Abstract

The number of pigs on hand, about one-seventh of which are breeding sows, is the major determinant of production of pigmeats (pork, bacon and ham) (see 'Forecasting Pigmeat Production for BAE Trends', Technical Paper VII, July 1977). A series of models is developed to forecast movements in sow numbers in response to changes in saleyard prices and feed costs. The results of these models are compared with an alternative formulation which seeks to explain pig numbers in terms of past values alone.

The implications of these models for forecasting sow numbers and total inventory of pigs are then discussed and the sensitivity of the forecasts to alternative estimates of future cost and price changes is examined.
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AN ANALYSIS OF PIG NUMBERS IN AUSTRALIA

1. Introduction

The supply or number of pigs in Australia, about one-seventh of which are breeding sows, is influenced by a large number of economic and expectational factors. This supply, in its turn, is the major determinant of production of pigmeat [1].

The main aim of this paper is to develop a method of forecasting numbers of pigs for a short period ahead (say one to five years), on the basis of a derived relationship between past sow numbers figures and other factors, such as saleyard prices and feed costs. Forecasts of this nature are the basis of much BAE work, such as BAE Trends estimates and Outlook Conference statements, and may be of use to the industry in planning future changes in productive capacity and/or adjustment between different competitive outputs. Of course, the extent to which the industry will place any faith in these projections will depend, among other things, upon the accuracy of previously published projections.

A model for forecasting the production of pigmeats from the stock of breeding sows has been developed [1]. We now need to derive a relationship which will permit us to forecast sow numbers.

The Australian Bureau of Statistics derives an estimate of stocks of pigs and breeding sows at 31 March each year, from its annual livestock census. Preliminary estimates of livestock numbers are published in late May and the updated and final figures are published later in the year. Numbers of pigs and breeding sows are available only on an annual basis and therefore seasonal fluctuations in pig numbers are not known.

Many econometric models of pig and pigmeat supply have been developed in recent years. Of these, Ness and Colman [10], Meilke, Zwart and Martin [9] and O'Connor [4] are of the most recent interest; the last is of particular interest as it applies specifically to Australian conditions.

Ness and Colman [10] analysed the size of the pig breeding herd in the United Kingdom, and for England, Scotland and Northern Ireland separately. The study encompassed a wide range of techniques, including a version of the asymmetric price-response model developed in Section 3 of this paper. An important section of their bulletin is devoted to means of comparing the efficiency of different forecasting techniques. It was found that either a simple structural model or an ARIMA model (see Section 4 of this paper) performed best in predicting movements in sow numbers.

The second study mentioned, by Meilke, Zwart and Martin [9], compared geometric with polynomial distributed lag models of pig supply. That is, the supply of pigs is related to past prices in periods (t-1), (t-2), ..., (t-n), the weights attached to each period declining as n increases, according to either a geometric or polynomial scheme. In a polynomial scheme, the weights may even increase at first, before they start to decline. Nerlove [18] has shown that a geometric lag is consistent with two types of behaviour - first, if producers adjust
production towards some desired level (the stock adjustment model), or second, if producers plan production on the basis of expected price, this being a function of past prices (the adaptive expectations model). In the former study, [9], the authors found that the polynomial supply functions performed better on quarterly data, but there were greater problems with serial correlation than with the geometric-lag model. It was found that the greatest response of pig supply to a price change occurs six quarters after the price change.

O'Connor's study [4] identified the major factors influencing pig supply in Australia, over the period 1953-54 to 1974-75, as being pig prices, grain prices, and the level of production and profitability of certain enterprises commonly occurring on holdings with pigs. An important conclusion was:

"...if the problem of supply instability is to be reduced, three sources of instability should be considered: that arising from the cobweb-cycle effect, that arising from feed price variability, and that arising from the influence of other industries" (page 55).

The present study will extend this work to cover the period up to 1976-77 and will attempt to develop and compare various models for estimating the supply of breeding sows in Australia. In Section 2 a structural econometric model is developed and tested, in an attempt to explain movements in sow numbers over the period 1950-51 to 1976-77. Section 3 extends this model to take account of asymmetric price responses, in which a supply response to a rising price is greater than the response to a falling price (because of the difficulty in turning pig housing and other fixed factors to alternative uses once built). In Section 4 an alternative model is developed, in which pig numbers are explained in terms of past values alone, while Section 5 discusses the relative performance of the different models and implications for forecasting pig numbers.

2. A Structural Model of Sow Numbers

Factors influencing producers' decisions to expand or decrease sow numbers include the prices being reached at the saleyard relative to other possible outputs and the cost of various inputs such as feed, capital, labour and pig housing. We can write the general form of this relationship as:

\[ \Delta SN = SN_t - SN_{t-1} = f(\text{relative prices, costs, exogenous factors}) \]

where

\[ SN = \text{sow numbers ('}000) \]

Very few studies have been undertaken of fixed-cost structures and economies of scale within the pig industry. An exception was a study by Van Haerigen [2], which looked at the Queensland industry. However, this study is now considerably dated, having been published in 1969.
The major variable cost in pig-raising is the cost of feed, which accounts for some 70% of total costs. Before the early 'sixties, most pigmeat was produced on dairy farms as a sideline to milk and cream production. About this time there was a major switch to grain feeding. This was particularly true during the period of wheat quotas (1969-70 to 1971-72) when many wheat producers raised pigs to dispose of over-quota wheat. In the model developed below, a dummy variable is included to account for this period. It is interesting to note that, even in the dairy feed period, an estimate of the cost of raising a pig to 140 lb (60 kg) apportioned over 65% of the cost of feed to wheat and only 10/-( $1) to skim milk (the protein component), at a nominal valuation of one penny per gallon (0.2c per litre) ([25], page 18).

The model is run for the two time periods 1950-51 to 1975-76 and 1962-63 to 1975-76 (referred to hereinafter as the whole period and the grain feed period respectively) and the results are compared.

