	7,925	8,989	Flat	Lohmann Brown
Average		11,401	3,915	5,281	16,013		

To show the dynamics of the housing order of these farms Figure 1 gives an overview of the individual farms, showing their production cycles and the period of the housing orders, denoted by the red lines. The figure shows weekly bird numbers against bird age in weeks. The farms were selected as large-scale poultry enterprises but representing varying experiences of the housing orders. Some of the farms in the first cycle did not experience a housing order (F5, F6 and F7). Some farms, due to the timing of production, experienced housing orders either early or late in layer development stage. A small number of farms experienced two housing orders during the same

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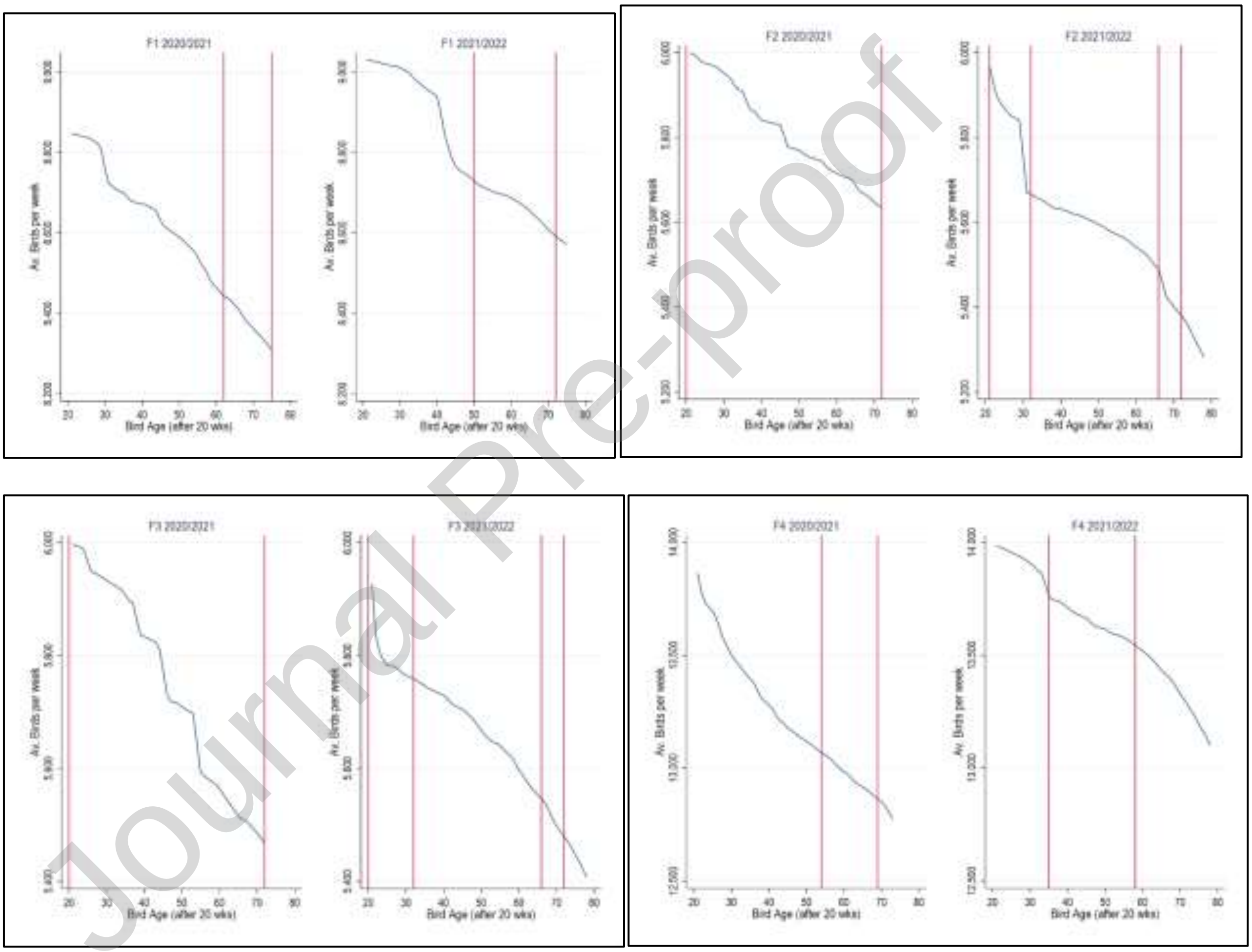
[3] https://www.eurogroupforanimals.org/files/eurogroupforanimals/2020-03/E4A-Optimising_Laying_Hens_Welfare.pdf

production cycle (F2 and F3). The production cycles of farms 2 and 3 coincided with housing orders in the first cycle. As such these birds were not ranged in the first cycle and were considered housed throughout the whole period.

