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Producing Higher Value Wool through a Transition from Romney to Merino Crossbred: Constraining Sheep Feed Demand

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Abstract: A strategy to increase wool income for coarse wool (fibre diameter > 30 µm) producers through a transition to higher value medium wool (fibre diameter between 25 and 29 µm) was identified, with previous analyses allowing sheep feed demand increases to impractical levels during the transition period. This study modelled a whole flock transition from Romney breed to a 3/4Merino1/4Romney flock through crossbreeding with Merino sires, with sheep feed demand constrained between 55% and 65% of total grown feed. Transition was complete after 12 years, and the final 3/4M1/4R flock had higher COS (cash operating surplus; NZD 516/ha) than the base Romney flock (NZD 390/ha). Net present value analyses showed the transition always had an economic benefit (up to 13% higher) over the Romney flock. In a sensitivity analysis with sheep and wool sale prices changed by ±10%, higher sheep sale prices reduced the economic benefit of the transition (NPV up to 11% higher) over the Romney flock, as sheep sales comprised a higher proportion of income for the Romney flock, and higher wool sale prices increased the benefit (NPV up to 15% higher) of the transition to 3/4M1/4R over the Romney flock. This study demonstrated a whole flock transition from Romney to 3/4M1/4R breed was profitable and achievable without large variation in sheep feed demand, although the scale of benefit compared to maintaining a Romney flock was determined by changes in sheep and wool sale prices.

Keywords: bio-economic; modelling; New Zealand; farm system; flock dynamics; ewe age

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1. Introduction

More than 50% of sheep in New Zealand are Romney breed, a dual-purpose breed producing lambs for meat and coarse wool (fibre diameter greater than 30 µm) [1]. Therefore, most wool produced in New Zealand is coarse wool, which has lost relative value while shearing (wool harvesting) costs have increased [1]. As a result, coarse wool producing New Zealand sheep farmers derive an increasingly small proportion of their revenue from wool sales [2]. In contrast, the medium wool price premium (fibre diameter between 25 and 29 µm) has increased compared with coarse wool over the past 30 years, with even higher prices available for fine wool (fibre diameter < 24 µm) [1]. In general, the composition of wool produced in New Zealand is 77% coarse, 15% medium and 8% fine [1]. Sheep producing medium and fine wool are typically farmed on relatively high-altitude, less-fertile, and steep land [1].

An industry strategy was identified for coarse wool producers to transition to higher value medium wool through use of Merino rams to breed a 3/4Merino1/4Romney (3/4M1/4R) flock, which could retain the lamb productivity of the Romney breed while taking advantage of increasing medium wool prices [3]. Such a grading up transition has previously been modelled with published data suggesting crossbred Merino–Romney offspring will

generally produce wool with mean fibre diameter of the approximate parental mean [4,5]. For example, crossbreeding Merino rams (21 μm) with Romney ewes (36 μm) would produce $1/2\text{Merino}1/2\text{Romney}$ ($1/2\text{M}1/2\text{R}$) progeny with a mean fibre diameter of approximately 28 μm , then crossbreeding the $1/2\text{M}1/2\text{R}$ ewes with Merino breed rams (21 μm) would produce $3/4\text{M}1/4\text{R}$ progeny with a mean fibre diameter of approximately 25 μm [4]. Farrell et al. [4] demonstrated that the fibre diameter of wool from the Merino–Romney crossbred flocks could also be further reduced through retention of crossbred ewe lambs with the finest wool during transition, i.e., 42% or 58% of crossbred ewe lambs retained for breeding each year during transition. Farrell et al. [4,5] showed that within eight to ten years a coarse (36 μm) wool producing Romney flock could undergo a whole flock grading up transition to a $3/4\text{M}1/4\text{R}$ flock producing finer (24 to 26 μm), higher value wool, resulting in greater annual cash flow than the Romney flock. The net present values of the whole flock transition were up to 26% higher than maintaining the Romney flock, with a longer transition period (ten years) and higher selection intensity for reductions in wool fibre diameter in crossbred ewe lambs having the highest overall economic benefit [5].

During the whole flock grading up transition modelled by [4], total annual sheep feed demand was not restricted as numbers of $3/4\text{M}1/4\text{R}$ ewes were increased as quickly as possible, to reduce the time frame for the transition to be complete. Levels of feed consumed by sheep during transition were outside of the typical range seen on farms of the type modelled (typically approximately 45% to 65%) as these are traditionally mixed sheep and beef cattle farms [2]. Therefore, the scenario modelled would not be practical for most commercial sheep farms, where sheep to cattle ratios are somewhat fixed within a defined range for income diversification and the role of cattle in maintaining pasture quality. The objective of the current analysis was to model a whole flock grading up transition from Romney to $3/4\text{M}1/4\text{R}$ while constraining sheep feed demand within a narrow range (between 55% and 65% of total farm feed supply) appropriate for the farm system under study [2]. The model outputs can provide insight into potential changes in sheep numbers, feed demand, production and profitability to inform the decision making of farmers considering a similar grading up transition when total sheep feed demand was constrained to the industry norm.

2. Materials and Methods

The ewe flocks were modelled as being on a New Zealand East Coast North Island hill country sheep and beef farm with mean values from industry survey data for this farm system [2]. The farm system was the same as was modelled by [4] with ewe flocks lambing once-a-year in spring (August to October), and grazing extensively on pasture year-round [2]. This farm typically has both sheep and beef production enterprises, and the sheep enterprise was the focus of this research. The modelled farm was 530 ha with an initial self-replacing flock of 2066 Romney ewes consuming 60% of total farm feed supply, which is the mean for farms of this type [2]. During the grading up transition to the $3/4\text{M}1/4\text{R}$ flock, the total annual sheep feed demand was constrained to between 55% and 65% of total farm feed supply, which represents the range of mean feed consumption of flocks on this type of farm [2] and was achieved through changes in ewe culling rates. The proportion of feed consumed annually by sheep was used to predict the share of operating expenses and farm area relevant to the sheep enterprise. The modified bio-economic system-dynamics model was developed in STELLA version 1.7.1 [6] with separate component models for flock dynamics for each breed, Romney, $1/2\text{M}1/2\text{R}$, and $3/4\text{M}1/4\text{R}$, and their movements entering (through birth and weaning) and exiting (due to death and culling) each flock. The wool production and feed demand of each flock was also modelled in separate components for each flock, with economics combined in a whole sheep enterprise profit module. The STELLA software was used in this analysis due to its ability to model dynamic transitions over multiple generations [7], such as changes over time in numbers of ewes for interacting flocks of different breeds. Further, STELLA is effective in modelling systems with numerous inter-connected feedback loops, such as in self-replacing flocks with inter-year variation

in lambing and culling rates [8]. Extensive detail of model workings and inputs is given in [4,5], therefore only brief detail is given in the following subsections.

