An Agent-Based Simulation Model of Structural Change in Agriculture

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Abstract

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An Agent-based Simulation Approach to Forecast Long-Run Structural Change in the Saskatchewan Grain and Livestock Sectors.
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Like many North American agricultural regions, Saskatchewan has experienced significant fundamental structural changes in farming. Structural change encompasses evolution in distribution of farm sizes, land tenure and financial characteristics, as well as variations in demographic and production characteristics. These issues are often a source of discontent among farm populations as it implies these populations are forced to adapt in a number of potentially unpleasant ways. These changes have profound and sometimes poorly understood effects on the rural economy – for example, structural change affects rural population and therefore demand for rural infrastructure.

Traditional agricultural farm level analysis is often conducted using a representative farm or group, but this framework cannot capture the growing heterogeneity of modern farm operators or the current operating environment in agricultural regions. Farm profiles vary by demographic characteristics, such as age and education, and resource endowments. Agent-based simulation captures this heterogeneity through a farm by farm analysis, where after initialization, the regional economy evolves over time.

A synthetic population is created based on survey data and the land characteristics based on the actual land data in CAR 7B of Saskatchewan. A number of different price and yield time paths were created using a bootstrap procedure on historical data and the model evolved to potential agriculture structures that may occur in the model region, 30 years in the future.

Structural change occurs endogenously as farms interact in land markets, and make decisions on land use. Agents compete for available land in a purchase and lease market with land selling to the highest bidder. The dynamic nature of agent-based models allows individual farms to adjust land use in response to changing economic conditions and individual preferences. How individuals organize their resources will be critical to farm survival and growth.

The results indicate that many of the trends are the same under the different price and yield time paths, however the rate of change is significantly impacted by the price and yield time path that occurs. The model predicted the trend to fewer and larger farms will continue into the future. The forecasted distribution of smaller farms will decline and proportion of large farms will increase, while mid sized farms will remain relatively unchanged. The proportion of mixed farms, land use, and total livestock numbers depend significantly on the price and yield time path. The actual structure that will occur will be the result of the actual individual price and yield time path that occurs.

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Chapter 1
Introduction

1.0 Introduction

Modern economies continually experience structural change as new technologies, policies, and markets emerge or change. For some people it results in discontent as they are forced to change, relocate, or adjust to lower earnings. This is evidenced by the debate about what the future holds for the "family farm" and the role of agricultural policy in determining that future. For others structural change can be viewed as a challenge that creates new market opportunities.

The changing structure of agriculture is often characterized by the decline in farm numbers accompanied by the increase in farm size. Goddard et al. (1993) identifies structural change as changes in essential characteristics of production activities. Therefore, structure of an industry can also include: 1) farm size and distribution 2) technology and production characteristics 3) demographic characteristics, and 4) resource ownership and financing. Changes in farm size and distribution are based on the number of farms in each size category. The production mix and how these products are produced are influenced by technology and production characteristics. Demographic characteristics include the age, education, and financial characteristics of farm operators. Land tenure, whether land is leased or owned, and how land and other assets are paid for is included in resource ownership and financing.

The farming sector is characterized by many different individuals with different financial and demographic characteristics. Traditional economic models, such as general or partial equilibrium models, are unable to capture the diversity and interactions apparent in agriculture system and cannot accurately forecast behaviour far beyond the years which the model parameters where derived (Freeman 2005). This has led researchers to utilize alternatives to traditional economics such as, agent-based modeling, when analyzing structure of the agricultural industry.

Public programs can have a significant impact on the agricultural structure. Agricultural policies can impede or encourage structural change by increasing the profitability of one production activity relative to others, resulting in an inefficient allocation of resources (Happe 2004). Agricultural support programs also create an incentive for inefficient producers to remain in operation by subsidising their income to an acceptable level (Happe 2004), slowing agricultural adjustment. As a result the direct costs and benefits of public programs interfere with the process of structural change in an economy (Goddard et al. 1993). It is critical that policy makers have the ability to accurately evaluate the impacts of agricultural policy both in the short run and many years into the future.

The structure of agriculture is an important issue because it has a large impact on rural communities. Fewer and larger farms lead to rural depopulation, which has an impact on the demand for infrastructure. With fewer people in rural areas there is less demand for schools, hospitals, recreational facilities, roads, and businesses and services in these areas. Closing of these businesses and services leads to concern of the remaining population of the rural areas and may feedback and influence their decision to remain in the rural area. The structure of agriculture also impacts the type and location of processing facilities, which can impact the marketing and production plans of producers.

1.2 Objectives and Expected Results

The primary purpose of this research is to project what the future agricultural structure in Saskatchewan will be in 30 years under alternative price scenarios. More specifically the farm numbers, farm size and distribution of size, production characteristics, demographic characteristics, and resource ownership and financing of the agricultural industry will be projected. This is achieved through expanding the agent-based model of Freeman (2005) to represent typical Census Agriculture Region in Saskatchewan, where structural change takes place endogenously within the model. Freeman's model was expanded to include: 1) mixed farms that are willing to use land in the highest and best use to produce forage and livestock or annual crops in addition to grain farms unwilling to produce livestock and 2) economies of size and lumpy machinery investments for the annual crop production enterprise. The inclusion of livestock allows farmers to make annual land use decisions and expected land use when creating bid values in the farmland markets based on profitability, with mixed farms having a bidding advantage on land suited for livestock production. The model is initialized with an exogenous price scenario and is allowed to evolve over time revealing the future agricultural structure.

It is expected that the price and yield scenarios will have an important role on the structural change that occurs. If the prices and yields are high it is likely that the farm numbers will not decline as quickly as a scenario with lower prices and yields. However, it is possible that the increase in income could be captured by the individuals selling and leasing land in the land markets and not have a significant impact on farm numbers. It is also expected that if the relative price of livestock increases to annual crops, the mixed farms will have a bidding advantage in the land markets and will likely increase farm size while grain farms may eventually be forced to exit the industry.

1.3 Thesis Organization

This thesis is composed of seven chapters. Chapter two is a brief discussion of the literature on agent-based models and their suitability to modeling a complex agricultural system, causes of structural change, farmland markets and bid values, land use, and forage markets. The following chapter develops a conceptual model of an agricultural system. The fourth chapter defines in detail the individual agents' behaviour. The fifth chapter outlines the model initialization and data, followed by a chapter describing the results. The last chapter contains summary and concluding remarks.

Chapter Two
Literature Review

2.0 Introduction

This chapter will review the literature that applies to modeling agricultural structural change. The first section deals with agent-based models and their advantages, including the ability to handle complex systems, build models at the individual level, produce emergent or unexpected results, and capture heterogeneity and spatial characteristics. This is followed by a discussion on how technology and economies of size, off farm employment, and demographic characteristics affect structural change. A discussion of the characteristics of equation models and agent-based models of land use and the factors that influence the land use decision follows. Next, a section focusing on other agent-based studies of structural change and their suitability to a Saskatchewan agricultural system. Following this, a discussion on how farmer's determine farmland bid values, from annual income, government payments, capital gains, and capital and liquidity constraints. Also included in this section is a discussion on the role of speculation in the farmland markets, description of farmland leasing, and farmland as an investment for non-farming individuals. There is then a brief discussion on forage markets, followed by a summery of the chapter.

2.1 What is Agent-based Modeling?

Agent-based modeling (AbM) is a relatively new methodology to economics (Rosser 1999), but it is an established methodology in other social science (Parker et al. 2003). AbM consists of autonomous, interacting agents who make decisions linking their behaviour to the environment (Parker et al. 2003). These models are computer simulations of individual agents used to study how their aggregation leads to complex macro behavior (Berger 2001). Increases in computing power have allowed increasingly complex problems to be analyzed using AbM.

Agent-based modelers initialize an economy with a population of agents distributed across a geographical landscape (Tesfatsion 2002). Common behavioral and decision rules are assigned to all agents, but each individual agent can vary according to demographic, financial, and other personal characteristics. Once the decision rules and initial attributes of the agents are set and exogenous data included, there is no further intervention by the modeler and the economy evolves over time (Tesfatsion 2002).

2.1.1 Advantages of Agent-based Models

AbM offers a number of advantages over traditional economic models. Freeman (2005) identifies some of these as: 1) the ability to obtain numerical solutions in complex systems that maybe unsolvable analytically, 2) flexibility, 3) emergent characteristics, and 4) spatial representation. AbM's ability to capture these characteristics gives it potential to overcome the limitations of previous farm level models (Freeman 2005) and include aspects such as heterogeneity and feedback that exist in an agricultural system.

2.1.1.1 Complexity

Agricultural economists have viewed agricultural structures as complex dynamic systems since the 1960s (Happe 2004). Complex systems are characterized by heterogeneity, interdependencies, and nested hierarchies among agents and their environment (Parker et al. 2003). Heterogeneity includes both differences in agents and land characteristics. Agents vary according to demographic characteristics, financial characteristics, and available resources. Land is heterogeneous in terms of soil quality, which can influence land use, farmable area and location. Interdependencies arise because agents rely on information from their past decisions and other agents' decisions to update their decision making strategy (Parker et al. 2003). An example of interdependencies in an agricultural region is the land market, where a farm is unable to expand unless another agent decides to sell (Happe 2004). Hierarchal structures occur as individuals interact to form households, which interact with other households to form villages, with multiple scales influencing individual agents (Parker et al. 2003). Rosser (1999) adds that in economics, an added layer of complexity results from interacting human calculations in decision making, which may not exist in other disciplines.

2.1.1.2 Flexibility

The flexibility of AbM allows for a "bottom up" approach to modeling that does not rely on exogenous assumptions that are required by "top down" approaches (Freeman 2005). Traditional equilibrium models require fixed decision rules, common knowledge assumptions, representative agents, and imposed market equilibrium constraints (Tesfatsion 2002). These assumptions are required to ensure consistency between the macro and micro level (Happe 2004). Once the mechanics of an AbM are understood and programmed, the researcher has greater flexibility to design and execute experiments to explore alternative causal mechanisms that are more complex and possibly easier to solve than equilibrium based solutions (Parker et al. 2003). In AbM's there are no market equilibrium constraints allowing the market to be out of equilibrium.

2.1.1.3 Emergence

The interactions of a complex system may give rise to emergent phenomenon. There are numerous definitions of emergence in the literature, but there are some commonalities. Gilbert and Troitzsch (2002) state a phenomenon is emergent if it requires new categories to describe it, which are not required to describe the behavior of the underlying components. Many of the definitions concern macro scale phenomena that arise as a result of complex, micro-scale interactions (Parker et al. 2003). Other definitions associate emergence with surprise or unanticipated results (Batty and Torrens 2001). An early example of emergence is in Schelling's (1978) model of how nieghbourhoods become segregated by race. Schelling found that a moderate urge to avoid being the minority in a particular neighbourhood results in highly segregated nieghbourhoods to develop.

2.1.1.4 Spatial Representation, Soil Quality and Land Use

Spatial representation is an important aspect of agriculture because it can have a significant impact on farm level decisions. An example is the transportation costs associated with machinery operations and its affect on farming geographically dispersed land (Freeman 2005). Transportation costs from farmstead to field increase with distance causing competition for land to be mainly between neighbours (Berger 2001).

Soil quality is often associated with certain geographical features such as glacial moraines, river deltas, ancient lake bottoms, or natural prairie/forest ecosystems. Production and land use decisions are based on soil quality and consequently, the difference in soil quality determines the spatial land use landscape (Berger 2001). AbM's have the ability to capture spatial characteristics, which are important to the agricultural structure.

2.2 Causes of Structural Change

Structural change is well documented in the literature. Although there is consensus that structural change has occurred in the form of decreasing farm numbers and increasing farm size, there often is no common agreement on the implications of these changes for the viability of the sector, rural community, environment, and society (Goddard et al. 1993). In order to understand the implications of structural change it is important to understand its underlying causes. The following section reviews possible causes of structural change such as technology and economies of size, off farm employment and demographic characteristics, and sectoral heterogeneity.

2.2.1 Technology and Economies of Size

A well known theory on possible cause of structural change is based upon Cochrane's technological treadmill. Cochrane (1958) maintained that new technology decreases the unit cost of production and early adopters of this technology realize increased net incomes. As the number of adopters increases, total output increases, resulting in lower prices, forcing other farmers to adopt the technology to remain competitive. Those who do not adopt the technology are forced out of the industry and their assets will be acquired by the producers that remain (Harrington and Reinsel 1995). The result is that each individual has incentive to adopt the new technology, even though their collective decision will not make them better off and could make them worse off (Harington and Reinsel 1995).

Another cause of structural change is the presence of economies of size. Economies of size imply that an increase in size will result in a decrease in the average total costs and therefore, large farms are more efficient then small farms. Optimal farm size is the minimum of the long-run cost curve (Goddard et al. 1993) and if an individual is not at this point there is incentive to adjust farm size or resource use to reach this point. Technological change shifts this curve to the right, increasing the number of farms with increasing returns to size and therefore increasing the number of farms with incentive for farm growth (Goddard et al. 1993).

The shape of the long-run cost curve has important implications on the desire for farm growth. Schoney (1997) identifies that the majority of studies find an "L shaped" curve where after a threshold point most economies of size are exhausted. This threshold for grains and oilseeds was estimated by Fleming and Uhm (1982) to be approximately 350 tonnes of production in the black soil zone of Saskatchewan. Schoney (1997) estimated this threshold to be 1,500 to 2,000 acres in the black soil zone and 2,500 to 3,000 acres in the brown soil zone of Saskatchewan. There is little evidence of diseconomies of size in the literature (Schoney 1997), which creates incentive to increase in size to obtain higher total returns even though cost will not decrease (Goddard et al. 1993).

2.2.2 Off Farm Employment and Demographic Characteristics

Structural change in agriculture can occur as a result of the ability for farm operators to use their labour to earn off farm income. Farmers optimize their economic well being through allocating their land, labour, and capital to farm and non farm uses (Harrington and Reinsel 1995). Kesliv and Peterson (1982) believed a rise in urban incomes creates incentive to leave agriculture, leaving the remaining land to fewer, but larger farms. With more resources, the remaining farms increase their incomes, closing the urban-rural income gap (Kesliv and Peterson 1982).

Others have argued that off farm employment helps ensure the survival of smaller farms. Off farm employment reduces the amount of farm income that is needed to meet a required standard of living (Goddard et al. 1993). Increases in productivity and a fixed land base along with the seasonal nature of agriculture causes farm families to have their available labour underemployed (Olfert 1992). This allows for the reallocation of excess labour to off farm activities, raising their household income. While once considered a transition phase for new entrants or a short-term crisis response, off farm employment is now recognized as a stable long term condition (Olfert 1992). The increase in off farm employment has increased the number of small part time farmers (Goddard et al. 1993).

Changing patterns of entry, growth, and exit can result in structural change (Harrington and Reinsel 1995). This theory is known as the life cycle hypothesis. The life cycle hypotheses is based on an agricultural ladder where operators enter through the renting of farm assets, add more rented land for part of their lives, progressively acquire ownership of land, and finally progressively relinquish control of rented and owned land during the exit stage (Harrington and Reinsel 1995). Different age cohorts experience similar patterns that are marginally affected by economic conditions, government policy, or external shocks (Harrington and Reinsel 1995).

Traditionally, farming entrants are young males that were raised on farms. However, this group is shrinking in size as a result of fewer farms and declining birth rates (Gale 1993). Fewer entrants implies continued aging of the current farm operators and fewer, larger farms (Gale 1993). Gale (1993) suggests that due to the fewer potential entrants, the number and size distribution of farms may not reach equilibrium even if returns from non farm employment were equivalent to farming.

There are a number of arguments on the causes of structural change in agriculture with little consensus on the issue. The next section will review various land use methodologies and the land use decision, which can influence structure.

