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Agent-Based Modelling to Improve Beef Production from Dairy Cattle: Young Beef Production

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Abstract: Approximately 42% of the total calves born in New Zealand's dairy industry are either euthanized on farms or commercially slaughtered as so-called bobby calves within 2 weeks of age. These practices have perceived ethical issues and are considered a waste of resources because these calves could be grown on and processed for beef. Young beef cattle harvested between 8 and 12 months of age would represent a new class of beef production for New Zealand and would allow for a greater number of calves to be utilized for beef production, reducing bobby calf numbers in New Zealand. However, the acceptance of such a system in competition with existing sheep and beef cattle production systems is unknown. Therefore, the current study employed an agent-based model (ABM) developed for dairy-origin beef cattle production systems to understand price levers that might influence the acceptance of young beef production systems on sheep and beef cattle farms in New Zealand. The agents of the model were the rearer, finisher, and processor. Rearers bought in 4-days old dairy-origin calves and weaned them at approximately 100 kg live weight before selling them to finishers. Finishers managed the young beef cattle until they were between 8 and 12 months of age in contrast to 20 to 30 months for traditional beef cattle. Processing young beef cattle in existing beef production systems without any price premium only led to an additional 5% of cattle being utilized compared to the traditional beef cattle production system in New Zealand. This increased another 2% when both weaner cattle and young beef were sold at a price premium of 10%. In this scenario, Holstein Friesian young bull contributed more than 65% of total young beef cattle. Further premium prices for young beef cattle production systems increased the proportion of young beef cattle (mainly as young bull beef), however, there was a decrease in the total number of dairy-origin cattle processed, for the given feed supply, compared to the 10% premium price. Further studies are required to identify price levers and other alternative young beef production systems to increase the number of young beef cattle as well the total number of dairy-origin beef cattle for beef on sheep and beef cattle farms. Some potential options for investigation are meat quality, retailer and consumer perspectives, and whether dairy farmers may have to pay calf rearers to utilize calves with lower growth potential.

Keywords: agent-based model; dairy cattle; young beef; price lever

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1. Introduction

Dairy-origin calves contribute significantly to beef finishing systems [1–4], accounting for more than 58% of the beef cattle finished annually on sheep and beef cattle farms in New Zealand [4,5], and over 60, 80 and 87% total beef processed from Ireland [6], Finland [7], and Russia [8] respectively. Holstein–Friesian (33.1%), Jersey (8.6%), and Holstein–Friesian–Jersey crosses (48.5%) represent most dairy cows in New Zealand [9,10].

From these cows, approximately 20% of calves born on New Zealand dairy farms are beef–dairy cross-bred, which are subsequently finished for beef on sheep and beef cattle farms [11]. Early-born and heavier beef-dairy cross calves are preferred for finishing as prime heifer or steer as they grow faster and attain better conformation than their dairy breed counterparts [12–14]. Well-marked, and therefore supposedly predominantly Holstein–Friesian bull calves, are favored in New Zealand for bull-beef production [15–19].

Dairy-origin calves which are not required for dairy heifer replacements nor beef finishing have traditionally been disposed of as bobby calves [20,21]. These include calves born to Jersey cows, calves from cows not suitable for breeding dairy herd replacements, calves born to first-calving heifers, or calves born to late-calving cows. Bobby calves in New Zealand are defined as calves that are commercially slaughtered within 2 weeks of age [21–23]. In 2020, New Zealand processed approximately 1.9 million bobby calves from the dairy industry [2]. Commercial slaughtering of excess calves from the dairy industry is also common in EU countries [24] and Australia [14]. Transporting and slaughtering these calves is fraught with welfare and ethical issues which can be considered a potential threat to New Zealand dairy and beef trading in the form of non-tariff barriers [23,25,26]. Furthermore, there are concerns due to there being a high prevalence of E.coli with the processing of calves [27], and concerns of dehydration in bobby calves prior to processing [20]. Bobby calf production is also considered a waste of animal resources, as these animals could be utilized for beef production if slaughtered at an older age [20,21,28]. To provide options for the utilization of surplus calves born on dairy farms, systems of young beef cattle production have been proposed to increase the number of dairy-origin cattle finished for beef [28–32] while accounting for a fixed quantity of grazing land.

