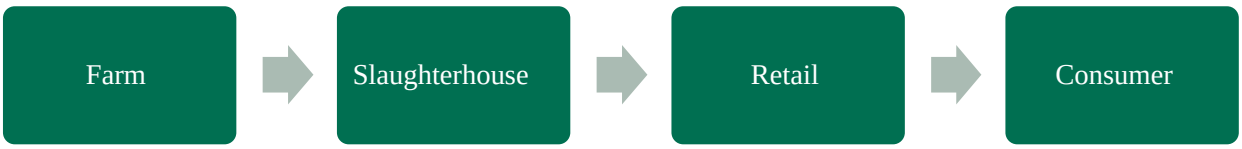
Risk of campylobacteriosis from low-throughput poultry slaughterhouses: Exposure assessment

The pathway of broilers from farm to fork is complex and includes multiple stages where the risk of *Campylobacter* contamination and/or cross-contamination may occur. We break down the exposure pathway into four key stages: production at the farm, processing at the slaughterhouse, post-processing at retail and home-preparation by the consumer. Each module contains variables likely to influence the presence of *Campylobacter* in poultry, summarised in the following sections. In this report, we focus on the differences in the production chain of low and high-throughput slaughterhouses. Semi-quantitative tools were used to give an approximate estimate of the number of illnesses and the *Campylobacter* risk (per portion and at the UK population level) from chicken produced by low-throughput poultry slaughterhouses in comparison to high-throughput poultry slaughterhouses.

Figure 2: The exposure pathway for this risk assessment, broken down into four key modules

- Farm
- Slaughterhouse
- Retail
- Consumer



4.1 Farm module

4.1.1 Factors affecting Campylobacter levels at a farm level

At the farm level, a number of factors have been found to affect the probability of contamination of a portion of broiler meat with *Campylobacter*. These include biosecurity procedures, organic farming methods, the practice of thinning, partial de-population, seasonality, and the age of the bird at slaughter, as summarised in a recent FSA-funded study on *Campylobacter* levels during the farm module of poultry production, FS307037 (Ausvet Europe et al., 2022).

Thinning

A major contributor to increased *Campylobacter* levels in poultry houses is thinning. Thinning is the removing of unwanted birds from flocks and is widely used by most commercial producers (Allen et al., 2008). This process may increase *Campylobacter* levels for two reasons; contamination by farm workers during the process (biosecurity hazard) and the stress it puts on the birds. In a study by Georgiev et al., even flocks raised with good levels of biosecurity had increased levels of *Campylobacter* of up to 54.7% after thinning and at processing, and carcases from flocks that were thinned were twice as likely to have *Campylobacter* than those that were not (Georgiev, Beauvais and Guitian, 2017).

Biosecurity

Farms with poor biosecurity practices were also found to have an increased risk of *Campylobacter* contamination. A conventional poultry house, that is modern and well maintained and with limited access, is considered to have good biosecurity (EFSA Panel on Biological Hazards (BIOHAZ), 2011). Common breaches of biosecurity measures occur through vectors such as vermin, insects or humans. Farm workers in particular have been reported to be a major source of *Campylobacter* spread via poor hygiene practices and contaminated clothing and boots (Battersby, Whyte and Bolton, 2016).

Organic farming

Studies show mixed results on the effects of organic farming procedures on the risk of *Campylobacter* colonisation in flocks. Organic farms are considered to have poor biosecurity due to exposure of the poultry to the outside environment, leading to transmission routes from wild birds and other wild animals (Ausvet Europe et al., 2022). Studies in Denmark have shown that while conventional and indoor broiler flocks have an infection rate of 36.7% (positive samples from 29 out of 79 flocks tested) and 49.2% (positive samples from 29 out of 59 flocks tested) respectively, organic flocks had an infection rate of 100% (positive samples from 22 out of 22 flocks tested) (Heuer et al., 2001). Furthermore, in Denmark, the prevalence of *Campylobacter* contamination in conventional carcases was found to be 19.7% while in organic carcases this was found to be higher at 54.2%.

Similar studies have not been carried out in the UK, however, our survey of low-throughput slaughterhouses found that in contrast to this, organic carcases and conventional carcases had a similar levels of samples with high *Campylobacter* levels (24.3% vs 26.6% respectively). A survey of chicken at major and non-major retailer stores also found no statistical difference in the percentage of highly contaminated samples between those obtained from free-range and organically reared birds and those reared under a standard regime (PHE, 2021; Jorgensen et al., 2019).

Seasonality

Seasonal variation of *Campylobacter* levels is also frequently reported. In the UK, prevalence of *Campylobacter* in flocks was found to increase between July and September. This peak was more clearly evident in the south, thought to be due to warmer climate (Jorgensen et al., 2011).

