final report

An Analysis of Animal Growth Path on the Eating Quality of Beef

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Introduction

A program to improve the eating quality of Australian beef must identify the factors that effect this trait. These factors may be genetic or environmental. Among the environmental factors the growth path of the animal from birth to slaughter is of particular interest since this is under the control of the grazier or feedlot operator.

Cattle raised for slaughter in Australia typically experience variable nutrition and this is expressed in growth paths which may vary widely depending on the food supply. While deficits in food supply may be supplemented this option incurs a cost which needs to be managed within the value of the product to the market. If growth path was shown to have an effect on the eating quality of beef then it might be economic to direct resources to achieving growth rates which improve eating quality.

Scope of this Report

This analysis is a pilot study to assess the application of a new statistical procedure which can identify the region of the growth path of a population of animals which has the largest relationship with a trait measured after animal slaughter. The traits chosen to represent the eating quality of beef were the variables Clipped Juicy and Clipped Mq4. As the study of growth path effects on eating quality is a new field it is not intended that this study be definitive. Rather it should assist in guiding future work in this area should the technique be shown to be useful. Further, it should be emphasised that this analysis considered variation in growth path originating from a mixture of genetic, nutritional and stage of maturity effects.

Methods

Data

There were 16 cohorts of animals supplied for analysis. These animals had measurements on liveweight at different times through to slaughter, and measurements on eating quality represented by the two variables Clipped Juicy and Clipped Mq4.

Within a cohort animals were identified by birthdate, herd of origin, breed, sire and week of eating quality measurement. In many cases these variables were confounded, particularly herd of origin and breed. Generally the numbers of animals in a cohort (Table 1) did not permit an accounting of all these effects in an analysis. This means that the residual variation in the eating quality variables included variation due to the effects not included in the analysis. Thus the residual variation may have been higher than it would be if these effects had been accounted for in the analysis.

There were 3 cohorts which did not have sufficient animals for an analysis and these were discarded. They were cohort numbers 3 (4 animals), 15 (1 animal) and 16 (4 animals).

The times over which the liveweights of animals within each cohort were measured were supplied with the data. It is not known by this analyst how these times relate to animal age or to the time of the year. Thus the results reported here will need further interpretation in the light of this information.

Analysis

Each cohort was analysed separately. The statistical model included breed, herd of origin, birthdate and carcass weight effects as well as the eating quality variable which was either Clipped Juicy or Clipped Mq4. The response variables were the cubic spline polynomial coefficients for the function describing the growth path (see appendix).

The analysis identified the time when differences between animals in their growth path is having the greatest effect on the eating quality of the beef.. Cubic spline polynomials were fitted to the liveweight measurements made on each animal through time. The between animal variation in the coefficients of these polynomials could be related to the between animal variation in the eating quality trait of interest. The time of closest relationship between these variables can then be identified using standard mathematical optimisation procedures. The details of the analysis are given in the appendix

The time intervals in days over which separate cubic polynomials were fitted to the liveweight data of each animal are shown in Table 1. These times varied by cohort. In cubic spline polynomials a cubic polynomial is fitted to the liveweight data within each interval with the polynomial curves constrained to agree at the ends of each interval. The number of intervals filled in for each cohort in Table 1 represents the number of separate polynomials required to represent the growth paths of the animals within the cohort. For example cohort 1 required 2 cubic polynomials linked at day 308 to fit the liveweight measurements, whereas cohort 4 only required 1 cubic polynomial to fit the liveweight measurements.

The effect of growth path on interactions between the eating quality variables and a main effect such as herd of origin were estimated by nesting the eating quality variable within the main effect during the analysis.

Results

The cohorts which had significant between animal growth path effects on the eating quality variables are shown in Table 2 (Clipped Juicy) and Table 3 (Clipped Mq4). These Tables also show the time at which the growth path response occurred within the intervals given in Table 1, and the regression coefficient relating the growth rate at this time to the eating quality variable. For example consider cohort 1 in Table 2. The growth path of the animals had the greatest effect on the eating quality variable Clipped Juicy at day 496 (P<0.01). The regression coefficient of -123 shows that for each 1 kg per day increase in the growth rate of the animals in this cohort the measure of Clipped Juicy decreased by 123 units.

The results in Tables 2 and 3 show that the responses of both Clipped Juicy and Clipped Mq4 have a more significant response to growth path within the first interval of time (P<0.01) than to growth path within the second interval of time (P<0.05). The response is such that

generally animals with higher growth rates at these times had reduced levels of Clipped Juicy and Clipped Mq4.

The growth paths of the animals in each of the cohorts in Tables 2 and 3 are shown in Figures 1 to 6. These figures have the times at which variation in growth between animals had the greatest effect on Clipped Juicy and Clipped Mq4 marked on them. There does not appear to be any feature of the growth path at these times (apart from rate of growth) which was consistent between cohorts.

These results suggest that:
- There is a statistically significant effect due to differences in growth path on the eating quality of the animals within a cohort.
- This response is associated with the earlier measurement of growth within each cohort
- This response is generally negative, high growth at these times reduces the eating quality of beef. However, note the contrary, but small, result from cohort 7.

Interactions With Main Effects

While there was no significant response to the effect of growth path on eating quality in cohorts 4, 9, and 10, there were significant growth path effects on interactions between growth path and herd of origin on eating quality in these cohorts. The effect of growth path on the interaction between herd of origin and Clipped Juicy is shown in Table 4. For Clipped Mq4 only herd AA06 in cohort 9 showed a significant response ($P<0.05$) of growth path. This occurred on day 926 and had a regression coefficient of growth rate on Clipped Mq4 of -31.7.

The herd BB24 within cohort 4 is listed in Table 4 although the response was not statistically significant. This was probably due to the low number of animals in the analysis (7 animals). However, the magnitude of the regression coefficient of growth rate on Clipped Juicy is consistent with other estimates of this parameter.

Cohort 12 is the only cohort to have a significant response to growth path on Clipped Juicy both as a main effect and as an interaction. This is probably due to there being only 2 herds of origin within cohort 2. Note that cohort 8a contained a large number of herds, too many to establish an interaction, while cohort 11 contained only 1 herd. Thus only cohorts 1 and 2 provided evidence of an effect of growth path on eating quality unaffected by external influences.

The average growth paths for each of the herds where a significant interaction occurred with eating quality are shown in Figures 7 to 11. There do not seem to be any consistent differences between the growth paths of the herds within each cohort that do show a relationship between growth path and eating quality and those that do not.

