Modelling Systems Dynamics for New Pastoral Industries

Keith B Woodford
School of Natural & Rural Systems Management
University of Queensland, Gatton Campus. Q443
tel 61754 601 320; fax 61 754 6010324
email: woodford@uqg.uq.edu.au

Abstract
New rural industries are often characterised by boom and bust cycles. These cycles derive at least in part from long biological lead times between investment decisions and production consequences. Also, for products that require animals to be slaughtered there is a negative short-run supply response. This occurs because female breeders are both capital goods and production goods. Accordingly, the industry dynamics can be characterised as a complex two-way interplay over time, where supply of product is a function of market prices, and market prices are a function of product supply. A systems dynamics model of a developing venison industry from farmed deer was constructed using ithink™ software. Production cycles were unstable (i.e. had boom and bust characteristics) in situations where all female progeny were retained as capital goods during industry expansion phases. This occurred regardless of biological parameters, age of slaughter, rate of market development, or form of price expectation model.

Introduction

One of the difficulties faced by many developing livestock industries such as deer, ostriches and emu, is the 'boom and bust' syndrome whereby prices for breeding animals reach very high values during the development phase, followed by a period of declining product and livestock prices, and fluctuating product volumes. In this paper these industry dynamics are modeled for farmed deer and the associated production of venison, first conceptually and then quantitatively using ithink™ software. The purpose of the modelling is to gain insights into bio-economic factors that contribute to the boom and bust cycles and to explore strategies to minimise these effects.

The Conceptual Model

Venison can only be produced when animals are slaughtered. Accordingly, in situations where individual animals are both capital goods (e.g. breeding females) and production goods (e.g. a source of marketable meat), investment in breeding females will lead to a negative *short-run* venison supply function. As a consequence, during an initial herd buildup phase, supply of product is constrained to small volumes which, under standard economic conditions of a backward sloping demand function, will lead to high product prices. These high product prices provide further encouragement for industry expansion. Eventually, the ongoing herd buildup will result in increased product entering the market (because the *long-run* supply response is positive). Given a finite market, this will lead to lower product prices, although the timing of this price decline can be forestalled by market development. Once farmers receive declining price signals they are likely to review their investment decisions, and move towards a stable-sized herd. As soon as breeding herd numbers are stabilised then venison supply will increase on account of increased females available to be slaughtered. In addition, pipeline effects, resulting from the biologically determined interval from conception to consumption, will cause the quantity of venison to increase for several more years and this will lead to further pressure on prices.

If the industry responds to these lower prices by dis-investing in breeding hinds (perhaps by reducing the intensity of operations, or by substituting other livestock species), then the short term effect will be a further increase in venison output, leading to a further price decline. Eventually the decline in breeding females will lead to a lagged decline in venison production and output, and this could be expected to lead to increased prices. In time these rising prices will lead to cessation of the dis-investment in breeding hinds, but the decline in venison output will continue for several years after this decision on account of the time lag from animal conception to time of slaughter. This ongoing decline in venison output will produce a further increase in prices, thereby setting the scene for a renewed ‘boom and bust’ cycle.

The above scenario of fluctuating volumes and price instability arises from the interaction of three relationships. The first of these is the link between past prices and expected future prices. The second is the biological lag between investment decisions and outcomes. The third is the dual role of females as capital stock (*i.e.* breeders) and as product (*i.e.* venison). There are strong similarities between this scenario and the original cobweb model of Ezekiel (1938). However, Ezekiel’s cobweb model was based on a one-period response function and did not consider the possibility of a negative short-run supply response.

Price expectation models, whereby expected future prices are estimated as some function of past prices, are known as adaptive expectation models following the work of Nerlove (1958). They have been widely used in economic modelling for both crop and animal industries (French & Mathews 1971; Rucker *et al.* 1984). The potential lack of decision rationality associated with these models has been understood for a long time (Muth 1961). However their explanatory capability in relation to empirical outcomes is widely acknowledged (Shonkwiler 1982; Knapp 1987).

