Dynamics of Herd Build-up in a New Industry: Commercial Red Deer Production in New Zealand

R. A. Sandrey and A. C. Zwart

A mathematical decision model is used to examine producers' decisions in selecting the optimum slaughter age for domestic deer and the subsequent impact of these decisions on aggregate stock numbers. Under current returns from velvet, producers are shown to be rational in keeping both male (stags) and female (hinds) animals in the herd until they approach their maximum biological age. A reduction in returns from velvet of 66% is needed to alter this age significantly for males. Data from the optimum slaughter age decision are used to project medium-term future venison production and herd numbers. The unique features of attempting to project future supplies in a newly developed livestock industry are discussed.

Key words: commercial deer, dynamics, slaughter age, supply.

The status of New Zealand's red deer population has changed substantially in the last twenty years. The deer has progressed from being a noxious animal to being the basis of a new domesticated livestock industry. The late 1970s saw a change in emphasis from slaughter of feral (wild) animals for venison to the recovery of hinds (females) to start the present farming industry, an industry which was illegal prior to 1969. Recently concern has been expressed that insufficient quantities of farm venison are available to maintain and develop what appear to be promising new markets.[1] Indeed, an increase in prices has not been accompanied by an associated increase in the quantities of venison supplied.

This situation may be the result of misinformation held by producers or it may reflect the dynamics associated with the rapid build-up of numbers, as in any livestock industry. In this paper it is suggested that the apparently anomalous supply relationship in New Zealand's emerging deer-farming industry may be the result of (*a*) a higher value of hinds for breeding stock than for venison production and (*b*) a higher value of stags (males) for velvet, an annual crop, than for venison production. The purpose of the research reported here is to estimate and compare these values.

The model used was developed by Jarvis (1974, 1982) to explain similar supply phenomena in cattle markets. There is an important distinction between deer and cattle production, however. For the latter, the primary product of the male animal is beef, so that males are slaughtered at an earlier age than females. For deer there is an annual harvest of velvet from stags, so that the optimum slaughter age for stags may be as long as that for hinds.

Another issue explored here is how the optimum slaughter age influences the growth path of the aggregate herd. The present study combines a modified version of the Jarvis investment model for the individual animal with a computer simulation model of the national herd structure.[2] The results suggest why the deer sector is growing as rapidly as it is in New

R. A. Sandrey and A. C. Zwart are, respectively, a lecturer and a marketing professor in the Department of Agricultural Economics and Marketing, Lincoln University College of Agriculture, Christchurch, New Zealand.

[1] The New Zealand Game Industry Association has publicly called for increased venison supplies to provide "the much needed throughput" (New Zealand Deer Farmers Association, p. 2).

[2] A preferred approach would be use of time-series data in an econometric model of supply and demand. The short history of deer farming in New Zealand precludes such an approach.

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Zealand and provide possible explanations of pricing behavior and supply relationships in this young industry.

The New Zealand Deer Industry

After deer were introduced into New Zealand late last century, herd sizes became so large that feral deer were declared noxious animals.[3] These numbers stayed high until the emergence of an export market for venison in the mid-1960s. This development placed substantial pressure on the size of the feral herd and provided the stimulus for domestication of the animals.

In 1969 commercial deer farming was officially sanctioned. This increased the demand for live deer for breeding purposes and, with high expected prices for velvet, resulted in prices for live deer (their capital prices) in excess of their meat value. This was particularly so for females. In April 1984, for example, the prices of mature, yearling, and weaner hinds were \$2,000–\$2,200, \$1,750, and \$1,500, respectively. Mature stags sold for \$250–\$450, while the slaughter value of mature animals was \$250–\$450.[4]

As commercial deer farming developed during the 1970s, the cost of capturing feral deer increased with the depletion of feral stocks. Venison supplies from feral deer diminished because the returns from live deer captured for commercial breeding stock exceeded their meat value. To date venison from commercial farms has not replaced venison from feral stocks.