2.1. Ewe Flocks

Within each ewe flock there were up to eight age classes of ewes, from weaned replacement ewe lambs through to seven-year-old ewes. Each year, those ewes which had not died or been culled moved through to the next age class. The age structure of the ewe flock affected lamb and wool production (Table 1), therefore changes in age structure due to numbers of ewe lambs entering the flock and numbers of ewes leaving the flock due to death and culling affected flock production. For example, numbers of lambs weaned were a product of flock lambing rate (Table 2), numbers of ewes in each age class, and the adjustment parameters from Table 1, where one year old ewes weaned lambs at only 22% of the rate weaned by three-year-olds. The flock was first modelled as a self-replacing Romney flock of a steady size, with the required number of replacement ewe lambs estimated as the sum of ewes lost to death (Table 2) and culling (Table 3). Six- and seven-year-old ewes in the Romney and Merino–Romney crossbred flocks, respectively, were culled for age after weaning according to typical New Zealand practice for their respective breeds. The Romney flock was modelled as self-replacing to establish the status quo flock age structure, production, feed demand, and profit. In order to model the transition to the $\frac{3}{4}M\frac{1}{4}R$ flock, all Romney ewes were assumed to produce first-cross, $\frac{1}{2}M\frac{1}{2}R$ lambs, and a proportion of ewe lambs from this cohort were retained to enter the $\frac{1}{2}M\frac{1}{2}R$ flock once mature to produce second cross $\frac{3}{4}M\frac{1}{4}R$ lambs (Figure 1). New Zealand farmers can choose whether to breed their ewes to first lamb at 14 months of age or two years old [9]. In this analysis it was assumed Romney ewes had been bred to potentially produce a lamb at 14 months old but Merino crossbred ewes did not produce a lamb until two years of age owing to their smaller size [4]. Ewes in the $\frac{3}{4}M\frac{1}{4}R$ flock were assumed to be bred with rams of similar breed and production, including wool fibre diameter, thus the $\frac{3}{4}M\frac{1}{4}R$ flock production per head was the same during and post-transition. In reality there may be reduced production post-transition when ewes no longer benefit from hybrid vigour due to crossbreeding, however there is insufficient published data on which assumptions of this potential reduction could be based.

Most production values in Table 2 were informed by a combination of recently published experimental data for Romney sheep and experimental data comparing Romney sheep with $\frac{1}{2}M\frac{1}{2}R$ and $\frac{3}{4}M\frac{1}{4}R$ sheep as detailed in [4,5]. For example, recently published mature liveweights of Romney ewes informed the assumption of Romney ewe liveweight (65 kg) in the model [10], then previous comparisons concluded $\frac{1}{2}M\frac{1}{2}R$ ewes were 9% lighter (60 kg) and $\frac{3}{4}M\frac{1}{4}R$ ewes a further 9% lighter (55 kg) [11–13]. Some data indicated there may be no difference between the breeds, such as for birth weights [14,15], hence parameter values were the same for all breeds. Data from comparisons between the breeds were inconsistent for lambing rate [11,12,16,17], therefore the modelled differences between breeds were informed by current differences between Romney (132%) and Merino (108%) sheep [2].

2.1.1. Selection Intensity Applied to Crossbred Ewe Lambs during Transition

The selection intensity applied to crossbred ewe lambs during transition was 35% of crossbred ewe lambs not retained on-farm at each of two annual selection events ($Sort_w$ at weaning and $Sort_{10}$ at 10 months of age). For illustration, from 1000 $\frac{3}{4}M\frac{1}{4}R$ ewe lambs weaned in late November, 650 ewe lambs remained on-farm over winter after $Sort_w$ and 423 (i.e., 35% of 650 ewe lambs were not retained) ewe lambs entered the $\frac{3}{4}M\frac{1}{4}R$ flock after $Sort_{10}$ in early July. This was the higher selection intensity utilised by [4] which was found to have the greatest economic benefit. The number of crossbred ewe lambs entering the one-year-old classes of $\frac{1}{2}M\frac{1}{2}R$ and $\frac{3}{4}M\frac{1}{4}R$ flocks during transition were determined by numbers remaining after both of the two selection events. At weaning ($Sort_w$) any ewe lambs visually identified without appropriate conformation were subsequently sold prime

(direct to slaughter) along with all ram lambs before winter (before mid-May). Selection of crossbred ewe lambs at $Sort_w$ was assumed not to have considered wool fibre diameter, thus selection intensity was assumed not to have affected the distribution of wool fibre diameters for crossbred ewe lambs retained after $Sort_w$. At $Sort_{10}$ (10 months of age) it was assumed crossbred ewe lambs were shorn with wool samples sent for fibre diameter testing. After $Sort_{10}$ crossbred ewe lambs of the lowest wool fibre diameter were retained and ewe lambs not retained after $Sort_{10}$ were subsequently sold prime.

Table 1. Adjustment parameters for lamb and wool production estimations of sheep of various age classes in the flock. Adapted from previous studies using the same model [4,5].

Age Class	Adjustment Parameter		
	Lambs Weaned	Fleece Weight	Wool Fibre Diameter
Lamb	-	0.50	1.02
One year old	0.22	0.95	1.02
Two year old	0.88	1.01	1.10
Three year old	1.00	1.08	1.12
Four year old	1.08	1.05	1.13
Five year old	1.13	1.01	1.12
Six year old	1.10	0.97	1.11
Seven year old	1.00	0.96	1.10

2.1.2. Ewe Culling Rates

Culling rates varied during transition to constrain sheep feed demand between 55% and 65% of total farm feed supply, from the base level of approximately 60%. Culling rates differed at times between flocks of the different breeds and between ewe age classes. The base Romney flock in year zero had a culling rate of 20% to achieve a typical replacement rate of approximately 25% (Table 3; [9]). It was assumed ewe culling rates would be minimal during transition to increase numbers of crossbred ewes and achieve the desired size of the $\frac{3}{4}M\frac{1}{4}R$ flock quickly. Therefore, only barren ewes were assumed to be culled during the transition and a typical barren rate for New Zealand flocks of 4% was applied as the minimum culling rate [18]. Total annual sheep feed demand was affected by ewe flock size and age structure for each breed, as they had different production levels (Table 2) and their per head production varied with ewe age (Table 1). Therefore, necessary changes in culling rates could be large between years for groups of ewes as shown in Table 3. In years seven and eight of transition, numbers of ewes on-farm increased sheep feed demand above 65% unless a higher culling rate was applied to a larger group of ewes. Ewes in the four-year old age class of the $\frac{1}{2}M\frac{1}{2}R$ flock were therefore culled at rates of 25% and 40% in years seven and eight of the transition, respectively (Table 3). In subsequent years this increase affected numbers of $\frac{1}{2}M\frac{1}{2}R$ ewes in older age classes and numbers of $\frac{3}{4}M\frac{1}{4}R$ lambs produced, with flow-on effects on $\frac{3}{4}M\frac{1}{4}R$ ewe numbers.

2.2. Feed Demand

Total annual sheep feed demand was 60% of total farm feed supply for the base Romney flock [2]. Sheep feed demand was constrained between 55% and 65% of total farm feed supply for all modelled scenarios during transition, then was approximately 60% post-transition. Feed demand was estimated for sheep of each age class and breed for maintenance, growth, gestation, lactation, and wool growth as detailed in [4]. Estimations of feed demand were informed by production levels from Table 2 with adjustments for age from Table 1 included.

Table 2. Production parameters assumed in the analysis for ewe flocks of Romney, $\frac{1}{2}$ Merino $\frac{1}{2}$ Romney, and $\frac{3}{4}$ Merino $\frac{1}{4}$ Romney breeds, adapted from [4,5].