O'Connor [4] gives a detailed discussion of the various lags involved in supply adjustment in the pig industry. The nature and length of the pig cycle, together with a study of the sow breeding cycle, suggests that:

'the time lag from the decision to retain a sow at the previous weaning (the decision on supply level) to the sale of the progeny of the sow will be approximately 10½ months for porkers and 13 months for baconers, an overall average of about 12 months. The twelve month average lag between the price signal and the production response would be a minimum, however, since the process would be a couple of months longer if gilts are used (gilts are first mated at approximately nine months of age) or if sows must be purchased to attain the desired level of production. In addition, there will be some delay in price signals being received and assimilated by producers (a certain price level would be unlikely to modify producers' price expectations unless it had prevailed for a couple of months)'.

O'Connor concludes that the total time lag between price signal and supply response is between twelve and twenty-four months. This suggests that a geometric lag model (stock adjustment or adaptive expectations) is appropriate.

As mentioned before, the paucity of data on fixed costs precludes the inclusion of these into the equation at this stage. We shall therefore include only a variable-costs term in the equation. The variable to be used is a feed-cost index (FCI) calculated by taking a weighted average of prices of wheat, barley, oats, maize and sorghum for the years under consideration. The weights used are estimated usage of each grain [6], multiplied by the respective TDN (Total Digestible Nutrients) factors. This index is then standardised to give an estimate of cost (in cents) of grain per kg of meat produced.

Saleyard price of pork (SPP) is estimated by taking a weighted average of average annual porker prices at Capital city saleyards [7]. The weights chosen are the number of pigs slaughtered in each State in each year.
Actual data series used in these calculations are shown in Appendix A.

The geometric-lag model to be used in this analysis is a form of the general distributed lag model

\[ SN_t = \delta + \beta_0 SPP_{t-1} + \beta_1 SPP_{t-2} + \ldots + \beta_{k-1} SPP_{t-k} + \mu_t \ldots 2 \]

where \( \beta_0 \) to \( \beta_{k-1} \) are weights assigned to prices in periods \((t-1)\) to \((t-k)\), and \( \mu_t \) is a random error with zero mean and unit variance, and the variables are as previously defined.

Because of the lack of degrees of freedom in this equation, a simplifying assumption (i.e. that of a geometrically-distributed lag) is made. That is, the \( \beta \)'s in Equation 2 are assumed to be of the following form:

\[ \beta(i) = \beta \lambda (1-\lambda)^i \quad i=0, 1, 2 \]
\[ 0 < \lambda < 1 \ldots 3 \]

Substituting Equation 3 in Equation 2 gives:

\[ SN_t = \delta + \beta \lambda SPP_{t-1} + \beta \lambda (1-\lambda) SPP_{t-2} + \beta \lambda (1-\lambda)^2 SPP_{t-3} + \ldots 4 \]

Lagging Equation 4 by one period and multiplying by \((1-\lambda)\) gives:

\[ (1-\lambda) SN_{t-1} = \delta (1-\lambda) + \beta \lambda (1-\lambda) SPP_{t-2} + \beta \lambda (1-\lambda)^2 SPP_{t-3} + \ldots 5 \]

Subtracting Equation 5 from Equation 4 gives:

\[ SN_t = \delta \lambda + \beta \lambda SPP_{t-1} + (1-\lambda) SN_{t-1} \ldots 6 \]

In this form, \( \lambda \) is the coefficient of adjustment and \((1-\lambda)\) represents the proportion of adjustment to a price change that will occur in the first period. In an adaptive expectations model (Nerlove [18]), \( \lambda \) is referred to as the coefficient of expectation. The closer \( \lambda \) is to zero, the more will producers cling to their previous expectations, i.e. the less will they revise their production in response to immediate price changes.

If we let \( \delta \lambda = a \)
\[ \beta \lambda = c \]
and \((1-\lambda) = b\),
then the general form of the equation to be estimated is

\[ SN_t = a + b SN_{t-1} + c SPP_{t-1} + d FCI_t + gWQD_t + \nu_t \ldots 7 \]

where

\[ WQD = \text{wheat quotas dummy} \]
\[ = (1 \text{ in years 1969-70 to 1971-72} \]
\[ (0 \text{ otherwise}, \]
and

\( v_t \) is a disturbance term whose properties remain to be examined.

Note that in the above form of this equation, the costs term (FCI) and the dummy (WQD) are assumed to be contemporaneous; that is, producers are assumed to have an adaptive adjustment reaction to prices only. Fitting this form of equation to the data (Appendix A) by ordinary least squares gives:

\[
\begin{align*}
SN_t &= 29.15 + 0.78SN_{t-1} + 1.96SPP_{t-1} - 3.00FCI_t + 52.70WQD_t, \\
(1.84) & \quad (14.14) & \quad (5.23) & \quad (-4.23) & \quad (3.75) \\
\hat{R}^2 &= 0.9494 \\
d &= 2.1053
\end{align*}
\]

with \( t \) statistics shown in parentheses.

Note that \( SN_t \) refers, for example, to 31 March 1951 when the subscript \( t \) of \( FCI_t \) refers to the fiscal year 1950-51. Fiscal years are used to permit comparison between the exogenous variables and other economic series. An alternative hypothesis, the rationale of which will be examined in Section 5, is that feed costs *lagged one year* are the major cost consideration. This implies a distributed-lag reaction to costs as well as to prices. As this variable is lagged and exogenous, it may be incorporated directly. The results for this formulation are:

\[
\begin{align*}
SN_t &= 45.80 + 0.69SN_{t-1} + 1.89SPP_{t-1} - 2.89FCI_{t-1} + 69.77WQD_t \\
(1.99) & \quad (10.10) & \quad (3.20) & \quad (-2.25) & \quad (4.35) \\
\hat{R}^2 &= 0.9245 \\
d &= 1.9803
\end{align*}
\]

The estimated value of the coefficient of adjustment (or expectations) for Equation 8 is 0.22. Substituting back into Equation 4, the price-response component of the model (i.e. omitting the lagged sow numbers and cost-response terms) may be written as:

\[
\begin{align*}
SN_t &= 6.4 + 1.96SPP_{t-1} + 1.52SPP_{t-2} + 1.19SPP_{t-3} \\
&\quad + 0.93SPP_{t-4} + \ldots \\
\end{align*}
\]

The weights of the \( SPP_{t-n} \) terms decline gradually as \( n \) increases, indicating that sow numbers are responsive primarily to immediately past prices but also to the pattern of price movements over the previous years. In the terminology of ARIMA processes (see Section 4 of this paper), the coefficients of the autoregressive terms decline gradually rather than cutting off abruptly.