A higher degree of fit (R^2) was apparent for the analysis within herd of origin (Table 4) than for the analysis across herd of origin (Table 2). However, the number of animals in a herd of origin within a cohort was low.

The results of these interactions with herd of origin suggest that:

- The response, and time of response, of eating quality variables to growth path effects depend on factors associated with the herd of origin before the cohort was formed.
- These pre-cohort factors could be genetic (sire or breed), or environmental (previous unmeasured growth responses).

There was no discernible effect of an individual animal's growth path on eating quality in cohorts 5, 6, 8b, 13 and 14. For illustration the growth paths of the individual animals over the period they were measured is shown for cohort 5 in figure 11, and for cohort 14 in figure 12. There do not appear to be any notable differences in the features of the growth paths of the animals in these cohorts from the growth paths of animals in the other cohorts.

Conclusions

This pilot study has been able to establish the existence of animal growth path effects on the beef eating quality variables Clipped Juicy and Clipped Mq4. These effects generally occur early within the period of measurement. However, the relationship of the time scale supplied needs to be matched to the time of the year and the age of the animals for further interpretation. Also it was not clear to the analyst the extent to which nutritional effects changed within a cohort over time. This information is not available to this analyst.

In several cases the response of eating quality to growth path depended on which herd of origin was being considered within a cohort. This suggested that the history of the animals before the cohorts were formed modified the response of eating quality to growth path. As herd of origin was sometimes confounded with breed, and could also include sire effects, the relationship between genetic and environmental influences could not be determined in this data set.

However, two cohorts (1 and 2) showed clear evidence of the effects of growth path on eating quality which did not interact with herd of origin. This suggests that environmental effects on growth path do occur. This is supported by cohorts 1 and 7 showing significant ($P<0.05$) responses of growth path to eating quality in the second interval of growth. This was after correction for the responses observed in the first interval. This correction should have also accounted for external influences such as genetic effects.

The amount of variation in the eating quality variables accounted for by the growth path response (the R^2) should be interpreted with caution. This measures the influence on the eating quality of the animal growth at the particular time of growth, in this case the time when growth is most strongly related to eating quality. This is a point estimate. Indeed further analysis could establish an 'interval' of response rather than a point. Considering this, it would be likely that the effect of growth path over an interval on the eating quality would account for more of the variation in eating quality than the effect of growth path at a point. However, the scope of this pilot study limits the extent of the investigation. This would be an issue for further investigation.

Recommendations

This pilot analysis has produced strong evidence that growth path influences the eating quality of beef. That was the goal of this analysis. Future work will need to study the elements affecting the strength of this relationship in order to incorporate this knowledge into practical beef production systems.

The first question should be what is the relative contribution of genetic and environmental factors to the strength and nature of the relationship between growth path and beef eating quality. The observed herd of origin effect on the effect of growth path on eating quality may be due to genetic or environmental effects. This analysis was unable to resolve this issue because the number of animals within each cohort was not large enough to establish this with confidence. Ideally this question should be settled at an early stage. An experiment can be designed, or a data set found, with sufficient identifiable genetic effects to make estimates of any genetic component. An experiment where animals of similar genetic background (e.g. half sibs) are fed on two different growth paths would assist interpretation.

The estimates of the effect of growth path on the eating quality of beef made in this study suggest that early growth has a stronger effect than later growth. However, all data in this study are post weaning, while the evidence of herd of origin interactions suggest pre-cohort environmental or genetic effects. Examination of growth stages earlier than those represented in this study should be made.

In summary further work should:
1. Establish estimates of any genetic effect on the relationship between growth path and beef eating quality.
2. Examine the period of early growth (pre-weaning) for the effect of different animal growth path.

Table 1: Time intervals for each cohort within which cubic polynomials were fitted to individual animal liveweights. knot points were at the end of each interval.

Cohort	First Interval (days)	Second Interval (days)	Third Interval (days)	Number of Animals
1	254 to 308	308 to 777		19
2	625 to 906	906 to 969		57
4	225 to 1031			18
5	625 to 907	907 to 976		17
6	478 to 765	765 to 1005		35
7	462 to 766	766 to 1005		41
8a	485 to 764	764 to 1050		23
8b	462 to 822	822 to 1033		30
9	815 to 876	876 to 946		54
10	815 to 899	899 to 971		48
11	465 to 780	780 to 983		19
12	556 to 801	801 to 940	940 to 1011	18
13	358 to 921			8
14	442 to 992			36

Table 2: Time (day) of growth effects on clipped juicy for cohorts with a significant response.

Cohort	Early Growth	Regression (R²%)	Late Growth	Regression (R²%)
1	496**	-123 (25%)	954*	-97 (25%)
2	762**	-41 (14%)	no response	
7	739**	18 (10%)	1006*	8 (10%)
8a	no response		935*	-0.2
11	630**	-76 (9.5%)	no response	
12	679**	-6.6 (8%)	no response	

* $P<0.05$

** $P<0.01$

Table 3: Time (days) of growth effects on clipped mq4 for cohorts with a significant response.

Cohort	Time 1	Regression (R²%)	Time 2	Regression (R²%)
1	496**	-87 (14%)	954*	-60 (15%)
2	762**	-30 (7%)	no response	
7	739**	11 (4%)	1006*	6 (5%)
8a	no response		931*	-0.8
11	630**	-60 (6%)	no response	
12	679**	-4.7 (3%)	no response	

* $P<0.05$

** $P<0.01$

Table 4: Time of growth effects on herd of origin within cohort for clipped juicy