The role of female breeders as both capital goods and also production goods was described by Jarvis (1974) in relation to cattle. Gordon (1990) has shown that the sufficient condition for a negative short-run supply response is that the discounted value of increased future profits from increased prices must exceed the profits foregone from withholding animals from sale for breeding purposes. Subsequent to the work of Jarvis (1974) there have been a number of studies for various species that show how exogenous shocks to demand or supply can have persistent effects by changing slaughter and breeding decisions (Chavas & Klemme 1986; Whipple & Menkhaus 1989; Foster & Burt 1992; Rosen *et al.* 1994). These decisions affect the age distribution of the herd and cause cyclical ‘echo’ responses as the herd converges to a stable structure. However none of these studies have integrated the concept of livestock inventory cycles and price expectation models with oscillating price cycles that are themselves influenced by changing supply volumes.

The Systems Dynamics Model

The model was developed using ithink™ software based on the concepts of systems dynamics as developed by Forrester (1968). Relationships are constructed and displayed as interconnecting stocks, flows, converters and connectors.

The model was developed under simplifying assumptions of a one-product-market and a single production system based on a closed herd. Accordingly, the potential complexity associated with retaining males for velvet antler production was not considered; nor was the potential impact of venison production from feral animals considered. These issues are taken up in the discussion section of the paper.

The systems dynamics module was divided into four sectors (or modules) and one sub-model for convenience of presentation. The four sectors operate at the same level, whereas the sub-model is a component of one of these sectors. The sectors are a female herd, a male herd, a venison production module and an economic module.

The *female herd module* is shown in Figure 1. The transfer of animals from one age group to another is depicted by a flow from the younger to the older age group. This occurs once per time period (defined as one year). Biological parameters such as death rates and reproduction rates are defined as converters, and these are linked by connectors to the flows that they regulate. Whereas flows occur per defined unit of time, converters are transferred instantaneously. Flows originating from clouds imply that the stock originates from outside the system boundary (although the size of this flow is determined by one or more converters within the system). A flow exiting into a cloud indicates that the stock is leaving the system under analysis.