The error term \( (v_t) \) of Equation 8 requires further consideration. Under a pure adaptive expectations model, \( v_t \) is given explicitly \([18]\) as:

\[
v_t = e_t - \lambda e_{t-1}
\]
where, for example,

(i) the $e_t's \sim N(0, \sigma^2_e)$

or

(ii) $e_t = \rho e_{t-1} + \epsilon_t$, $|\rho| < 1$, $\epsilon_t \sim N(0, \sigma^2_e)$

i.e. the disturbances follow a first-order autocorrelation scheme in which the $e_t's$ may be either normally distributed or themselves follow a first-order Markov process ([20], page 304).

These are only a couple of possibilities for the distributions of $v_t$ and $e_t$. Kmenta [30] shows that, in general, the inclusion of a lagged dependent variable brings in some kind of correlation between the error term ($v_t$) and the lagged dependent variable ($Y_{t-1}$). For comparison, see Equation 2 in which no lagged term is included.

If $v_t$ is simply assumed to be normally distributed with zero mean and $\sigma^2_v$ variance (i.e. the adaptive expectations component is discounted) then ordinary least squares applied to Equation 7 will yield consistent and asymptotically efficient estimators. However, the estimates will be biased for small samples ([20], pp. 305-307), with a bias approximately equivalent to $-\frac{1}{n} (1+3\beta)$ where $\beta$ is the coefficient of the lagged dependent variable. In this case, with 27 observations, the order of the bias is small, estimated at approximately -.12. For the forecasting Equation 16 used in Section 5 of this paper, the bias is of the order of -.097, i.e. the true value may be about 0.1 higher than estimated values. This should be kept in mind when interpreting the figures in Table No. 1 and in Column 5 of Appendix C.

The Durbin-Watson test for autocorrelation of the residuals is shown by Taylor and Wilson ([21], p. 337), to be fairly efficient in small samples. Therefore the value of $d=2.1053$ in Equation 8 gives us little reason to suspect autocorrelation. A further test is Durbin's $h$ statistic [22], used to test for serial correlation when a lagged dependent variable is included on the right-hand side. (1) For Equation 8, $h = -.283$ and $|h| = 0.283$, well below the critical level 1.645, above which one would reject the hypothesis of zero autocorrelation at the 5% level. For Equation 9, $h = 0.06$. Where appropriate, $h$ statistics will be presented for the rest of the estimated equations given in this paper.

\[ h = (1-2d)\sqrt{\frac{n}{1-n \hat{V}(b_1)}} \text{ where } \hat{V}(b_1) \text{ is the estimated variance of the coefficient of the lagged dependent variable.} \]
Equation 8 calculated for the grain feed period only is:

$$\text{SN}_t = 35.72 + 0.77\text{SN}_{t-1} + 2.27\text{SPP}_{t-1} -3.64\text{FCI}_t + 46.67\text{WQD}_t$$

$$\text{(1.05)} \quad \text{(7.88)} \quad \text{(3.4)} \quad \text{(-2.97)} \quad \text{(2.56)} \quad \ldots \quad 12$$

$$\bar{R}^2 = 0.8869$$
$$d = 2.3582$$
$$h = -1.019$$

In both this and Equation 8, it was found that the inclusion of variables lagged more than one year either decreased the explanatory power of the equation (as measured by $\bar{R}^2$) or led to insignificant $t$-values.

Another equation using $\Delta \text{SN}$ (i.e. $\text{SN}_t - \text{SN}_{t-1}$) as the dependent variable needed a complicated series of lags to give sufficient explanatory power. The best-fit equation (whole period) was:

$$\Delta\text{SN} = 22.86 + 0.496\text{SPP}_t + 2.37\text{SPP}_{t-1} -1.53\text{SPP}_{t-2} -7.05\text{FCI}_t$$

$$\text{(0.98)} \quad \text{(1.05)} \quad \text{(5.26)} \quad \text{(-3.83)} \quad \text{(6.49)}$$

$$+ 3.77\text{FCI}_{t-1} + 29.08\text{WQD}_t$$

$$\text{(3.44)} \quad \text{(2.54)}$$

$$\bar{R}^2 = 0.7958$$
$$d = 2.4358$$

In every case, this equation predicted the direction of the change; however, percentage errors in predicting the magnitude of the change were sometimes high. The coefficients of the lagged variables indicate a response of supply to prices between 12 and 24 months, as hypothesised previously. However, the difficulty in using it for forecasting is that current exogenous variables are included (see Section 5).

The model specification so far used assumes saleyard price of pork to be a strictly exogenous variable. On the other hand, it might be argued that prices are a function of the interaction between supply and demand, and hence influenced by sow numbers themselves. If this is so, a simultaneous equation model will be more appropriate than ordinary least squares.

This argument may be evaluated by examining the relative elasticities of supply and demand for pigmeat. If supply were in fact more elastic than demand, then sow numbers would be a major determinant of price, and would have to be regarded as an endogenous variable in a properly specified model.

Several estimates of supply elasticities for pigmeats have been published. Gruen et al [26], estimated an elasticity of supply (sow number response) of 0.4, while Hill [27] gave price elasticity of supply estimates at the means of 0.54 for coastal areas and 0.7 for inland areas of New South Wales. Equation 8 of this paper gives an estimate of 0.5 for the period under consideration.
On the other hand, estimates of demand elasticity are considerably higher, ranging from -1.6 (Main, Reynolds and White [28]) to -3.3, (Pender and Erwood [29]). These results suggest that price is not particularly responsive to short term supply variations and, hence, that saleyard price may be treated as exogenous in the development of this forecasting model.