2.3 Land Use

Land use denotes the human employment of the land (Meyer and Turner 1992). The land use decision of an individual farmer will impact the level of income they are able to generate from their available resources. Each individual's land use decision is important in determining farm profitability and survival. The income generated from land can also have an impact on the desire for farm growth and the ability to bid for additional farmland.

Land use decisions not only impact the income of farmers, but also the location of infrastructure. Processing facilities and services will locate in regions that have a large production of a specific product. For example, in order to minimize travel and transportation costs, a veterinarian will locate in a region that has large number of livestock and not in an area that is strictly grain and oilseed farms. Infrastructure location can also feed back and impact land use decisions. If there is a veterinarian in the area, a farmer will be more willing to switch land from grain and oilseed to livestock production. The land use of each individual will therefore have a significant impact on the structure of agriculture.

2.3.1 Land Use Methodologies

There are a number of methodologies used to analyze land use. Parker et al. (2003) identifies the following models: 1) system models, 2) statistical techniques, 3) expert models, 4) evolutionary models, 5) cellular models, and 6) agent-based models. This section will focus on equation modeling and agent-based models of land use.

2.3.1.1 Equation Models

Most models are mathematical in some way, but some are especially so, that models rely on equations that seek a static or equilibrium solution (Parker et al. 2003). One of these models is the computable general equilibrium model (CGE). The CGE model has been used for land use studies by Darwin et al. (1996), Ianchovichina, Darwin, and Shoemaker (2001), and Wong and Alavalapati (2003).

CGE models are based on general equilibrium theory and assumptions. These assumptions include perfect competition, full employment of resources, perfectly mobile factors of production, complete information, and market clearing conditions (Scriecu 2005). CGE models usually cover economy wide impacts on resource allocation and income, but at a very aggregate level (Scriecu 2005). As a result, CGE models are weak at assessing and predicting the effects across various households (Scriecu 2005).

To achieve analytical or computational tractability, equation models require simplifying assumptions (Parker et al. 2003). Due to the highly aggregated results and the restrictive assumptions of these types of models, the implications of a shock at the farm level may not be accurately represented.

2.3.1.2 Agent-based Models of Land Use

A number of researchers have utilized AbM for analyzing land use (See Evans and Kelly 2004; Kelly and Evans 2005; Balmann 2000; Huigen 2004; Robinson 2003). Land use AbM consist of two components: 1) a cellular component that represents biophysical and ecological aspects of the model and 2) an agent component that represents human decision making (Parker et al. 2003).

Traditionally land use models have incorporated biophysical attributes, such as soil quality as primary land use determinants and have emphasized human decision making as having a smaller role (Veldkamp and Lambin 2001). However, it is likely that human decision making plays a role and is evidenced by the fact that land with similar attributes is often used differently (Kelly and Evans 2005). Land use decisions are made by the individual household or owner of the land and to understand land use requires learning about how private owners make decisions (Koontz 2001, Messina and Walsh 2001). Individuals make land use decisions based on constraints that they face (Messina and Walsh 2001).

2.3.2 Land Use Decisions

The most common theory of land use decisions is based on the individual who is primarily motivated by economic and financial returns (Koontz 2001). Any parcel of land is assumed to be put its highest and best economic use, given its attributes and location (Lambin, Geist, and Lepers 2003).

Farming, haying, and grazing are primarily motivated by economic return, however many other land use activities are motivated by other factors (Koontz 2001). Hosier (1988) maintains that land use decisions are based on economic, environmental, aesthetic, and personal reasons. In addition to economic reasons, Koontz (2001) identifies that non-monetary benefits may play a large role in land use decisions. Based on interviews with land owners, Koontz (2001) found that 80% of individuals largely base their land use decisions on non-monetary benefits including aesthetics, hobbies, and recreation. Non-monetary benefits vary across activity type, parcel size, and land owner characteristics (Koontz 2001). Varying land use may be caused by heterogeneous preferences. In the model developed by Kelly and Evans (2005), agents maximize their expected utility from various activities by choosing how to allocate their labour and land. In their model, utility is the weighted sum of expected pecuniary and non pecuniary aspects of each activity. Each activity is assigned a preference weighting that can be different for different agents. Kelly and Evans (2005) results indicate that land owners' preferences are equally or more important than land suitability for determining land use.

2.4 Agent-based Models of Structural Change

Agent-based models of structural change view agriculture as a complex system. One of the first models was developed by Balmann (1997) for a hypothetical region in Germany, where structural change occurred endogenously in the model. Largely based on the original model of Balmann (1997), the AgriPoliS model subsequently developed by Balmann, Happe, and Kellermann was used to analyze a number of agricultural policies and their impact on structural change (See Happe 2004; Happe and Balmann 2003; Happe, Kellermann, and Balmann 2006; Sahrbacher et al 2005). However, the AgriPoliS model does not include some aspects which are important to Saskatchewan agriculture. Farm growth in the AgriPoliS model is limited to producers renting land as opposed to purchasing (Happe, Balmann, and Kellerman 2004). Another shortcoming of this model is that it does not include a forage market, limiting livestock herd size.

Building upon the AgriPoliS model, Freeman (2005) developed a model to analyze differing management styles and their impact on farm structure in Saskatchewan. Freeman's model enhanced the AgriPoliS model to include a land purchase market in addition to a lease market. The land market included both a purchase market and a leasing market. This model imposes the assumption that all farmers prefer to purchase land first and will lease land only if unsuccessful in the purchase market. Freeman's model had simulated results for the period of 1960 to 2000, which replicated the actual structural change that occurred over the same period, validating AbM as a methodology for predicting structural change. However, Freeman's model does not include economies of size, the ability to change land use, or livestock, which are important aspects of Saskatchewan agriculture.

2.5 Farmland Markets

In Saskatchewan, farmers are able to gain control of additional farmland through a primary land purchase market and a secondary leasing market. Farmland markets are characterized by: 1) few buyers and sellers, 2) farmland rarely being sold, often averaging only once a generation, 3) a relatively localized market, where competition is traditionally between neighbours, and 4) imperfect information. To reach economies of size or increase profitability, farmers must compete in farmland markets to gain control of additional farmland. Once a farmer gains control of a parcel of land they can then make decisions on the best use of the land.

The following section will deal with some of the issues related to farmland markets. There will be a brief discussion on the influences of farmland bids. This will be followed by the possibility of speculation in the farmland markets. The remainder of this section will be a discussion on farmland leasing and non farm operators investing in farmland.

2.5.1 Farmland Bid Value

The current value of farmland is the present value of the expected future economic return to land (Pederson 1982). There have been a number of past studies that have attempted to identify major sources of farmland value. Important sources of farmland value are: 1) market based annual rent, 2) government payments, and 3) capital gains. There has also been discussion on the possibility of speculation in the farmland market, where individuals believe that the value of farmland will likely increase in the future. This would cause the bid values of these individuals to increase as a result of the expected capital gain.

2.5.1.1 Market Based Annual Rent

The underlying source of farmland value is the annual income it can generate (Burt 1986). Rensiel and Rensiel (1979) thought that the changes in land values are a result of the changing expectations that individuals have about the annual income. Alston (1986) found that most of the real growth in land price can be accounted for by growth in real income. Although changes in annual income are an important component in farmland valuation, they are not the only cause of the changes in farmland price. Land prices tend to rise faster than income when both are rising and fall faster when both are falling (Melichar 1979; Clark, Fulton, and Scott 1993). This has lead to other theories of the causes of change in farmland values.

2.5.1.2 Government Payments

In Saskatchewan, a portion of annual farm income is made up of government support, paid to farm operators. The size of these payments impacts the maximum bid of each individual farmer. The level at which the government payments are capitalized into the bid value depends upon the level of certainty that the support will continue in the future (Goodwin and Otalo-Magne 1992).

The level of support capitalized into land values has not been agreed upon in the literature. Moss, Shonkwiler, and Reynolds (1989) believed that in the short run, an increase in government support may signal future problems in agriculture and result in a decline in real asset values. Both Turvey et al. (1995) and Goodwin and Ortalo-Magne (1992) found that a portion of government payment are capitalized into land value. Shaik, Helmers, and Atwood (2005) estimated that since 1980 government payments represented between 15% and 20% of land value in the U.S. Government payments are an important consideration in determining a bid value, but it is unclear the level of impact they have.

2.5.1.3 Capital Gains

An important major source of farmland value is expected capital gains. Melichar (1979) found that a large portion of the growth in the land value was the result of capital gains and not current income. Similarly, Castle and Hoch (1982) found that increases in land values in the late 1970's cannot be explained on the basis of earnings in production alone and that capital gains have a significant impact on the value of farmland. It is important to note that capital gains also have differential taxation and rollover provisions.

2.5.1.4 The Role of Capital and Liquidity Constraints

The previous discussion on farmland value was based on profitability. However, in purchasing farmland, a bid may not be based on profitability, but may be constrained by the individual farmer's ability to make cash flows. Oltmans (1995) identifies three primary reasons for cash flow problems that can occur when purchasing farmland. The first occurs when the capital repayment period is less than the economic life of the asset. This is likely the case with an asset such as farmland as the economic life is, for all practical purposes, infinite. Secondly, an asset that is expected to have capital gains will have cash returns below the cost of capital. Thirdly, higher returns only benefit current asset owners' cash flow and profitability and not new owners seeking to buy the asset. Increases in annual income will be capitalized into the value of farmland increasing the price, benefiting current land owners. This will also increase the value that prospective buyers will have to pay and will result in further cash flow difficulties.

2.5.2 The Role of Speculation

Because bid values are based on expectations as to future profitability, there is always the possibility of speculation in the farmland market. In the case of investors, taking a "long" position occurs when an asset is purchased with the belief that it will increase in value. During the late 1970's and early 1980's there was a rapid increase in the price of farmland, which caused many farmland market observers to believe that farmland prices reflected speculative mania rather than market fundamentals (Tegene and Kuchler 1993). Featherstone and Baker (1987) suggest that historic annual rents cannot explain a large portion of the movement in farmland prices and speculative forces maybe driving price determination.

Farmland price movements are composed of two sources: 1) a fundamental component and 2) a non-fundamental or fad component (Falk and Lee 1998). Falk and Lee (1998) found that in the short run, the fad component accounted for approximately 50% of farmland price movements. However, in the long run, they found that most price movements were caused by fundamental shocks. Tegene and Kuchler (1993) found evidence against the presence of speculation and concluded the rapid increase in land values was caused by a change in investors expectations.

2.5.3 Farmland Leasing

The farmland lease market allows a producer to gain control of farmland without the large capital requirements associated with purchasing. Leasing agricultural land has advantages over land purchased on credit. Leasing allows farmers to operate with less debt, without the large capital requirements of farmland purchases, reducing the likelihood of bankruptcy and also gives flexibility to increase or decrease acreage farmed easily (Bierlen, Parsch, and Dixon 1999). There are two types of common leases, a share lease and a cash lease. A share lease means income or production is divided proportionally to the inputs that each individual contributes. A cash lease means a fixed payment is made to the landowner.

Lease choice depends on risk preferences, management skills, financial position, and farm size. In a cash lease, all risk is assumed by the farm operator. Landowners with high risk aversion and farm operators with low risk aversion, prefer cash leases over share leases (Paterson, Hanson, and Robison 2000). Management ability can affect the level of production and profits and as a result it has been argued that tenants with better management skills will prefer a cash lease where they have greater managerial discretion over a share lease (Bierlen, Parsch, and Dixon 1999). Large scale producers usually have contracts with many landlords and cash leasing provides greater flexibility than share leases (Sotomayor, Ellinger, and Barry 2000). Bierlen, Parsch, and Dixon (1999) test what affects the type of preferred lease agreement and their results indicate that tenant's financial position and the size of the operation are important variables, while rejecting the risk aversion and managerial ability hypotheses.

2.5.4 Farmland as an Investment

Investors may consider farmland as a possible candidate to maximize the return of the portfolio for a given risk level. Investors only need to be compensated for systematic risk, which is the risk the asset will contribute to a well diversified portfolio and not the risk that can be diversified away (Barry 1980). Using a capital asset pricing model (CAPM) both Barry (1980) and Arthur, Carter, and Abizadeh (1988) found investment in farmland contributed little systematic risk to a well diversified portfolio. Barry (1980) also found that farmland offered returns above those for systematic risk. The inability of the CAPM to account for the illiquidity, indivisibility, and thin markets of farmland could bias the returns to farmland upwards (Barry 1980). Lins, Sherrick, and Venigalla (1992) also found that investment in farmland is a good way to diversify a portfolio because the returns to farmland were negatively correlated with stocks and bonds.

2.6 Forage Markets

Forage markets are of interest because they offer an additional cropping alternative to grain farmers and also allow mixed farms to have a herd size that is larger than their land base can support. However, forage markets are very different than grain and oilseed markets. Forage markets are typically thin, local markets, where quality is not easily determined.

The bulky nature of forage makes it expensive to transport to other regions; volume is the limiting factor. Therefore, forage markets tend to be local (Rudstrom 2004; Tronstad and Aradhyula 2004). For example, corn is about four times more valuable than alfalfa based on a volume basis, but sells for a similar price based on weight (Tronstad and Aradhyula 2004). Thus, in a localized market high forage yields will result in lower prices for that region (Tronstad and Aradhyula 2004). Forage markets also tend to be thin, with approximately 70% of the hay production consumed on the farm where it was produced (Tronstad and Aradhyula 2004) leaving the rest to be sold and consumed on other farms.

Hay quality is an important factor in determining price (Grisley, Stefanou, and Dickerson 1985). In Canada, grains and oilseeds quality assessment is based on a grading system; however, such a system does not exist for hay. Hay quality is often based on protein content and digestibility (Rudstrom 2004). Although, these quality measures can be tested for, they are not easily determined visually.

2.7 Summary

This chapter identified a number of advantages of agent-based models including the ability to handle complexity, flexibility, emergence, and spatial representation. The advantages of AbM, along with their success in the past, indicates they are a suitable methodology to analyze structural change and land use. This chapter also reviewed a number of theories about the sources of structural change in Saskatchewan agriculture. These include technology, economies of size, off farm employment, demographic characteristics, and sectoral heterogeneity.

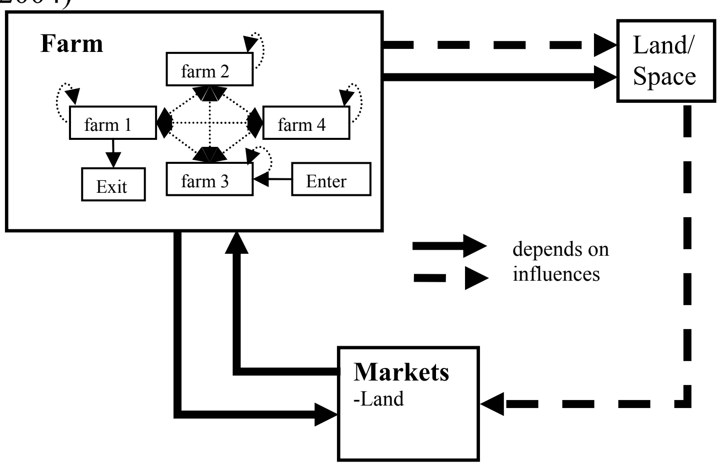
Farmers interact in two markets, the farmland markets and the forage markets. Bids for land in farmland markets are based on the income generating ability of land or the capital and liquidity constraints of the individual farmer. Finally, forage markets were classified as local markets due to the bulky nature of forage.