Figure 1. Average weekly bird numbers by production cycle and bird age for each farm, the red bars indicate the duration and timing of housing orders for each farm and by each cycle.



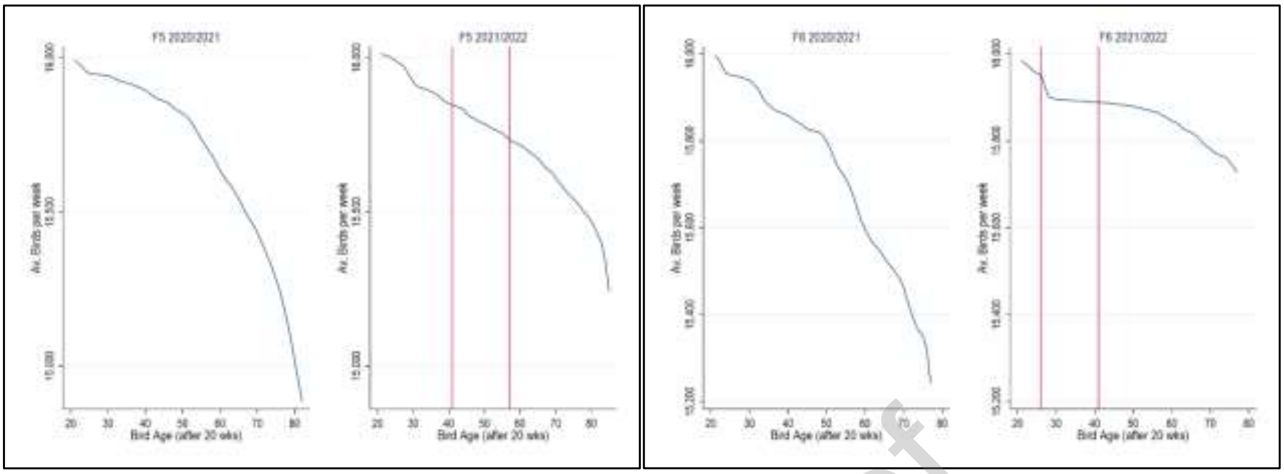
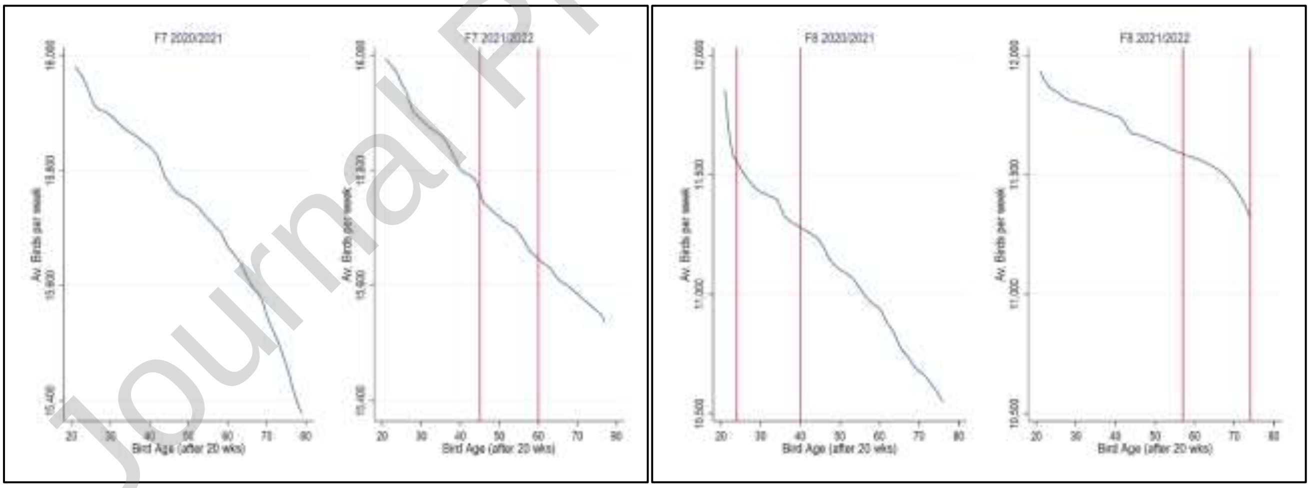
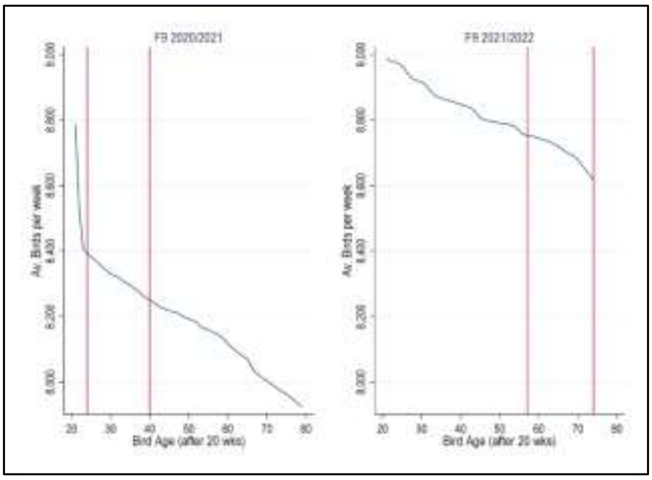