Some studies on carcass and meat qualities of young beef [29,31,32] and profitability and pasture utilization of young beef cattle production at the farm level [28,30] have been conducted in New Zealand. However, as a new potential class of beef finishing, its acceptance level in the existing New Zealand beef cattle finishing system is unknown. Therefore, this study utilized Agent-Based Modelling (ABM) to represent young beef cattle production systems that would finish dairy-origin calves for beef before their first winter (i.e., 8 to 12 months of age) in a New Zealand context. Agent-based modeling allows for repetitive and competitive interactions between agents which enables the exploration of dynamics over time and captures the adaptive and emergent phenomenon from the interaction [33–36]. A base ABM model for dairy-origin beef finishing using rearer, finisher, and processor agents, accounting for the specifics of dairy-origin beef cattle has been developed [37]. This was modified in the current study to understand the influence of cattle sale prices on the uptake of young beef cattle on sheep and beef cattle farms. The present study modeled unselected dairy-origin calves as identified in the previous study [37] for beef production slaughtered at either 8, 10, or 12 months with a weaner cattle and manufacturing beef price of NZ$4.50 per kg carcass. It was hypothesized that an increase in price would increase the number of calves selected for young beef cattle finishing systems, enabling a greater number of dairy-origin beef cattle to be finished for a given feed supply. Premiums of 10 or 20% both for weaner cattle and young beef were modeled in comparison to the current calf price and also in comparison to a scenario where rearers were provided with calves for free from dairy farms which is a possible scenario if there was a mandate for calves from dairy farms to be reared.

2. Materials and Methods

2.1. Agent-Based Modeling Development

In New Zealand, sheep and beef cattle finishing farms' pasture provides up to 95% of the diet [17,38,39]. In dairy-origin beef cattle finishing, calf producers, rearers, finishers, and processors influence each other in determining the type and number of cattle that move along the supply chain from the dairy industry to the beef industry. The interactions between rearers, finishers, and processors for weaning and finishing dairy-origin beef cattle on New Zealand beef cattle and sheep farms were modeled using "Agents.jl" [37,40] which is a Julia framework for ABM. A base ABM model for dairy-origin beef cattle finishing had previously been developed [37] and is briefly described below.

2.2. The Base Model

The number of 4-day-old, spring-born calves, available on a daily basis was assumed to follow a Poisson distribution based on the date of birth [41] over a three-month, Spring-calving period. A multivariate, normal distribution function applied to the Cholesky decomposition of the assumed variance-covariance matrix [42] was employed to simulate a positively correlated birth weight, growth rate, and price for each calf [43]. Calves with a likely higher marginal return (due to being heavier and likely to be faster growing, i.e., Holstein–Friesians and Holstein–Friesian–Jersey crossbreds were finished via the existing beef cattle finishing systems on sheep and beef cattle farms, and the remainder were processed as bobby calves.

The rearer, finisher, and processing agents simultaneously and repetitively, interacted with each other to determine the number and type of dairy-origin cattle moving along the supply chain. Rearers preferentially brought 4-day-old calves that were heavier and had the potential for faster growth and managed them until weaning at approximately 100 kg live weight, before on-selling to a finisher. If the rearing capability of the rearers (i.e., the number of calves they could successfully rear) was higher than the demand for weaned calves by finishers, they subsequently reduced their rearing capability to balance the demand for weaners by the finishers. Finishers primarily bought weaners from rearers, however, if the weaner supply from rearers was insufficient relative to their finishing capability, they sourced more weaners directly from dairy farms. Increased demand for weaner calves encouraged dairy farmers to rear more calves along with their own replacement heifer calves [44].

2.3. Agent-Based Modelling for Young-Beef Cattle Production: Price Levers on Adoption

The model was parameterized with 45,000 spring-born calves, representing 1% of the total calves produced annually on dairy farms in New Zealand, the same as was used in the previously published base model for traditional dairy-origin beef cattle finishing systems [37]. Unlike the base model, the current study fitted the growth curve of beef cattle for young and traditional beef production using seasonally adjusted von Bertalanffy growth equations [45]. This allows animals to grow faster during spring and gain less live weight change during winter to match the feed supply in pasture-based systems [28].