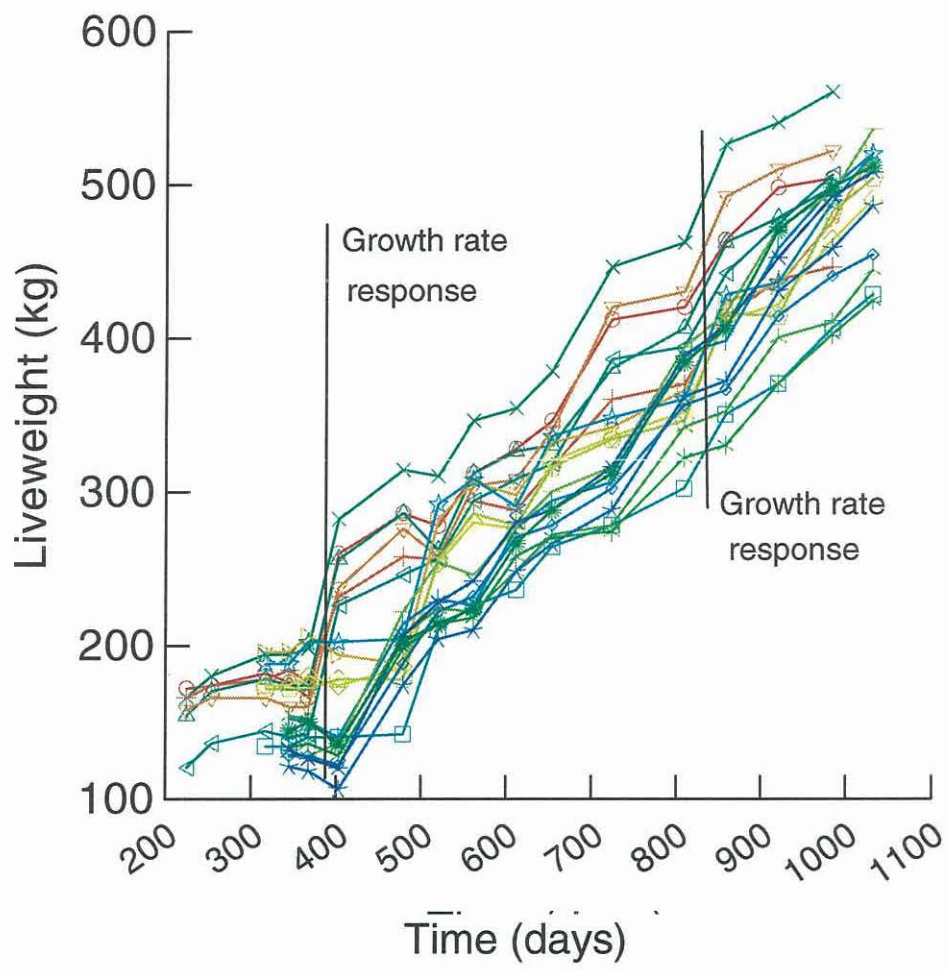| Cohort	Herd within Cohort	Time	Regression (R²%)
4	BB24	386	-27.9
9	AA06	926***	-31.8 (80%)
10	AA02	860***	26.6 (66%)
12	XBBG	676**	-6.52 (20%)

*** $P<0.001$

Figure 1. Cohort 1 individual animal liveweights through time.

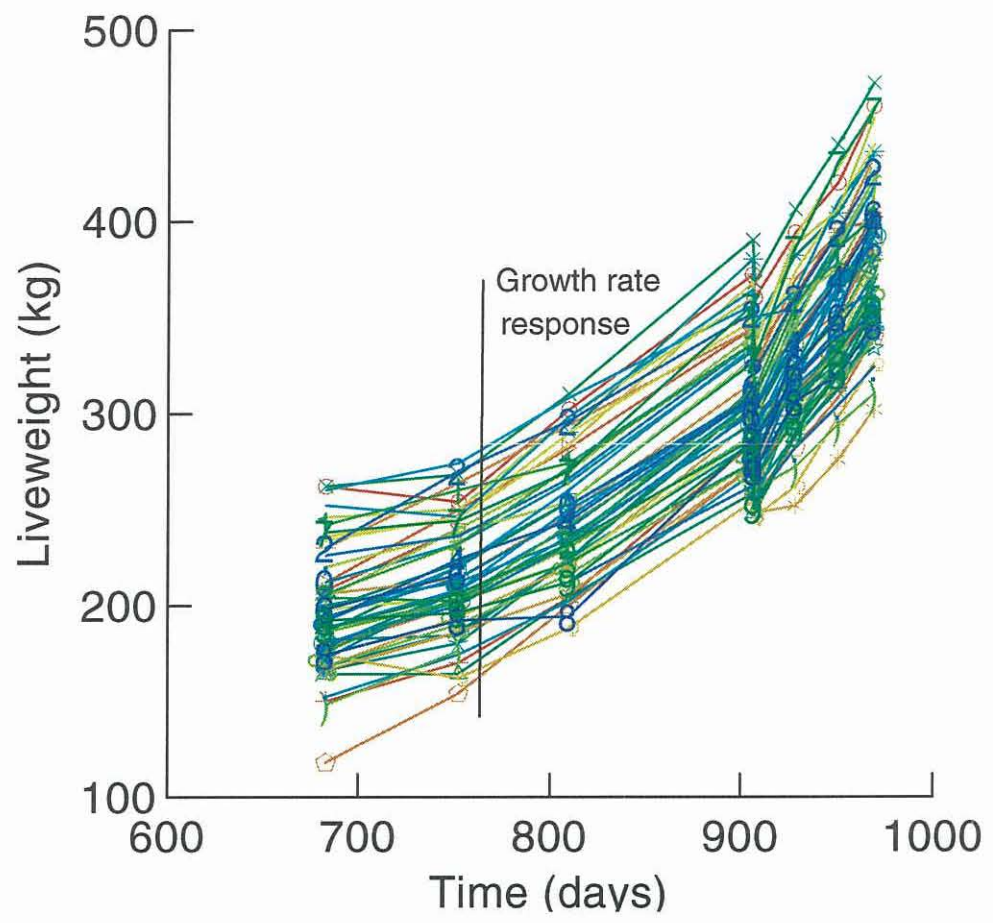Figure 2: Cohort 2 individual animal liveweights through time

