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Norwegian Dairy Farm and Direct-to-Consumer Cheese Production

Case Study of Harold's Dairy Farm

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Table of Contents

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Problem Introduction

The small-scale dairy farms in Norway are disappearing. According to Statistics Norway, small farm holders are increasingly giving way to large scale agriculture (Statistics Norway, accessed 2023). Since 2000, the number of dairy farm holdings fell *more than 50%*, down to 11,400 in year 2022 from 24,300 in year 2000 (Statistics Norway, accessed 2023). The only farms that managed to increase in numbers were the very largest, 50 hectares or more.

In the midst of this worrying trend lies Harold, a sole owner of an average mountain pasture dairy farm in Norway. His farm is 22 hectares, with 22 cows, from which he obtains raw milk that he sells to the dairy processors such as TINE. His cash saving reserve is gradually dwindling, and he is able to support a decreasing number of cows.

As a lifelong learner and desiring to keep up-to-date with the dairy industry, one day Harold was reading an academic paper by Asheim et al (2014) that stated that processing raw milk into cheese can earn him up to double what he gets from just selling milk. So, he tried starting a small-scale cheesemaking operation and compared it to his business-as-usual practice (Figure 1).

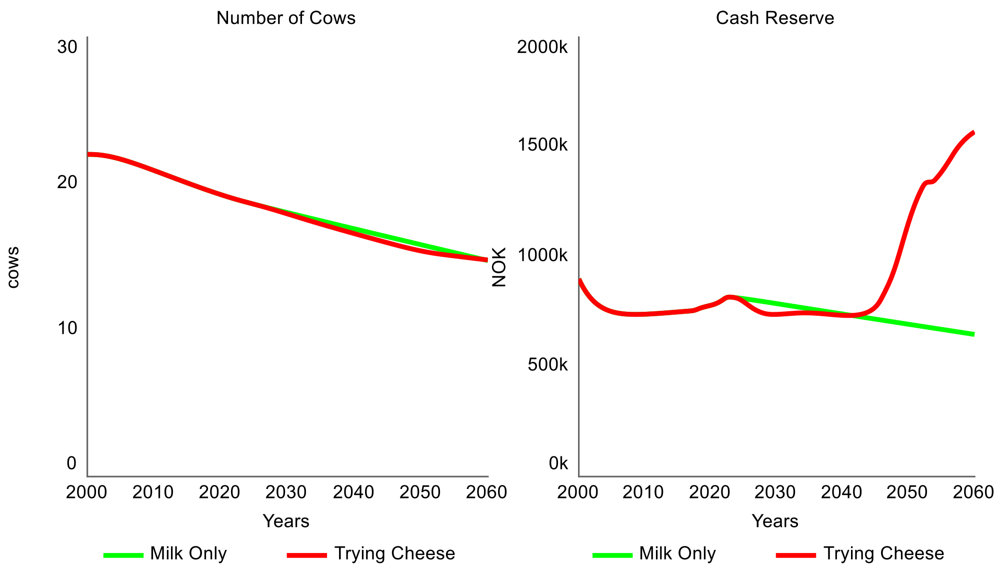

Figure 1: Number of cows and cash reserve for baseline scenario with milk sales only, and trying cheesemaking

The paper was actually correct, Harold is able to accumulate a nice cash reserve saving, but it does not seem to translate to a bigger cow herd population, which he considered a very important farm key performance indicator (KPI). But he sees promising results in diversifying revenue stream and wants to investigate more into difference management strategies that could translate to better success.

Harold contacted a local university, University of Bergen, and asked whether a System Dynamics analysis could be constructed to analyze his challenges. What cheesemaking strategy can help Harold's dairy pasture farm escape the steady decline? Luckily, there was an ongoing course, SD304, where students were hungry for interesting case studies. The following is the documented System Dynamics work that was done on behalf of Harold's dairy farm business.

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Model Description

The overview of the proposed model structure is presented in the *causal loop diagram* (CLD) below in Figure 2. The pink arrow describe a positive causal link, such as if *Desired Herd Size* increases, then the result is that *Increasing herd* would also increase. Blue arrows denote a negative causal link, such as if the *Culling* rate increases, then the *Cow herd* would decrease. The double hashes in the arrows indicate that there is a delay in that portion of the system. The circled arrows denote feedback, *R* for reinforcing and *B* for balancing. Each feedback loop will be described below.

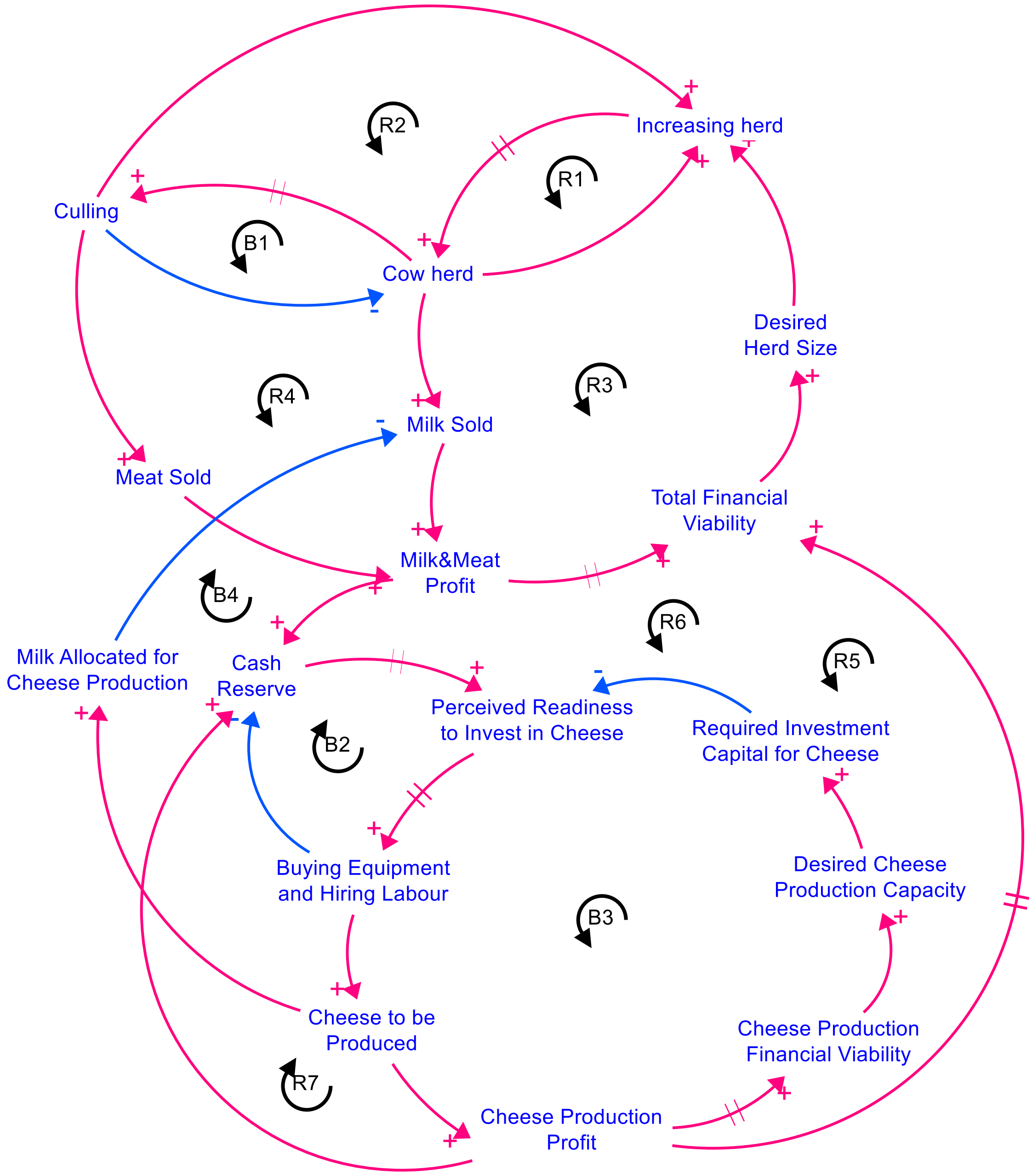

Figure 2: Causal loop diagram (CLD) of milk production and its processing for on-farm cheese production

R1 – Cows beget more cows: When there is a population of cows, or a herd, then then they will reproduce more cows. But there is a time delay where birthed calves will take several years to become adult cows.

R2 - Goodbye cows, hello to cows: Culling cows for meat leads to a need to elevate the increasing herd rate to compensate for the lost cows.

R3 – More cows, more milk: The milk sold from the existing cows lead to an improvement in the perceived financial viability, which leads to a desire to increase the herd, so that even more milk can be sold.

R4 – More cows, more meat: As a counterpoint to R3, having a cow herd means eventually retiring cows for meat. This serves as another revenue stream on a dairy farm; therefore, it also leads to improving the financial viability, and thus increasing the desired herd size..

R5 – New revenue stream, even more cows: As cheese sales contribute to a further increase of financial viability, it signals that the farmer should desire more of the main ingredient, the milk. So, the desired cow herd size increases. Greater milk sales led to a larger cash reserve, which allows for ability to invest in cheese processing equipment and hiring labour. This leads to more cheese production.

R6 – New revenue, more retirement: As the financial viability improves from cheese sales, the increase desired cow herd eventually lead to more culling of retiring cows and revenue from meat. Like loop R5, this revenue can then be reinvested back to cheese production ability.

R7 – Cheese revenue reinvestment: A more direct causal effect, this loop takes profit from cheese sales and reinvests into more hiring of labour and buying of equipment, bettering cheese production ability.

B1 – Great pasture in the sky: A simple “first-order” balancing loop, where culling of cows for meat results in a smaller cow herd.

B2 – Spending cash means less cash to spend: As cash reserves accumulate, the perceived readiness to invest increases, eventually leading to more investment, but this of course leaves the farm with less cash, and thus reduced ability to invest.

B3 – Suffering from cheesy success: As profits from cheese sales increase, the perceived financial viability of the operation improves, thus increased desire to expand operations lead to a greater amount of investment capital to meet the desired production capacity. Higher required investment capital reduces the farm’s ability to meet that requirement, and thus ability to hire and buy to meet that elevated expectation.

B4 – Tug-of-war of dairy: As cheese production increases, more and more raw milk is diverted away from selling to processors and instead is kept on-farm for cheese production. This leads to reduced revenue from raw milk sales, and thus decreased contribution of raw milk profit to cash reserves, and by extension the ability to buy equipment and hire labour for cheesemaking.

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Model Validation

Model validation was conducted in accordance with guidelines documented by Barlas (1995) and Rahmadad & Sterman (2012). Model equations are documented in Appendix B: Model Documentation. Detailed sensitivity analysis is documented in Appendix C: Model Validation and Sensitivity Analysis. Minimum simulation reporting requirements (MSRR), described in Rahmadad & Sterman (2012) is documented in Appendix D: Simulation Experiment Report. The following is the simulation configuration.

Table 1: Simulation software configuration settings

Run Specs	
Start Time	2000
Stop Time	2060
DT	1/32
Time Units	Years
Integration Method	Euler

Dimensional consistency

The model was confirmed to have dimensional consistency and no unit errors.

Structure confirmation

The model and associated parameters were based on studies and non-academic sources as documented in Appendix B: Model Documentation. The model structure was based on consultation with the course assistant as well as conventional knowledge, such as dairy cows produce raw milk and are eventually retired (Oubrhou, N., personal comm.).

Integration and time step (DT)

The integration method used was Euler, and the time step (DT) was 1/32, or 0.03125 years. This was considered to be well beyond the requirement, as the “rule-of-thumb” is that the DT should be at least half the fastest rate employed in the model. The fastest rate in the documented model is the *normal birth rate*, at 1.0 year^{-1}.

Extreme conditions and Indirect structure test

Extreme condition and indirect structure tests were combined into one approach with the Sensitivity test, as documented in Appendix C: Model Validation and Sensitivity Analysis. The extensive sensitivity analysis allowed for evaluating model behavior in extreme parameter conditions, as well as making sure that the model structure changed in a way that was reasonable and explainable. Also, “impossible” values were not observed, such as negative Number of Cows.

Partial model (sector) testing

Each identified sub-models (sectors) were run individually as a partial model test to evaluate further validity. With constant input from other sectors, every individual sector was found to be structurally sound and behaving appropriately in isolation.

Baseline Model Scenario Analysis

In this section the baseline model scenario is described by walking through the KPIs throughout the simulation, by time segments. The model configuration setting and parameters are summarized in *Appendix D: Simulation Experiment Report*. The KPIs discussed in the Problem Introduction are shown below for the baseline scenario (Figure 3). The dashed lines denote the three time segments which will be discussed below.

It should be noted when discussing feedback loop names used (e.g., R1, B1) will refer to the loops identified in the CLD (Figure 2) instead of ones generated automatically in the Stella model.

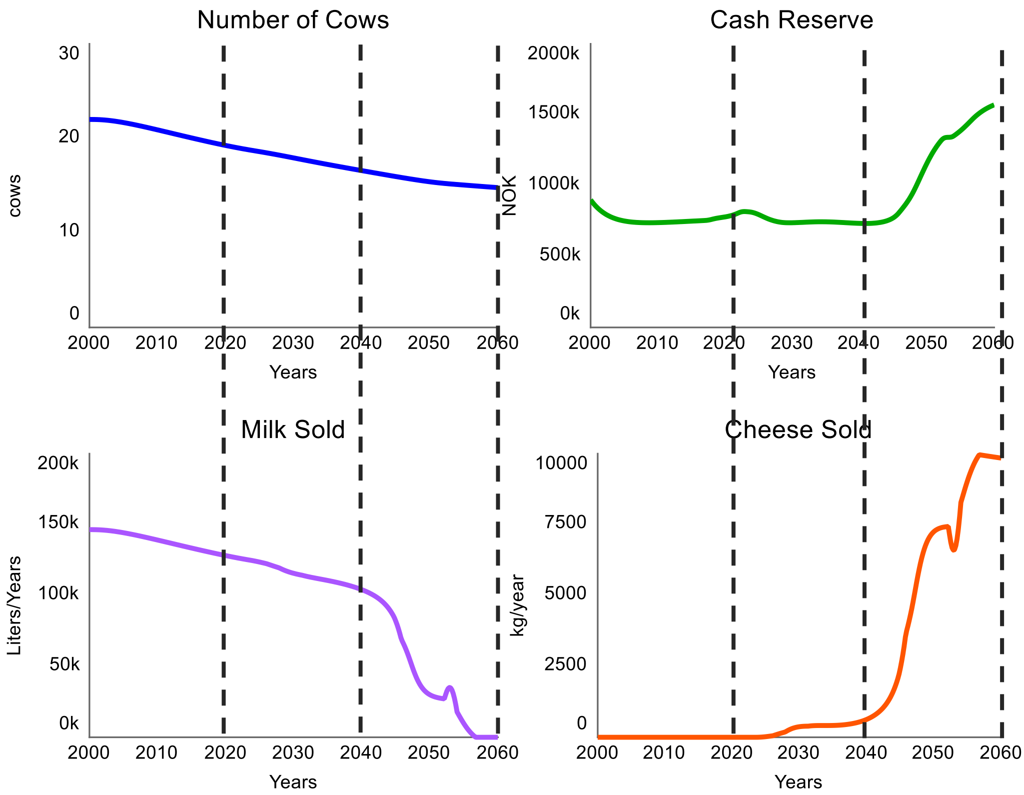


Figure 3: KPI results for the baseline scenario simulation with dashed lines denoting time segments discussed

Years 2000 – 2020

The first two decades do not appear to have much visible dynamics. However, there is an interplay of loops that affect the "stock-balance" of the cow herd, namely loops R1 – Cows beget more cows; R2 - Goodbye cows, hello to cows; B1 – Great pasture in the sky. As evidenced by the cow herd and milk production gradual decline, the total spending (farm cost and personal spending) is exceeding the profits from milk and meat (Figure 3). Cheese production has not begun yet, as the policy start year is 2023 for the baseline scenario. There is a sudden small dip in the cash reserve KPI, which is attributed to the assumption that 30% of cash is used for disposable income and consumption. After 2010 the revenue from milk and meat (loops R3 R4) stabilizes this decline.

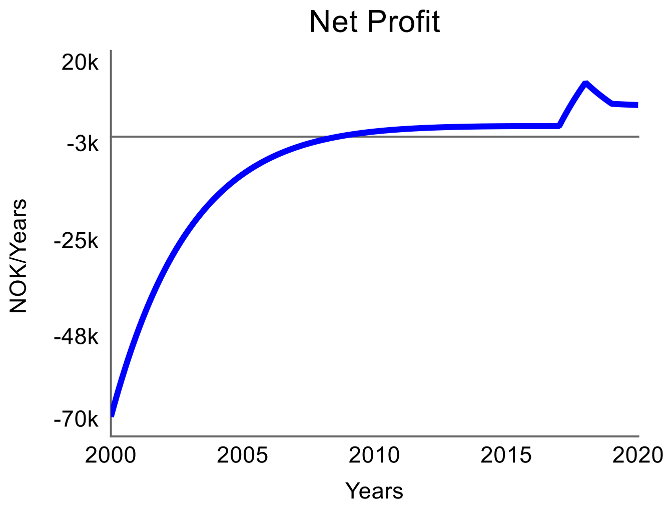


Figure 4: Net Profit showing negative values in the first 10 years of simulation

Years 2020 – 2040

In year 2023, the farm begins evaluating whether they have enough cash reserve to meet the investment requirement to start cheese production. Figure 3 shows that cheese production begins and plateaus around a modest 400-500 kg/year.

Because of the higher margin of cheese over raw milk, it was initially expected that there would be an increase in cash reserve and subsequently cow herd (loop R5, R7). However, the baseline scenario setting shows that cow herd continued their trends of a gradual decline while cash reserve seems to be stabilized. It could be that there are enough delays in the system that although cheese production set in motion an eventual uptick, this simulation time segment does not benefit from cheese production yet.