Chapter 3
Conceptual Model

3.0 Introduction

This thesis is concerned with understanding long run structural change in rural areas and individual farming operations. Structural change is affected by heterogeneity in individuals' resources and preferences, demographic changes, and technology. Farm operators rely on crop and livestock income, each of which cannot occur independently, from a scarce, immobile, land resource. A changing economic environment, along with advances in technology, has encouraged farms to expand and to transfer resources to different enterprises in order to remain profitable. To expand, farms must gain control of additional farmland through land markets. Farmland markets are imperfect, being the result of small groups of people bidding under incomplete information on heterogeneous land, which rarely becomes available for purchase. As a result, regional agricultural structure is a complex evolving system, caused by the interaction of three major components: farms, markets, and land (Happe, Balmann, and Kellermann 2004) (see figure 3.1). The use of AbM is appealing because each individual farm can be endowed with specific characteristics and resource endowments. In addition, heterogeneous and spatial characteristics of land can be included, meaning markets can be modeled using agents that coordinate market activity (Happe, Balmann, and Kellermann 2004).

Figure 3.1: Conceptual Model of an agricultural system (Adapted from Happe, Balmann, and Kellermann 2004)



3.1 NetLogo© Platform

NetLogo© is a freeware platform suitable for modeling complex systems that develop over time (Wilensky 1999). It is quite likely the most widely used platform for AbM research (Railsback, Lytinen, and Jackson 2006). NetLogo© is continuously upgraded by the Center for Connected Learning and Computer Based Modeling at Northwestern University, Evanston Illinois.

Within the NetLogo© platform, users provide rules to thousands of independent agents operating concurrently, making it easier to analyze how micro level behaviour leads to macro level patterns (Wilensky 1999). NetLogo© is fully programmable with the user creating the spatial environment and the agents' behavioral rules (Railsback, Lytinen, and Jackson 2006). NetLogo© has three classes of agents: turtles, patches, and observer (Wilensky 1999). Turtles are mobile agents, which can move around the artificial world. Patches are fixed and represent the spatial or geographic environment grid. The observer agent has no location, but has some control over other agent classes. In this model, turtles represent the individual farming household located on various patches of land. The observer represents the market auctioneer and coordinates land markets.

3.2 Heterogeneity

In traditional economic models, homogeneity among agents is often assumed for simplicity and mathematical tractability. A major strength of AbM's are their ability to incorporate heterogeneity in a relatively transparent manner. The agricultural region under study is characterized by two main sources of heterogeneity: 1) individual agents and 2) land.

3.2.1 Agent Heterogeneity

There are three main agent types in this model: 1) farmers, 2) non-farming land owners, and 3) the auctioneer, with the farmer being the most numerous. Farmers purchase and rent land used for production activities while non-farming land owners hold land as an investment, and the auctioneer coordinates the land markets.

Farming agents are endowed with different resources, abilities, and demographic characteristics. Resources include capital, land, and labour. These are used for crop or livestock production by farm agents in an attempt to generate income and wealth. Demographic characteristics include age, education, and preferences. Although each agent has a common goal of maximizing wealth, resource organization varies based on the individual's preferences and resource endowment. Agents also vary based on the risk aversion and preference for livestock production. In order to increase wealth, the farm must expand by acquiring more land to increase production.

3.2.2 Land Heterogeneity

Land is arranged in plots of 640 acres and each plot consists of five categories of land: 1) tillable, 2) hay, 3) improved pasture, 4) natural pasture, and 5) waste. Tilled land can be used as pasture, hay, or crop production. Hay land, consisting of natural hay, is unsuitable to be tilled and can be used as either hay or pasture. Both improved pasture and natural pasture are used only as pasture land and waste land is unsuitable for any use.[1]

The area and quality of each category of land for each plot included in the simulation are based on Saskatchewan Assessment and Management (SAMA) agency Data. Forage yields and land value are based on SAMA quality, while annual crop yield indexes are also included for each plot of land from Saskatchewan Crop Insurance Data.[2]

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[1] Although it may be possible to improve land quality, it is likely very expensive. An example is the ability to haul in top good top soil, or remove water from a slough.

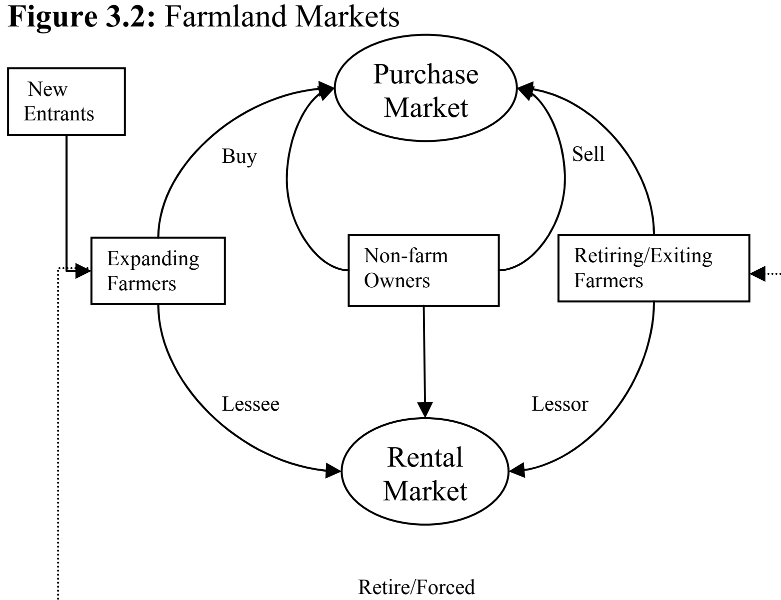
[2] Land value is adjusted to represent quality and is required to value the assets of the farmer.

The spatial heterogeneity of land is captured through transportation costs for both hay and crop production to the farmstead. Farm agent bid values for land will be directly affected by the relative location of the plot in the land market.

3.3 Dynamics

Farm structure is largely influenced by a farmer's ability to compete in farmland markets. Farmland markets are the source of growth and represent change in land use when a new individual gains control of additional farmland. The desire for farm growth causes farm agents to compete in the farmland markets for the scarce immobile land resource. Farm operators in this region are able to gain control of additional farmland through a primary farmland purchase market and a secondary lease market (figure 3.2). Demand in the farmland purchase market is created by farming operators hoping to expand and non-farming investors. Farmland is supplied by exiting farmers and non-farming investors. The latter sell farmland when its return falls below other investment opportunities. In the land lease market, demand is generated from farm operators seeking to expand, but are unsuccessful, unable, or chose not to compete in the farmland purchase market. Leased land is supplied by 1) retired farmers, who want to keep control of their land, and 2) non-farming investors.

Figure 3.2: Farmland Markets



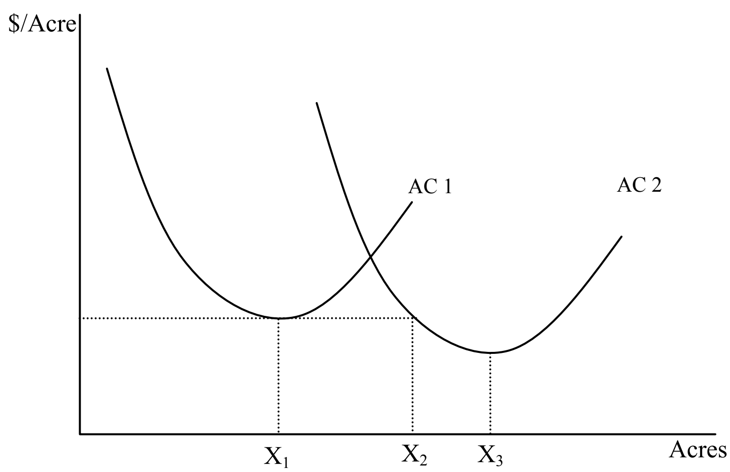
3.3.1 Farmer Bid Values in Land Markets and Land Use

Change over time largely stems from changes in control of land through the land market. Changes in farm size along with farm numbers and a large portion of the transition of land use occurs through a new individual gaining control of additional land and making the land use decision. Farmers with sufficient capital and labour required to expand from one efficient point to another, create bids based on their expected income from controlling the plot. Bid values are therefore dependent on production costs, land use, and expectations, which determine how competitive a farmer is in the farmland markets.

3.3.1.1 Cost of Production

In an environment where technology is constantly changing, machinery sizing is a major concern. Varying cost structures are caused by the indivisible and lumpy nature of machinery and land. Figure 3.3 demonstrates that as size increases the fixed costs of the investment are spread over more units and decrease until an efficient point is reached. After the efficient size, diseconomies are present due to farm operator's inability to do work in a timely manner (or at all) with their existing machinery. Past the efficient point, diseconomies set in and the per unit cost increases until investment in more machinery allows the shift to AC 2.

Figure 3.3: Average Cost of Production with Lumpy Investments



Accordingly, farms will jump from efficient point to efficient point as they expand their farm operations. The fixed plot size of farmland does not allow farm operators to expand from an efficient point without investing in more machinery and shifting to a new cost curve. The result is that farm operators attempt to expand from efficient point on one cost curve (X_1) to a point of the next cost curve that is at least as efficient as they previously were (X_2). However, a farm operator maybe unsuccessful in gaining control of enough land to make it to this point, forcing them to aggressively attempt to reach this point in the following periods.

Farmers on different cost curves will have varying abilities to compete for farmland. Farmers who are on a cost curve where the marginal revenue is lower than their average cost will eventually be forced out of the industry unless they are able to increase their size to an efficient point lowering their average cost or increase marginal revenue to a profit generating level. However, this same farmer is at a bidding disadvantage because other farm operators are already much more efficient and have the ability to pay more for land.

3.3.1.2 Land Use

Farm operators who are unwilling to adjust may not use their land in its highest and best use. However, if their crop income is low or negative, this could eventually force them out of the industry, allowing the remaining farm operators the opportunity to gain control of additional farmland from leasing or purchasing.

Mixed farms use land in the highest and best use, annual crops or livestock production, and create a bid value based on this use. Grain farms base their bid value on crop and hay production. If the land is best suited for livestock production, it is likely that a mixed farm will generate a higher bid and will gain control of that land. As a result, poor quality crop land will likely move to its highest and best use in livestock production if it is already in control of a mixed farm or when it enters the land markets.

3.3.1.3 Incomplete Information

The uncertainty of both future prices and yields affects land use, the ability to compete in farmland markets, and farm survival. Errors in expectations can result in land being used in a manner that does not yield the highest income. Errors in expectations can also result in bid values that are higher/lower than the actual income earning ability of the land, and a person with the most optimistic expectations may bid too high. If these optimistic expectations are not realized, it is possible that the farmland owner maybe unable to maintain positive cash flows and eventually be forced out of the industry. A bid value that is not large enough can have an equally negative impact. If a farmer is unable to expand their farm operation to an efficient point, given their machinery, they may be operating at a loss and if there is no farm expansion in the near future they may also be forced out of the industry.

3.5 Summary

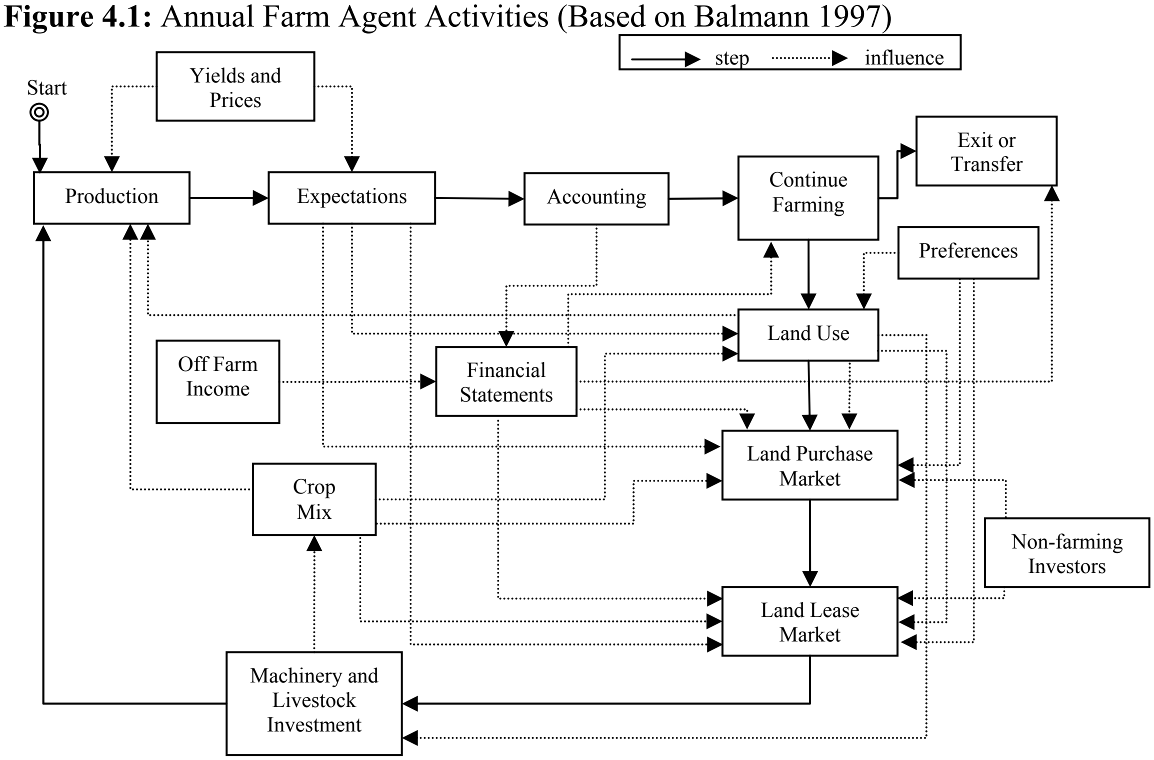
Structural change is influenced by heterogeneity of farmer's resource endowments, demographic characteristics, and individual preferences. In many cases change occurs in farmland markets where an individual exits, allowing the scarce land resource to be purchased by other farm operators. Cost structure dictates that before farmers can expand their operations, they must have sufficient capital to "jump" to the next efficient size point. Eligible farmers must have sufficient capital (both equity and debt) to meet additional operating costs, machinery investments, livestock investments, as well as land costs, while staying within conventional financing constraints. Economies or diseconomies of size, land use, and expectations are reflected in farmland bid values.

Chapter 4
The Model

4.0 Introduction

In this chapter, the key elements of the model are described. This begins with a list of model assumptions, followed by a description of the annual farm agent activities (See Figure 4.1).

Figure 4.1: Annual Farm Agent Activities (Based on Balmann 1997)



Farm agents annually undertake production, accounting, management, and investment activities. Production includes activities related to annual crop, forage, and livestock production. The farm agent's annual cash flow and balance sheet is monitored in the simulation. Management decisions include exiting or transfer along with the decision to use land in forage or annual crop production. Investment includes land, livestock, and machinery. The equations describing the agents presented in this chapter are structural, behavioural, and accounting relationships, with many of them being well established in the relevant literature.

4.1 Model Assumptions

Of central importance are increases in farm size in order to achieve economies of size and increase wealth, while maintaining financial viability. It is therefore assumed that farm agents have an innate desire to increase farm size to increase profitability and wealth. Farm agents increase farm size through competing for additional farm land in two separate land auctions, a land lease and a land purchase auction. Their ability to compete in land markets are determined by their individual preferences, technology, expectations, and financial constraints.

It is assumed that grain farms, who initially do not produce livestock, will not switch into livestock production. This assumption is consistent with the findings of Highmoore (2002), who discovered that a very small portion of the increase in cattle in southern Saskatchewan came from farms who switched to livestock production. As a result, when a farm increases livestock numbers there are no additional fixed costs for machinery or buildings because they are assumed to already exist and be capable of handling a larger herd.