Parameter	Romney	$\frac{1}{2}$ M $\frac{1}{2}$ R	$\frac{3}{4}$ M $\frac{1}{4}$ R
One year old death rate (%)	1.9	1.9	1.9
Two- to seven-year-old death rate (%)	5.2	5.2	5.2
Lambing rate (%) ¹	132	120	114
Mature liveweight (kg)	65	60	55
Mature ewe greasy fleece weight (kg)	4.57	4.16	3.75
Fleece yield (%)	75.3	75.3	75.3
Lamb survival (%) ²	84	84	84
Birth weight of single-born lambs (kg)	5.5	5.5	5.5
Birth weight of multiple-born lambs (kg)	4.5	4.5	4.5
Weaning age (weeks)	12	12	12
Weaning weight of single-born lambs (kg)	28	25	24
Weaning weight of multiple-born lambs (kg)	26	23	23
Post-weaning growth of single-born lambs (g/day)	130	120	109
Post-weaning growth of multiple-born lambs (g/day)	100	92	84
Carcass weight of prime lambs (kg)	17.9	17.9	17.9
Carcass dressing out rate of prime lambs (%)	41	41	41

¹ Lambs weaned per ewe presented for breeding. ² Lambs surviving from pregnancy diagnosis to weaning.

Table 3. Culling rates (%) for ewe of various age (*i*) classes (Y_i) and breeds during a grading up transition. Culling rates are only presented when ewes of the age class are on farm, for example, Romney ewes were not replaced from year one onwards so there were no Romney ewes in $Y_{2\text{ to }3}$ after three years of transition.

Year	Romney				$\frac{1}{2}$ Merino $\frac{1}{2}$ Romney					$\frac{3}{4}$ Merino $\frac{1}{4}$ Romney		
	$Y_{2\text{ to }3}$	Y_4	Y_5	Y_6	$Y_{2\text{ to }3}$	Y_4	Y_5	Y_6	Y_7	$Y_{2\text{ to }6}$	Y_7	
0	20	20	20	100								
1	4	4	4	100								
2	4	4	4	100								
3	4	4	4	100								
4		4	4	100	4							
5			100	100	4							
6				100	4	4				4		
7					4	25	4	4			4	
8						40	4	4			4	
9							4	4	100		4	
10								100	100		4	
11											4	100
12											4	100
13											20	100

2.3. Wool

Wool produced by the purebred Romney flock was assumed to have a mean of 36 μm , classed as coarse, and variation in fibre diameter was ignored. It was assumed all Romney lambs on-farm in January were shorn. For each flock, total wool production was estimated from mean mature greasy fleece weight (Table 2) in combination with sheep numbers and adjustment parameters from Table 1.

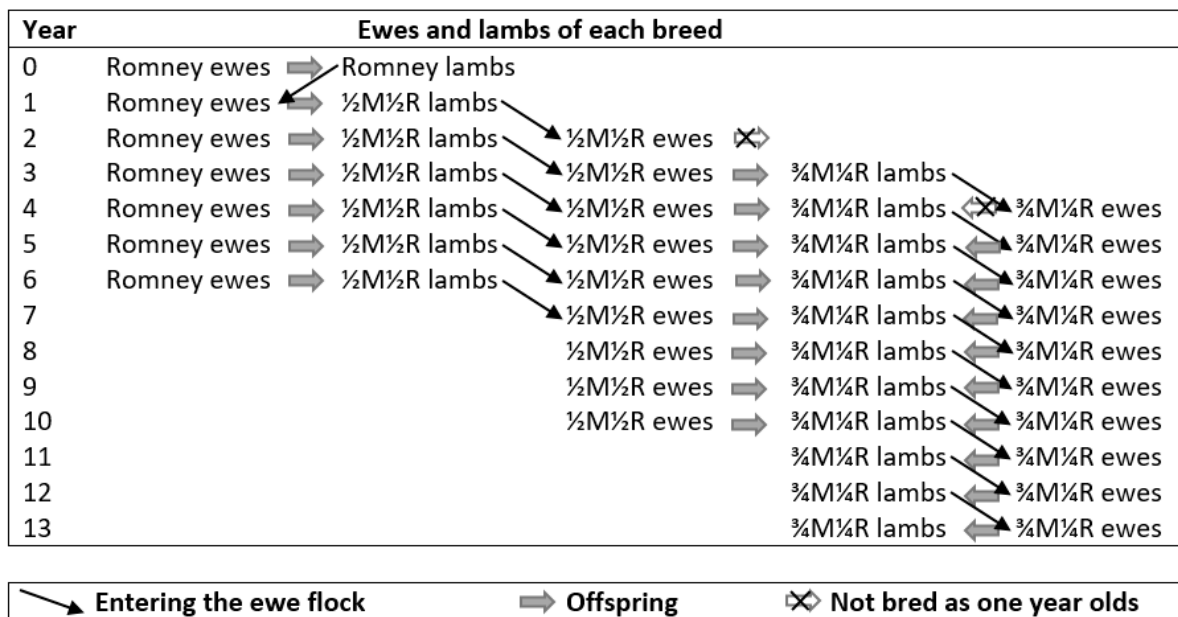


Figure 1. Simplified diagram of sheep breeds on-farm during a whole flock grading up breed transition from Romney to second cross 3/4Merino1/4Romney, showing production of Romney and crossbred Merino–Romney lambs and also lambs entering ewe flocks (ewes aged one to seven years old) each year from the start of breed transition. Where 1/2M1/2R lambs and ewes were first cross 1/2Merino1/2Romney sheep. Reprinted with permission from ref. [5]. 2021 Elsevier.

For the grading up transition, Merino rams with a fibre diameter of 21 µm were bred with Romney ewes which resulted in 1/2M1/2R ewes. Merino-crossbred lambs were assumed to have mean wool fibre diameter similar to their parental mean according to published data [11,17,19–23] and shown in [4]. For example, 1/2M1/2R lambs born to Romney (36 µm) ewes and Merino (21 µm) sires were assumed to have a mean fibre diameter of 28.5 µm. Retention of 1/2M1/2R ewe lambs with the finest wool after *Sort*₁₀ resulted in the mean fibre diameter of remaining ewe lambs being 25.5 µm. However, fibre diameter increases as ewe age (Table 1) so the approximate mean fibre diameter of 1/2M1/2R mature ewes during the transition was 29 µm. The 3/4M1/4R ewe lambs from these 1/2M1/2R dams and Merino sires (21 µm) had mean fibre diameters of 24.3 µm and 21.4 µm pre- and post-*Sort*₁₀, respectively. As 3/4M1/4R ewes aged their mean wool fibre diameter increased, and the mean fibre diameter of the 3/4M1/4R flock was 24 µm once numbers of 3/4M1/4R ewes in each age class had stabilised post-transition.