Figure 2. Average weekly bird numbers by production cycle and bird age for each farm, the red bars indicate the duration and timing of housing orders for each farm and by each cycle.





To assess the impacts from a housing order a series of indicator variables were generated from the data. These are presented in Table 2 below and indicate weekly mortality, production impacts (feed intake, feed conversion, physical output) and financial impacts (total revenue, feed costs, margins over feed costs).

Table 2. Description of main outcome variables

Indicator	**Calculation**	**Mean**	**Standard deviation**	**Median**	**Inter-quartile range**
Weekly mortality	Number of weekly dead birds by average weekly bird numbers (%)	0.13	0.22	0.08	0.10
Feed intake	Average daily intake of feed per bird in grammes (Grammes per hen per day)	126.07	8.94	126.90	10.10
Feed conversion/bird	Average graded egg weight by feed intake in grammes per hen per day (ratio)	0.46	0.04	0.46	0.04
Average weekly graded egg weight	Average weight of grades produced per week (in grammes per week)	58.12	3.89	58.82	3.30
Proportion of Seconds	The proportion of liquid, farm and graded seconds to total eggs produced per week (%)	7.6	6.3	6.5	4.1

Total revenue/bird*	The quantity of each egg grade produced per dozen per week multiplied by the price per dozen for each grade per week and divided by average weekly bird numbers (£ per bird per week)	0.69	0.23	0.71	0.37
Feed costs/bird*	Weekly feed per bird, in tonnes per week, multiplied by cost per tonne for each weekly ration divided by average weekly bird numbers (£ per bird per week)	0.37	0.10	0.41	0.20
Margin over Feed Costs (MOFC)/bird	The value of weekly total revenue less the weekly cost of feed per bird (£ per bird per week)	0.35	0.17	0.38	0.20

***** These were deflated by the monthly prices for poultry feed costs and free-range eggs supplied by Defra

We take a mixed linear regression approach and apply a random intercept model to control for variance within each shed environment and breed. This modelling framework has proven popular in studies of other farmed species outbreaks (Varga et al., 2009; Schielzeth et al., 2020; Persson et al., 2022). Our random intercept approach takes the form:

$$y_{it} = (\beta_1 + \zeta_t) + \beta_2 x_{2it} + \beta_3 x_{3it}^2 + \beta_4 x_{4it} + \beta_5 x_{5it} + \beta_5 H_{it} + \beta_6 P_{it} + \beta_7 D_i + \epsilon_{it}$$

Where y_{it} is the outcome of interest (listed in Table 2), *i* is the shed in which the poultry were housed, and *t* a weekly time step. The intercept (β_1) is augmented with a random intercept error term (ζ_t) as the permanent error component, e.g., of the lasting characteristic of the different sheds, including breed used and (ϵ_{it}) the transitory component, e.g., of the individual production effects.