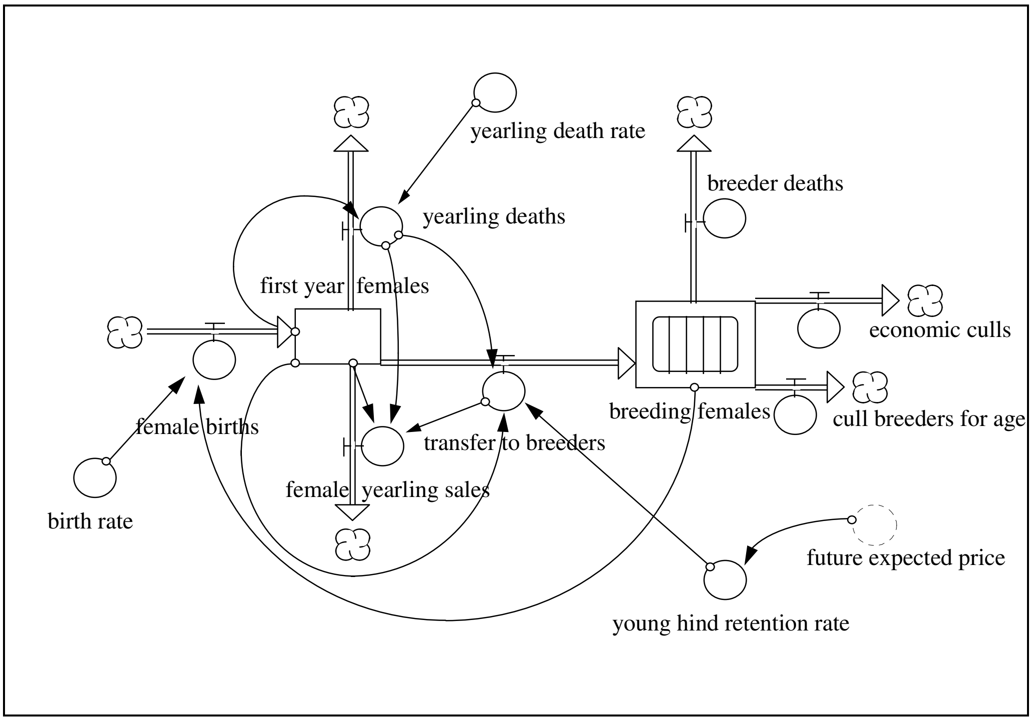

Figure 1 Female herd module

The decision as to the proportion of juvenile females to enter the herd, i.e. the young hind retention factor, has been defined as a function of the long term expected price of venison. When this price is high farmers will wish to build up their herds and therefore the retention rate is high. Conversely, when long term prospects are considered poor, then the retention rate is low. This expected price shows in Figure 1 as a 'ghost' of the 'real' entity for price expectation which will be described later as part of the economic module. This concept of ghosting allows links between various sectors of the model to be represented more neatly by avoiding 'spaghetti' diagrams.

The specific characterisation of the stock for breeding females in Figure 1 indicates that there is a sub-model associated with this stock. This breeder sub-model allows females to progress through to successive age categories, with the number proceeding to each successive year being determined by age-specific death rates and culling rates. Further details are available in Woodford (1997).

The *male herd module* was constructed according to similar principles as the female herd model. However, only a very small proportion of males are required for breeding purposes (about 3% of breeding females) and hence nearly all males are slaughtered. The *venison production module* converts slaughtered animals into tonnes of venison. Details of both these modules are provided in Woodford (1997).

The *economic module* determines the current price of venison, the long term expected price of venison, and the size of the market (Figure 2). The current price of venison is determined by the demand function for venison and the current supply. The long term expected price is a function of current and recent prices. The size of the market is determined by the initial market size, the rate of market development, and the length of time that market development has been occurring.

It was assumed that market demand could be represented by a downward-sloping straight line demand function. Two alternative scenarios of market development were explored. The first was where the point of intersection of the demand function with the *x*-axis moved to the right but the point of intersection with the *y*-axis remained fixed. This is consistent with a 'scaling up' model of development whereby the number of people prepared to buy the product at a particular price increases. The second scenario was where the slope of the demand function remained constant and the point of intersection with both axes increased. This scenario is consistent with a model of market development where both more people are prepared to buy the product at a particular price and where some buyers are also willing to pay more than what any buyers were previously willing to pay.

It was assumed that there was no carry-over of venison between periods. This was considered realistic because, although it is feasible to freeze and store the venison, there is a considerable price penalty associated with venison carrying a packing date older than one year.