A further model, combining a dynamic analysis of supply and demand with an analysis of retail and wholesale margins for pigmeat, is now under way.

The models so far examined assume that a producer's response will be price-symmetric, i.e. he will decrease sow numbers in response to a falling price by the same percentage as he would increase them in response to an equivalent rise in price. In practice this may not be so because of the difficulty of turning pig housing and other fixed capital stock to alternative uses once built. The next section examines some models designed to test this proposition.

3. An Asymmetric Price-Response Model

To test the proposition that the size of the sow herd responds asymmetrically to upward and downward movements in expected prices, the price variable may be segmented as follows [12]:

\[
S_{NT} = f(SPP_{t-1}^R, SPP_{t-1}^F)
\]

where

\[
SPP_{t-1}^R = (SPP_{t-1} \text{ if } SPP_{t-1} > SPP_{t-2}) \quad (0 \text{ otherwise})
\]

\[
SPP_{t-1}^F = (SPP_{t-1} \text{ if } SPP_{t-1} < SPP_{t-2}) \quad (0 \text{ otherwise})
\]

and the \( R \) superscript denotes a rising price while the \( F \) superscript denotes a falling price.

Fitting an equation to the data by this method, with other variables defined as previously, gives:

\[
S_{NT} = 57.84 + .85S_{NT-1} - .40FCI_t + .0018SPP_{t-1}^R - .47SPP_{t-1}^F + 60.45WQD
\]

\[
(2.59) (11.48) (-.65) (.57) (-2.4)
\]

\[
R^2 = .9098 \quad d = 1.52 \quad h = 1.35
\]

According to this equation, there is virtually no response to a rising price (\( t = .57 \)), while the response to a falling price is of the expected
sign and significant. However, according to Wolfram [13], the use of this method frequently results in insignificant variable coefficients. An alternative method is needed to ensure that the variance of the dependent variable explained by the two segmented variables is equal to that of the original price series. Wolfram defines the two variables $p^R(W)$ and $p^F(W)$ as follows:

$$p^R(W)_1 = p_1$$

$$p^R(W)_2 = p^R(W)_1 + \varnothing(p_2 - p_1)$$

$$p^R(W)_3 = p^R(W)_2 + \varnothing(p_3 - p_2)$$

$$\ldots$$

$$p^R(W)_n = p^R(W)_{n-1} + \varnothing(p_n - p_{n-1})$$

where

$$\varnothing = \begin{cases} 1 & \text{if } p_t > p_{t-1} \\ 0 & \text{otherwise} \end{cases}$$

For the second segmented series $p^F(W)$, the process is similar except that the absolute value of the term in parentheses is taken while the multiplication factor $\varnothing^F$ (in place of $\varnothing$) is defined:

$$\varnothing^F = \begin{cases} 0 & \text{if } p_t > p_{t-1} \\ 1 & \text{otherwise} \end{cases}$$

Using this method of segmentation results in the following parameter estimates:

$$SN_t = 82.28 + .61SN_{t-1} - 2.28FCI_t + 1.06p^R(W)_{t-1} - .29p^F(W)_{t-1} + 52.51WQD$$

$$R^2 = .9330$$

$$d = 1.7478$$

$$h = 0.73$$
The results of this segmentation are interesting, showing a significant
difference ($P(SPP^R(W) = SPP^F(W)) < .01$) between the response to a rising
price and the response to a falling price, although the coefficient of
$p_{t-1}^F(W)$ is significantly different from zero only at the 15% level. Further,
we may accept the hypothesis of no serial correlation. If $FCI_t$ is
replaced by $FCI_{t-1}$ and the equation re-estimated (as in Equation 9), we
find the coefficient of $p_{t-1}^F(W)$ becomes insignificant ($t=.33$). Omitting
this term, we have:

$$
SN_t = 72.46 + .54SN_{t-1} - 1.60FCI_{t-1} + .85P_{t-1}^R(W) + 65.21WQD
$$

\[ \begin{array}{ccc}
\text{R}^2 & = 0.9171 \\
\text{d} & = 1.8924 \\
\text{h} & = 0.34 \\
\end{array} \]

The uses of this equation for forecasting (as compared with
Equation 9) will be examined in Section 5 of this paper.

4. Autoregressive Moving-Average Models

The Autoregressive Integrated Moving-Average (ARIMA) models
developed by Box and Jenkins [14] are important members of a class of
models which attempt to explain the values of a variable and to forecast
not-yet-experienced values solely in terms of past observations on that
variable. ARIMA models assume that the values of a variable are a
function of past values of the variable, or a distributed lag function of
the error term, or both.

The autoregressive (AR) component of an ARIMA model may be
expressed as:

$$
Y_t = a + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + e_t 
$$

where $e_t$ is a disturbance term, and there are $n$ lags ($ns p$) up to and
including order $p$. (Note that not all the lags may be significant so
that, for example, a second-order term may be omitted. Unless there are
seasonal factors (which are dealt with separately) it is often found that
1-, 2- and/or 3-period lags are sufficient to explain the autoregressive
component. Monthly or quarterly data may require a higher order of
lagging.

The moving average (MA) component of the model is:

$$
e_t = u_t + \theta_1 u_{t-1} + \theta_2 u_{t-2} + \ldots + \theta_q u_{t-q} 
$$

That is, the $e_t$ of Equation 17 has been decomposed into the
moving average series given by the right-hand side of Equation 18. In a
pure moving-average model (i.e. no AR component), the $e_t$ in Equation 18
would be replaced by $y_t$, and a constant term may be incorporated on the
right-hand side.
The models (AR, MA and a mixture of the two, ARMA), rely on stationarity (i.e. no trend) of the series of observations (see [14]). If this does not hold, then taking first differences of the raw data will often do the trick. If not, second differences (i.e. the differences of the differences) may be tried, and so forth, up to the dth differences. In most annual economic time series, $d \leq 2$ is sufficient to induce stationarity.