Modelling poultry growth and production requires a non-linear formulation, which is further complicated by management and breed (Aggrey, 2002; Narinc *et al*., 2017; Selvaggi *et al*., 2015). As our purpose is to explore the effect of changes in output revenue and commercial production, we discount the first 20 weeks of development before the hen comes into production. This helps to simplify our curve fitting and we impose both a linear term (x_2) and squared term (x_3) to capture this growth over the bird's weekly lifecycle from 20 weeks onwards. Various components which pertain to explaining the outcome of interest are measured in x_4 and x_5. We add a categorical term for the housing order (H). This compares the period of housing (*H=0*) with pre-housing (*H=1*) and post-Housing (*H=2*) to measure the impact of housing and capture the dynamics of production when the housing order occurred, a dummy to reflect production cycle (P) and a dummy (D) to control for multi-tier to single deck systems. All modelling was conducted in Stata 17 (Stata Corp, 2021).

3.0. Results and Discussion

3.1. Production and zootechnical impacts

Table 3 shows the results of the random intercept model on the key production impacts. The Wald chi^2 shows these variables are collectively and individually significant. The Likelihood Ratio test confirms that the random intercept model is more appropriate than a simpler linear regression model.

Across all three outcomes bird age is consistently significant showing the influences of changing growth patterns on the outcomes. Weekly mortality rates (Model 1) indicate that as birds age this will lead to slightly lower mortalities. This trend is positive, reflecting fewer health challenges of the flock as hens adapt to their environment. This is consistent with the expectation that birds that had to be housed in the period leading up to, or around, peak production – a time of increased physiological stress – would be affected more than older, post-peak, birds (Samiullah *et al* 2017).

The multi deck system leads to lower mortality than the single deck. Rodenberg *et al.* (2008) found little difference between these systems, but a recent study found flat decks to have higher mortalities than a multideck, though this was not statistically significant (British Free Range Egg Producers Association, 2017). For the housing order dummy, there was no significant impact on mortality rates. A number of studies have found mortality rates to be higher in ranged compared to caged systems (e.g. Weeks *et al*., 2012) but a global metareview of mortality in caged and cage-free birds found no significant difference, which the authors argued was a result of management experience (Schuck-Paim *et al*., 2021). To date no published studies have explored the impact on mortality when birds are transitioned between non-housed and housed systems.

Feed Intake per hen (Model 2) and Feed Conversion (Model 3) show a positive relationship with growth, indicating as birds mature, they will take in more feed but this will lead to more efficient conversion. Feed price negatively affects feed intake, which reflects the commercial objectives of these producers when adjusting appropriate rations. Moreover, the farms are specialised large poultry enterprises and buy-in feed rather than produce their own. Feed intake is predicted to be lower on multideck systems compared to single decks. Multidecks provide a proxy for more intensively monitored systems where feed provision would be expected to be optimised. The production cycle variable reflects differences between years and shows a positive influence on feed intake in the second period compared to the first. This may also be reflective of experience of the first housing order on the management of hens.

There was a significant and negative effect on feed intake both pre and post-housing. This would agree with a previous study in Northern Irish systems which found that when birds are housed this offers more control over nutrients and feeding regimes but that birds consume more compound feed in place of food sources that they would have foraged from the range (Poultry World, 2017).

The random part captures the difference in production variables between the farm sheds. The random intercept standard deviation is 0.02% mortality a week, 4.6 grams per hen per day of feed intake and feed conversion is 0.006 grammes egg weight per grammes of feed between the different sheds.

Table 3. Maximum likelihood estimates for key outcome production variables at bird age above 20 weeks.