There are a number of different machinery options that the farm agent can use, and these are determined by farm size. Smaller farm operators are forced to use old seeding technology, though purchasing used farm equipment, while larger farmers utilize new seeding technology and purchase new equipment. Although there are different technologies available, it is assumed that these technologies will remain constant throughout the remainder of the simulation.[3] To keep the model tractable, it is assumed that all hay is custom made.

In this simulation each plot has water access and a fence. It is also assumed that the cost of inputs for crops and livestock, with the exception of forage, remains constant throughout the simulated period.

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[3] It is likely that new technology will become available in the future, however it is unknown what this technology will be and the impact on the cost structure or output of a farm.

Ultimately, the farm's ability to compete in a land market is determined by their available capital and their expected annual cash flow. This constraint is imposed to ensure that farm agents only purchase land when they believe they can make a financially successful jump in farm size.
It was initially hypothesized that forage markets are regional due to the large transportation costs. However, much of the forage produced is used by the farmers who produce it. Thus, forage markets are exogenous to the model.

Crop prices are independent from yields as are livestock prices from livestock numbers. Saskatchewan is a relatively small producer in the world markets for grains, oilseeds and beef and has little impact on world prices. The exception is hay, which is a "thin", localized market; the effects are captured in the yield and price generating process.

Finally, agricultural support payments and taxation likely have a significant impact on agricultural structure. However, agricultural support programs are often short lived, making them difficult to project into the future. Therefore, government support programs are excluded from the model. Income taxation is assumed to be included in the annual family living withdrawal.

4.2 Farm Production Activities

Farmland can be used to generate income through the production and sale of crops and forage production used as feed for livestock.[4]

4.2.1 Crop Income

Crop income is generated from the production of grains and oilseeds. A farm agent's crop income is sum of each individual plot income (equation 4.1).

$$TCI = \sum_{i=1}^{n} GI_i^c \qquad 4.1$$

Where: TCI = total crop income of farm agent
GI_i^c = gross crop income from crop plot i

[4] Many of the equations presented in this section are based on Freeman (2005).

Each plot's gross crop income is calculated based on common, exogenous annual price and crop yields that are the same for all farm agents, but yield is adjusted to represent the soil quality of the plot, crop mix, and a yield multiplier (equation 4.2). Crop yields are adjusted to account for variations in soil quality by multiplying the average yield by the crops index rating on the plot.

Each plot's crop index rating is based on Saskatchewan Crop Insurance data for each crop included in the model which is specific to that plot.[5] The yield multiplier of the farm agent is assigned value of 1 if the farm operator uses conventional tillage and assigned a value greater than one for no till.[6] Much of the yield increase is due to increase with no till seeded crops is attributed to improvements in spring soil water conditions (Zentner et al. 2002).

$$GI_i^c = \sum_{j=1}^{n} \hat{P}_j \cdot \hat{Y}_j \cdot YI_j \cdot Y^{mult} \cdot A_j \qquad 4.2$$

Where: $\hat{P}_j$ = exogenous price crop j

$\hat{Y}_j$ = average yield of crop j

YI_j = yield index of crop j on plot

Y^{mult} = yield multiplier of farm agent

A_j = total acres of crop i on the plot

4.2.2 Forage and Livestock Production

Livestock producers (mixed farms) require forage production as a primary source of feed. Grain farms do not produce livestock and consequently must sell annual hay production and rent pasture land in their control to other farming agents.

4.2.2.1 Livestock Income

Mixed farms will generate income annually from the sale of the calves. Livestock production income is the value of the calves less the costs. Note that raised feed and labour costs are excluded (equation 4.3).[7]

[5] This allows the land quality to have a different impact on each crop included in the model based on historical records.

[6] Zentner et al. (2002) found that many crops had higher yields when seeded using no-till technology in the black soil zone of Saskatchewan.

[7] Feed costs are the annual cost of pasture and hay production in addition to any purchased feed. Labour costs are calculated as outlined in section 5.6.

$$LI = \left(P_l \cdot \overline{W} - VC^{cow}\right) \cdot NC \qquad 4.3$$

Where: LI = livestock income
P_l = price per pound of calf
$\overline{W}$ = average weight of calf
VC^{cow} = variable cost of cow and calf, excluding feed and labour
NC = total cows of the farm operator

4.2.2.2 Hay and Pasture Production

Livestock production requires an adequate supply of feed for the entire year. Although feeds sources (such as barley) other than forage could be used, it is assumed that livestock are fed only forages in the form of hay or pasture. In the winter months, cattle are fed hay and in the summer pasture is grazed. Pasture production is often greater early in the summer months and lower later in the year, therefore pasture production is divided into two periods: 1) early pasture and 2) late pasture, each with its own yield. The first period forage yield corresponds to early pasture or in the case of hay production, the first cutting of hay. The second period forage production is the subsequent re-growth for both hay land and pasture, which is assumed to only be used as late pasture. Total energy production of each feed type, hay, early pasture, and late pasture is the sum of the feed type production from all plots (equation 4.4).

$$TP_j = \sum_{i=1}^{n} P_{i,j} \qquad 4.4$$

Where: TP_j = the total energy production of feed type j of the farm agent
$P_{i,j}$ = the energy production of feed type j on plot i

The production of hay and each period of pasture production is the sum of the production of all categories of land used in that method of forage production (equation 4.5). Each land category may potentially have a different quality and therefore the yields may differ.

$$P_{i,j} = \sum_{k=1}^{n} A_{j,k} \cdot Y_{j,k} \cdot E_j^{ton} \qquad 4.5$$

Where: $P_{i,j}$ = the total energy production feed type j on plot i
$A_{j,k}$ = acres of land category k used for feed type j on the plot i
$Y_{j,k}$ = the yield of forage on land category k in tons[8]
E_j^{ton} = energy in a ton of forage j

[8] To see how forage yields are calculated see Appendix C.

4.2.2.3 Hay and Pasture Usage

Farmers must have an adequate inventory of feed for the year. Pasture shortages can be offset by feeding summer hay. If a farmer has excess early pasture, pasturing can be delayed until late summer pasture; however there is nutrient loss due to over maturity. The total quantity of excess early pasture that can be delayed for late pasture usage is:

$$EP_1 = TP_1 - E_1 \cdot NC \qquad 4.6$$

Where: EP_1 = excess early pasture energy
TP_1 = total early pasture production
E_1 = energy required per cow of early pasture
NC = total cows of the farm operator

Excess late pasture is assumed to be unavailable for hay; as it increases the risk and extent of winter kill and regrowth potential (Belanger et al. 1999). All the excess early pasture energy is carried over to late pasture increasing the total late pasture production (equation 4.7). Late pasture production has not occurred at the time of early pasture and therefore late pasture cannot be transferred to early pasture. Early pasture shortages are offset by feeding hay. Therefore, if excess early pasture is less than zero and there is no transfer of early pasture to late pasture and the late pasture available is simply equal to late pasture production.

$$TP_2^{new} = TP_2 + (1 - L) \cdot EP_1 \qquad 4.7$$

Where: TP_2^{new} = the new total late pasture energy available for farmer
TP_2 = total late pasture production
L = the loss from delaying early pasture to late pasture

Hay is fed in winter months and to supplement pasture, if short in summer months. The total quantity of hay fed is the sum over the summer and winter (equation 4.8).

$$HF = \frac{H_s + NC \cdot E_H}{E_H^{ton}} \qquad 4.8$$

Where: HF = total hay fed in tons for the farm agent
H_s = hay fed in summer in energy units
E_H = total energy required over the winter months
E_H^{ton} = energy in a ton of hay

4.2.2.4 Hay Reserves, Sales, and Purchases

Farm operators put hay in reserves (inventories) from years of high forage yields to avoid purchasing hay when production is low. The quantity of hay in reserves is the sum of the current hay reserves, new production, and hay purchases less hay fed and sold (equation 4.9).

$$HR_t = HR_{t-1} \cdot (1 - SP) + \frac{TP_H}{E_H^{ton}} + HP - HF - HS \qquad 4.9$$

Where: HR_t = hay reserves at time t in tons
SP = spoilage to hay reserves
HP = hay purchases in tons
HS = hay sales in tons

Farmers adjust their hay reserves based on a minimum, maximum, and target level of hay reserves through purchasing and selling hay.[9] If a farmers hay reserves go below a minimum threshold level, the farmer purchases hay to raise the hay reserves back to the threshold level. When hay reserves exceed a maximum threshold level hay is sold to lower the hay reserves to the target reserves level.

The net hay income is the sales value of hay less purchase cost (equation 4.10). A fixed transaction fee for all hay sales is included to cover the cost of finding a buyer and transportation expenses.

$$NHI = (P_H - TF) \cdot HS - P_H \cdot HP \qquad 4.10$$

Where: NHI = net hay income
P_H = the market price of hay per ton
TF = the transaction fee when selling hay

Although in reality hay quality can vary within a region, it is not easily determined visually and therefore it is assumed that all hay produced is of similar quality.

[9] These levels are a percentage of the farmer's expected annual hay requirement, therefore farmers who produce hay with no livestock will sell all their hay.

4.2.3 Variable Costs and Forage Establishment and Breaking

Annual production activities have variable costs assigned based on a per acre basis and a per unit of output. The farm operator's annual variable cost is the sum of the variable costs of all plots in their control.[10] Each plot's variable cost is calculated as:

$$VC_i = \sum_{j=1}^{n} \left(A_{i,j} \cdot VC_j^{acre} + V_{i,j} \cdot VC_j^{vol} + TE_{i,j} \right) \qquad 4.11$$

Where: VC_i = total variable cost for plot i
$A_{i,j}$ = acres of crop j of plot i
VC_j^{acre} = variable cost per acre for crop j
$V_{i,j}$ = volume of crop j on plot i
VC_j^{vol} = variable output cost per unit of j
$TE_{i,j}$ = transportation expense for plot i for output j

The cost of forage establishment is seeding:

$$TES = A_F^{new} \cdot SF \qquad 4.12$$

Where: TES = the total establishment cost of the farm agent
A_F^{new} = total acres seeded to forage
SF = seeding cost per acre

At the end of the forage rotation all forage grown on tillable land is broken. The farmer's total breaking cost for the year is calculated as:

$$TBC = A_F^{b} \cdot BC \qquad 4.13$$

Where: TBC = the total breaking cost of the farm agent
A_F^{b} = acres of forage broken
BC = per acre breaking cost

4.2.4 Transportation Expense

The transportation expense for hay and crop is linked to the distance the farm operator must transport product from the plot to the farmstead (equation 4.14). The first part of the equation represents the fixed cost and the second a variable cost for each additional mile of transportation. The fixed cost represents the cost to load and unload and is captured in the first mile transportation cost to the farmstead.

[10] It is assumed there is no increase in cost to having multiple crops or uses on a single plot.

$$TE_j = V_j \cdot TR_j^1 + V_j \cdot TR_j^{loaded} \cdot (D-1) \quad 4.14$$

Where: TE_j = transportation expense for crop j
D = distance to the farmstead
V_j = volume of crop j transported
TR_j^1 = the transportation expenses per unit of crop j for the first mile
TR_j^{loaded} = the transportation expenses per unit of crop j for each additional mile

4.2.5 Annual Machinery Repairs

Annual machinery repair costs are the sum of all repair costs for the machinery the farm agent owns. Each machine is tracked individually, with annual repair costs calculated based on total accumulated repairs that would have occurred with a specific level of use. Using this method allows for old machinery to have a larger annual repair cost than new machinery. The annual repair cost for a machine is:

$$AR_{j,t} = TAR_{j,t} - TAR_{j,t-1} \quad 4.15$$

Where: $AR_{j,t}$ = annual repairs for machinery j at time t
$TAR_{j,t}$ = total accumulated repairs for machinery j at time t

The calculation for total accumulated repairs is different depending on how use is measured, hours or acres. For machinery where use is measured in hours, total accumulated repairs are calculated as:[11]

$$TAR_t = \frac{V_0}{100} \cdot B \cdot \left(C \cdot \sum_{n=1}^{t} H_n \right)^A \quad 4.16$$

Where: V_0 = new machinery cash price
A,B,C = estimated parameters specific to machinery type
H_n = hours of use in year n

For machinery where annual use is measured in acres, total accumulated repairs are calculated as:

$$TAR_t = \frac{V_0}{100} \cdot B \cdot \left(C \cdot \sum_{n=1}^{t} \frac{U_n}{W} \right)^A \quad 4.17$$

Where: U_n = acres of use in year n
W = width in feet

[11] Formulas and estimated parameter for annual repairs are based on Schoney (1980).

4.2.6 Cash Commitments

Cash commitments are made up by two components, the total annual debt servicing and total annual land lease payments (equation 4.18).

$$CC = DP + LP \tag{4.18}$$

Where: CC = cash commitments
DP = total debt servicing
LP = total land lease payments

All machinery, livestock, and land purchases are assumed to be financed with 75% debt capital. The sum of all the annual loan payments is the farm agents total debt payment. In turn, the total lease payment is the sum of all land lease payments.

4.3 Off Farm Employment and Family Living Withdrawal

Farm agents may have the opportunity for off farm employment. Off farm employment is set at model initialization and remains constant throughout the simulation. At retirement, if the farm is transferred to the next generation, the new farm agent possesses a random probability that they will have off farm income, with smaller farms having a higher probability. If the new farm agent has off farm income, the value of this income is set between an upper and lower bound and remains constant for the remainder of the simulation. Off farm income is defined as OFI in the following equations.

Farm agents require a minimum family living withdrawal and increasing propensity to consume. Farm family living withdrawal is the greater of either the minimum required withdrawal or the propensity to consume from their annual net cash flow before investments, including any off farm income after all debt and land lease payments are made (equation 4.19). A maximum ceiling value is also incorporated into the simulation.

$$FL = Max(FL^{\min}, \delta NCFBI) \tag{4.19}$$

Where: FL^{min} = minimum family living withdrawal
δ = propensity to consume from profits
NCFBI = net cash flow before investments

4.4 Farm Accounting

In order to assess farm viability, financial characteristics are tracked. In the short run, farms must maintain positive annual cash flows. The long growth in wealth (net worth) is tracked through a simplified balance sheet.

4.4.1 Cash Flows

Annual cash flows are generated by the household and consist of all cash inflows and outflows from farming and investment activities as well as off farm income. In addition to cash flow elements described earlier, pasture rental income, hired labour expense, borrowed money and net of new investments are included. Grain farms receive pasture rental income for land in their control that is natural or improved pasture. Net of new investments is the difference between assets purchased and sold. Each agent's annual net cash flow is

$$\begin{aligned} NCF = TCI + LI + NHI + OFI + Past - TES - TBC - VC \\ - CC - Inv + B - FL - HL - AR \end{aligned} \qquad 4.20$$

Where: NCF = net cash flow
TCI = total crop income
LI = total livestock income
NHI = net hay income
OFI = off farm income
Past = pasture rental income
TES = total forage establishment cost
TBC = total forage breaking cost
VC = total variable cash costs
CC = cash commitments (debt servicing and lease payments)
Inv = the net new investment
B = new borrowed money
FL = family living withdrawal
HL = hired labour expense
AR = annual repair expense

4.4.2 Balance Sheet

Farm agents also track assets and liabilities, which influences their exit decision and also their ability to receive credit and participate in land markets. Assets include owned land, livestock, and machinery, which are all valued at their current market price. Individual plot current value is its market price, adjusted for the quality:[12]

$$LV_i = \frac{PR_i}{\overline{PR}} \cdot P_{land} \qquad 4.21$$

Where: LV_i = value of plot i
PR_i = productivity rating of plot i
$\overline{PR}$ = mean productivity rating of all plots
P_{land} = current market price of land

Agricultural machinery generally do not exhibit straight-line depreciation (Cross and Perry 1995), therefore depreciation is calculated using a method where machinery stocks depreciate at a constant percent of the remaining machinery value, with the exception of the first year for new machinery. The estimated parameter 0.948 allows for a greater rate of depreciation in the first year for new machinery. The current market value years greater than zero is calculated as:[13]

$$V_n = V_0 \cdot 0.948 \cdot 0.901^n \qquad 4.22$$

Where: V_n = value of machinery at age n
V_0 = value of new machinery
n = age of machinery

Livestock does not depreciate over time due to constant replacement[14] and is therefore the current quantity of cows multiplied by the value of a cow.