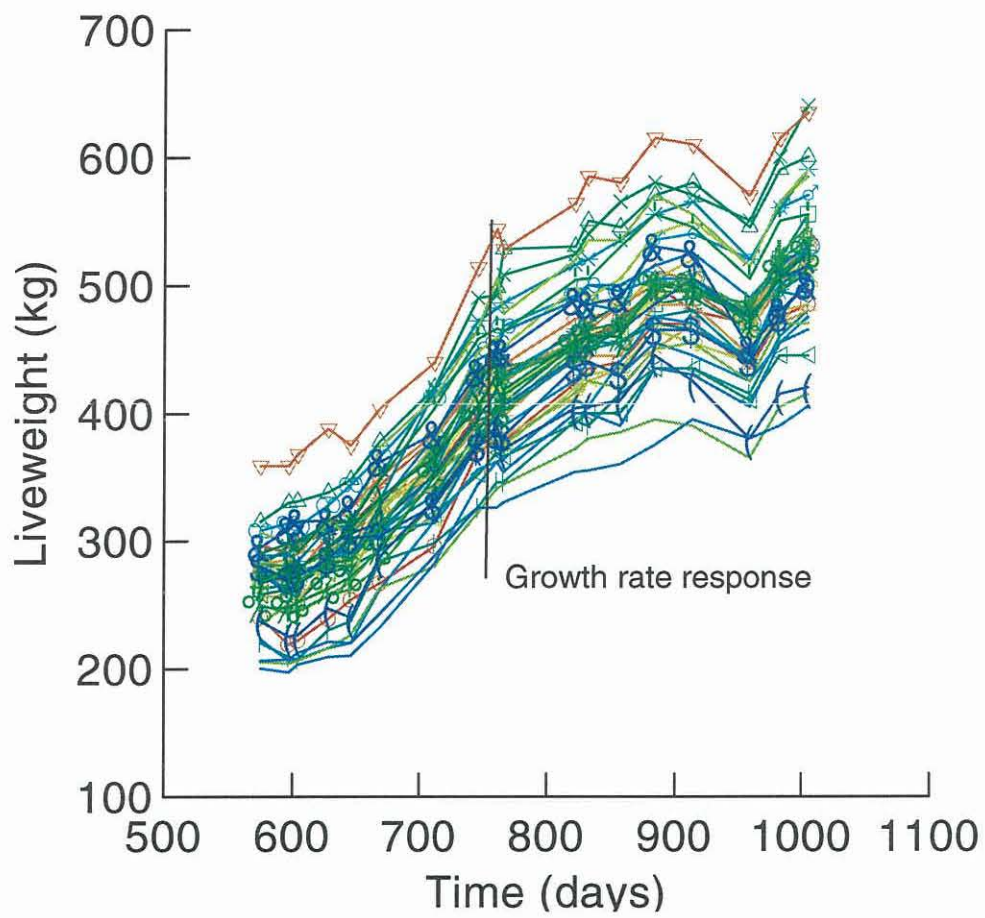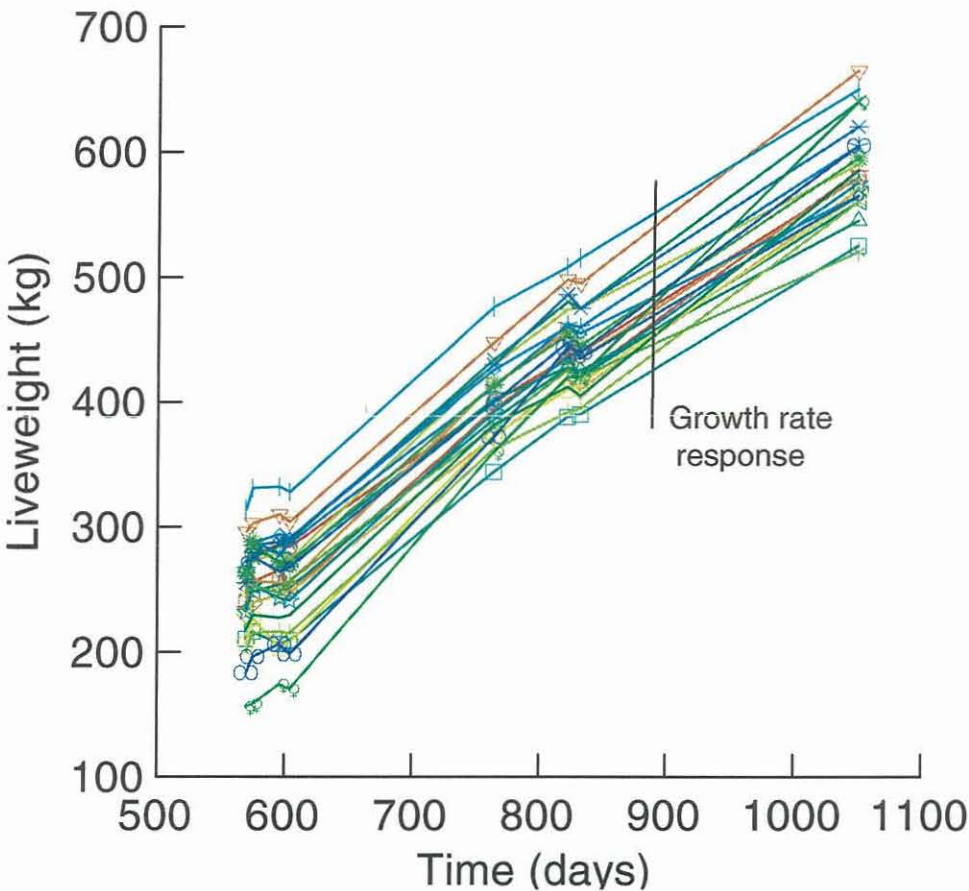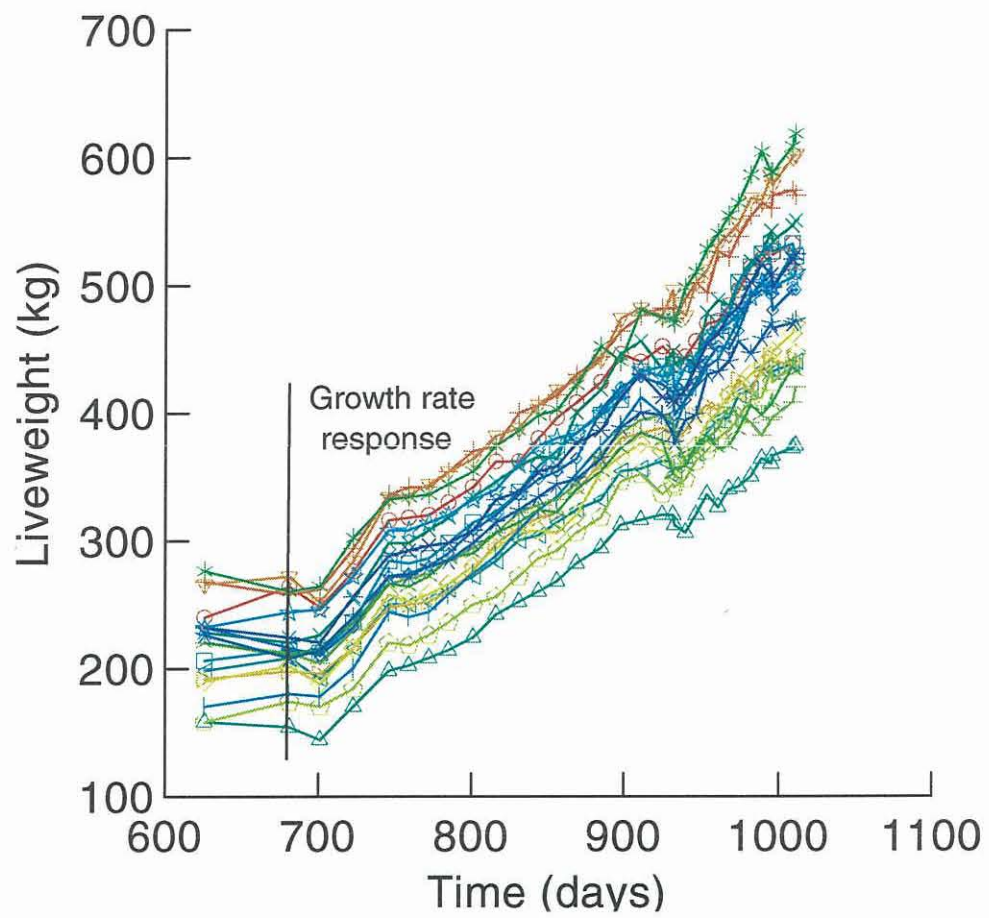Figure 3: Cohort 7 individual animal liveweights through time