Bird age

The age of the flock has been found to correlate with increasing *Campylobacter* levels. Conventionally produced birds are consistently reported to have higher levels of Campylobacter contamination by the end of the production cycle compared to younger birds (EFSA Panel on Biological Hazards (BIOHAZ) et al., 2020).

Transport

Crates used to transport live poultry to slaughterhouses can be contaminated with *Campylobacter spp.* and provide a risk of cross-contamination between flocks (Hastings et al., 2011).

Other factors for consideration

As part of the AusVet Europe et al., 2022 study, two workshops were held to discuss the findings of their literature search with key representatives from the UK poultry industry. Additional risk factors were identified at these meetings, including the effect of stocking density. Also, a need for additional information regarding organic versus conventional production methods was highlighted, as well as information on the effect of bird age on contamination levels and the effect of breeder flock.

4.1.2 Effect of controls applied at farm level

Some effective controls that could be applied at farm level in response to an exceedance, are outlined below and have been discussed at length in a recent EFSA report (EFSA Panel on Biological Hazards (BIOHAZ) et al., 2020). It is of note that an FSA funded study estimated that on-farm factors were 3.5x more important at influencing levels of *Campylobacter spp*. in neck skins than slaughterhouse factors (Hutchison et al., 2016).

Addition of disinfectants to drinking water and avoiding drinkers that allow standing water

One significant source of *Campylobacter* on farms is contaminated drinking water. It has been reported that adding organic acids, chlorine-based biocides or hydrogen peroxide to the drinking water could reduce the risk of *Campylobacter*-positive flocks by up to 55% (EFSA). In the UK, chlorination of drinking water has been found to be effective (Ellis-Iversen et al., 2009), while acidification and hydrogen peroxide have also been reported to be successful in France and Spain, respectively (Torralbo et al., 2014; V. Allain et al., 2014). Drinker types that allow for standing water are also associated with increased risk. One study found that removing drinking devices that included trays/cups etc reduced the risk of *Campylobacter* contamination in water sources by up to 78% (Näther et al., 2009).

Effective rodent control and proximity to other animals

Another common source of *Campylobacter* contamination on farms is rodents, with some studies estimating that effective rodent control can decrease prevalence in flocks by up to 19% (McDowell et al., 2008; V. Allain et al., 2014). This has been found for both indoor and outdoor flocks (Huneau-Salaün et al., 2007).

As well as rodents on farms, other animals in adjacent fields have been speculated to be a source of *Campylobacter* contamination. Several studies have sequenced *Campylobacter* found in both broilers and animals in the surrounding area and identified them as the same strains, although the direction of spread is often hard to determine (Weis et al., 2016).

Employing few and well-trained staff

Another commonly accepted source of *Campylobacter* contamination on farms is from farm workers (including maintenance staff and handlers), often via poor hygiene techniques and contaminated footwear (Battersby, Whyte and Bolton, 2016). Several studies have shown infection decreases with increased education of staff on good hygiene practices (Ansari-Lari et al., 2011; Van Limbergen et al., 2018). Furthermore, limiting the number of farm workers with access to the flock was also found to be effective. For example, studies in Denmark and France concluded that having more than one farm worker managing a flock was sufficient to significantly increase the risk of *Campylobacter* infection (Refrégier-Petton et al., 2001; Chowdhury et al., 2012).

Hygiene anterooms at broiler house entrance

The presence of an anteroom (a room between the outside door and the entry to the housing unit) on farms are an important addition to farm control measures and are effective at reducing *Campylobacter* risk when used along with good hygiene practices. The anterooms allow staff to put on clean overalls/change footwear/wash hands etc. before entering the production unit. They have been shown to result in between 5% and 13% reduction in the *Campylobacter* prevalence only, however, when kept clean and used correctly (McDowell et al., 2008; Borck Høg et al., 2016).

Supply of birds with full crops

Another factor identified in a slaughterhouse study as responsible for cross-contamination is the supply of birds with full crops (IPSOS Mori, 2016). Farmers are encouraged to leave enough time before the last feed and transport to the slaughterhouse, to ensure the crop is empty, which presents less chance of cross-contamination during evisceration.

4.1.3 Differences in the Campylobacter levels of birds supplied to low-throughout and high-throughput premises

Following a farm to fork approach, ideally *Campylobacter* levels in birds supplied to low- and high-throughput slaughterhouses would be compared. However, these data were not available. Instead, an attempt was made to identify the proportion of different types of poultry processed in the two types of slaughterhouses, specifically; conventional, organic, free range and the types of cages and/or barns used. The literature suggests there is a difference in *Campylobacter* risk for birds reared under different conditions.

