ANALYZING FARM LEVEL PRACTICES AND POLICIES FOR A FINANCIALLY VIABLE SHEEP FARM ENTERPRISE USING SYSTEM DYNAMICS: FOCUSING ON FIBER PRODUCTION AND MARKETING

A Thesis

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by

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ABSTRACT

Small flock ruminant fiber producers in the Northeastern United States (NE US) find themselves at a disadvantage when attempting to market their fibers. Besides having limited market options there are a variety of bottlenecks in the direct market supply chain that they must navigate (e.g. fragmented supply chain, vintage machinery that is costly to run and maintain, and a limited scale/volume due to limited quantity of quality fibers).

There are a number of hypotheses in the NE US small flock fiber community concerning how to increase the profit from fiber, from increasing the quality of fiber on the animal to collectively producing products for the consumer market. But the question remains as to what actions would truly result in a successful fiber-producing business.

To identify interventions that may help the farmer to increase profits this thesis focuses on analyzing farm level practices and policies. To do this a system dynamics model was built using data gathered from interviews and literature. Once built, shocks were applied to model parameters and the resulting trends were discussed including policy and practice recommendations including: 1) developing a loan program that would enable beginning small ruminant farmers to start with larger herd sizes coupled with educational program that will help them to identify markets and navigate their supply chain; 2) developing a regional check-off program to support branding and marketing efforts and related research; 3) recommending farmers to raise small ruminants that would increase production of all products (wool, meat, livestock) and; recommending farmers to grow storage capacity with their inventory.

Dana Michele Havas

BIOGRAPHICAL SKETCH

Before pursuing an M.S. in Agricultural Applied Economics at Cornell University Dana M. Havas had previously studied Chemical and Material Science Engineering (and earlier still had a career as a NYC union carpenter). It was through her volunteer work with CNY regional animal fiber producers that Dana decided to pursue a graduate degree with the goal of conducting research that could aid the CNY fiber producing community in becoming more economically sustainable.

This thesis is dedicated to the farmers who cloth us; may your work never be forgotten or taken for granted.

ACKNOWLEDGMENTS

Thank you to the many people who contributed to this text especially Alethia Chan and Andrea Hohman, my two amazing undergraduate research assistants who contributed so much of their time to building a stronger understanding of the NYS and NE US animal fiber supply chain. My advisors; Dr. Miguel Gomez, Dr. Mark Milstein, & Dr. Luis Luna-Reyes my who helped me stay on track when something shiny came along and asked probing questions that made me think more deeply about this work. And of course, the many fiber farmers and other NYS and NE US fiber supply chain stakeholders, who have answered my unending questions and always seemed to magically make time in their very busy schedules, I am forever grateful and count myself lucky to be considered a part of this amazing community.

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Chapter 1 Introduction

NYS & NE US small ruminant fiber[1] producers are primarily small flock farmers, with over 87% of all wool producing sheep farmers having less than 100 head herds. Besides sheep there are also goat, alpaca, rabbit, and bison farmers in NYS and the NE US that also produce fiber, but wool is the most common with over 250,000 lbs. wool produced in 2017 according to the USDA agricultural census of that same year.

These small flock producers only produce 41% of the wool in NYS indicating the scale of their enterprises. This small scale restricts the availability of markets which these producers can contribute to and increases costs associated with reaching a market forcing these farmers to become creative with their marketing and distribution channels. This creativity appears in their willingness to pursue value-added products and direct marketing which increases the income from their wool, but also increases the costs associated with processing their wool as a result of economy of scale and the infrastructure available to these producers. Regardless small flock producers do receive more USD/lb.-wool than the larger producers as is evidenced by the significant drop-off of price per lb.-wool from $1.53 per lb.-wool for farmers with 25 – 99 head to $0.56 per lb.-wool for farmers with 100 – 299 head. Even still, this increase is rarely enough to help these farmers break even, an often-indicated goal, as feed costs alone are often thousands of dollars a year for an operation with just 25 head (overwinter). All of these considerations

[1] There are numerous types of animal fibers produced throughout the world: wool, cashmere, mohair, angora, to name a few. Moving forward when discussing all manner of animal fibers, the word ‘fiber’ will be used; when a specific animal fiber is discussed the specific fiber will be referred to by name, as is the case later in the thesis when the discussion turns specifically towards sheep’s-wool (wool).

result in the problem statement that this thesis seeks to address; What can small flock small-ruminant fiber producers in NYS and the NE US do to increase profit from their wool.

This thesis uses System Dynamics (SD) to address this question. SD is a modeling technique that is ideal for complex, dynamic systems that involve multiple components and feedback loops – as is often the case in agricultural settings. SD modeling enables the user to change a single parameter and see how that parameter affects the remainder of the system. This is ideal for exploring potential practices and policies.

To analyze the system the author considered the many hypotheses she encountered in the interviews concerning what actions (may) help these farmers increase profits and ensure longevity of their enterprise. Including: What role do different breeds play in sheep farm enterprise profitability; Should farmers max-out pasture capacity from the start or grow the enterprise; To what extent does initial capital affect the success of the enterprise; What role does farm storage capacity play in the success of the enterprise; Would increasing wool pool prices increase the longevity of the enterprise; and What role does market frequency play in the success of the enterprise?

After analyzing the system the author found that breed selection plays a significant role in the success of the sheep farm enterprise and the decision on the part of the farmer depends greatly on what market channels they have identified; By maxing out their pasture capacity from the beginning the farmers makes greater profit over the lifetime of the enterprise, even if capital is limited; Farm storage capacity should grow as needed; access to wool pool does not help, and my in fact hurt, the success of the sheep farm enterprise and no reasonable wool pool price changes this outcome; and as inventory increases the farmer should search out more opportunities for a market.

Chapter 2 Literature Review

Agricultural systems are complex interconnected systems that involve many different players, environments, feedback systems. etc.…. To make successful farm management decisions the various components of agricultural systems cannot be considered in isolation (Higgins et al., 2010; Jones et al., 2017; Mccown & Parton, 2006; Rich, Brent Ross, Derek Baker, & Negassa, 2011; Tedeschi, Nicholson, & Rich, 2011). According to Jones et. al. (2017) there are 2 types of models that are useful in making farm management decisions: statistical and dynamic. Both of these models can "provide information for supporting decisions and policies [by] describing how the agricultural system responds to the external environmental drivers as well as decisions or policies under consideration."

Statistical models are the typical model one would expect to see in economic studies. They take historical data and calculate historical trends in production, supply, demand, prices, etc. Due to the static nature of these models they are most helpful to "provide insights about historical influences on past yields and used to inform other kinds of models"(Jones et al., 2017). Dynamic models based from both qualitative and quantitative data "explicitly modeling the structure and dynamics of the supply chain" (Rich et al., 2011) involve feedback systems and interact the various components of the model. This modelling technique offers the farm manager an opportunity to explore a variety of different policy actions and can help design responses to a system shock. While these characteristics are attractive some researchers have identified drawbacks/concerns as discussed by McCown (2006), including: 1) by overinvesting in the modeling of production systems and underinvesting in the modelling of farm management systems; 2) failing to engage with the stakeholder farmers; and 3) preoccupation of researchers with model building opposed to the application of the model for the farmer. These three identified concerned are addressed by the practitioner and the use of system dynamics modelling.

System Dynamic (SD) models are a type of dynamic model that simulates, over time, the comprehensive structure and dynamics of a given system within a defined system boundary (Rich et al., 2011). SD models are unique in that when properly constructed they aggregate knowledge from throughout the system and can be applied to a broad range of complex applications. An ideal system for which SD models can be applied involve exogenous factors, interdependent “components, mutual interaction, information feedback, and circular causality” (Tedeschi et al., 2011). With SD models it is the resulting trends and patterns that are important because it is these trends and patterns that offer the user an opportunity to explore the system reaction to different policy options and applied shocks. According to Vennix (1996) there are four specific types of problems which SD models are appropriate: 1) a dynamically complex problem (one for which the dynamics are important and for which unintended responses or outcomes are likely); 2) a recurring or persistent problem, perhaps one that has been unsuccessfully addressed in the past; 3) a problem for which is it possible to generate a “reference mode” behaviour over time that describes the inter-temporal nature of the problem; and 4) a problem involving a system that lends itself to thinking in stock and flow processes.

Considering Vennix’s description of an ideal problem for which SD is applied easily translates to agricultural systems, including improvement of the farm level wool supply chain.

While SD has not been overwhelmingly applied to agricultural models there are a number of researchers who have done so, a sampling of which is represented in Table 1.

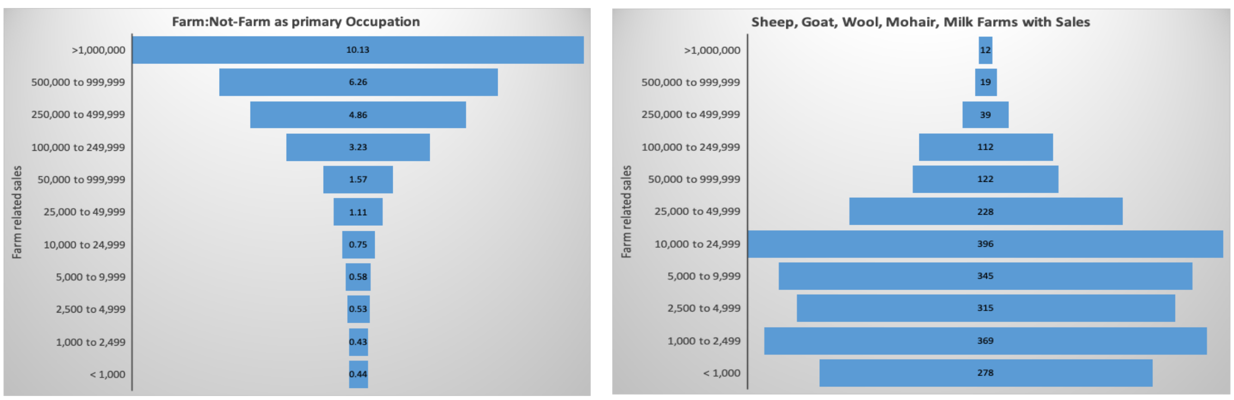
Table 1. Examples of SD uses in agriculture research

Author/Year	Topic	Location
(Meadows, 1970)	devise stabilization policies of these hog, chicken, and cattle industries production activities	USA
(Conrad, 2004)	understand the propagation of effects of large-scale disruptive events on cattle and corn production cycles	USA
(Rich, Perry, & Kaitibie, 2009)	feasibility of certification system in beef export value chain	Ethiopia
(Guimarães, Tedeschi, & Rodrigues, 2009)	biological impact on the herd dynamics of dairy goats"	Brazil
(Parsons et al., 2011)	integrated crop-livestock model to study the sheep farming systems	Yucatán peninsula, Mexico
(McRoberts, Nicholson, Blake, Tucker, & Padilla, 2013)	feasibility of rural dairy cooperative	Mexico
(Naziri, Rich, & Bennett, 2015)	examine potential of CBT approach to enhance market access for livestock	Namibia
(Lie & Rich, 2016)	examine feeding systems to achieve higher milk productivity and increased income for producers	Nicaragua

This body of work contributes to previous research in that adds to the ever-growing list of agricultural SD models while it explores a topic not before studied using system dynamics – the small-flock small ruminant fiber production and marketing of NYS & NE US wool. This system is a dynamic, complex system that involves multiple components and feedback loops, as you will see in Chapter 4, an ideal setting for SD modeling.

Chapter 3 Context: NYS fiber production & markets

Just under half of all farmers in NYS consider farming their primary occupation (28,343:29,522), but when broken down in respect to farm sales the number of farmers who consider farming their primary occupation decreases as sales decrease (Figure 1a). For these farmers, more often than not, farming is a lifestyle choice. This is often the case with small-flock small ruminant farmers which include fiber producing animals (Figure 1b) (USDA, 2017c). From conversations with a number of such farmers in the NE US it was found that these farmers are often looking to simply 'break-even' with their flocks (or at least cover the cost of feed and hay).



(a) ratio of farm:not farm as primary occupation (b) fiber producing farms and their farm related sales

Figure 1. Trends related to fiber production in NYS according to the 2017 USDA Ag. Census

To do this small ruminant fiber producing farmers often rely on all of the markets that are available for their animals; livestock sales, meat sales, and fiber sales. While each of these market avenues are important for the small flock producer, this thesis focuses on the fiber market as a revenue source. There are a variety of fibers produced by small ruminant in NYS and the NE US including: mohair, alpaca, and wool amongst others.

Mohair production

According to the USDA Agricultural Census 50 NYS farms reported mohair related sales in 2017, totaling 4,447 lbs. worth $5,000. While the number of farms and sales decreased from

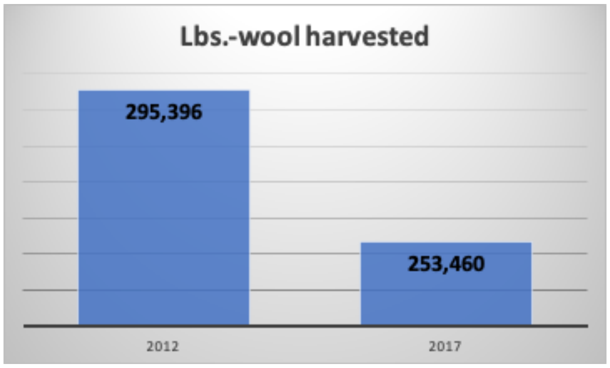
2012 to 2017, from 54 farms and $6,000, the total production increased by 416 lbs. from 4,031 lbs.-mohair (USDA, 2017a).

Alpaca production

According to the same USDA census there were 462 alpaca farms in NYS with a total of 6,069 alpacas. This different from the 2012 census with 449 farms and 6,403 alpacas, 2017 had more farms and fewer alpacas. The USDA census does not record lbs.-alpaca fiber. Since, in the United States consideration of alpaca as a fiber animal is a recent occurrence (Sodums, 2019). On average an alpaca grows 5-10 lbs.-fiber per year (Alpaca Owners Association, n.d.). This leads to an estimate of approximately 45,518 lbs.-fiber/year (using the average of 7.5 lbs.-fiber/animal-year). Just as with any other fiber there are a variety of grades suitable for a variety of end uses.

Wool Production

The same 2017 census reported that there are 2113 farms with sheep in NYS, of these only 801 claim wool production with a total of 253,460 lbs.-harvested wool worth $215,000. While the total wool-related profit increased from 2012 the wool harvest decreased (Figure 2). Being that the intermediated (wool pool) price for wool was lower by $0.02 in March of 2017 than in March of 2012, $0.55 on 03/14/2017 and $0.57 on 03/13/2012 (Robison, 2012, 2017), one possible explanation for the increase in value alongside a decrease in production may be that more farmers are pursuing direct market channels as has been seen in small family-farm food operations (Bauman, Mcfadden, & Jablonski, 2018; Low et al., 2015). While this is a positive trend these farmers still face numerous challenges in reaching a value-add market due to economies of scale and limited available supply chain infrastructure.



(A) lbs. of wool harvested

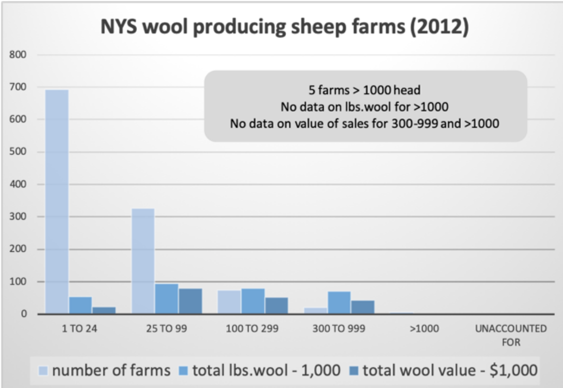
(B) total value of harvested wool

Figure 2. Comparison of wool harvest from 2012 and 2017 USDA Agricultural Census

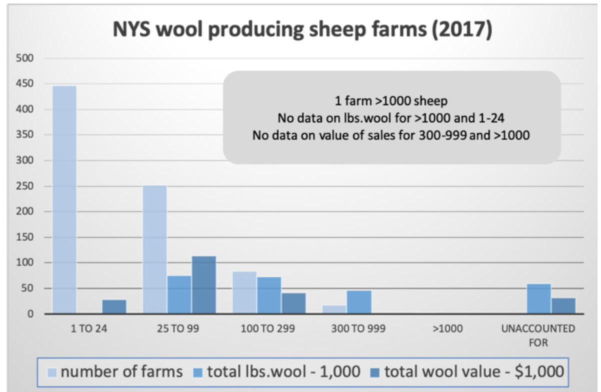
Of the 801 wool-producing sheep farms in NYS 447 farms have less than 25 sheep, 252 have between 25 and 99 sheep, 83 have 100 to 299 sheep, 18 have 300 to 999 sheep and 1 has greater than 5,000 sheep, making the majority, ~87%, of NYS wool producers, small flock shepherds (here defined as < 100 head). Of the 253,460 lbs.-harvest wool in 2017; 30,553 lbs.-wool was produced by the < 25 head sheep farms, 74,734 lbs.-wool was produced by 25-99 head sheep farms, 73,227 lbs.-wool produced by 100-299 head sheep farms, 46,416 lbs.-wool produced by 300 – 999 head sheep farms, and 28, 480 lbs.-wool by the >5,000 head sheep farm[2]. To break down the value of the 2017 wool harvest (clip), $28,000 was attributed to the 447 1-24 sheep farms, $114,000 was attributed to the 252 25-99 sheep farms, and $41,000 was attributed to the 83 100-299 sheep farms, leaving $32,000 attributed to the 18 300-999 sheep farms and the 1 > 5000 sheep farm (Figure 3b) (USDA, 2017b). Figure 3a shows the same data from the 2012 USDA Agricultural Census.[3]

2 * estimated using an average of 12 sheep per farm for >25 sheep farms and 5001 sheep on the >5000 sheep farm and the 59,003lbs wool produced by <25 & >5,000

3 Because this important data is missing this report refers back to 2012 data on wool production per farm which has data on wool produced for the 1 – 24 head farms.



Total 1117 wool producing farms
(see Figure A 1for census data)
(a) 2012



Total of 801 wool producing farms
(see Figure A 2 for census data)
(b) 2017

Figure 3. Farms, volume, and value of wool produced in NYS from the 2012 and 2017 USDA Ag Census

While producing only ~41% of the wool the small flock farmers, <100 head, received a greater per pound income from their wool than farmers with 100 head or more. According to data from the 2017 USDA Census producers with less that 25 head & 25 – 99 head sheep received $0.92 & $1.53/lb.-wool (Figure 4) respectively, one hypothesis is that this is likely due to there being a number of farmers in these groups that focus on wool as a product. The slightly higher income in the 25 – 99 head group is likely due to them having enough quantity to create value-added products and offer consistent goods to a direct market. Producers with 100 – 299 and over 300 head sheep made $0.56 & $0.43/lb.-wool respectively. They had the quantity to reach a market, but the focus of their business is often on meat production and creating a consistent supply to meet lamb and mutton demand. Therefore, there is little reason make an effort to reach a market their wool beyond baling and selling to a wool pool.

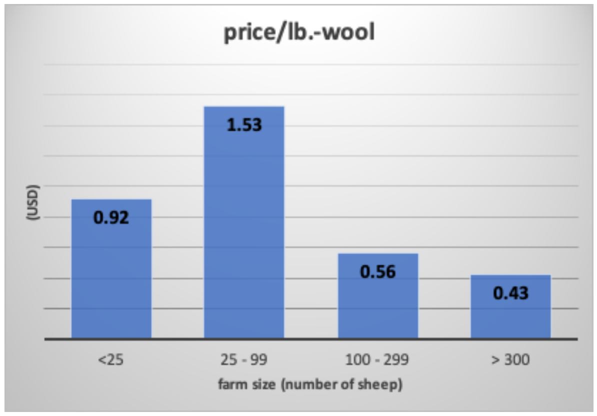


Figure 4. Price received per pound-wool according to number of sheep on farm (2017 USDA Ag. Census)

Even with the higher average price per pound that the small flock producers receive for their wool, it is still not enough to help these farmers break even. Figure 5 shows expenses from a 25 head sheep farm from 2018. The feed expense alone is greater than 10 times the average calculated wool-income of a 25 – 99 head farm (Figure 6).

EXPENSES	
FEED	& 8 round
Hay, 1154 bales	-4337.50
Grain, 35 bags	-577.05
Misc.	-43.16
MEDICAL	-609.76
WOOL	-974.91
PRODUCT MATERIALS	0.00
SHEEP	0.00
SHEEPDOG	-520.24
INFRASTRUCTURE	-1216.73
BUSINESS	-178.42
DONATION	-25.00
Total Expenses	-8482.77

Figure 5. 2018 list of expenses of a 25 head sheep farm (from anonymous farmer in CNY)

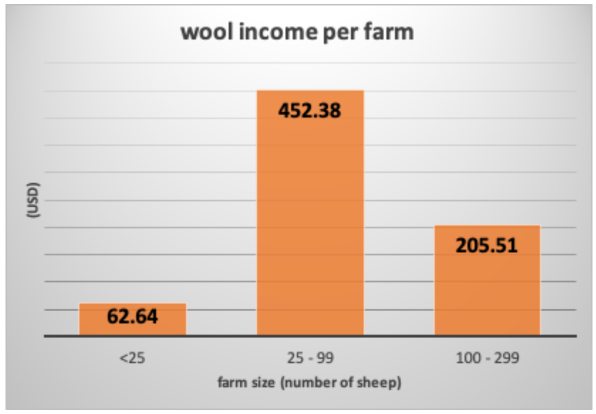


Figure 6. Wool income per farm calculated using data from the 2017 USDA Ag Census

Considering this income versus expense discontinuity, the question remains – What can NYS & NE US small-flock small-ruminant fiber producers do to increase profit from their wool harvest?

Chapter 4 System Dynamics

Model

The SD model for this thesis was built using the Stella software from isee systems, this software is specifically designed for "dynamic modeling, policy analysis, and strategy development" (isee systems, 2020). One of the helpful components of this software package is the ability to create an interactive interface (used in this application to get stakeholder feedback on the system design – an integral part of building a successful and accurate system dynamics model).