Years 2040 – 2060

In this final time segment, Loop R7 (Cheese revenue reinvestment) has prominence at this time, and cash reserve begins increasing. Notably, the benefits from cheese sales are not reflected in the cow herd increase (loop R5). As seen in Figure 3, although the farm is experiencing financial success, the cow herd is still declining, due to the series of delays in the system such as the growing of calves into heifers (loops R1). The fast-increasing cheese production leads to diverting raw milk away from selling to processors for “in-house” production of cheese (loop B4). Although this decreases the contribution of raw milk to the total farm profit, the high margins of cheese sales outweigh this loss.

Cheese production dramatically increases early in this time segment, and the other KPIs show its effects to the system. This is due to the procuring of necessary cheesemaking equipment after a long delay (baseline of 5 years). The actual cheese shipped is limited by the minimum of either the cheesemaking potential of hired labour or cheesemaking equipment. Around 2045 the cheesemaking potential from equipment finally catches up and exceeds the hired labour, and this shift in trend is observed (Figure 5). Ten years later around 2055 there is an observed decline and then increase in equipment cheesemaking capacity.

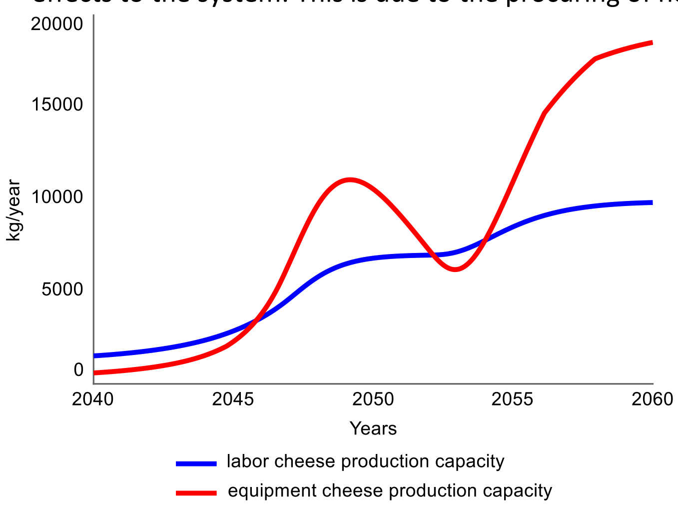


Figure 5: Equipment cheese production capacity exceeding labour capacity in 2045 and then dipping below again around 2055

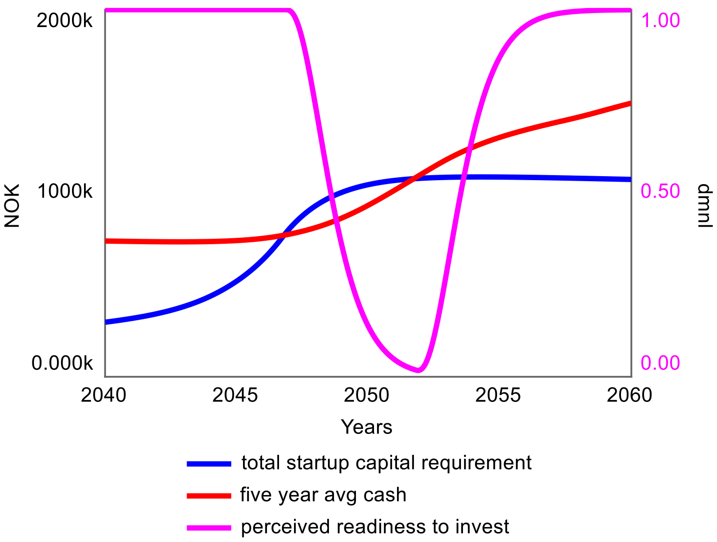


Figure 6: Required capital exceeding cash reserve and perceived readiness to invest for years 2040 - 2060

Concurrently around the same years there is a sudden uptick in raw milk sold, and a similar decline in cheese sold (loop B4). In the baseline simulation, there is a brief period where the ever-increasing desired cheese production capacity leads to an amount of required capital that cannot be met by the available cash reserve (Figure 6). Therefore, for a brief time perceiving readiness to invest declines, while loop B3 (Suffering from cheesy success) allows for the system to self-correct, and investment can resume.

Scenarios and Policy

The policy scenarios identified in this study focused on the more tangible changes that a farm holder can employ, *given the circumstances described in the Baseline scenario*. There is a plethora of parameters such as producer price on milk, subsidies, milk needed per cheese, and farm area size that can significantly affect the KPIs. However, these parameters are either have physical limitations (e.g., milk protein content needed for cheese), or sufficiently complex dynamics that it was determined the structure for effecting change is outside the scope of this model (e.g., expanding farm area or negotiating higher producer price for milk). Thus, emphasis was instead placed on changes that are deemed to be more easily implemented by the farm holder.

Increasing Hiring Effort

The model assumed that the actual cheese production possible is the lesser of these two model variables: *labor cheese production capacity* and *equipment cheese production capacity*. Regardless of how much cheese the farm holder wants to produce (Desired Cheese Production Capacity), if the labour and equipment cannot meet this expectation, the cheese production must be scaled back to a manageable level.

A simple parameter is added to the model, *POLICY hiring effort* which multiplies the *adjusting staff* biflow proportionally (baseline is 1.0 [dimensionless]). To make the impact of this change apparent, the parameter is uncreased threefold to 3.0 [dimensionless], which leads to changes to the KPI as shown below (Figure 7).

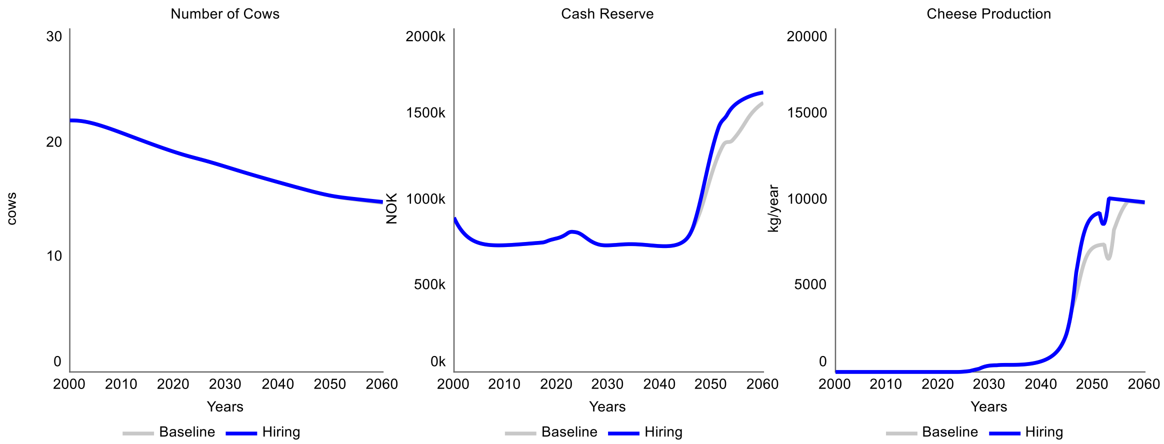


Figure 7: Increased hiring effort scenario compared with Baseline scenario

This scenario does not substantially improve the overall selected KPIs. Cash Reserve and Cheese Production do improve beyond Baseline, but the results show that hiring was not severely limiting the farm's ability to realize its full desired capacity. The cheese production improvement is most prominent at year 2050, where production is 25% greater than Baseline.

There is also a small dip, and a "ceiling" that Cheese Production goes through at around year 2052 that should be analyzed. This small dip is due to a brief moment where the capital investment requirement outpaces the cash reserve, and the perceived readiness to invest declines (loop B3). This scenario also suffers the same event as the Baseline scenario.

The ceiling portion, however, requires a different explanation. This abrupt change in course for cheese production actually follows a different variable: *milk allocated for cheese.* Instead of a limitation on the production size, in this scenario there is a milk supply issue, in that there are not enough cows producing enough raw milk to satisfy the cheese production capacity (Figure 8).

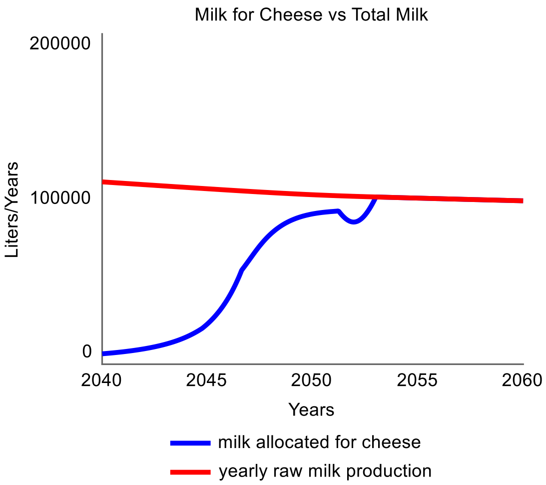


Figure 8: Amount of milk needed for cheese running up against total milk production for years 2040 - 2060

Because of the long delays in the system, the recovery of the Number of Cows is too slow, with milk production increase lagging (loop R5), that it cannot meet the increase in hired labour with greater capacity to process milk (loop B4).

Expediting Equipment Procurement

Instead of improving the labour, the other option of relieving the production bottleneck would be to have quicker access to cheesemaking equipment. The baseline scenario assumes that 5 years is needed to provide the totality of the capital needed. What additional effort could be given to hiring is instead diverted to reducing the procurement delay to half (2.5 years).

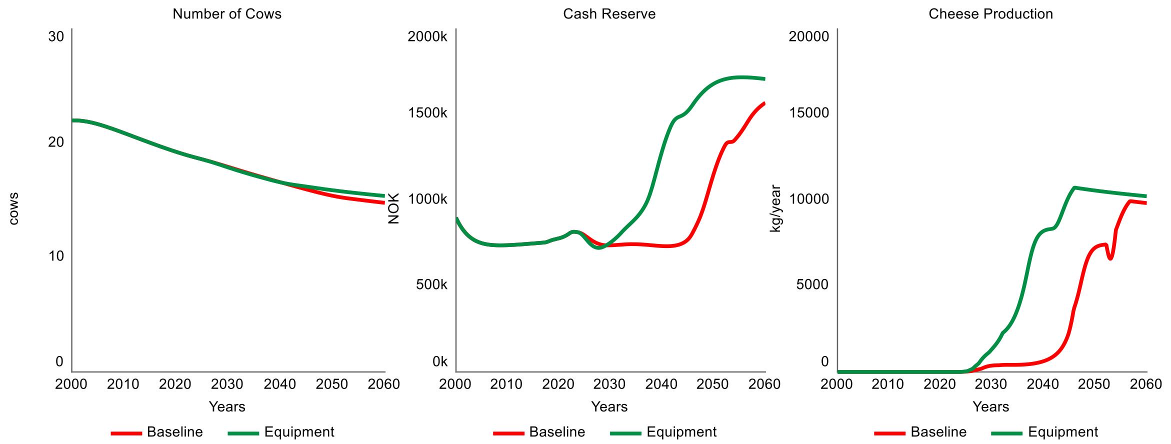


Figure 9: Expediting equipment procurement scenario compared with Baseline scenario

The KPI results for this scenario (Figure 9) is markedly better compared to the hiring effort scenario. It avoids the "dip" problem with loop B3 that was present in the hiring scenario. The increase in Cheese Production occurs much faster, with the increase occurring at the policy year of 2023. As a result the Cash Reserve stock accumulates faster, with as much as double the Cash Reserve at year 2045, although it plateaus for the remainder of the simulation.

The flattening is again due to the total availability of milk being less than the amount of milk required *should the Desired Cheese Capacity is realized.* Although the beginning of a recovery in Number of Cows is more visible in this scenario (loop R5), it is still not fast enough to meet the increased availability of equipment and the raw milk processing capacity it would now have (loop B4).

Increasing Price of Cheese

The previous two scenarios showed the farm holder trying to address the problem by increasing the amount of cheese sold. This scenario looks at raising the price per cheese from the baseline of 150 NOK/kg to 200 NOK/kg. There is abundant competition from high volume low margin products at the store, so change to a more specialized customer base could be explored. The cheese could be marketed as a premium, direct-to-consumer product that can charge a premium.

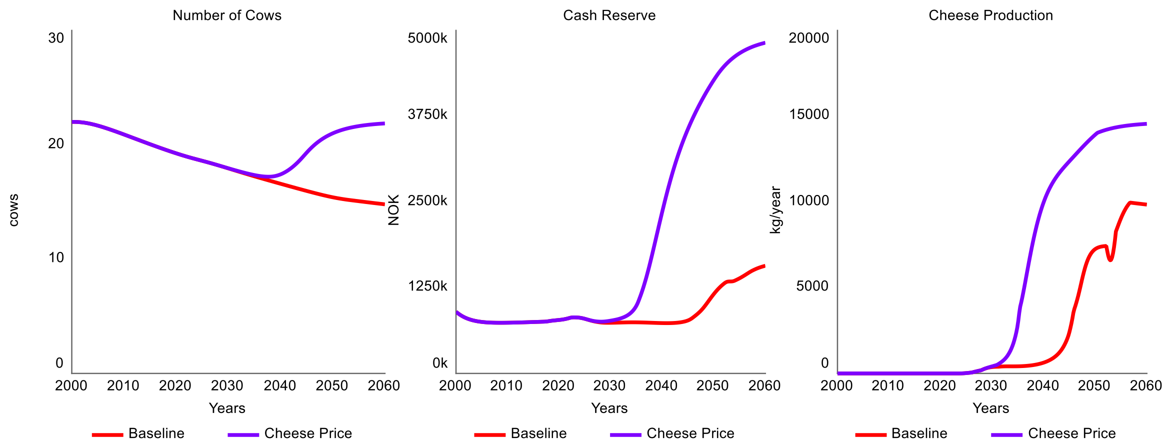


Figure 10: Cheese price scenario compared with Baseline scenario

As seen above in Figure 10, this scenario shows the greatest increases, especially in Cash Reserve and Number of Cows. Instead of attempting to improve cheese production, this scenario bypasses the delays in capacity-building, and increases the profits from cheese sales directly. This engages loop R5 quickly, and the Desired Herd Size can respond well within the simulation time. The Number of Cows approach the maximum limit of 22 cows by the year 2060.

Cheese Production performs well, and it is able to prevent the barriers to growth from the balancing loop B4 because the cow population grows enough that the raw milk supply continues to satiate the demands from the cheesemaking operation.

Discussion and Conclusions

The ideal policy for Harold, who is the main stakeholder in this analysis, would be to dedicate all of their milk output to cheesemaking and sell to a premium high margin market. As such, this model supports the economic analyses conducted by Asheim et al (2014) and Nyamakwere et al (2022) in that small-scale artisanal dairy products can be profitable, and an important value-add revenue stream for dairy farms like one owned by Harold.

In reality this is not easy to implement. Dairy farmers are good at raising cows and deriving raw milk from them, but this does not automatically make them good at making downstream products like cheese or butter. This recommended policy presumes that farmers would be comfortable with deviating from their core competency to seek alternative revenue streams. In fact, the South Africa study by Nyamakwere et al (2022) noted that a cheese expert from Italy had to be hired for consultation.

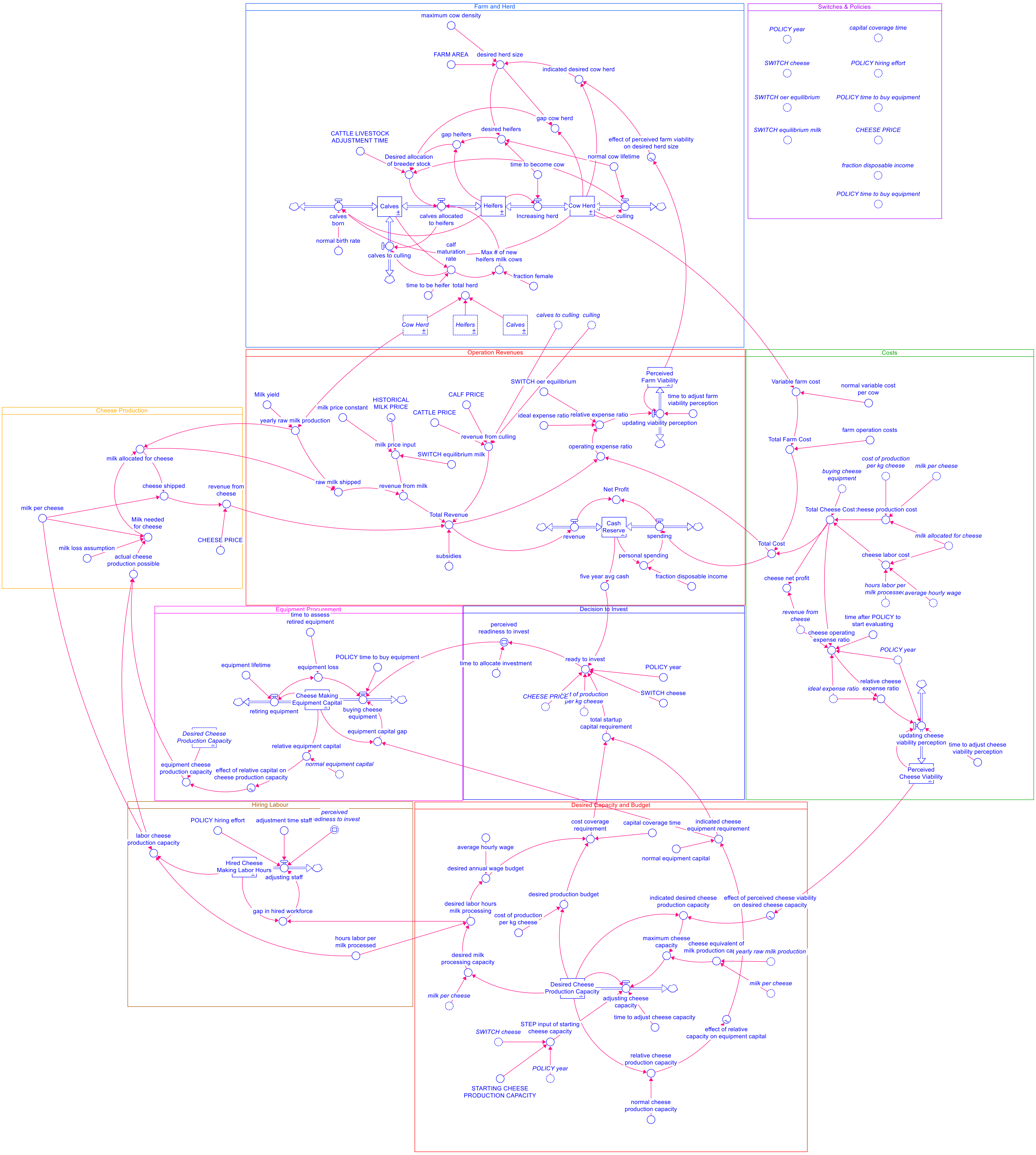
This lends to one of the important assumptions that the farm holder like Harold has sole agency in how the raw milk is used. The other important stakeholder not considered in the current analysis would be the dairy processors such as TINE that buy the raw milk from farms. There may be complex business relationships such as purchasing agreements that was not elucidated in this initial analysis. What would be the reaction by TINE, who has their own brand of specialty cheeses, if enough dairy farms cut back on selling raw milk and started selling their own cheese directly to consumers?