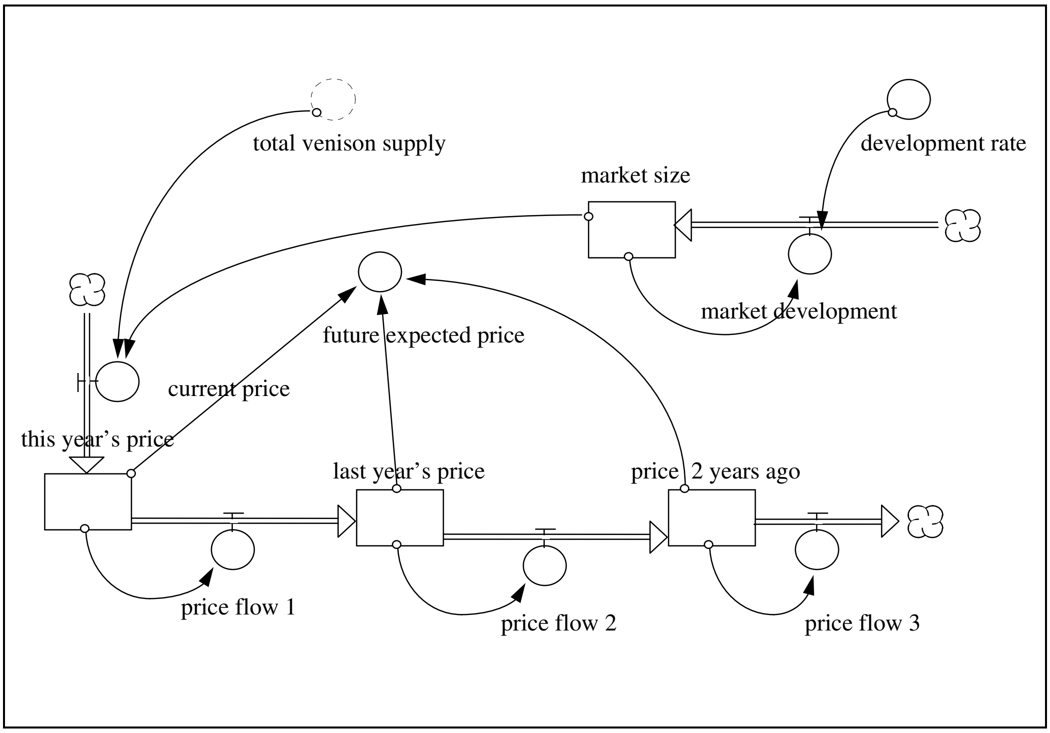

Figure 2 Economic module

Investigations

Key biological parameters of this base model simulation are a reproductive rate of 80% (defined as the number of surviving progeny at three months divided by the number of breeding females at the start of the year), annual death rates of 4%, and slaughter of non-breeding animals at between one and two years of age.

The base model investment response function had two parts. The first, relating to retention of young hinds for breeding, showed the proportion of hinds retained increasing linearly from zero at an expected long-term price of $2 per kg carcass to 100% at $6 per kg. The second part of the function was that an additional 10% of breeding hinds were culled (over and above those culled for age) when the expected venison price dropped below $2.50. The initial market size was set by arbitrarily fixing the y-axis point of intersection of the demand function at $8, and the x-axis intersection at 100 tonnes.

The base model simulation was run over a 100 year period and focused on female breeding numbers, venison production and venison price per kg of carcass. It was found that all three variables have a very long cycle (28 years), that the cycle of venison production follows the cycle of female breeding numbers with the lag being greatest in the phase of herd build-up, and that price is counter cyclical to herd numbers and venison supply. The cycles are ongoing without any tendency for decline either in amplitude or cycle length.. Analysis of the tabulated model output showed that the venison supply increased by approximately 80% over a two year period after the decision was made to reduce female breeder numbers. Maximum venison production was reached four years after the slaughter of young females commenced.

Herd Productivity Factors

Initial investigations focused on whether these key attributes of long cycle length, price instability and volume instability were an artefact of the chosen biological parameters. Accordingly the model was rerun using different combinations of parameters for reproductive rate and mortality rates. For reproductive rates within the range of 50-90% there was a tendency for the amplitude of the cycles to be lower and for the cycle lengths to be longer at the lower levels of performance. However this trend was minor until the reproductive rate dropped below 60%. By combining very high reproductive rates such as 130% with very low death rates such as 2%, the amplitude of the breeding herd cycle increased to the point that the system 'crashed', with no breeding animals retained. At the other extreme, by combining very low reproductive performance levels such as 50% with high mortality rates such as 10%, the cycle amplitude was not only smaller but declined over time such that production and price would have eventually stabilised (although not for more than 100 years). However, both these upper and lower performance levels are outside the range of expected industry performance from farmed deer. In all situations the changes in cycle length for one variable (*e.g.* breeder herd size, venison supply and price) were mirrored by changes in the other two cycles.

Age of Male Slaughter

The second set of investigations addressed the impact on cycle characteristics of delaying the age of slaughter to between 18 months and 30 months. This analysis was undertaken assuming the original base model figures for reproductive rate and mortality rates. In this situation the cycle length (all three variables) increased to 36 years, the amplitude of the price cycle was essentially unchanged, the amplitude of the herd size cycle increased by 32%, and the amplitude of the venison supply cycle increased by 16%. The reasons for these changes are that the increase in age-of-slaughter increased the response time between farmer investment decisions on the one hand and market supply responses and associated price information on the other hand.