4.5 Farm Agent Expectations

Farm operators make investment and land use decisions based on future profitability and therefore must form expectations as to future yields. It is assumed that yield expectations remain constant throughout the simulation and price expectations change in response to current market conditions. Fisher and Tanner (1978) found evidence that a farmer's price expectations are based on a weighted moving average of past prices, with the weights declining over time. In this simulation farmers use adaptive expectations in forming their expected output prices; these are

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[12] The value of a plot must change as the market value changes. This method allows the land value to change annually as the market value changes, adjusting for the productivity of the specific plot. The computed market value is based on an average quality plot.
[13] Formulas and estimated parameter for machinery values are based on Schoney (1980).
[14] The replacement cost is captured in the value of a calf, with a cost for replacement of animals.

calculated as the weighted moving average of the previous five years plus a random error term (equation 4.23).[15]

$$E\left[P_t\right] = \sum_{i=1}^{5} w_{t-i} \cdot P_{t-i} + \varepsilon \qquad 4.23$$

Where: E [ ] = expectation
P_t = price at time t
ε = error term

4.6 Farm Agent Crop Mix

Crop mix affects profitability and therefore competitiveness in land markets. Two crop mixes are available in the simulation, one made up of wheat and fallow (traditional crop mix) and the other with oilseeds, wheat, and no fallow (zero till crop mix), each depending on the seeding equipment technology employed. Farm operators with no till seeding equipment have a rotation with no fallow and oilseeds. No till seeding conserves soil moisture allowing for continual cropping. The farmers with conventional seeding equipment must include fallow in their rotation to conserve soil moisture.

4.7 Farm Exits and Transfers

Farms exit agriculture for both financial problems and due to old age retirement. Financial problems can cause both voluntary and forced exits. Farms are forced to exit due to insolvency (equation 4.24) or voluntarily due to prolonged equity erosion. The latter is generated by a random increasing probability of exit if negative net cash flows occur for 5 or more consecutive years (equation 4.25).[16]

$$farm\,libailties \geq 0.9 \cdot farm\,assets \quad \left(forced\;exit\right) \qquad 4.24$$

$$NCF \leq 0 \quad \left(voluntary\,exit\right) \qquad 4.25$$

Farms also voluntarily exit due to old age retirement. Farm operators are assigned a probability of retirement based on their age, with older farm operators having a higher probability. At retirement, farm succession is also probabilistic. Intergenerational wealth transfers are an

[15] Price expectations do not allow for an expected price trend, however the prices generated in the model are based on historic detrended prices.
[16] The exit decision is based on Freeman (2005).

important factor in agricultural structure, but vary considerably from farm to farm and are complicated by factors such as age, off farm income, capital gains laws, farm wealth, and number of children in the family. Farms with high levels of equity have a transfer value based on the minimum value that the exiting farmer will require for retirement and a portion of the remaining equity (equation 4.26). The transfer value is deducted from the farms cash account, all debt paid, and the remaining wealth transferred to the next generation. If there is insufficient cash to account to pay off all debts and cover the transfer value, the new farmer will finance this deficit with debt financing over 25 year period.

$$transfer\ value = retire^{\min} + \alpha \cdot \left(equity - retire^{\min}\right) \qquad 4.26$$

Where: α = proportion of farm equity that is included in transfer value
$retire^{min}$ = minimum cash for retirement

If a farm does not have enough equity to meet the minimum retirement requirements, farm assets have a transfer value equal to the market value of all non cash assets and will be financed over a 25 year period.[17]

However, the ability to transfer assets does not necessarily mean that succession takes place as the succeeding farmer must be able to cash flow the annual loan payment using the transferred assets and off farm income. As described earlier, off farm income is randomly assigned according to probabilities based on farm size. If the incoming farmer believes they can cash flow the transfer value and will not have a debt to asset ratio greater than 0.6, the farm is not transferred. If the farm is not transferred, the farm agent retires and their land enters the land markets.

4.8 Land Use

Farm agents make land use decisions annually in response to changing output prices and when bidding on additional farmland in the lease and purchase markets.[18] The annual land use decision involves shifting land that is currently tilled into a forage rotation, based on its highest and best

[17] The retiring farmer will take all the cash out of the farm cash account.
[18] Due to the lumpy nature of crop machinery, the land use decision and machinery sizing should be solved simultaneously. However, due to the constraints imposed by the Netlogo platform the decisions are solved independently.

use.[19] At the end of the forage rotation, land is broke and undergoes a land use decision by the farmer to determine if it will be put back into forage or used as crop land.

The land use decision is based on the highest and best use of each plot and the farmer's preferences and net income expectations (equation 4.27). Costs associated with equipment investment and hired labour are not considered when a farm operator is switching additional cultivated land to forage production.[20]

$$LU = Max\left(AC, AF\right) \qquad 4.27$$

Where: LU = land use
AC = net income from annual crops
AF = annualized income from forage rotation

A plot's expected crop income is calculated using the farm agent's current crop mix. Plot crop yield is based on the current average yield, which is adjusted to represent the crop's yield index.[21] Variable costs of production are the summation of a per acre, per unit, and transportation expense for each crop. The annual expected return from crop production is then:

$$E\left(AC\right) = \left(\sum_{i=1}^{n} E\left(Y_i\right) \cdot E\left(P_i\right) \cdot A_i \cdot Y^{mult} \cdot YI_i^{xy} - \sum_{i=1}^{n} VC_i\right) \cdot TA^{tilled} \qquad 4.28$$

Where: Y_i = yield of crop i
P_i = price crop i
A_i = proportion of annual crop mix in crop i
YI_i^{xy} = yield index for crop i on plot
VC_i = per total variable cost per acre of crop i
TA^{tilled} = acres of tillable land

A forage rotation's annual value is the present value of all cash inflows less the present value of all cash out flows, which is then annualized over the forage rotations length (equation 4.29).[22] It

[19] It is assumed that grain farmers will not use tilled land in forage production. This section outlines how these farmers would value land only suitable for hay production when creating a bid value.
[20] These costs are excluded from this section because the land use, machinery sizing, and hired labour all should be solved simultaneously. The Netlogo platform does not allow this to easily be solved and is therefore simplified to exclude these costs in the land use decision.
[21] Each plot's annual crop yield indices are based on Saskatchewan Crop Insurance historical yields.
[22] Although forage rotations may be different lengths, to reduce the complexity it is assumed they are all the same length.

is assumed that the first year of the forage crop is an establishment year where the farmer receives no production and that there is no companion crop.

$$AF = \left(-S + \sum_{t=1}^{n} \frac{FI_t}{(1+r)^t} - \frac{BR}{(1+r)^n} \right) \cdot \frac{r}{\left(1-(1+r)^n\right)} \qquad 4.29$$

Where: S = forage seeding cost
FI_t = forage income at time t
r = risk-free rate
BR = breaking cost at the end of the rotation

The annual forage income for mixed farmers differs from grain farmers. For grain farms, forage income is based on hay sales:[23]

$$FI = \left(E\left[(P_H - TF) \cdot Y_F \right] - VC_H \right) \cdot A_t \qquad 4.30$$

Where: P_H = the market price of hay
TF = transaction fee for selling hay
Y_F = yield of forage
VC_H = variable cost of hay production per acre

For mixed farms, forage income comes indirectly from additional cow income and directly from the net change in hay sales/purchases (equation 4.31).[24] Pasture land has no annual variable cost.

$$FI = NC \cdot E(P_c) + NHP - VC_H \cdot A_H \qquad 4.31$$

Where: NC = additional new cows if land converted
P_c = residual value of calf to land and labour
NHP = net hay purchases and sales
A_H = acres of hay land

Net hay purchases and sales considers the value of hay that would be purchased or sold without a change, compared to that purchased or sold after a change in use (equation 4.32).

$$NHP = (HB^{old} - HB^{new}) \cdot P_H + (HS^{new} - HS^{old}) \cdot \left(P_H - TF\right) \qquad 4.32$$

Where: HB^{old} = quantity of hay purchased if no change
HB^{new} = quantity of hay purchased if change use
P_H = market price of hay
HS^{new} = hay sold if change use

[23] It is assumed that this income remains the same for all years other than the establishment year. This is due to the assumption that forage yields to not decrease as the age of the forage stand increases.
[24] See Appendix A for a description of how the additional cow numbers are calculated and Appendix B for the proportion of land in hay and pasture.

HS^{old} = hay sold if no change
TF = transaction fee for selling hay

Land to be purchased or leased is assessed in the same manner as above.

4.9 Machinery and Livestock Investment

As identified in section 3.3.1.1, machinery used in crop production is a lumpy investment and when a farm increases crop acres past a threshold level, additional investment in machinery is required. This is consistent with Doms and Dunne's (1998) findings that firms alter capital stocks in a lumpy fashion and these large adjustments account for a significant portion of a firm's total investment. This is captured in the current model through creating various machinery options that have a maximum capacity. Once the maximum machinery capacity is exceeded, additional investment is required to shift to the next feasible machinery size. Large farms also replace their machinery periodically to keep a relatively new machinery stock, decreasing repairs and down time, subject to 1) sufficient available cash and 2) not exceeding a maximum debt to asset ratio. Net machinery investment is the value of the new machinery required less trade ins (existing machinery) (equation 4.33). In cases where farms are reducing their crop acreage, they sell the machinery that they currently own and will resize their machinery. In this case, it is assumed that the value of their old machinery is sold and the appropriate machinery option purchased. Their cash account then increases/decreases by the required net machinery investment.

$$Inv^{mach} = RI^{mach} - MV^{cur} \qquad 4.33$$

Where: Inv^{mach} = net of machinery investment
RI^{mach} = required machinery investment
MV^{cur} = current value of machinery

Investment in livestock is based on the expected livestock stocking capacity. It is assumed that farm operators can buy and sell livestock to match their pasture production. At the end of the production year, farm operators calculate their expected pasture production (with the exception of newly seeded forages) and set their cow numbers accordingly.[25] The net investment in cows is then the value of the new cows less the value of current cows (4.34).

[25] This calculation is in Appenidx A.

$$Inv^{cows} = \left(Cows^{new} - Cows^{old}\right) \cdot P^{cows} \qquad 4.34$$

Where: Inv^{cows} = net investment in cows
$Cows^{new}$ = new quantity of cows
$Cows^{old}$ = old quantity of cows
P^{cows} = value of a cow

It is assumed that all machinery and livestock investments are financed with 25% equity and 75% borrowed formula, with repayment over a 5 year period, with the exception of down sizing machinery.[26]

4.10 Farmland Markets

Farmland markets are the main area where interaction occurs between farmers. Here farmers compete with one another and non-farming investors in an attempt to expand. Farmers gain control of additional farmland through either the farmland purchase market or the farmland leasing market. It is assumed here that the farmland purchase market occurs first and the leasing market second, which is consistent with a strong preference for land ownership.

Farmland enters the purchase or lease market when a lease expires, a current farmer exits, or non-farming land owners decide to sell. Land enters each market based on the following rules:

1) Expiring lease agreement – land enters the purchase market and receive bids. If the bids are unsatisfactory, the land enters the lease market.

2) Voluntary farmer exit – a random portion directly enters the lease market and the remainder enters the land purchase market to receive bids. All leased plots are treated as though the lease agreement expired.

3) Forced farmer exit – all owned land enters the purchase market. All leased plots are treated as though the lease agreement expired.

[26] This is similar to Freeman (2005) who assumes all non-land capital expenditures are financed with a 25% cash down payment and the remainder financed over a 5 year amortization period.

In both the farmland markets, an auctioneer agent randomly selects an available plot and collects bids for that plot. This process occurs each time period until there are no remaining plots for sale or lease.

4.10.1 Bidding Eligibility Criteria

Before farmers can compete in land markets, they must meet initial bidding eligibility requirements:

$$Age < Age^{Max} \tag{4.35}$$

$$D / A < DA_{before}^{\max} \tag{4.36}$$

$$Cash > TCA \cdot \gamma + THA \cdot \phi + CR \tag{4.37}$$

Where: Age^{Max} = maximum age farm for bidding on farmland
D/A = debt to asset ratio
$DA_{before}^{\max}$ = maximum debt to asset ratio before buying land
TCA = total crop acres
γ = minimum cash balance per crop acre
THA = total hay acres
ϕ = minimum cash balance per hay acre
CR = capital reserve requirement

Farms are not allowed to bid on additional farmland if they are above a specific age and preparing for retirement (equation 4.35). The second constraint (equation 4.36) requires a current debt to asset ratio greater than a threshold value. The final constraint (equation 4.37) forces farmers to have minimum cash balance to cover production cost in the following period.

The initial screening requirements do not yet include the anticipated capital requirements for machinery investment or minimum cash balance per acre of the new land purchases because the quality of farmland available for sale is not yet known. These factors will be taken into account when creating a bid in the farmland markets.

A final screening requirement limits farmer bidding to land within a maximum distance from the farmstead. This constraint is added to reduce the computational requirement of farmland markets and will likely not affect the land markets due to transportation expenses.

4.10.2 Farmland Purchase Market

Farmers who meet the eligibility requirements, create a maximum willingness to pay based on the minimum of 1) the bid based on expected income earning ability and 2) the bid based on financial constraints:

$$Bid = Min(Bid_{income}, Bid_{financial}) \qquad 4.38$$

Where: Bid = the bid for farmland
Bid_{income} = bid value for plot based on income earning ability
$Bid_{financial}$ = the bid value from financial characteristics

In order for the bid to be accepted, farmers bid value must be greater than a minimum acceptable price to the land owner and greater than any non-farming investor bids.

4.10.2.1 Maximum Bid Based on Income Earning Ability

Bid value based on income earning ability is the certainty equivalent of the annual economic return and ending land value, which is discounted to the present value (equation 4.39).[27] To calculate the certainty equivalent the expected income is multiplied by the farm agent's risk aversion parameter.[28]

$$bid_{income} = \sum_{t=1}^{n} \frac{E\left[CE\left(R_t^{xy}\right)\right]}{\left(1+r\right)^t} + \frac{E\left[CE\left(EV_n\right)\right]}{\left(1+r\right)^n} \qquad 4.39$$

Where: CE = certainty equivalent
bid_{income} = bid value for plot
R_t^{xy} = annual net return from plot
r = risk-free rate
EV_n = value of land at the end of the planning horizon
n = planning horizon

[27] It is important to note that the opportunity cost of capital for land and annual economic return can be different.
[28] The risk aversion parameter is randomly assigned at initialization and remains constant throughout the simulation. There are equal proportion of agents with a risk aversion parameter of 0.7, 0.6, and 0.5.