The model assumes only single-owner pasture raised dairy farming. There are other types of dairy farming, such as the more intensive feed-based operations. Moreover, co-operative farming allows multiple farm owners to share resources and knowledge which may allow for optimized practices. Co-ops can allow owners of small parcels to engage in viable dairy farming operations (Bjørlo, B., Statistics Norway, personal com., November 17, 2023).

For the cheesemaking operation, one of the key assumptions was that any amount of cheese produced will have a buyer. This is of course not realistic, as there are factors that contribute to whether or not there is a market for a new product such as price sensitivity and willingness to pay.

Possible future work would build upon the foundations of this model first by identifying stakeholders that would have further insight into the parameter assumptions currently based on literature. For example, engaging with real dairy farmers like Harold would shed light on data such as per-cow operation cost and wages paid to hired labour. Finally, it would be highly valuable to elucidate the "soft" elements of the decision-making structure by interviewing dairy farms. For example, what kind of mental criteria does Harold employ when deciding to expand the number of cows? When does he know that the farm is ready to invest in the production of a new, value-add dairy product such as cheese?

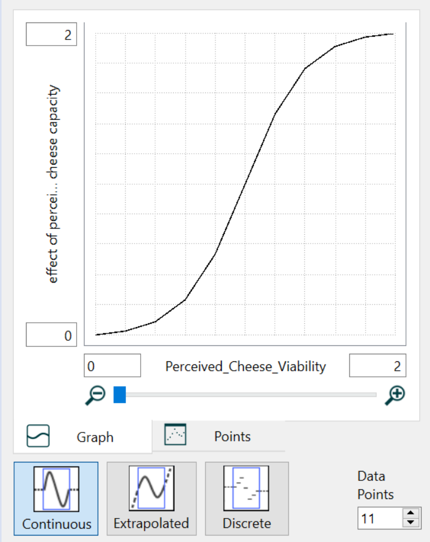
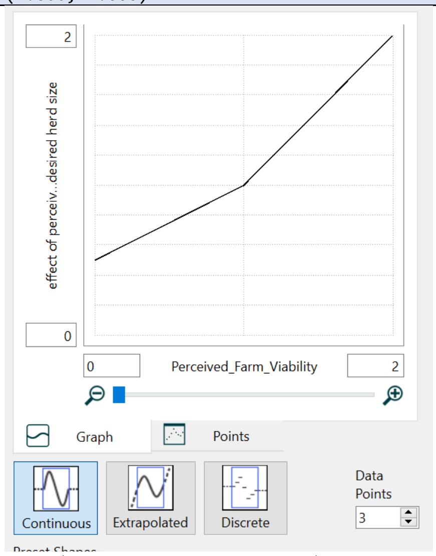
Appendix A: Stella Stock-and-Flow Structure

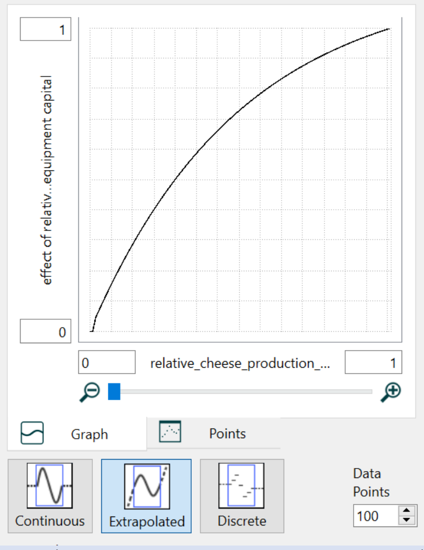


Appendix B: Model Documentation

Variable [unit]	Equation	Documentation
Calves(t) [cows]	INIT Calves = (Cow_Herd + Heifers) * normal_birth_rate * time_to_be_heifer	Stock: The initial value is determined analytically. Because in an equilibrium inflows must be equal to outflows. calves_born = calves_allocated_to_heifers + calves_to_culling (Cow_Herd + Heifers) * normal_birth_rate = calves_allocated_to_heifers + calf_maturation_rate - calves_allocated_to_heifers (Cow_Herd + Heifers) * normal_birth_rate = calf_maturation_rate (Cow_Herd + Heifers) * normal_birth_rate = Calves / time_to_be_heifer Calves = (Cow_Herd + Heifers) * normal_birth_rate * time_to_be_heifer
Cash_Reserve(t) [NOK]	INIT Cash_Reserve = 900000	Stock: This is the accumulation of revenue minus spending over the simulation.
Cheese_Making_Equipment_Capital(t) [NOK]	INIT Cheese_Making_Equipment_Capital = 0	Stock: The amount of cheese making equipment starts at 0, since at first the farm is a milk-only operation. When the five year average surpasses the required initial startup capital, the equipment buying is started.
Cow_Herd(t) [cows]	INIT Cow_Herd = 22	Stock: Cows are the only cattle population that is actively producing milk on a farm. The initial value is set to the same value as farm size, as on average there is 1 cow to 1 hectare of dairy farm land (TINE.no, accessed 2023).
Desired_Cheese_Production_Capacity(t) [kg/year]	INIT Desired_Cheese_Production_Capacity = 0	Stock: Desired capacity starts with 0, since no operation is taking place. If investing then starting cheese production capacity is 2 tons, which is approximately 20000 liters of raw milk plus processing loss (Asheim et al., 2014).
Heifers(t) [cows]	INIT Heifers = desired_herd_size * time_to_become_cow/normal_cow_lifetime {In equilibrium, all flows should be equal. So you can make retiring = maturing; which is mature trees/lifetime = young trees/time to bear fruit. You can rearrange the equation to find out what the equilibrium young trees are: young trees = mature trees/lifetime*time to bear fruit. You use the desired matured trees instead of mature trees in the equation to get the "desired young trees" such that the system will be in equilibrium, given a certain desired mature tree. }	Stock: Heifers are female cows allocated for milk production but have not given birth yet. The number of initial heifers is calculated analytically, since at equilibrium all flows should be equal. Therefore the flow increasing herd should equal culling. Increasing herd = culling Heifers / time_to_become_cow = Cow_Herd / normal_cow_lifetime and since at equilibrium Cow_Herd should equal the desired cow herd size: Heifers = desired_herd_size * time_to_become_cow/normal_cow_lifetime
Hired_Cheese_Making_Labor_Hours(t) [hours/years]	INIT Hired_Cheese_Making_Labor_Hours = 0	Stock: The hired labor will be calculated in hours rather than employees.
Perceived_Cheese_Viability(t) [dmnl]	INIT Perceived_Cheese_Viability = 1	Stock: This is a soft value of how the farm holder feels about the viability of the new cheese production venture, with 1 being neutral. > 1 is good, < 1 is bad.
Perceived_Farm_Viability(t) [dmnl]	INIT Perceived_Farm_Viability = 1	Stock: This is a soft value of how the farm holder feels about the viability of the farm, with 1 being neutral. > 1 is good, < 1 is bad.
adjusting_cheese_capacity [kg/year/Years]	(maximum_cheese_capacity - Desired_Cheese_Production_Capacity) / time_to_adjust_cheese_capacity + STEP_input_of_starting_cheese_capacity	Flow: The Desired Cheese Production Capacity will adjust to the indicated cheese capacity with a small time delay
adjusting_staff [hours/years/Years]	perceived_readiness_to_invest * (gap_in_hired_workforce / adjustment_time_staff) * POLICY_hiring_effort	Flow: The actual rate of labour hiring is tempered by the perceived willingness to invest, and the delay in hiring.
buying_cheese_equipment [NOK/year]	{IF ready_to_invest = 1 THEN (equipment_capital_gap / time_to_buy_eqipment) + retiring_equipment ELSE 0} perceived_readiness_to_invest * (equipment_capital_gap + equipment_loss) / POLICY_time_to_buy_equipment	Flow: The rate at which equipment is purchased depends on the gap between the indicated cheese equipment requirement and the current stock of equipment, delayed by the time to procure the equipment. Only positive values are considered using MAX function as, it is not possible to buy negative equipment. Negatives values are considered in the retirement outflow.
calves_allocated_to_heifers [cows/Years]	MIN(Desired_allocation_of_breeder_stock, Max_#_of_new_heifers_milk_cows)	Flow: This flow takes the lesser of the two - the maximum available female calves ready to become heifer, or the desired number of new heifers
calves_born [cows/Years]	(Cow_Herd + Heifers) * normal_birth_rate	Flow: Both heifers and cows are assumed to have the same birth rate, 1 calf per year per cow.
calves_to_culling [cows/Years]	calf_maturation_rate - calves_allocated_to_heifers	Flow: Out of all of the calves not allocated to heifer population is assumed to be sent out for culling and meat production
culling [cows/Years]	Cow_Herd / normal_cow_lifetime	Flow: After the productive years of a dairy cow, it is assumed that they are sent for meat processing.
Increasing_herd [cows/Years]	Heifers / time_to_become_cow	Flow: As heifers give their first birth, they are considered cows, and go to the main milk producing population.

retiring_equipment [NOK/year]	Cheese_Making_Equipment_Capital / equipment_lifetime	Flow: After some years it is expected that through either normal wear-and-tear or accident that equipment will need to be retired. The amount of equipment retired it assumed to be repurchased automatically. In addition to normal retirement, if equipment capital cap is negative, this value is also included in the retirement flow. Potential revenue from selling still usable equipment is outside the model scope.
revenue [NOK/year]	Total_Revenue	Flow: Total revenue is the only contributor to the inflow to Cash Reserve.
spending [NOK/year]	Total_Cost + personal_spending	Flow: Total spending outflow comes from farm operation cost, cheese production cost, and fraction from personal consumption
updating_cheese_viability_perception [1/years]	IF TIME > POLICY_year THEN (relative_cheese_expense_ratio - Perceived_Cheese_Viability) / time_to_adjust_cheese_viability_perception ELSE 0 {SMTH3(operating_expense_ratio_OER - perceived_risk_of_farm_viability , time_to_adjust_risk_perception)}	Flow: This bidirectional flow adjusts the farmers' perception of cheese production viability up/down according to the relative expense ratio.
updating_viability_perception [1/years]	(relative_expense_ratio - Perceived_Farm_Viability) / time_to_adjust_farm_viability_perception {SMTH3(operating_expense_ratio_OER - perceived_risk_of_farm_viability , time_to_adjust_risk_perception)}	Flow: This bidirectional flow adjusts the farmers' perception of farm viability up/down according to the relative expense ratio.
actual_cheese_production_possible [kg/year]	MIN(equipment_cheese_production_capacity, labor_cheese_production_capacity)	Min: The cheese production potential must be the smaller of the two between the production capacity of the equipment and the production capacity of the hired labour.
adjustment_time_staff [years]	2	Parameter: Labour cannot be hired instantly, so there will be a minor delay in closing the gap between actual and desired labour hours hired.
average_hourly_wage [NOK/hours]	160 {https://www.arbeidstilsynet.no/en/working-conditions/pay-and-minimum-rates-of-pay/minimum-wage/}	Parameter: There are different rules for seasonal and permanent agricultural workers. We assume that this is a part time seasonal operation (arbeidstilsynet.no, accessed 2023)
calf_maturation_rate [cows/Years]	Calves / time_to_be_heifer	Variable: This is the total number of calves that become cattle ready to either be allocated to be heifers or sent to culling. This variable also includes males.
CALF_PRICE [NOK/cows]	1700 {https://www.agproud.com/articles/54372-prices-for-dairy-replacements-cull-cows-all-jump} {Asheim}	Parameter: Calfs are sold at a much lower price each since they are smaller than heifers (Asheim et al., 2014).
capital_coverage_time [years]	1	Parameter: Also referred to as "runway" it is the amount of money that should be available so the operation doesn't run out of money too quickly. Default is 12 months (forbes.com, accessed 2023).
CATTLE_LIVESTOCK_ADJUSTMENT_TIME [years]	5	Parameter: The long adjustment time is rooted in the long lifetime of cattle livestock buildings and related infrastructure, which limit the flexibility with which farmers enter and exit the cattle sector.
CATTLE_PRICE [NOK/cows]	13000 {https://www.agproud.com/articles/54372-prices-for-dairy-replacements-cull-cows-all-jump} {Asheim}	Parameter: Culled cows as sold for additional value after a productive milking life (Asheim et al., 2014).
cheese_equivalent_of_milk_production_capacity [kg/year]	yearly_raw_milk_production / milk_per_cheese	Variable: If all of the cheese on the farm is processed into cheese, this is the amount of product possible
cheese_labor_cost [NOK/year]	milk_allocated_for_cheese * hours_labor_per_milk_processed * average_hourly_wage	Variable: The amount of milk allocated for cheese is converted into the labor equivalent, then the per hour wage of cheese production labor is multiplied.
cheese_net_profit [NOK/year]	revenue_from_cheese - Total_Cheese_Cost	Variable: For analysis purpose only comparing cheese revenue with cheese production costs
cheese_operating_expense_ratio [dmnl]	IF TIME > (POLICY_year + time_after_POLICY_to_start_evaluating) THEN Total_Cheese_Cost // revenue_from_cheese ELSE ideal_expense_ratio	Variable: Like the farm expense ratio, the cost is divided by the revenue to indicate the fraction of revenue that is eaten up by the cost (zebrabi.com, accessed 2023).
CHEESE_PRICE [NOK/kg]	150 {235}	Parameter: The price of direct-to-consumer cheese from small dairy farms is considered to have higher margin than cheese from grocery stores (Asheim et al., 2014).
cheese_production_cost [NOK/year]	milk_allocated_for_cheese / milk_per_cheese * cost_of_production_per_kg_cheese	Variable: The amount of milk allocated for cheese is converted into the cheese equivalent, then the per kg cost of cheese production is multiplied.
cheese_shipped [kg/year]	milk_allocated_for_cheese / milk_per_cheese	Variable: The milk allocated for cheese is finally converted to the final shipped cheese value.
cost_coverage_requirement [NOK]	capital_coverage_time * (desired_annual_wage_budget + desired_production_budget)	Variable: The cost of production and labour must be covered for investing in the cheese making operation. Depending on the farm's situation a full year's coverage may not be necessary, but for baseline a full year coverage is desired.
cost_of_production_per_kg_cheese [NOK/kg]	35 {Asheim}	Parameter: The cost of cheese includes electricity, rennet, packaging, and other ingredients for production (Asheim et al., 2014)
Desired_allocation_of_breeder_stock [cows/Years]	MAX(0, (gap_cow_herd + gap_heifers)//CATTLE_LIVESTOCK_ADJUSTMENT_TIME + culling)	Max: The desired number of new calves allocated for milk production should equal the number of desired number of cows and heifers PLUS replacement of culled cows. However, due to the dynamic this value may be negative, which is not

		possible in a cow herd, so a floor of 0 desired new cow is implemented.
desired_annual_wage_budget [NOK/year]	desired_labor_hours_milk_processing * average_hourly_wage	Variable: Desired labor hours are converted to desired wage cost budget
desired_heifers [cows]	desired_herd_size * time_to_become_cow/normal_cow_lifetime	Variable: This value is calculated the same as the initial Heifer stock value. The equation shows the analytical relationship between the current desired cow herd and the desired heifer cow herd
desired_herd_size [cows]	MIN(maximum_cow_density * FARM_AREA, indicated_desired_cow_herd)	Min: Desired cow herd can be increased up to the ceiling of maximum allowed herd density for a given farm size.
desired_labor_hours_milk_processing [Hours/Years]	desired_milk_processing_capacity * hours_labor_per_milk_processed	Variable: with the average hour of labor required per volume of milk processed, we estimate the amount of labor hours needed to fulfill the desired raw milk processing.
desired_milk_processing_capacity [Liters/Years]	(Desired_Cheese_Production_Capacity * milk_per_cheese)	Variable: This is the amount of raw milk required to meet the desired cheese production capacity
desired_production_budget [NOK/year]	Desired_Cheese_Production_Capacity * cost_of_production_per_kg_cheese	Variable: The cheese production capacity is translated to production budget with the cost per kg cheese parameter
effect_of_perceived_cheese_viability_on_desired_cheese_capacity [dmnl]	 GRAPH(Perceived_Cheese_Viability) Points: (0.000, 0.000), (0.200, 0.02526), (0.400, 0.08682), (0.600, 0.2331), (0.800, 0.5352), (1.000, 1.000), (1.200, 1.465), (1.400, 1.767), (1.600, 1.913), (1.800, 1.975), (2.000, 2.000)	Table: Because this is a new venture, if cheese production is performing poorly, it may be subject to a total closure if viability is very low. On the other hand, a well performing cheese could increase as much as double in desired capacity due to optimism from the farm holder.
effect_of_perceived_farm_viability_on_desired_herd_size [dmnl]	 GRAPH(Perceived_Farm_Viability) Points: (0.000, 0.500), (1.000, 1.000), (2.000, 2.000)	Table: The more a farmer perceives that their farm is financially successful, they will want to continue their success by expanding further. If they find that their farm is not successful, they may look to reducing their farm for cost savings. "Success to successful" archetype.