The parameters $p$, $d$ and $q$ are sufficient to define the form of an ARIMA ($p$, $d$, $q$) model. For example, a model ARIMA $(3, 1, 2)$ has autoregressive terms up to order three and moving average terms up to order two, while the first-difference series of observations is used for modelling. Identifying an ARIMA model is an art in itself. This is facilitated by means of computer packages such as BOX JEN, a system in use by the BAE ([23], Chapter 7), which calculates an autocorrelation function (ACF) and partial autocorrelation function (PACF) for the data or for specified regular and/or seasonal differences of the data, together with appropriate diagnostic statistics. Nelson [24] discusses methods which may be used to decide between an AR and an MA model, or a combination of the two.

In the case of pig numbers, the series was found to be non-stationary, so first differences were taken. The first differences ACF showed that lags of one and two periods were the only significant lags (measured by testing the autocorrelation coefficient divided by its standard error against a $t$ statistic with, in this case, 24 degrees of freedom). Lags at periods 9 ($t = 1.35$) and 18 ($t = 1.0$) were thought to indicate a 9-year seasonal (or cyclical) lag component, but the $t$ statistics were not sufficiently high to warrant their inclusion.

An inspection of the PACF led to the specification of a model with a 2-period lag autoregressive term and a one-period lag moving average term, and a trend constant; that is, an ARIMA ($2, 1, 1$) model, with the AR(1) term omitted. Alternative models tried, such as including an AR(1) in addition to or in place of an MA(1) term, gave a higher residual variance.

This model (ARIMA $(2, 1, 1)$) was fitted to the figures for pig numbers estimated at 31 March 1901 to 1977. The long time span was chosen to give sufficient observations for the estimation procedure (an insufficient time span was available for sow number figures):

$$a = 26.095$$
$$\theta_2 = .396$$
$$\theta_1 = .420$$

The resulting estimating equation was:

$$\Delta PN = (PN_t - PN_{t-1}) = -26.095 - .396 (PN_{t-2} - PN_{t-3}) + .420 (u_{t-1} + u_{t-2}) \ldots 19$$

$$(0.93) (-3.42)$$

$$(3.65)$$

$R^2 = .9160$ (uncorrected for d.f.)

$\chi^2_{17} = 7.54$
Residual variance = 26,910

t values are shown in parentheses

where

\[ PN = \text{pig numbers ('000)}. \]

The \( \chi^2 \) statistic with \( n \) degrees of freedom is provided for testing the hypothesis that the residuals are 'white noise', an engineering term very conveniently and belatedly adapted to economic analysis. The residuals from this equation had a non-significant mean \( (\mu_\sigma = .012) \) and the residual autocorrelations were all insignificant at the 90% level. Only in three cases, i.e. at lags 9, 16 and 20, did the \( t \) value greater than unity. Further, \( \chi^2 = 7.54 \), well below the critical level. In this case, we cannot reject the hypothesis that the residuals are white noise. That is, we conclude that all the significant non-random variation in the series has been accounted for by the model.

A comparison of Equation 19 with the results of Sections 2 and 3 provides some interesting results. Although the two series (pig numbers and sow numbers respectively) are not strictly comparable, the first is a remarkably stable multiple of the latter (see Appendix B and [1], page 3). The weights of the ACF of the undifferenced data decline in a manner similar to the weights of the geometric-lag model (Equation 10). A second feature is that the moving average term in the ARIMA model may have captured some residual autocorrelation present in the system. In the geometric lag model, the inclusion of additional variables such as costs and wheat quotas would have accounted for the acceptance of the hypothesis of no serial correlation.

Both these considerations point to the need for further research into the combining of the two systems (econometric and Box-Jenkins analysis) through the transfer-function class of models [15] now being developed.

5. Forecasting

It is often of great value both to researchers and to industry personnel to have forward estimates of sow numbers and pigmeat production. The extent to which these forecasts are reliable depends on the skill and judgment of the forecaster, the adequacy or lack thereof of the assumptions underlying the chosen model, and the statistical confidence limits that may be placed upon the estimates. In the case of the structural model, the forecasts will also depend upon the accuracy of forecasts of the current exogenous variables. If the forecast is being made only one year ahead and if all the exogenous variables are current, forward estimates of these variables must be made. Values for the lagged endogenous variable are obtained by solving the forecasting equation iteratively.
Several approaches to this problem are possible. Estimates from other sources or simple forward projections may be made, or other models may be used to forecast values of the exogenous variables. An approach briefly examined below is to use an ARIMA model to forecast minimum mean square error values of the exogenous variables, which are then fed into the equation to obtain forward estimates of the endogenous variable. If a lagged endogenous term is included, as in this case, the process is an iterative one.

To permit the forecasting equation to be solved iteratively, two approaches may be adopted:

(i) the current exogenous variable FCI may be 'estimated', even though its true value will not be known at the time the forecast is made. In this case, either Equation 8 (symmetric price response) or Equation 15 (asymmetric response) will be used, or

(ii) the specification of the model may be changed, so that the response to feed prices is assumed to be lagged one year. In this case, Equation 9 (symmetric response) or Equation 16 (asymmetric response) will be chosen.

Neither of these approaches is very satisfactory. The first approach introduces forecast error, while the second assumes a high correlation between FCI \(_t\) and FCI \(_{t-1}\). Fortunately, \(r(FCI_t, FCI_{t-1}) = 0.88\) in this case, so alternative (ii) will be chosen. However, the use of Equation 9 for forecasting is believed to give misleadingly low forecasts of sow numbers (e.g. 259,000 in 1978-79), principally because of its assumption of symmetric price response. Hence, the asymmetric price response Equation 16 will be used below.

Appendix C provides a comparison between ex-post (see [1]) forecasts of sow numbers for the years 1950-51 to 1976-77 from:

(i) the structural model (Equation 16), and

(ii) the ARIMA (2, 1, 1) model.