2.4. Economics

Sheep enterprise cash operating surplus (COS) was estimated as an indicator of annual cashflow and profit in this analysis. Gross sheep income (from sheep and wool sales) and sheep-related operating expenses were used to calculate sheep enterprise COS. For estimations of sheep enterprise COS (COS_{Sheep}) on a per hectare basis, the farm area included in calculations was adjusted with changes in the proportion of total farm feed consumed by sheep. For example, when sheep feed demand increased there was a proportionate increase in the area over which sheep enterprise COS was spread. Survey data for commercial farms of the system modelled (New Zealand North Island hill country) in 2017/18 indicated mean COS per ha for sheep and beef cattle (COS_{Beef}) enterprises to be approximately NZD 390/ha and NZD 280/ha, respectively [2]. Thus changes in the size of the sheep and beef cattle enterprises due to changes in sheep feed demand during transition were accounted for according to Equation (1).

$$Total\ COS = Feed_{Sheep} \times COS_{Sheep} + (1 - Feed_{Sheep}) \times COS_{Beef} \tag{1}$$

where $Feed_{Sheep}$ was the proportion ($0 \leq Feed_{Sheep} \leq 1$) of total farm feed supply consumed by sheep (60% for the base Romney flock; [2]).

2.4.1. Income from Sheep Sales

For the base Romney flock producing purebred Romney lambs, 65% were sold prime (direct to slaughter) with a mean carcass weight of 17.87 kg [2]. Timings of prime lambs sales were dependent on mean growth rates of lambs born as singles and multiples (Tables 2 and 4). Remaining Romney lambs were sold store (for another farmer to grow for slaughter) in early May weighing 32 kg, lighter than typical weights of lambs sold prime in New Zealand [24].

Table 4. Sheep sale prices and sheep enterprise expenses (in New Zealand Dollars) used in model for Romney, 1/2 Merino 1/2 Romney, and 3/4 Merino 1/4 Romney flocks. The base prices shown for sheep sales were also changed by $\pm 10\%$ in a sensitivity analysis.

Breed	Sheep Type	Sheep Sale Prices		
		Timing	Price (NZD/Head) ¹	Source
Romney	Prime lambs	Late-December	5.70/kg	[24]
	Prime lambs	Early February	6.00/kg	
	Store lambs	Early May	99.44	[2]
	Cull ewes < 3 years old	December	134.64	
	Mature cull ewes		113.73	
1/2M1/2R	Prime lambs	Mid-January	6.06/kg	[24]
	Prime lambs	Mid-March	6.13/kg	
	Cull ewes < 3 years old	December	125.22	[2]
	Mature cull ewes		105.77	
3/4M1/4R	Prime lambs	Mid-February	6.00/kg	[24]
	Prime lambs	Start of May	6.31/kg	
	Cull ewes < 3 years old	December	116.45	[2]
	Mature cull ewes		98.37	
Sheep Enterprise Expenses				
Breed	Item		Cost (NZD)	Source
All	Operating ²		47.79 /SU ³	[2]
	Animal health		9.00/SU	
	Shearing		6.00/SU	
1/2M1/2R and 3/4M1/4R	Wool testing ⁴		2.25/fleece	[25]

¹ Prime lamb prices were per kg of carcass weight. ² Including operating costs for repairs and maintenance, vehicles, administration, ACC, and insurance while excluding drawings, tax, interest, depreciation, and rent [26]. ³ A stock unit is approximately 5500 MJ metabolisable energy of feed consumed annually [27]. ⁴ Fleece testing of 10-month-old Merino–Romney crossbred ewe lambs during transition.

Merino–Romney crossbred ram and ewe lambs sold post- $Sort_w$ were all sold prime once at the target carcass weight of 17.87 kg, with timing dependent on their growth rates. Lamb growth rates were determined by breed and birth rank (i.e., 1/2M1/2R lambs had higher growth rates than 3/4M1/4R lambs and single-born lambs had higher growth rates than lambs born as multiples; Table 2) and growth rates dictated lamb sale timings, with all prime lamb prices taken from the same schedule price data (Table 4). Merino–Romney lambs sold after $Sort_w$ were all sold prime due to the lower feed demand of the crossbred ewe flocks (with lower liveweights than the Romney ewes) allowing for more feed to support lamb growth. Prices assumed for Merino–Romney cull ewes and ten-month-old ewe lambs sold after $Sort_{10}$ were based on industry prices for Romney ewes [2] with proportionate price reductions to the lower liveweights of 1/2M1/2R and 3/4M1/4R ewes (Table 2).

Since the 2017/18 production year modelled, prices received by New Zealand farmers for sheep sales have increased [2]. For example, lamb prices from the same sources with the same timings for the farm type under study were approximately 10% higher in the 2019/20 production year compared with the 2017/18 year prices used as a base in this study (Table 4; [2]). Reductions in lamb production during the transition and post-transition are a potential disadvantage of undertaking the modelled grading up transition to a $\frac{3}{4}$ M $\frac{1}{4}$ R flock [4,5]. Therefore, sheep sale prices were changed by $\pm 10\%$ in a sensitivity analysis to investigate the effect of these potential higher and lower sheep sale values on profit and the relative economic benefit of the transition compared to maintenance of the base Romney flock.

2.4.2. Wool Prices

Prices for wool of various fibre diameters were obtained from industry sources on a per kg clean basis [28,29]. The prices were transformed to a farmgate price assuming a fleece yield of 75.3% (Table 2) and discounts of 10.7% for the 25% of the fleece which was skirtings [28,30]. The resulting farmgate prices for wool of varying fibre diameter used in this analysis are shown in Figure 2 and these prices were applied to all wool sold pre-, during, and post-transition.

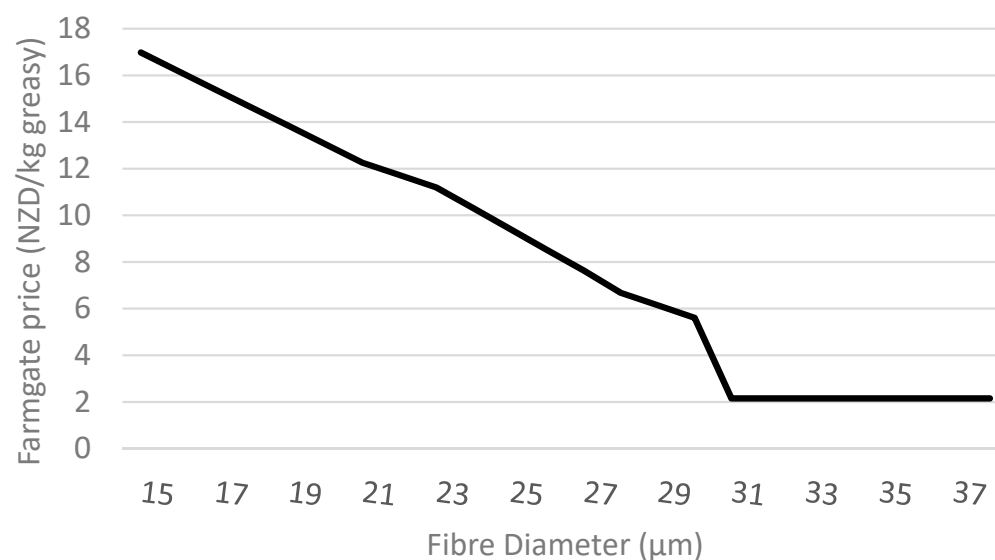


Figure 2. Farmgate wool prices in 2017/18 for various fibre diameters used in this analysis. Reprinted with permission from ref. [5]. 2021 Elsevier.