Although some slaughterhouses provided these details, the information was limited and often slaughterhouses receive a mixture of differently reared flocks. It was therefore not possible to compile a reliable and comprehensive list to enable the comparison of birds supplied to low-throughput slaughterhouses with birds supplied to high-throughput slaughterhouses for the purposes of this report (uncertainty).

With the data available, it was not possible to assess any difference in the *Campylobacter* levels between broilers being sent to low and high-throughput slaughterhouses that we can quantify in this module.

4.2 Slaughterhouse module

4.2.1 Factors affecting changes in *Campylobacter* levels during slaughter

At the slaughterhouse level, a number of factors have been found to affect the probability and levels of contamination of a portion of broiler meat with *Campylobacter*. These include how process steps such as scalding, washing, chilling, cutting, defeathering and evisceration are carried out.

The recent FS307037 study indicated an increase in prevalence of contamination as well as the level of contamination per product during slaughter (Ausvet Europe et al., 2022).

Scalding and washing:

Studies have shown that scalding can lead to a 2 log decrease in *Campylobacter* levels, however some evidence suggests that *Campylobacter* may survive in scalding water due to the presence of organic matter (Rasschaert et al., 2020). Other studies have shown that kosher abattoirs often have higher levels of contamination (94%) compared to conventional abattoirs (32%); one reason being due to the fact defeathering is carried out using cold water, rather than scalding methods (Guirin et al., 2020).

Defeathering and evisceration:

Defeathering puts pressure on the carcase which may lead to increased defecation and therefore possible contamination (Rasschaert et al., 2020). Evisceration may also rupture the intestines if machinery isn't adjusted adequately to bird size. Batches of chickens with <10% ruptured intestines have significantly lower levels of *Campylobacter* compared to those with >10% (Rasschaert et al., 2020).

he FS307037 study found that defeathering and evisceration increased the risk of cross-contamination of flocks which had been negative for *Campylobacter*, potentially due to cross-contamination and/or contamination associated with faecal content leakage (Ausvet Europe et al., 2022). This was consistent with much of the literature, such as (Allen et al., 2007) and (Dogan et al., 2019) which estimated *Campylobacter* prevalence at the end of the slaughterhouse process to be 60% and 30% respectively.

Chilling

Air-chilling (the only type practised for broiler carcases) has been shown to result in a significant reduction of 0.83 log10 CFU/g (Rosenquist et al., 2006).

Other considerations

It should be noted that neck skin samples are likely to be more highly contaminated than breast skin (Hutchison et al., 2016).

4.2.2 Effect of controls applied at slaughterhouse level

If the proportion of samples with high *Campylobacter* levels exceeds 15/50 over a ten-week period, the PHC requires interventions to be put in place to reduce this.

An FSA-funded study on "Reducing *Campylobacter* cross-contamination during poultry processing" (FS9990010) looked at the practical control strategies that can be used within slaughterhouses to reduce cross-contamination of poultry with *Campylobacter* (Corry et al., 2017). This survey revealed that techniques used between different chicken slaughterhouses were similar and that the cleaning and disinfecting methods were effective against *Campylobacter* . It is noted that cleaning and disinfecting was only possible between shifts (overnight) or at the weekend and that cross-contamination between carcases on the line was unavoidable (Corry et al., 2017).

The rubber fingers of the plucking and evisceration equipment as well as the conveyer belts have been found to be key contamination points even after cleaning (Rasschaert et al., 2020). This may be due to the presence of organic matter which may protect *Campylobacter* spp. or the pathogen may form biofilms with Pseudomonads for protection (Rasschaert et al., 2020). Chillers have also been found to be a source of cross-contamination as they are seldom empty between batches and they are very hard to clean (Hutchison et al., 2016).

The most effective *Campylobacter* reduction methods were end-product treatment of the fully processed carcases (Corry et al., 2017). Steam treatment for 15 seconds was found to reduce levels by 1.28 log10 CFU/g on breast skin and 0.53 log10 CFU/g on neck skin. Heat treatment with steam or hot water has been previously shown to be effective in studies (Corry et al., 2007; James et al., 2007).

Processing of *Campylobacter* negative flocks after positive flocks was not found to have a significant effect on *Campylobacter* levels (Corry et al., 2017).

A review of the effects of transport and slaughter on *Campylobacter* spp. levels found that the use of steam-ultrasound treatment on carcases was effective (Rasschaert et al., 2020).