Unselected calves, which were comparatively slower-growing and lighter, were modeled to determine whether they could be finished at the ages of 8, 10, or 12 months for young beef. In New Zealand, pasture supply is typically highest in spring and lowest in winter. Young beef cattle finishing would allow finishers to start in Spring with a higher number of beef cattle including traditional and young beef cattle and then progressively harvest animals prior to the winter from 8 months of age to ensure feed demand equaled feed supply as pasture growth declines over the winter period. Slaughter started in May, with those approximately 8-month-old young beef cattle that were heaviest, and was completed with the harvesting of young cattle at approximately 12 months of age by August, freeing up pasture demand for the next crop of animals.

Energy requirements for maintenance and live weight gain for traditional and young beef cattle were estimated using values from [46,47]. Calves were sold from dairy farms to rearers at 4-days of age from NZ$70 to 120 per head and weaner cattle were sold to finishers from NZ$3.00 to 4.50 per kg live weight, based on values reported in [43,44] (Table 1). Carcass weights from 8–10-month old beef cattle were estimated as 0.48 times the live weights, increasing to 0.5 times the live weight for 12-month-old beef cattle [29–32]. Young beef was valued at the manufacturing beef price of NZ$4.50 per kg carcass weight [48] plus an additional 10% or 20% premiums applied for both weaner cattle and young beef. Each scenario was also simulated with the calf sale price from the dairy farm set to zero, reflecting dairy farmers giving excess calves to rearers for free which simulates a scenario where mandates for no calf wastage are in place and all excess calves need to be directed to beef production. Calves were provided to commercial rearers to avoid dairy farms bearing the cost burden of additional calf rearing. A total of 30 ABM simulations for each price scenario were conducted [37].

Table 1. Birth weight, minimum weight at slaughter, slaughter age, price per head 4-day old calves, and price per kg live weight weaner cattle parameters of various classes of dairy-origin beef cattle for traditional beef cattle finishing.

Attributes	Holstein–Friesian			Holstein–Friesian–Jersey			[a] Jersey			References
	Heifer	Steer	Bull	Heifer	Steer	Bull	Heifer	Steer	Bull	
[b] Birth weight, kg	36.1	38.2	38.2	31.7	33.9	33.9	27.6	29.8	29.8	[13]
[c] Minimum weight at slaughter (kg)	500	-	550	500	580	550	500	580	550	[49–55]
[d] Adjusted average age at slaughter (d)	610	-	600	679 *	896	805	700 *	920	880 *	[50–52,56]
4-day-old calf price/head (NZ$)	90	-	110	80	100	100	70	90	90	[57,58]
Weaner price/kg live weight (NZ$)	3.70	-	4.50	3.60	3.70	4.00	3.00	3.20	3.20	[57,58]
	Beef–Holstein–Friesian cross			Beef–Holstein–Friesian–Jersey cross			Beef–Jersey cross			
[a] Birth weight, kg	38.3	40.2	40.2	37 *	39 *	39 *	35 *	37 *	37 *	[43,53]
[c] Minimum weight at slaughter (kg)	500	580	550	500	580	550	500	580	550	[49–55]
[d] Adjusted average age at slaughter (d)	561	663	625	579 *	689	640	600 *	750 *	703 *	[50,59]
4-day-old calf price/head (NZ$)	95	120	120	90	110	110	75	95	95	[57,58]
Weaner price/kg live weight (NZ$)	3.90	4.00	4.70	3.60	3.70	4.00	3.00	3.20	3.20	[57,58]

[a] includes the "other breed" category; [b] Male calves' birth weight was 2.2 kg heavier [13]; [c] minimum slaughter weight for young beef cattle was 250 kg; [d] young beef cattle were slaughtered at ages of either 8, 10, or 12 months. * estimated based on the value of other classes and breeds; heifers', steers', and bulls' carcass weights from traditional beef cattle were estimated as 50, 54, and 52% of live weight, respectively [41,42,45].

3. Results

Allowing for the harvest of young beef cattle in the existing beef production systems, without any price premium, led to the finishing of an additional 5% of cattle compared to the traditional beef cattle production system only (Figure 1: existing calf price at 0% premium scenario vs. base model scenario). Of the total beef cattle finished for young beef, young bull beef cattle contributed 79% followed by young steers (12%) and heifers (9%). This modified farming system meets the feed demands of the young cattle by farming 20% fewer traditional beef cattle in total, with the most pronounced reduction being in the numbers of traditional heifer cattle finished for beef (Figure 1: 44% lower than that in the base model).