Prices for wool of medium fibre diameter would be a key factor in the decision making of farmers considering a grading up transition from Romney to $\frac{3}{4}$ M $\frac{1}{4}$ R. Wool prices fluctuate between years by amounts in excess of $\pm 10\%$ [5] and such changes would affect the relative profitability of undertaking the transition. Therefore, as part of a sensitivity analysis in this study, prices for wool of all fibre diameters was modelled at the base prices in Figure 2 and also separately at both 10% higher and lower.

2.4.3. Expenses

Sheep enterprise operating, animal health, and shearing expenses were assumed to be consistent between breeds on a per stock unit basis as shown in Table 4 [2]. Disposal of dead sheep was handled on-farm without incurring additional costs. Rams of all breeds used in the modelled transition (Romney, Merino, and Merino–Romney crossbred) were assumed not to differ in cost per stock unit, and breeding costs were included in operating expenses.

2.4.4. Net Present Value

For analysis of modelled transition scenarios as alternative options for investment, net present value (NPV) analyses were conducted (Equation (2) [31]). The NPVs captured the time value of cashflow during transition, allowing for the valuation of timings of peak and nadir COS as they differed for modelled scenarios. Estimations of NPVs were conducted for the status quo Romney flock and each transition scenario separately for 14 years which included the total time taken for the transition to the final $\frac{3}{4}M\frac{1}{4}R$ flock size. Numbers of ewes in each age class of the $\frac{3}{4}M\frac{1}{4}R$ flock changed until approximately 30 years from transition start, which affected flock production (Table 2) and COS. Thus NPV analyses were also conducted for 30 years.

$$NPV = \sum_{t=1}^{14 \text{ or } 30} \frac{\text{Total } COS_t}{(1+r)^t} \quad (2)$$

where *Total COS* was estimated on an annual basis according to Equation (1), t = each year included in the analysis (14 or 30 years), and r = the discount rate. Discount rates used in the analysis were 6% to represent 2017/18 interest rates [32] or 10% to reflect long-term New Zealand business lending interest rates [33]. Economic values were all in real 2017/18 terms in this analysis with discount rates representing opportunity costs in real terms for farmers investing in the modelled breed transition strategies.

2.5. The Post-Transition $\frac{3}{4}Merino\frac{1}{4}Romney$ Flock

The grading up transition was considered complete once the $\frac{3}{4}M\frac{1}{4}R$ flock reached a size with total annual feed demand similar to that of the base Romney flock. The $\frac{3}{4}M\frac{1}{4}R$ flock was then modelled as self-replacing. The culling rate was increased to 20% (Table 3) to model a typical New Zealand flock replacement rate of 25%. Production of ewes in the $\frac{3}{4}M\frac{1}{4}R$ flock is specified in Table 2.

3. Results

Model output for the grading up transition for sheep feed demand (constrained between 55% and 65% of farm feed supply), ewe numbers, production, and economics is presented in the following subsections. Output is presented for the pre-transition base Romney flock in year zero, then during transition when crossbreeding occurred, and then post-transition after the $\frac{3}{4}M\frac{1}{4}R$ flock had achieved an annual feed demand similar to that of the base Romney flock. Output is presented for the $\frac{3}{4}M\frac{1}{4}R$ flock post-transition flock until 30 years after the transition start. The $\frac{3}{4}M\frac{1}{4}R$ flock age structure continued to change post-transition, affecting lamb and wool production which influenced profit. At 30 years after the transition start, changes in numbers of ewes in each age class between years were small, i.e., changed by less than 5%.

3.1. Ewe Numbers

The base Romney flock consisted of 2490 ewes and the $\frac{3}{4}M\frac{1}{4}R$ post-transition consisted of 2871 ewes (Figure 3). From the base level of 2490 ewes, the Romney ewe flock decreased in size during transition as ewes left the flock due to death and culling without replacement, then all remaining 384 Romney ewes were culled in year six of transition (Figure 3). The $\frac{1}{2}M\frac{1}{2}R$ flock size increased to a peak of 1828 ewes in year five of transition while Romney ewes were on-farm producing $\frac{1}{2}M\frac{1}{2}R$ lambs, then their numbers declined until all remaining $\frac{1}{2}M\frac{1}{2}R$ ewes were culled in year ten of the transition. Numbers of $\frac{3}{4}M\frac{1}{4}R$ ewes grew until the desired flock size of 2871 ewes was reached, with the same approximate feed demand as the base Romney flock. At a $\frac{3}{4}M\frac{1}{4}R$ flock size of 2871 ewes the transition was considered to be complete, occurring after 12 years.

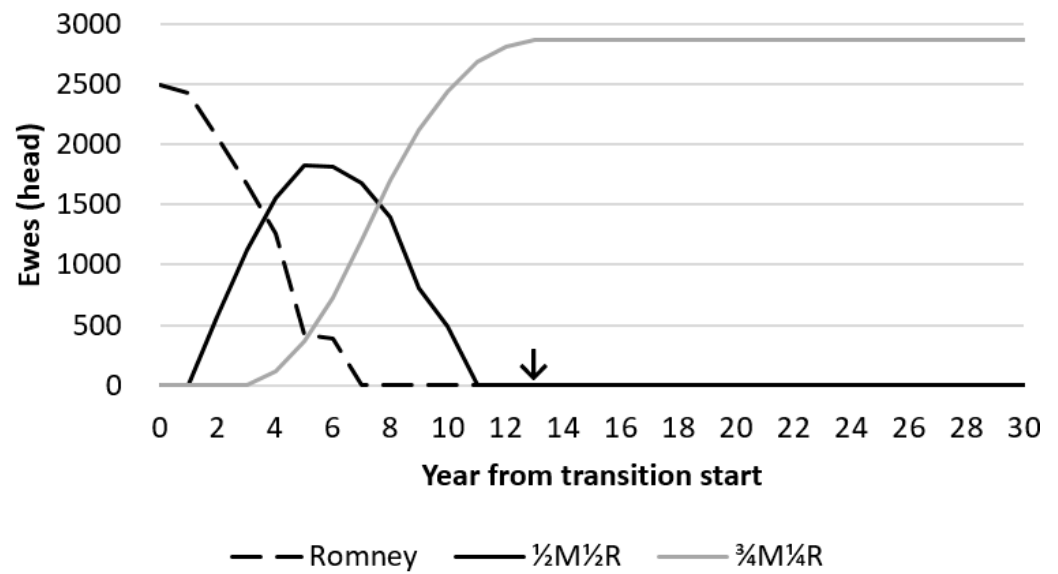


Figure 3. Numbers of Romney, 1/2Merino1/2Romney, and 3/4Merino1/4Romney ewes during a grading up transition. ↓ indicates where the 3/4Merino1/4Romney flock has reached the same annual feed demand as the base Romney flock.

3.2. Feed Demand

Total annual sheep feed demand first decreased, from a base level of 60% of total farm feed supply (with the remainder consumed by the on-farm beef herd) to a nadir of 56% in year two of the transition as the Romney flock decreased in size (Figure 4). Sheep feed demand peaked at 64% in year eight of transition and was 61% once the transition was complete in year 13. Once the transition was complete there was some fluctuation in feed demand until it stabilised from approximately year 21 onwards.