effect_of_relative_capacity_on_equipment_capital [dmnl]	 GRAPH(relative_cheese_production_capacity) Points: (0.000, 0.0001), (0.01010101, 0.0001), (0.02020202, 0.0458), (0.03030303, 0.06801), (0.04040404, 0.08978), (0.050505051, 0.1111), (0.060606061, 0.132), (0.070707071, 0.1525), (0.080808081, 0.1726), (0.090909091, 0.1923), (0.101010101, 0.2116), (0.111111111, 0.2305), (0.121212121, 0.249), (0.131313131, 0.2671), (0.141414141, 0.2849), (0.151515152, 0.3023), (0.161616162, 0.3194), (0.171717172, 0.3362), (0.181818182, 0.3526), (0.191919192, 0.3686), (0.202020202, 0.3844), (0.212121212, 0.3998), (0.222222222, 0.415), (0.232323232, 0.4298), (0.242424242, 0.4443), (0.252525253, 0.4586), (0.262626263, 0.4725), (0.272727273, 0.4862), (0.282828283, 0.4996), (0.292929293, 0.5128), (0.303030303, 0.5256), (0.313131313, 0.5383), (0.323232323, 0.5506), (0.333333333, 0.5627), (0.343434343, 0.5746), (0.353535354, 0.5863), (0.363636364, 0.5977), (0.373737374, 0.6088), (0.383838384, 0.6198), (0.393939394, 0.6305), (0.404040404, 0.641), (0.414141414, 0.6514), (0.424242424, 0.6615), (0.434343434, 0.6714), (0.444444444, 0.6811), (0.454545455, 0.6906), (0.464646465, 0.6999), (0.474747475, 0.709), (0.484848485, 0.718), (0.494949495, 0.7267), (0.505050505, 0.7353), (0.515151515, 0.7438), (0.525252525, 0.752), (0.535353535, 0.7601), (0.545454545, 0.768), (0.555555556, 0.7758), (0.565656566, 0.7834), (0.575757576, 0.7909), (0.585858586, 0.7982), (0.595959596, 0.8054), (0.606060606, 0.8124), (0.616161616, 0.8193), (0.626262626, 0.826), (0.636363636, 0.8326), (0.646464646, 0.8391), (0.656565657, 0.8454), (0.666666667, 0.8517), (0.676767677, 0.8578), (0.686868687, 0.8637), (0.696969697, 0.8696), (0.707070707, 0.8753), (0.717171717, 0.881), (0.727272727, 0.8865), (0.737373737, 0.8919), (0.747474747, 0.8972), (0.757575758, 0.9023), (0.767676768, 0.9074), (0.777777778, 0.9124), (0.787878788, 0.9173), (0.797979798, 0.9221), (0.808080808, 0.9268), (0.818181818, 0.9314), (0.828282828, 0.9359), (0.838383838, 0.9403), (0.848484848, 0.9446), (0.858585859, 0.9488), (0.868686869, 0.953), (0.878787879, 0.9571), (0.888888889, 0.9611), (0.898989899, 0.965), (0.909090909, 0.9688), (0.919191919, 0.9725), (0.929292929, 0.9762), (0.939393939, 0.9798), (0.949494949, 0.9834), (0.95959596, 0.9868), (0.96969697, 0.9902), (0.97979798, 0.9935), (0.98989899, 0.9968), (1.000, 1.000)	Table: Due to economies of scale, as the cheese capacity increases, there is a diminishing increase in the requirement of additional equipment.

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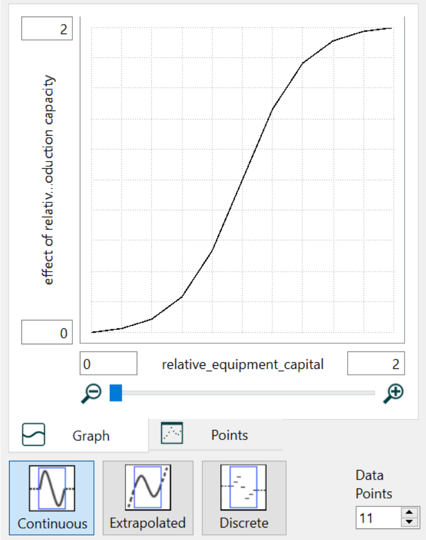
effect_of_relative_capital_on_cheese_production_capacity [dmnl]	 GRAPH(relative_equipment_capital) Points: (0.000, 0.000), (0.200, 0.02526), (0.400, 0.08682), (0.600, 0.2331), (0.800, 0.5352), (1.000, 1.000), (1.200, 1.465), (1.400, 1.767), (1.600, 1.913), (1.800, 1.975), (2.000, 2.000)	Table: The availability of equipment does not affect the amount of cheese production possible linearly. As the equipment capital accumulates, there may be a tipping point where viable production is possible, but then at a certain point there is diminishing return on production.
equipment_capital_gap [NOK]	MAX(0, indicated_cheese_equipment_requirement - Cheese_Making_Equipment_Capital)	Variable: In the start of the simulation there will be no equipment, so when purchasing begins the gap will be equal to the total initial startup capital, but will close as purchasing occurs. There is a floor for
equipment_cheese_production_capacity [kg/year]	Desired_Cheese_Production_Capacity * effect_of_relative_capital_on_cheese_production_capacity	Variable: The desired cheese production capacity is converted into actual production capacity depending on the normalized equipment availability at the time.
equipment_lifetime [years]	10	Parameter: Various sources state lifetime for cheese making equipment ranging from 7 years up to 15 years. A middle ground of 10 years is chosen as baseline. (Bouma et al., 2014; depreciationrates.net.au, accessed 2023).
equipment_loss [NOK]	retiring_equipment * time_to_assess_retired_equipment	Variable: Equipment retired due to age will be note for repurchase along with the indicated cheese equipment requirement
FARM_AREA [ha]	22	According to TINE, the average dairy farm is 22 hectares, which this parameter represents (TINE.no, accessed 2023).
farm_operation_costs [NOK/year]	225000 {Asheim}	Parameter: The fixed costs include farm structures, machinery, maintenance, as well as administration and management. Costs also include hired labour (Asheim et al., 2014).
five_year_avg_cash [NOK]	RUNMEAN(Cash_Reserve, TIME-5, TIME)	Variable: A running average of 5 years is calculated as the basis for whether the farmer wants to look into investing into cheese production
fraction_disposable_income [1/year]	0.3	Parameter: It is assumed a certain portion of the earned profit will go to disposable income, such as personal consumption.
fraction_female [dmnl]	0.5	Parameter: While sexed breeding is possible with cows, for simplicity the biological 50-50 chance is used (geno.no, accessed 2023).
gap_cow_herd [cows]	desired_herd_size - Cow_Herd	Variable: The difference between the current cow herd size and the desired cow herd size is the basis for driving herd growth behavior.
gap_heifers [cows]	desired_heifers - Heifers	Variable: Once the number of desired heifers is determined then the difference between the current number of heifers can be calculated
gap_in_hired_workforce [hours/years]	desired_labor_hours_milk_processing - Hired_Cheese_Making_Labor_Hours	Variable: Once investment is an interst, gap between current workforce (0 in the beginning) and the desired labour hours is calculated.
HISTORICAL_MILK_PRICE [NOK/liters]	GRAPH(TIME {TINE annual reports}) Points: (2016.000, 5.030), (2017.000, 5.050), (2018.000, 5.160), (2019.000, 5.160), (2020.000, 5.190), (2021.000, 5.280), (2022.000, 5.400), (2023.000, 5.238), (2024.000, 5.238)	Table: Historical milk prices come from TINE, the largest purchaser of raw milk from dairy farms in Norway (TINE.no, accessed 2023). Beyond the current date, future milk price value is a constant value which is the average of the 5 recent years.
hours_labor_per_milk_processed [hours/liters]	3.5/200 {Asheim}	Parameter: For every 200 liters processed, 3.5 hours are required (Asheim et al., 2014).
ideal_expense_ratio [dmnl]	0.7	Parameter: operating expense ratio of 0.7 is considered healthy for a dairy farm (dairyherd.com, accessed 2023).
indicated_cheese_equipment_requirement [NOK]	normal_equipment_capital * effect_of_relative_capacity_on_equipment_capital	Variable: The normal equipment capital is scaled up by the effect from the current desired cheese production capacity
indicated_desired_cheese_production_capacity [kg/year]	Desired_Cheese_Production_Capacity * effect_of_perceived_cheese_viability_on_desired_cheese_capacity	Variable: The current desired cheese capacity is adjusted up or down affected by the perception of how well the cheese operation is going financially.

indicated_desired_cow_herd [cows]	Cow_Herd * effect_of_perceived_farm_viability_on_desired_herd_size	Variable: The current herd is influenced by the effect of perceived farm viability, and the desired herd is adjusted up or down.
labor_cheese_production_capacity [kg/year]	Hired_Cheese_Making_Labor_Hours // hours_labor_per_milk_processed // milk_per_cheese	Variable: The labor capacity of cheese production is calculated by taking the hours of labor hired and first converting into how many liters of milk can be processed, then convert that value into the equivalent amount of cheese.
Max_#_of_new_heifers_milk_cows [cows/Years]	calf_maturation_rate * fraction_female	Max: The maximum number of new heifers is the number of female weaned calves each year.
maximum_cheese_capacity [kg/years]	MIN(indicated_desired_cheese_production_capacity, cheese_equivalent_of_milk_production_capacity)	Min: Although desired cheese production is increasing, eventually it will hit the ceiling of the amount of available raw milk on the farm. Purchasing extra milk is not within the bounds of the mode, as everything is assumed to be produced in-house.
maximum_cow_density [cows / ha]	1	This parameter limits the maximum allowed density of cow in a pasture with a ceiling of 1 cow / hectare. This limitation is mandated by Norwegian regulation (Oubrhou, N, personal communication). This is corroborated by TINE, which states average dairy farm is 22 hectares, and on an average farm there are 24 cows (TINE.no, accessed 2023).
milk_allocated_for_cheese [Liters/Years]	MIN(Milk_needed_for_cheese, yearly_raw_milk_production)	Min: Milk allocated for cheese cannot exceed the amount of raw milk produced, so it is the lesser of the total production vs amount needed for cheese
milk_loss_assumption [dmnl]	0.06 {Asheim}	Parameter: This is the portion of raw milk that is lost during the cheese making process (Asheim et al., 2014)
Milk_needed_for_cheese [Liters/Years]	milk_per_cheese * actual_cheese_production_possible / (1 - milk_loss_assumption)	Variable: Once the actual cheese production potential is calculated, then the value is converted back to the raw milk equivalent then this value is increased to compensate for the expected processing loss.
milk_per_cheese [liters / kg]	10	Parameter: The milk-to-cheese ratio is 10:1. That is, for 10 liter of milk about 1 kg of cheese is produced (Asheim et al., 2014)
milk_price_constant [NOK/liters]	5.18	Parameter: For model testing and model equilibrium, this constant value is provided as an option to be used via switch. The values are averaged over all of the available annual report from TINE for years 2016 - 2022 (tine.no, accessed 2023).
milk_price_input [NOK/liters]	IF SWITCH_equilibrium_milk = 0 THEN milk_price_constant ELSE HISTORICAL_MILK_PRICE	Variable: The SWITCH_equilibrium_milk determines whether this value is a constant average or derived from historical producer price (TINE.no, accessed 2023).
Milk_yield [liters/(cows*year)]	6656	Parameter: On average Norwegian Red cows, dominant breed in Norway, produces more than 6000kg of milk per year (thedairysite.com, accessed 2023).
Net_Profit [NOK/Years]	revenue - spending	Variable: Simple revenue minus spending total. Not used in model, report only.
normal_birth_rate [cows/(cows*year)]	1	Parameter: Dairy cows typically produce a new calf once every year, which is required to maintain milk production (geno.no, accessed 2023).
normal_cheese_production_capacity [kg/year]	2000 {25 tons milk processed into ~2 tons cheese per Asheim}	Parameter: A small on-farm cheese making operation is cited as 2 tons per year which needs about 20,000 liters of raw milk (Asheim et al., 2014).
normal_cow_lifetime [years]	4	Parameter: Determines the average productive life in years that mature cows are milked. After the milking period they are assumed to be processed for meat. Due to variability by region, practice, and breed, the productive life can range from 3 up to 6 years. A conservative estimate of 4 years is used (Dallago et al., 2021).
normal_equipment_capital [NOK]	200000	Parameter: A small-scale cheese production equipment is estimated to cost 150,000 - 250,000 NOK (Asheim et al., 2014)
normal_variable_cost_per_cow [NOK/(cows*year)]	27000 {Asheim}	Parameter: variable costs for dairy cows include forages, concentrates, and miscellaneous needs in livestock care (Asheim et al., 2014)
operating_expense_ratio [dmnl]	Total_Cost // Total_Revenue	Variable: Operating expense ratio can help gauge the efficiency of a company. It is the fraction of revenue that is spent on operation (zebrabi.com, accessed 2023).
perceived_readiness_to_invest [dmnl]	SMTH3(ready_to_invest, time_to_allocate_investment)	Smoothing: Although the farm is ready to invest, the farm holder may not realize, or may take some time before "pulling the trigger" on the decision.
personal_spending [NOK/year]	Cash_Reserve * fraction_disposable_income	Variable: A fraction of the available cash reserve is spent on discretionary and disposable consumption.
POLICY_hiring_effort [dmnl]	1	Parameter: This value multiplies the hiring adjustment flow as a simple test of simulating degree of hiring effort.
POLICY_time_to_buy_equipment [years]	5	Parameter: It is assumed that there is a short delay in purchasing the required specialized equipment for small scale cheese production.
POLICY_year [year]	2023	POLICY: The year to engage with policy is defaulted to the current year (2023).
raw_milk_shipped [Liters/Years]	yearly_raw_milk_production - milk_allocated_for_cheese	Variable: the amount of raw milk shipped is the total raw milk production minus milk allocated for cheese production
ready_to_invest [dmnl]	IF SWITCH_cheese = 1 AND TIME >= POLICY_year AND five_year_avg_cash >= total_startup_capital_requirement AND CHEESE_PRICE > cost_of_production_per_kg_cheese THEN 1 ELSE 0	Boolean: There are many criteria which must be met before a farmer is ready to invest - first the cheese switch must be set to 1, and the simulation year must be after the policy year of (2023). Then, the market price of cheese must be above the cost of production, otherwise it would lose money. Only then , the farmer looks at the running 5 year