Market Demand

Alternative market sizes were specified by alternative specifications of the downward sloping demand function. This was first done by retaining the point of intersection with the y-axis (set arbitrarily at $8), but allowing the point of intersection with the x-axis to slide to the right. Not unexpectedly, the length of the initial herd growth phase was a function of the relativity between the starting size of the herd and the size of the market. However, once the initial herd growth phase ended the cycle characteristics remained unchanged, with cycle length constant at 28 years, venison price fluctuating between zero and close to $8 (i.e. the arbitrarily set point of intersection with the y-axis). Subsequently, the demand function was reset with the y-axis point of intersection increased to $16. The effect of this change was to markedly increase cycle length to 38 years. Venison prices now fluctuated between zero and almost $16. This increase in cycle length and amplitude arose directly from the higher prices achieved during periods of low venison supply, and the associated longer time period over which farmers retained all their female numbers.

Market Development

Most industries undertake market development to stimulate market demand. This market development can focus on increasing the size of the market, increasing the price that existing consumers will pay, or a combination of both. These respective situations can be characterised in relation to the demand function by shifting the point of intersection with the x-axis to the right, an upward shift of the point of intersection with the y-axis, or a combination of both.

From initial simulations it soon became evident that an ongoing upward shift of the demand function is unrealistic, creating a situation where, in the phase of the cycle when venison supply was low, the prices in later years of the simulation rose to thousands of dollars per kg. These results helped identify that sustained market development inevitably flattens the demand function.

It was found that market development can reduce markedly the amplitude of all the cycles. For example, at 15 % increase in market size per annum, the price fluctuated between $3.33 and $6.35 on a 21 year cycle. The herd grew in all years but at differing rates depending on the current expectation of future prices. There were short periods of up to five years when venison production declined as a result of increasing female retention rates, but the overall reduction in venison production during these periods was less than 10%.

Analysis of the underlying relationships indicated that market development eliminated the 'boom and bust' cycles only in situations where the rate of market development approached the biological potential for herd growth. For the tested scenario (with reproductive rate set at 80%, mortalities at 4 % and female longevity set at 10.5 years) this biological potential is 24%. However, such high rates of market development eventually become non-sustainable.

Price Expectations

Alternative price expectations models can be formulated by changing the number of years of historical data in the model and also by changing the weightings applied to each year. In a naive situation, future prices could be estimated solely from the price in the most recent year. In this situation the cycle length declined by 10 years to 18 years, the amplitude of the price cycle remained unchanged, and the amplitude of both the herd size cycle and the venison supply cycle declined by approximately 30%. Changing the price expectation model to the average of the last five years price data increased the cycle length to 40 years and increased the amplitude of the venison supply cycle by approximately 30%. These results illustrate that price expectation models based on a short set of historical prices produce faster responses to emerging market situations than where a longer set of historical prices is used.

Random Shocks

All of the investigations reported so far assume that market demand is unaffected by external factors such as general economic cycles or changes in the prices of competing products. These assumptions can be relaxed by introducing a random element to the current price of venison, which will transfer through into expected prices. Accordingly, the model was run with the per kg price of venison subject in any year to a random adjustment between negative $3 and positive $3. This was run for two price expectation scenarios, namely that expected price was an average of prices over the preceding three years, and that expected future price was the price obtained in the most recent season. Each simulation was run five times using different seed values for the random number generator. It was found that these shocks were sufficient to produce short term disturbances to the herd size cycle and venison supply and this was particularly evident with the one-year price expectation model. However, the disturbances were insufficient to alter the key characteristics of these two cycles.

Herd Investment Response Function

The investigations to this point have shown that, except in situations where biological productivity is well below the expected industry limits for farmed deer, or in situations where ongoing market development is projected at an unsustainable level, that the price of venison, the volume of venison produced, and investment in breeding females all follow boom and bust cycles. Both the amplitude of these cycles and also their length vary somewhat in response to biological parameters, age of slaughter, market demand characteristics and the way in which price expectations are formed. However none of these variations are sufficient to provide exceptions to the generalised finding that venison prices and venison supply follow boom and bust cycles with long cycle lengths. It appears therefore, that the only way to break these cycles is if the industry has a much more conservative herd investment response function than in the base model, and it is this issue that is now investigated.