Growth rate response

Figure 4: Cohort 8a individual animal liveweights through time.

Growth rate response

Figure 5: Cohort 11 individual animal liveweights through time

Figure 6: Cohort 12 individual animal liveweight through time

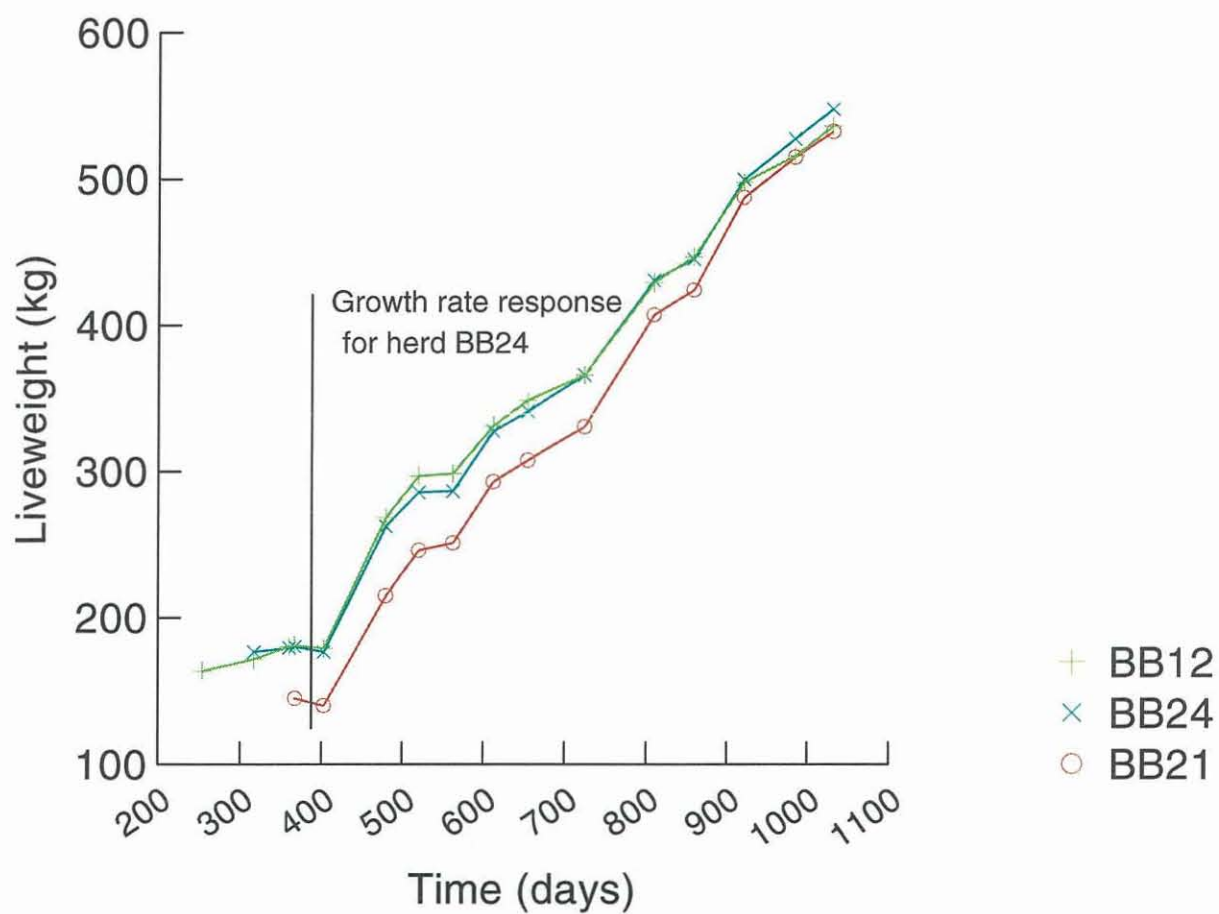Figure 7: Cohort 4 average animal liveweight through time for each of the three herds in the cohort.