SD Models: a quick overview

> *"The behaviour of a system arises from its structure. That structure consists of the feedback loops, stocks and flows, and nonlinearities created by the interaction of the physical and institutional structure of the system with the decision-making processes of the agents acting within it."*
>
> - John D. Sterman, Business Dynamics pg. 107, 2000

SD models are system representations of material and information and their interconnections. There are a few important components to a SD model that need to be discussed before the model can be described (Figure 7). The main components of an SD model are stocks and flows. Stocks are a collection of a material or information (an integral), and 'flow' is the rate of that information or material into or out of the stock (a time derivative). There are also a number of additional variables and parameters that help to describe the system and variables themselves may be defined by the stocks and/or flows (variables are items whose amounts change over time and are calculated by the model while parameters are constant and defined by the user). Finally a defining attribute of dynamic systems for which SD models are ideal, are feedback loops.

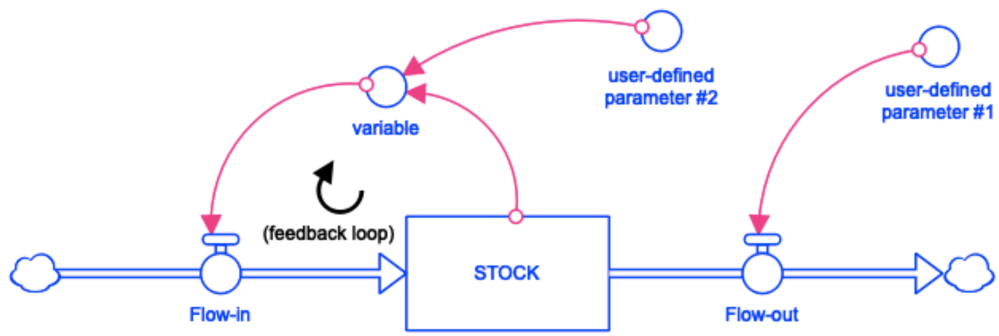


Figure 7. Components in a system dynamics model

The feedback of the dynamic systems is at the core of how the system reacts to change (policy and/or shock). Depending on the nature of the relationships between the components of the model feedback may be positive (growth), negative (goal-seeking), and oscillatory (time-delayed & negative) with more complex modes resulting from nonlinear interaction of these basic feedback structures (Sterman, 2000).

Data Collection

The model was built and parameterized primarily from interviews, site visits, surveys, and focus groups conducted from the fall of 2018 through the spring of 2020. The respondents are representatives from throughout the NE, primarily NYS, and represent a variety of components in the NE small flock fiber supply chain. They included farmers, mill owners, wool co-op members, artisans, designers, and retailers. Secondary data, from a variety of sources including academic literature and extension publications, was also used to build and populate the model.

Model Description

The model is comprised of three sectors and represents the farm level supply chain, the boundary of the model is the farm itself, with potential to expand beyond the farmgate in the future. Each sector represents a different material flow: sheep, wool, and finance. The time unit used for the model is month.

Sheep Sector

The farm starts with a given number of breeding ewes. Each breed of sheep has a unique breeding fraction, or average number of lambs per ewe – the national average is 1.5. Small flock fiber farms in the NE US typically breed once per year to match the high meat market season (the Muslim Eid and Christian Easter holidays). Many sheep are seasonal 'short day breeders' and prime breeding season is in the fall. The gestation period for sheep is five months and before selling to market lambs are typically matured (between 6 – 8 months). Sheep producers have options when it comes to selling meat, in this case meat sales are either direct or intermediated. To simplify the model, it is assumed that all meat income and expenses are generated by intermediated auction sales.

Besides the natural attrition rate of ewes, in this model the farmer will choose to increase, or decrease breeding ewes by gaining from the mature lamb stock or removing ewes to livestock market respectively. This is a yearly decision made at the time of breeding (this model does not consider purchased ewes). This decision is made after careful consideration of capital and profit implication on the part of the farmer and takes into account the lifestyle choice (how much loss the farmer is willing to accrue in order to have sheep) of the farmer to have sheep. The only limitation to growth, in this model, is available pasture.

Figure 8 is the causal loop diagram (CLD) for the sheep sector. This CLD shows a basic overview of how the different components of this sector affect each other. Components in blue are in the finance sector but effect or are affected by the decisions made in the sheep sector.

Similarly, components in purple are in the wool sector but effect of are affected by the decisions made in the sheep sector.

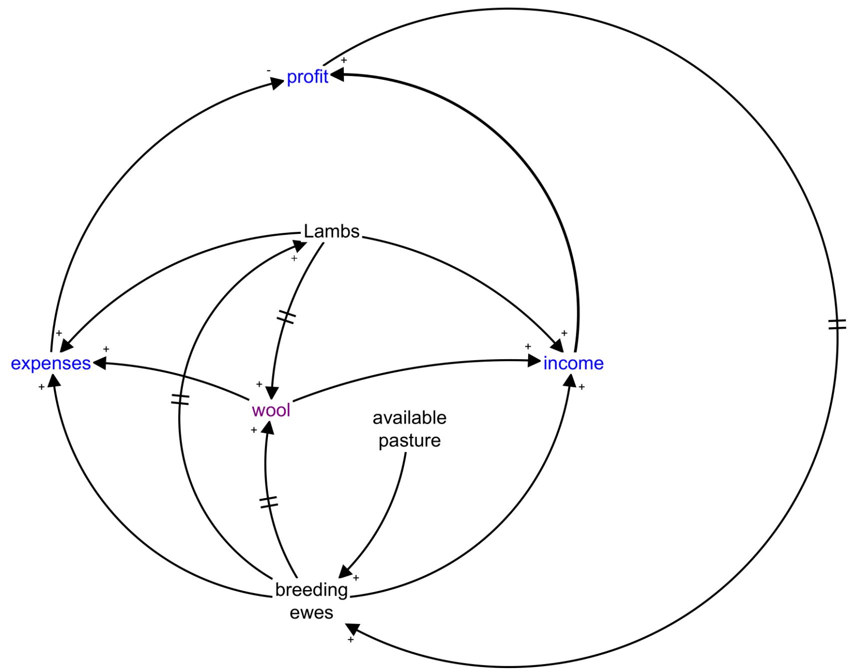


Figure 8. Causal loop diagram: sheep sector

In this causal loop diagram, there are 8 feedback loops present; 4 positive/reinforcing and 4 negative/balancing. The reinforcing feedback loops present in the sheep sector are:

- Feedback loop A – breeding ewes – income – profit
- Feedback loop B - breeding ewes – lambs - income – profit
- Feedback loop C - breeding ewes – lambs - wool - income – profit
- Feedback loop D – breeding ewes – wool - income – profit

As described earlier negative, or balancing feedback loops, result in goal seeking behavior. The balancing feedback loops present in the sheep sector are:

- Feedback loop E – breeding ewes – expenses – profit
- Feedback loop F – breeding ewes – wool - expenses – profit

- Feedback loop G - breeding ewes – lambs - expenses – profit
- Feedback loop H - breeding ewes – lambs - wool - expenses – profit

The main material flow of the sheep sector is sheep, and its primary units are number of sheep. The stocks and flows present in the sheep sector represent the increase and/or decrease of breeding ewes and lambs on the farm (Appendix Figure A 6). The stocks, flows, variables, parameters and assumptions that were used to build the sheep sector are listed in Table 2.

Table 2. Sheep sector components

Stocks	breeding ewes fetal lambs baby lambs mature lambs
Flows	breeding rate gestation rate maturation rate lamb selling rate breeding ewe addition rate ewe attrition rate breeding ewe removal rate
Variables	desired breeding stock
Parameters	breeding fraction ewe productivity decline lamb selling frequency initial breeding ewes acres of pasture and number of sheep per acre lifestyle choice delay
Assumptions	zero mature lambs at model start 1 breeding and lambing season per year no lamb losses no rams or wethers maximum two sheep per acre gestation period of 4.99 months maturation rate of 7 months, attrition rate of 7 years all ewes are breed (no non-breeding ewes)

Wool Sector

Wool is typically harvested, or sheared, once per year (some breeds require multiple shearings per year due to their wool growth rate). Shearing is a labor-intensive endeavor requiring a skilled hand that ensures a quality cut. This is especially true when the farmer is trying to get the highest value for their wool. After shearing the wool is skirted and graded. Skirting, removal of waste wool, is typically done at or immediately after the wool is shorn from the sheep while grading may be performed at a later time. This model assumes that skirting waste wool (bellies and tags) is 10% of the harvest on average. According to interviews grading may take up to 5 months after shearing to be completed. Once graded, wool is ready to go to the wool pool and/or the direct market. There are numerous cases, in NYS and throughout the NE US, where the farmers themselves are the direct market buyer of their raw wool and they will then produce value-add from their own wool in order to reach a wider market and gain a higher retail price (in this model the buyer is the person who buys the raw wool prior to processing).

Wool condition is an integral component of this sector. Farmers who are invested in producing wool to sell to direct markets will make specific choices related to the raising of their sheep in order to improve the condition of the wool. They may choose to elevate the feed to decrease the amount of hay and other vegetable matter in the fleece from feeding (Farmer #4, 2019). They may also coat the sheep – a practice that requires diligence throughout the year to refit coats and ensure the sheep are comfortable (Farmer #5, 2019). These practices are more common with farmers who have access to direct markets where customers are willing to pay a premium for the wool and/or value-added products. It should be noted that when producing value-added products the cleaner the fleece the lower the cost of processing and the higher the quality of the end product (Packer, 2019).

Figure 9 represents the CLD for the wool sector. This CLD shows a basic overview of how the different components of this sector affect each other. Components in blue are in the finance sector but affect or are affected by the decisions made in the wool sector. Similarly, components in green are in the sheep sector but effect of are affected by the decisions made in the wool sector.

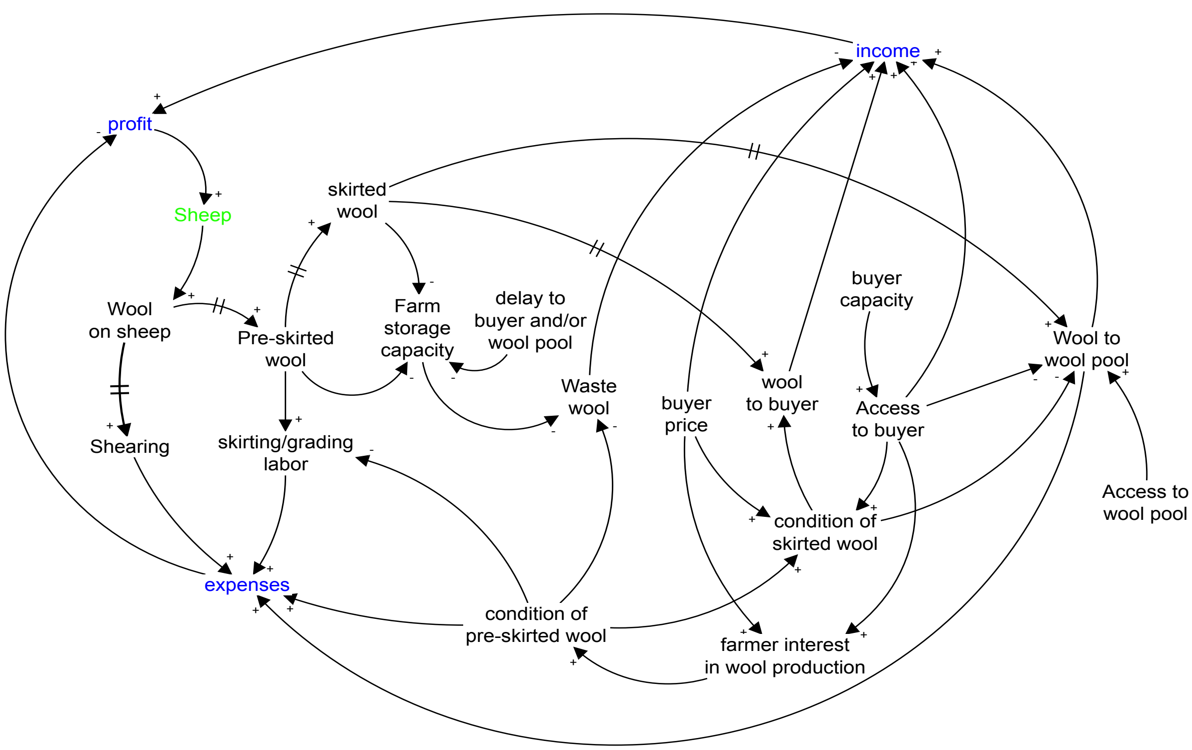


Figure 9. Causal loop diagram: wool sector

In this causal loop diagram, there are 7 feedback loops present; two positive/reinforcing and 5 negative/balancing. The reinforcing feedback loops present in the wool sector are:

- Feedback loop A: wool on sheep - pre-skirted wool - skirted wool - wool to direct market – income – profit - sheep
- Feedback loop B: wool on sheep - pre-skirted wool - skirted wool - wool to wool pool – income – profit - sheep

As described earlier negative, or balancing feedback loops, result in goal seeking behavior. The balancing feedback loops present in the sheep sector are:

- Feedback loop C: wool on sheep – shearing – expenses – profit - sheep
- Feedback loop D: wool on sheep - pre-skirted wool -skirting/grading labor – expenses – profit - sheep
- Feedback loop E: wool on sheep - pre-skirted wool - farm storage capacity - waste wool – income – profit - sheep
- Feedback loop F: wool on sheep – pre-skirted wool – skirted wool – farm storage capacity – waste wool – income – profit, sheep
- Feedback loop G: wool on sheep – pre-skirted wool – skirted wool – wool to wool pool – expenses – profit – sheep

The main material flow of the wool sector is wool, and its primary units are pounds of wool. The stocks and flows present in the wool sector represent the flow of the wool from sheep to direct market, wool pool, and waste (Figure A 7 & Figure A 8). The stocks, flows, variables, parameters and assumptions that were used to build the wool sector are listed in Table 3.

Table 3. Wool sector components

Stocks	direct market inventory wool on the sheep (breeding ewes and mature lambs) pre-skirted & skirted wool pre-skirted and skirted wool condition
Flows	wool growth rate shearing rate wool to waste rate wool to skirting rate wool to wool pool rate wool to direct market rate
Variables	farm wool inventory farm & direct market capacity fractions vegetable matter in raw fleece average pre-skirted & skirted wool condition skirting effort & delay

	buyer delay
Parameters	average pounds of wool per breed per year access to direct market and/or wool pool fiber production desire factor total farm and direct market storage capacity direct market & wool pool price delay to buyer
Assumptions	skirting time (min. 3 days & max 5 months) direct market capacity represents direct market demand all very low-quality wool goes to waste at least 10% of wool goes to waste (bellies and tags) all lambs are shorn prior to being sold really good or bad pre-skirted condition lowers skirting effort and delay

The wool sector also involves a coflow that represents the fiber condition at the pre-skirted wool and the skirted wool stocks. Coflows enable the modeler to represent attributes that affect the flow of the stock. In this case the condition of the wool plays a crucial role in whether the wool goes to waste, to the wool pool, or is sold through a direct market channel. A coflow is a parallel flow that mimics the flow of the attribute with a multiplicative weight factor. By comparing the material stock to the attribute stock, one is able to assess the average attribute in relation to the stock. The stocks in this case are average pre-skirted wool condition and average skirted wool condition (Figure 10).

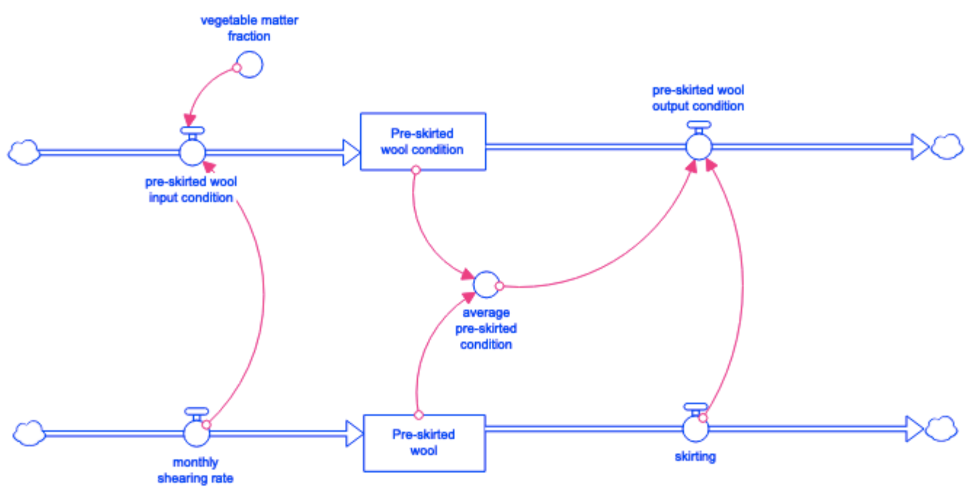


Figure 10. Coflow representing pre-skirted wool condition

Finance Sector

Small flock fiber producers in NYS and the NE US typically produce three main products that incur both income and expenses; meat, fiber, and livestock. All of these products have a variety of ways they can be marketed and each of these market channels are associated with specific costs. To simplify the model only one market channel was considered for each product (the fiber market channel was discussed previously in the wool production sector).

Many fiber producers also produce meat as a product. Small flock producers typically slaughter once per year at maturation (6 – 8 months old). Meat sales can happen throughout the year or once per year depending on the market channel. Once per year market channels include direct market sales to the Muslim, Christian, and Jewish markets for holiday feasts – especially spring holidays including Ramadan, Easter, and Passover (Barkley, 2012; Farmer #6, 2019) and intermediated market sales to the livestock auction or live animal market (Farmer #4, 2019). Yearlong market channel sales are typically direct market freezer lambs and require access to a farmer's market or similar (Farmer #5, 2019). To simplify the model, only livestock auction sales were considered. Expenses related to livestock auction sales are transportation costs, and income is a product of the number of lambs sold and the market rate of lamb - $167.50 CWT for lamb as of 05/25/2020 (84 Auction Sales Inc, 2020).

Livestock sales are an additional income generator. Small flock producers will often sell breeding and/or fiber stock to other producers, or hobbyists. The income generated from these sales is highly dependent upon breed and quality of the animal. It is common practice to sell such animals for no less than $250 pedigree and $175 non-pedigree (Atkins, 2020; Glaser, 2020). In the model there are no additional costs associated with livestock sales, it is assumed any additional costs are paid for by the buyer.

As is common with small holder farms and family farms in the US there is often external income that supports the farm business. This external income supplies capital for start-up and loans to overcome times of hardship (Farmer #2, 2019; Farmer #6, 2019).

Figure 11 is the CLD for the finance sector. This CLD shows a basic overview of how the different components of this sector affect each other. Components in purple are in the wool sector but effect or are affected by the decisions made in the finance sector. Similarly, components in green are in the sheep sector but effect of are affected by the decisions made in the finance sector.

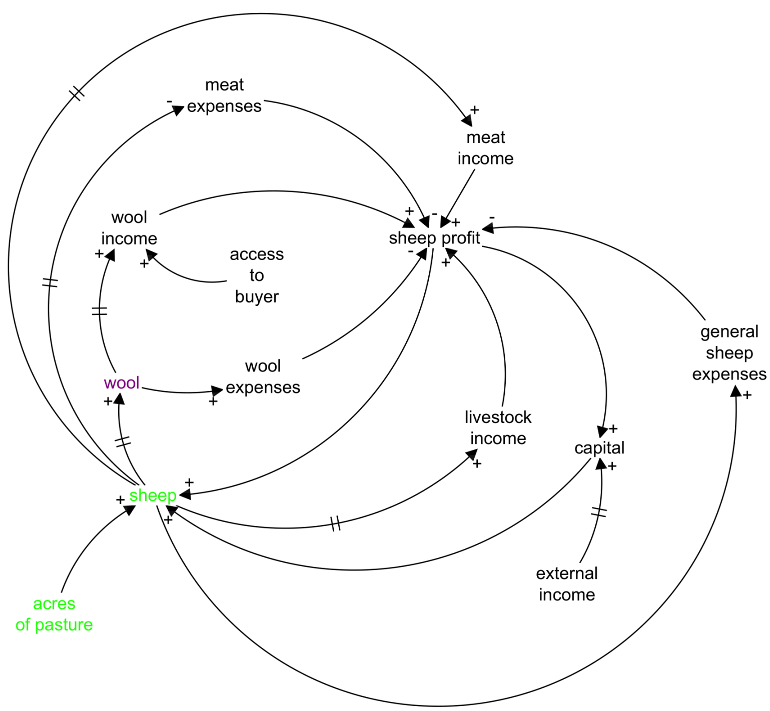


Figure 11. Causal loop diagram: finance sector

In this causal loop diagram, there are 12 feedback loops present; 6 positive/reinforcing and 6 negative/balancing. The reinforcing feedback loops present in the finance sector are:

- Feedback loop A: sheep – wool – wool income – sheep profit
- Feedback loop B: sheep – wool – wool income – sheep profit – capital
- Feedback loop C: sheep – meat income – sheep profit
- Feedback loop D: sheep – meat income – sheep profit – capital
- Feedback loop E: sheep – livestock income – sheep profit
- Feedback loop F: sheep – livestock income – sheep profit – capital

As described earlier negative, or balancing feedback loops, result in goal seeking behavior. The balancing feedback loops present in the sheep sector are:

- Feedback loop G: sheep – wool – wool expenses – sheep profit
- Feedback loop H: sheep – wool – wool expenses – sheep profit – capital
- Feedback loop I: sheep – meat expenses – sheep profit
- Feedback loop J: sheep – meat expenses – sheep profit – capital
- Feedback loop K: sheep – general sheep expenses – sheep profit
- Feedback loop L: sheep – general sheep expenses – sheep profit – capital

The main material flow of the finance sector is US dollars (USD), and its primary units are USD (currency). The stocks and flows present in the finance sector represent the relationship between the farm's sheep profit (income and expenses) and its capital (debt and equity) (Appendix: Figure A 9). The stocks, flows, variables, parameters and assumptions that were used to build the finance sector are all laid-out in Table 4.