A price premium of 10% for weaner cattle and for the beef schedule price (Figure 1: existing calf price at 10% premium scenario) resulted in an additional 7% of calves of dairy origin being utilized for beef production compared to the traditional beef cattle finishing system (Figure 1: base model scenario). Further premium prices for young weaner cattle and beef (i.e., 20%), and the provision of free calves from the dairy farm to the rearer, increased the proportion of cattle used for young beef production, in particular, young bull beef cattle. However, in order to source pasture for the young cattle, the system decreased the total number of dairy-origin calves utilized compared to the 10% premium scenario (Figure 1).

Calves born from Holstein–Friesian dams accounted for 60% of total harvested cattle (young and traditional beef cattle). However, calves from Jersey cows contributed less than 2% of total dairy-origin beef breed cattle processed in this study (Table 2). Young bull beef cattle from Holstein–Friesian dams contributed approximately 65% of total young beef cattle processed when a 10% increased price scenario was utilized for weaner cattle and schedule prices for young beef.

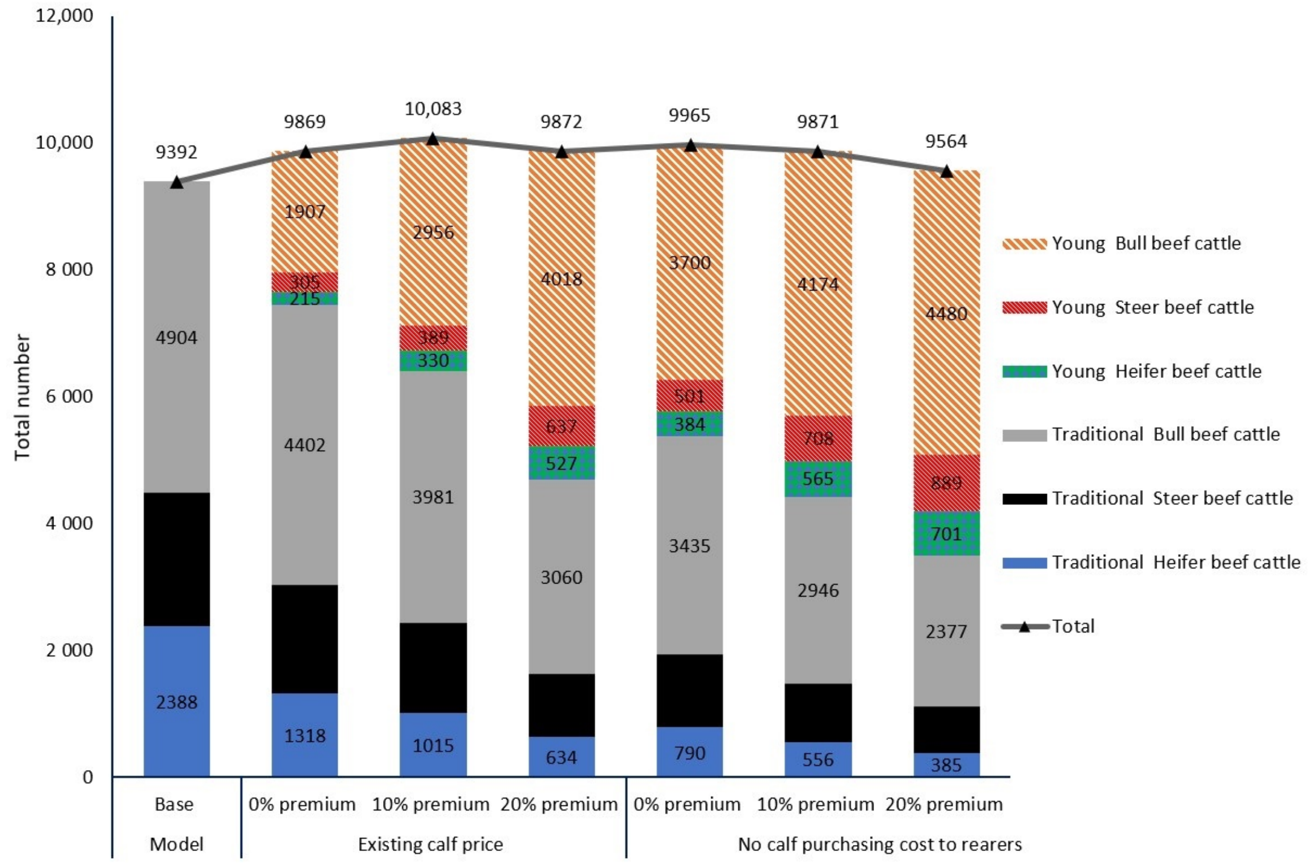

Figure 1. The mean number of traditional beef cattle (i.e., finished 20 to 30 months old) and young beef cattle sold at NZ$4.50 per kg carcass and premiums of 10% and 20% for both weaner cattle and young beef (i.e., finished at 8, 10 or 12-months old) with or without the current calf price for 45,000 modeled calves across 30 ABM simulation runs. 0%, 10%, and 20% premiums were for both weaner cattle and young beef values.

Table 2. Mean number (sd) of traditional beef cattle (finished 20 to 30 months old) and young beef cattle (finished at 8, 10, or 12 months old) at a 10% premium scenario (an existing calf price at 10% premium for both weaner and young beef) per sex and dam breed out of 45,000 modeled calves across 30 ABM simulation runs.

	Heifer				Steer				Bull			
	HF	**HJ**	**Jr**	**Other**	**HF**	**HJ**	**Jr**	**Other**	**HF**	**HJ**	**Jr**	**Other**
Traditional beef cattle	619 (43)	351 (92)	26 (5)	19 (8)	-	1308 (169)	60 (10)	44 (12)	2869 (57)	1046 (103)	33 (4)	33 (10)
Young beef cattle	228 (15)	101 (11)	1 (1)	0	-	371 (17)	16 (4)	2 (1)	2378 (101)	552 (61)	12 (5)	13 (4)

HF: Holstein–Friesian; HJ: Holstein–Friesian–Jersey cross, Jr: Jersey cattle, and others: other dairy breed cattle.

4. Discussion