Expected net annual income is defined in the same fashion as section 4.8.[29] Total annual net return is calculated as the annual return less fixed costs, hired labour, and unpaid family labour (equation 4.40).[30]

$$R_t^{xy} = AR - FC - HL^{crop} - UL \qquad 4.40$$

Where: AR = annual value added when used in best use
FC = fixed cost of plot
HL^{crop} = hired labour for the crop enterprise
UL = unpaid labour

Fixed costs for the plot is the sum of fixed costs for capital invested in crop machinery and livestock. Fixed machinery costs consist of depreciation and an opportunity cost of capital investment.[31] The value of machinery are calculated using the equation 4.22. This is calculated using the capital recovery charge:

$$CRC_i = (V_{0,i} - V_{n,i}) \cdot \frac{i}{(1-(1+i)^{-n})} + \left(i \cdot V_{n,i}\right) \qquad 4.41$$

Where: CRC_i = capital recovery charge for capital in use i (crop machinery or livestock)
$V_{0,i}$ = current capital value for use i
$V_{n,i}$ = capital value at end of planning period for use i
i = nominal interest rate
n = planning period for capital investments

The crop machinery capital recovery charge is spread over the total acres that the farm operator has in that particular land use (equation 4.42). Farm operators believe that they will gain enough land used in crop production to get to the next efficient point for their machinery package. Therefore, when creating a bid value, they spread their fixed machinery cost to the point where their machinery option is efficient. For livestock, the capital recovery charge is based on the additional cow value that will be added if the plot is purchased.

$$FC_i = \frac{CRC_i}{AC_i^{eff}} \cdot A_i^{plot} \qquad 4.42$$

Where: FC_i = fixed cost for crop acres on the plot

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[29] When calculating the annual return it is assumed that all tillable land is broken, therefore making the calculation the same as in the section of land currently in crop production. This annual return includes a value on the existing pasture and hay production in addition to the value of tilled land when used in its highest and best use.

[30] Repair costs are not included in the bid value because it is believed that they will not significantly impact the value.

[31] The capital recovery charge for livestock is only the opportunity on investment as the value of livestock remains constant.

AC_i^{eff} = efficient acres for machinery option
A_i^{plot} = acres in use i on the plot

For the land bid value, the family living withdrawal is the propensity to consume from the annual gross income from the plot less any variable costs.

Hired labour is only considered for the crop production enterprise.[32] Hired labour for the crop enterprise has a lumpy component, due to full-time hired labour, and a per acre cost based on the quantity of part time labour required (equation 4.43). The total labourers required are determined by the crop machinery option that the farmer requires because each machinery component requires a person to operate it.

$$HL^{crop} = \frac{FT \cdot S}{TCA + CA^{plot}} + PT^{hours} \cdot W \cdot CA^{Plot} \qquad 4.43$$

Where: FT = number of full time employees
S = full time labour salary
TCA = total crop acres of the farm agent
CA^{plot} = crop acres on plot bidding on
PT^{hours} = part time labour hours per acre of crop
W = part time labour hourly wage

Unpaid family labour is computed in relation to the marginal propensity to consume (equation 4.44). This value is different than that discussed in section 4.3 because the this is consumption from income before debt or lease payments are made. It is calculated in this manner because the debt payment or lease payment is not known until after the auction process is over.

$$UL = \beta \cdot AR \qquad 4.44$$

Where: β = marginal propensity to consume from annual return
AR = annual value added when used in best use

It is assumed that farmers believe the salvage land value at the end of the planning period is equivalent to the current land value.

[32] It is assumed that the hired labour for livestock production will have a marginal impact and is not included in the bid value.

4.10.2.2 Maximum Financial Bid

The financial bid is based on essential accounting relationships and is the minimum of 1) current cash available for the down payment, 2) the maximum new debt to remain below the allowable asset ratio, and 3) the ability to maintain a positive annual cash flow (equation 4.45).

$$Bid_{financial} = \min\left(Bid^{cash}, Bid^{D/A}, Bid^{CF}\right) \qquad 4.45$$

Where: Bid^{cash} = bid based on the available cash
$Bid^{D/A}$ = bid based on maximum debt to asset ratio
Bid^{CF} = bid based on cash flow

The maximum that a farm agent can bid, based on their available cash is:

$$Bid^{cash} = \frac{Cash^{Avail}}{\lambda} \qquad 4.46$$

Where: $Cash^{Avail}$ = cash available for down payment on land
λ = portion of land investment required as down payment

Available cash requirements includes a minimum cash balance per acre of hay land and crop land, the down payment of new investments in machinery and livestock, and a minimum capital reserve (equation 4.47).

$$Cash^{Avail} = Cash - \alpha \cdot CA^{mach} - \beta \cdot \left(THA + HA^{plot}\right) - \lambda \cdot \left(MI + CI\right) - CR \qquad 4.47$$

Where: CA^{mach} = crop acres when machine used to capacity
HA^{plot} = total acres used in hay on plot
MI = new investment in crop machinery required
CI = total investment in cows for farm agent with the plot bidding on included
CR = capital reserve of the farm agent

The bid based on the farm agent's debt to asset ratio includes the new debt and new assets required from the purchase of farmland, machinery, and livestock. This bid identifies the maximum that the farm agent is willing to pay, assuming that they purchase the required investment in livestock and machinery, and maintain a debt to asset ratio that is equal to the maximum debt to asset ratio. The maximum bid based on debt to asset ratio is define as:

$$Bid^{D/A} = \frac{D/A^{\max} \cdot \left(NA + LV\right) - ND}{D/A^{\max} \cdot \lambda + (1-\lambda)} \qquad 4.48$$

Where: $Bid^{D/A}$ = maximum bid based on debt to asset ratio
D/A^{max} = maximum debt to asset ratio

NA = value of new assets
LV = market value of land
ND = total new debt
λ = proportion of new investments equity financed

The value of new assets includes current assets, new machinery and cow investment required. In turn, this is reduced by the value of the down payment on the new cow and machinery investment (equation 4.49).

$$NA = A^{cur} + (1-\lambda)(MI + CI) \qquad 4.49$$

Where: A^{cur} = current assets

New debt consists of current debt in addition to the new debt for required machinery and cow purchases (equation 4.50).

$$ND = D^{cur} + \left(1-\lambda\right)\cdot\left(MI + CI\right) \qquad 4.50$$

Where: D^{cur} = current debt of the farm agent

The market value of land is calculated based on the value of land in the previous period adjusted for the quality of the land and as shown in section 4.4.

Maximum cash flow represents the maximum amount that can be used to service debt. Expected annual income is the total net income from off farm employment, livestock income, and annual crop income less the total debt payment, land lease payment, hired labour, and family living withdrawal. The annual cash flow includes the expected income from the plot being bid on as well as the annual debt payment if a investment in machinery or livestock are required if the plot is purchased. It is assumed that the farm agent will attempt to maintain the same level of family living as they had prior to the land purchase.

4.10.2.3 Investor's Bid Value and Minimum Acceptable Price

Random plots are selected to receive a bid from non-farming investors. This is the capitalized expected annual lease rate less a management fee (equation 4.51), adjusted for plot quality:[33]

[33] Investor's risk parameter are set at 0.7.

$$Inv_{bid} = \frac{CE\left(E\left(L_t\right) - MF\right)}{r} \qquad 4.51$$

Where: Inv_{bid} = investor bid value
L_t = the income from leasing an average quality plot
MF = management fee

The expected annual lease rate is based on the actual lease rate that occurred in the previous period and the expected change in the lease rate as a result of changing output price expectations (equation 4.52). The expected change in the lease rate is the weighted change in the expected output prices multiplied by the lease rate. The outputs are classified as either grain or livestock. Expected grain prices are the weighted changes of the annual crops included in the model, weighted by the no-till technology crop mix. The relative weights for the outputs are based on the simulated land use that occurred in the previous period for each annual crop and hay and pasture land for livestock.

$$E\left(L_t\right) = L_{t-1} + \sum_{i=1}^{2} w_i \cdot \psi_i \cdot \frac{\left(E(P_{t,i}) - E(P_{t-1,i})\right)}{E(P_{t-1,i})} \cdot L_{t-1}$$
$$St \quad \sum_{i}^{2} w_i = 1 \qquad 4.52$$

Where: w_i = weight for output i
ψ_i = scaling factor for output i
$P_{t,i}$ = price of output i at time t

Expected prices are calculated as in section 4.5, but without an error term and hence are non-stochastic.

The minimum selling price a land owner will accept is the capitalized expected lease rate less a management fee (equation 4.51), with the expected lease rate calculated as in equation 4.52. A random number of plots that enter the purchase market have a greater urgency to sell due to death, divorce, or financial hardships encountered by the land owner and the minimum price accepted for these plots will be lowered to 65% of the usual minimum accepted price.

4.10.3 Auction Process

The auctioneer agent then selects the individual with the highest bid for the plot of land. If this agent is a farmer, they can adjust their bid to reflect the current market conditions.[34] An adjusted bid value is the average of their current bid and the next highest bid, either an investor bid or farmer bid. This is done to mitigate the "winners curse" phenomenon, where the highest bidder tends to over estimate the value of the plot. If the bid value is acceptable, the actual transacted price is the average of the bid and minimum the acceptable price for the parcel (equation 4.53).[35] If the maximum bid value is lower than the minimum price, the parcel is not sold and enters the leasing market.

$$PP = \frac{\min_{accept} + Bid^{adjust}}{2} \qquad 4.53$$

Where: PP = actual price paid for the plot

Bid^{adjust} = adjusted bid to reflect current market conditions

4.10.4 Farmland Lease Market

Farm agents must meet the same cash eligibility criteria imposed in the farmland purchase market before a bid can be made in the lease land market. Farmers above the maximum age can bid on land as long as they do not have to purchase additional machinery. After an available plot has been identified, the best use for the land is determined. Next, available resources must be present before a lease bid can be submitted. If the farm agent has sufficient capital (equation 4.54) and a debt to asset ratio no greater than the maximum, after all necessary machinery and livestock purchases are made (equation 4.55), a lease bid is submitted.

$$Cash^{Avail} > 0 \qquad 4.54$$

$$\frac{ND}{NA} < D/A^{\max} \qquad 4.55$$

Lease bids are created in a similar fashion to the purchase market. Bid values are based on the residual from the plots highest and best use (equation 4.40). The farmer with the maximum lease bid will gain control of the plot for a negotiated annual lease rate equal to the average of their bid

[34] It is assumed that investors do not adjust their bid value if they are the highest bid because their bid is based off the same procedure as the sellers minimum acceptable price.

[35] This price is adjusted to represent average quality land per acre and is recorded to determine the market price of land in that period.

and the second highest lease bid for the plot. The term of the lease is the length of a forage rotation. This allows farm agents who use land in a forage rotation to gain the full benefit of growing forage.[36]

4.10.4 Lease Renegotiation

Leases are renegotiated based on the lease market at that time. Leases are renegotiated if the prevailing market leases have either increased or decreased by 20% since the last adjustment to the lease (equation 4.56).[37]

$$LP^{new} = \frac{LR^{cur}}{LR^{last\,adj}} \cdot LP^{old} \qquad 4.56$$

Where: LP^{new} = new lease payment

LR^{cur} = current lease rate

$LR^{last\ adj}$ = lease rate when the plot last adjust the lease payment

LP^{old} = the old lease payment

4.11 Summary

This chapter presented the behavioural equations used in the simulation. The next chapter will discuss the model region, population characteristics, the data used in the model, and model validation.

[36] It is assumed that if used in forage, the tillable land is broke by the farm agent at the end of the lease term.

[37] This is required due to the long term of lease agreements. Lease agreements have a term equal to the length of a forage rotation. This allows the adjustments to lease rates during changing market conditions during the term of the lease.

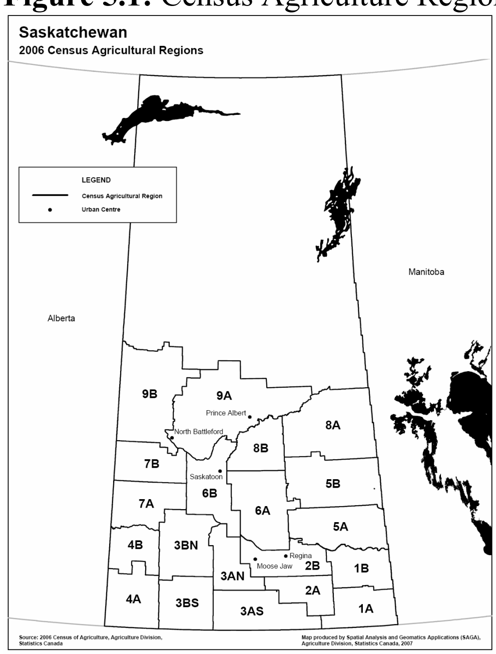
Chapter 5
Model Initialization, Data, and Validation

5.0 Introduction

The following chapter outlines the detailed model population profile representative of Census Agricultural Region (CAR) 7B of Saskatchewan. This chapter also describes the process for generating the price and yield data used in the model. Production data used in the model, and model validation are also explained in this chapter.

CAR 7B is located in western Saskatchewan (See figure 5.1), in the dark brown soil zone. This CAR has a total of 1,818 cattle and grain and oilseed farms and 2,774,158 acres of farmland used in annual crop or forages for livestock (Census of Canada: Agriculture Saskatchewan CAR 7B 2001).

Figure 5.1: Census Agriculture Regions of Saskatchewan



Source: Census of Canada: Agriculture Saskatchewan (2006)

5.1 Synthetic Farm Population

The synthetic farm population created for the simulation is based on the Whole Farm Survey for CAR 7B (Statistics Canada 2004). These data are expanded to the actual population in this region taking into account farm size, livestock numbers, age, debt, land value and off farm income. Next, the synthetic population is matched to actual farmland plots of 640 acres according to average land value. Plots with the highest farmland value are matched to highest land quality. Land quality is based on the SAMA average productivity rating.[38] Leased land is assigned randomly to match the land tenure in the region. Each expanded farm is randomly assigned debt per acre. Age and off farm employment are assigned using a similar method. Farms are assumed to be willing to produce livestock if their representative farm currently produces livestock. The result of this process is a synthetic farm population representative of CAR 7B with land parcels in the simulation based on actual land parcels in that region.

5.1.1 Farm Size, Operator Age, and Off Farm Income

Each farm agent is governed by over 100 equations per year, making the model very computationally intense. As a result only a sample of the synthetic population is included to complete the study in an acceptable timeframe. A random sample of 600 farmers is selected and their corresponding plots are included in the model (see table 5.1). This yields a total area of 867,485 acres of farmland, with an average farm size of 1,446 acres. This amount is consistent with the average farm size of 1,440 for the region according to Statistics Canada (2001). The average age of this initial farm population is 52 years.

[38] The SAMA data has the acres of each category of farmland, natural pasture, improved pasture, hay, and tilled, along with a productivity rating for each category of land.

Table 5.1: Initial Distribution of Farms by Age and Farm Size (Synthetic Population)

	Acres									
Age	< 640	641-1280	1281-1920	1921-2560	2561-3200	3201-3840	3841-4480	4481-5120	> 5120	Total
30 and Under	10	4	0	0	0	0	0	0	0	14
31 - 35	20	0	0	0	0	0	0	0	0	20
36 -40	0	3	7	6	2	2	1	0	0	21
41-45	10	32	22	17	11	1	0	0	0	93
46 -50	18	68	37	13	6	0	2	2	0	146
51-55	15	45	30	16	7	5	3	3	7	131
56-60	10	17	4	1	2	3	0	1	3	41
61-65	19	16	4	2	0	0	0	0	0	41
66-70	30	6	6	0	2	0	0	0	0	44
Over 70	40	8	1	0	0	0	0	0	0	49
Total	172	199	111	55	30	11	6	6	10	600

A total of 346 farms are initialized with an average off farm income of $47,837. Table 5.2 shows the distribution of off farm income by farm size.