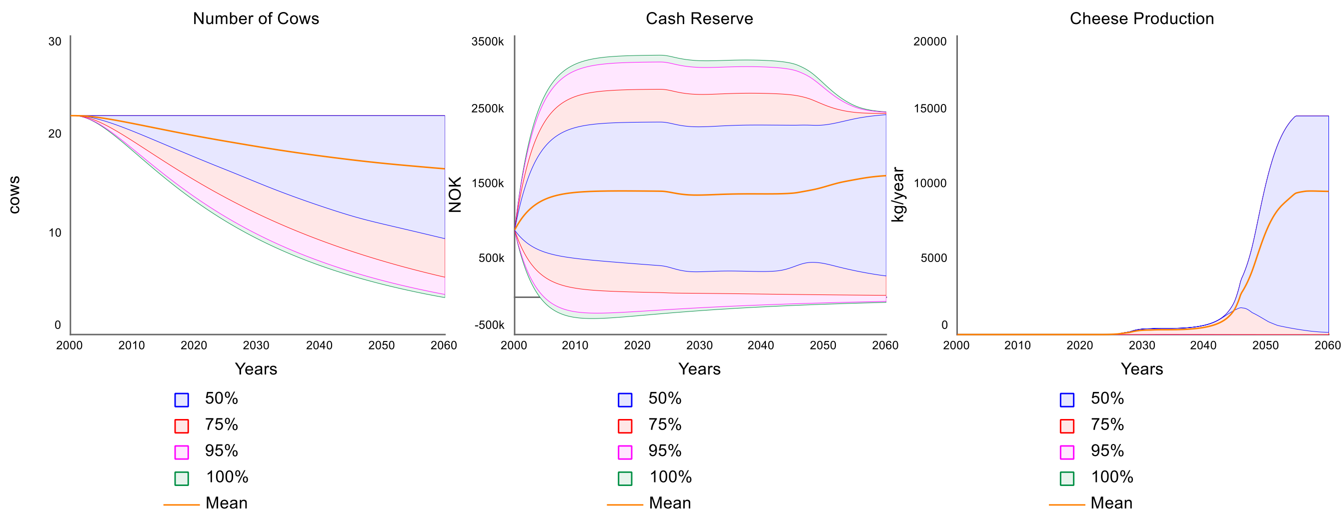
		average cash reserve and see if it's more than the total initial startup capital. If all of these criteria are met, the farmer can finally start to consider investment.
relative_cheese_expense_ratio [dmnl]	ideal_expense_ratio // cheese_operating_expense_ratio	Variable: Because for operating expense ratio lower is better, the ideal value is divided by the cheese production value so that when the cheese production value goes down it is considered a good thing (i.e. higher number).
relative_cheese_production_capacity [dmnl]	Desired_Cheese_Production_Capacity / normal_cheese_production_capacity	Variable: The current desired cheese production capacity is normalized for the table function.
relative_equipment_capital [dmnl]	Cheese_Making_Equipment_Capital / normal_equipment_capital	Variable: Current stock of equipment is normalized by the normal startup equipment capital for an on-farm cheese making operation.
relative_expense_ratio [dmnl]	IF SWITCH_oer_equilibrium = 0 THEN 1 ELSE ideal_expense_ratio // operating_expense_ratio	Variable: Because for operating expense ratio lower is better, the ideal value is divided by the farm value so that when the farm value goes down it is considered a good thing (i.e. higher number). But if the switch is 0 then the initial value of the farm ratio is used.
revenue_from_cheese [NOK/year]	CHEESE_PRICE * cheese_shipped	Variable: Revenue from cheese is the amount of shipped cheese multiplied by its price.
revenue_from_culling [NOK/year]	culling * CATTLE_PRICE + calves_to_culling * CALF_PRICE	Variable: Number of culled calves and cows are multiplied by their respective values to get the total revenue from culling activities.
revenue_from_milk [NOK/year]	raw_milk_shipped * milk_price_input	Variable: Revenue from raw milk shipment is the amount of shipped raw milk multiplied by its price.
STARTING_CHEESE_PRODUCTION_CAPACITY [kg/year/year]	2000 {25 tons milk per Asheim}	Parameter: A small on-farm cheese making operation is cited as 2 tons per year which needs about 20,000 liters of raw milk (Asheim et al., 2014). This value is added as a step function over 1 year.
STEP_input_of_starting_cheese_capacity [kg/year/year]	IF SWITCH_cheese = 1 AND TIME >= POLICY_year THEN STEP(STARTING_CHEESE_PRODUCTION_CAPACITY, POLICY_year, 1) ELSE 0	Step: If the cheese switch is active and simulation time is after the policy year, then a one-time value of starting cheese production capacity is "injected" as the desired capacity to start the investing.
subsidies [NOK/year]	225000 {Asheim}	Parameter: Subsidies are given from the government for practicing pasture grazing as well as livestock herd support (Asheim et al., 2014).
SWITCH_cheese [dmnl]	1 {0 = no investment; 1 = look into investment}	SWITCH: This switch converter = 1 enables consideration of cheese production or = 0 business as usual.
SWITCH_equilibrium_milk [dmnl]	1	Switch: 0 = constant milk price; 1 = historical milk price and last 5 year average after policy year.
SWITCH_oer_equilibrium [dmnl]	1	Switch: If 0 = for purpose of equilibrium and model testing, the expense ratio will be initial value of the farm ratio so that viability remains at 1. If 1 = then the cited ideal value of 0.7 is used.
time_after_POLICY_to_start_evaluating [years]	5	Parameter: This value serves a logical as well as corrective measures. It is assumed that it takes several years before the viability of cheese production can be evaluated. Also, due to the cheese cost and revenue values being small in the beginning, a division causes very large or small values at the very start of the policy year.
time_to_adjust_cheese_capacity [years]	2	Parameter: A short delay is assumed in adjusting the desire cheese production capacity.
time_to_adjust_cheese_viability_perception [years]	5	Parameter: Default is 5 years, which is cited by dairy economics studies as a medium-term outlook of dairy farms (Réquillart et al., 2008).
time_to_adjust_farm_viability_perception [years]	5	Parameter: Default is 5 years, which is cited by dairy economics studies as a medium-term outlook of dairy farms (Réquillart et al., 2008).
time_to_allocate_investment [years]	2	Parameter: This delay time smooths out the instantaneous status of whether the farm is ready to invest or not.
time_to_assess_retired_equipment [year]	2	Parameter: This is a simulated delay in the producer realizing that the retired equipment must be replaced
time_to_be_heifer [years]	2	Parameter: Cows typically give birth for the first time (i.e. allocated to be heifers) 2 to 3 years of age (ciwf.org.uk, accessed 2023).
time_to_become_cow [years]	1	Parameter: Once a heifer births her first calf, it is considered a cow (swandairy.com, accessed 2023).
Total_Cheese_Cost [NOK/year]	buying_cheese_equipment + cheese_labor_cost + cheese_production_cost	Variable: Cheese production, cheese production labour, and equipment purchasing are combined to get the total cheese operation cost.
Total_Cost [NOK/year]	Total_Farm_Cost + Total_Cheese_Cost	Variable: Total cost comes from farm operation and cheese production.
Total_Farm_Cost [NOK/Years]	Variable_farm_cost + farm_operation_costs	Variable: Total farm cost is the sum of cow herd management and on-farm operation costs.
total_herd [cows]	Cow_Herd + Heifers + Calves	Variable: Sum of cows, heifers, and calves. Not used in model, only potentially for report.
Total_Revenue [NOK/Years]	revenue_from_milk + revenue_from_culling + revenue_from_cheese + subsidies {+ revenue_from_agritourism??}	Variable: Sum of revenue from selling milk, cheese, and any subsidies.
total_startup_capital_requirement [NOK]	cost_coverage_requirement + indicated_cheese_equipment_requirement	Variable: This is the amount of NOK required before investment should happen.
Variable_farm_cost [NOK/year]	normal_variable_cost_per_cow * Cow_Herd	Variable: The per cow cost is multiplied by the cow herd
yearly_raw_milk_production [Liters/Years]	Cow_Herd * Milk_yield	Variable: Only cows that have given birth can produce milk, and milk yield is averaged out for all cows.

Appendix C: Model Validation and Sensitivity Analysis

Sensitivity analysis was conducted on parameters as well as table functions. For numerical parameter inputs, the default test was to assume that the baseline scenario uses a middle value. Then, lower and higher values were entered and the main KPIs as well as relevant variables were observed. By default the lower and higher value ranges were bounded by half and double the baseline input, respectively. If not enough differences are observed with this default approach, an even smaller or larger value will be used.

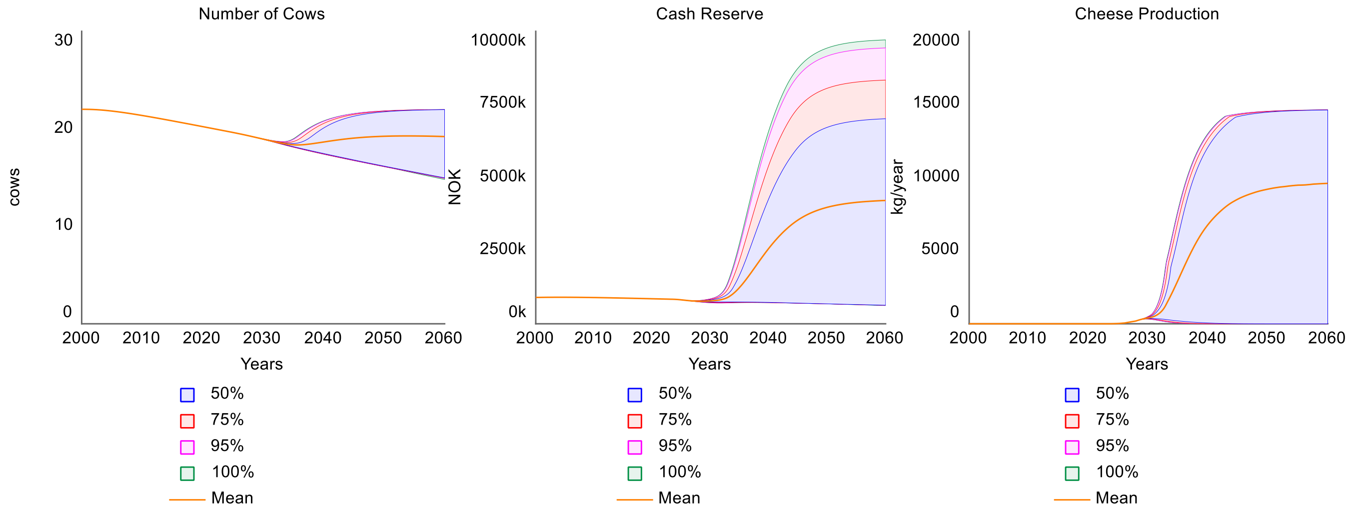
Milk price, which uses historical data by default, will instead use a mean value (5.18 NOK/liter) for the purpose of sensitivity analysis to minimize influencing factors. The parameter range will be entered using a *uniform distribution* with *Latin Hypercube sampling* over 100 runs.

Milk Price (2.5 – 10 NOK/Liter)



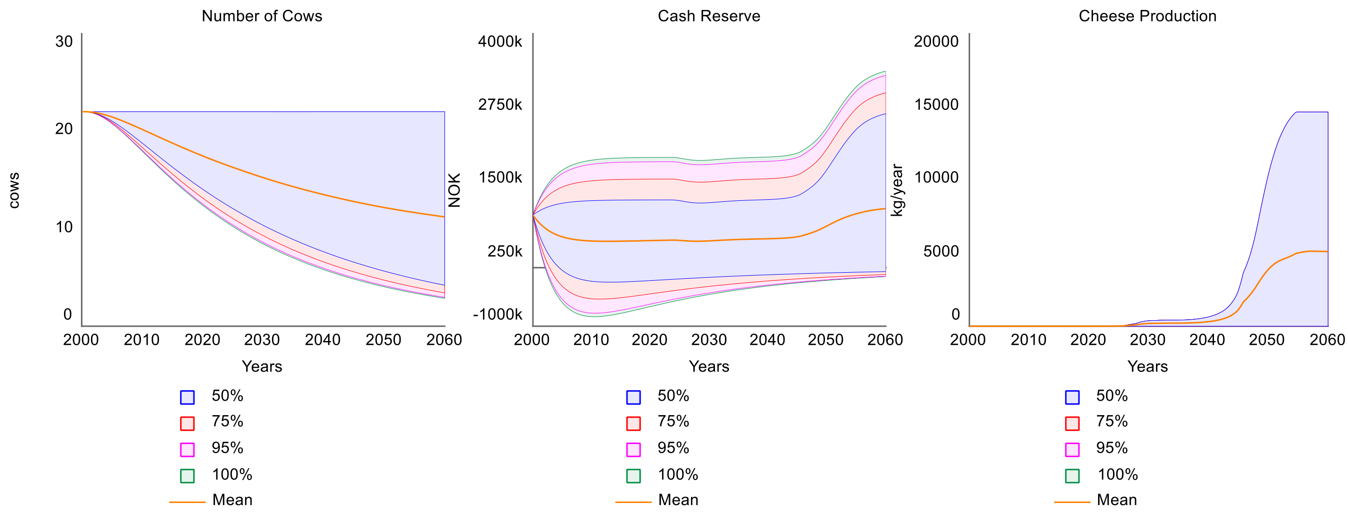
As expected, no matter how high the milk price, cow herd size will not exceed the hard cap of maximum allowed cow herd density, which is 1 cow/hectare. However, at half the usual milk price the cow herd can decline to as low as less than 5 cows. At the lowest milk price cash reserve does become negative (i.e. debt) but over the simulation it does appear that cash recovers to at least 0 NOK. At high milk prices the maximum cash reserve is around double the mean, but seems to decline to a lower value in the last decade of the simulation. For cheese production the 50% band is dominant over the course of the simulation, which suggests that the cheese price value is very sensitive, and any small deviation from the mean value of milk price can lead to substantial differences in cheese production. Interestingly when milk prices are lower than the middle value, some investment attempts may be made, but eventually shuts down the operation due to lack of profits.

Cheese Price (75 – 300 NOK/kg)



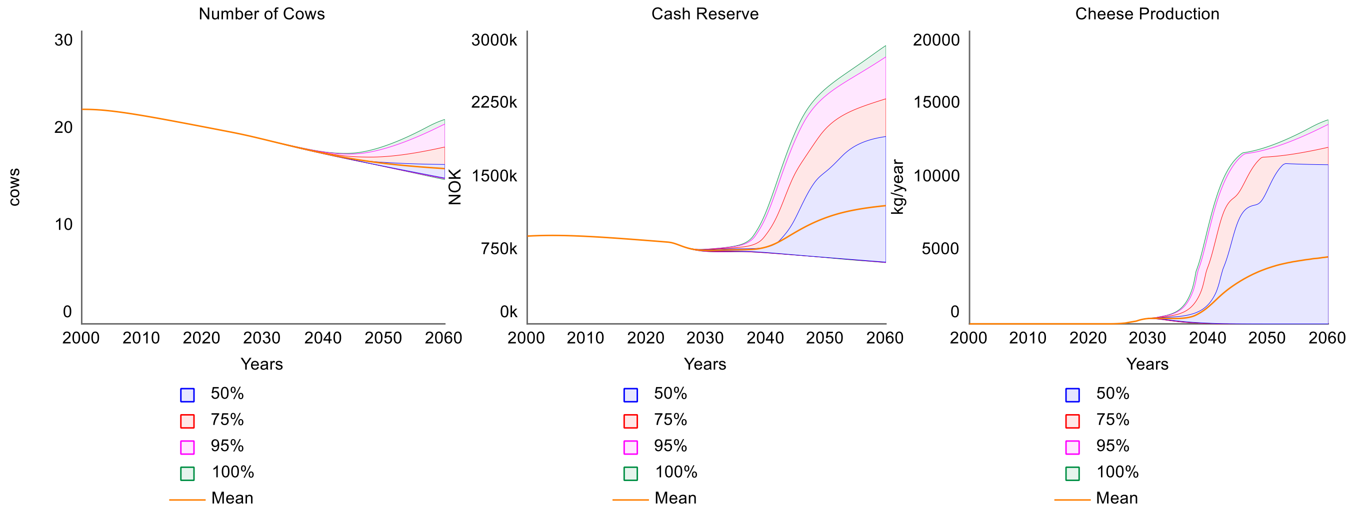
It seems in general that cheese price is very sensitive in the system, as very wide 50% bands are observed across all KPIs. Most notably, cash reserve has a hard floor in terms of possible values, but the upper limit does not show any bounds in the maximum value tested. Cheese production is very sensitive in that cheese prices lower than 150 NOK/kg could lead to near 0 investment in cheese production capacity.

Normal variable cost per cow (13,500 – 54,000 NOK/(cow*year))



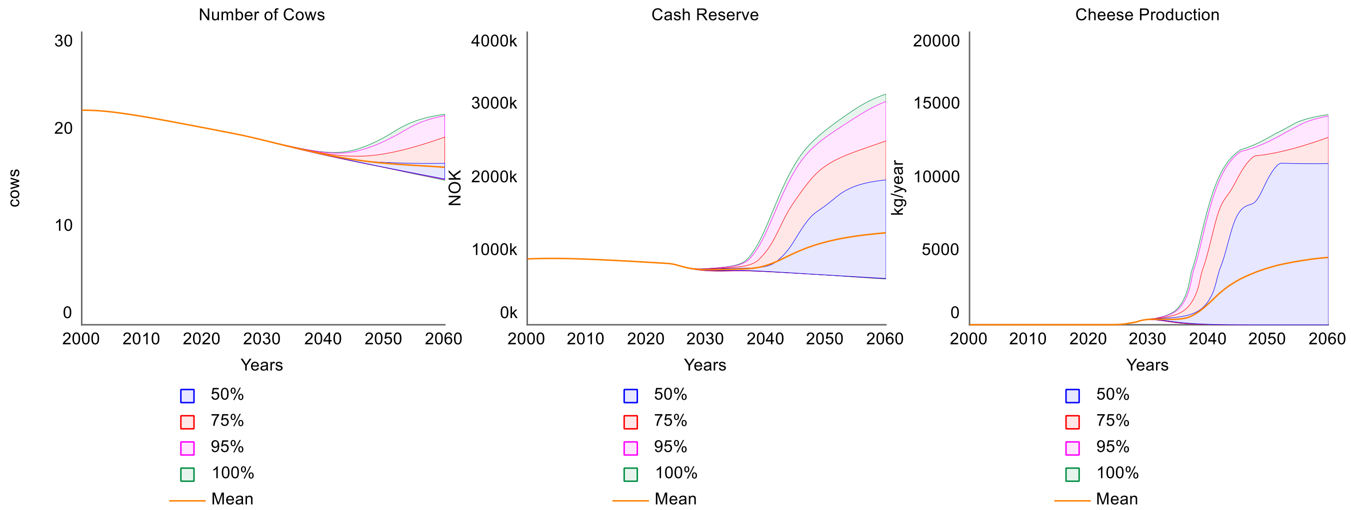
Cash reserve shows fairly normal confidence bands, while number of cows and cheese production show that they are very sensitive to cost per cow, as demonstrated by the nearly dominant 50% bands. Cash reserve can go negative with a high enough per cow cost, but it does seem to trend back towards 0 eventually.

average hourly wage (80 – 320 NOK/hr)



Interestingly, all KPIs have a firm “floor” value that is dominated by the lower 50% confidence band. The upper confidence bands have normal characteristics. Around 180 NOK/hr was found to be the threshold where cheese production is not profitable, and the operation shuts down.

cost of production per kg cheese (17.5 – 70 NOK/kg)



Similar to hourly wage, this parameter also influences the overall cost of cheese production; therefore, it was expected that similar uncertainty bands would form. Again, at a certain cost threshold, cheese production is not profitable, and shuts down. For cost of production per kg cheese, this threshold was approximately 38 NOK/kg. This value is close to the baseline value of 35 NOK/kg.