4.2.3 Probability that action is taken as a result of an exceedance

Following a farm to fork approach, we tried to gather evidence to understand the actions being taken as a result of failing PHC requirements (having more than 15/50 samples with high levels of *Campylobacter* over a 10-week period). Currently, no enforcement actions are taken as a result of slaughterhouses failing to sample or failing the PHC requirements (FSA, 2022). Interventions are left to the discretion of the slaughterhouse, although it should be noted that major retailers can apply pressure on the plants to provide poultry with low levels of *Campylobacter* (Antic, 2022).

4.2.4 Sampling from low and high-throughput slaughterhouses

The total throughput of UK slaughterhouses based on 2021 data is shown in Table 1, with individual throughout data in Appendix Section 8.2. For the purposes of this assessment, the definition of a low-throughput slaughterhouse is one that processes 7,500,000 birds a year or fewer; high-throughput slaughterhouses process more than 7,500,000 birds (FSA, 2019b). There were 38 low-throughput slaughterhouses and 22 high-throughput slaughterhouses registered in the UK, although only 34 in total have provided *Campylobacter* samples (uncertainty).

Table 1: Annual throughput of poultry (units) in low and high-throughput slaughterhouses in 2021

Low-throughput (%)	High-throughput (%)	Combined
53,630,892 (5%)	965,216,124 (95%)	1,018,847,016

In order to compare low and high-throughput slaughterhouses, 50 samples from some low-throughput slaughterhouse were taken over an approximately 10-week period from September to December 2021 by the FSA (see Section 8.1 for a description of the sampling and Annex 1 for the raw data) to supplement *Campylobacter* sampling data provided to the FSA by FBOs. In brief, a sample consists of 26 grams from 3 pooled neck skins obtained after slaughter and after chilling. If neck skin was not available, a swab of the carcase was used instead. Five samples are taken at random each week from 15 birds from the same batch on a given day. While the regulation requires 50 samples to be submitted over a 10-week period, some slaughterhouses perform and submit more sample results to the FSA.

Seventeen slaughterhouses of each type submitted results over this 10-week period. Data from the FSA survey contains enumeration of *Campylobacter* levels, while data submitted by slaughterhouse FBOs only contains information on whether samples had Campylobacter levels above or below 1,000 CFU/g.

The number of samples in the low-throughput slaughterhouse group was 934 across 17 slaughterhouses, as part of the FSA survey and the regular PHC reporting protocol. The high-throughput slaughterhouses reported 1972 results across 17 slaughterhouses as part of the regular PHC reporting protocol. Table 2 shows the percentage of samples (neck skin only and swab) taken in both low and high-throughput slaughterhouses that had high levels of *Campylobacter*.

Table 2: Number and percentage of total samples taken in low-throughput and high-throughput slaughterhouses that had high (>1,000 CFU/g) and low (<1,000 CFU/g) levels of Campylobacter over the 10-week period of study

Samples	Low-throughput	High-throughput
Samples above 1,000 CFU/g	197 (21%)	352 (18%)
Samples below 1,000 CFU/g	737 (79%)	1620 (82%)
Total samples	934 (100%)	1972 (100%)

4.2.4.1 Campylobacter results over 10-week period - pooled

Given that slaughterhouses can be said to have “passed” or “failed” the PHC criteria, a binomial process can be used to model the outcome of testing for both types of slaughterhouse.

The prevalence of samples with high *Campylobacter* levels in low-throughput and high-throughput slaughterhouses was modelled using a beta distribution. The modelling confirms that, when pooled, the percentage of highly contaminated samples was not significantly different (Figure 2). For slaughterhouses who had submitted over 60 samples for assessment, only 60 random results were assessed. This was done in order to reduce the risk of bias from an individual plant submitting many samples in this period and thus skewing the pooled results. The number of samples assessed were 844 for low and 915 for high-throughput slaughterhouses. 22% of samples from low-throughput slaughterhouses had high contamination levels compared to 22% of high-throughput slaughterhouses.

As shown in Figure 2, the distributions of prevalence overlap quite closely, and there is no significant difference at the 5% level between the two types of plant when the results are pooled.

Figure 3: Distributions for the modelled prevalence of highly contaminated samples in low and high-throughput slaughterhouses. A maximum of 60 sample results were randomly selected for each slaughterhouse. Results were available from 17 low and 17 high-throughput slaughterhouses.

4.2.4.2 Enumeration of *Campylobacter* levels from low-throughput slaughterhouses

Campylobacter enumeration was provided for results sampled by the FSA from low-throughput slaughterhouses. This consisted of 501 samples – of which 161 (33%) did not have detectable *Campylobacter* levels. A histogram of the log-transformed values is shown in Figure 4 (top). Poultry with high levels of *Campylobacter* poses the most risk to consumers, as it is more likely that ingestion of undercooked material will deliver a dose large enough to cause infection.