However, production of the more lucrative velvet continues to increase, principally from commercial farms. In addition, farm inventories of deer are increasing (table 1).[5]

A Model of Production Decisions

To the producer the slaughter age of an animal is determined by the value of the outputs and inputs associated with the animal over its lifetime. Following Jarvis (1974, 1982) the present value of a stag deer at birth can be expressed mathematically as follows:

$$(1)\qquad \pi_0(\sigma) = p(i, \sigma)w(i, \sigma)e^{-r\sigma} + \int_0^{\sigma} p_v(i, t)w_v(i, t)e^{-rt}\,dt - ci\int_0^{\sigma} e^{-rt}\,dt$$

where $\pi_0(\sigma)$ is value of male animal at birth, slaughtered at age σ; p, unit price of venison; w, slaughter weight; t, age of animal, where 0 is date of birth and σ is slaughter date; c, unit costs of inputs over the life of the animal; i, vector of inputs per unit time; r, interest rate; σ, age of animal at slaughter; p_v, price of velvet; and w_v, weight of velvet produced by an animal at age σ having been fed inputs i.[6]

The producer can maximize the value of $\pi(0)$ by choosing the optimal input stream ($\hat{\imath}$) and the age of slaughter ($\hat{\sigma}$).[7] This would be accomplished by differentiating (1) with respect to both inputs, i, and age, σ. The resultant first-order conditions would be the familiar equating of marginal benefits and marginal costs.

At present relatively little is known about alternative feeding regimes for deer production. Thus, in this paper, it is assumed that the animals are fed the optimum input stream and that the optimum slaughter age can be found

Table 1. Deer on New Zealand Farms (End of June Data)

Year	Male	Female	Total
1981	45,000	64,160	109,160
1982	60,670	90,120	150,790
1983	74,380	121,270	195,650
1984 (estimated)	100,000	160,000	260,000

Source: New Zealand Department of Statistics.

[3] Red deer are the predominant species, with some fallow, sika, and wapiti locally important.

[4] All monetary figures quoted in the text are in New Zealand dollars. At the time of writing, one New Zealand dollar was equivalent to 66¢ in U.S. funds.

[5] Information on numbers of deer on New Zealand farms has been published by the Department of Statistics since 1981. These figures, shown in Table 1, include all deer, although the red deer predominate (83%). Production data used in the remainder of the paper are for red deer only; thus, because some fallow, sika, and wapiti-cross (elk-cross) are also farmed, the data are biased downward.

[6] An assumption implicit in (1) is that velvet production is continuous throughout the life of the animal. This, however, is not the case, and a discrete summation of benefits would correctly reflect the velvet production and harvest process. The continuous assumption makes the derivation of the optimal conditions easier, and little is lost by using the approximation.

[7] Once the decision has been made to remove an animal from the herd for slaughter, a second issue arises, that of timing of slaughter (Yager, Greer, and Burt). This paper does not examine this decision.

simply by differentiating (1) with respect to σ and equating the result to zero, as follows:

$$\text{(2)}\quad \frac{\partial \pi}{\partial \sigma} = e^{-r\sigma}\left[p\frac{\partial w}{\partial \sigma} + w\frac{\partial p}{\partial \sigma}\right] - rpwe^{-r\sigma} + p_v(i, \sigma)w_v(i, \sigma)e^{-r\sigma} - cie^{-r\sigma} = 0.$$

Dividing (2) by $e^{-r\sigma}$ yields, after restructuring,

$$\text{(3)}\quad p\dot{w} + w\dot{p} + p_v w_v = rpw + ci$$

where $\dot{w}$ and $\dot{p}$ are the time rates of change in w and p, respectively.

The first two terms of the left-hand side of (3) are the incremental value of venison (the change in weight times the price plus the change in price times the weight) at slaughter, while the final term is the value of velvet produced during slaughter period t. Optimality is reached when these terms are equated to interest earnings forgone during t by not slaughtering at the beginning of t, plus other costs incurred during the period.[8]

The decision model for hinds differs from that for stags because velvet is not produced and because of the income stream generated from the progeny produced. Once herd sizes stabilize and the number of females born exceeds that required for breeding, their value as capital assets declines relative to their slaughter value and profit-maximizing farmers will slaughter more hinds. Thus, the value of a female will be the discounted net slaughter value. The value of an animal retained for breeding will be the net discounted stream of future returns generated by that animal.