Note that, because the ARIMA model was estimated for pig numbers rather than sow numbers, an estimate of sow numbers must be made. This is done in two ways, first, by using the actual proportion of sows to pigs in that year (which in fact would only be known after the event), and second by taking a ratio of \(0.142857 (1/7)\) of pig numbers (Appendix B).

It can be seen that, contrary to the author's bias and hopes, the structural model does slightly better in predicting sow numbers than does the ARIMA model. This would be accentuated if estimates from Equation 8 rather than Equation 16 were used (because of the higher \(R^2\)). However, it has been pointed out (e.g. [10]) that the standard error of ex-post forecasts from econometric models may be biased downwards because true values of both exogenous and endogenous variables are known.

Finally, a series of forecasts of sow numbers to 1980-81 (i.e. March 1981) by Equation 16, based on projections of the exogenous variables SPP and FCI, is given in Table No. 1.
The SPP variable is projected by fitting an ARIMA (1, 1, 0) model to Homebush pork prices from 1950-51 (by the procedure outlined in Section 4 of this paper) and assuming that the same proportional change in forecast Homebush prices to 1979-80 will apply Australia-wide. Since a price fall is projected, the SPPR(W) variable will remain unchanged up to 1978-79 at a value of 193.3 and increase to 195.1 in 1979-80. Feed costs are difficult to forecast, but tend to follow an upward trend with a marked 6 to 7 year cycle; that is, prices peak every three years or so. A graphical extrapolation of the FCI variable gives forward estimates as shown.

Table No. 1
FORECAST OF SOW NUMBERS
1976-77 to 1980-81

<table>
<thead>
<tr>
<th>Year</th>
<th>Sow Numbers at 31 March</th>
<th>Saleyard Price (SPP)</th>
<th>Feed Cost Index (FCI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976-77</td>
<td>316(p)</td>
<td>114.0</td>
<td>64.4</td>
</tr>
<tr>
<td>1977-78</td>
<td>304(f)</td>
<td>112.0(a)</td>
<td>67.5(e)</td>
</tr>
<tr>
<td>1978-79</td>
<td>293(f)</td>
<td>111.5(a)</td>
<td>66.7(e)</td>
</tr>
<tr>
<td>1979-80</td>
<td>288(f)</td>
<td>113.3(a)</td>
<td>65.5(e)</td>
</tr>
<tr>
<td>1980-81</td>
<td>289(f)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(a) Estimated by forecasting from an ARIMA (1, 1, 0) model. (e) Estimated by forward extrapolation. (f) Forecast from Equation 16. (p) Preliminary estimate from ABS.

Obviously, the degree of reliance that may be placed on these estimates will be influenced in large measure by the accuracy of the forward projections of the exogenous variables (saleyard prices and feed costs). The sensitivity of forecast sow numbers to changes in prices and feed costs is shown in Table No. 2. (Note that, due to the asymmetric specification of the price variable in the forecasting model Equation 16, a fall in saleyard price would be registered as equivalent to zero change.)

As an example, if feed costs increase by 1% per annum and saleyard prices increase by 5% per annum between 1976-77 and 1979-80, we may expect a stock of 305 000 sows at 31 March 1980.

For comparison, forecasts made by solving the ARIMA (2, 1, 1) model (Equation 19) iteratively are shown in Table No. 3.
Table No. 2

EFFECT OF CHANGING PRICE AND COST ASSUMPTIONS ON FORECAST
SOW NUMBERS AS AT 31 MARCH
('000)

<table>
<thead>
<tr>
<th>Annual Change in Price</th>
<th>-10%</th>
<th>-5%</th>
<th>-1%</th>
<th>0%</th>
<th>1%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>308</td>
<td>303</td>
<td>299</td>
<td>298</td>
<td>297</td>
<td>293</td>
<td>288</td>
</tr>
<tr>
<td>1%</td>
<td>309</td>
<td>304</td>
<td>300</td>
<td>299</td>
<td>298</td>
<td>294</td>
<td>289</td>
</tr>
<tr>
<td>5%</td>
<td>313</td>
<td>308</td>
<td>304</td>
<td>303</td>
<td>302</td>
<td>298</td>
<td>292</td>
</tr>
<tr>
<td>10%</td>
<td>318</td>
<td>313</td>
<td>311</td>
<td>310</td>
<td>304</td>
<td>305</td>
<td>300</td>
</tr>
</tbody>
</table>

1978-79

<table>
<thead>
<tr>
<th>Annual Change in Price</th>
<th>-10%</th>
<th>-5%</th>
<th>-1%</th>
<th>0%</th>
<th>1%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>320</td>
<td>312</td>
<td>297</td>
<td>295</td>
<td>291</td>
<td>281</td>
<td>267</td>
</tr>
<tr>
<td>1%</td>
<td>322</td>
<td>310</td>
<td>300</td>
<td>297</td>
<td>295</td>
<td>284</td>
<td>270</td>
</tr>
<tr>
<td>5%</td>
<td>332</td>
<td>320</td>
<td>310</td>
<td>305</td>
<td>305</td>
<td>294</td>
<td>280</td>
</tr>
<tr>
<td>10%</td>
<td>345</td>
<td>333</td>
<td>324</td>
<td>321</td>
<td>319</td>
<td>308</td>
<td>295</td>
</tr>
</tbody>
</table>

1979-80

<table>
<thead>
<tr>
<th>Annual Change in Price</th>
<th>-10%</th>
<th>-5%</th>
<th>-1%</th>
<th>0%</th>
<th>1%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>334</td>
<td>317</td>
<td>297</td>
<td>293</td>
<td>288</td>
<td>269</td>
<td>244</td>
</tr>
<tr>
<td>1%</td>
<td>339</td>
<td>319</td>
<td>302</td>
<td>297</td>
<td>293</td>
<td>274</td>
<td>248</td>
</tr>
<tr>
<td>5%</td>
<td>356</td>
<td>337</td>
<td>319</td>
<td>314</td>
<td>311</td>
<td>292</td>
<td>266</td>
</tr>
<tr>
<td>10%</td>
<td>380</td>
<td>360</td>
<td>344</td>
<td>339</td>
<td>335</td>
<td>316</td>
<td>291</td>
</tr>
</tbody>
</table>