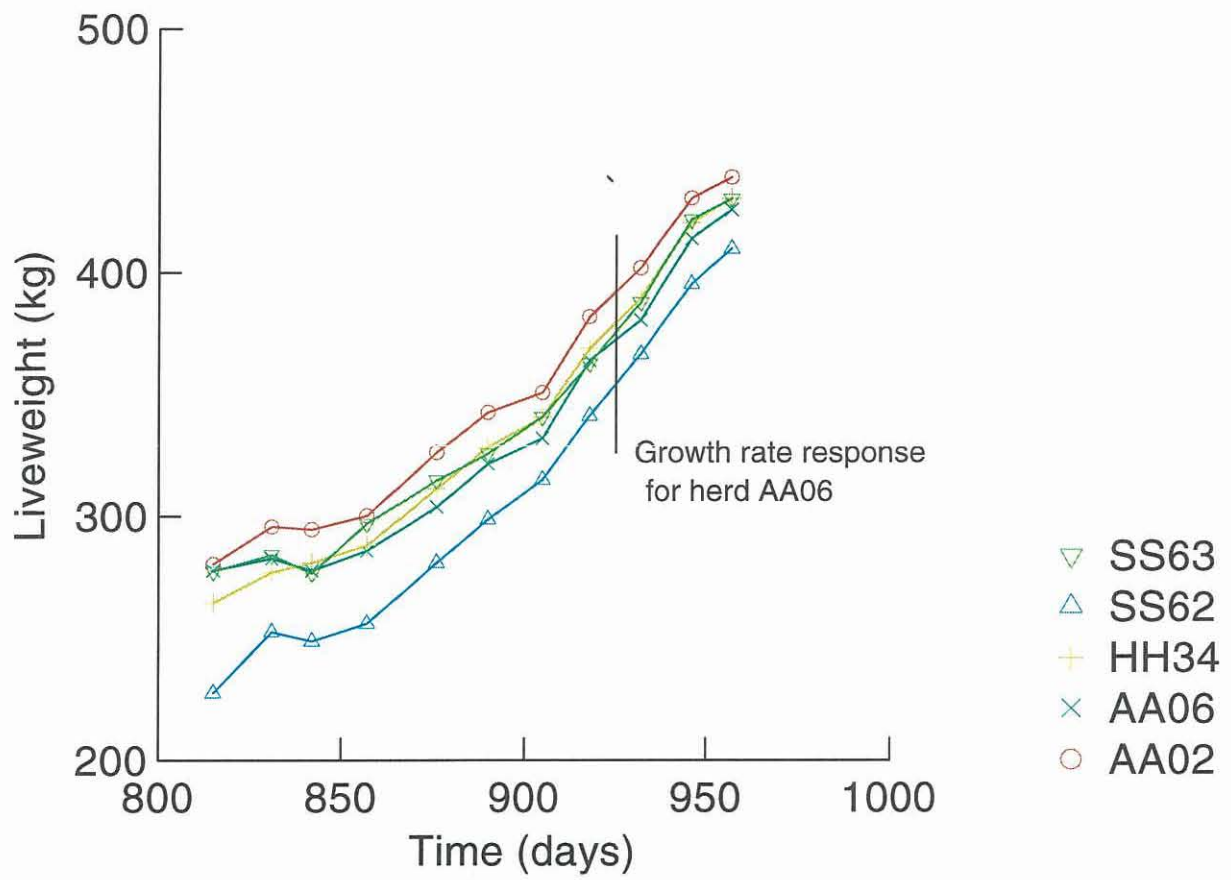Figure 8: Average animal liveweight through time for each of the five herds in cohort 9