A log-normal distribution is a good approximation for modelling the samples with detectable *Campylobacter* levels seen at this type of slaughterhouse, as indicated by the Bayesian Information Criterion (Figure 4 - bottom).

Figure 4: Histogram of Campylobacter levels in low-throughput slaughterhouses sampled by the FSA (top). The initial bar represents samples below the limit of detection (33% of samples). Distribution fit for Campylobacter contamination in low-throughput slaughterhouses (bottom). The best fit was the lognormal distribution. The samples below the limit of detection were removed prior to distribution fitting.

4.2.4.3 *Campylobacter* exceedances over 10-week period

When looking at individual slaughterhouses, more than half of low and high-throughput plants had compliant samples over the 10-week period in 2021.

The percentage of samples with high *Campylobacter* levels in individual low and high-throughput slaughterhouses are reported in Figure 4. Within the low-throughput category, 5 plants out of 17 exceed the 30% level, while in the high-throughput category, 3 out of 17 exceed this level.

There is a range of exceedances across the slaughterhouses, with 4 plants (S, AA, AC and AZ) reporting no samples above 1,000 CFU/g in the 10-week recording period whilst others having in more than 60% of their samples exceeding *Campylobacter* counts of 1,000 CFU/g (plants AK and AW). AK is a low-throughput plant and AW is a high-throughput plant.

Figure 5: Bar plots to show the percentage of all samples taken in low (top) and high-throughput (bottom) slaughterhouses that exceed 1,000 CFU/g Campylobacter over 10 weeks. The red line represents the 30% “accepted level of exceedance” according to current regulation.

4.2.4.4 Effect of slaughterhouses type - Halal and non-Halal

It was possible to identify certain slaughterhouses approved for religious slaughter which produce Halal or Kosher products, as they require a specific certification for this technique (Table 3). This was used to assess whether slaughterhouses of a certain type are more or less likely to have high levels of *Campylobacter*.

Table 3: The number and percentages of Halal, Kosher and non-Halal/Kosher slaughterhouses

Slaughterhouse type	Low-throughput slaughterhouses	High-throughput slaughterhouses
Halal	9 (24%)	9 (41%)
Kosher	1 (3%)	0 (0%)
Non-Halal/Kosher	28 (74%)	13 (59%)
Total	38 (100%)	22 (100%)

The type of slaughterhouse (Kosher/Halal and non-Kosher/Halal) was plotted in Figure 5, along with the percentage of samples that exceeded 1,000 CFU/g Campylobacter, to see if there is any clustering effect due to slaughterhouse type. The data used was all available data for slaughterhouses of both sizes – ranging from 10 weeks' worth of sampling to 2 years.

Figure 6: Percentage of samples exceeding 1,000 CFU/g Campylobacter from UK slaughterhouses.

4.2.5 Estimate of contaminated poultry on UK market

It is possible, from the 10-week sampling data, to estimate of the total number of chickens originating from low and high-throughput slaughterhouses with high levels of *Campylobacter* per year.

The yearly throughput of the individual slaughterhouses is given in the Appendix – Section 8.2. All sampling data available from 2020 onwards was used to estimate the proportion of highly contaminated carcases from individual slaughterhouses, and multiplied with the yearly throughput to roughly estimate the contribution of each type of slaughterhouse to highly contaminated poultry on the market.

Low-throughput slaughterhouses processed 53,630,892 birds in 2021 compared with 965,216,124 birds in high-throughput slaughterhouses. From the data available on the proportion of highly contaminated carcases (Section 4.2.4.1) we estimate that low-throughput slaughterhouses contribute 12 million highly contaminated birds each year compared to 212 million birds from high-throughput slaughterhouses. Given that the proportion of highly contaminated carcases is roughly the same for low and high-throughput slaughterhouses, the volume of production is the main factor influencing the number of highly contaminated carcases on the market. This does not take into account potential variations due to risk mitigations applied, further processing, seasonal variation, etc. as data are not available (uncertainty).

4.2.6 Differences in the Campylobacter levels of poultry meat leaving low throughput and high-throughput abattoirs

As noted in the previous section, there was limited data to assess differences in the *Campylobacter* levels between poultry being processed by low- and high-throughput slaughterhouses during the individual stages of processing. Furthermore, although data were gathered on the levels of *Campylobacter* contamination after slaughter but before retail, no data were available on the actions that were taken as a result of exceeding the target threshold. In

addition, the data that were collected at low-throughput abattoirs were collected over a limited period and may not be fully representative.