Table 4. Finance sector components

Stocks	accumulated meat, sheep, and fiber profit capital sheep related balance
Flows	meat, sheep, and fiber income and expense rates sheep related debt and equity rates external money to capital rate
Variables	income from lamb, stock, and fiber-direct market and wool pool total wool pool expenses skirting expenses vegetable matter-related expenses total general sheep expenses (shearing, feeding) travel expenses to meat auction and wool pool average monthly sheep profit
Parameters	cwt price and pounds per lamb fraction of lambs to meat sales average livestock, and fiber-wool pool & direct market price distance to & from meat auction and wool pool IRS mileage rate yearly overhead maintenance expenses meat sale frequency number of months for averaging external income and fraction of external income to savings/capital per head shearing price days of work per wool pool per year feed costs per hour labor cost
Assumptions	meat sales occur at one point in time meat price is $167.50 CWT vegetable matter control costs are maximum of $30/sheep (based on $6/coat for 5 years) overwinter feeding costs are $214 per sheep only breeding ewes are kept overwinter (no other feeding costs are applied)

Inter-sector

It is apparent from the CLDs of the sheep, wool, and finance sectors that these sectors do not work in isolation but in fact affect each other. Figure 12 illustrates this point: The more sheep present in the sheep sector directly correlates with more wool in the wool sector (sheep sheared) and increasing income and expenses in the finance sector (lambs for sale, sheep sheared, and overwinter sheep); the more wool in the wool sector directly correlates with increasing income and expenses in the finance sector (wool sold, wool related labor costs); and the more money in the finance sector directly correlates with more sheep in the sheep sector (capital, monthly profit)

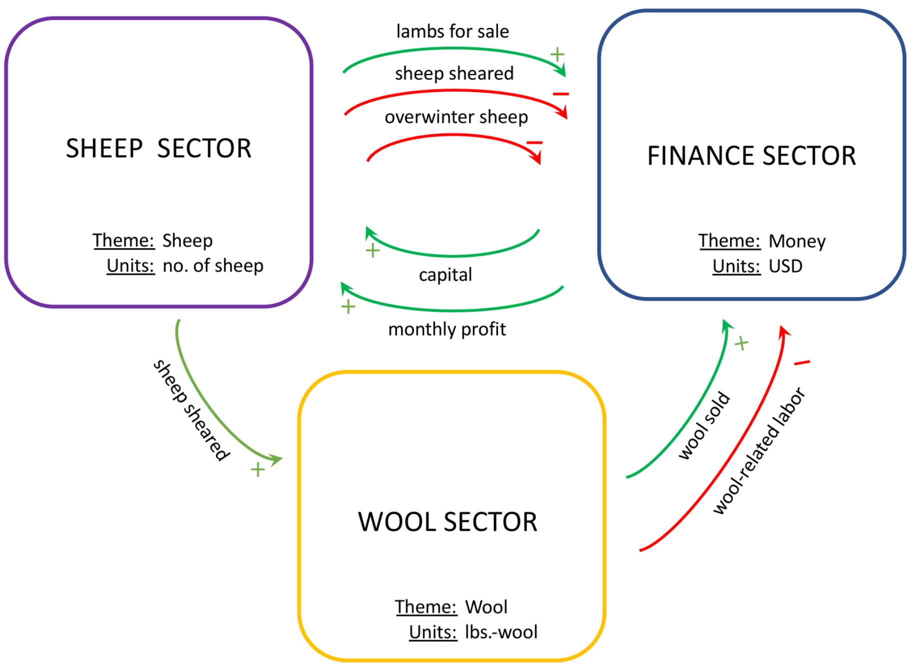


Figure 12. Inter-sector relationships (feedback loops)

Of course, there are assumptions associated with the model as a whole, these are shown in Table 5.

Table 5. Overall model assumptions

Assumptions	Meat and fiber markets are available, and demand is unlimited. If capital is negative the farmer will decrease their herd. An increase in monthly sheep profit results in an increase in flock size (if enough acreage). A decrease in monthly sheep profit results in a decrease in flock size (if enough acreage). All sheep are sheared prior to meat or livestock sales.

Analysis

The simulations are run for 120 months, or 10 years, giving enough time to see how the farm will react after production and inventory ramp-up. In this model there are four types of parameters – biologically defined, farmer defined, policy defined, and miscellaneous (Table 6). The analysis that follows will focus primarily on how changing various parameters effect the number of breeding ewes, monthly fiber & sheep profit, and capital. Other variables will also be discussed when relevant.

Table 6. Parameters present in the SD model

Parameter type	Model parameters	Units	Baseline
Biologically defined	ewe productivity decline/attrition rate (Schoenian, 2020)	years	7
	sheep per acre (Whiteheart & Kintzel, 2010)	sheep/acre	2
(defined by breed type)	average pounds meat per lamb	lbs.-meat/sheep	95
	average pounds wool per sheep – annually	lbs.-wool/sheep	7
	shearing frequency	months between	12
	breeding fraction	lambs/ewe	1.5
Farmer defined	acres of sheep pasture	acres	21
	cubic feet of available storage	cubic feet	200
	external income	USD	200,000
	fraction of external income to capital	unitless	0.005
	fraction of lambs to auction (remaining to livestock sales)	unitless	0.9
	fiber production desire factor	unitless	0.5
	initial capital	USD	25,000
	initial number of breeding ewes	sheep	42
	initial number of lambs	sheep	0
	maintenance and overhead costs	USD	2,000
	number of months for averaging	months	12
	stock adjustment delays due to lifestyle choice	months	60
Policy defined	access to direct market	on/off	1
	access to wool pool	on/off	1
	average direct market price	USD/lbs.-wool	30
	average feed costs per sheep	USD/sheep/year	214
	average lamb selling frequency	months between	12
	average livestock price	USD/sheep	250
	average shearing cost per head	USD/sheep	7

	average wool pool price (Harth & Harth, 2019)	USD/lbs.-wool	0.45
	wool buyer capacity (demand)	lbs.-wool	inf
	CWT price per lamb (84 Auction Sales Inc, 2020)	CWT(USD)/lamb	167.50
	distance to/from auction	miles	120
	distance to/from wool pool	miles	100
	IRS mileage rate	USD/mile	0.58
	labor cost per hour	USD/hour	15
	buyer delay	months between	6
Miscellaneous	number of 8-hour days associated with wool pool	days/wool-pool	2
	pounds wool per cubic feet storage	lbs.-wool/cubic ft.	2.5

Key Stocks and Parameters

Breeding ewes, capital, monthly fiber profit, and monthly sheep profit are investigated throughout the analysis.

Breeding ewes is a good first glimpse at the potential of the enterprise. If this stock is declining towards zero during the lifetime of the simulation, then the enterprise in not considered to be successful. This does not imply, however, that a decreasing stock is always indicative of a failing enterprise. There are many situations where a decreasing breeding ewe stock simply implies that the farmer is attempting to find a new equilibrium. Breeding ewes' stock is responsive to the capital and monthly sheep profit and clearly shows the effects of these variables on the farm practices.

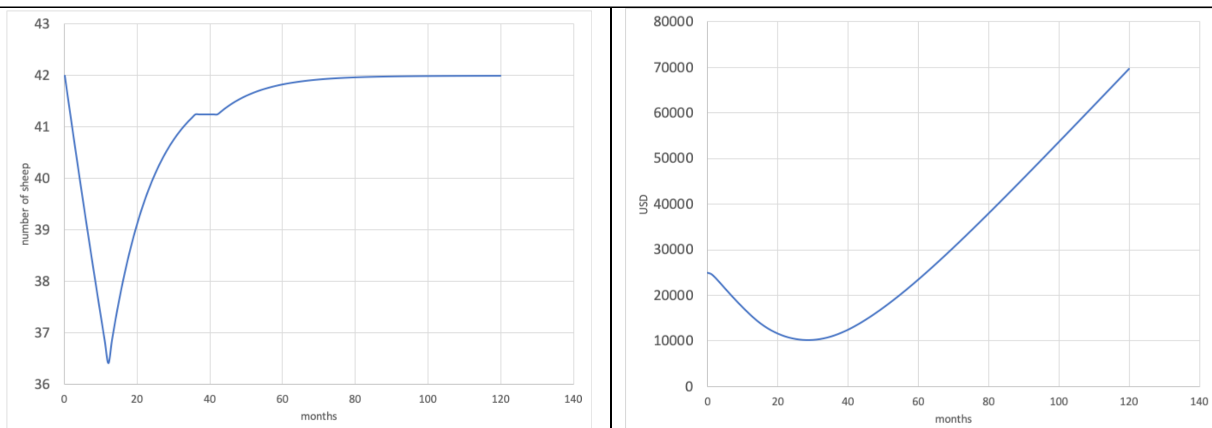
Capital is another window into the potential of the sheep farm enterprise. Capital is the combination of accruing profit and a fraction of external income allocated to capital. Capital trends similar to accumulated sheep profit; growing capital is in response to positive sheep-related profit (successful enterprise), if it is holding steady then sheep profit & external income allocation are in balance, and if it is negative then the enterprise is losing money.

Monthly sheep profit plays a role in the growth of the sheep farm enterprise in that growing sheep profit may lead to increasing herd size (if capacity is not reached) and similarly, declining sheep profit may lead to decreasing herd size. Monthly wool profit is included in the analysis to show the reader the contribution of wool to the monthly sheep profit.

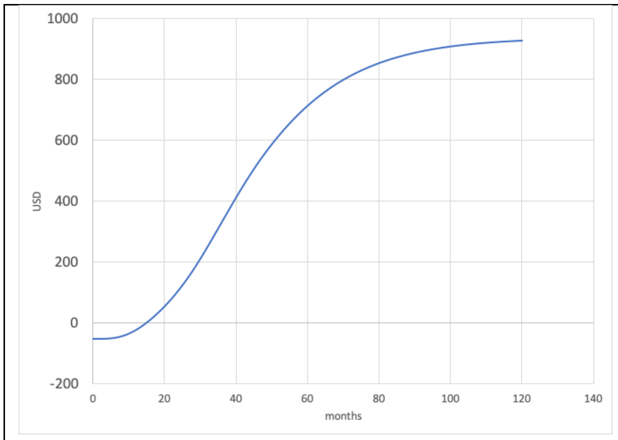
In addition to these variables two additional calculations are regularly observed, meat:fiber profit ratio and profit per breeding ewe (both at month 120). Meat:fiber profit ratio and profit per breeding ewe are included in the analysis to help the reader better understand how different parameters affect these relationships and subsequently how these relationships affects the success and longevity of the enterprise. In addition meat:fiber profit ratio also brings to light the relationship between meat and fiber profit and the success of the enterprise.

Baseline Model

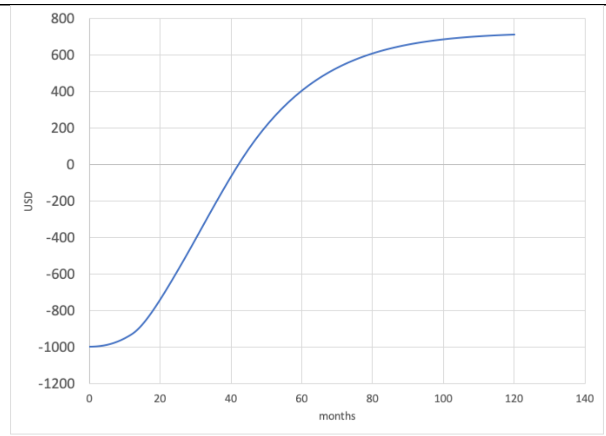
The baseline model (Figure 13 & Table 7) is a profitable farm with parameters defined in Table 6.



(a) number of breeding ewes (b) capital



(c) monthly fiber profit



(d) monthly sheep profit

Figure 13. Results of baseline simulation

Table 7. Results of baseline simulation

Model	meat:fiber profit ratio	sheep profit per breeding ewe (USD)
Baseline model	0.69	17.00

The model starts with no mature lambs, so while attrition rate is slowly decreasing the number of breeding ewes there are no mature lambs available to replace this stock, or go to meat market, until the 12th month at which point the number of breeding ewes begins to increase again. This increase is in response to positive capital, and the time period being less than 36 months. (It takes approximately 36-months for a sheep farm enterprise to receive income from their wool (Edens, 2019). Therefore this model assumes that for the first 36 months the desired number of breeding ewes is the initial breeding ewes – the farmer plans on a loss for the first three years. Only after the first 36 months will the farmer adjust their breeding stock according to their sheep profit. The exception is loss of capital; if capital becomes negative, regardless of when, the farmer will attempt to sell their flock until capital is positive.) After month 36 the farmer holds their number of breeding ewes at 41.25 ewes until sheep profit becomes positive at month 43, after which the rate of breeding ewe increase is related to the rate of profit increase. This increase continues until the pasture capacity is reached, in this case 42 breeding ewes on 21 acres (two breeding ewes per acre).

In this scenario meat profit, at month 120, is greater than wool profit by a small margin. This implies that the success of the sheep farm enterprise relies on both meat and wool sales to a fairly equal extent. By the end of the simulation this farmer expects profit per breeding ewe to be $17/month.

Analyzing the Hypotheses

Biologically Defined Parameters

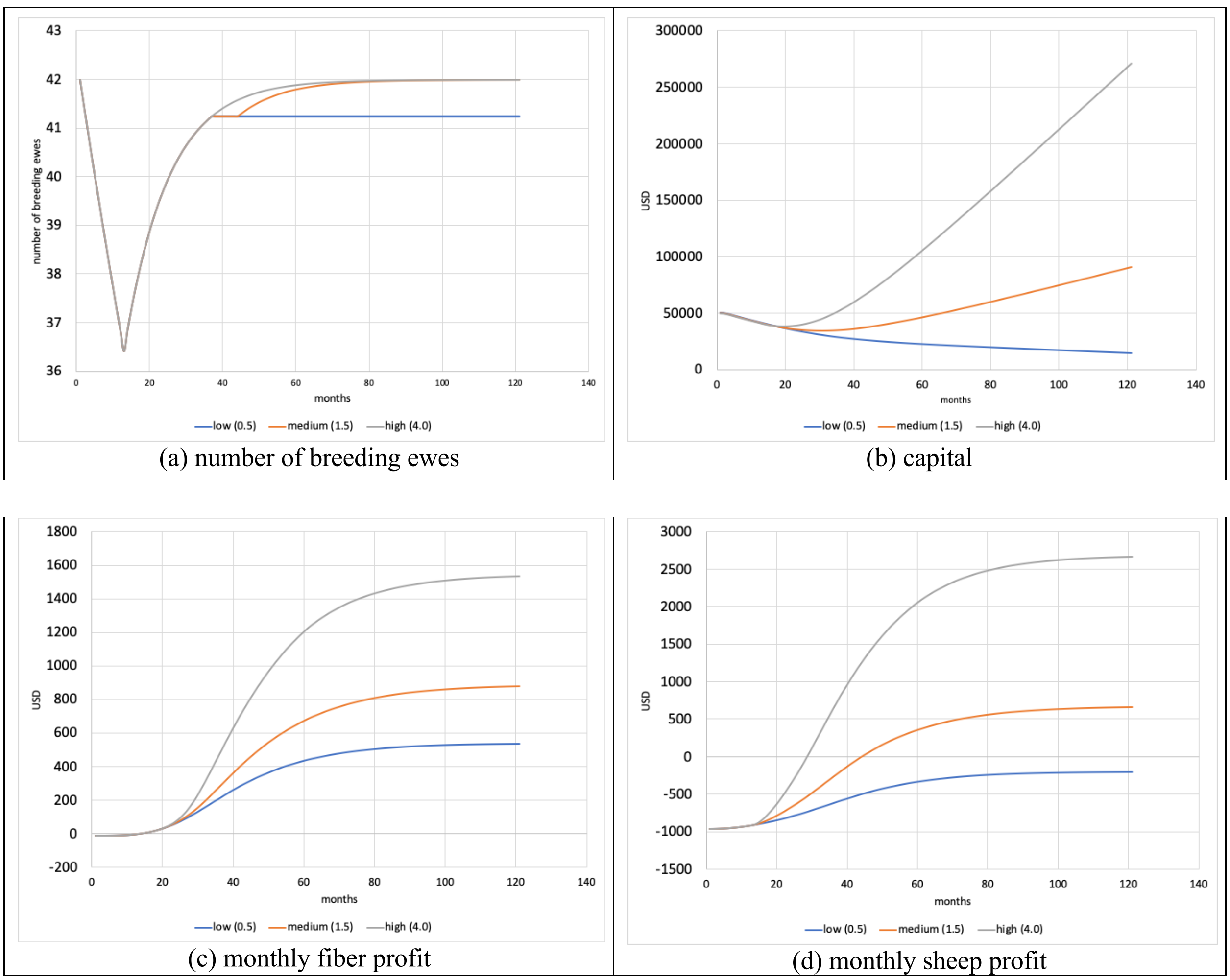
Choice of breed

Farmers have a variety of breeds to choose from. The breed they choose greatly depends on the markets they want to pursue as well as their own personal interests. Breed choice effects the breeding fraction (lambs/ewe) and average pounds of wool per sheep (annually) – which of course affects their business.

The effect of breeding fraction:

Figure 14 shows the effect of breeding fraction on the (a) number of breeding ewes, (b) capital, (c) monthly fiber profit, and (c) monthly sheep profit. Low breeding fraction (0.5 lambs per ewe) represents the farmer who chooses to breed only a portion of their ewes, medium (1.5 lambs per ewe) represents the national average, and high (4.0 lambs per ewe) represents a breed which breeds wither multiple times per year or is capable of breeding quadruplets – both of which are viable.

Unsurprisingly increasing the breeding fraction correlates with a quicker recovery, faster growth, and an increase in profits. Quicker recovery and faster growth are attributed to an increase in the farmers desire to increase the number of breeding ewes due to an increase in profits correlated with the increase in breeding fraction (more lambs to meat market and more wool to wool market). This is evidenced by looking at the point at which sheep profit becomes positive. For the high and medium breeding fractions positive profit occurs in the 28^{th} and 44^{th} month, respectively. Once sheep profit is positive and increasing, as long as capital is positive, in this model the limiting factor to enterprise growth is available pasture. In the low simulation sheep profit remains negative and increasing with positive albeit decreasing capital. As long as the sheep profit remains negative the farmer will not attempt to grow their herd.



(a) number of breeding ewes

(b) capital

(c) monthly fiber profit

(d) monthly sheep profit

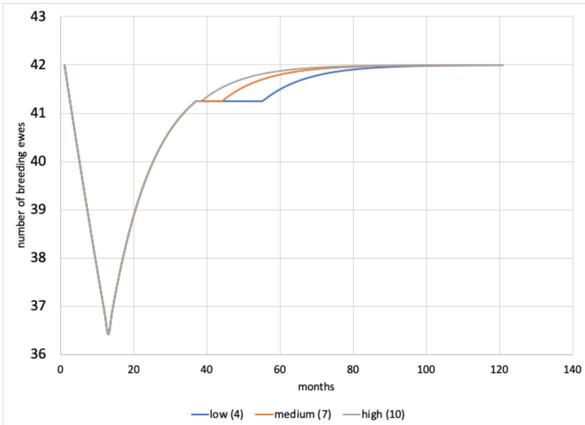
Figure 14. Effect of breeding fraction

It is interesting to consider the relationship between monthly meat, fiber, and sheep profits. At the end of the simulation the monthly meat:fiber profit ratio, shown in Table 8, for low, medium, and high breeding fractions are 0.30, 0.73, and 1.20 respectively. This stresses the relationship between meat sales and breeding fraction. In this case, when monthly meat profit is 30% of monthly fiber profit, the sheep profit plateaus at a loss compare to when meat profit is 73% of fiber profit where monthly sheep profit plateaus at a gain, albeit a small one. This is not to say that a 30% ratio will always result in a negative sheep profit plateau, as there are many factors that contribute besides the comparison of meat and fiber profit (i.e. meat auction price, wool buyer price, pounds of wool, other expenses etc.….) what is being emphasized here is how strongly meat sales can impact the sustainability of a sheep enterprise.

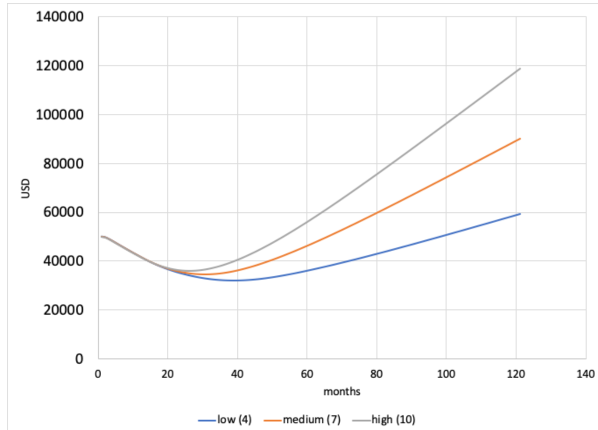
The effect of average pounds of wool per sheep per year:

Figure 15 shows the effect of wool per sheep annually on the (a) number of breeding ewes, (b) capital, (c) monthly fiber profit, and (c) monthly sheep profit. Low wool per sheep (4 lbs.-wool/year) represents smaller breeds such as Icelandic or Shetland, medium (7 lbs.-wool/year) represents breeds such as Finn-sheep or Border Leicester, and high (10 lbs.-wool/year) represents breeds such as Lincoln Longwool or Wensleydale – all of which are common in the NE US.

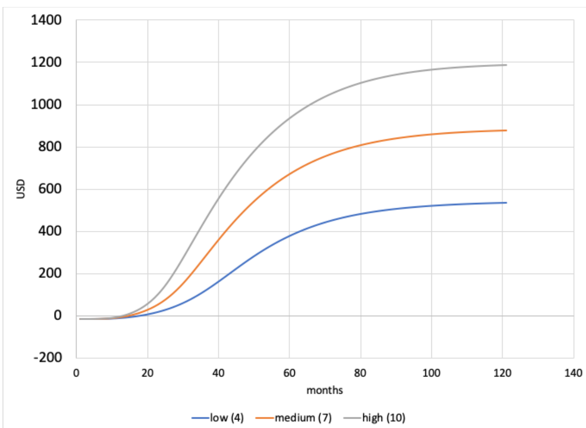
As the amount of wool per sheep increases so does the monthly fiber profit, which increases monthly sheep profit which, in turn increases the farmers desire to grow the sheep enterprise. The moment of breeding ewe increase, as discussed prior, is related to the point where monthly sheep profit becomes positive. The limit to growth is available pasture. For the low, medium, and high simulations this occurs as months 55, 44, and 38 respectively.