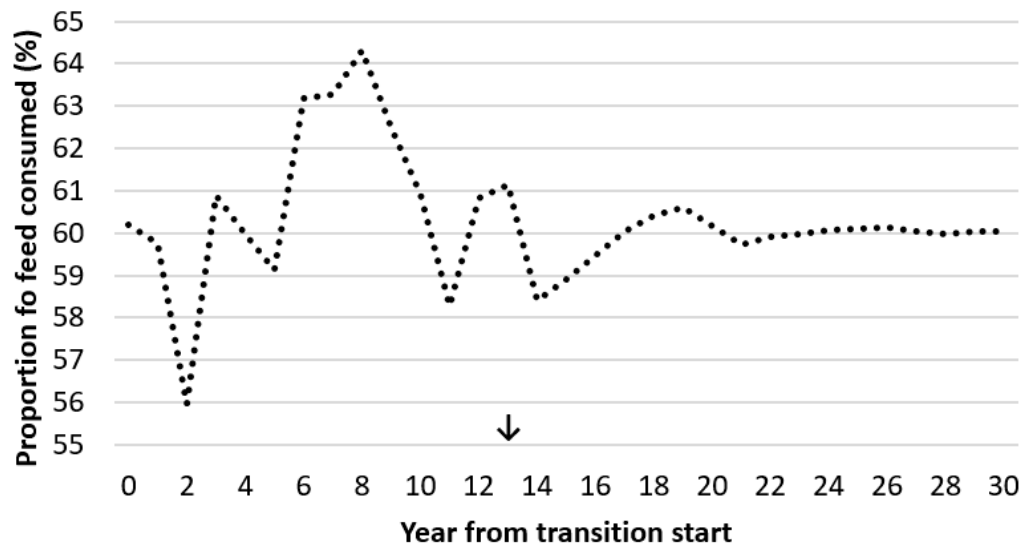


Figure 4. Total annual sheep feed demand as a proportion of farm feed supply during a grading up transition. Annual sheep feed demand was constrained between 55% and 65% of total farm feed supply, from a base level of 60% typical of East Coast North Island hill country farms [2]. ↓ indicates where the 3/4Merino1/4Romney flock has reached the same annual feed demand as the base Romney flock.

3.3. Production

Total wool production decreased during the transition from the base Romney level of 15,252 kg, and was 10,811 kg once the $\frac{3}{4}M\frac{1}{4}R$ flock had stabilised post-transition (Figure 5). There were 2930 Romney lambs weaned by the pre-transition base Romney flock. Numbers of weaned lambs decreased overall during the transition but were higher than the base Romney production level during years four, six, and eight of transition. Numbers of lambs sold followed the same general pattern as numbers of lambs weaned during the transition, with the difference being ewe lambs kept to enter the ewe flocks (ranging from 471 to 841 during transition). Once the $\frac{3}{4}M\frac{1}{4}R$ flock had stabilised there were 2461 lambs weaned annually with 682 ewe lambs not sold and kept for flock replacement.

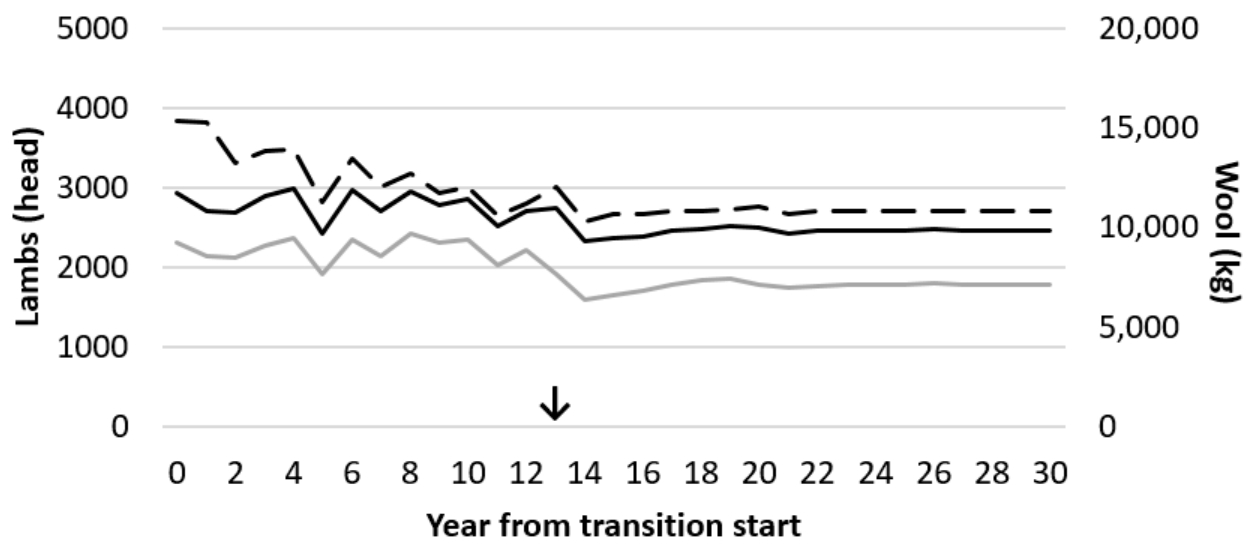


Figure 5. Numbers of lambs weaned, lambs sold, and wool sold (right hand side y axis) during a grading up transition. ↓ indicates where the $\frac{3}{4}M\frac{1}{4}R$ flock has reached the same annual feed demand as the base Romney flock.

3.4. Economics

The base Romney flock had a sheep enterprise COS of NZD 390/ha and COS was fluctuating higher and lower than the base value at various time points during the transition (Figure 6). There were peaks in COS and income in years one, four, six, eight, ten, and 14 of transition. Three of these peaks in COS were above the NZD 516/ha COS of the stabilised post-transition $\frac{3}{4}M\frac{1}{4}R$ flock, which was itself 32% higher than the base Romney flock. Total sheep enterprise expenses had much smaller fluctuations during and post-transition, from a base Romney level of NZD 184,000 and stabilising at approximately NZD 200,000 for the post-transition $\frac{3}{4}M\frac{1}{4}R$ flock.

Net Present Value

The highest overall NPV was estimated when sheep and wool sale prices were both increased from the base level, at NZD 4,003,641 (Table 5). The lowest overall NPV was estimated to occur when both sheep and wool sale prices reduced from the base level, at NZD 1,446,172. The NPVs of the transition scenarios were always higher than that of their respective Romney scenarios, with either discount rate used, either time period analysed, and any sheep sale or wool price modelled. With base 2017/18 sheep sale and wool prices, the scale of the increase (benefit) in NPV that the transition scenarios had over the Romney scenarios varied from 8.38% to 12.86%. The lowest benefit over the Romney flock NPV (NZD 1,886,994) was predicted with higher sheep sale prices and lower wool prices (sensitivity analysis) and a 10% discount rate over 14 years, at NZD 1,992,763 (3.18% higher than Romney). The greatest benefit over the Romney flock NPV (NZD 2,732,111) was predicted with lower sheep sale prices and higher wool prices (sensitivity analysis),

with a 6% discount rate analysed over 30 years, at NZD 3,223,131 (17.97% higher than Romney). For a given discount rate and time period, the benefit in NPV of the transition over the Romney flock was greatest with lower sheep sale prices and higher wool prices and the benefit was smallest with the inverse sensitivity analysis (higher sheep sale prices and lower wool prices).