We could find no significant difference in the proportion of high levels of *Campylobacter* contamination between poultry produced in low- and high-throughput slaughterhouses at the point of testing. Given these limitations, we are not able to differentiate between two possible explanations for this result.

The first possible explanation is that the level of contamination on birds entering both types of plant is similar and that there are no differences in the effects of processing at the different plant sizes. The second possible explanation is that the levels of contamination are different upon entry, but that differences exist between the effects of processing at each types of plant, possibly including risk management activities in response to PHC results, and that the net effect of these two differences results in similar overall levels of contamination. The first scenario may be more likely as on-farm factors were found to be more important at influencing levels of *Campylobacter spp.* in neck skins than slaughterhouse factors (Hutchison et al., 2016). Therefore, it's less likely that activities in a slaughterhouse have as much of an effect on *Campylobacter* levels as the on-farm factors.
Differentiating between these scenarios is not possible with the data that are currently available, but might become possible if additional evidence was gathered on the prevalence of *Campylobacter* in birds arriving at plants before slaughter or on the type and timing of interventions implemented at individual plants.

4.3 Retail module

4.3.1 Factors and controls affecting Campylobacter levels at retail

This module explores the effect of retail processing and storage on levels of *Campylobacter* in poultry.

Processing of poultry after slaughter can affect the levels of *Campylobacter* on the meat. Temperature is one such key factor, with refrigeration, and freezing especially, leading to a decrease in pathogen levels. Campylobacter spp. are highly sensitive to freezing temperatures, which is a well-known mitigation measure for chicken contaminated with the pathogen applied in countries such as Iceland (Tustin et al., 2011), Norway and Denmark (Nastasijevic et al., 2020). At refrigeration temperatures, a slower decrease in pathogen levels over time can be seen (ACMSF, 2019). Additional reduction can be seen in *Campylobacter* levels on chicken stored in oxygen-containing gas mixtures (Boysen, Knøchel and Rosenquist, 2007) – modified atmosphere packaged raw poultry at retail often includes oxygen.

It is extremely unlikely for *Campylobacter* to grow on processed raw poultry as its optimum growth range is around 40°C (Davis and DiRita, 2008).

4.3.2 Consumer supply chain

Once poultry has been slaughtered, it can be sold to retailers who supply raw chicken directly to consumers, or FBOs who cook the chicken before supplying it to consumers (either in ready meals or restaurants, or other catering), or it is frozen or exported.

Following slaughter, it was not possible to find information on who the poultry from low and high-throughput slaughterhouses is supplied to (uncertainty). The websites of low-throughput slaughterhouses suggest that they are suppliers of a premium product that is primarily used by local restaurants and butchers. However, there are no quantitative data available to support this statement, and it is unclear if this is true for all low-throughput slaughterhouses. This distinction

could affect the risk – for example, chicken in ready-meals is less likely to cause campylobacteriosis due to being cooked at the manufacturer's and cooked while sealed at the consumer's, compared to raw chicken purchased by consumers. Freezing chicken will also decrease the risk as it significantly affects *Campylobacter* levels.

There may also be a difference in the level of processing carried out between low and high-throughput slaughterhouses, in terms of selling whole chickens compared to cuts such as breasts, thighs etc. The additional processing steps involved in selling cuts of meat could also affect the *Campylobacter* levels due to cross contamination. Again, insufficient information was available on processing practices of specific slaughterhouses to be able to quantify this risk (uncertainty).

4.3.3 Predicted decrease at retail

In this section, the focus is on *Campylobacter* sampling data from raw chicken sold at retailers, to understand how levels of the pathogen change at this step of the exposure pathway. Laboratory-based experiments are first used to predict the effects of refrigeration before comparing these with observed *Campylobacter* enumeration in retail chicken.

ComBase is a database and predictive microbiological model (Baranyi and Tamplin, 2004). Plots of ComBase data were generated to visualise the reduction in *Campylobacter* levels of raw chicken held at refrigeration temperatures within its shelf-life by retailers and UK consumers. A variety of temperatures were investigated – this is based on the fact that domestic refrigerators in the UK run at higher than the recommended temperature of between 1 and 5°C (Evans and Redmond, 2016) (Biglia et al., 2018).

ComBase data on *Campylobacter* levels in chicken broiler breast and chicken broth across different temperatures (4°C and 12°C) and (4°C, 5°C, 10°C, and 15°C) were used to estimate log10 CFU/g changes over time. *Campylobacter* levels in chicken broiler breast decreased by around 1 log10 CFU/g after 12 hours at 4°C (Figure 7). In comparison, *Campylobacter* levels tend to decrease by 1 log10 CFU/g after 6-hour storage at 12°C (Figure 7). Storage at 12°C effectively decreased *Campylobacter* presence on the chicken broiler breast by 2 log10 CFU/g after 15 hours.