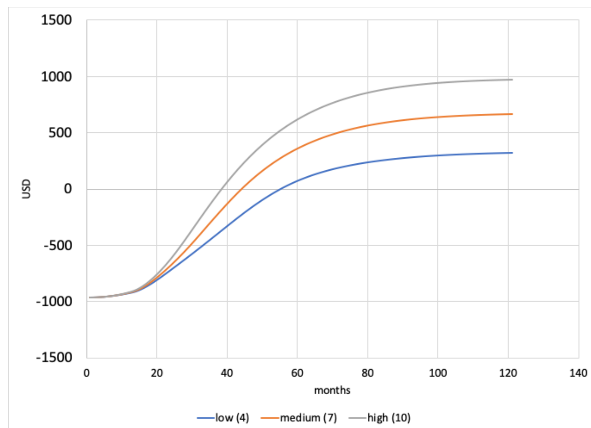
(a) number of breeding ewes



(a) capital



(c) monthly fiber profit



(d) monthly sheep profit

Figure 15. Effect of average pounds of wool per sheep per year

As with breeding fraction it is worth considering the relationship between the monthly meat, fiber, and sheep profits. In this case the meat:fiber profit ratio, shown in Table 8, is 1.20, 0.73, and 0.54 for the low, medium, and high wool growth rates respectively. Notice the opposite trend between the meat:fiber profit ratio with sheep profit, as realized in breeding fraction. In this case the lower meat:fiber profit ratio correlates to a higher sheep profit, whereas with breeding fraction a higher meat:fiber profit ratio correlates to a higher sheep profit. By increasing the wool produced per animal holding all else constant, only the amount of wool produced increases resulting in a lower meat:fiber profit ratio and increase wool profit, therefore any increase in profit is solely the result of an increase in wool. Earlier, when breeding fraction is increased both wool and meat production increased resulting in a larger increase in potential profit than increasing wool production alone, evidenced by profit per ewe in Table 8.

Table 8. Meat:Fiber profit ratio and profit per ewe for biological parameters (at month 120)

Model	meat:fiber profit ratio	sheep profit per breeding ewe (USD)
Average wool per sheep (10)	0.54	23.20
Average wool per sheep (7)	0.73	15.84
Average wool per sheep (4)	1.20	7.63
Breeding fraction (4)	1.20	63.60
Breeding fraction (1.5)	0.73	15.84
Breeding fraction (0.5)	0.30	-4.98

Summary of analysis of biologically defined parameters

Considering breed type and the related biologically defined parameters, breeding fraction has a greater effect on the success of the sheep farm enterprise. By increasing breeding fraction sheep enterprises have an opportunity for successful growth through increasing the volume of all sheep-related products. Interestingly, an increase in this parameter results in an increase in the meat-fiber profit ratio, meaning that an increase in breeding fraction directly correlates with meat becoming the primary market of the sheep farm enterprise. Therefore, having a market for lamb in this scenario is imperative to the success of the enterprise. On another note, an increase in the amount of wool produced per animal correlates to an increase in sheep profit through fiber profit. While encouraging, an increase in fiber profit alone is not as growth inducing for the enterprise, as increasing profit through all sheep-related products as evidenced by increasing breeding fraction.

Farmer Defined Parameters

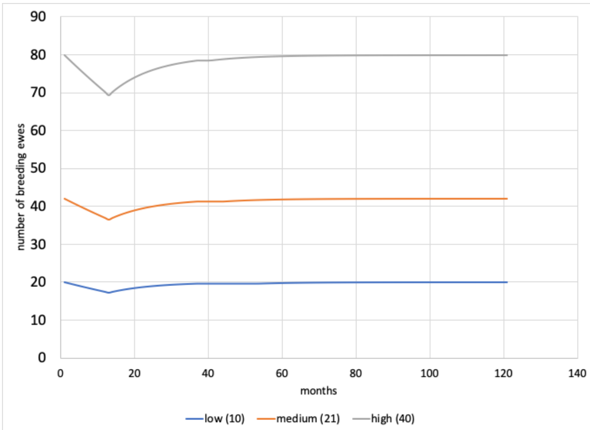
Choice of initial flock size

Many farmers chose to start off with smaller flocks and then grow their herd over time. How exactly does this choice affect the profit and longevity over the lifetime of the enterprise? This question is explored by looking closely at the relationship between acres of pasture and initial number of breeding ewes, since the size of the pasture defines the maximum capacity of the farm.

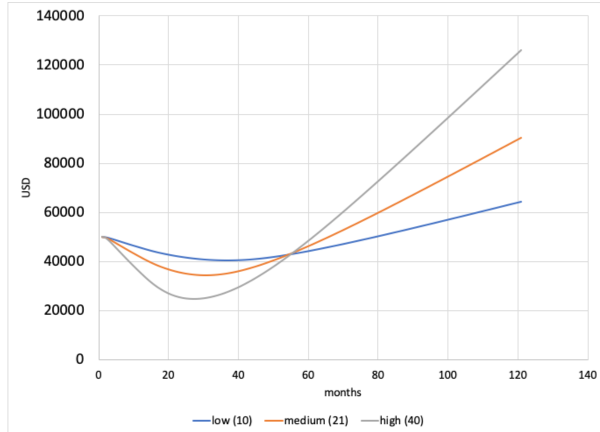
The effect of acres of pasture & initial number of breeding ewes:

Consider the following two simulations; the first set of simulations the number of initial breeding ewes maxed out the pasture capacity and were varied according to available acreage ; 20 breeding ewes for 10 (low) acres, 42 breeding ewes for 21 (medium) acres, and 80 initial breeding ewes for 40 (high) acres (Figure 16). The second set of simulations initial breeding ewes were held constant at 20 and acreage was varied 10 (low & maxed-out), 21 (medium & growing enterprise), and 40 (high & growing enterprise) acres (Figure 17). The acreage in these simulations represent the baseline (medium - 21 acres), larger than the baseline (high - 40 acres), and smaller than the baseline (low - 10 acres).

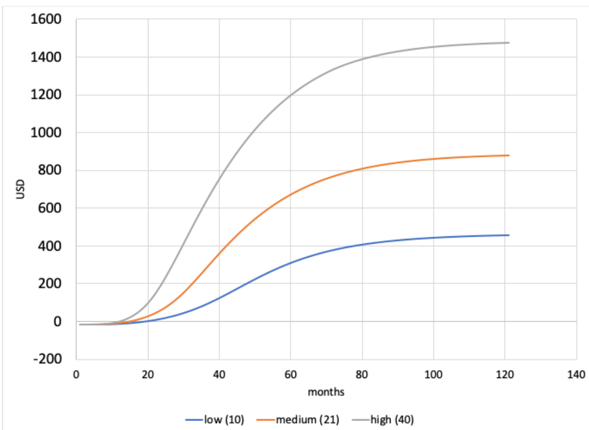
Figure 16 shows the results from the first set of simulations, varying acreage & initial breeding ewes while maxing-out pasture capacity. In this set each enterprise, regardless of initial parameters, attempts to keep their flock at capacity. As expected, the larger the flock the greater the loss, during the phase where expenses are greater than income, but also the higher the positive profit when income becomes greater than expenses. Ultimately the larger the flock the greater the lifetime profit, as reflected by capital.



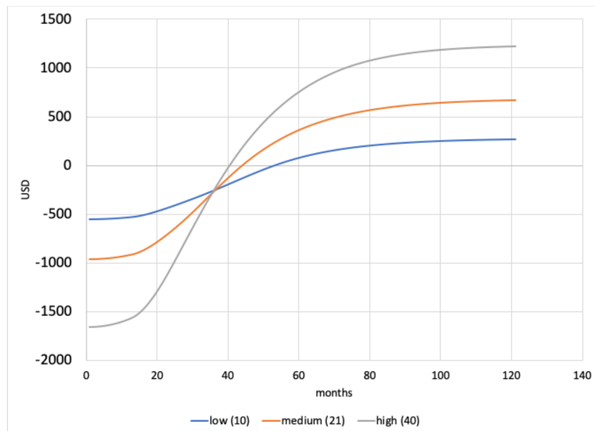
(a) number of breeding ewes



(b) capital



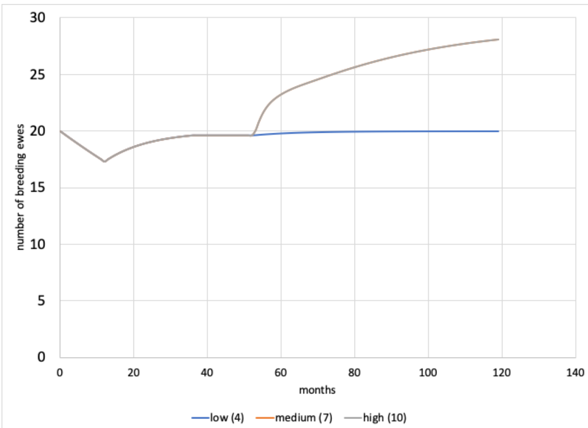
(c) monthly fiber profit



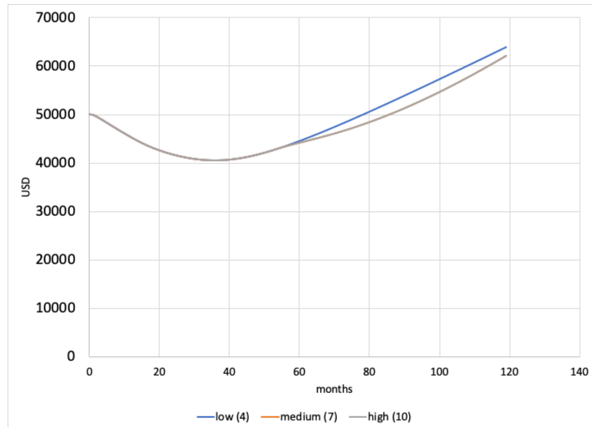
(d) monthly sheep profit

Figure 16. Effect of pasture acreage (variable initial breeding ewes)

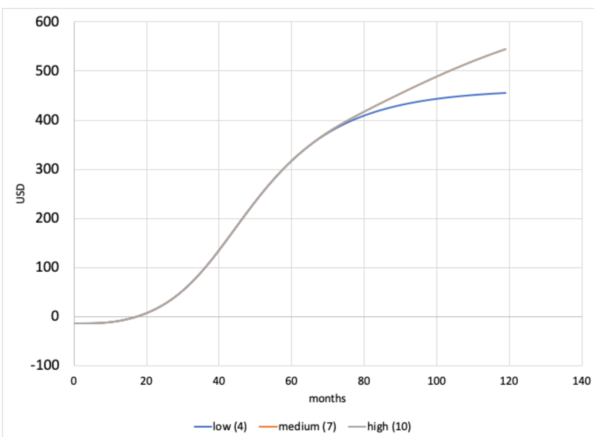
The second set of simulations, shown in Figure 17, constant initial breeding ewes with varying available acreage, all enterprises hold the flock at initial size of 20 breeding ewes until sheep profit is positive and increasing – this means that the medium and high acreage represent growing enterprises while the low acreage represents a maxed out pasture. What is interesting here is that after sheep profit becomes positive the enterprises, medium & high acreage, start to grow their flocks. This growth initially leads to a lower sheep profit and hence capital, compared to the enterprise which is not increasing their flock size. This loss of profit is attributed to losing income from lambs being converted to breeding ewes opposed to being sold at auction (an assumption made in this model). However, given enough time, sheep profit surpasses that of the smaller enterprise as the number of breeding ewes and therefore wool, lamb, and livestock sales increase (~month 108 in Figure 17d).



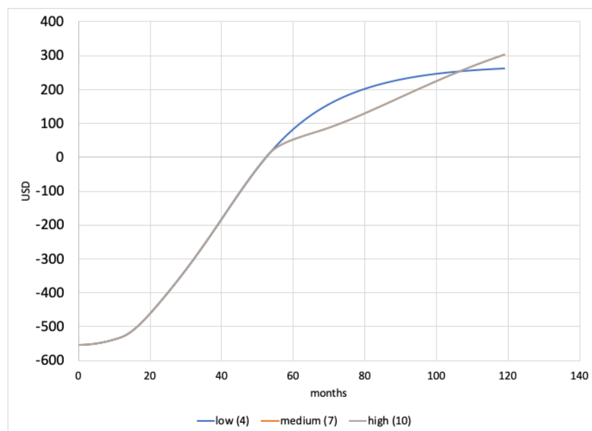
(a) number of breeding ewes



(b) capital



(c) monthly fiber profit



(d) monthly sheep profit

Figure 17. Effect of pasture acreage (constant initial breeding ewes)

According to the model it behooves sheep farm enterprises to max out their pasture from the start, as is evidenced by regarding sheep profit per breeding ewe (Table 9). This ensures the greatest profit per breeding ewe, compared to starting at a smaller flock and growing – losing potential profits. As expected, increased scale means higher profits (monthly sheep profit) but there seems to be a point at which as the size of the operation grows the contribution of each ewe to the income decreases (averaged sheep profit per breeding ewe).

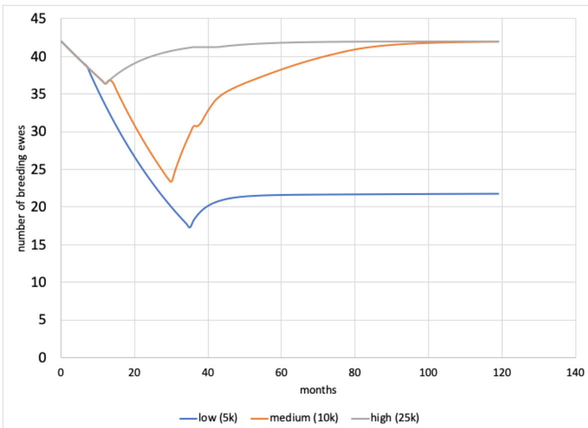
Table 9. Monthly profit per ewe & monthly sheep profit regarding acres of pasture and number of initial breeding ewes (at month *120)*

Model	averaged sheep profit per breeding ewe (USD)	monthly sheep profit (USD)
10 Acres 20 initial breeding ewes	13.19	263.69
21 Acres 42 initial breeding ewes	15.84	665.40
40 Acres 80 initial breeding ewes	15.31	1224.51
10 Acres 20 initial breeding ewes	13.19	263.69
21 Acres 20 initial breeding ewes	10.86	305.42
40 Acres 20 initial breeding ewes	10.86	305.42

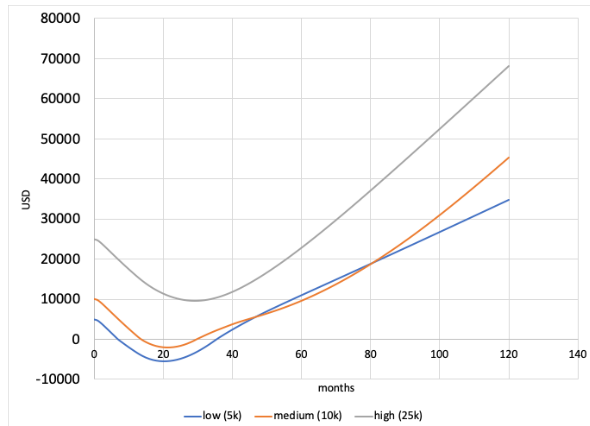
The effect of limited capital on the results of max-out versus growing enterprise scenarios

Many farmers choose to grow over time, opposed to maxing out their herd, due to limited initial capital. How would limited initial capital affect the results of the previous simulations?

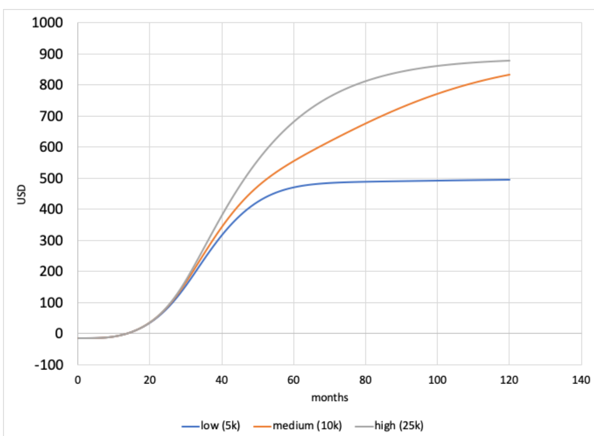
One would guess that having sufficient initial capital is a make or break scenario for a sheep farm enterprise and in fact the model shows that the amount of initial capital leads to one of three different types of outcomes (Figure 18); no loss/no change in production level, loss with recovery to initial production levels, and loss with recovery at a lower production level. It is worth remembering that it takes roughly three years until sheep producers see profit from fiber, consequently fiber production plays little to no role in the success of the enterprise in its early stages. In contrast, livestock sales begin to reach a market as soon as lambs are mature with a delay of 12 months, resulting in livestock sales playing a much more significant role in the success of the sheep farm enterprise early on. It is the combination of the gestation, maturation, and livestock delays together with the period of breeding ewe decline, due to negative capital, that determines the scale of enterprise recovery. In other words, once the farmer starts to disperse the herd, due to negative capital, the farm will not fully experience the effects of this decrease for another 24 months, due to the aforementioned delays. The final production level of the farm depends on how much recovery (herd increase) occurs before the farm fully experiences the effects of the market loss due to the herd dispersal. All together this implies that the period of negative capital remarkably important.



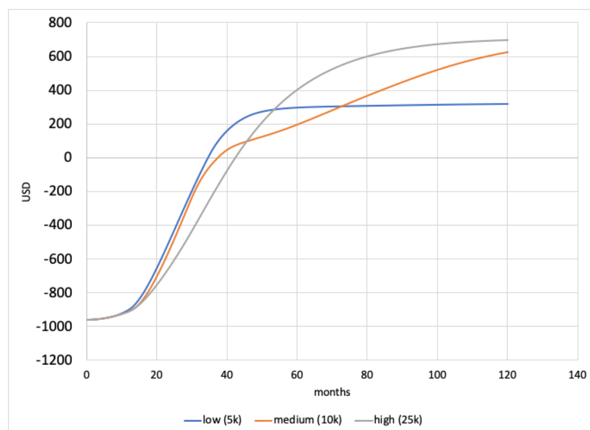
(a) number of breeding ewes



(b) capital



(c) monthly fiber profit



(d) monthly sheep profit

Figure 18. Effect of initial capital

To better understand the nuances of each simulation breeding ewes, mature lambs, capital and monthly meat profit are studied. Table 10 takes a closer look at these parameters and the order of events that leads to the different outcomes. Holding all else at the system parameters described in Table 6, initial capital is $5,000 for loss with recovery at lower production, $10,000 for loss with recovery to initial production, and $25,000 for no loss/no change to production, Loss with recovery to lower production level ($5,000 initial capital)

29-month negative capital/herd dispersal period (4 months longer than the 24 months of gestation, maturation, and livestock delays).

In this scenario capital goes negative at month 7. When capital goes negative the farmer starts to disperse their herd in order to recover losses and increase profit and capital. Herd dispersal happens gradually over time as defined by the farmer's lifestyle choice (desire to raise sheep) and access to livestock buyers. As the herd size decreases the number of mature lambs produced also decreases with a gestation and maturation delay equivalent to 12 months (in this model the breeding fraction does not change as a response to flock dispersal). Meanwhile capital is still decreasing as costs accrue until, midway between month 7 and month 36, the income from wool, meat, and livestock sales outweigh expenses (but capital is still negative, and the farmer is still working to decrease the herd). Together the herd dispersal and the delays associated with the mature lamb stock result in a lagged maximum of mature lambs at month 32, after which this stock starts to decrease. At month 36 capital becomes positive and the farmer starts to increase the number of breeding ewes once again, but around month 43 livestock-related profits begin to fall in response to the minimum breeding ewes just 12 months before.

Loss with recovery to initial production levels ($10,000 initial capital)

16-month negative capital/herd dispersal period (8 months shorter than the 24 months of gestation, maturation, and livestock delays).

In this scenario capital goes negative at month 14. When capital goes negative the farmer starts to disperse their herd to recover losses and increase profit & capital. Herd dispersal happens gradually over time as defined by the farmers lifestyle choice (desire to raise sheep) and access to livestock buyers. As the herd size decreases the number of mature lambs produced also decreases with a gestation and maturation delay equivalent to 12 months. Meanwhile capital is still decreasing as costs accrue until, midway between month 14 and month 30, the income from wool, meat, and livestock sales outweigh expenses (but capital is still negative, and the farmer is still working to decrease the herd). Together the herd dispersal and the delays associated with the mature lamb stock result in a lagged local maximum of mature lambs at month 30, after which the number of mature lambs start to decrease. In this simulation the local maximum of mature lambs occurs in the same month as capital goes positive and the farmer starts to increase their breeding ewes. There is no maximum associated with livestock-related profit in this model, instead livestock profit continually increases – albeit at varying rates.

No loss/ no change in production levels ($25,000 initial capital)

0-month negative capital/herd dispersal period (24 months shorter than the 24 months of gestation, maturation, and livestock delays).

In this scenario capital does not go negative and all other parameters continually increase until external constraints limit system growth.

Table 10. Timeline of events for 5k, 10k, & 25k initial capital scenarios

5k Initial Capital						
variable	month 7	month 14	month 30	month 32	month 36	month 43
breeding ewes					minimum	
mature lambs				maximum		
capital	negative				positive	
meat profit						maximum
10k Initial capital						
breeding ewes			minimum			
mature lambs			local max			local min

capital		negative	positive	
meat profit	continually increases (rate of increase varies)			
25k Initial capital				
breeding ewes	continually increases (after initial loss due to attrition/non-replacement)			
mature lambs	continually increases (once initial lambs are mature)			
capital	does not go below zero			
meat profit	continually increases (rate of increase varies to plateau)			

While initial capital greatly affects the overall profits of the enterprise – how does maxing out a herd with low initial capital compare with growing a herd with the same low initial capital? Figure 19 shows a scenario that starts with 10k initial capital on 21 acres. The blue line represents a growing enterprise and the orange line represents a maxed-out enterprise. Even with low initial capital, and a period of negative capital, the maxed-out enterprise results in greater lifetime profit (reflected by lifetime capital) than one that grows their enterprise. This is likely due to the loss of income from holding back lambs to become breeding ewes and the conservative rate at which the model farmer grows their flock

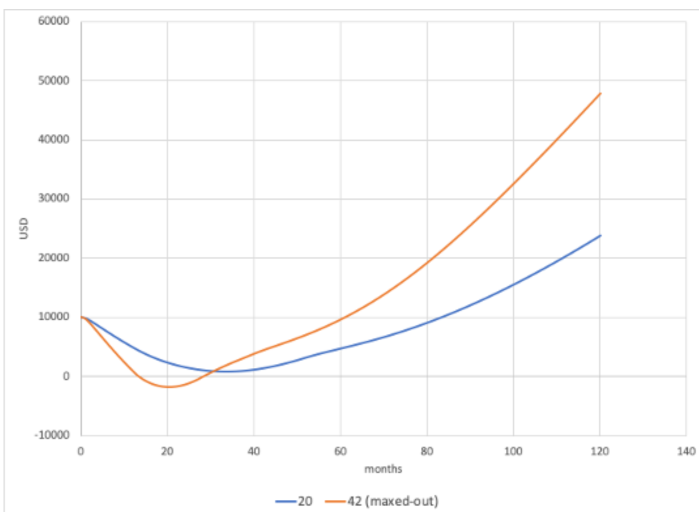
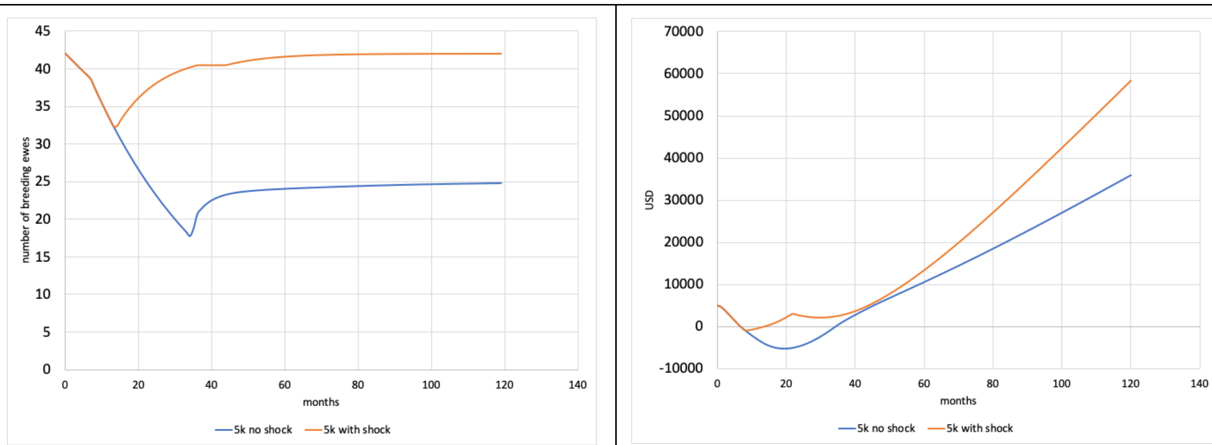


Figure 19. Comparison of capital on growing enterprise and maxed out enterprise on 21 acres

The effect of a loan on limited initial capital

One way to mitigate challenges associated with limited initial capital is by a loan. In this scenario fraction of external income is used to represent a loan (Figure 20). Initial capital is 5k, at month 9 (when capital is negative) the fraction of external income to capital is increased for a 12-month period to 5% from 0.5%.