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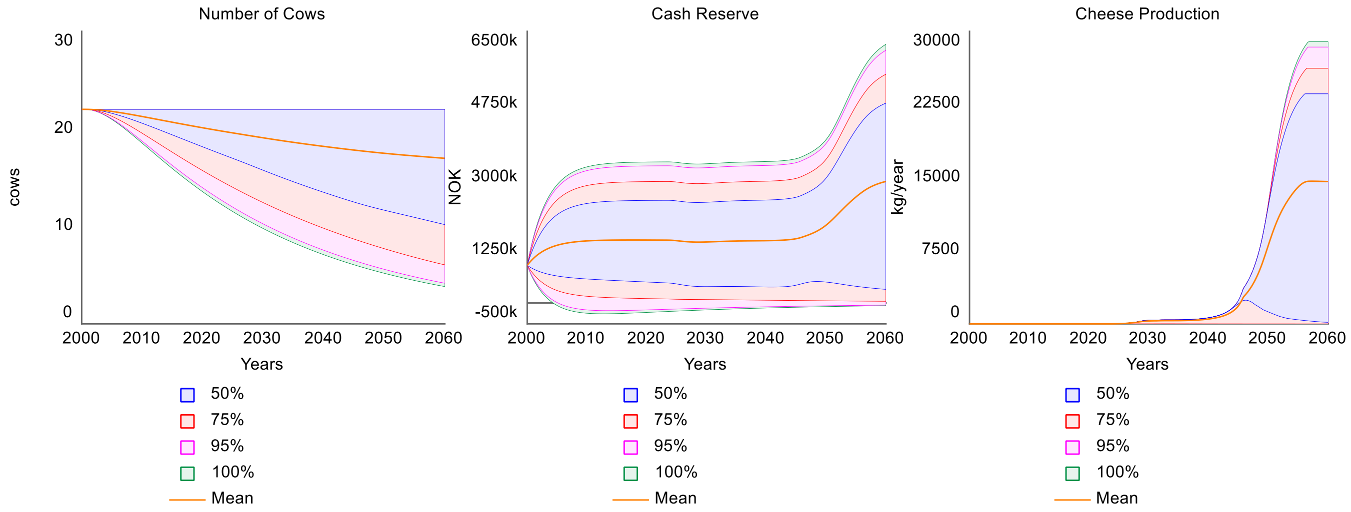
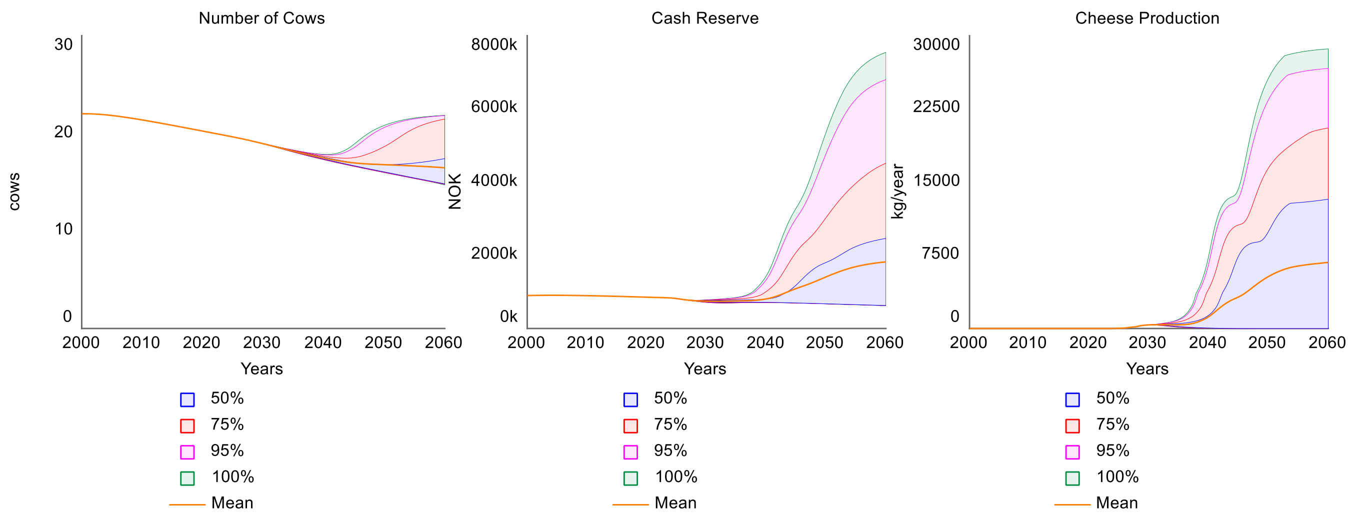
Milk yield (3300 – 13200 Liter/(cow*year))



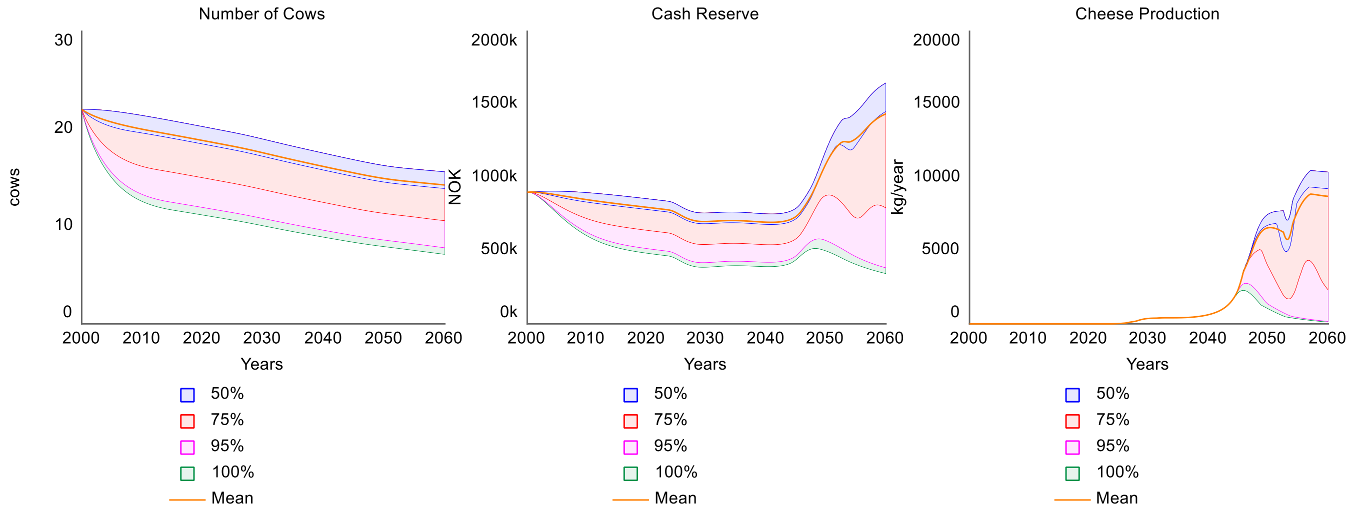
The cow herd again shows a hard ceiling determined by the farm area (22 hectare baseline) and maximum density of cow herd (1 cow/hectare baseline). As expected, as the milk yield declines, the desire to grow the herd size diminishes. When the yield is assumed to be as low as half the baseline, the herd size declines to around 5 cows. Cash reserve goes negative, but shows “normal” confidence bands with no floor or ceiling. Cheese production shows that it is sensitive to milk yield, and the operation can shut down when the yield goes down below 6,000 Liter/(cow*year).

milk per cheese (5 – 20 Liter/kg)



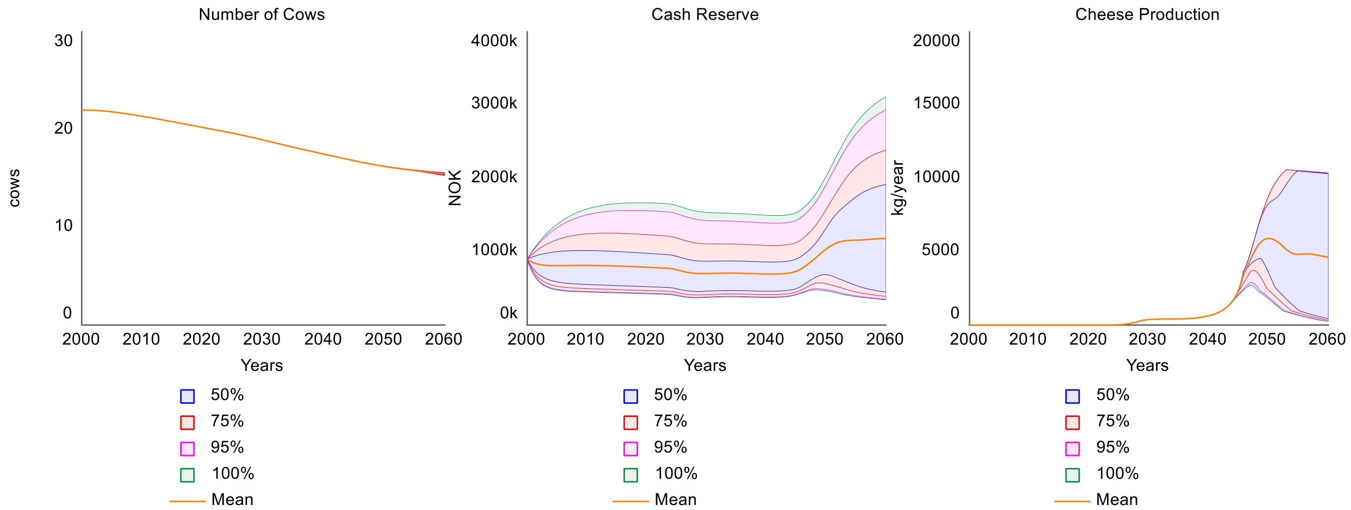
The confidence bands for KPIs again show a floor that indicate that at a certain point the cheese production shuts down, and the simulation becomes a scenario without any profit from cheese. This threshold is around 11.5 Liters/kg.

FARM AREA (11 – 44 hectare)



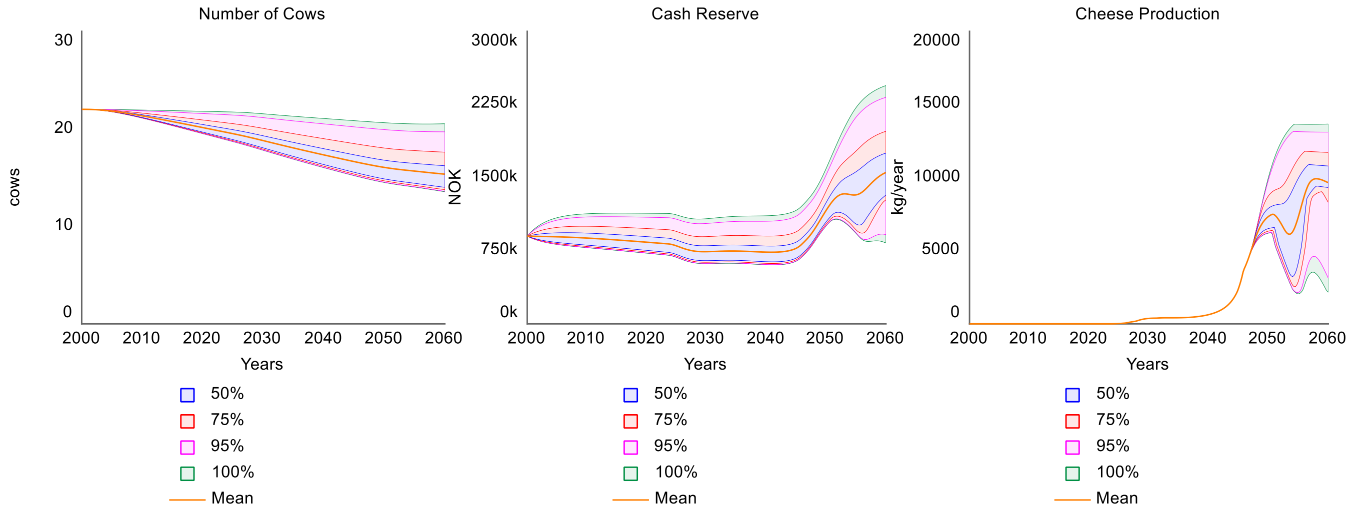
Interestingly, there is a clear ceiling for all three KPIs. It seems that with the current model structure, there is no incentive to expand the farm if it is not perceived to be profitable, regardless of the available area. When the farm is too small, then there is a requirement to reduce the herd size, and the farm cannot produce enough milk to allocate to a viable cheese production operation. This lower threshold is approximately 14.5 hectares.

fraction of disposable income (0.15 – 0.6 year^{-1})



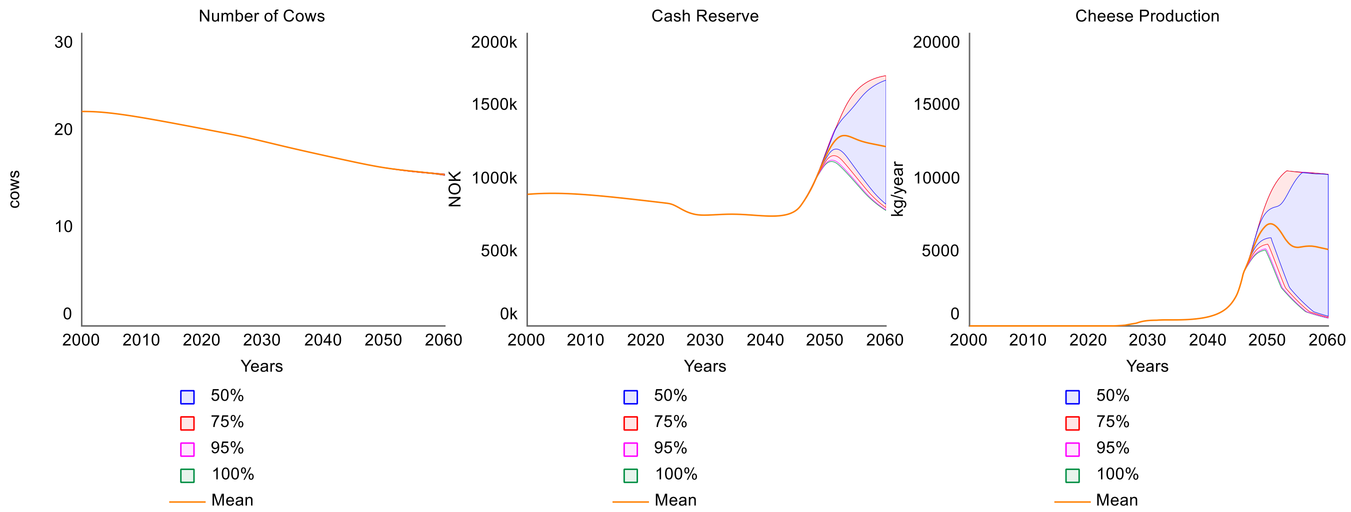
The number of cows is not affected by the fraction of cash reserve allocated to disposable income. The farm operation does not depend at all on the amount that the farmer "pays himself." As expected cash reserve has normal confidence bands ranging from 50% to 100%. Cheese production is again sensitive to availability of cash, as it is dependent on investment. At around the 0.35 year^{-1} value the cheese production operation ceases to be viable and shuts down.

normal cow lifetime



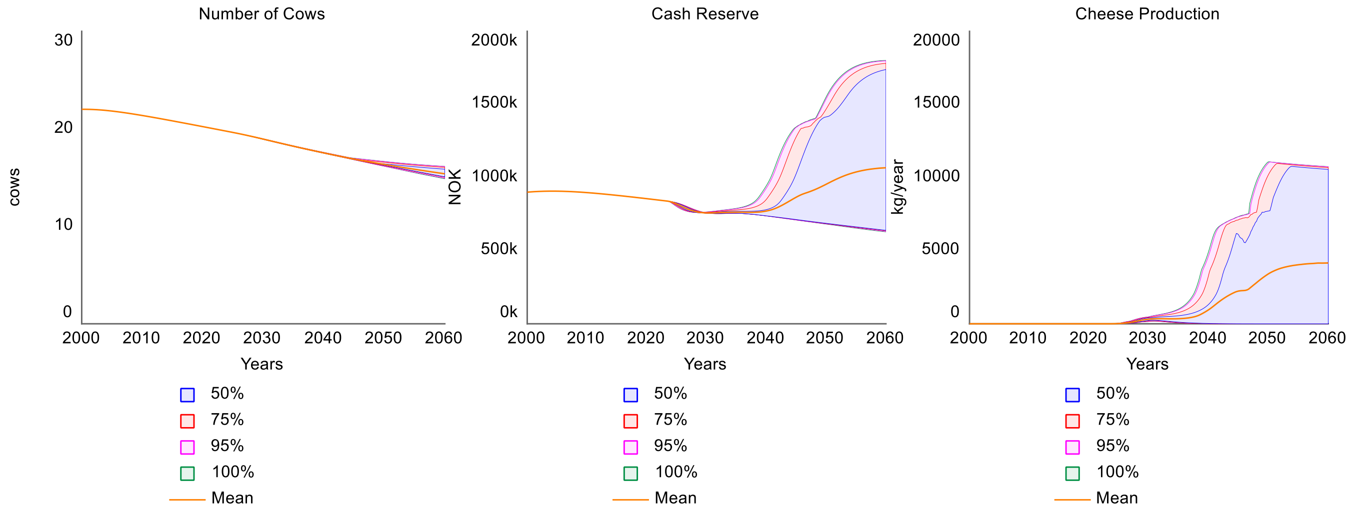
This is a very interesting test because it is in fact the longer cow lifetime that lead to the overall lower KPI values. This is because cows living longer means fewer cows are being retired, so there are less revenue from meat. Therefore, it has the equivalent effect of lowering the total farm revenue, so the ability to invest in cheese production declines. On the other hand, decreasing cow lifetime means more revenue from meat, so in future work this value can be better optimized.

capital coverage time (0.5 – 2 years)