Experiments in chicken broth produced more variable results (Figure 8). A similar trend of more *Campylobacter* death was observed as the temperature increased. *Campylobacter* levels also took longer to decrease by 1 log10 CFU/g in chicken broth - around 50 hours of storage at 4, 5, 10 and 12°C (Figure 8). Naturally, the decrease observed in chicken breast is taken to be more representative of the real-life scenario at retail.

Figure 7: Change in Campylobacter levels in chicken broiler breast at 4°C (A) and 12°C (B) over time. Data from ComBase (Baranyi and Tamplin, 2004). Different coloured lines refer to different samples

Figure 8: Change in Campylobacter levels in chicken broth at 4°C (A), 5°C (B), 10°C (C) and 15°C (D) over time. Data from ComBase (Baranyi and Tamplin, 2004). Different coloured lines refer to different samples.

4.3.4 Sampling results at large and small retailers

The FSA and major retailers carry out surveys of *Campylobacter* levels on chicken at retail. There were no data available on whether poultry from low-throughput slaughterhouses is more likely to be sold at large or small retailers (uncertainty). The difference in *Campylobacter* levels found at large and small retailers is discussed nevertheless, in case such information becomes available in future.

Surveys of whole chicken at retail found that a higher proportion of samples from small retailers had high levels of *Campylobacter* compared to those from large retailers, but did not find a cause of these differences (PHE, 2021). The difference could not be explained by remaining shelf-life, chicken weights, time of year sampled or type of chicken rearing (free-range, organic, etc).

Data from years 4, 5 and 6 of the "Microbiological survey of *Campylobacter* contamination in fresh whole UK-produced chilled chickens at retail sale" (FSA-funded project FS102121), was used to model the levels of *Campylobacter* found on Halal and non-Halal retail chickens at large retailers (year 4) and small retailers (years 4, 5 and 6). There were not enough data points for Kosher retailers to be included in this analysis.

The results, including the percentage that fall in the undetectable and high *Campylobacter* categories, are in Table 4 below. There are similar proportions of highly contaminated samples from Halal and non-Halal chicken. As noted by PHE, large retailers have a smaller proportion of highly contaminated chicken samples than small retailers (5% vs 12%). Large retailers also have more samples with undetectable levels of *Campylobacter* compared to small retailers (48% vs 39%).

Table 4: Number of results below the limit of detection, or >1,000 CFU/g Campylobacter in large and small retailers, broken down into Halal and non-Halal categories

Retailer	Below limit of detectoin	>1,000 CFU/g Campylobacter	Number of total results
Small, Halal	275 (43%)	84 (13%)	641
Small, Non-Halal	1225 (38%)	383 (12%)	3200
Small (all)	1500 (39%)	467 (12%)	3841
Large, Halal	8 (35%)	46 (5%)	932
Large, Non-Halal	447 (48%)	46 (5%)	932
Large (all)	455 (48%)	50 (5%)	955
Halal (all)	283 (43%)	88 (13%)	664
Non-Halal (all)	1672 (40%)	429 (10%)	4132

Figure 8 and Figure 9 show the distribution of the levels of Campylobacter in raw whole chicken from large, and small retailers, and by Halal and non-Halal categories. A lognormal distribution was chosen as best fitting (compared to uniform, normal and Weibull fits), given the AIC/BIC scores. Due to the heavy skew of the raw data, it was log-transformed before distribution fitting.

Figure 9: *Campylobacter* levels in whole chicken from large and small retailers. The best fitting distribution for the data is the lognormal. Samples with undetectable *Campylobacter* levels are not included.

Figure 10: *Campylobacter* levels at retail in Halal and non-Halal whole chicken. The best fitting distribution for the data is the lognormal. Samples with undetectable *Campylobacter* levels are not included.

Of the chicken that had detectable levels of *Campylobacter*, it was noticeable that retail chicken had lower levels compared to those measured after slaughter (Figure 10). This is presumably due to the influence of cold storage, as predicted by the ComBase data presented in the previous section (Section 4.3.3). The percentage of samples that did not have detectable levels of *Campylobacter* also increased at retail, from 33% (low-throughput slaughterhouses) to 39% (small retailers) and 48% (large retailers).

Figure 11: Fitted log normal distributions for *Campylobacter* levels sampled at low-throughput slaughterhouses, small retailers and large retailers. Chicken sampled at retail level had lower levels of contamination than at the slaughterhouse.