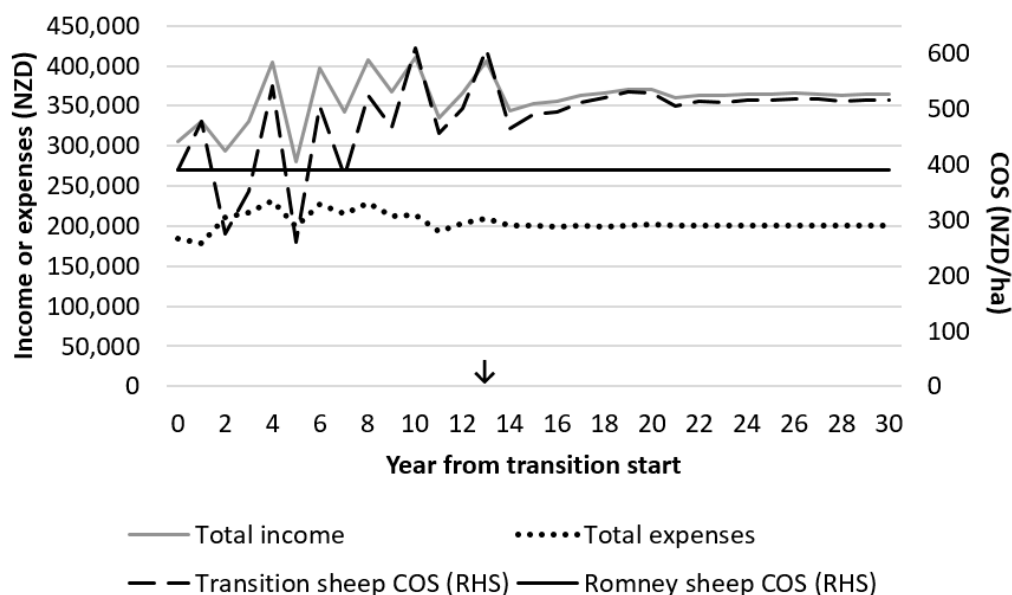


Figure 6. Sheep enterprise income, expenses, and cash operating surplus (COS on the right hand side y axis) during a grading up transition. Sheep enterprise COS (on the right hand side y axis) from the original Romney flock is also displayed. ↓ indicates where the 3/4Merino1/4Romney flock has reached the same annual feed demand as the base Romney flock.

Table 5. Net present values of modelled scenarios of maintenance of the status quo Romney flock with the change (%) in NPV for a whole flock grading up transition to 3/4Merino1/4Romney. Sheep and wool sale prices were either at a base 2017/18 level, or changed by ± 10% in a sensitivity analysis. Net present value analyses were conducted over 14 (transition period) and 30 years (time taken to reach stable ewe numbers in the 3/4M1/4R flock). Discount rates of 6% and 10% were used to reflect 2017/18 and long-term New Zealand lending interest rates, respectively [32,33].

Sheep Prices	Wool Prices	Scenario	6% Discount Rate		10% Discount Rate	
			14 Years	30 Years	14 Years	30 Years
Base	Base	Romney Transition	2,151,176 9.60	3,085,167 12.86	1,748,251 8.38	2,178,743 10.72
+10%	Base	Romney Transition	2,326,748 8.39	3,486,771 11.05	1,913,638 7.35	2,462,355 9.27
−10%	Base	Romney Transition	1,790,762 11.17	2,683,564 15.21	1,472,816 9.72	1,895,131 12.61
Base	+10%	Romney Transition	2,091,151 11.65	3,133,714 15.31	1,719,871 10.24	2,213,027 12.88
Base	−10%	Romney Transition	2,026,360 7.48	3,036,620 10.33	1,666,583 6.46	2,144,459 8.49
+10%	+10%	Romney Transition	2,359,144 10.23	3,535,317 13.25	1,940,282 9.02	2,496,639 11.02

Table 5. Cont.

Sheep Prices	Wool Prices	Scenario	6% Discount Rate		10% Discount Rate	
			14 Years	30 Years	14 Years	30 Years
−10%	−10%	Romney	1,758,367	2,635,017	1,446,172	1,860,847
		Transition	8.76	12.34	7.53	10.08
−10%	+10%	Romney	1,823,158	2,732,111	1,499,459	1,929,415
		Transition	13.50	17.97	11.83	15.05
+10%	−10%	Romney	2,294,353	3,438,224	1,886,994	2,428,072
		Transition	3.89	6.62	3.18	5.08

4. Discussion

The post-transition flock was required to have the same approximate annual feed demand (approximately 60% of total farm feed supply; Figure 4) as the base Romney flock, and this was possible with 381 more ewes (Figure 3) due to the lower size (live weight) and productivity per $\frac{3}{4}M\frac{1}{4}R$ ewe, resulting in a lower feed demand per head [34]. These results suggest farmers undergoing a similar transition to $\frac{3}{4}M\frac{1}{4}R$ ewes can expect to farm a larger flock of ewes producing fewer weaned lambs post-transition. Ewe numbers peaked in year eight of the transition, at 3093 total ewes (Figure 3), and this was also when annual sheep feed demand peaked at 64% of total farm feed supply (Figure 4), which was within the range allowed. In previous modelling of the same grading up transition with the same crossbred ewe lamb selection intensity, sheep feed demand was not constrained and peaked at 75% [4], and was even higher with a lower selection intensity applied to crossbred ewe lambs. It can be assumed that constraining sheep feed demand during the transition would reduce disruption to the other on-farm enterprises such as the beef herd, which is important for pasture management [34] and diversification of income sources, indicating the transition modelled in the current analysis is likely more appealing and achievable for New Zealand farmers. Further, with constrained feed demand, the grading up transition scenario presented here, would also be more realistic for other international sheep production systems that do not have the ability to reduce on-farm beef stock numbers to mitigate sheep feed demand.

A similar transition process to $\frac{3}{4}M\frac{1}{4}R$, without the restriction on sheep feed demand, was modelled by [4] and the transition in that study was completed after ten years of crossbreeding compared with 12 years in the current analysis. Therefore, in the current study, the timing of the culling of all remaining Romney and $\frac{1}{2}M\frac{1}{2}R$ ewes and the timing of the transition period being complete, both occurred later compared to the scenario modelled by [4]. In the current analysis total sheep feed demand was constrained through variation in ewe culling rates, so numbers of ewes could not increase during the transition to the levels modelled by [4] and the final flock size of 2871 $\frac{3}{4}M\frac{1}{4}R$ ewes was achieved two years later. Therefore, an additional two years of transition appears to be the trade-off of constraining sheep feed demand between 55% and 65% of farm feed supply as modelled in this analysis, but constraining feed is likely more representative of actual farm management practices. The reduced disruption to the whole farm system due to constraining feed for the ewe flock, resulting in minimally affected beef enterprise operations, is likely more appealing to farmers. However, during these additional two years a continued focus is required on producing $\frac{3}{4}M\frac{1}{4}R$ lambs and selection for lower fibre diameter, which may require the farmer to forgo opportunities such as breeding terminal sires with a proportion of ewes for increased lamb production. Modelling of the transition to produce higher value wool in this analysis and by [4] both assumed culling rates of ewes during the transition to be minimal, in order to increase $\frac{3}{4}M\frac{1}{4}R$ ewe numbers quickly, using a minimum culling rate of 4% (Table 3) based on a typical New Zealand flock barren rate [18]. However, farmers may need to cull for additional reasons during the transition, such for health issues, which would potentially increase the time taken to complete the transition.