Figure 9: Average animal liveweight through time for each of the five herds in cohort 10.
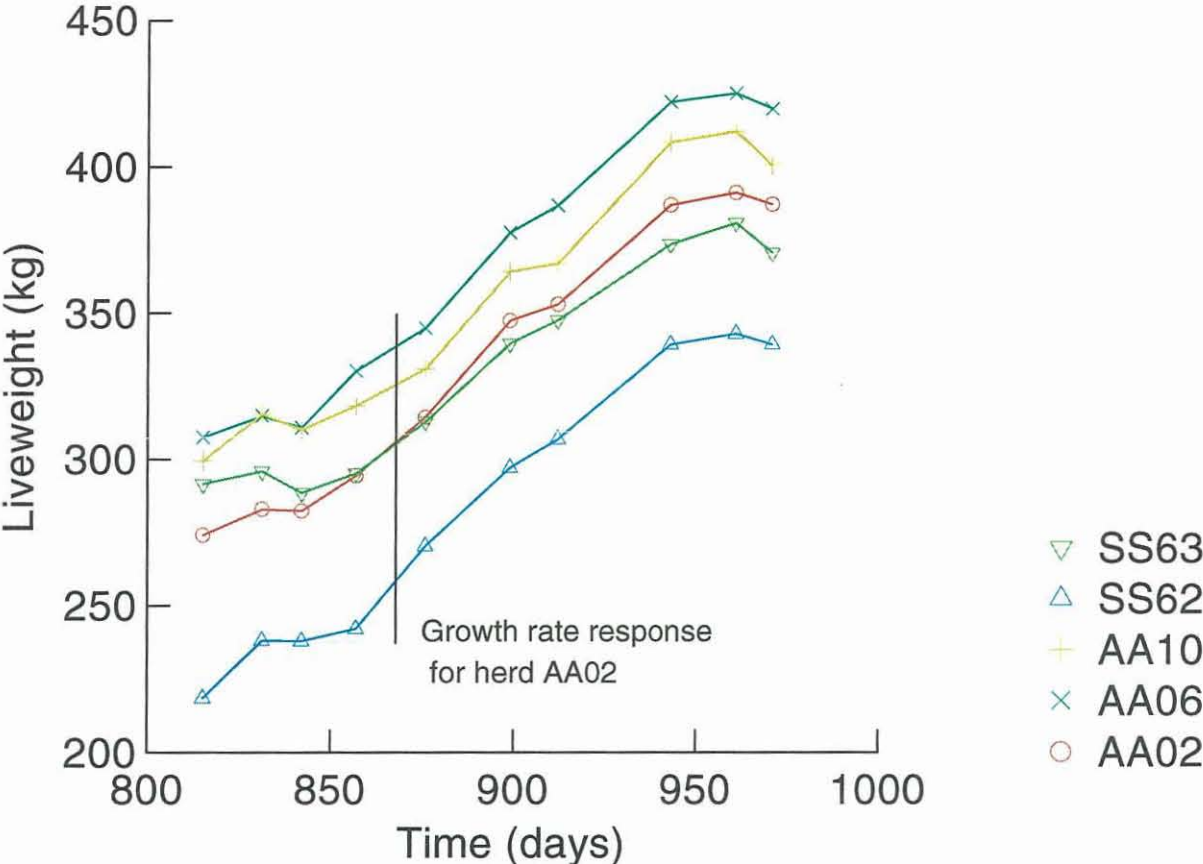
Figure 10: Average animal liveweight through time for each of the two herds in cohort 12.
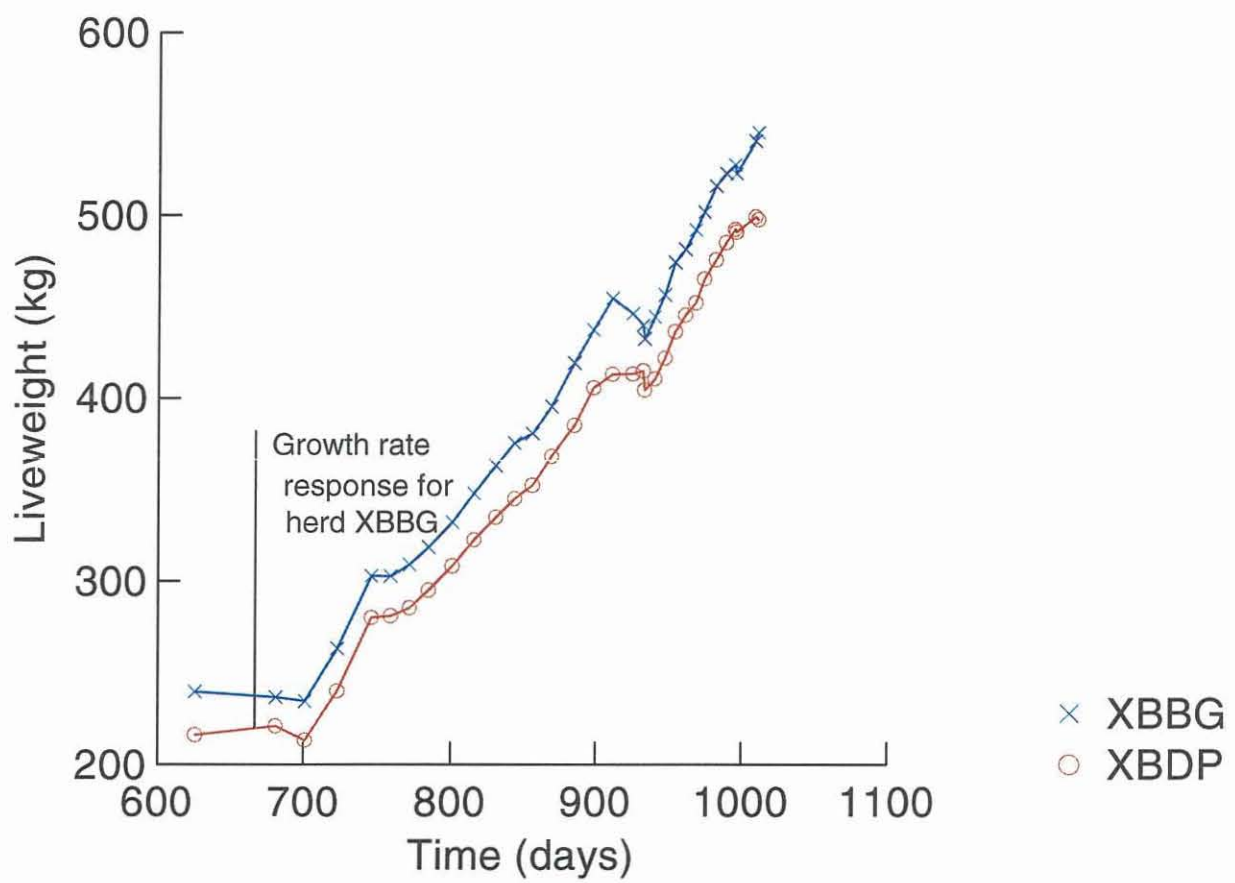
Figure 11: individual animal liveweights through time for cohort 5. no response of eating quality to growth path
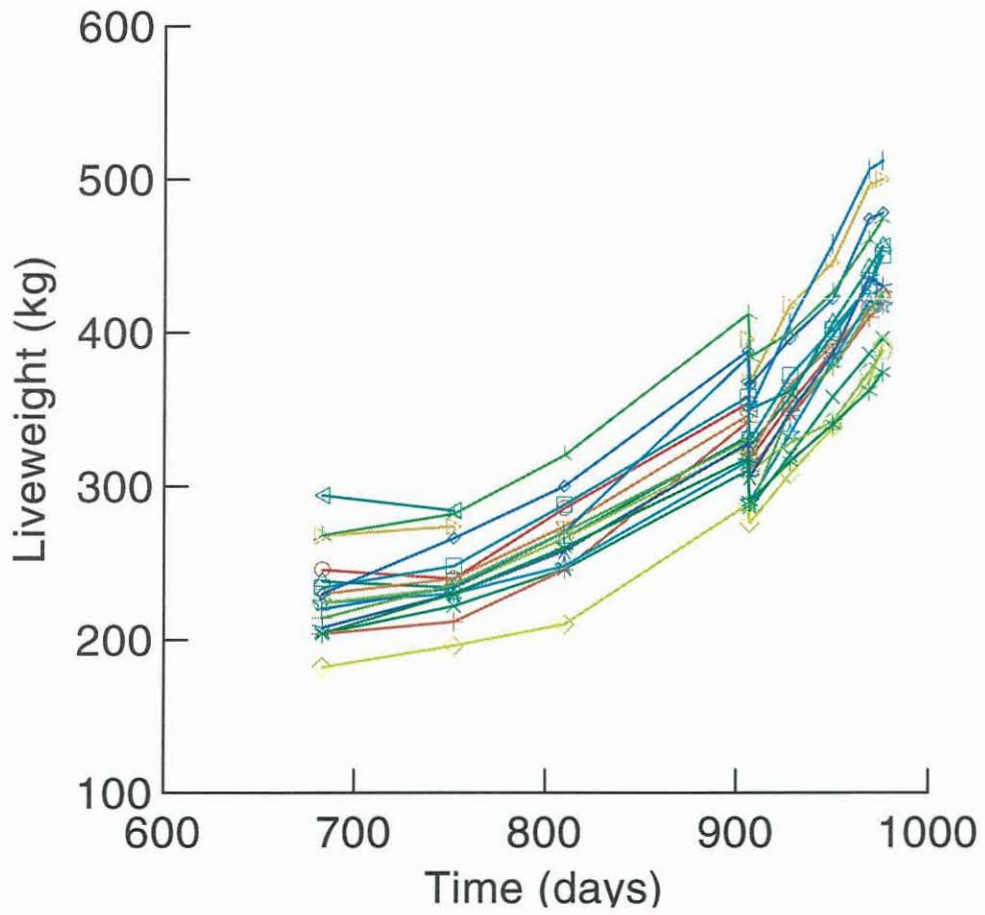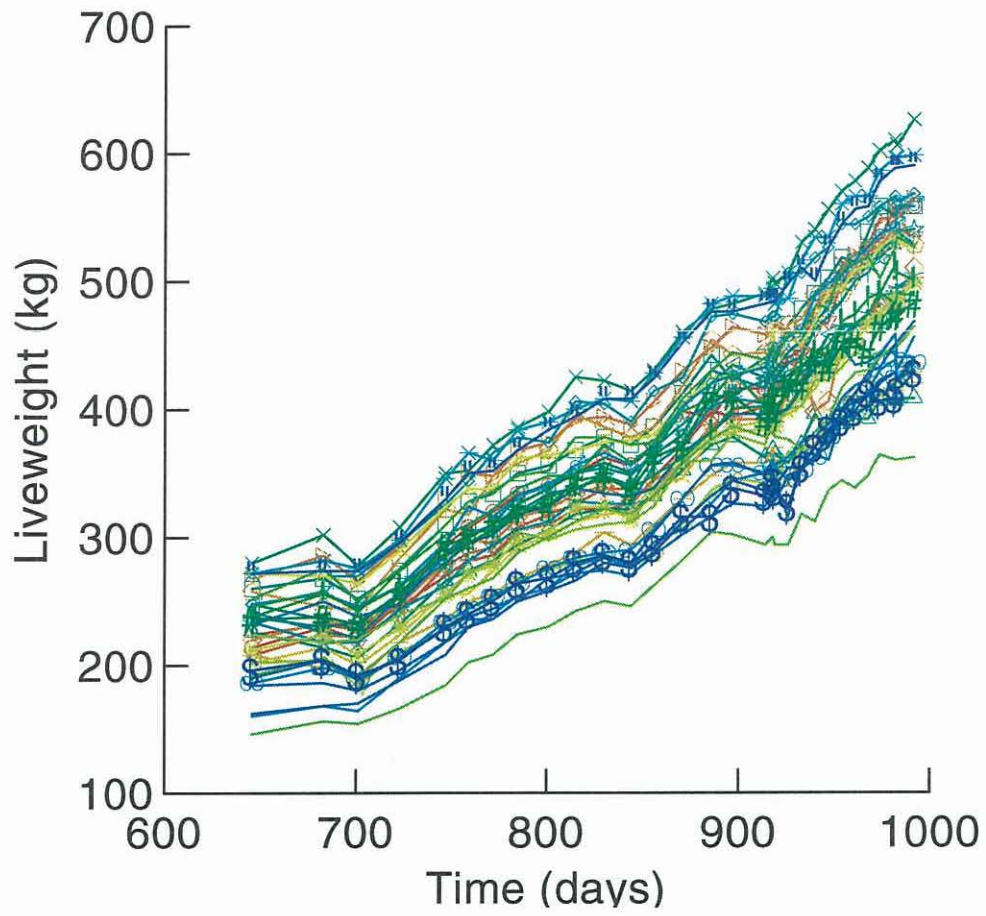
Figure 12: individual animal liveweights through time for cohort 14. no response of eating quality to growth path