4.3.5 Differences in the *Campylobacter* levels of products at retail originating from low-throughput and high-throughput abattoirs

Campylobacter levels in chicken decrease following slaughter, as measured at retail and evidenced by experimental studies, likely due to the pathogen's sensitivity to refrigeration temperatures.

The proportion of highly contaminated samples at retail is similar in Halal and non-Halal chicken. Large retailers had a smaller proportion of highly contaminated chicken samples (5%) compared to small retailers (12%).
No information was found on the proportions of poultry meat from low- and high-throughput slaughterhouses used in different sectors (for example, catering, large and small retailers, ready-meals etc).

Therefore, although the available data indicate a difference in the proportion of chickens with high levels of *Campylobacter* contamination sold at major versus non-major retailers, in the absence of information on the relative volumes of chicken sold through each of these types of retailer that originated from low-throughput versus high-throughput abattoirs, it was not possible to assess whether a difference in risk exists.

4.4 Consumer module

4.4.1 Factors affecting Campylobacter levels due to consumer behaviour

Poultry with high levels of *Campylobacter* will pose the highest risk of campylobacteriosis for consumers. Thorough cooking will eliminate the pathogen, however, cross-contamination of

kitchen surfaces and ready-to-eat foods may also cause illness. Certain behaviours such as freezing poultry and washing raw chicken will affect the risk.

While data for the UK were not available, a quantitative risk assessment for antimicrobial resistant *Salmonella* in poultry estimated that 50% of Canadian consumers freeze their chicken *(Collineau et al.*, 2020). A UK study found that, 67% of consumers were observed to wash their hands with soap immediately after handling raw chicken (Didier et al., 2021).

According to a behavioural study in the US, 45% of participants washed raw chicken (a potential source of cross-contamination), and in 17% of cases, the internal temperature of the chicken dish was less than 70°C. Oven cooking was found to result in the lowest proportion of undercooking of chicken, compared to grilling, frying and boiling on top of the stove (Bruhn, 2014).

4.4.2 Differences in Campylobacter levels at consumption

Chicken is the foremost cause of campylobacteriosis in the UK (Oxford University, 2021). It should be noted that these cases of illness linked with chicken are not necessarily direct cases through consumption of chicken, and could be due to cross-contamination or other sources of exposure. In this report, we assume that all cases of campylobacteriosis linked with chicken are caused by chickens that are slaughtered in the UK, not including imports. We also do not have information on whether chicken from low-throughput slaughterhouses reaches a different subpopulation of consumers, who are likely to treat it differently (uncertainty).

To determine the number of cases that can be directly attributed to chicken, we have used the recently completed surveillance and source attribution research (Oxford University, 2021). This identified that 90% of *Campylobacter* cases are caused by *C. jejuni,* with 70% able to be linked to chicken as the source. The remaining 10% of Campylobacter cases are predominantly caused by *C. coli,* around 50% of which are associated with chicken.

Using this, and the total number of campylobacteriosis cases from the 2018 burden of Foodborne Disease (Holland and Mahmoudzadeh, 2020), we can estimate the number of Campylobacter infections linked to chicken as the source (Table 5). This was done by estimating the total number of *Campylobacter* cases linked to chicken from the frequency of *C. jejuni* and *C. coli* attribution, and then attributing the number of campylobacteriosis cases to low and high-throughput slaughterhouses by their proportional market share.

This estimate assumes that all cases of campylobacteriosis linked with chicken are caused by chickens slaughtered in the UK, as we don't have sufficient evidence on the rates of contamination of fresh imported chicken or the levels in frozen chicken when it reaches the consumer.

Table 5: The total number of Campylobacter cases in 2018, and an estimate of the number that can be attributed to chicken.

Cases	Median number of cases	Lower 95% CI	Upper 95% CI
2018 *Campylobacter* cases	299,392	127,128	571,332
C. jejuni cases attributable to chicken	188,616	80,090	35,993
Cases from other species of *Campylobacter* attributable to chicken	14,969	6,356	28,566
Total *Campylobacter* cases attributable to chicken	203,586	86,447	388,505
Campylobacter cases attributable to low-throughput slaughterhouses	10,771	4,573	20,554
Campylobacter cases attributable to high-throughput slaughterhouses	192,815	81.873	367,951

4.4.3 Differences in Campylobacter levels of products in the home

Because we were unable to find any information on differences in the products manufactured with chicken from low- versus high-throughput abattoirs, or in the volume of chicken products sold through different types of retail outlets, it was not possible to assess whether consumer behaviours will differentially affect the probability of exposure to *Campylobacter* via poultry produced in low and high-throughput slaughterhouses. Assuming all else being equal, the yearly throughput has the only impact on risk at a population level.