	Weekly Mortality			Feed Intake			Feed Conversion		
	Est.		*(SE)*	Est.		*(SE)*	Est.		*(SE)*
Fixed part									
Bird age	-0.011	***	*(0.002)*	1.430	***	*(0.088)*	0.012	***	*(0.000)*
Bird age^2	0.0001	***	*(0.000)*	-0.014	***	*(0.001)*	-0.00004	***	*(0.000)*
Feed Price				-0.106	***	*(0.013)*			
Bird age * Feed Intake							-0.0001	***	*(0.000)*
Housing order (reference: housed)									
Free range: Pre-housed	0.016	-	*(0.011)*	-3.679	***	*(0.524)*	-0.003	-	*(0.002)*
Free range: Post-housed	-0.013	-	*(0.015)*	-5.224	***	*(0.725)*	0.002	-	*(0.003)*
Shed environment (reference: single tier deck)									
Multi-tier deck	-0.064	***	*(0.016)*	-20.890	***	*(4.343)*	-0.0003	-	*(0.005)*
Production Cycle (reference: first cycle)									
Second Cycle	-0.028	**	*(0.009)*	6.120	***	*(0.584)*	0.001	-	*(0.002)*
Random part									
Farm	0.018		*(0.007)*	4.599		*(1.171)*	0.006		*(0.002)*
Residual	0.142		*(0.003)*	6.335		*(0.151)*	0.023		*(0.001)*
Wald Chi^2	88.2	***		434.1	***		1166.5	***	
Log Likelihood	521.1			-2922.3			2080.6		

LR Test	6.3	**	324.2	***	33.3	***

* sig. at 0.05, ** sig. at 0.01, ***sig.at 0.001

3.2. Egg quality and grades

Figure 2 shows the mean proportion of egg grades and shows some differences across most graded categories aside from seconds. The number of large and very large eggs increase from 38% to 48% of all eggs produced. Conversely, the proportion of medium sized and small eggs reduced from 55% to 44% of all eggs produced. There was some shift between different grades within the seconds categories though the proportion overall stayed the same, at 8%.

Figure 2. Mean proportion of graded eggs across two production cycles for all farms above 20 weeks

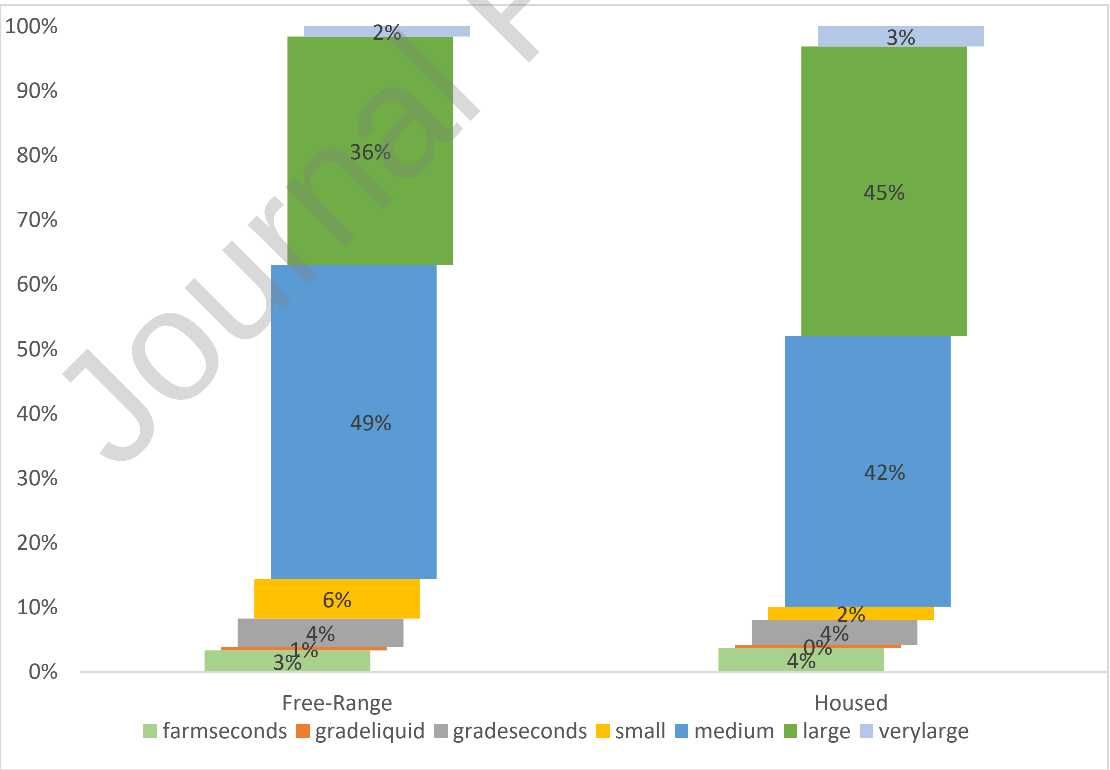


Table 4 shows the result of a two-sample t-test that these changes were significantly different between housed and ranged periods in all categories, aside from seconds. Seconds are a mixture of different grades that do not meet the criteria for Grade A eggs but which, following processing, may still go into the supply chain. These do not show a significant increase between free range and housed.