Preliminary exploration indicated that the key issue was the low slaughter rate of females during times of high venison prices. A higher rate of slaughter could be achieved by either slaughtering a proportion of breeding hinds regardless of price, or reducing the proportion of young hinds retained for breeding, or a combination of both. For convenience, the analysis that follows focuses initially on increased slaughtering of the existing breeding hinds.

With market development set at zero, the economic cull rate for breeder hinds had to be set at a minimum of 19% before there was any trend towards stabilisation of prices, stabilisation of venison output, and stabilisation of herd numbers. At 15% level of economic culling the price of venison fluctuated between $2.08 and $6.67, which avoided the extreme troughs and peaks but did not create stability. Small increases in the economic cull rate above 19% had a marked impact on stability, such that at an economic cull rate of 22% the venison price dropped to a minimum of $4.15 and stabilised eventually at $4.98 (Figure 3).

Further investigation showed there was a strong link between the required culling rate to achieve stability and the rate of market development. In a situation where market size was increasing at 5% per annum then a culling rate of 17% produced a minimum venison price of $4.52, and an eventual stable price of $5.08. If market size were to increase at 10% per annum then an economic cull rate of 10% would be sufficient to produce a minimum venison price of $4.49 and an eventual stable price of $5.09.

Similar effects were achieved by reducing the age of culling. For example, if all females were culled at 6.5 years of age and assuming 10% market development, then

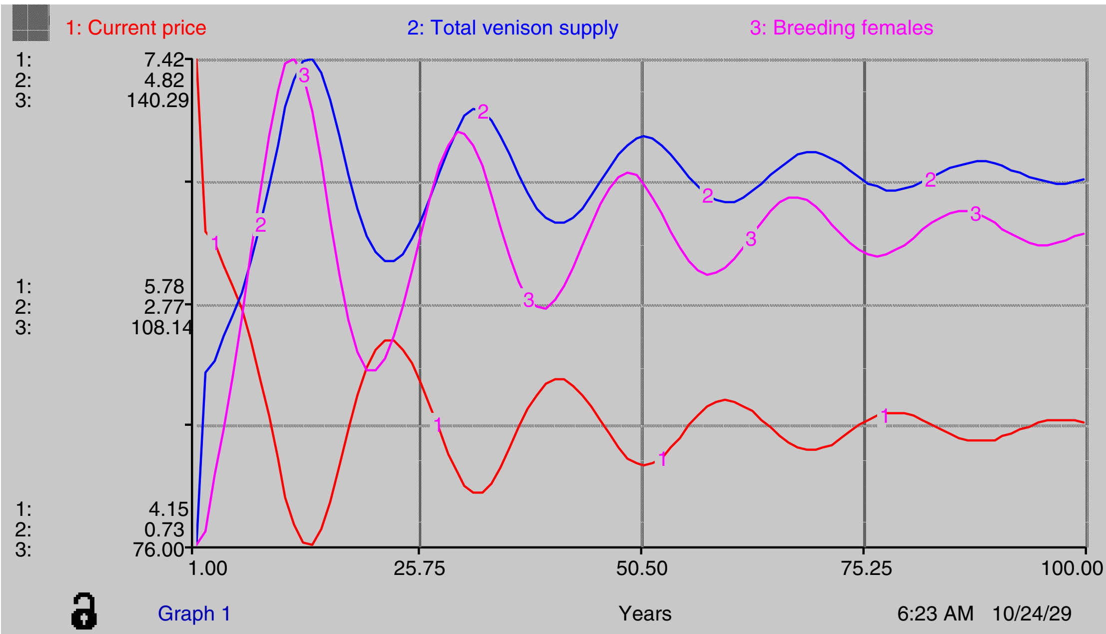

Figure 3. Price cycles, venison production, and breeding herd cycles with zero market development and a minimum annual cull rate of 22% of breeding females

the venison price dropped to $4.50 after 15 years and then followed a 20 year cycle of declining amplitude, eventually stabilising at about $5.20.