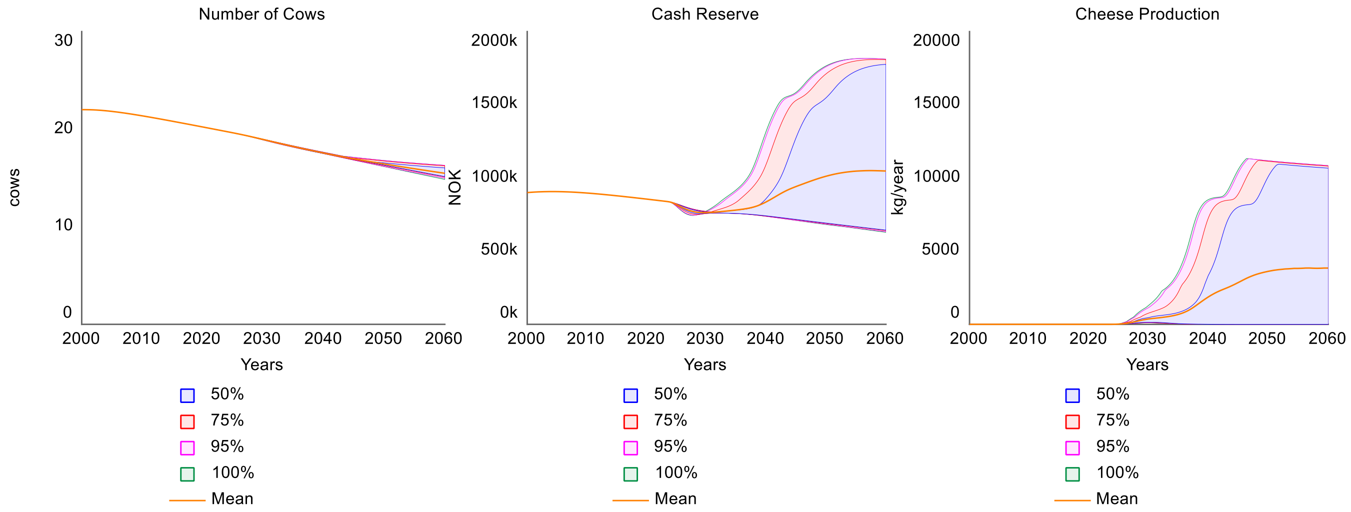
There is negligible effect on the number of cows, or due to delays in the system the effect is not reflected over the course of the simulation time. Because this parameter directly affects the readiness to invest capital into cheese production, it was expected that cash reserve and cheese production would be affected substantially. At around 1.25 years of coverage requirement, the cheese production operation stops being attractive.

time to allocate investment (1 – 4 years)



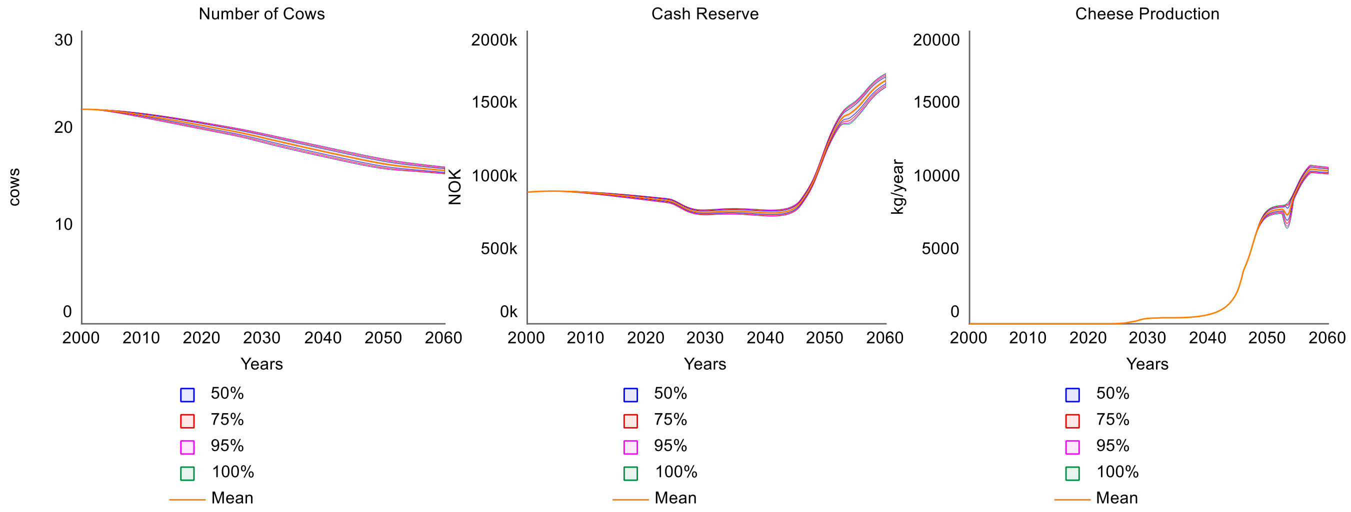
Cash reserve and cheese production are both very sensitive to how quickly the money is allocated to the cheesemaking operation; however, it doesn't appear to substantially affect the cow herd population. Cash reserve again has a "floor" that denotes a shutdown of cheesemaking operations, which occurs at the threshold of around 2.5 years or longer.

time to buy equipment (2.5 – 10 years)



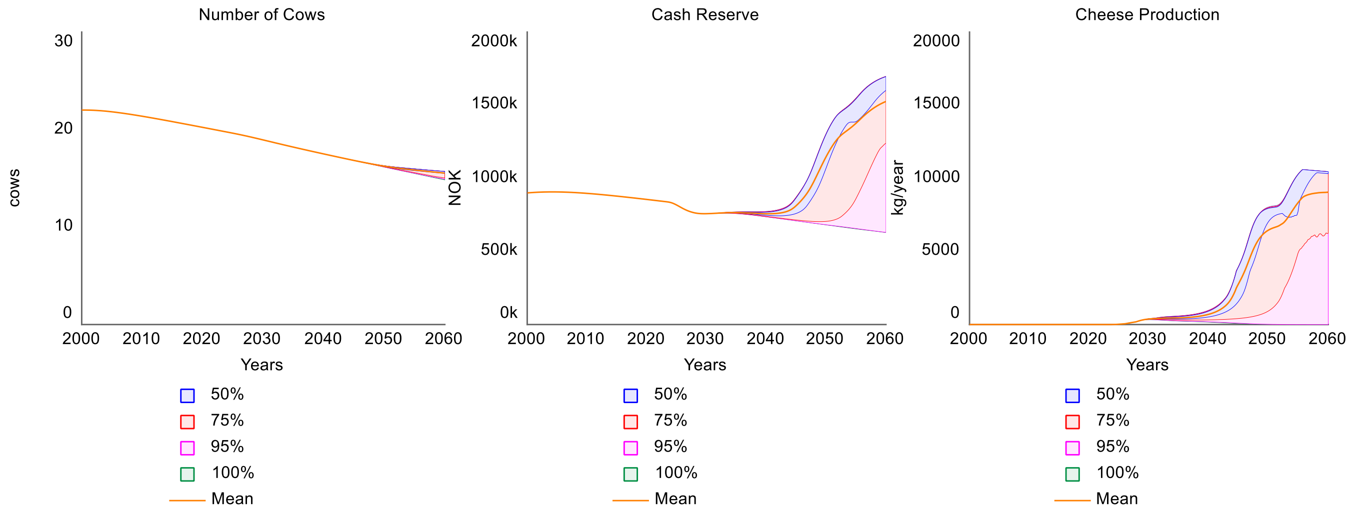
This is a remarkably similar result as the time to allocate investment, except that the number of cows is slightly more responsive. Cheese production is very sensitive to this parameter as well, with the lower 50% band dominating the lower half of the mean.

time to adjust farm viability perception (2.5 – 10 years)



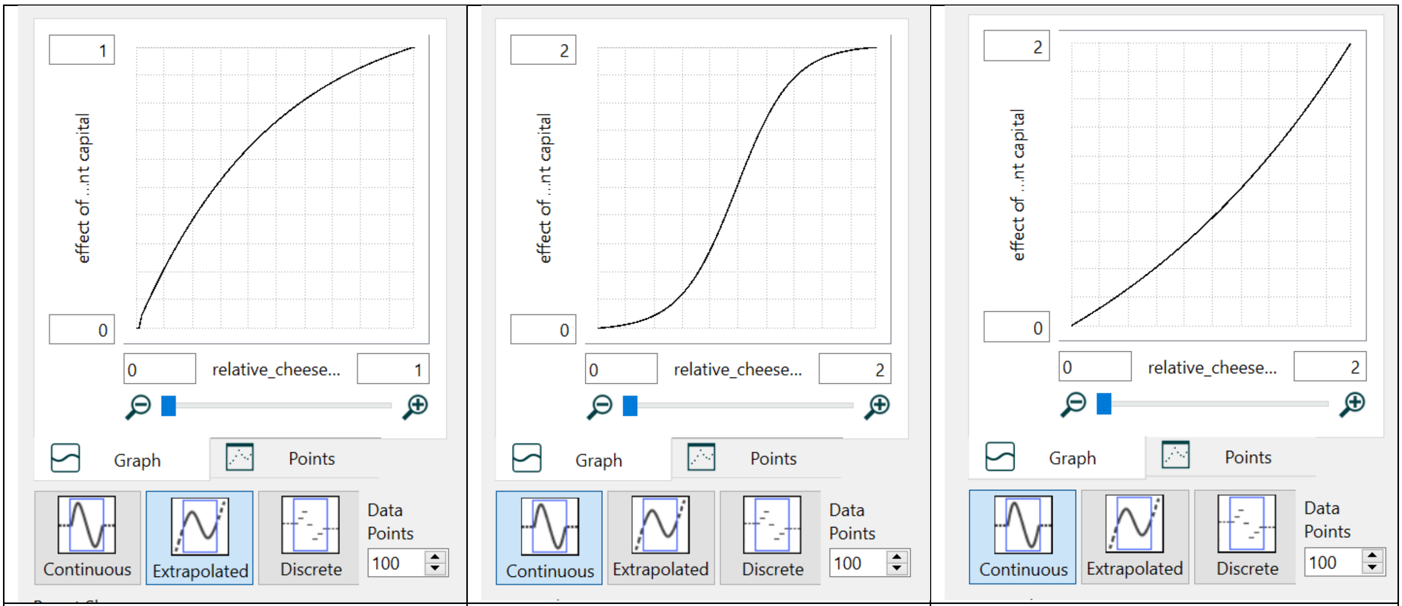
Surprisingly, there was negligible effect to the KPIs, including the number of cows, which the farm viability perception is most closely related to. It appears that regardless of the delay in perception, the farm holder eventually comes to a similar conclusion about the state of the farm, and behaves similarly.

time to adjust cheese viability perception (2.5 – 10 years)

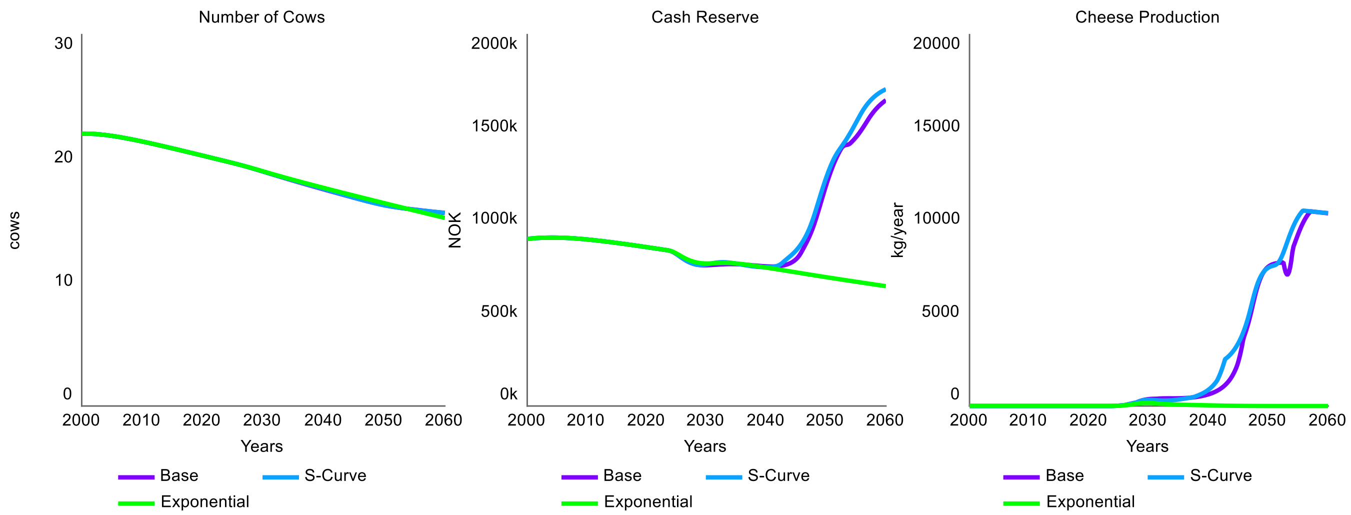


Paradoxically, it is the faster time to perceive viability that causes the cheesemaking operation to shut down. When the farm holder sees a decline in profit and operating expense ratio is elevated, it is the farmer that has a longer-term thinking strategy that persists through the financially difficult times. If the farm holder is too quick to act, then they forego the potential recovery and profit in the future, and shut down prematurely.

effect of relative capacity on equipment capital

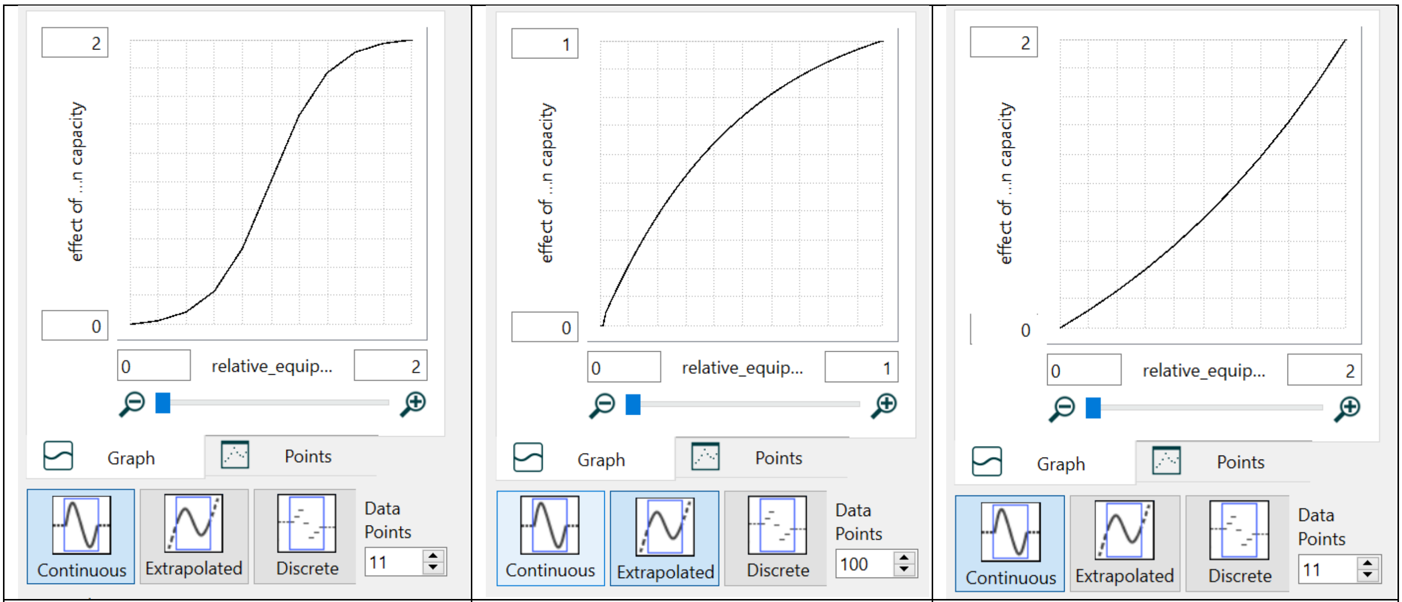


Baseline	S-Curve	Exponential

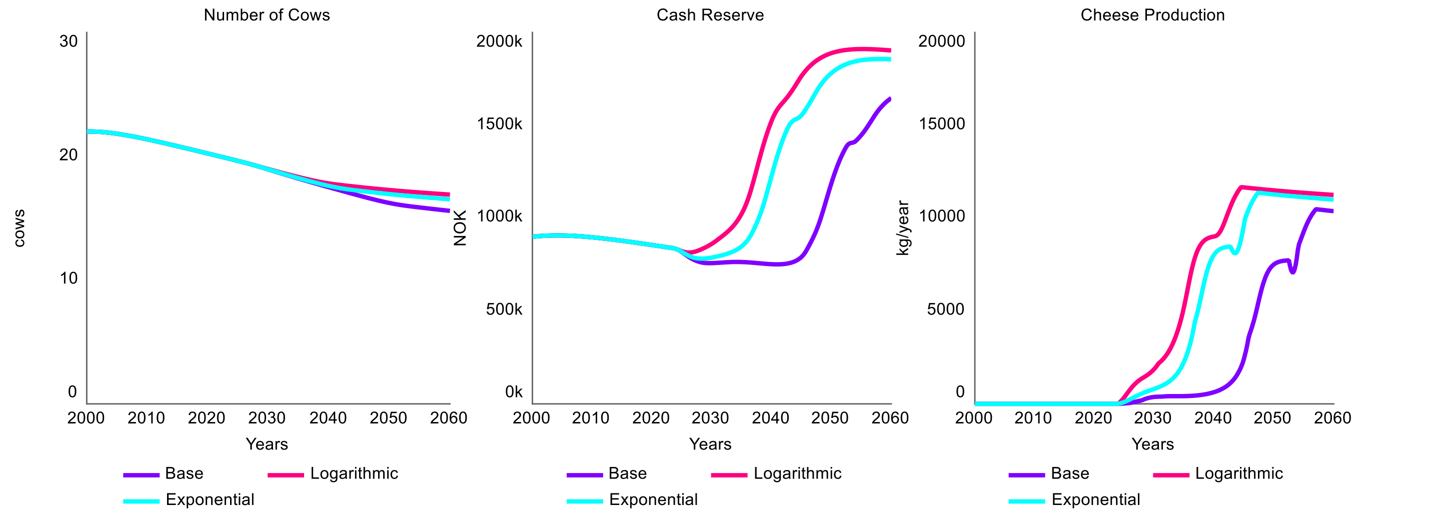


The baseline table function for effect of relative capacity is the leftmost shape. S-curve and exponential curves were evaluated in this converter. The exponential shape is notable because the cheese production operation never "gets off the ground" in this test. This is because of the relatively lower effect value when relative capacity is greater than 1.0. This leads to a desired equipment requirement that is markedly lower than the other two scenarios, and this leads to insufficient equipment purchase, and thus inadequate cheese sales.