(a) number of breeding ewes

(b) capital

Figure 20. Effect of positive shock to capital (from external income) when capital is negative.

As expected, the temporary increase in money into capital from an external force helps to restore the sheep-farm enterprise back to initial production levels by decreasing the duration of negative capital – resulting in larger capital at month 120.

Farm storage capacity

Many farmers will start with limited storage capacity and the grow this capacity as needed – as their inventory grows. How does this affect their farms overall profit?

The effect of farm storage capacity

Storage capacity restricts the amount of fiber that can be stored on the farm and has a significant effect on potential fiber profit and therefore sheep profit (Figure 21). The lower capacity simulation initially exhibits a larger profit. This is due to a lower skirting delay as a result of lower capacity which results in the fiber being available to the buyer and wool pool at a faster pace. The pace at which the buyer and wool pool purchase the wool, however, is not controlled by the farmer and eventually the farm's capacity decreases as their fiber inventory increases resulting in more wool going to waste to make room for the newer wool. This decrease in capacity places emphasis on significance having available storage capacity. Therefore, a combination of an initial lower capacity then increasing capacity at a later point is the most beneficial for the farmer. This initially encourages the farmer to move their wool to market during the period when expenses are typically greater than income, and then later decreases the need to send wool to waste by increasing capacity. This combination results in an overall higher accumulated sheep-related profit (

Table 11).

It is worth noting that most wool pools will not accept fiber older than two years and the longer the fiber is stored, the lower the quality of the fiber due to lanolin reset, and possible infestation (Farmer #1, 2020; Surber, 2018).

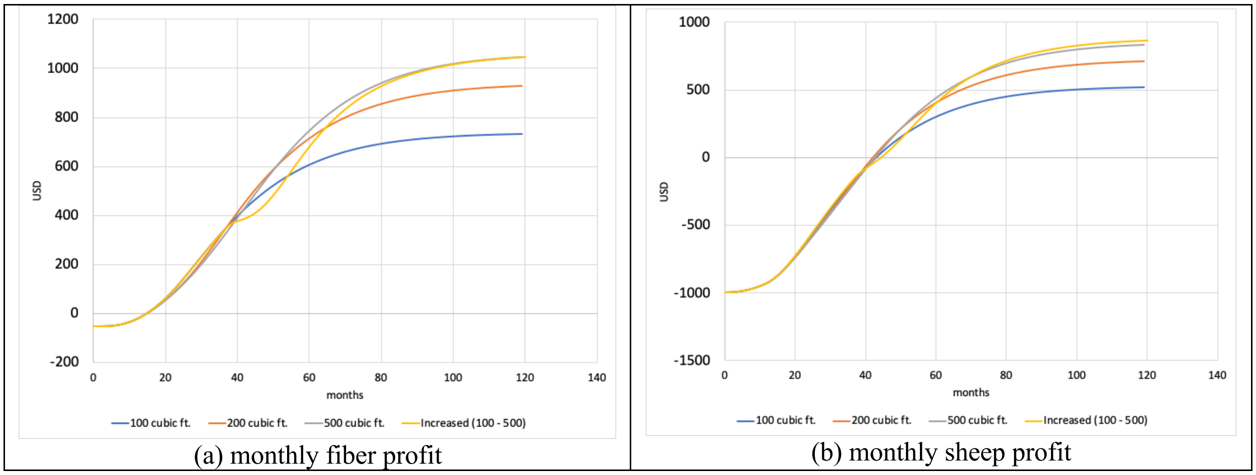


Figure 21. Effect of farm storage capacity on (A) monthly fiber profit; (B) monthly sheep profit.

Table 11. Accumulated and additional profits in response to storage capacity

Farm storage capacity (ft^3)	Accumulated Sheep Profit at month 120 (USD)	Additional profit from added storage capacity (USD)
100	21,927.40	baseline
200	35,471.46	13,544.06
500	42,397.06	20,469.66
increased capacity (100 – 500)	43,216.01	21,288.61

Summary of analysis for farmer-defined parameters

Sheep producers make decisions every day regarding how to increase profits. Some of these decisions include the decision to increase their pasture, farm storage capacity, and the amount of initial capital. Each of these decisions significantly affect the success and equilibrium point of the enterprise.

Ideally sheep farmers will max out their pasture capacity from the beginning, even if capital is limited, and if so it behooves them to seek out financial support such as a loan. Of course, maintaining this and receiving profit from their efforts is highly dependent upon a number of items including access to markets for meat and/or wool. It is worth noting that in the disconfirmatory interviews it was identified that a farmer can increase the size of their herd without increasing the pasture but they would then need to consider the additional cost of feed to supplement natural forage ((Farmer #1, 2020; Farmer #4, 2020).

Farm storage capacity plays a significant role in the fiber-related profit over the lifetime of the sheep enterprise. Farmers should grow storage capacity as needed, by doing so the limited capacity encourages the farmer to get their wool to a market but is not so great that they are forced to send wool to waste and lose income. A future iteration of the model should address the fact that storage capacity when added to incurs an expense (Farmer #4, 2020).

Policy defined Parameters

Analysis of buyer & wool pool effects

Buyer and wool pool access and prices are critical components of the farm level supply chain much discussed in the fiber community. How critical is it to have a buyer (and/or wool pool); and would an increase in wool pool prices lead to enterprise longevity and success?

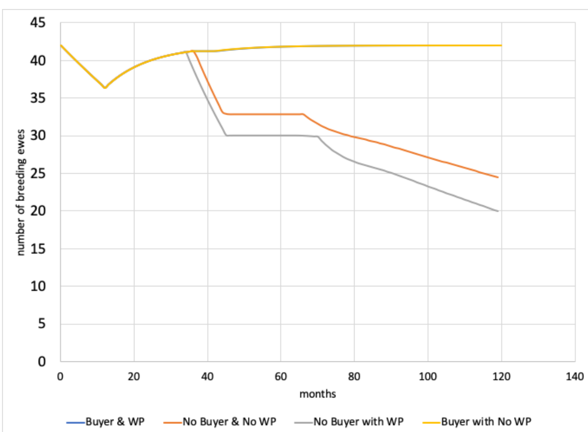
The effect of access to buyer and wool pool

Figure 22 shows the effects of access to wool pool and buyer. There are 4 scenarios 1) access to buyer & wool pool (blue), 2) no access to buyer and no access to wool pool (orange), 3) no access to buyer and access to wool pool (grey) & 4) access to buyer and no wool pool (yellow). These four scenarios represent realistic situations the farmer may find themselves in when searching for a market for their wool. The first two graphs (Figure 22 a & b) represent the instance where producers consider the cost of labor (15 USD/hour) and the second two graphs (Figure 22 c & d) represent instances where producers do not consider labor costs as is often the case in small farms (Lowder, Skoet, & Raney, 2016).

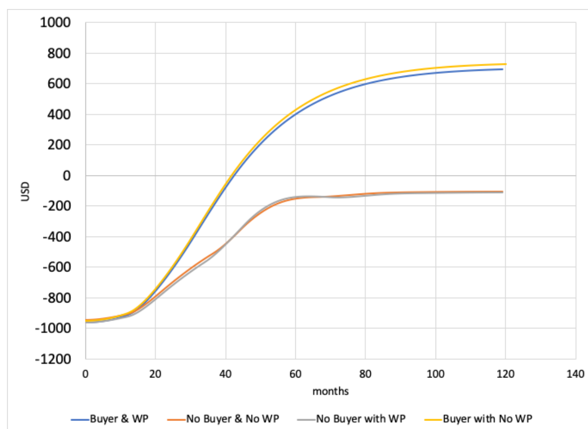
The potential of wool sales, by having access to a buyer and/or a wool pool, has on the sustainability of a sheep farm enterprise is undeniable. While the extent of wool sales contribution on the success of the enterprise depends greatly on a number of factors especially how well the meat and livestock markets are developed, it goes without saying that a successful wool sales channel will add to the farms GCFI.

What is interesting in all cases is how access to wool pool affects the outcome. In the first two cases, with labor costs, there is actually a loss associated with bringing wool to a wool pool whereas in the second two cases, no labor costs, access to a wool pool hardly affects the sheep profit and business decisions, namely the decision to increase or decrease the flock. In contrast access to a buyer, in this instance with all other parameters held at the values shown in Table 6, ensures success of the sheep farm enterprise.

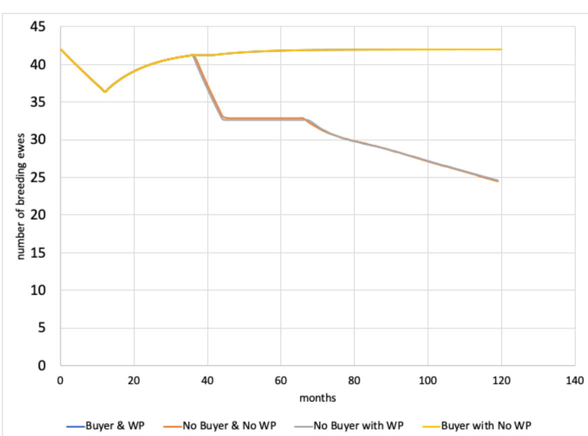
It is worth noting that this model does not consider costs associated with waste wool and will need to be addressed in future iterations. While not all small-flock producers incur a cost from their waste wool it is negligent to not address this as it has been identified as a component that may significantly affect the outcome of the model (Farmer #6, 2019). It is assumed that when this is added to the model access to wool pool will result in higher profit than no access to wool pool.



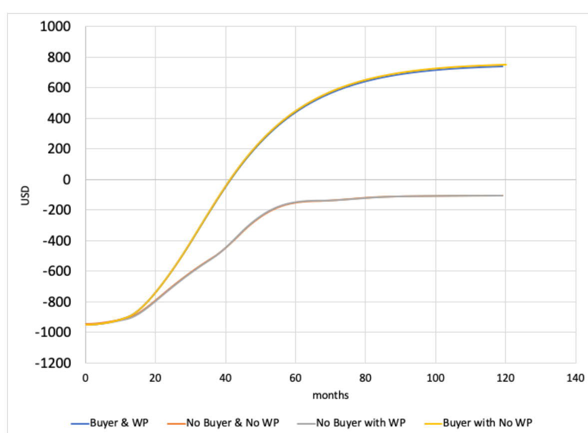
(a) breeding ewes with labor costs



(b) monthly sheep profit with labor costs



(c)breeding ewes without labor costs



(d) monthly sheep profit without labor costs

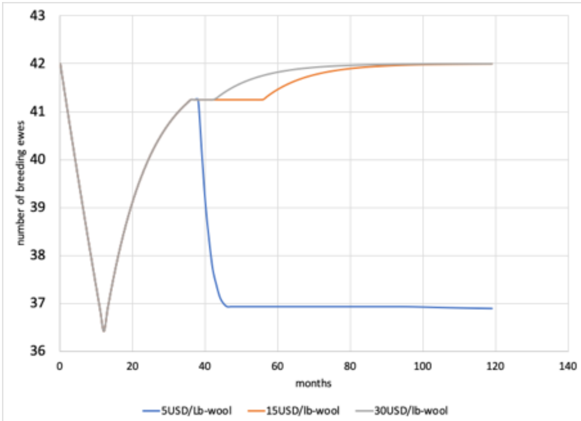
Figure 22. Effect of access to buyer and/or wool pool on a sheep farm enterprise (a & b) considering labor costs, and (c & d) not considering labor costs.

The effect of buyer & wool pool prices

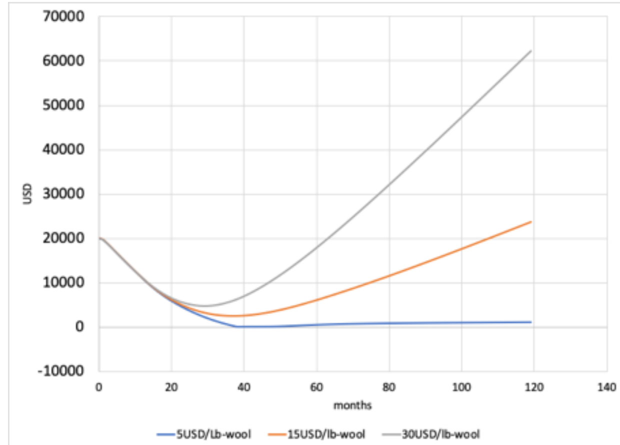
Of course, having access to a buyer is only one aspect of how wool sales may contribute to a sheep farm's sustainability and it goes without saying that the prices paid for the wool will alter the effects of wool sales on farms' GCFI. There are two sets of simulations presented in this section, one representing the effect of direct market price (Figure 23) and the other the effect of wool pool price (Figure 24).

Figure 23 show how changes to the direct market price affects breeding ewes (a), capital (b), monthly fiber profit (c), and monthly sheep profit (d). The average price varies from low ($5/lb.-wool), medium ($15/lb.-wool), and high ($30/lb.-wool). These prices represent realistic prices farmers may encounter in the direct market.

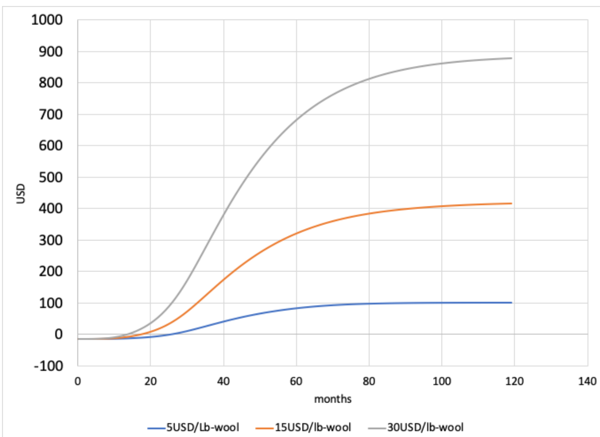
In this model when the direct market buyer price is below a certain value the contribution of wool sales to the sheep farm enterprise results in a negative profit, initially decreasing capital until it goes negative and the farmer works to decrease their herd. The farmer will decrease their herd until they see increasing profit and positive capital. In the 'low' scenario sheep profit remains negative but the positive capital is balanced by the input from external income. In this case the farmer will maintain their herd size at a new, lower, equilibrium. Above this price (medium and high scenarios) wool sales enable the farmer to recover to their initial herd size by contributing to a positive profit and increasing capital.



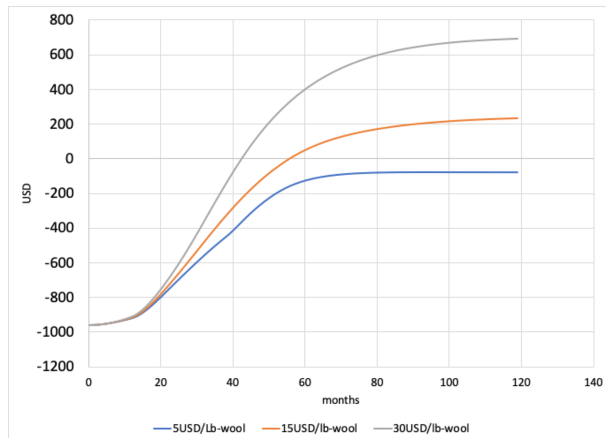
(a) breeding ewes



(b) capital



(c) monthly fiber profit

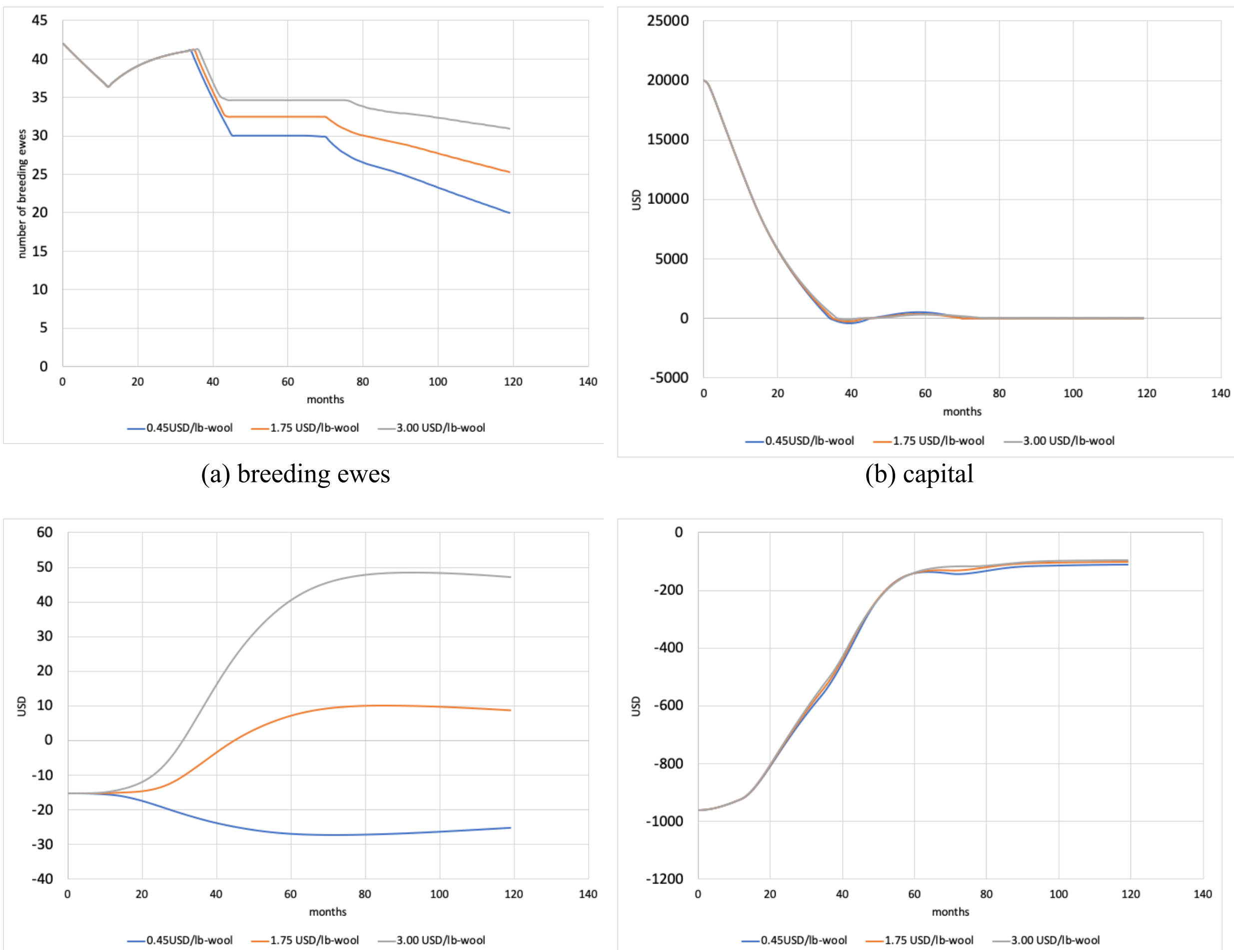


(d) monthly sheep profit

Figure 23. The effect of direct buyer price on sheep farm sustainability

Figure 24 shows how changes to the wool pool price affects breeding ewes (a), capital (b), monthly fiber profit (c), and monthly sheep profit (d). The average price varies from low ($0.45/lb.-wool), medium ($1.75/lb.-wool), and high ($3.00/lb.-wool). It is worth noting that the low price of $0.45/lb.-wool was the 2019 wool pool price in the NE US and $3/lb.-wool is a private wool pools pay for NE US wool with the goal in increasing farm success and longevity.

Many in the NE US fiber community hypothesize that increasing wool pool prices will help sheep farmers to become more profitable. This model agrees to an extent, showing that, with all other parameters held at the values in Table 6, an increase in wool pool prices may encourage farmers to decrease their herd to a lesser extent. Regardless if wool pool is the only income being generated by the wool capital will still hover just above zero with a negative sheep profit balanced by input from external income. Recalling that depending on how the farmer deals with their waste wool and considers labor costs contributing to a wool pool may actually cost the farmer more money than they will generate. By increasing the value of the wool to even $3 it does not seem to alleviate this challenge.