The income from the hinds as breeding animals can be represented as follows:

$$\tfrac{1}{2}[\pi_0(\hat{\sigma}) + P_0(\hat{\sigma})] \int_0^{\sigma} F(i, \sigma)e^{-rt}\, dt$$

where $\pi_0(\hat{\sigma})$ is the value at birth of a male offspring held until the optimum slaughter period; $P_0(\hat{\sigma})$, the value at birth of a female offspring held until the optimum slaughter age or sale; and $F(i, \sigma)$, a probability function reflecting the birth rate and mortality of the female.

Restructuring equation (1) to incorporate this relationship enables the profit function for young females to be specified.

$$\text{(4)}\quad P_0(\sigma) = \tfrac{1}{2}[\pi_0(\hat{\sigma}) + P_0(\hat{\sigma})] \cdot \int_0^{\sigma} F(i, \sigma)e^{-rt}\, dt + p(i, \sigma)w(i, \sigma)e^{-rt} - ci \int_0^{\sigma} e^{-rt}\, dt.$$

By differentiating (4) with respect to σ, equating the result to zero, and simplifying, it is possible to derive the first-order condition for the optimum slaughter of females:

$$\text{(5)}\quad \tfrac{1}{2}[\pi_0(\hat{\sigma}) + P_0(\hat{\sigma})]F(i, \sigma) + p\dot{w} + w\dot{p} = rpw + ci.$$

This relationship is similar to that derived for stags except that the first term on the left-hand side of (5) measures the income associated with offspring produced, instead of the income from velvet.

The difficulty associated with measuring the future income stream of a hind is that the value of a female calf is endogenous to such a calculation. One possible approach to this problem would be to use an iterative procedure, selecting the value of male calves $[\pi_0(\hat{\sigma})]$ for $P_0(\hat{\sigma})$ initially, and replacing this with the computed value of $P_0(\sigma)$ from equation (4) until convergence was achieved.

An alternative approach is taken in the present study, where it is assumed that female calves have the same value as male calves at weaning. This approach, taken for computational ease, leads to an understatement of the future income stream when herd numbers are increasing (and future female calves have a higher marginal value in breeding than in slaughtering). The approach highlights the dependence of the value of the female animal on the value of the males produced and the residual value at slaughter.

[8] In this paper input costs include direct costs (feed, medicine, etc.) and the opportunity costs of money capital, pasture, fences, etc., measured as the returns from producing sheep, an alternative livestock product. New Zealand technology for deer farming is based upon a grasslands system similar to that of sheep and cattle production, although some additional fixed costs (fencing, yards, expertise) are needed for deer.

Treatment of opportunity cost in the literature varies. Jarvis states that "there is no opportunity cost to cattle production other than the interest forgone on invested capital" (1974, p. 492). The more traditional replacement model regards the opportunity cost as including the value foregone by not replacing the animals with another group of feeder animals (McLemore and Butts; Dillon). Using sheep returns to reflect opportunity cost, as in this paper, follows the traditional approach. Sheep are used instead of replacement deer because the deer industry is in an expansion phase, replacing both sheep and cattle production in New Zealand.

Table 2. Production Characteristics of Red Deer

Age	Estimated Weight	Slaughter Value[a]	Probability of Survival to Next Age[b]	Velvet Weight[c]	Velvet Value[d]	Sheep Equivalents
(Years)	(kg)	($)	(%)	(kg)	($)	
(a) Stags						
1	42.5	212.5	.96			1.5
2	55	286	.96	1.0	35	2.0
3	65	345	.96	1.6	112	2.2
4	70	378	.96	1.9	200	2.2
5	75	405	.96	2.2	253	2.2
6	75	405	.96	2.4	288	2.2
7–12	75	405	.96	2.4	288	2.2
13	75	405	.80	2.4	288	2.2
14	75	405	.50	2.4	288	2.2
(b) Hinds				Weaning (%)		
2				77		1.5
3–14	55	286	as for stags	86		1.5

[a] Calculated from current (Dec. 1983) venison schedule and slaughter weights provided by Canterbury Venison (NZ) Ltd. (personal communication).
[b] Estimates only, especially at the older age range as few animals with a known age at this extreme exist. Probability for hinds is assumed to be the same as for stags.
[c] Fennessy and Moore; Moore.
[d] Estimated from current (Dec. 1983) velvet schedule and grades provided by Wrightson NMA Ltd.