The production of lambs and wool by the $\frac{3}{4}M\frac{1}{4}R$ flock was lower than that of the base Romney flock (Figure 5), despite the $\frac{3}{4}M\frac{1}{4}R$ flock having higher ewe numbers (Figure 3) and a similar annual feed demand (Figure 4). This lower flock lamb production reflects the lower per head reproductive rate assumed (Table 2) and suggests the modelled $\frac{3}{4}M\frac{1}{4}R$ flock would use a greater proportion of the total feed for flock maintenance than lamb production, compared to the base Romney flock.

The published data which informed assumptions of Merino–Romney crossbred production were mostly from animals which were likely benefitting from hybrid vigour. In this analysis their production was consistent across the transition period and post-transition, while in reality during transition the crossbred animals may have higher production than the $\frac{3}{4}M\frac{1}{4}R$ flock, which would be a further benefit of transition. There is currently insufficient published data, on which assumptions around the effect of any hybrid vigour could be based. However, a potential drop in production post-transition should also be noted when considering this grading up transition.

Economics

Total annual income was greater for the $\frac{3}{4}M\frac{1}{4}R$ flock compared with the base Romney flock, with relatively smaller increases in expenses resulting in a higher COS. The higher COS of the $\frac{3}{4}M\frac{1}{4}R$ flock compared with the base Romney flock was not unexpected as it agrees with the findings of [5] and [35] that a transition to a medium wool producing flock was more profitable. Although there were fewer lambs produced by the $\frac{3}{4}M\frac{1}{4}R$ flock, they were sold prime and therefore at a higher per head price than Romney lambs. Further, although the $\frac{3}{4}M\frac{1}{4}R$ flock produced less wool than the Romney flock on both a per head and whole flock basis (Table 2 and Figure 5), the price received for wool produced by the $\frac{3}{4}M\frac{1}{4}R$ flock was higher (NZD 10.31/kg greasy) than the price for coarse wool produced by the Romney flock (NZD 2.15/kg greasy). The variation in COS for the grading up transition suggest farmers would have some years during the early years of transition with lower profit than their pre-transition level, though long term the transition would be more profitable than maintaining a purebred Romney flock.

With higher sheep sale prices (sensitivity analysis), NPVs increased across wool prices, discount rates, and time periods for both scenarios, although the increase was greater for the Romney flock due to its greater lamb production (Table 5). Higher sheep sale prices reduced the relative difference in NPV between the transition and Romney scenarios, for a given discount rate and time period. For NPVs estimated over 30 years with a discount rate of 6% and base wool prices, the NPV of the transition scenario was 13% higher than the respective Romney scenario NPV with the base 2017/18 prices and was then only 11% higher with higher sheep sale prices (sensitivity analysis). Conversely, with lower sheep sale prices and base wool prices (sensitivity analysis), the gap between Romney and transition NPVs widened (to be up to 15% higher), with the transition to $\frac{3}{4}M\frac{1}{4}R$ having a larger economic benefit over Romney as the value of medium wool relative to sheep meat increased. Changes in wool prices (sensitivity analysis) had the inverse effect, where increases in the relative value of wool over sheep sales increased the economic benefit of transition over the Romney flock due to wool sales constituting a larger proportion of total income for the $\frac{3}{4}M\frac{1}{4}R$ ewe flock. Reductions in the relative value of wool compared with sheep sales thus decreased the economic benefit of transition. These results suggest that the economic benefit of the grading up transition, although always more profitable than maintenance of the Romney flock, will be affected by changes in the relative values of sheep and wool sales. The majority of sheep meat and wool produced by New Zealand farmers is exported and so the prices they receive are driven by changes in global market conditions and the value of \$ NZD, with price fluctuations between years of $\pm 10\%$ not unusual [2].

The transition had a 12.86% economic benefit over the Romney flock, when the NPVs were compared, with base 2017/18 sheep and wool sale prices and analysed over a 30-year period with a discount rate of 6% (Table 5). In a similar scenario previously modelled

with the same crossbred ewe lamb selection intensity, crossbred lambing rates, and NPV discount rate and time period, the transition took 10 years and had a 13% higher NPV than the Romney flock [5]. Therefore, with constrained sheep feed demand in the current analysis, the transition a similar benefit over the Romney flock but took two years longer than the scenario with unconstrained feed demand [5]. Both [5] and [35] have identified a longer transition period to be more profitable for a whole flock grading up transition from Romney to $\frac{3}{4}M\frac{1}{4}R$. Results from modelling by [5] suggested the economic benefit of a longer transition was driven by the higher crossbred ewe lamb selection intensity used which resulted in finer, higher value wool for the $\frac{3}{4}M\frac{1}{4}R$ flock. The current analysis used this same selection intensity (35% of crossbred ewe lambs not retained at each of two annual selection events during the transition) to produce wool of the same fibre diameter as [5] during the transition. Therefore, the similar economic benefit over the Romney flock indicates the same overall profitability of transition can be achieved by having a longer transition period with smaller fluctuations in cashflow and stock numbers. During the transition modelled by [5], COS rose as high as NZD 1060/ha and fell as low as NZD 263/ha, from a base level of NZD 390/ha. In the current analysis, from the same base level, COS rose as high as NZD 609/ha and fell as low as NZD 260/ha during transition. There were fewer years during the transition with COS lower than the base Romney level in the current analysis, compared with [5], and the difference between the transition COS and Romney COS were generally smaller during these years, compared with modelling by [5]. The transition scenario modelled in the current analysis had constrained feed demand, reducing disruptions to the overall farm system and fewer years with reduced cashflow, with an overall economic benefit compared with the Romney flock.

5. Conclusions

Sheep feed demand was able to be maintained at a relatively stable level during the transition through varying ewe culling rates, with the transition completed after 12 years. The increase in income from producing higher value wool resulted in greater COS (cash operating surplus) for the post-transition $\frac{3}{4}M\frac{1}{4}R$ flock (NZD 516/ha) compared with the base Romney flock (NZD 390/ha), resulting in an NPV (net present value) of transition up to 13% greater than maintenance of the Romney flock. The difference in NPV of transition compared to the Romney flock was reduced (NPV of transition up to 11% greater) when sheep sale prices increased by 10% and increased (NPV of transition up to 15% greater) when wool sale prices were 10% higher. The results of this analysis suggest that a whole flock grading up transition from Romney to $\frac{3}{4}M\frac{1}{4}R$ to produce higher value wool can be undertaken without large changes in sheep feed demand and with a 13% greater NPV compared with maintenance of the base Romney flock.

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