It was presumed that similar effects could be achieved by reducing the maximum retention rate for young hinds but simulations indicated this was difficult to achieve. The required reduction was large and had to be adjusted over time. For example, with zero market development, a maximum retention rate of 25% was insufficient to sustain herd numbers. However, when this was increased to 35% there was a very slow but ongoing herd build up, a very slow but ongoing price decline, and very low production of venison. At higher maximum rates of retention such as 50%, the cycles showed all the elements of instability that were associated with the base model.

A range of alternative investment decision models were explored. These included young females being retained for breeding only in years where the venison price was higher than in the previous year, and young hinds only being retained when the venison price was above a specified price such as $5 or $6. In all cases the price information was received too late to avoid the occurrence of boom and bust cycles.

Discussion

The investigations undertaken in this paper have been based on assumptions of a single market and a single production industry. In particular, it has been assumed that all venison comes from farmed production, *i.e.* the supply of venison from wild and feral deer has been ignored. Also, the possibility of commercial velvet antler production from some species, and consequential culling of males based on the relative price of velvet and venison, has not been considered. Under these simplifying assumptions it has been found that, in situations where herd size grows at the biological maximum (*i.e.* with all females retained as breeders), it appears inevitable that there will at some point in time be a dramatic price collapse. This situation prevails regardless of the biological parameters, age of slaughter, market size, or form of price expectation model. Indeed the only way that a price collapse can be avoided is if significant slaughter of females commences prior to the advent of price signals providing information that further herd growth should be constrained.

The time taken for such a price collapse to occur depends on the initial size of the production industry, the growth capacity of the herd, the initial size of the market, and the rate of market development. In some situations, for example where there is a small initial herd, low biological growth capacity, large market, and high rate of market development, then the price decline may be forestalled for a considerable period. However, long term market development at the same or similar rates as potential herd growth would seem unsustainable.

In situations where future price expectations are derived from present and past prices, then industry cycles for female breeding herd, venison production, and venison price typically exceed 25 years and have high amplitudes. Both the amplitude of these cycles and also their length vary somewhat in response to biological parameters, age of slaughter, market demand characteristics and the way in which price expectations are formed. However none of these variations are sufficient to provide exceptions to the generalised finding that venison prices and venison supply follow cycles with large amplitude and long length.

Industry attributes that contribute to the cycle characteristics include the capacity for high rates of herd growth that exceed the *long term* sustainable rate of market development, and the long lead times between investment decisions and venison supply response. *As a consequence, current and past prices are inappropriate indicators on which herd investment decisions should be made*. The key to avoiding price crashes is to maintain a significant level of female slaughter during times of high prices, combined with an ongoing market development program.

There appear to be two special factors that impact upon product supply and price cycles for a developing deer industry that do not necessarily apply to other animal species and other industry situations. The first factor is that developing industries are seldom constrained in an absolute context by land resources, and hence there are unlikely to be physical factors that prevent 100% female retention. For example, if a farmer wishes to double the size of a small deer unit then typically this can be achieved by reassigning land resources from a traditional activity such as cattle raising. However the same pastoralist would often be prevented by overall carrying capacity from making a similar upward adjustment with the herd of cattle. The second factor is that deer have a longer breeding life than is usual for the traditional domestic species. This reduces the number of animals that are culled-for-age. Both of these factors tend to increase the amplitude associated with production cycles and price cycles.

Relaxing the assumption in regard to a single farm-based production system is likely to impact both on cycle amplitude and cycle length. In the case of venison production from wild or feral animals it would seem much less likely than for farm-based production that there would be a negative short term supply response. Also, feed constraints create a situation where most of the wild and feral deer herds are unlikely to be growing at anywhere near the biological rate that is possible with a developing farm-based industry. The impact of these factors is likely to be similar to the modeled situations where there was a forced minimum cull rate of breeding females; *i.e.* cycle amplitude and length will be reduced.

The impact of incorporating velvet production into the model as a co-product could lead to two potential impacts, depending on the correlation between venison price and velvet price. To the extent that culling of stags is a function of velvet price, and if velvet price is unrelated to venison price, then changes in velvet price are likely to take the form of a random shock. However, to the extent that culling of the velvet herd is influenced by venison prices, then increased venison price would lead to increased male slaughter rates in the short-run situation.