Table 5.2: Distribution of Off Farm Income by Farm Size (Synthetic Population)

	Off Farm Income									
Acres	No Off farm Inc	$1-$10,000	$10,001-$20,000	$20,001-$30,000	$30,001-$40,000	$40,001-$50,000	$50,001-$60,000	$60,001-$70,000	> $70,000	Total
<640	87	4	14	12	0	2	3	6	44	172
641-1280	71	6	22	32	9	6	16	12	25	199
1281-1920	46	9	3	20	8	1	7	7	10	111
1921-2560	18	6	4	11	8	2	0	1	5	55
2561-3200	8	3	1	6	10	0	0	0	2	30
3201-3840	4	0	0	3	2	0	0	0	2	11
3841-4480	4	0	0	0	0	1	0	0	1	6
4481-5120	6	0	0	0	0	0	0	0	0	6
>5120	10	0	0	0	0	0	0	0	0	10
Total	254	28	44	84	37	12	26	26	89	600

5.1.2 Land Tenure, Land Use, and Livestock Numbers

The model is initialized with 32% leased land. This is consistent with a total land area of 35% under lease agreements in CAR 7B (Statistics Canada 2001).

The model is reinitialized at the beginning of each run. Plot location is randomly assigned, changing the transportation costs of each land use. As a result, at initialization, land use, cow numbers, and number of farms with cows may slightly differ from run to run. Also, the relatively large plot size can result in slight errors in land use and cow numbers when compared to Census data. The initialization process for land use gives similar values to that of Census data for CAR

7B (See table 5.3). Census land use has a category labeled other, which is land not used as pasture or crops and is not of importance to this simulation.

Table 5.3: Initial Land Tenure, Land Use, and Cow Numbers

	Land Tenure		Land Use			Cows	
	Owned Land	Leased Land	Crop, Hay, and Summer Fallow	Pasture	Other	Farms With Beef Cows	Avgerage Beef Cows Per all farms
Census	65%	35%	74%	23%	3%	46%	24
Model	68%	32%	70%[a]	30%[a]	0%	53%[a]	33[a]
[a] Average of 100 intializations							

Source: Census of Canada: Agriculture Saskatchewan CAR 7B (2001)

5.1.3 Assets and Debt

Assets include all owned farmland, livestock, machinery, and cash. The base land value is initialized at $350 per acre and represents 2004 average land quality (Saskatchewan Agriculture and Food 2007a). Plot value is then adjusted according to plot quality, as described in section 4.4. Cow values are initialized at $1,000 per cow and remain constant throughout the simulation.[39] The bull to cow ratio is fixed at 1:25.[40] Accordingly, the bull value of $1,500 can be combined with cow investment and an additional $60 dollars added to the cow value for the value of the bull. Farms are initialized with the crop machinery option that corresponds to their farm size and machinery age is randomly generated.[41] The value of machinery is then the current market value adjusted for the machinery option and age (equation 4.22). Each farm agent's cash account is initialized based on their area of crop land and the size of their livestock herd (equation 5.1).[42] Their cash account is initialized with a value of $30 plus a random value that is less than or equal to $5, which is multiplied by the farmers total crop acres and four times their cow herd.

$$cash = (30 + \varepsilon) \cdot (TCA + 4 \cdot NC) \qquad 5.1$$

Where: ε = random cash value

[39] Cow values are constantly changing and depend on age. Therefore an approximate estimate was made.
[40] Alberta Agriculture and Food (2004b) suggests that a yearling bull can breed 10-15, a 2 year old bull 18-24, and bull older than 2 years old 25 females.
[41] Farm operators only have crop machinery because it is assumed that all hay machinery is custom made.
[42] This process is similar to Freeman (2005) who initializes the cash account with a fixed amount per cultivated acre.

Initial farm debt averages $69,329 and distribution of debt by farm and age is displayed in table 5.4. Although farm debt is randomized per acre to create the entire synthetic population, the sampled population and their land base is the same at each initialization. Therefore, the initial distribution of farm debt to is the same for each initialization.

Table 5.4: Distribution of Farm Debt by Age (Synthetic Population)

	Total Debt									
Age	No Debt	$1-$50,000	$50,001-$100,000	$100,001-$150,000	$150,001-$200,000	$200,001-$250,000	$250,001-$300,000	$300,001-$350,000	> $350,000	Total
30 and Under	0	14	0	0	0	0	0	0	0	14
31 - 35	0	20	0	0	0	0	0	0	0	20
36 -40	0	9	4	2	1	2	0	2	1	21
41-45	9	23	20	11	15	5	9	1	0	93
46 -50	60	40	23	6	7	5	2	1	2	146
51-55	33	43	18	11	7	3	3	3	10	131
56-60	1	29	2	5	0	1	1	1	1	41
61-65	3	30	5	2	1	0	0	0	0	41
66-70	18	9	3	6	4	3	1	0	0	44
Over 70	30	7	3	3	4	2	0	0	0	49
Total	154	224	78	46	39	21	16	8	14	600

All new purchases in the simulation are assumed to be made with a 25% down payment and the remainder debt financed at a 7% annual interest. Loan terms are 20 years for land purchases and 5 years for livestock or machinery purchases.

5.2 Stochastic Prices and Yields

Price and yields are stochastic over time. Each run or replicate follows a different time path. Generally, time paths are generated based on a theoretical model and/or historical records (Huang and Willemain 2006). Here, yield and price time paths are based on a bootstrap procedure that randomly samples, with replacement from a historical data set. Accordingly, a virtually unlimited number of alternative sample paths can be generated (Huang and Willemain 2006). The bootstrap procedure uses historic annual price changes and average crop yields.[43]

[43] Historic hay yields are available at the CAR level for only the period of 1984 to 1997. To create a hay yield for the years of missing data, an estimate is created based on historic provincial hay yields and the local wheat yield:

$$HY^{CAR} = -0.479 + 0.266 \cdot HY^{Prov} + 0.46WY^{CAR}$$

$$Adjusted\ R^2 = 0.76$$

Where: HY^{CAR} = hay yield in tons per acre for CAR 7B
HY^{Prov} = hay yield in tons per acre for the province
WY^{CAR} = wheat yield in bushels per acre for CAR 7B

Each individual time path is created by randomly selecting a historic year from a uniform distribution. The output price change that occurred for this year are added onto the previous years price to generate a new price (equation 5.2), yields are the actual yield that occurred.

$$P_t = P_{t-1} + \Delta P_n \qquad 5.2$$

Where: Pt = price at time t
ΔP n = randomly selected change in price

The historic data used is presented in table 5.5. Price data is based on Saskatchewan Agriculture and Food (2007a) and yields from Saskatchewan Crop Insurance data specific to CAR 7B. A minimum output price and maximum price for each output is included. If the price goes below or above that value, a new historic year is randomly selected. The minimum value for each output is the historic average price less 2 standard deviations of the historic changes and the maximum is the historic average plus 3 standard deviations of the historic changes.[44] To ensure that the hay price and yield maintain an appropriate correlation, it is assumed that forecasted yields of the various outputs are the historic yield that occurred in the randomly sampled year.

[44] The change in prices that occurred from 1972 to 1973 is not included in the calculation of standard devotion for setting the minimum and maximum prices because these changes were relatively large compared to all other changes and appear to be an outlier.

Table 5.5: Historic Yields and Detrended Prices

Year	Prices					Yields			
	Wheat ($/Bu)	Barley ($/Bu)	Canola ($/Bu)	Hay ($/Tons)	Calves ($/Lb)	Wheat (Bu/acre)	Barley (Bu/acre)	Canola (Bu/acre)	Hay Yield (tons/acre)
2004	3.08	2.09	6.26	65.34	1.05	33.21	49.29	24.31	1.37
2003	4.27	2.64	7.91	80.78	1.28	21.30	31.50	12.62	0.72
2002	4.79	3.31	8.49	113.61	1.40	9.69	14.61	10.26	0.15
2001	4.41	3.02	7.18	79.13	1.74	22.94	34.62	15.48	0.79
2000	3.70	2.52	5.49	61.16	1.85	30.58	44.76	24.54	1.25
1999	3.32	2.35	5.55	58.91	1.63	37.79	58.44	30.49	1.66
1998	3.89	2.23	7.74	80.35	1.38	24.77	38.12	18.68	0.96
1997	3.79	2.64	8.35	84.34	1.29	26.51	38.91	19.05	0.99
1996	3.98	2.65	8.58	83.26	0.95	37.18	54.99	25.86	1.35
1995	5.28	3.52	7.91	58.15	1.15	24.27	35.47	19.38	0.72
1994	4.08	2.39	7.50	51.87	1.44	31.63	50.25	24.33	1.55
1993	2.83	1.69	6.35	59.23	1.57	35.53	52.27	25.01	1.61
1992	2.79	1.80	5.31	47.41	1.32	25.06	42.39	24.71	1.04
1991	2.61	1.90	4.84	43.62	1.33	32.42	43.05	21.43	1.48
1990	2.72	1.77	5.35	59.40	1.40	31.29	43.98	21.72	0.94
1989	3.65	2.47	5.75	65.00	1.43	21.99	32.99	15.15	0.92
1988	4.48	2.77	6.62	81.04	1.55	17.23	30.38	18.37	0.56
1987	2.84	1.77	5.90	69.53	1.70	27.94	45.38	30.15	1.15
1986	2.62	1.82	4.58	70.22	1.50	37.85	58.70	27.66	1.89
1985	3.38	2.41	6.08	86.87	1.30	25.89	37.09	18.07	1.03
1984	4.45	2.83	8.29	85.42	1.34	22.63	28.05	15.06	1.00
1983	4.58	2.87	9.26	74.05	1.33	30.59	45.71	23.27	1.38
1982	4.54	2.55	6.72	75.83	1.20	35.33	51.33	25.60	1.60
1981	5.37	3.36	7.64	93.95	1.31	31.27	45.33	22.73	1.28
1980	6.40	4.13	8.32	100.95	1.77	27.80	41.07	20.00	0.99
1979	5.85	3.38	8.49	94.05	2.29	31.80	45.00	22.40	1.39
1978	5.01	2.65	9.51	78.87	1.68	26.13	39.20	17.20	1.20
1977	3.84	2.66	10.23	78.64	0.93	25.80	40.27	20.67	1.08
1976	4.05	3.21	10.14	88.02	0.85	33.47	48.20	24.93	1.46
1975	5.14	4.01	8.74	87.60	0.83	26.13	40.07	18.57	1.18
1974	6.48	4.06	13.27	93.47	1.29	25.53	36.67	17.60	1.12
1973	7.47	5.08	11.59	78.95	1.99	25.87	38.87	18.00	1.11
1972	3.06	2.60	6.88	56.25	1.68	24.20	38.60	18.80	1.01
1971	2.48	1.43	4.70	58.23	1.52	27.60	45.47	20.53	1.19
1970	2.67	1.71	5.14	55.96	1.53	30.20	46.87	20.40	1.37
1969	2.35	1.46	4.96	59.61	1.50	25.73	38.60	18.67	1.08
1968	2.42	1.74	4.14	62.73	1.23	21.13	31.33	22.00	0.81
1967	3.00	1.92	4.43	56.61	1.26	24.47	33.53	23.38	0.94
Average	3.99	2.62	7.21	73.12	1.42	27.65	41.35	20.98	1.14

Source: Saskatchewan Agriculture and Food (2007a)

5.3 Crop Production Data

Crop production data are required to calculate farm annual income. This section discusses the variable costs of crop production, crop machinery options, and the farm agent's crop mix.

5.3.1 Crop Variable Cost

Variable crop costs include the cost for seed, fertilizer, and chemicals. These costs are different for each crop that is produced (table 5.6). In addition to the seed, fertilizer, and chemical cost, a fuel cost is added which varies with the type of technology the farm uses. Conventional tillage generates a $12.47 per seeded acre fuel cost and while no-till generates a $8.73 per seeded acre fuel cost: the higher fuel cost is due to greater tillage operations.[45]

Table 5.6: Variable Cost per Acre of Various Cropping Alternatives

	Variable Cost ($/Acre)				
	Chem Fallow	Fallow Seeded Spring Wheat	Stubble Seeded Spring Wheat	Stubble Seeded Canola	Stubble Seeded Barley
Seed		9.64	9.64	24.64	7.61
Fertilizer					
Nitrogen		9.83	19.66	19.66	19.66
Phosphourus		7.77	7.77	5.18	7.77
Sulphur and Other		0.00	0.00	2.88	0.00
Chemical					
Herbicides	11.15	15.48	18.64	25.59	17.76
Insecticides/Fungicides		1.06	1.06	1.02	0.00
Other		2.59	2.59	0.00	2.28
Total	**11.15**	**46.36**	**59.35**	**78.96**	**55.08**

Source: Saskatchewan Agriculture and Food crop planning guide for the dark brown soil zone (2006a) deflated to 2004 base.

5.3.2 Crop Machinery Options

Machinery sizing is based on farm size in crop acres and include a tractor, seeder, combine, and a combine header. Although farmers in reality use other machinery, they represent a relatively small proportion of total investment and are not considered here. In the simulation different machinery control, replacement, and seeding technology options include: 1) all work is custom hired, 2) used equipment is purchased and conventional tillage seeding technology, 3) used equipment purchased and no-till seeding technology, and 3) various new machinery and no-till seeding technology.[46] The used conventional tillage option utilizes equipment that is 10 years old combined with conventional tillage technology. The used direct seeding technology machinery option has newer equipment, which is 5 years old. The investment requirement for each machinery option and associated sizing parameters is displayed in table 5.7.

[45] Based on the Saskatchewan Agriculture and Food crop planning guide for the dark brown soil zone in Saskatchewan (2006a) deflated to 2004.
[46] A detailed description of the various machinery options can be seen in Appendix D.

Table 5.7: Crop Machinery Options

	Machine Option											
	1	2	3	4	5	6	7	8	9	10	11	12
New Value (Thousands)	$ -	$ 430	$ 481	$ 610	$ 688	$ 1,376	$ 2,064	$ 2,752	$ 3,440	$ 4,128	$ 4,816	$ 5,504
Purchase Value (Thousands)	$ -	$ 144	$ 271	$ 610	$ 688	$ 1,376	$ 2,064	$ 2,752	$ 3,440	$ 4,128	$ 4,816	$ 5,504
Min Acres	-	500	982	2,000	3,200	3,900	7,800	11,700	15,600	19,500	23,400	27,300
Max Acres	500	982	2,000	3,200	3,900	7,800	11,700	15,600	19,500	23,400	27,300	31,200

Source: Based on Saskatchewan Agriculture and Food (2006b) deflated to 2004.

Farmers with no machinery must hire custom operators to perform all crop production activities. The cost for seeding is $10.71 per acre and for combining is $21.71 per acre for a total of $32.42 per seeded acre of crop (Saskatchewan Agriculture and Food 2006b deflated to 2004) and is constant throughout the simulation.

5.3.3 Farm Crop Mix

Farms produce four different crops in the simulation: canola on stubble, barley on stubble, and wheat on fallow or stubble. Furthermore, there are two crop mix options depending on the seeding technology (table 5.8). Conventional tillage technology incorporates fallow in their crop mix, while the no-till technology omits fallow. Historically, the recommended canola rotation has been 1 year in 4 due to disease (blackleg). But more recently resistant varieties have made a 1 year in 3 rotation successful (Saskatchewan Agriculture and Food 2007b). Also, Cathcart et al. (2006) find no yield significant yield difference between a 1 in 4 compared to a 1 in 3 year rotation, supporting the use of a 1 in 3 year canola rotation in Western Canada. The crop mix remains constant throughout the simulation and is only adjusted with technology.

Table 5.8: Farmers Crop Mix

	Technology	
Crop Mix Wieght	Conventional Tillage	No-Till
% Canola on Stubble	10%	30%
% Wheat on Stubble	0%	40%
% Barley on Stubble	20%	30%
% Wheat on Fallow	35%	0%
% Fallow	35%	0%

Farms using no-till technology are assumed to have an increase in yields on stubble crops over conventional seeded stubble crops due to increased soil moisture. Clearly, yield increases vary between crops. However, it is determined that an average increase of 7% for the no-till seeded crops included in the model is correct based on a recent discussion with an industry professional (Brandt 2007).