(a) breeding ewes

(b) capital

(c) monthly fiber profit

(d) monthly sheep profit

Figure 24. The effect of wool pool price on sheep farm sustainability

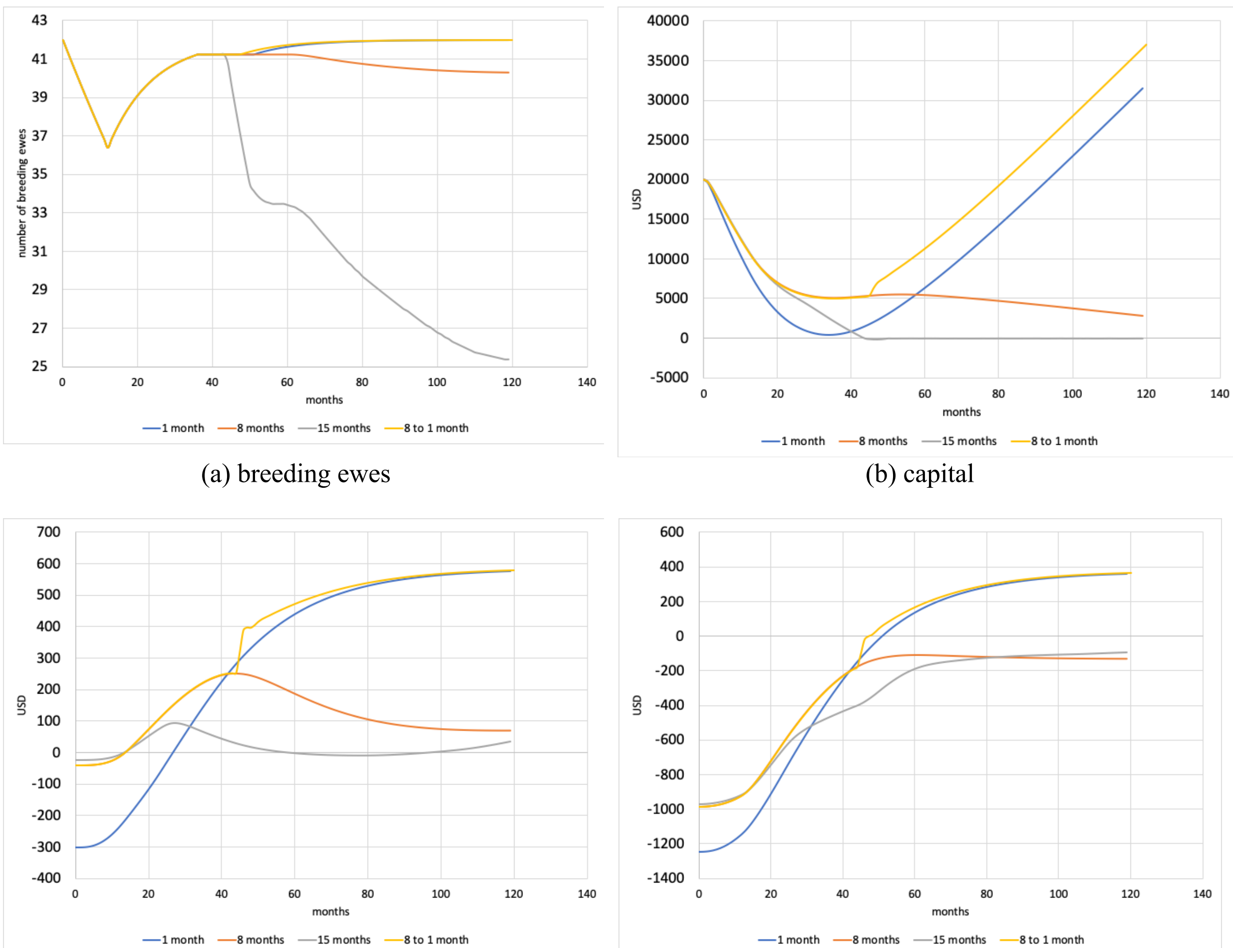
The effect of market frequency

Once a farmer has established access to a buyer and a buyer price, direct market or wool pool, the they must also stop to consider market frequency. In this model this is represented by the 'buyer delay'. This delay may vary depending on the market channels and frequency of access to these market channels. The lower the delay the quicker the farmer is able to move inventory out and increase the available farm storage.

The simulations in Figure 25 show how a change in the 'buyer delay' may affect the sheep farm enterprise. In these examples the buyer delay was varied from low (1 month), medium (8 months), and high (15 months) with a storage capacity of 50 cubic feet, all other parameters were held at the values shown in Table 6. The low market delay represents regular sales through online or boutique channels, 8 month delay represents a farmer who pursues the festical markets, and 15 month delay was chosen to show an extreme case which may represent irregular marketing and distribution by a farmer who does not search out opportunities to reach a market other than when the 'need' arises. Storage capacity was altered to 50 cubic feet in order to emphasize the effects of changes to the buyer delay.

One can easily see that limited access to a buyer over the lifetime of the business will significantly reduce the success of this sheep farm enterprise. The 'high' (15 months) and 'medium' (8 months) delays in this scenario result in a negative sheep profit for the lifetime of the simulation. The slower delay of the two, the 'high' delay, results in such a slow rate of income generation that there was not enough capital to carry the sheep farm enterprise and the farmer continuously reduced their herd. In contrast the 'medium' delay experienced a faster increase in sheep profits early on but still the sheep profits remained below zero with a steady decrease in sheep profits starting at month 62. This decreasing sheep profits with positive capital leads to a slow decrease in herd size while the farmer searches for a new equilibrium (not reached for the duration of this simulation). The negative sheep profit in both of these scenarios is attributed to the loss of income due to lack of storage capacity; without a market to move inventory away from the farm the farm storage capacity decreases and more wool goes to waste.

This is further highlighted by looking at the ‘low’ (1 month) delay with a steady market access. In this scenario the farm has a market to move its wool and therefore sees sheep profit, and increasing capital, encouraging the farmer to increase its herd. The most successful scenario in this set of simulations is where the farmer starts with ‘medium’ market frequency and then shifts to ‘low’ (1 month) market frequency once they notice signs of recovery from the initial start-up expenses.



(a) breeding ewes (b) capital

(c) monthly fiber profit (d) monthly sheep profit

Figure 25.The effect of buyer delay on sheep farm sustainability

The success of shifting market frequency is further emphasized in Table 12. It is important to remember that to emphasize the effects of market frequency, storage capacity was decreased to 50ft^3 which significantly increases the amount of wool that goes to waste and hence the low and even negative accumulated sheep profit. What is being emphasized here is that by having a low market frequency (long delay) early on, decreasing expenses associated with marketing during this sensitive time of enterprise start-up, and then later increasing market frequency when capital shows sign of recovery the farmer will increase their chance of success.

Table 12. Effect of market frequency on accumulated sheep profit.

Minimum buyer frequency (months)	Accumulated Sheep Profit at month 120 (USD)
1	2,339.56
8	-27,435.33
15	-32,404.11
increased frequency (8 – 1)	7,407.70

Summary of analysis for policy-defined parameters

While access to a buyer is often out of the hands of the farmer it can play an essential role on the success of the sheep farm enterprise to varying degrees depending on the type of market channel, the price, and the frequency. Identifying the value of these markets may lead to potential policy or consumer group initiatives to increase wool market access to sheep farm enterprises in the NE US.

Many sheep producers in the NE US contribute to wool pools as a primary way to market their wool. This model shows that access to a wool pool, regardless of price, not only plays an insignificant role in the sustainability of a sheep farm but may in fact serve to decrease profits (depending on the costs associated with waste wool, labor, etc.). On the other hand, access to a direct market buyer has a strong positive contribution and this success increases with price. It is worth noting that an increase in direct market price is typically related to an increase in effort on improving the condition of the wool discussed earlier and this must be considered. The buyer price will likely help to define where the equilibrium point of the sheep enterprise is and is highly dependent upon other factors such as breeding fraction, percentage of livestock sold as breeding or fiber stock, price of breeding or fiber stock, etc. Establishing a minimum buyer price is key. Finally, market frequency also plays an important role and is highly dependent on the storage capacity of the farm.

Chapter 5 Conclusion

Future Work

This study is only the beginning – besides improving the model through an iterative process using disconfirmatory interviews and recommendations discussed below – there are many other ways this work can grow.

- The model itself can be added to in the direction of meat and the value-add supply chain.
- A grant can be pursued to design and implement a regional check-off program, as discussed in 'Recommendations and Policy Implications'
- Similarly, a grant can be pursued to design and implement a beginning small ruminant farmer loan program and educational series – with an effort to include wool production and marketing to direct markets.

Disconfirmatory Interviews

Methodology

Disconfirmatory interviews were first identified as a technique for SD model building in 2012 by Anderson et. al. SD modeling is generally accepted to be an iterative process which requires engagement with the community which the model is representing. Disconfirmatory interviews enable feedback from the community without having to utilize group model building. This is especially valuable when working with the farming community as the unavailability and remoteness of its members make it difficult to gather together for days at a time.

There are three purposes for disconfirmatory interviews 1) increase user confidence; 2) improve model structure; and 3) problem and policy focus (Andersen et al., 2012). In this thesis the disconfirmatory interview approach was used to help improve the model structure and identify areas for future research. One of the key aspects of developing such interviews is "to use the deference effect to focus clients on disconfirmation". Throughout the interview process interviewees were regularly asked "what is wrong with the model" or similarly "what is wrong with what you are seeing"?

Model & Data Collection

A presentation was developed using isee Systems Stella interface and power point. There were two sections of the presentation/interview.

The first section introduced the SD model and model terminology. In this section interviewees were shown symbols of each sector and how they are connected, including feedback loops, with same and opposite flows between sectors being shown and discussed (the phrasing same and opposite flow was used opposed to positive and negative due to some confusion that arose from the use of positive and negative – this confusion was not present when using the term same and opposite). In this section interviewees were also presented assumptions, stocks, and inputs present in each sector. At the end of every slide the interviewees were given as much time as needed to look over the slide and were then asked, "What is wrong with what you see here?".

The second section of the interview the interviewees had an opportunity to work with the model by regarding the output of stocks or other relevant variables while making changes to parameters that directly affect the input or output rates of these stocks. This was made possible using to the isee Systems Stella interface. Again, interviewees were allowed to take as much time as they wanted and were then asked, "What is wrong with the trends you see here?". It is worth noting that in both of the interviews conducted this section lead to difficulty in getting feedback as the farmers were either: 1) tired at this point; 2) found it difficult to respond to 'obvious' trends (e.g. more breeding ewes results in more baby lambs): or 3) found the data itself difficult to follow as it was presented as continuous data opposed to discrete which they are more accustomed to measuring on the farm. In the second interview the farmer requested to see the full model which led to an active and valuable discussion. Limited feedback was received in this section of the model. It is not clear if the lack of feedback had to do with interview exhaustion or there being little to respond to. Either way both interviewees found this section interesting and it is advised to have some sort of model engagement in future disconfirmatory interviews. It is also recommended that in future interviews that after giving guidance and description of how output is presented the interviewee be given control of the model. It is important, in this case, to make the model itself easy to navigate by collecting parameters into a sector and highlighting stocks and variables of interest.

Ultimately two disconfirmatory interviews were conducted. More farmers were contacted but the late spring early summer season made it difficult to set a time for the interviews. The two interviews that were conducted were with two upstate NY sheep farmers who sell to all of the markets included in the model (wool, livestock, and meat). Regardless of the lack of interviewees the substance of the conversations were informative and a number of improvements that could be addressed in future iterations of the model were noted.

Recommended Model Improvements

In the first section of the interview process the overall model was introduced with feedback loops and assumptions. This was followed by an exploration of the assumptions, stock and inputs of each sector at a time. The following recommendations were from interviews conducted with Farmer #1 and Farmer #4, on June 24th 2020 and July 2nd 2020, respectively.

Overall model

Both of the farmers interviewed expressed disappointment at the lack of addressing the supply chain and profit related to value-added products. This is important because many sheep producers in the small flock sector create value-added products to help increase their profits. While it was explained and accepted that this model integrates farm-level value-added products by considering the farmer as its own buyer in future iterations the supply chain and markets should be addressed to better understand how navigating the supply chain affects sheep-related profit.

Sheep sector

Table 13 shows recommended changes for future iterations of the model, concerning the sheep sector, as well as a short description of the current state of the related variable and/or subject and the suggested changes.

Table 13. Recommended changes in sheep sector from disconfirmatory interviews

Subject	Current state	Recommendation
Feed costs	Embedded within overwinter costs which also addresses the cost of bedding, and only applied to breeding ewes.	Should be year-round (depending on pasture, breeding schedule, and lamb preparation) • as pasture decreases and sheep increase more feed. • Feed ewes at end of pregnancy and during lactation • Some lambs are fed grain to speed up maturation
Maturation rate	A constant 7 months	Can vary from 4 – 12 months depending on use of grain and breed of animal
Acreage as sheep capacity limiting factor	two sheep per acre.	Increasing infrastructure and feed can increase sheep capacity (depending on market forecasting)

A key take-away that came out of the disconfirmatory interviews and will need to be addressed in future model iterations is that feed costs are year-round and vary depending on breeding schedule, available pasture, and lamb preparation. Additional feed is typically given to pregnant ewes late in the pregnancy and during lactation. Lambs may also be kept overwinter ('overwinter costs' – feed and bedding), depending strongly on the farm's meat/lamb schedule. Feed costs can also increase depending on the sheep/acreage ratio, as some farms do not have enough natural forage to maintain their sheep and purchase additional hay throughout the year. In addition, both farmers emphasized the need to include mineral and veterinary costs along with feed.

In relation to feed, the mature lamb rate can vary amongst farms and per farmer discretion. A farmer may choose to 'speed-up' the maturation process by feeding lambs grain, creating market ready lambs by 5 or even 4 months. On the other end of the spectrum it can take up to 12 months to prepare market ready lambs when solely using pasture (grass-fed lambs) and varies depending on the breed of sheep.

While both farmers questioned the lack of rams in the model, one of the farmers emphasized the importance of including a ram. Without a ram, farmers are forced to use artificial insemination, which works 50% of the time, and even then, may require 'follow-up' from a ram. By including a ram costs associated with this addition will need to be addressed.

Finally, both farmers did not consider acreage a primary limiting factor, as infrastructure could be built, and feed bought to address this lack of forage. Instead they both felt that market forecasting, infrastructure, the cost of additional infrastructure has much more important roles in limiting the growth of the sheep enterprise.

Wool sector

Table 14 shows recommended changes for future iterations of the model concerning the wool sector, as well as a short description of the current state of the related variable and/or subject and the suggested changes.

Table 14. Recommended changes in wool sector from disconfirmatory interviews

Subject	Current state	Recommendation
Shearing lambs	All lambs are shorn before being sold to meat market.	Most, if not all, lambs are not shorn before being sold to meat markets. Volume of wool from lambs is less per sheep than ewes. Include income and expenses associated with sheep skin sales.
Bellies and tags	10% of wool produced considered waste.	There is a market for bellies and tags, albeit not typical for farmers to pursue.
Waste wool	No cost to farmer	May incur a cost.
Storage capacity	Constant	May be increased and will depend on cost comparison of additional infrastructure versus forecasted income.

Both farmers stated, to varying degrees, that they do not shear lambs before meat sales. Farmer #1 said that she occasionally shears prior to meat sales and farmer #4 says that she never shears prior to meat sales. It is worth noting that farmer #1 raises a breed that produces both meat and wool while farmer #4 raises two sheep breeds; 1 breed specifically for meat and the other specifically for wool. When selling lambs to the meat market both farmers said that they can make more money from sheep skins opposed to wool as sheep skins are easier to sell. Farmer #1 also mentioned that it is worth separating the lamb's wool from the ewes wool in the model due to the fact that lambs produce a significantly smaller volume per lamb.

Farmer #1 also mentioned that she has found a market for bellies and tags (typically waste as the model assumes). She also acknowledged that while this is not common it is feasible. Further waste wool, of which bellies and tags are a portion of may incur a cost (this model assumes there is no additional cost associated with waste wool).

Finally, it was pointed out that storage capacity need not be static, as a farmer may choose to build additional storage capacity to increase income. Of course, adding storage capacity will likely add expenses related to additional infrastructure and will need to be addressed.

Finance sector

Table 15 shows recommended changes for future iterations of the model concerning the finance sector, as well as a short description of the current state of the related variable and/or subject and the suggested changes.

Table 15. Recommended changes in finance sector from disconfirmatory interviews

Subject	Current state	Recommendation
Capital	Includes initial capital, accrued profit, and input from external income.	Should also include loans.
Infrastructure	Included in overall maintenance and overhead costs	Should be pulled out of overall maintenance and overhead costs. Infrastructure affects costs associated with quality of wool. Increasing capacity involves additional costs.
Livestock prices	$250/sheep	Price can vary depending on breed, registration (purebred), and sale purpose (breeding, fiber, pet).
Meat markets	Only considers auction prices for lamb as meat and once per year.	Meat lamb prices vary throughout the year. Meat lamb auctions occur weekly. There are other meat markets (may only require a name change)
Profit/breeding-ewe ratio	Moves together (increase in profit implies increase in breeding ewes until pasture capacity is reached)	Does not necessarily move together, need to consider market forecast and available infrastructure (currently market demand is assumed unlimited).

Farmer #4 pointed out that capital may include a variety of items besides profit and input from external income. It is not uncommon for farmers to seek out loans to help build their business. When adding loans to the model one would need to also include information related to the loan period and interest rate.

Infrastructure came up many times during the interviews and was mentioned prior when considering the sheep capacity of the farm. It was also pointed out that infrastructure affects yearly costs related to wool condition, as with more infrastructure there may be less need for coating and other actions that increase wool condition. Infrastructure is currently included in the umbrella ‘maintenance and overhead costs’ and may need to be ‘pulled-out’ to make it more dynamic.

Livestock prices, breeding, fiber, and pet, all result in different average price depending on end market and breed type. Further a registered animal may demand a higher price than an unregistered animal. Due to the nuances of SD models this may be too detailed and need to be addressed by some creative means.

The most discussed portion of the model, with both farmers, centered around meat markets. This is likely due to the simplification made in assuming all meat sales are meat auction sales when, in fact this is not always the case. There are many markets available to lamb and mutton producers including auctions, feeder auctions, and direct-to-consumer markets. Each market will incur specific expenses; lamb auction – expenses present in this model; feeder auctions – similar to this model but can sell earlier for lower price and incur less costs; and direct-to-consumer – farmer navigates the supply chain, incurs expenses related to packaging and marketing, but can demand a higher price.

Farmer #4 also pointed out that lamb auctions occur on a weekly basis, but many farmers will aim for holiday markets. Further, farmers will breed according to these markets and may even breed multiple times per year to sell to the high price markets (if they have a breed of sheep that can breed year-round). It should be noted however that year-round sheep breeds do not typically produced high quality wool.

Finally, market forecasting and available markets needs to be introduced into the model and added to the feedback loop addressing enterprise growth. To simplify the model when developing this iteration consumer demand (market forecasting and available markets) was considered unlimited and therefore profit and available capital were the deciding factors for growth. It was recognized from the start that this is a false but necessary assumption that could be addressed in future iterations.

Recommendations and Policy Implications

One of the first choices a sheep producer makes is what breed of sheep will they choose to raise – this choice defines which markets they will need to have access to and how much profit over the lifetime of the farm that they can make. By choosing a breed with a higher breeding fraction they increase their likelihood of success and longevity but must identify a market for lambs, as this will become their primary product. By choosing a breed with a higher wool production rate the farmer will also increase their likelihood of success and longevity, but the profit will not be as great as the farmer who chooses increased breeding fraction. In both cases a market must be identified.

It is common for small flock small ruminant producers to grow their enterprise over time versus max out their pasture from the start. This model shows that while growing over time may be successful, the lifetime profit, at year 10, is much lower than that of a farmer who maxes out their pasture from the start. This is true even if capital is limited.

These farmers often chose to grow over time because of limited initial capital and lack of knowledge concerning marketing and production. To address these issues policies could be put in place to ensure beginning small flock small ruminant farmers have the support they need to max-out capacity and identify markets. For instance, a specific small flock small ruminant loan, or similar monetary assistance, program could be implemented for these farmers. This loan program could have stipulations related to production quality and offer educational opportunities needed to ensure their wool and meat quality meets a certain specification, and the farmers learn about the various market options – how to find and navigate.

Many farmers will grow their storage capacity over time, and this model shows that this is an appropriate response to inventory growth as it encourages the farmer to seek a market and helps to reduce waste wool. Waste wool was identified as one of the greatest points of profit loss in the model. Researchers with Vermont Extension had previously studied options on how to promote waste wool to help increase profits for regional farmers and found that there is a potential market for it as insulation – but there are currently many hurdles to overcome in order to produce wool insulation (e.g. a scouring facility) (Hagen & Hodgson, 2019). This is one point where a regional check-off program would be beneficial. By contributing to a check-off program regional small flock producer would be able to combine their financial support for efforts such as this – develop a feasibility study, business plan, and perhaps even financially support efforts to start a regional scouring & insulation production facility.

A regular discussion point in the NE US fiber community concerns access to wool pools and the prices paid at these wool pools with a common statement being that an increase in wool pool prices will enable regional farmers to increase their profits and enterprise longevity. This model clearly shows that an increase in wool pool prices, within a reason, does nothing of the sort. In fact, contributing to a wool pool, depending on how the farmer accounts for labor, may even decrease their overall profit. These farmers need to clearly define the lowest required price for their wool and then not go below it, even with the direct market buyers. Identifying the lowest acceptable price could be incorporated into the education component of the aforementioned small flock small ruminant loan program.

Many wool producers increase market frequency overtime, as they grow more accustom to their options. Increasing market frequency over time, as it turns out this is an appropriate response that increases profitability of the enterprise over its lifetime. However, in order to do this, there must be markets available to the farmer. In this model it was assumed that demand is unlimited, and markets are available, this is not always the case. Two concurrent studies are looking at just this – understanding consumer demand (Chan & Havas, 2020) and developing a marketing and branding strategy (Hohman & Havas, 2020). While this information is valuable it needs to be implemented to be useful. One way this information can be useful to help increase available markets is through the aforementioned regional check-off program, where funds could also be allocated towards branding and marketing NYS & NE US fiber and fiber-goods.

Research Reflection

A variety of animal fibers are produced in NYS and the NE US, with small flock sheep's-wool being the most prevalent. Farmers with 25 – 100 head sheep get the most profit from their wool likely due to their creating value-added products for a variety of markets and having sufficient quantity to sell consistently to direct and/or niche markets where they can demand a higher price. Even still, this income does not come close to balancing these farmers' expenses. While wool is one of three products sheep produce for market, increasing the value of the wool harvest will help to increase the enterprises chance at success and longevity.