Table 4. Differences in mean proportion of egg grades to total graded eggs between ranged (FR) and housed (HO), two-sample t-test. This shows that for most egg grades there is a significant difference between ranged and housed states.

	Mean FR	Mean HO	Diff.	T-value	Sig.
Very Large	1.6%	3.1%	1.5%	-9.728	***
Large	36.0%	44.9%	8.9%	-8.217	***
Medium	49.4%	41.9%	-7.5%	7.553	***
Small	5.8%	2.1%	-3.7%	5.004	***
Seconds^	7.4%	8.0%	0.6%	-1.396	

^ these are composed of grade seconds, graded liquid and farm seconds
** Sig difference at 0.05., ** Sig. different. at 0.01, *** Sig.different. at 0.001*

Table 5 shows the effect of a housing order on the different grades of seconds as well as the overall average graded egg weight. Indicators of growth are all significant and show that as birds mature the proportion of lower grade eggs per week reduces. Similarly, the average weight of all graded eggs produced increases.

Compared to the period of the housing order, the proportions of graded seconds and liquid eggs were lower pre-housed compared to housed. Whilst we accommodate for bird age and feed intake there was a positive effect on liquid graded eggs post-housing. This would suggest that management mitigations prevented an increase in the proportion of eggs laid in the litter or eggs laid with obvious shell or other defects. Where farm specific effects were present this may be the result of reduced moisture or dirt being deposited on the shells by housed birds compared to those with access to range, leading to cleaner eggs. In addition, housing birds may lead to them consuming a more balanced diet (i.e., compounded feed only), leading to improved shell quality.

Table 5. Maximum likelihood estimates for seconds at bird age above 20 weeks

	Av. Graded Egg Weight			Prop. Farm Seconds			Prop. Grade Seconds			Prop. Grade Liquid		
	Est.		*(SE)*	Est.		*(SE)*	Est.		*(SE)*	Est.		*(SE)*
Fixed part												
Bird age	1.465	***	*(0.071)*	-0.017	***	*(0.001)*	-0.005	***	*(0.000)*	-0.001	***	*(0.000)*
Bird age^2	-0.005	***	*(0.000)*	0.00002	*	*(0.000)*	0.00003	***	*(0.000)*	0.00001	***	*(0.000)*
Bird Age*Housing	0.018	-	*(0.012)*	0.000	-	*(0.000)*	-0.0002	***	*(0.000)*	-0.0002	***	*(0.000)*
Feed Intake	0.522	***	*(0.030)*	-0.009	***	*(0.001)*	-0.001	***	*(0.000)*	0.000	-	*(0.000)*
Bird age*Feed Intake	-0.007	***	*(0.001)*	0.000	***	*(0.000)*	0.0002	***	*(0.000)*	0.000	-	*(0.000)*
Prop Mortality				0.047	***	*(0.008)*	0.011	***	*(0.002)*	0.003	***	*(0.001)*
Housing order (reference: housed)												
Free range: Pre-housed	0.746	-	*(0.565)*	-0.007	-	*(0.011)*	-0.008	**	*(0.003)*	-0.006	***	*(0.001)*
Free range: Post-housed	-0.797	-	*(0.823)*	-0.022	-	*(0.017)*	0.005	-	*(0.004)*	0.010	***	*(0.001)*
Shed environment (reference: single tier deck)												
Multi-tier deck	-0.110	-	*(0.658)*	-0.011	-	*(0.007)*	0.011	*	*(0.007)*	0.002	*	*(0.001)*
Production Cycle (reference: first cycle)												
Second Cycle	-0.206	-	*(0.178)*	0.002	-	*(0.004)*	-0.005	***	*(0.001)*	0.000	-	*(0.000)*
Random part												
Farm	0.866		*(0.236)*	0.007		*(0.003)*	0.005		*(0.001)*	0.001		*(0.000)*
Residual	2.495		*(0.059)*	0.051		*(0.001)*	0.013		*(0.000)*	0.004		*(0.000)*
Wald Chi^2	1310.9	***		451.9	***		598.9	***		543.0	***	
Log Likelihood	-2082.4			1373.5			2570.6			3696.8		