Appendix

Finding the Relationship Between Growth Path of the Animal and Eating Quality of the Beef After Slaughter

Estimating the growth path of an individual animal

Liveweight measures body weight and gut fill. The gut fill introduces a significant error, especially when measuring animal growth rate by the difference of two liveweights. For this reason it is usual to smooth the liveweight curve by some kind of averaging. The deviations from this average curve can be *ad hoc* attributed to gut fill. The most common averaging technique used in this way has been the cubic spline polynomial. This function has the advantage of sufficient flexibility of curvature to model a variety of animal growth curves. The spline knot points may be placed to account for known circumstances (for example a change in feeding strategy) or estimated as a parameter during fitting. In this analysis cubic spline polynomials were used with knot points placed to isolate phases of the growth curve of interest (see below).

The growth rate of each animal is given by the first differential of the cubic spline polynomial. Other functions may also be of interest, for example the acceleration of growth given by the second differential of the cubic spline polynomial.

At each time t within the interval of interest each animal will have an estimated growth rate given by the first differential of the cubic spline polynomial fitted to the liveweights of that animal. The set of the growth rates for all animals in the cohort at each time t can be correlated with another measurement made on each of these animals. For example carcass bone, or a measure of the eating quality of the animal made after slaughter. The objective of the analysis is to find the time within the interval of interest when growth rate has the greatest correlation with the attribute of interest, in this case a measurement of eating quality.

Relating the growth path of an animal to post-slaughter measurement

Since the first differential of the cubic spline polynomial (growth rate) is a linear function of the cubic spline polynomial coefficients this is the same as finding the canonical correlation between the cubic spline coefficients and the attribute of interest. The canonical correlation finds the linear function of the spline coefficient which maximises the correlation with the attribute of interest. However, this linear function may not be related to the linear function of the spline coefficients which estimates growth rate. But if the linear function which maximises the canonical correlation is significant then any other linear function may be tested for significance in the theory of the multivariate analysis of variance. A linear function of interest is that linear function of the spline coefficients which estimates growth rate and is maximally correlated with the measurement of the attribute of interest.

Let the growth rate be wg, then for spline coefficients a, b, and c corresponding to the cubic, quadratic and linear components of the spline polynomial:

$$wg = 3at^2 + 2bt + c$$

This can be written as:

$$wg = (3t^2)a + (2t)b + (1)c \qquad (1)$$

From this it can be seen that the time t needs to be chosen so that the weights $3t^2$, 2t, 1 form the linear function (1) which maximises the correlation with the eating quality attribute of interest.

Let **H** be the hypothesis matrix formed by regressing the 3 spline coefficients on the eating quality attribute. Let **E** be the error matrix associated with this process where the main diagonal has the residual mean squares of the cubic, quadratic and linear terms respectively. Let τ be the time vector, i.e.:

$$\tau = \begin{bmatrix} 3t^2 \\ 2t \\ 1 \end{bmatrix}$$

Then the value of t which maximises the correlation with the eating quality attribute will be given by finding the maximum of the F ratio over time.

$$\max \quad \frac{\tau' H \tau}{\tau' E \tau}$$

The linear function of the spline coefficients formed by finding the time which maximises the relationship with the eating quality attribute and entering this into (1) can then be tested for significance through the usual process in the multivariate analysis of variance for testing assigned linear functions of the dependent variables.

The cubic spline polynomial presents the liveweight curve as a sequence of cubic polynomials valid over an interval defined by the knot points. It may be desirable to consider the relationship between the growth rate and the eating quality in such a defined interval, but independently of the relationship between growth rate and eating quality in another interval. It may be that growth rate at one time is related to the eating quality through correlation with the growth rate that is really effecting eating quality rather than through a direct relationship. In this case one of the spline's can be used as a covariate. Because of difficulties with multicollinearity between the spline coefficients the regression should take place on the principal components of the between animal spline coefficients.