To help determine practices and policies that can contribute to the success & longevity of NYS and NE US sheep farm enterprises a SD model of the farm level supply chain was developed during the period starting in the fall of 2018 to the spring of 2020 using primary and secondary research. SD models are not uncommon in agricultural research and are specifically helpful in analyzing the impact of practices and policies of complex and dynamic systems that include feedback loops, as does the farm level gate fiber supply chain. The results of this analysis point to a variety of potential practice and policy recommendations that can be pursued in future work

Chapter 6 Appendix

Table 28. **Sheep and Lambs – Inventory, Wool Production, and Sales by Size of Flock: 2012**

[For meaning of abbreviations and symbols, see introductory text.]

Sheep and lambs inventory	Sheep and lambs inventory				Wool production			Sheep and lambs sold		
	Total		Ewes 1 year old or older							
	Farms	Number	Farms	Number	Farms	Pounds	Value ($1,000)	Farms	Number	Value ($1,000)
Total	2,017	86,286	1,587	50,267	1,117	295,396	196	1,183	62,997	10,093
Farms with inventory of-										
1 to 24	1,364	11,843	1,026	6,974	693	52,909	23	619	5,680	834
25 to 99	498	22,233	414	13,071	326	93,405	80	414	13,490	2,120
100 to 299	118	19,553	110	12,371	73	78,761	51	114	18,531	2,809
300 to 999	31	18,138	31	9,766	20	37,103	(D)	30	10,963	1,763
1,000 to 2,499	4	(D)	4	(D)	3	(D)	(D)	4	(D)	(D)
2,500 to 4,999	2	(D)	2	(D)	2	(D)	(D)	2	(D)	(D)
5,000 or more	-	-	-	-	-	-	-	-	-	-
No sheep and lambs as of Dec. 31, 2012	(X)	(X)	(X)	(X)	27	7,881	1	98	1,806	285

Figure A 1. 2012 USDA Agriculture census data, sheep & lamb

Table 27. **Sheep and Lambs Flock Size by Inventory, Sales, and Wool Production: 2017**

[For meaning of abbreviations and symbols, see introductory text.]

Flock size	Sheep and lambs inventory		Sheep and lambs sold			Wool production		
	Farms	Number	Farms	Number	Value ($1,000)	Farms	Pounds	Value ($1,000)
Farms with December 31, 2017 flock size of-								
1 to 24	1,440	12,376	588	6,116	(D)	447	(D)	28
25 to 99	525	24,145	453	15,419	2,496	252	74,734	114
100 to 299	118	16,933	118	13,645	2,038	83	73,277	41
300 to 999	25	13,591	25	(D)	1,432	18	46,416	(D)
1,000 to 2,499	4	(D)	4	11,142	2,892	-	-	-
2,500 to 4,999	-	-	-	-	-	-	-	-
5,000 or more	1	(D)	1	(D)	(D)	1	(D)	(D)
All farms with December 31, 2017 inventory	2,113	80,195	1,189	62,498	11,560	801	253,460	215
Farms with no sheep or lamb inventory, on December 31, 2017	-	-	117	4,201	634	17	1,653	4
Total	2,113	80,195	1,306	66,699	12,194	818	255,113	219

Figure A 2.2017 USDA Agriculture census data; sheep & lamb

breed name	number of registeed farms NYS (09/2019)	breed micron range	Avg. micron for breed	micron range per class	ASI wool class
Cormo	2	17-23	20	<=22	fine
Merino	4	11.5-25	18.25	<=22	fine
Rambouillet	2	18-24	21	<=22	fine
BFL	1	24-28	26	22 <= 31	medium
Tunis	36	24-29	26.75	22 <= 31	medium
Suffolk	10	25-33	29	22 <= 31	medium
Southdown	25	24-29	26.5	22 <= 31	medium
Shropshire	4	25-33	29	22 <= 31	medium
Shetland	13	22-24	23	22 <= 31	medium
Romeldale/CVM	4	21-25	23	22 <= 31	medium
Polypay	1	22-29	25.5	22 <= 31	medium
Montadale	1	25-30	27.5	22 <= 31	medium
Karukal	1	25-36	30.5	22 <= 31	medium
Icelandic	10	19-31	25	22 <= 31	medium
Hog Island	1	22-32	27	22 <= 31	medium
Hampshire	12	25-29	27	22 <= 31	medium
Finn	7	24-31	27.5	22 <= 31	medium
East Friesian	0	28-33	30.5	22 <= 31	medium
Dorset	27	25-29	27	22 <= 31	medium
Corriedale	0	25-31	28	22 <= 31	medium
Columbia	2	23-30	26.5	22 <= 31	medium
Clun Forest	2	25-28	26.5	22 <= 31	medium
Cheviot	16	26-33	29.5	22 <= 31	medium
Charollais	20	23-27	25	22 <= 31	medium
California Red	2	26-31	28.5	22 <= 31	medium
Wensleydale	2	30-36	33	31 <= 36.2	coarse
Teeswater	6	30-36	33	31 <= 36.2	coarse
Romney	27	29-36	32.5	31 <= 36.2	coarse
Oxfords	11	28-34	31	31 <= 36.2	coarse
Leicester Longwool	3	32-38	35	31 <= 36.2	coarse
Jacob	10	27-35	31	31 <= 36.2	coarse
Gotland	4	29-34	31.5	31 <= 36.2	coarse
Border Leicester	18	30-38.5	34.25	31 <= 36.2	coarse
Romanov	1	35-55	45	>36.2	carpet
Navajo Churro	2	19-70	44.5	>36.2	carpet
Lincoln Longwool	7	33.5-41	37.25	>36.2	carpet
Cotswold	8	33-42	37.5	>36.2	carpet

Figure A 3. Data collected from breed registries concerning sheep farms in NYS (2019)

2019 Southern Adirondack Fiber Producers Wool Pool

June 13, 14 and 15, 2019

9:00 a.m. – 4:00 p.m.

Washington County Fairgrounds, State Rte 29, Greenwich, NY

Farms with large lots (1000 lbs+), please bring your fiber on June 13

2017, 2018, and 2019 shearing only!

For more information about the Southern Adirondack Fiber Producers Cooperative, contact: [redacted]

Again this year, the Coop is planning to have a unique Southern Adirondack blanket made using just the wool collected from producers at the pool. The machine-knitted blanket will be throw size with one or more patterns such as ribbing or basket stitch. Your cost will depend on the total number of blankets ordered, but will be around $100 each + 10 lbs. of wool/blanket. Suggested retail is $250. We need to have orders for at least 20 blankets in order to proceed with the project.

Join us on Instagram @soadkfiberproducers

We don't have prices yet from the same large national wool buyer that has bought our pool in the last several years, but at least he's agreed to take it. The buyer hopes to be able to pay us slightly more than he did last year and he assures us that these are the highest prices possible for wool right now (due to the world wool market being in flux, in part related to US tariffs on Chinese yarn).

We will be accepting three classes of grease wool:

- Clean white long, medium and fine wool (at least 2-1/2" in length) $.60
- White offsorts (including short and dirty fiber, head and belly wool, etc.) $.40
- Natural color long, medium and fine wool $.40

The buyer has lost his premium market for the longwool and as such, the Coop will have to class this fiber with other materials this year. Battenkill Fibers will evaluate any white or natural color Romney, Border Leicester, etc. that comes in for possible private purchase. $.60

This event will be run as a traditional wool pool - all sellers must plan to unload their own vehicle, assist in weighing and filling the baler, etc. **If you can't participate and choose to drop your fiber and leave, then a handling fee of $50/farm will be charged.**

Fees:

- $15/farm - annual cooperative dues fee will go toward the cost of pool administration (including wool sacks, tax return preparation, incorporation fees, insurance, rental of the Fairgrounds, and other); *
- $5/farm - dues for farms with 50 lbs or less;
- 4H youth members – no charge.

Figure A 4. 2019 Southern Adirondack wool pool advertisement

Finger Lakes Sheep Producers Coop-Our 99th year

[redacted]

March 30, 2019

Dear Sheep Producers,

The Finger Lakes Wool Pool will be held Wednesday May 8th, Friday May 10th and Saturday May 11th. Please note that no wool will be accepted on Thursday May 9th. We will again be at the Empire Farm Days site at Lott Farm, 2973 Route 414, Seneca Fall, N.Y. 13148. This is one mile south of Seneca Falls. Hours will be 8:30-4:00 on Wednesday and Friday and 8:30-2:00 on Saturday.

The wool market is slightly improved form last years very depressed level, although still a long way from the levels we would all like to see. This years price to producer will be 45 cents per pound for clean white wool at least 2 ½ inches in length and 15 cents for off-sorts. We were not able to get any bid for colored wool this year.

We are well aware that these prices are disappointing to all, and those with especially nice wool may want to look elsewhere for a better market-- we certainly would not fault anyone for doing so , but at the same time want to provide a market for those who need to move their wool.

When you arrive, please sign in at the desk and ask what you can do to help. Even if it looks like all is running smoothly, some workers may need a break. We have jobs suitable for everyone.-young and old!

All consignors will be expected to, at a minimum empty their bags and take home their garbage. Anyone who dumps their wool and runs will be assessed an additional 5 cents per pound.

Our pool has always been an ALL VOLUNTEER EFFORT, for almost 100 years, so please plan to spend some time helping as you are able, at least in proportion to the amount of wool you bring. We again particularly need help on feeding the balers, if we can keep 2 balers running, a few people will not have to bale late into the night.

One thing that all have appreciated was providing lunch for the workers, so we will again provide sandwich fixings and drinks for workers. Saturday will be reserved for small producers, so this year we will not accept lots of over 1000 lbs on Saturday, except by prior permission, in order to expedite wool receiving for the smaller producers who can only come on Saturday. Small producers will not need to pre-consign their wool, however, those planning to bring over 1,000 lbs will need to call [redacted] for scheduling. Please call Gary by May 1st as this will help us plan the trucking. You may get an answering machine as Gary is a busy farmer, but he will return your call.

Figure A 5. 2019 Finger Lakes wool pool advertisement

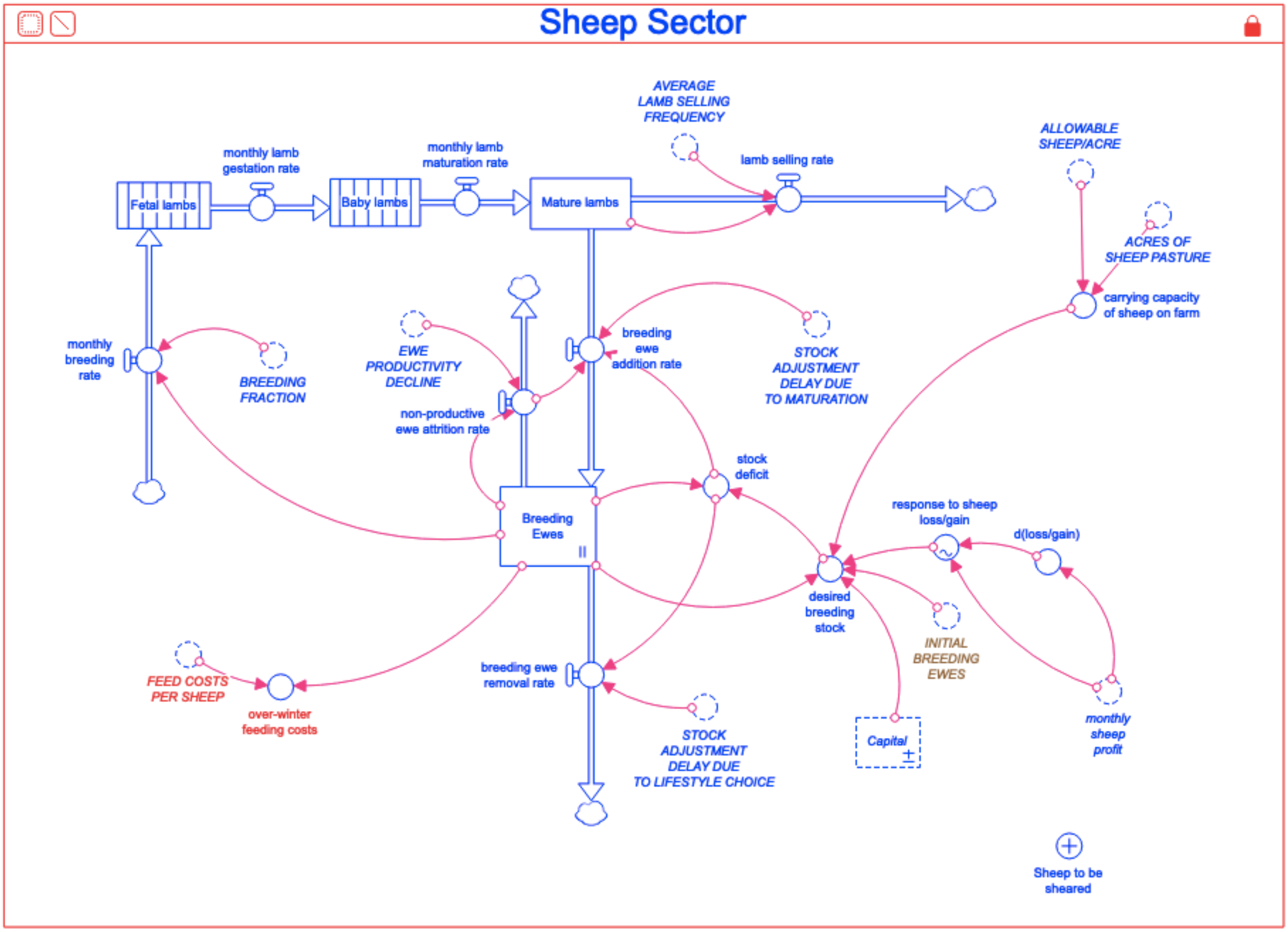


Figure A 6. Sheep sector

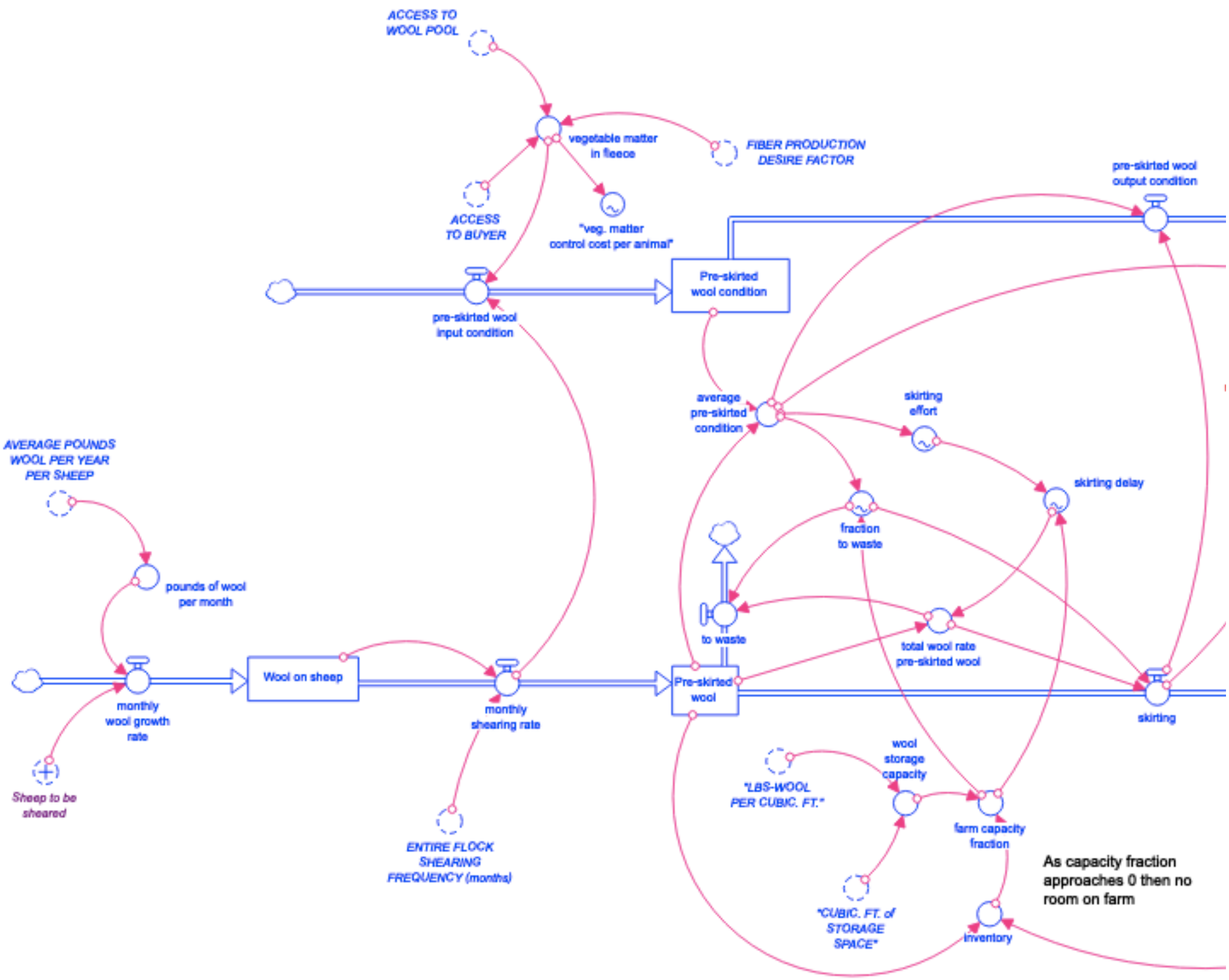


Figure A 7. Wool production sector (left)

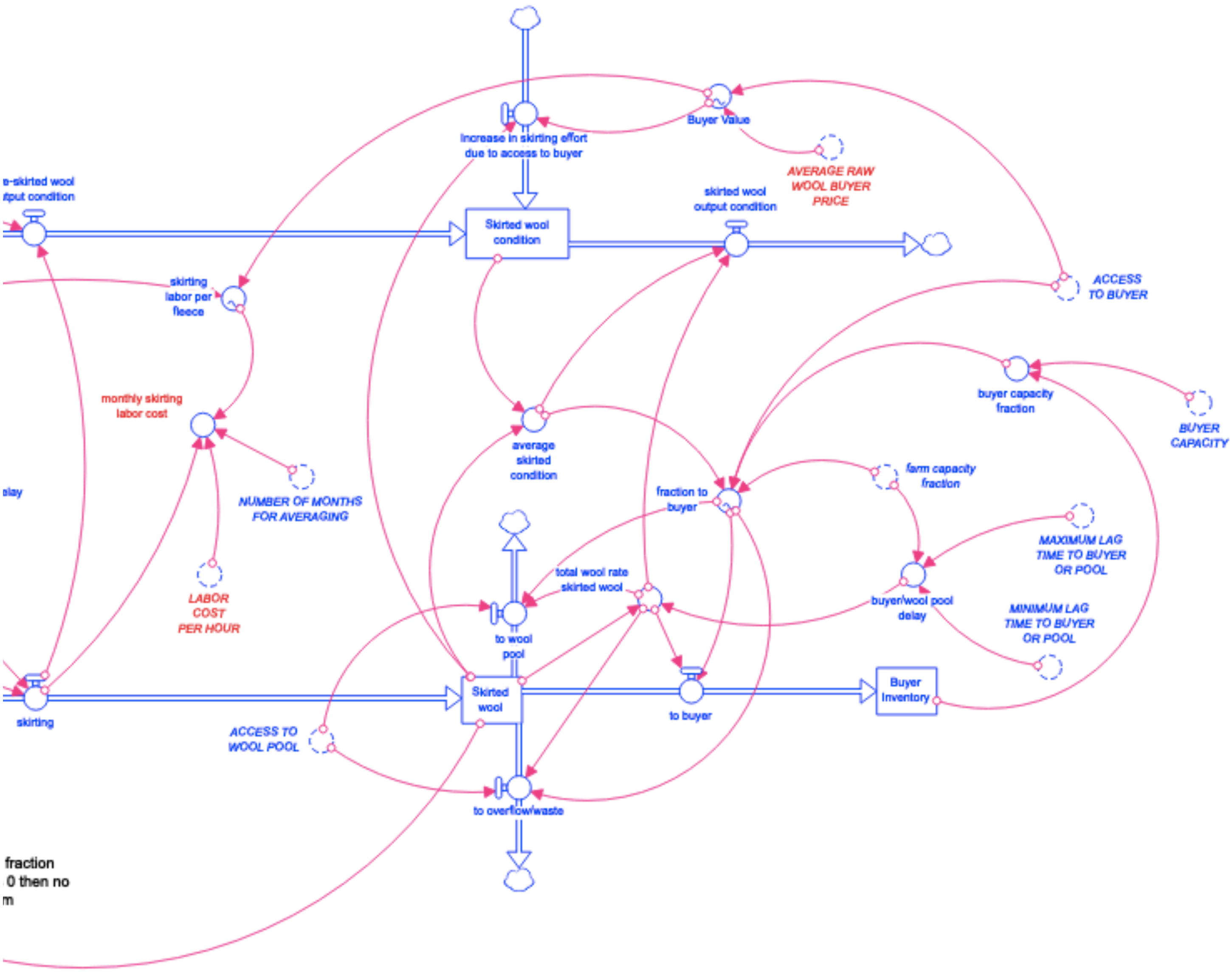


Figure A 8. Wool production sector (right)