Empirical Analysis

In this section the analytical framework is utilized to select the age at which a producer should slaughter a stag under different economic conditions. Production data from table 2 are used for velvet and venison and are weighted by the probability of an animal's survival. Interest costs are assessed at 10% of the opportunity value of the investment (the slaughter value of the animal) and reflect the interest which could be earned from the proceeds of the slaughter decision. A figure of $18.37 per stock unit,[9] which is the gross margin from sheep production (McGregor), is used to reflect the opportunity cost of the fixed resources (land, pasture, labor, etc.). Additional annual costs of $15 per stag, reflecting special handling costs, are also included in subsequent analyses. These data, all of which are expressed in real terms, comprise the information required for solving equation (3).

Benefits and costs of keeping an animal in each age group for an extra year are shown in table 3. Column 1 shows the expected change in the slaughter value, at the end of each year, adjusted for probability of death. Velvet is harvested at the end of each year, and the expected values of that year's harvest, net of all costs but forgone interest earnings, are shown in column 2. In column 3 each year's opportunity cost of the capital, which is tied up in the animal, is presented.

Marginal benefits (columns 1 and 2) less marginal costs (column 3) are calculated in column 4, and, if positive, represent a situation in which the optimum decision is to keep the animal for a further year. Under the present venison and velvet pricing structure, it is optimum to keep the animal until the end of year thirteen before slaughtering.

Present values (PVs) of the expected returns are shown in column 5, assuming a 10% discount rate. These figures represent the value of the different aged animal assuming that it is slaughtered at the optimum age (13 years).

Uncertainty about future velvet prices suggests that the exercise should be conducted for a range of prices. To test the sensitivity of results, four price scenarios have been developed to reflect more conservative values of both velvet and venison. Velvet prices are varied to the greater extent because they are generally

[9] One stock unit is equivalent to an ewe weighing 55 kg and eating 600 kg/DM per day. A lambing percent of 105–110 and wool weight of 4.5 kg annually are expected. The dollar figure reflects a downward adjustment of $2.05 per stock unit to allow for interest charges of 10% on the value of the capital stock required in sheep production. This is done to be consistent with allowing an interest charge on the capital stock used in deer production.

Table 3. Determining the Optimal Slaughter Age for Stags at Present Prices for Velvet and Venison

Age (Start of Year)	Expected Change in Slaughter Value during Year[a]	Expected Value of Velvet at End of Year Net of Costs[b]	Opportunity Cost of Not Slaughtering at 10% Interest	Summation of Benefits and Costs during Year (columns 1 & 2, minus 3)	Present Value at (Start of Year)[c]
			($)		
0		−27.56			972.94
1	+62.1	−8.96	21.25	31.85	1,108.60
2	+45.2	55.78	28.6	72.38	1,240.73
3	+17.9	136.58	34.5	119.96	1,322.81
4	+10.8	187.46	37.8	160.46	1,333.21
5	−16.2	221.06	40.5	164.36	1,293.89
6	−16.2	221.06	40.5	164.36	1,216.59
7	−16.2	221.06	40.5	164.36	1,130.71
8	−16.2	221.06	40.5	164.36	1,035.28
9	−16.2	221.06	40.5	164.36	929.26
10	−16.2	221.06	40.5	164.36	811.45
11	−16.2	221.06	40.5	164.36	680.55
12	−16.2	221.06	40.5	164.36	535.10
13	−81.0	174.98	40.5	53.48	336.15
14	−202.5	88.58	40.5	−154.42	

[a] Adjusted for probability of death.
[b] Except forgone interest earnings, shown in column (3).
[c] Assumes animal is slaughtered at end of year 13, with an expected value of venison (adjusted by probability of death from birth) of $190.57.

considered to be the most variable and likely to fall as production increases.

The four scenarios are as follows, where "present returns" refers to values reported in table 2:

A—Present returns for both venison and velvet.[10]

B—Present returns for venison, half of present returns for velvet.

C—Present returns for venison, one-third of present returns for velvet.

D—Eighty percent of present returns for venison, velvet returns as in C.