LR Test	67.2***	6.5**	84.6***	66.5***

* sig. at 0.05, ** sig. at 0.01, ***sig.at 0.001

3.3. Financial Impacts

A number of variables proved significant and indicate a strong fit against the financial indicators (Table 6). Bird age positively affected revenue and margins per bird. Increasing the level of feed intake increases feed costs per bird as well as revenue per bird. The impact on revenue is greater which leads to a strong positive impact on margins over feed cost. Average graded egg weight, as would be expected, is also positively related to revenue. Costs and revenues were negatively affected in the second cycle relative to the first production cycle. Prices and costs were deflated by the appropriate indicators to accommodate inflationary effects but may not fully capture the variance over this period due to high price inflation. This may also reflect a greater severity of the second housing order in terms of both the access to raw materials as well point of sale issues.

The housing orders had a range of significant impacts on the financial indicators. Feed cost was lower pre-housing by around £0.01 per bird per week, or around 3% of weekly feed cost per bird. This reflects the observed increased feed consumption when birds were housed. Revenue was also lower pre-housing order of £0.04 per bird per week, which equates to around 6% of weekly revenue per bird per week across all farms. Revenue was higher during the housing order, potentially as a result of the increases in graded egg weights observed as a result of more controlled feeding. Margins over feed cost were lower when pre-housed, at £0.03 per bird per week, or around 9-10% of weekly margins per bird. Post-housing order margins were higher by £0.03 per bird per week, though at a lower level of significance. Overall, the impact of the housing order was positive on revenues and this exceeded the increased feed cost burden from feed per bird.

Some caution is needed as this is only a partial analysis of the main costs within free range egg production. The impacts on energy costs, labour and general consumables, such as protective equipment and clothing would, we expect, be higher during a housing order. Brannan and Anderson (2021) point out the lack of studies focused on labour demands in different poultry systems. Through a farm-level survey of typical North American systems found that ranged systems had the highest labour cost requirement and conventional systems, the lowest. This varied by season, with ranged labour cost increasing during the summer through pasture management. Hence, although there would be a dampening effect on labour costs from housing ranged flocks, this would still be moderated by the needs to comply with high biosecurity requirements, as well as monitoring cost, but also lags in labour contracts. Energy consumption is a significant cost factor for poultry sheds, but few studies have compared free ranged to housed systems. Mostert *et al.* (2022) compared higher welfare Dutch broiler systems, which includes an outdoor run, to conventional intensive systems, finding that conventional systems consumed less electricity and gas to higher welfare systems per hen. The impact on energy cost would also depend on the level of renewable energy installed. As we have no information on the energy source within the sheds, we cannot make a valid comparison of energy costs between the ranged and housed periods.

Moreover, the result of higher revenues has been compounded by changing egg prices during the outbreak period and supply factors beyond the control of the commercial unit. Thus, whilst the revenues and margins are positive, extensions in the length of the housing period could degrade overall margins as producers adjusted for the housing period. Mullaly and Lusk (2017) explored the effect of welfare related housing restrictions in Californian egg producers, finding prices rose for the consumer by 22% but then supply was compensated by out of state eggs to dampen the price premium. Accordingly, in the long run, prices would fall as supply issues are overcome.

The UK Egg Marketing Standards imposed a 16-week derogation for free range producers and after that period eggs needed to be labelled as barn eggs and would have merited a lower premium. Hence, the gains identified here would have been eroded if the derogation period were reduced. In response to this an ongoing consultation is exploring the dropping of the derogation, to enable free-range eggs to be marketed as such during any mandated housing period[4]. Extending the derogation period would therefore support some of the financial impacts highlighted here. However, this potentially raises another issue of how producers may respond under these periods. If there are short-term gains to housing free range layers, and biosecurity limitations are in place to limit external monitoring and inspection, a ‘gameplaying’ producer could house free range birds earlier or later than the housing order. However, whilst there is some literature which has theoretically explored the potential of avoiding compliance (Barnes et al., 2016; Zhou et al., 2022), it is doubtful, given the severity of the fines for non-compliance, that farms would consider this as a potential strategy either pre or post housing order.