The industry response function in regard to investment in breeding females is not a simple additive function of the responses of individual farmers. This arises because of the internal market within the industry for breeder females, which effectively prevents the slaughter of females unless the market price for females as breeders is less than the market value of female carcasses. This leads to a question as to whether counter-cyclical production-focused investment strategies by industry entrepreneurs might alter the overall industry decision response function. It would seem that any entrepreneur acting alone would face a major problem as a consequence of the cycle length being very long. However, if a large number of entrepreneurs undertook counter-cyclical herd build-up and dis-investment activities, then the impact would be to dampen the cycle amplitude and reduce the cycle length. This in turn would make further counter-cyclical investment activities more attractive.

Concluding comments

The investigations presented in this paper provide insights in relation to the historical volatility of the farmed deer industry both in Australia and New Zealand. In both cases the industries expanded in the early years at the maximum biologically constrained rate, and this was followed by a period of price decline for venison which coincided with a major increase in the supply of product. The modelling has shown that in situations where farmers use past and present prices to form expectation of future prices, there is a short-run negative supply response that reinforces price cycles and leads to industry instability. It is only where the investment in breeding females is limited by other factors, such as availability of land resources or by counter-cyclical investment activities, that the volatility reduces.

It is perhaps obvious to suggest that farmers are unlikely to make economically efficient herd investment decisions unless they have appropriate information on industry prospects. However, what was previously less obvious is the extent to which past and present prices are seriously deficient as an information source on future prices. Accordingly, there is a need for ongoing interpretation of market prospects using models such as the one described within this paper. These models can only be informative if there is an ongoing market research program that monitors both market conditions and the herd cycle, and thereby provides the necessary model input data.

References

Chavas, J. and Klemme, R.M. (1986). Aggregate milk supply response and investment behaviour on U.S. dairy farms. *American Journal of Agricultural Economics* 68, 55-56.
Ezekiel, M. (1938). The cobweb theorem. *Journal of Political Economy* 52, 225-280.

Forrester, J.W. (1968). *Industrial Dynamics*, M.I.T. Press, Cambridge, Massachusetts.

Foster, K.A. and Burt, O.R. (1992). A dynamic model of investment in the U.S. beef-cattle industry. *Journal of Business & Economic Statistics* 10, 419-416.

French, B.C. and Mathews, J.L. (1971). A supply response model for perennial crops. *American Journal of Agricultural Economics*, 53, 478-490.

Gordon, D.V. (1990). Negative response and the role of price expectations in a two-period model of cattle production. *Journal of Agricultural Economics*, 4:2, 184-195.

Jarvis L.S. (1974). Cattle as capital goods and ranchers as portfolio managers: an application to the Argentine cattle sector. *Journal of Political Economy* 82, 480-520.

Knapp, K.C. (1987). Dynamic equilibrium in markets for perennial crops. *American Journal of Agricultural Economics* 69, 97-105.

Muth, J F. (1961). Rational expectations and the theory of price movements. *Econometrica*, 29, 315-335.

Nerlove, M. (1958). Adaptive expectations and the cobweb phenomena, *Quarterly Journal of Economics* 72, 227-40.

Rosen, S., Murphy, K.M. and Scheinkman, J.A. (1994). Cattle cycles. *Journal of Political Economy*, 102:3, 468-492.

Rucker, R.R., Burt, O.R. and LaFrance, J.T. (1984). An econometric model of cattle inventories. *American Journal of Agricultural Economics* 66, 131-144.

Shonkwiler, J.S. (1982). An empirical application of agricultural supply response mechanisms. *Applied Economics*, 12, 183-194.

Whipple, G.D. and Menkhaus, D.J. (1989). Supply response in the U.S. sheep industry. *American Journal of Agricultural Economics* 71, 126-135.

Woodford, K.B. (1997). Bio-economics, development and management within the Australian deer and antelope industries, Ph.D. Thesis, University of Queensland.