Results of following the decision criteria are summarized in table 4 for stags and table 5 for hinds. The optimum slaughter age for stags changes from thirteen years under scenario A to twelve years under B. A more dramatic change occurs under scenario C, with velvet returns reduced to one-third of present returns. The optimum slaughter age falls from twelve years to two years.

Opportunity costs of maintaining a hind are estimated to be $18.37 until one year of age

[10] This is the scenario underlying the table 3 results.

Table 4. Summary of Slaughter Decisions for Stags

	Scenario[a]			
	A	B	C	D
Velvet returns	present[b]	.5 × present	.33 × present	.33 × present
Venison	present	present	present	.8 × present
Optimum slaughter age (end of year)	13	12	2	4
PV at birth ($)[c]	972.94	336.78	117.51	110.56
PV at one year ($)[c]	1,108.60	394.96	156.33	150.41
Residual slaughter value ($)	190.57	248.15	263.58	256.84

[a] Refers to the alternative scenarios described in the text regarding both venison and velvet returns.
[b] Present refers to the present returns to producers for both velvet and venison, as shown in table 2. In scenario B, for example, 5 × present refers to velvet returns of one-half of the present returns.
[c] A 10% interest rate is assumed.

Table 5. Summary of Slaughter Decisions for Hinds

	Scenario[a]			
	A	B	C	D
Optimum slaughter age (end of year)	13	12	9	11
PV at weaning ($)	3,168.71	998.12	250.15	229.19
Residual slaughter value ($)[b]	139.57	168.23	190.14	158.45
PV at birth ($)	972.94	336.78	117.51	110.56
PV at one year ($)	1,108.60	394.96	156.33	150.41
Marginal cost at age 10 ($)[c]	67.60	67.60	67.60	59.59

[a] Refers to the alternative scenarios described in the text regarding both venison and velvet returns.
[b] Calculated to reflect survival probabilities.
[c] Includes the opportunity cost of not slaughtering the animal.

and $27.56 thereafter (1.0 and 1.5 stock units, respectively). The value of the female progeny at birth is considered to be the present value at weaning of a male calf (table 4), weighted by the probability of a calf being born and raised to weaning. Marginal benefits are the value of progeny and the expected change in venison value, while costs include forgone interest earnings and revenues forgone by raising deer instead of sheep. Moving from scenario A to D changes the optimum slaughter age, as shown in table 5. Lowering the venison price in scenario D reduces slaughter value and thus the opportunity cost of capital, resulting in a higher slaughter age under D than under C.

Notice that the PVs reported in tables 4 and 5 can be interpreted to represent the amount a producer is willing to pay for animals of different ages under the alternative scenarios. A comparison of these values to current, lower, market prices (discussed earlier) helps explain why a strong demand exists for live deer.

Projections

The decision criteria formulated above yield optimum slaughter ages for individual animals. To examine supply relationships at the industry level, a computer simulation model was developed to project herd build-up and production in the medium term.[11] This model uses estimates of the 1981 and 1982 age structures of the commercial herd, which, because of the new nature of the industry, are biased towards young animals. Population and production parameters are as previously used, with an additional 2% and 3% annual slaughter of hinds and stags, respectively, for all age groups up to the optimum age. This culling is presumed to account for obvious defects in individuals animals. A live capture of a constant 11,500 animals per annum is assumed in the initial model (scenario A).

The simulation model is a population dynamics model using both the production parameters shown in table 2 and the optimal slaughter ages for stags and hinds derived from the decision model (tables 4 and 5). Models of this type can be useful for projecting time paths of herd expansion and deer production under the fixed production parameters used. Some price variability is incorporated by using the different price assumptions (scenarios A through D) outlined earlier.

Projections to 1991 under scenarios A and C, representing the lowest and highest levels of projected venison production, respectively, are shown in table 6. This table clearly demonstrates the potential build-up of deer over the time period, and the resulting venison production if velvet returns remain at present levels. The actual herd size increased by 38% between 1981 and 1982 (table 1), the same as simulated under scenario A. The actual increase from 1982 to 1983 was 30%, less than the simulated increase, although only a one percent error in forecasted female numbers occurred. Percentage increases in herd numbers decline through time because the impact of live captured animals is reduced with increasing domestic herd build-up. Total farm venison slaughter rises slowly as animals move through the herd and reaches a peak at 2,915 tons by 1991.