(a) Annual percentage changes from 1976-77.
Table No. 3
ARIMA(2.1.1) FORECASTS OF PIG AND SOW NUMBERS AS AT 31 MARCH ('000')

<table>
<thead>
<tr>
<th>Year</th>
<th>Pig Numbers</th>
<th>Est. Sow Numbers (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977-78</td>
<td>2235</td>
<td>319</td>
</tr>
<tr>
<td>1978-79</td>
<td>2189</td>
<td>313</td>
</tr>
<tr>
<td>1979-80</td>
<td>2159</td>
<td>308</td>
</tr>
<tr>
<td>1980-81</td>
<td>2151</td>
<td>307</td>
</tr>
</tbody>
</table>

(a) 1/7 of forecast pig numbers.

It should be particularly noted that these forecasts take no account of the three major changes expected in the industry over the next few years, i.e. an increase in average pig weight at slaughtering, the introduction of carcass classification and measurement and, on the retail marketing side, the introduction of 'continental' cuts of meat [8]. All these factors may combine to shift both the supply and demand functions, so that the projected decrease in sow numbers may not be so severe as expected.

A further consideration in forecasting production is the fact that average carcass weight has changed over the years, as shown in the following table.

Table No. 4
AVERAGE CARCASS WEIGHTS: 1925-26 TO 1975-76 (Kilograms)

<table>
<thead>
<tr>
<th>Year</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1925-26</td>
<td>49.67</td>
</tr>
<tr>
<td>1930-31</td>
<td>48.54</td>
</tr>
<tr>
<td>1935-36</td>
<td>46.12</td>
</tr>
<tr>
<td>1940-41</td>
<td>48.03</td>
</tr>
<tr>
<td>1945-46</td>
<td>66.45</td>
</tr>
<tr>
<td>1950-51</td>
<td>57.26</td>
</tr>
<tr>
<td>1955-56</td>
<td>52.08</td>
</tr>
<tr>
<td>1960-61</td>
<td>49.22</td>
</tr>
<tr>
<td>1965-66</td>
<td>48.85</td>
</tr>
<tr>
<td>1970-71</td>
<td>48.89</td>
</tr>
<tr>
<td>1975-76</td>
<td>52.76</td>
</tr>
</tbody>
</table>

Source: BAE.

As can be seen, there has not been a monotonic trend in pig weights. During the war and in the immediate postwar period the tendency was to turn off very heavy pigs; later the average weights decreased but there is now a trend back to heavy weights. This trend will be accentuated with the introduction of the 'superporker' [8].
A producer's decision whether or not to retain a pig to the baconer stage (45-68 kg) will presumably be influenced by relative prices of porkers and baconers in the immediately preceding period. Insofar as this is a short term decision, it will affect pigmeat production (see [1], p. 2) rather than sow numbers. In the long run the baconer-porker price ratio may affect producers' investment decisions (e.g. provision of bigger pens) and marketing costs, and may reflect changes in feed conversion efficiency and hence unit feed costs at higher weights. This in turn will depend upon whether the market demands lean or fat pigs. All these matters will need to be closely examined when the proposed carcass measurement and classification scheme is introduced.

In conclusion, the author would like to make the observation that most pig research to date has been fragmented. It is suggested that industry-wide systems studies, on a scale comparable to that undertaken by the U.S. Department of Agriculture [16], are now needed.
## Appendix A

### DATA SERIES

<table>
<thead>
<tr>
<th>Year</th>
<th>Sow Numbers (a) at 31 March</th>
<th>Feed Cost Index</th>
<th>Saleyard Price of Pork</th>
<th>Wheat Quota Dummy</th>
</tr>
</thead>
<tbody>
<tr>
<td>'000</td>
<td>c/kg</td>
<td>c/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1950-51</td>
<td>155</td>
<td>25.5</td>
<td>40.5</td>
<td>0</td>
</tr>
<tr>
<td>1951-52</td>
<td>135</td>
<td>36.4</td>
<td>56.6</td>
<td>0</td>
</tr>
<tr>
<td>1952-53</td>
<td>141</td>
<td>35.7</td>
<td>59.7</td>
<td>0</td>
</tr>
<tr>
<td>1953-54</td>
<td>178</td>
<td>28.4</td>
<td>62.6</td>
<td>0</td>
</tr>
<tr>
<td>1954-55</td>
<td>176</td>
<td>31.3</td>
<td>44.8</td>
<td>0</td>
</tr>
<tr>
<td>1955-56</td>
<td>163</td>
<td>27.5</td>
<td>62.3</td>
<td>0</td>
</tr>
<tr>
<td>1956-57</td>
<td>198</td>
<td>27.6</td>
<td>65.3</td>
<td>0</td>
</tr>
<tr>
<td>1957-58</td>
<td>191</td>
<td>31.5</td>
<td>51.3</td>
<td>0</td>
</tr>
<tr>
<td>1958-59</td>
<td>179</td>
<td>28.9</td>
<td>55.6</td>
<td>0</td>
</tr>
<tr>
<td>1959-60</td>
<td>211</td>
<td>27.9</td>
<td>66.4</td>
<td>0</td>
</tr>
<tr>
<td>1960-61</td>
<td>236</td>
<td>28.1</td>
<td>61.6</td>
<td>0</td>
</tr>
<tr>
<td>1961-62</td>
<td>236</td>
<td>30.0</td>
<td>48.2</td>
<td>0</td>
</tr>
<tr>
<td>1962-63</td>
<td>208</td>
<td>30.0</td>
<td>61.7</td>
<td>0</td>
</tr>
<tr>
<td>1963-64</td>
<td>224</td>
<td>29.8</td>
<td>66.0</td>
<td>0</td>
</tr>
<tr>
<td>1964-65</td>
<td>252</td>
<td>30.2</td>
<td>65.1</td>
<td>0</td>
</tr>
<tr>
<td>1965-66</td>
<td>252</td>
<td>32.3</td>
<td>62.9</td>
<td>0</td>
</tr>
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<td>1966-67</td>
<td>263</td>
<td>31.7</td>
<td>68.1</td>
<td>0</td>
</tr>
<tr>
<td>1967-68</td>
<td>305</td>
<td>31.8</td>
<td>71.4</td>
<td>0</td>
</tr>
<tr>
<td>1968-69</td>
<td>320</td>
<td>29.3</td>
<td>61.1</td>
<td>0</td>
</tr>
<tr>
<td>1969-70</td>
<td>338</td>
<td>26.4</td>
<td>61.7</td>
<td>1</td>
</tr>
<tr>
<td>1970-71</td>
<td>367</td>
<td>28.7</td>
<td>65.3</td>
<td>1</td>
</tr>
<tr>
<td>1971-72</td>
<td>460</td>
<td>26.8</td>
<td>66.5</td>
<td>1</td>
</tr>
<tr>
<td>1972-73</td>
<td>414</td>
<td>32.3</td>
<td>59.2</td>
<td>0</td>
</tr>
<tr>
<td>1973-74</td>
<td>323</td>
<td>45.0</td>
<td>91.5</td>
<td>0</td>
</tr>
<tr>
<td>1974-75</td>
<td>311</td>
<td>54.6</td>
<td>114.5</td>
<td>0</td>
</tr>
<tr>
<td>1975-76</td>
<td>308</td>
<td>56.0</td>
<td>120.2</td>
<td>0</td>
</tr>
<tr>
<td>1976-77</td>
<td>316 (p)</td>
<td>64.4</td>
<td>114.0</td>
<td>0</td>
</tr>
</tbody>
</table>