Finally, whilst these data are typical of a type of commercial flock enterprise, they cannot be representative of the entire commercial free-range egg sector. The sector is composed of a large body of medium and smaller scale producers that may suffer incrementally more damage from a housing order due to lack of labour, appropriate housing and the ability to cover additional costs of feed. Smaller backyard keepers have been found to lack knowledge of AI clinical signs and a lower engagement in housing regimes (Jewitt et al., 2023; McClaughlin et al., 2024). For these smaller enterprises there may also be a lack of consistent weekly data on both the economic and biophysical aspects of production which would limit a robust investigation of their impacts. There is now a legal requirement in the UK to register smaller flocks of 50 birds and above, and voluntary registration of 49 or less birds in the UK. This may allow for some analysis across these smaller units.

Table 6. Maximum likelihood estimates for key outcome financial variables at bird age above 20 weeks.

	Feed Cost/bird		Revenue/bird		MOFC/bird	
	Est.	*(SE)*	Est.	*(SE)*	Est.	*(SE)*
Fixed part						

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[4] The consultation closes in March 2024. https://consult.defra.gov.uk/ahdb-relationship-team/consultation-on-removing-the-16-week-derogation-pe/

Bird age	-0.0002	-	*(0.000)*	0.021	***	*(0.004)*	0.053	***	*(0.003)*
Bird age^2	0.0000	-	*(0.000)*	0.000	***	*(0.000)*	0.000	***	*(0.000)*
Feed Intake	0.003	***	*(0.000)*	0.008	***	*(0.002)*	0.018	***	*(0.001)*
Bird age*Feed Intake	0.000	-	*(0.000)*	0.000	***	*(0.000)*	0.000	***	*(0.000)*
Feed Price	0.001	***	*(0.000)*	0.000	-	*(0.000)*	0.000	-	*(0.000)*
Av.Graded Egg Weight				0.020	***	*(0.001)*			
Housing order (reference: housed)									
Free range: Pre-housed	-0.008	***	*(0.001)*	-0.041	***	*(0.009)*	-0.030	**	*(0.010)*
Free range: Post-housed	0.002	-	*(0.001)*	0.017	-	*(0.013)*	0.030	*	*(0.014)*
Shed environment (reference: single tier deck)									
Multideck	0.017	**	*(0.006)*	-0.245	***	*(0.051)*	-0.160	**	*(0.056)*
Production Cycle (reference: first cycle)									
Second Cycle	-0.037	***	*(0.001)*	-0.047	***	*(0.011)*	-0.030	*	*(0.012)*
Random part									
Farm	0.006		*(0.002)*	0.021		*(0.007)*	0.020		*(0.007)*
Residual	0.010		*(0.000)*	0.108		*(0.123)*	0.123		*(0.003)*
Wald Chi^2	6333.8	***		*1199.9*	***		567.4	***	
Log Likelihood	2790.0			*702.5*			599.3		
LR Test	216.8	***		*15.2*	***		8.7	**	

* sig. at 0.05, ** sig. at 0.01, ***sig.at 0.001

4.0 Conclusions

Control of HPAI, which is carried by annual wild bird migrations, is a recurring problem for policy makers who need to identify an optimal cost-effective intervention regime, especially as it poses a low but potentially catastrophic risk to the human population (Bernstein *et al*., 2022). Imposing housing orders on free-range poultry systems is, along with heightened biosecurity measures, a common intervention for limiting the impact of HPAI transmission between commercial and wild bird species. The short-term impacts on the supply of eggs and the long-term financial sustainability of commercial enterprises are consequences of this measure.

We find a positive effect on margins over feed costs, principally due to the benefits of controlled nutrition leading to higher returns. Whilst there will be variance in the severity of impact on individual businesses this paper finds some support for imposing housing orders as they minimise private economic costs and provide societal benefits from reducing external threats from the disease.

Whilst we present an ex-post analysis, the impact of a housing order will be context dependant and we show fluctuations between the two recent cycles. There is therefore a need to establish the impact of experience of risks in managing large flocks and market fluctuations if housing orders are to become an regular occurrence. We undertook an analysis over two production cycles against macroeconomic trends that had increasingly high food and feed prices (House of Lords, 2022), and these trends will further squeeze margins for producers.

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Conflict of interest

Each author of this research article has declared no conflict of interest.

Highlights

- First UK estimates of mandatory AI housing order impacts at commercial farm scale.
- Increased feed and feeding costs observed during a housing order.
- Higher revenues and margins over feed, dependant on duration of housing order.