Dairy-beef animals harvested at a young age (8 to 12 months) represent a new beef production system being considered in New Zealand. It aims to finish as many calves as possible, to reduce the bobby calf slaughter. Understanding the level of acceptance of these systems by existing sheep and beef cattle production farmers who are used to finishing animals at older ages and heavier weights, and recognition of the main constraints associated with their use, would allow farmers and processors to make informed decisions regarding the utility of such systems. The current study simulated the use of dairy-origin heifer, steer, and bull beef cattle slaughtered from 8 to 12 months of age using a previously reported ABM model [37]. It utilized historical average weaner and manufacture beef prices and 10% and 20% premiums on these prices by utilizing current sale prices for calves sold to rearers. The provision of calves to the rearer at no cost was also considered.

Young beef cattle are slaughtered at lighter weights compared to the traditional classes of cattle used for beef production and so, under the current carcass classification and payment system used for beef in New Zealand, the carcasses would be categorized into a manufacturing price of NZ$4.50 per kg carcass weight [3,22]. At that price and with a 4-day-old calf purchasing cost included, a mix of young and traditional beef cattle finishing systems processed an extra 5% of cattle compared to the traditional beef production system (i.e., without young beef cattle). A farm optimization study [28] identified that including young beef cattle in the existing beef finishing system and processing them at NZ$4.50 per kg, the carcass would enable the processing of 5% more beef cattle per farm than the traditional beef cattle finishing system. These relatively low percentage increases in the numbers of cattle indicate that young beef cattle would need to be incentivized to increase the uptake of dairy-origin calves into beef production systems. One such incentive is the price obtained for the carcass. A study conducted by [30] identified that young steers slaughtered at 8 to 12 months would require more than NZ$6.00 to break even with a traditional bull finishing system. This 33% increase in price would require a major change by the processing companies and would be unlikely to happen unless new high-value markets were identified.

Young beef is more tender due to being finished at an earlier age than beef from traditional beef cattle [29] which might enable a premium price over either traditional beef (heifer or steer beef) or processed beef (bull beef). This requires the identification of high-value markets and selling valuable cuts at a higher price to lift the value of the whole carcass. This would increase the profitability of young beef cattle production [60–62] and make the system more attractive for rearers and finishers thereby enabling the processing of more dairy-origin beef cattle for beef to reduce bobby calves numbers.