(a) e.g. The figure for 1950-51 is the census figure at 31 March 1951.
(p) Preliminary.
Appendix B

RATIO OF SOW NUMBERS TO PIG NUMBERS
1950-51 TO 1976-77

<table>
<thead>
<tr>
<th>Year</th>
<th>Ratio (SN/PN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950-51</td>
<td>.136684</td>
</tr>
<tr>
<td>1951-52</td>
<td>.132095</td>
</tr>
<tr>
<td>1952-53</td>
<td>.141994</td>
</tr>
<tr>
<td>1953-54</td>
<td>.135698</td>
</tr>
<tr>
<td>1955-56</td>
<td>.139794</td>
</tr>
<tr>
<td>1956-57</td>
<td>.149434</td>
</tr>
<tr>
<td>1957-58</td>
<td>.134223</td>
</tr>
<tr>
<td>1958-59</td>
<td>.138867</td>
</tr>
<tr>
<td>1959-60</td>
<td>.148174</td>
</tr>
<tr>
<td>1960-61</td>
<td>.146130</td>
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<td>.142857</td>
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<tr>
<td>1962-63</td>
<td>.144444</td>
</tr>
<tr>
<td>1963-64</td>
<td>.152589</td>
</tr>
<tr>
<td>1964-65</td>
<td>.151807</td>
</tr>
<tr>
<td>1965-66</td>
<td>.144247</td>
</tr>
<tr>
<td>1966-67</td>
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<tr>
<td>1967-68</td>
<td>.148346</td>
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<td>1968-69</td>
<td>.142033</td>
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<tr>
<td>1969-70</td>
<td>.140951</td>
</tr>
<tr>
<td>1970-71</td>
<td>.141699</td>
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<td>1971-72</td>
<td>.143795</td>
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<td>.127033</td>
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<td>1974-75</td>
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</tr>
<tr>
<td>1975-76</td>
<td>.141740</td>
</tr>
<tr>
<td>1976-77</td>
<td>.142086</td>
</tr>
</tbody>
</table>

Mean: .141768 ≈ 1/7
## Appendix C
### SOW NUMBERS - COMPARISON OF EX-POST FORECASTS

<table>
<thead>
<tr>
<th>Year</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'000</td>
<td>Percentage Error</td>
<td>'000</td>
<td>Percentage Error</td>
<td>Structural</td>
<td>Percentage Error</td>
<td>Actual</td>
<td></td>
</tr>
<tr>
<td>1950-51</td>
<td>164.1</td>
<td>5.9</td>
<td>157.0</td>
<td>1.3</td>
<td>162.1</td>
<td>4.6</td>
<td>155</td>
</tr>
<tr>
<td>1951-52</td>
<td>169.0</td>
<td>25.2</td>
<td>156.3</td>
<td>15.8</td>
<td>150.6</td>
<td>11.6</td>
<td>135</td>
</tr>
<tr>
<td>1952-53</td>
<td>139.5</td>
<td>-1.1</td>
<td>138.6</td>
<td>-1.7</td>
<td>136.0</td>
<td>-3.5</td>
<td>141</td>
</tr>
<tr>
<td>1953-54</td>
<td>153.0</td>
<td>-14.0</td>
<td>159.1</td>
<td>-10.6</td>
<td>143.1</td>
<td>-19.6</td>
<td>178</td>
</tr>
<tr>
<td>1954-55</td>
<td>184.1</td>
<td>4.6</td>
<td>174.9</td>
<td>-0.6</td>
<td>177.4</td>
<td>0.8</td>
<td>176</td>
</tr>
<tr>
<td>1955-56</td>
<td>177.9</td>
<td>9.1</td>
<td>174.0</td>
<td>6.7</td>
<td>171.6</td>
<td>5.3</td>
<td>163</td>
</tr>
<tr>
<td>1956-57</td>
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RMSE(%)  
- 12.7  
- 9.2  
- 8.0

* $\frac{1}{7}$ of total pig numbers.

** based on actual proportion of total pig numbers.

*** square root of mean square percentage error.

(2), (4) and (6): (Forecast - Actual)/Actual x 100%. (5): Equation 16.
REFERENCES