Scenario A represents the most optimistic velvet return scenario; and, thus, projections probably represent the lowest potential veni-

[11] Lack of historical data for this new industry precluded the development of an econometric model of supply and demand.

Table 6. Projections of Deer Numbers and Production

Year Ending June	Hinds, as at June	Total Deer	Increase in Total Deer	Venison
	(thou.)		(%)	(tons)
		Scenario A[a]		
1981	64	109	–	241
1982	90	151	38	327
1983	120	203	35	403
1984	158	270	33	533
1985	205	356	32	696
1986	264	457	31	906
1987	337	605	30	1,150
1988	426	776	28	1,448
1989	536	990	27	1,816
1990	671	1,254	27	2,297
1991	839	1,584	26	2,915
		Scenario C[a]		
1983	120	203	33	403
1984	158	270	32	6,090[b]
1985	205	357	3	2,466
1986	236	367	22	3,175
1987	286	449	21	3,798
1988	348	545	21	4,671
1989	422	662	21	5,707
1990	513	805	21	6,976
1991	622	976	21	8,450

[a] As before, these scenarios refer to alternative assumptions made about future venison and velvet returns and live capture of hinds.
[b] This figure represents a 40% increase in venison exports from the peak feral years, 1972.

son production in the medium term. Scenario C, with velvet returns assumed at one-third of their present level and venison returns the same as present, generates the highest potential venison production over the same period. Recall that in scenario C slaughter age is reduced to two years for stags and nine years for hinds. It is unlikely, of course, that producers would react in this manner to a sudden fall in velvet prices, an adjustment period forming expectations over a period of greater than one season would be more realistic. No live capture of hinds is incorporated into the simulation model for the post-1984 period in scenario C because live capture would not be viable under a lower hind value.

Differences between the two scenarios are apparent. Altering the optimum slaughter age of hinds has little impact upon numbers of hinds; most of the differences in hind numbers as between scenarios A and C are due to cessation of live capture in scenario C. Dramatic differences are apparent in venison production, which highlights the uncertainty about future supplies in the venison-processing industry.

Conclusions and Implications

This study provides some insights into producer decision making regarding the optimum slaughter age of animals, and into how factors influencing this decision are likely to affect growth in the New Zealand commercial red deer industry. The analysis of optimum slaughter ages is important in understanding the lack of venison currently supplied. The analysis showed that under current prices it is profitable for producers to retain both stags and hinds until they are thirteen or fourteen years old, which is close to their life expectancy. This situation would lead to the maximum possible build-up in both hind and stag herds and a low level of venison supplied from cull stock.

The optimum slaughter age was seen to be most sensitive for stags. A drop in velvet returns to 33% of their current levels would lead to increased venison production in the short and medium terms. Even at these lower velvet returns it appears that slaughter ages for hinds would be maintained and the herd size would increase.

The derived value of livestock also contributes to an understanding of the current situation. The results suggest that weaner hinds and stags, at current prices and a 10% discount rate, would have current values of approximately $3,200 and $1,000, respectively. These values suggest that market prices understate the current values of these animals and provide an explanation of why producers are currently retaining both hinds and stags. Also, the derived values suggest that stags are relatively more undervalued than hinds, but this may be a reflection of the manner in which female offspring were valued in the analysis.

It is possible that the differences between the current market and estimated values are caused by producers' attitudes to risk. It is interesting to note that for stags, a discount rate of approximately 35% or a drop in velvet prices to below 50% of their current level would produce valuations similar to current market prices. These figures suggest relatively high margins for risk in the current market valuations.

The results from the population simulation model show the two extreme time paths for industry development. In both cases the profitability of deer in comparison to sheep farming suggests that the female herd will continue to grow, although at a slower rate if velvet prices fall. The major impact of lower velvet prices would be a rapid increase in venison output in the short to medium term. A current danger for the industry is that a substantial drop in velvet returns could set off a reaction in which the growth in the hind herd is reduced, venison production is increased, and market values of stock fall in a relatively short period.

The methods and models used in this study provide a first step for producers and policy makers to understand the dynamics involved in a new and rapidly growing industry. The methods used in this research may be applicable to other new potential livestock industries where time-series data are not available to estimate the response to changes in market conditions.

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