effect of relative capital on cheese production capacity

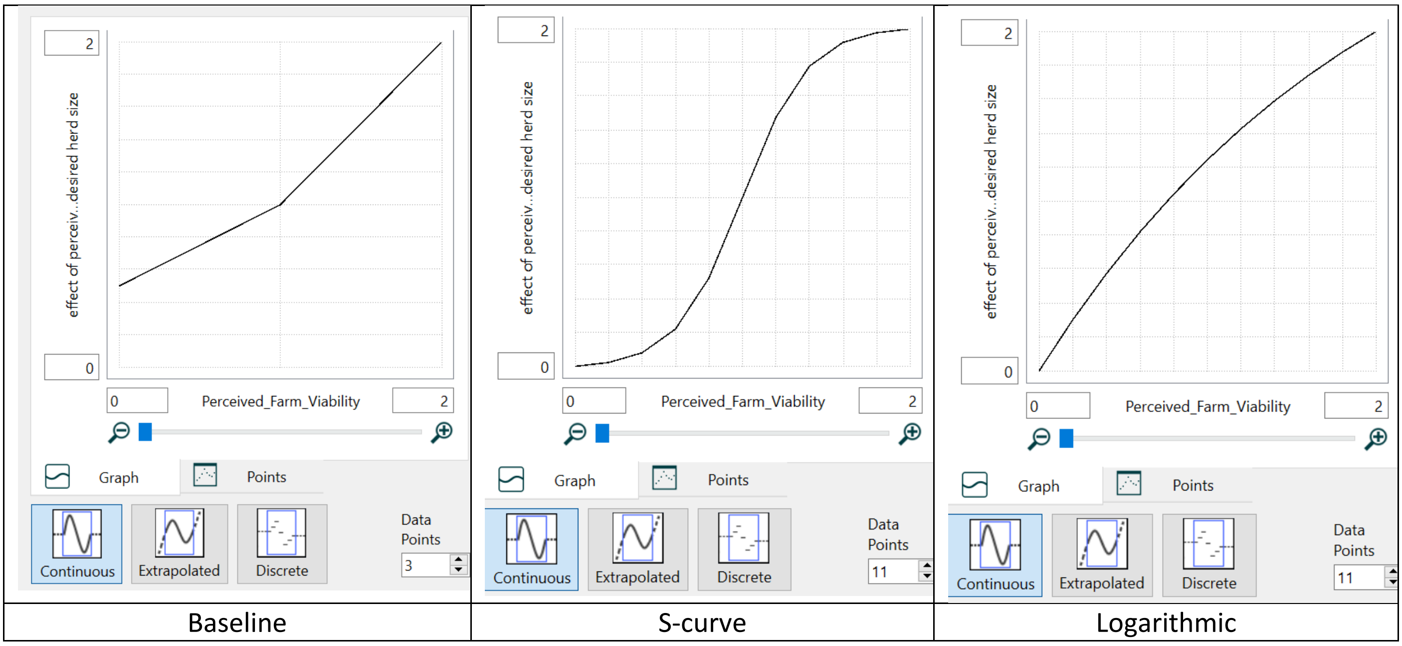


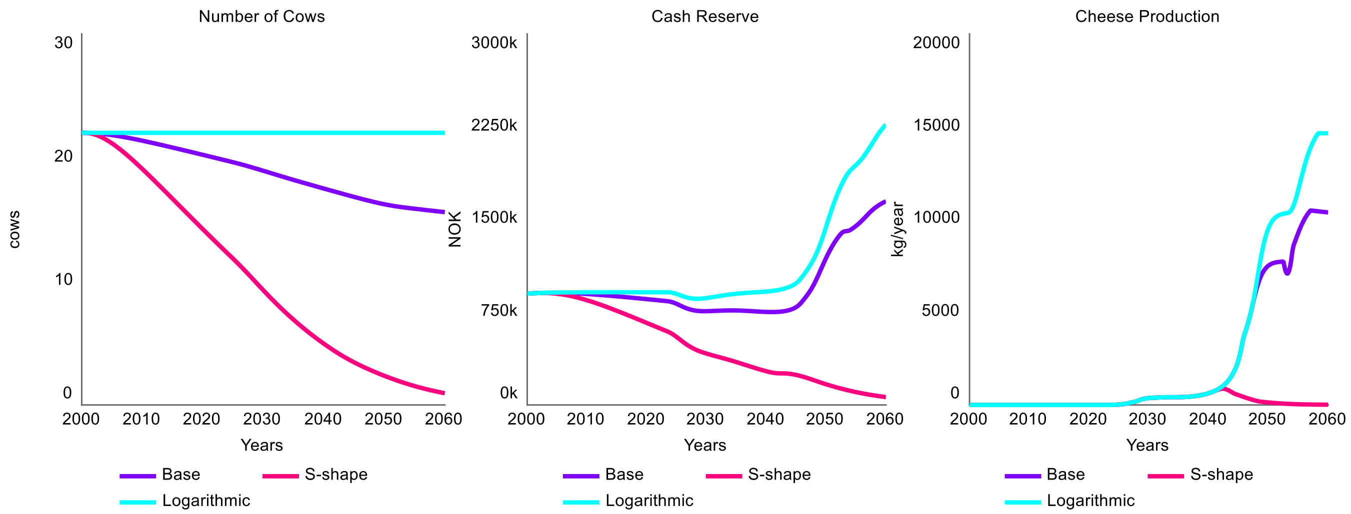
Baseline	Logarithmic (Extrapolated)	Exponential



Regardless of the shape of the table function, the system reaches the cheese production capacity of the baseline scenario. However, the alternative tests reach the end values much quicker than the baseline scenario. This is because of the S-curve baseline shape that is slow to "take-off," and delays the system from reaching its full cheese production capacity. Exponential test also has a scooped, concave shape, but it is still not as low as the S-curve, thus it is still quicker to increase compared to baseline.

effect of perceived viability on desired herd size





This sensitivity is essentially testing how strictly the farm holder evaluates the farm's financial performance. For S-curve, a lower than normal financial performance is viewed harshly, while greater than normal is viewed more favorably. Logarithmic has a harsher stance than baseline when lower than normal, but is more favorable when greater than normal financials. This disparity allows for the Logarithmic test to thrive beyond baseline, but the S-curve test becomes trapped in the strict views of less ideal financials, and cheesemaking never becomes viable.

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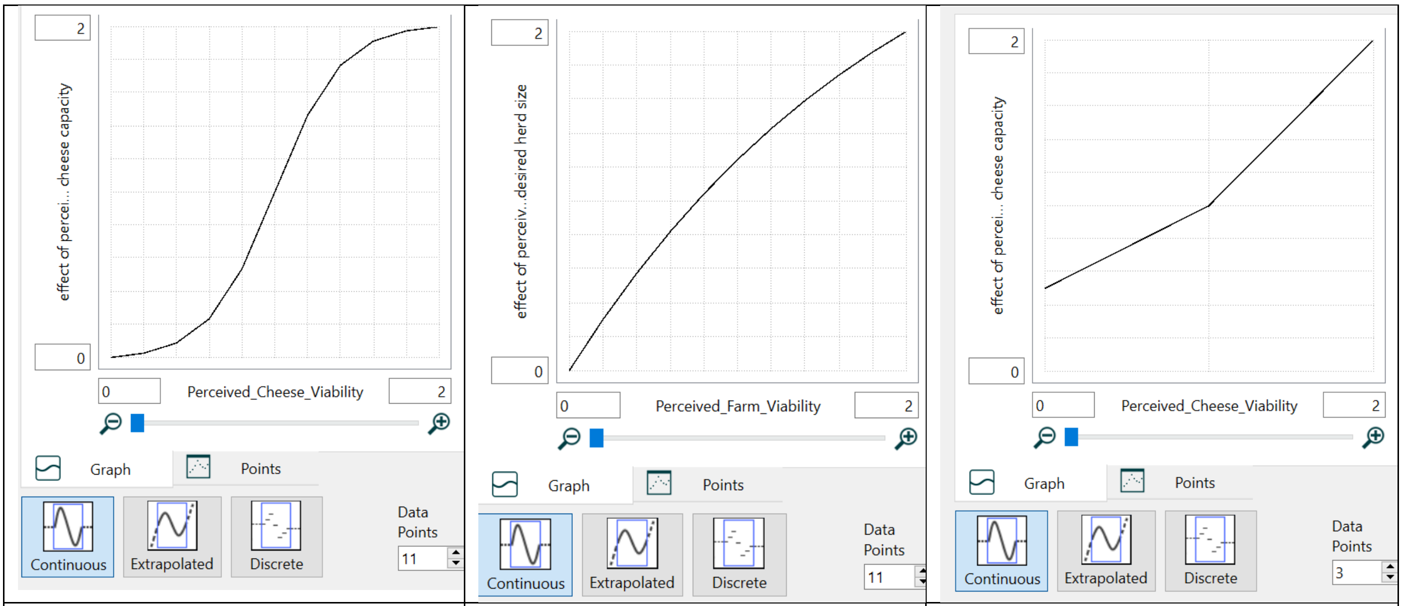
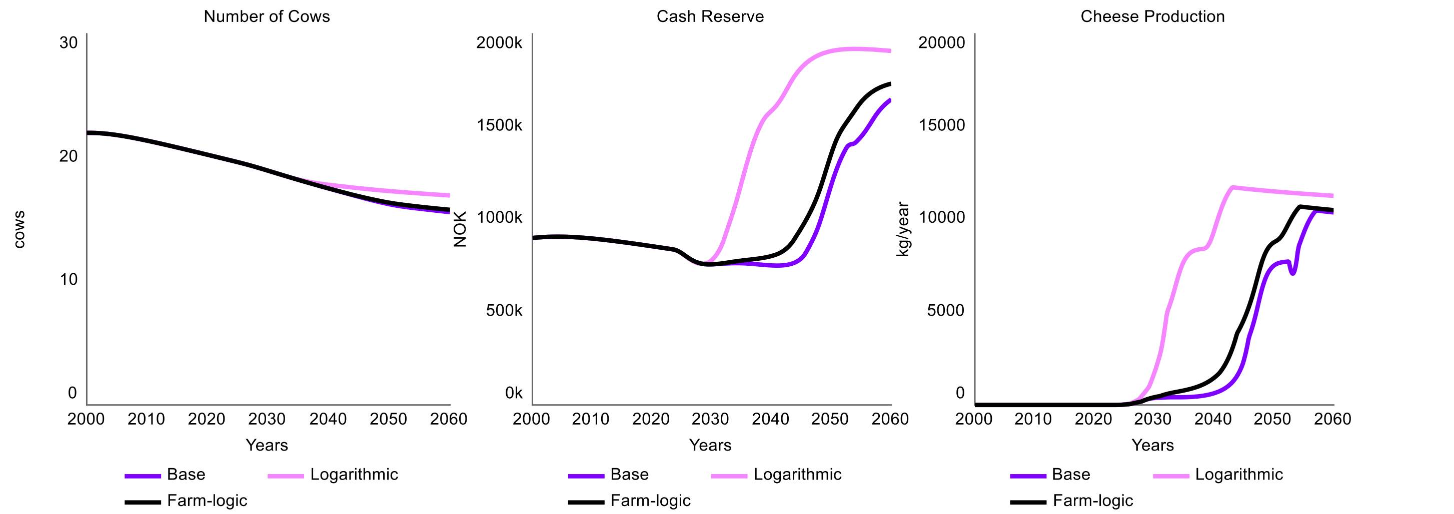
effect of perceived cheese viability on desired cheese capacity



Baseline	Logarithmic	"Farm-logic"



Similar to the farm viability effect, S-curve has a distinct disadvantage when the input value is less than 1, because of the drastically "scooped", concave shape. If the initial state of the simulation leads the input to be < 1.0, then the baseline scenario would be the last to "take-off," which is what is shown in both cash reserve and cheese production. Because of the arched shape of the Logarithmic test, the perceived viability of cheese production leads to a consistently elevated desired cheese capacity. The Logarithmic test does hit a ceiling eventually, where the desired cheese capacity and the required equipment investment amount cannot be met by the available cash reserve, and investment ceases around 2045.

Appendix D: Simulation Experiment Report

Per guidelines describe in in Rahmandad and Sterman (2012), the *minimum simulation reporting requirements* (MSRR) are summarized in this section.

- ***Software*** – Stella® Architect version 3.5 (3121)
- ***Simulation algorithm*** – Euler integration, DT = 0.03125 years
- ***Pre-processing*** – most base case exogenous inputs were unprocessed data points, except for the following:
    - Historical milk prices were extracted from the TINE.no annual reports, and an average of the 5 most recent years was used as the future projected milk producer price.
    - Cheese production cost described in Ashem et al (2014) was normalized into per cow cost and used as a parameter input as a per cow farm operation cost.

Equilibrium Setting

For the model to run at equilibrium, several switch parameters must be set with certain values. Most notably, the baseline simulation uses historical milk price data, which causes disequilibrium, so it must be switched to a constant average value. All the appropriate switch and parameter values are as follows:

- SWITCH_cheese = 0 (dimensionless)
- SWiTCH_oer_equilibrium = 0 (dimensionless)
- SWITCH_equilibrium_milk = 0 (dimensionless)

Baseline Scenario

The baseline scenario must engage the switches disabled in the equilibrium, and the following list of parameters must be set to the prescribed values:

- Switches
    - SWITCH_cheese = 1 (dimensionless)
    - SWITCH_oer_equilibrium = 1 (dimensionless)
    - SWITCH_equilibrium_milk = 1 (dimensionless)
    - POLICY_year = 2023
- Sector - Farm and Herd
    - Maximum_cow_density = 1 (cow/ha)
    - FARM_AREA = 22 (ha)
    - Normal_cow_lifetime = 4 (years)
    - Time_to_become_cows = 1 (years)
    - Time_to_be_heifer = 2 (years)
    - Fraction_female = 0.5 (dimensionless)
    - CATTLE_LIVESTOCK_ADJUSTMENT_TIME = 5 (years)
    - Normal_birth_rate = 1 cows/(cow*year)
    - [INITIAL] Cow_Herd = 22 (cows)
- Sector – Operation Revenues
    - [INITIAL] Perceived_Farm_Viability = 1 (dimensionless)
    - Time_to_adjust_farm_viability_perception = 5 (years)
    - Ideal_expense_ratio = 0.7 (dimensionless)
    - Fraction_disposable_income = 0.3 (dimensionless)
    - CALF_PRICE = 1700 (NOK/cows)
    - CATTLE_PRICE = 13000 (NOK/cows)
    - Subsidies = 225000 (NOK/year)
    - Milk_yield = 6656 (Liters/(cow*year))
- Sector – Costs

- Normal_variable_cost_per_cow = 27000 (NOK/(cow*year))
- Farm_operation_costs = 225000 NOK/year
- [INITIAL] Perceived_Cheese_Viability = 1 (dimensionless)
- Time_to_adjust_cheese_viability_perception = 5 (years)

- Sector – Decision to Invest
  - Time_to_allocate_investment = 2 (years)
- Sector – Desired Capacity and Budget
  - [INITIAL] Desired_Cheese_Production_Capacity = 0 (kg/year)
  - Time_to_adjust_cheese_capacity = 2
  - STARTING_CHEESE_PRODUCTION_CAPACITY = 2000 kg/year/year
  - Normal_cheese_production_capacity = 2000 kg/year
  - Normal_equipment_capital = 200000 NOK
  - Capital_coverage_time = 1 (year)
  - Average_hourly_wage = 160 NOK/hour
  - Cost_of_production_per_kg_cheese = 35 NOK/kg
- Sector – Hiring Labour
  - Hours_labour_per_milk_processed = 3.5/200 (hour/Liter)
  - Adjustment_time_staff = 2 (years)
  - POLICY_hiring_effort = 1 (dimensionless)
- Sector – Equipment Procurement
  - Time_to_buy_equipment = 5 (years)
  - Time_to_assess_retired_equipment = 2 (years)
  - Equipment_lifetime = 10 (years)
- Sector – Cheese Production
  - CHEESE_PRICE = 150 (NOK/kg)
  - Milk_per_cheese = 10 (Liters/kg)
  - Milk_loss_assumption = 0.06 (dimensionless)

Increased Hiring Effort

This scenario is aimed at trying to increase the *actual cheese production possible* variable. The desired cheese production capacity could be very high, but if there is not the labour to support it, then hiring would be a limiting factor.

- POLICY_hiring_effort = 3 (dimensionless)
- All other switches and parameters = baseline

Expediting Equipment Purchase

Actual cheese production possible has two limiting factors: labour and equipment availability. If increasing hiring effort does not improve the bottleneck, then the farm holder can try buying equipment faster.

- Time_to_buy_equipment = 2.5 (years)
- All other switches and parameters = baseline

Shifting to Direct-to-Consumer Premium Market

Instead of competing for the lowest price at the grocery store, the dairy farm can market as a premium product to be sold directly to customers over the internet or at a farm stand or local market stalls.

- CHEESE_PRICE = 200 NOK/kg
- All other switches and parameters = baseline

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