A 10% increase in the sale price per kg live weight for weaners and per carcass weight for young beef resulted in young beef cattle contributing 7% of the total dairy-origin beef cattle processed. In this scenario, Holstein Friesian young bulls contributed more than 65% of the total young beef cattle. This could be due to Holstein Friesian bull beef cattle across both systems growing faster compared to other sexes and classes [48,63]. Further, a premium of 20% both for weaner cattle and processed young-beef cattle increased the proportion of young beef cattle and the uptake of young bull beef cattle. However, this decreased the total number of cattle processed for beef compared with the 10% premium scenario. This is likely explained by a greater per-head feed requirement for bulls to achieve the target weight which decreases the total number of cattle processed for beef for the given feed supply. Thus, alternative finishing systems that would increase the uptake of slower-growing beef cattle classes would be required to increase the uptake of dairy-origin beef cattle for traditional as well young beef cattle. Alternatively, assisted reproduction techniques or better selection of beef bulls for mating with dairy cows could be used to produce better quality calves from dairy cows [64] which would increase growth rates and on-farm efficiency and the quality of meat from dairy-origin calves [65,66].

The current carcass weight payment system encourages the harvest of those fast-growing cattle that can achieve the highest carcass weights. As more fast-growing young beef cattle entered the modeled system, the per-head demand increased and thus a smaller number of traditional beef cattle would be farmed for the given feed supply. Considering value-based market beef production for slower-growing cattle including Jersey calves would make them more competitive and allow a higher number of beef cattle for the given feed resource. A study by [67] identified that beef-Jersey cross-breed cattle had higher marbling scores which increased carcass value resulting in higher value carcasses than from pure Jersey cattle.

Dairy-origin beef cattle produce 29% less greenhouse gas emissions (GHG) compared to cow-calf beef production system per kg carcass [4]. This is due to them being a byproduct of cows that provide milk for sale and calves for beef production for the same amount of dry matter consumed. Further, at a younger age (less than 12 months of age), growth is faster and there is less fat in the gain compared to older cattle [63], which would make younger cattle more efficient in terms of feed converting to saleable product [68]. Young beef cattle increased pasture utilization efficiency and reduced silage preparation and utilization [28]. It also processed higher gross carcass output per farm for a given feed supply, which meant they produced lower GHG emissions per kg carcass [68]. This implies young dairy-origin beef cattle production should be considered as a mitigation strategy to reduce GHG emissions from livestock production [69]. Finishing dairy-origin cattle for beef at a young age would have also less impact on the soil compared to heavier animals in wet seasons [4,70]. These positive environmental impacts might allow young beef to attract a higher per kg carcass value driven by consumer demand which would potentially increase the uptake of young beef cattle systems. Identifying markets that would pay extra for ethical and welfare-friendly beef and/or reducing calf selling price at 4-day old would also allow young beef to earn higher value per kg live/carcass weight [71,72].

The current study did not include beef retailer or consumer perspectives. Consumer perspectives associated with meat quality (meat color, tenderness, juiciness, flavor) and extrinsic characteristics (brand, price, labeling, package, and outlet) [73–76] and origin of beef are important factors in determining breed, sex, and class of beef cattle required for beef production and the likely premium that could be achieved for the meat product [77,78]. Considering these parameters in future studies would allow the model to provide full insight into the uses of young beef cattle in New Zealand and other countries where bobby calf production needs to be discontinued.

5. Conclusions

Young beef cattle production systems represent a new beef cattle finishing option in New Zealand, aiming to process a greater number of dairy cattle for beef. This would reduce bobby calf numbers and the associated potential ethical issues and could increase the profitability of both the beef and dairy industries. Utilizing young beef cattle production systems enabled a greater number of beef cattle to be managed on-farm and greater throughput of beef cattle from weaning to slaughter per hectare for a given feed supply. Processing young beef cattle at NZ$4.50 per kg carcass with a 10% premium allowed the system to finish only 5% and 7%, respectively, greater numbers of beef cattle compared to the traditional beef cattle production system. This small increase in uptake suggests further research is required before firm conclusions on the uses of young beef cattle can be made. Some examples include higher premium prices, lower 4-day-old calf costs, alternative finishing systems which encourage the uptake of slower-growing dairy-origin beef cattle, meat quality traits, and retailer and consumer perspectives. Given the minimal use of young beef production of dairy origin in New Zealand, agent-based modeling is a useful tool to examine the efficacy of these options.

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