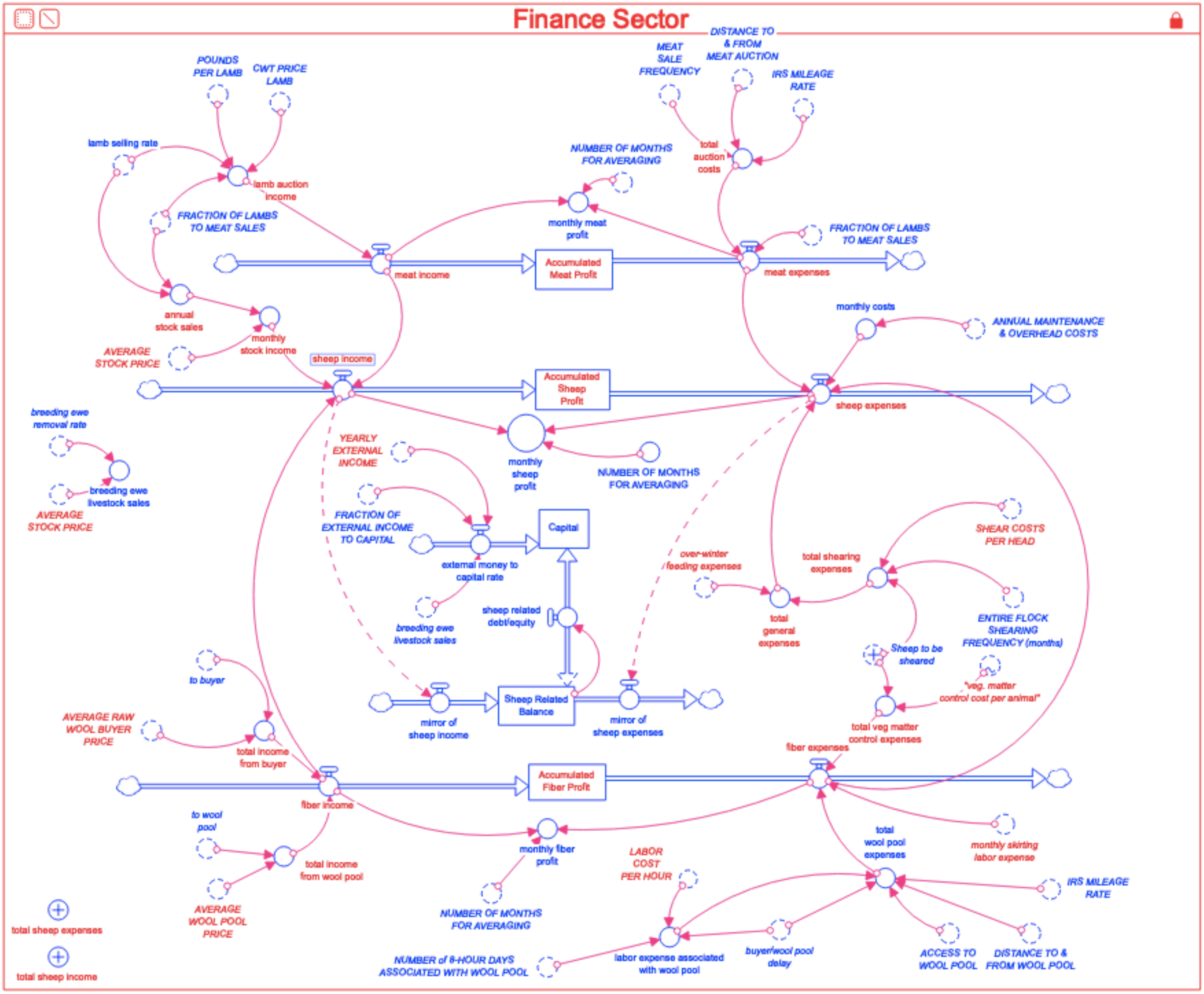


Figure A 9. Finance sector

Chapter 7 Model Equations

Notes for reading:

- All caps implies user defined parameter
- Sentence case (first letter capitalized) implies stock
- Lower case implies flow or variable

Model Parameters

"LBS-WOOL_PER_CUBIC._FT." = 2.5
"ALLOWABLE_SHEEP/ACRE" = 2
AVERAGE_POUNDS_WOOL_PER_YEAR_PER_SHEEP = 7
"ENTIRE_FLOCK_SHEARING_FREQUENCY_(months)" = 12
EWE_LONGEVITY = 7*12
LAMBS_PER_EWE = 1.5
POUNDS_PER_LAMB = 95
STOCK_ADJUSTMENT_DELAY_DUE_TO_MATURATION = 12
"CUBIC._FT._of_STORAGE_SPACE" = 200
ACRES_OF_SHEEP_PASTURE = 21
FIBER_PRODUCTION_DESIRE_FACTOR = 0.5
FRACTION_OF_LAMBS_TO_MEAT_SALES = 0.9
INITIAL_BREEDING_EWES = 42
INITIAL_CAPITAL = 25000
INITIAL_LAMBS = 0
STOCK_ADJUSTMENT_DELAY_DUE_TO_LIFESTYLE_CHOICE = 60
ACCESS_TO_BUYER = 1
ACCESS_TO_WOOL_POOL = 1
ANNUAL_MAINTENANCE_&_OVERHEAD_COSTS = 2000
AVERAGE_LAMB_SELLING_FREQUENCY = 12
AVERAGE_LIVESTOCK_PRICE = 250
AVERAGE_RAW_WOOL_BUYER_PRICE = 30
AVERAGE_WOOL_POOL_PRICE = 0.45
BUYER_CAPACITY = INF
BUYER_DELAY = 6
CWT_PRICE_LAMB = 160
DISTANCE_TO_&_FROM_MEAT_AUCTION = 120
DISTANCE_TO_&_FROM_WOOL_POOL = 100
FEED_COSTS_PER_SHEEP = 214
FRACTION_OF_EXTERNAL_INCOME_TO_CAPITAL = 0.005
IRS_MILEAGE_RATE = 0.58
LABOR_COST_PER_HOUR = 15
MAXIMUM_LAG_TIME_TO_BUYER_OR_POOL = 24
NUMBER_OF_MONTHS_FOR_AVERAGING = 12
"NUMBER_of_8-HOUR_DAYS_ASSOCIATED_WITH_WOOL_POOL" = 2
SHEAR_COSTS_PER_HEAD = 7
YEARLY_EXTERNAL_INCOME = 200000

Finance Sector

Accumulated_Fiber_Profit(t) = Accumulated_Fiber_Profit(t - dt) + (fiber_income - fiber_expenses) * dt
INIT Accumulated_Fiber_Profit = 25
INFLOWS:

```
    fiber_income = total_income_from_buyer+total_income_from_wool_pool
  OUTFLOWS:
    fiber_expenses = total_veg_matter_control_expenses +"monthly_skirting/grading_labor_expense" +
       total_wool_pool_expenses

Accumulated_Meat_Profit(t) = Accumulated_Meat_Profit(t - dt) + (meat_income - meat_expenses) * dt
  INIT Accumulated_Meat_Profit = 0
  INFLOWS:
    meat_income = lamb_auction_income
  OUTFLOWS:
    meat_expenses = IF(FRACTION_OF_LAMBS_TO_MEAT_SALES<=0) THEN(0) ELSE(total_auction_costs)

Accumulated_Sheep_Profit(t) = Accumulated_Sheep_Profit(t - dt) + (sheep_income - sheep_expenses) * dt
  INIT Accumulated_Sheep_Profit = 0
  INFLOWS:
    sheep_income = monthly_stock_income+meat_income+fiber_income
  OUTFLOWS:
    sheep_expenses = meat_expenses+fiber_expenses+total_general_expenses+monthly_costs

annual_stock_sales = lamb_selling_rate*(1-FRACTION_OF_LAMBS_TO_MEAT_SALES)

breeding_ewe_livestock_sales = breeding_ewe_removal_rate*AVERAGE_LIVESTOCK_PRICE

Capital(t) = Capital(t - dt) + (external_money_to_capital_rate + "sheep_related_debt/equity") * dt
  INIT Capital = INITIAL_CAPITAL
  INFLOWS:
    external_money_to_capital_rate = FRACTION_OF_EXTERNAL_INCOME_TO_CAPITAL *
       YEARLY_EXTERNAL_INCOME/12+breeding_ewe_livestock_sales
    "sheep_related_debt/equity" = Sheep_Related_Balance

labor_expense_associated_with_wool_pool = "NUMBER_of_8-HOUR_DAYS_ASSOCIATED_WITH_WOOL_
   POOL"*8*LABOR_COST_PER_HOUR/BUYER_DELAY

lamb_auction_income = lamb_selling_rate*FRACTION_OF_LAMBS_TO_MEAT_SALES*POUNDS_PER_
   LAMB/100*CWT_PRICE_LAMB

meat:fiber_ratio = SAFEDIV(monthly_meat_profit, monthly_fiber_profit,  0.000001)

monthly_costs = ANNUAL_MAINTENANCE_&_OVERHEAD_COSTS/12

monthly_fiber_profit = SMTH1((fiber_income-fiber_expenses), NUMBER_OF_MONTHS_FOR_AVERAGING)

monthly_meat_profit = SMTH1((meat_income-meat_expenses), NUMBER_OF_MONTHS_FOR_AVERAGING)

monthly_sheep_profit = SMTH1((sheep_income-sheep_expenses),
   NUMBER_OF_MONTHS_FOR_AVERAGING)

monthly_stock_income = annual_stock_sales*AVERAGE_LIVESTOCK_PRICE

profit_per_ewe = monthly_sheep_profit/Breeding_Ewes
```

```
Sheep_Related_Balance(t) = Sheep_Related_Balance(t - dt) + (mirror_of_sheep_income -
  mirror_of_sheep_expenses -"sheep_related_debt/equity") * dt
   INIT Sheep_Related_Balance = 0
   INFLOWS:
     mirror_of_sheep_income = sheep_income
   OUTFLOWS:
     mirror_of_sheep_expenses = sheep_expenses
     "sheep_related_debt/equity" = Sheep_Related_Balance

total_auction_costs = DISTANCE_TO_&_FROM_MEAT_AUCTION*IRS_MILEAGE_RATE/AVERAGE
   _LAMB_SELLING_FREQUENCY

total_general_expenses = total_shearing_expenses+"over-winter_feeding_expenses"

total_income_from_buyer = to_buyer*AVERAGE_RAW_WOOL_BUYER_PRICE

total_income_from_wool_pool = to_wool_pool*AVERAGE_WOOL_POOL_PRICE

total_shearing_expenses = SHEAR_COSTS_PER_HEAD*Sheep_to_be_sheared/"ENTIRE_FLOCK_SHEARING_
   FREQUENCY_(months)"

total_sheep_expenses = fiber_expenses + meat_expenses

total_sheep_income = monthly_stock_income + fiber_income + meat_income

total_veg_matter_control_expenses = "veg._matter_control_cost_per_animal"*Sheep_to_be_sheared/12

total_wool_pool_expenses = ACCESS_TO_WOOL_POOL*(labor_expense_associated_with_wool_pool+
   DISTANCE_TO_&_FROM_WOOL_POOL*IRS_MILEAGE_RATE/BUYER_DELAY)
```

Sheep Sector

```
Baby_lambs(t) = Baby_lambs(t - dt) + (monthly_lamb_gestation_rate - monthly_lamb_maturation_rate) * dt
   INIT Baby_lambs = INITIAL_LAMBS
     TRANSIT TIME = 7
   INFLOWS:
     monthly_lamb_gestation_rate = CONVEYOR OUTFLOW
   OUTFLOWS:
     monthly_lamb_maturation_rate = CONVEYOR OUTFLOW

Breeding_Ewes(t) = Breeding_Ewes(t - dt) + (breeding_ewe_addition_rate - "non-productive_ewe_attrition_rate" -
  breeding_ewe_removal_rate) * dt
   INIT Breeding_Ewes = INITIAL_BREEDING_EWES
   INFLOWS:
     breeding_ewe_addition_rate = SAFEDIV(stock_deficit,
         STOCK_ADJUSTMENT_DELAY_DUE_TO_MATURATION,  0.00001)+"non-
         productive_ewe_attrition_rate"
   OUTFLOWS:
     "non-productive_ewe_attrition_rate" = Breeding_Ewes/EWE_LONGEVITY
     breeding_ewe_removal_rate = -SAFEDIV(stock_deficit, STOCK_ADJUSTMENT_
         DELAY_DUE_TO_LIFESTYLE_CHOICE,  0.00001)

carrying_capacity_of_sheep_on_farm = "ALLOWABLE_SHEEP/ACRE"*ACRES_OF_SHEEP_PASTURE
"d(loss/gain)" = DERIVN(monthly_sheep_profit,  1)
```

desired_breeding_stock = IF(Capital <0) THEN(0) ELSE(IF(TIME<36)
THEN(MIN(INITIAL_BREEDING_EWES, carrying_capacity_of_sheep_on_farm))
ELSE(MIN(carrying_capacity_of_sheep_on_farm, Breeding_Ewes+Breeding_Ewes *
"response_to_sheep_loss/gain")))

Fetal_lambs(t) = Fetal_lambs(t - dt) + (monthly_breeding_rate - monthly_lamb_gestation_rate) * dt
INIT Fetal_lambs = 0
TRANSIT TIME = 4.99
CAPACITY = INF
INFLOW LIMIT = INF
INFLOWS:
monthly_breeding_rate = Breeding_Ewes*LAMBS_PER_EWE/12
OUTFLOWS:
monthly_lamb_gestation_rate = CONVEYOR OUTFLOW

Mature_lambs(t) = Mature_lambs(t - dt)+(monthly_lamb_maturation_rate - lamb_selling_rate-
breeding_ewe_addition_rate)*dt
INIT Mature_lambs = 0
INFLOWS:
monthly_lamb_maturation_rate = CONVEYOR OUTFLOW
OUTFLOWS:
lamb_selling_rate = Mature_lambs/AVERAGE_LAMB_SELLING_FREQUENCY
breeding_ewe_addition_rate = SAFEDIV(stock_deficit, STOCK_ADJUSTMENT_DELAY_DUE
_TO_MATURATION, 0.00001)+"non-productive_ewe_attrition_rate"

"over-winter_feeding_expenses" = Breeding_Ewes*FEED_COSTS_PER_SHEEP/12

"response_to_sheep_loss/gain" = GRAPH(IF("d(loss/gain)"/monthly_sheep_profit<0) THEN(0)
ELSE(IF("d(loss/gain)"<0 AND monthly_sheep_profit<0) THEN(-"d(loss/gain)"/monthly_sheep_profit)
ELSE("d(loss/gain)"/monthly_sheep_profit))):(-1.000, -0.500), (-0.800, -0.500), (-0.600, -0.467390544693), (-0.400, -0.40550963105), (-0.200, -0.255838899095), (0.000, 0.000), (0.200, 0.255838899095), (0.400, 0.40550963105), (0.600, 0.467390544693), (0.800, 0.500), (1.000, 0.500)

Sheep_to_be_sheared = Breeding_Ewes + Mature_lambs

stock_deficit = desired_breeding_stock-Breeding_Ewes

Wool Sector

"veg._matter_control_cost_per_animal" = GRAPH(vegetable_matter_fraction):(0.000, 6.000), (0.100, 4.02192027621), (0.200, 2.6959737847), (0.300, 1.80716527147), (0.400, 1.21137910797), (0.500, 0.81201169942), (0.600, 0.544307719736), (0.700, 0.364860375751), (0.800, 0.24457322387), (0.900, 0.163942334684), (1.000, 0.109893833332)

actual_buyer_delay = MAX(BUYER_DELAY, BUYER_DELAY*farm_capacity_fraction)

"average_pre-skirted_condition" = SAFEDIV("Pre-skirted_wool_condition", "Pre-skirted_wool", 0.000001)

average_skirted_condition = SAFEDIV(Skirted_wool_condition, Skirted_wool, 0.000001)

buyer_capacity_fraction = MAX((BUYER_CAPACITY-Buyer_Inventory)/BUYER_CAPACITY, 0)

Buyer_Inventory(t) = Buyer_Inventory(t - dt) + (to_buyer) * dt
INIT Buyer_Inventory = 0
INFLOWS:
to_buyer = total_wool_rate_skirted_wool*fraction_to_buyer

Buyer_Value = GRAPH(ACCESS_TO_BUYER*AVERAGE_RAW_WOOL_BUYER_PRICE):(3.00, 0.21438896797), (3.60, 0.221277594861), (4.20, 0.231332578237), (4.80, 0.245859340719), (5.40, 0.266538157195), (6.00, 0.295362337618), (6.60, 0.334385291893), (7.20, 0.385180173201), (7.80, 0.448020415098), (8.40, 0.52104987191), (9.00, 0.6000), (9.60, 0.67895012809), (10.20, 0.751979584902), (10.80, 0.814819826799), (11.40, 0.865614708107), (12.00, 0.904637662382), (12.60, 0.933461842805), (13.20, 0.954140659281), (13.80, 0.968667421763), (14.40, 0.978722405139), (15.00, 0.98561103203)

farm_capacity_fraction = MAX(0, (wool_storage_capacity-inventory)/wool_storage_capacity)

fraction_to_buyer = GRAPH(fraction_to_buyer_multiplier):(0.000, 0.0000), (0.100, 0.00534646997851), (0.200, 0.0189372123184), (0.300, 0.0645817880374), (0.400, 0.195795201219), (0.500, 0.4500), (0.600, 0.704204798781), (0.700, 0.835418211963), (0.800, 0.881062787682), (0.900, 0.894653530021), (1.000, 0.898507079028)

fraction_to_buyer_multiplier = average_skirted_condition*buyer_capacity_fraction*ACCESS_TO_BUYER*farm_capacity_fraction

fraction_to_waste = GRAPH("average_pre-skirted_condition"*farm_capacity_fraction):(0.000, 1.0000), (0.050, 0.83685767777), (0.100, 0.703288041432), (0.150, 0.593930472485), (0.200, 0.504396067705), (0.250, 0.431091497054), (0.300, 0.371074790721), (0.350, 0.321937267547), (0.400, 0.281706866195), (0.450, 0.248768999399), (0.500, 0.221801754913), (0.550, 0.199722842526), (0.600, 0.18164615796), (0.650, 0.166846220393), (0.700, 0.154729056363), (0.750, 0.144808361531), (0.800, 0.136685983581), (0.850, 0.130035942964), (0.900, 0.124591350203), (0.950, 0.120133694671), (1.000, 0.116484075)

inventory = "Pre-skirted_wool"+Skirted_wool

"monthly_skirting/grading_labor_expense" = SMTH1(skirting_labor_per_fleece*skirting_and_grading*LABOR_COST_ PER_HOUR, NUMBER_OF_MONTHS_FOR_AVERAGING)

pounds_of_wool_per_month = AVERAGE_POUNDS_WOOL_PER_YEAR_PER_SHEEP/12

"Pre-skirted_wool"(t) = "Pre-skirted_wool"(t - dt) + (monthly_shearing_rate - skirting_and_grading - to_waste) * dt
INIT "Pre-skirted_wool" = 0
INFLOWS:
monthly_shearing_rate = Wool_on_sheep/"ENTIRE_FLOCK_SHEARING_FREQUENCY_(months)"
OUTFLOWS:
skirting_and_grading = "total_wool_rate_pre-skirted_wool"*(1-fraction_to_waste)
to_waste = fraction_to_waste*"total_wool_rate_pre-skirted_wool"

"Pre-skirted_wool_condition"(t) = "Pre-skirted_wool_condition"(t - dt) + ("pre-skirted_wool_input_condition" - "pre-skirted_wool_output_condition") * dt
INIT "Pre-skirted_wool_condition" = 0
INFLOWS:
"pre-skirted_wool_input_condition" = monthly_shearing_rate*(1-vegetable_matter_fraction)
OUTFLOWS:
"pre-skirted_wool_output_condition" = skirting_and_grading*("average_pre-skirted_condition")

Skirted_wool(t) = Skirted_wool(t - dt)+(skirting_and_grading - to_buyer - to_wool_pool - "to_overflow/waste") * dt
INIT Skirted_wool = 0
INFLOWS:
skirting_and_grading = "total_wool_rate_pre-skirted_wool"*(1-fraction_to_waste)
OUTFLOWS:
to_buyer = total_wool_rate_skirted_wool*fraction_to_buyer
to_wool_pool = IF(ACCESS_TO_WOOL_POOL=1) THEN((1-fraction_to_buyer)*total_wool_rate_skirted_wool) ELSE(0)"to_overflow/waste" = IF(ACCESS_TO_WOOL_POOL=0) THEN((1-fraction_to_buyer)*total_wool_rate_skirted_wool) ELSE(0)

Skirted_wool_condition(t) = Skirted_wool_condition(t - dt) + ("pre-skirted_wool_output_condition" +

Increase_in_skirting_effort_due_to_access_to_buyer - skirted_wool_output_condition) * dt
INIT Skirted_wool_condition = 0
INFLOWS:
"pre-skirted_wool_output_condition" = skirting_and_grading*("average_pre-skirted_condition")
Increase_in_skirting_effort_due_to_access_to_buyer = Skirted_wool*Buyer_Value
OUTFLOWS:
skirted_wool_output_condition = total_wool_rate_skirted_wool*average_skirted_condition

skirting_labor_per_fleece = GRAPH(SAFEDIV((Buyer_Value-"average_pre-skirted_condition"), Buyer_Value, -0.00001)):(0.000, 0.00753626065304), (0.050, 0.0100616290052), (0.100, 0.0133621787531), (0.150, 0.0176235783423), (0.200, 0.0230397582748), (0.250, 0.0297877968519), (0.300, 0.0379894844077), (0.350, 0.0476630575297), (0.400, 0.0586766503396), (0.450, 0.0707227496048), (0.500, 0.0833335), (0.550, 0.0959442503952), (0.600, 0.10799034966), (0.650, 0.11900394247), (0.700, 0.128677515592), (0.750, 0.136879203148), (0.800, 0.143627241725), (0.850, 0.1517), (0.900, 0.1569), (0.950, 0.1621), (1.000, 0.1654)

"skirting/grading_delay" = GRAPH("skirting/grading_effort"*farm_capacity_fraction):(0.000, 0.212589112559), (0.100, 0.33238677857), (0.200, 0.567212378006), (0.300, 0.993885066651), (0.400, 1.67202437404), (0.500, 2.550), (0.600, 3.42797562596), (0.700, 4.10611493335), (0.800, 4.53278762199), (0.900, 4.76761322143), (1.000, 4.88741088744)

"skirting/grading_effort" = GRAPH("average_pre-skirted_condition"):(1e-7, 0.000), (0.10000009, 0.207), (0.20000008, 0.394), (0.30000007, 0.766), (0.40000006, 0.920), (0.50000005, 0.973), (0.60000004, 0.936), (0.70000003, 0.840), (0.80000002, 0.676), (0.90000001, 0.505), (1.0000, 0.319)

"total_wool_rate_pre-skirted_wool" = "Pre-skirted_wool"/"skirting/grading_delay"

total_wool_rate_skirted_wool = Skirted_wool/actual_buyer_delay

vegetable_matter_fraction = IF(ACCESS_TO_BUYER=1) THEN(1-ACCESS_TO_BUYER*FIBER_PRODUCTION_DESIRE_ FACTOR) ELSE(1-ACCESS_TO_WOOL_POOL*(FIBER_PRODUCTION_DESIRE_FACTOR))

Wool_on_sheep(t) = Wool_on_sheep(t - dt) + (monthly_wool_growth_rate - monthly_shearing_rate) * dt
INIT Wool_on_sheep = 0
INFLOWS:
monthly_wool_growth_rate = Sheep_to_be_sheared*pounds_of_wool_per_month
OUTFLOWS:
monthly_shearing_rate = Wool_on_sheep/"ENTIRE_FLOCK_SHEARING_FREQUENCY_(months)"

wool_storage_capacity = "LBS-WOOL_PER_CUBIC._FT."*"CUBIC._FT._of_STORAGE_SPACE"

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