5.4 Livestock and Forage Production Data

Forage and livestock data described in this section include cow and forage variable costs, cow feed requirements and energy from different feed sources, as well as forage establishment and breaking costs.

5.4.1 Cow and Forage Variable Costs

Livestock variable costs include all annual production costs associated with livestock production, with the exception of feed and labour. An annual replacement charge is included, which keeps the livestock herd value constant (table 5.9).

Table 5.9: Cow Production Variable Costs Excluding Labour and Feed

	$/Cow
Veterinary and Medicine	18.64
Bedding	25.03
Breeding Stock Replacement	67.39
Fuel	17.43
Machinery Repairs	12.43
Building Repairs	5.03
Utilities	15.65
Custom Work	15.28
Total	176.89

Source: Western Beef Development Centre (2006) and Saskatchewan Agriculture and Food (1999) deflated to 2004

The average calf weaning weight is set at 550 pounds.[47] A 10% death loss results in an average calf weaning weight per cow of 495 pounds.[48]

[47] Western Beef Development Center 2006 estimates an average weaning weight of 565 pounds and in 2003 estimates 523 pounds.
[48] Saskatchewan Agriculture and Food (1999) estimates that approximately 88% calf crop is weaned per cows exposed to bulls.

Annual variable forage costs are the custom harvesting rates. The rate of cutting forage for hay is $14.79 per acre and the cost to bale forage is $10.72 per bale (Saskatchewan Agriculture and Food 2006b deflated to 2004). Each bale is assumed to way 1,600 pounds.[49]

5.4.2 Livestock Energy Requirements and Energy from Various Feed Sources

Energy is required to produce milk and to initiate and maintain pregnancy, making energy the most important nutritional requirement of a beef cow (Alberta Agriculture and Food 2000). Nutrient requirements for a beef cow are divided into three periods: 1) early pasture (May to July), 2) late pasture (August to October), and 3) winter (November to April). The energy required in early pasture, late pasture, and winter is 3,009, 2,313, and 5,719 mega calories (Mcals) per cow respectively based on the data presented in Table 5.10.

Table 5.10: 1,300 lb beef cow Energy requirements as predicted by CowBytes©

Month	Mcals Per Day	Mcals Per Month
Jan	29.52	915
Feb	31.5	882
Mar	38.6	1197
Apr	39.6	1188
May	36.52	1132
June	32.5	975
July	29.12	903
Aug	26.91	834
Sept	25.68	770
Oct	22.86	709
Nov	25.27	758
Dec	25.14	779

Source: Marx (2005)

A bull requires an equivalent of 1.23 times the daily forage consumption of a 1,300 lb cow (Based on Manske 1998) and therefore has the following energy requirements 3,701, 2,845, and 7,034 mcals in early pasture, late pasture, and winter respectively. Given this information, bull feed requirements are combined with cow energy requirements giving a total cow requirement of 3,157 for early pasture, 2,426 for late pasture, and 6,000 for winter.[50]

[49] This is required when calculating variable cost based on volume and for transportation.
[50] This is given that 1 bull breeds 25 cows.

Sources of forage include natural pasture, seeded pasture, and hay. Seeded pasture and hay are a mix of alfalfa and grass. Natural grass has a energy content of 1933 mcals per ton and in the alfalfa grass mixture has an energy content of 2196 mcals per ton (Alberta Agriculture and Food 2003). About twenty percent of hay feed is wasted (Alberta Agriculture and Food 2004a) and pasture efficiency is 50% to account for waste (Nielsen 1997). It is also assumed that any early pasture saved for late pasture grazing deteriorates by 40%.[51] The pasture stocking rate is set at 65% of the maximum that is expected yields to ensure an adequate summer pasture supply in years of low forage yields.

5.4.3 Forage Establishment and Breaking Costs

Forage establishment cost includes seeding and spraying machine operations as well as seed, fertilizer, and herbicide costs and breaking cost at the end of the production cycle (table 5.11). The total seeding cost in the first year is $50.17 per acre and in last year, the breaking cost is set at $14.06 per acre. It is assumed that a forage rotation lasts 7 years.[52]

Table 5.11: Forage Seeding and Breaking Cost for the Dark Brown Soil Zone

Seeding Cost	$/Acre
20-Foot air disk drill and tractor (custom hired)	$ 13.24
Spraying (twice)	$ 2.61
1 litre glyphosate	$ 8.66
Annual weed control - .36 litre 2 4-D	$ 2.95
Alfalfa seed (4 lb/acre)	$ 7.33
Meadow bromegrass (5 lb/acre)	$ 12.73
Ferrtilizer (15 lb Phosphorus/acre)	$ 4.12
Total Seeding Cost	$ 51.64
Breaking Cost	
20-foot Tandem Disc twice (custom hired)	$ 14.32
Total Breaking Cost	$ 14.32

Source: Saskatchewan Agriculture and Food (2003) deflated to 2004

[51] Henning and Wheaton (1993) state that delaying hay harvest by only 10 days causes a 20% loss in hay value due to over maturity. A 40% loss is therefore chosen as the delay is likely more than 10 days past the optimal harvest period.
[52] This is consistent with the use of an 8 year rotation by Saskatchewan Agriculture and Food (2003) and a 6 year rotation by Manitoba Agriculture, Food, and Rural Initiatives (2007) when estimating cost of production.

5.4.4 Forage Reserves and Transaction Fee

A forage reserve is required and ranges between 5% and 30% of annual requirements. If hay inventories exceed 30% of their annual requirement, hay is sold until inventories are to a level of 15% of their annual requirement. A transaction cost is incurred of $15 per ton on all hay sales. If hay inventories are insufficient to meet demands, hay is purchased until inventories are equal to 5% of their annual requirement. Stored hay deteriorates by 6% a year.[53]

5.5 Transportation Costs

Transportation costs include the cost of moving grain and hay from the field to the farmstead. Grain trucking transportation cost is set at $0.13 per bushel for the first mile and $0.014 per bushel for each additional mile (Saskatchewan Agriculture and Food 2006b deflated to 2004). Hay transportation cost is set at $3.98 per bale for the first mile and $0.92 per bale for each additional mile (Based on Saskatchewan Agriculture and Food 2006b).

5.6 Hired Labour Costs

Labour is supplied by the farm family, full time hired labour, and part time hired labour. It is assumed that the farming unit can supply 1.5 labourers and the remaining labour must be hired. At specific sizes, farms hire full time employees (table 5.12) with an assumed salary of $40,000, which is constant throughout the simulation. Based on the man power required for the machine option, family labour and full time employees, plus the work rate of the machine options, the hours of part time labour per acre of crop land is calculated. Part time labour is hired for $15 per hour.

[53] This is consistent with Alberta Agriculture and Food (2002) who state that hay stored outside in horizontal rows end to end had a total feed loss of 6.4% over a 16 month period.

Table 5.12: Crop Enterprise Hired Labour

Machine Option	Max Size (acres)	Labour Required Seeding (Men/Hr)	Seeding Rate (Ac/Hr)	Labour Required Harvest (Men/Hr)	Harvest Rate (Ac/Hr)	Family Labours	Full Time Labours Required	Part Time labourers Seeding (Men/Hr)	Part Time Labour Harvest (Men/Hr)	Part Time Hired Labour Seeding (Hrs/Ac)	Part Time Hired Labour Harvest (Hrs/Ac)	Total Part Time Hired Labour Option (Hrs/acre)
Option 1	500	0	0	0	0	1.5	0	0	0	0	0	0
Option 2	982	1.5	13.09	2.5	9.70	1.5	0	0	1	0	0.103	0.103
Option 3	2,000	1.5	17.45	2.5	9.70	1.5	0	0	1	0	0.103	0.103
Option 4	3,200	1.5	21.82	2.5	14.55	1.5	0	0	1	0	0.069	0.069
Option 5	3,900	1.5	26.18	2.5	17.45	1.5	1	0	0	0	0.000	0.000
Option 6	7,800	3	52.36	5	34.91	1.5	1	0.5	2.5	0	0.072	0.081
Option 7	11,700	4.5	78.55	7.5	52.36	1.5	2	1	4	0	0.076	0.089
Option 8	15,600	6	104.73	10	69.82	1.5	2	2.5	6.5	0.024	0.093	0.117
Option 9	19,500	7.5	130.91	12.5	87.27	1.5	3	3	8	0.023	0.092	0.115
Option 10	23,400	9	157.09	15	104.73	1.5	3	4.5	10.5	0.029	0.100	0.129
Option 11	27,300	10.5	183.27	17.5	122.18	1.5	3	6	13	0.033	0.106	0.139
Option 12	31,200	12	209.45	20	139.64	1.5	3	7.5	15.5	0.036	0.111	0.147
Assumes need 1.5 labours per seeder and 2.5 per combine												

Both the crop and cow enterprises incur a hired labour cost. Crop hired labour cost is based on a cost per full time hired man and a cost per acre of crop land. Hired labour is based on the machinery sizing option. It is assumed that for each seeder requires 1.5 labourers and each combine requires 2 labourers. During seeding, 1 labourer is required to operate the machine and 0.5 labourer are required to haul seed and fertilizer and perform other miscellaneous tasks. For each combine, 1 labourer is required to run the combine and the other is required for hauling grain.

It is assumed that hired labour for livestock production is only required during the calving period, which lasts approximately 60 days. One hired labourer is required for every 300 cows and the family supplies the labour for the first 300 cows. This labour is also paid $15 an hour and works a 10 hour day.

5.7 Retirements and Farm Transfers

In the simulation, farm operators can retire after they reach an age of 55 years. The probability of a farmer retiring increases with the farm operators age, with all farmers who hit 80 years old forced to retire (table 5.14).

Table 5.13: Probability of Farm Exits by Farm Operator Age

Age	5 year period	Annual Probability of Exit
55-59 years	25%	6%
60-64 years	40%	10%
65-69 years	64%	18%
70 years and over		30%
80 years		100%

Source: Freeman (2005)

In the simulation, it is assumed that 95% of financially viable farms will be taken over by a farming child. When transferring the farm, the minimum amount that is required for the exiting farmer's retirement is set at $500,000.[54] Any equity the farm has in excess of this the minimum retirement amount is transferred at a rate of 20%.

Farms that are transferred are assigned a random probability that they will generate off farm income based on the size of the operation. This remains fixed over the simulation time period (see table 5.13). The level of off farm income is randomly assigned according to a normal distribution with a mean of $50,934 and a standard deviation of $36,493. Incoming farms have existing savings according to a normal distribution with a mean of $50,000 and standard deviation of $10,000. This is to account from any employment activities that the incoming farmer may have taken prior to entering the agricultural industry.

Table 5.14: Probability of Off Farm Employment by Farm Size

Total Farm Size (Acres)	Probability Off Farm Employment
0 - 640	100%
640 -1280	85%
1280 - 1920	75%
1920 - 3200	50%
3200 and over	40%

5.8 Family Living Withdrawal

Family living withdrawal is set at a minimum of $26,228, which marks the poverty line for a 4 person family living in rural areas of Canada (Canadian Council on Social Development 2002

[54] This will provide the retiring farmer $40,293 per year for the next 30 years, assuming a 7% growth rate on the investment.

inflated to 2004). The propensity to consume from annual net cash flow before investment is 50% with a maximum annual family withdrawal of $125,000.

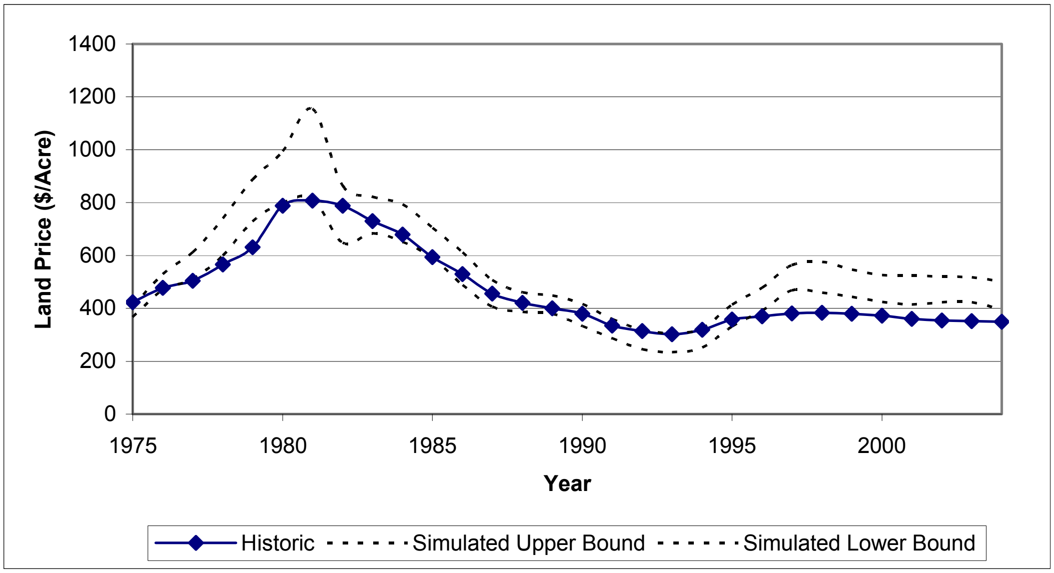
5.9 Model Validation

Validation is concerned with determining if the simulation is a good model of the target (Gilbert and Troitzsch 2002). It is inherently difficult to validate a forecasting model. In this case, the model can be partially validated based on comparisons of historic land prices and simulated land prices. Historic 1975 to 2004 output prices and yields are inserted in to the model and farmland prices tracked. This is a reasonable test as land markets are the major source of agent interaction; land bids are a complex process based on expected income and financial constraints and the auction mechanism is also complex and an integral part of the model. Note that the validation is necessarily incomplete as the model initial structure is based on 2004 and not past data. Each simulation replication can have a different result due to random components of the model.

Unfortunately, historic CAR 7B farmland prices are unavailable and comparisons must be based on provincial averages. Moreover, historic land values include buildings where the simulated land value does not. Land values are also influenced by cost structures, off farm employment, initial farming population, taxes, and non-farming investors, factors that may not be the same in the 1975 as in 2004, the year for which the model is initialized.

In the following comparison, the intent is not to directly assess the model's ability to track historical prices, but rather to try to replicate the peaks and valleys and turning points of historical data. In figure 5.1, a 90% confidence interval is compared to historical price data. The simulation captures the turning points of the land price. Overall, the simulated values tend to over react, with simulated land prices higher when the land prices are increasing and lower when they are decreasing compared to the historic value.

Figure 5.2: Historic Land Prices and Simulated Land Prices



Source: Saskatchewan Agriculture and Food (2007a)

A Kruskal-Wallis non-parametric test is preformed to identify if the average simulated land price is from the same general distribution as historic land prices. The test results in a p-value of 0.1393 and therefore the null hypothesis that they are from the same general distribution cannot be rejected at the 10% significance level. Upon inspection, the simulation appears to capture the trends and turning points in the historic land prices and also the results of the Kruskal-Wallis test allow it to be accepted that the model is functioning properly.

5.10 Summary

In this simulation exercise, farms are endowed with different characteristics, such as 1) quantity and quality of land, 2) financial characteristics, 3) preferences, 4) age, and 5) off farm income. Farms seek to maximize profits and interact via land market purchases and leases. Price and yield time paths are created using historical data combined with a bootstrap resampling procedure. The model is initially validated by comparing simulated land values to historical values. It is concluded that the model captures data trends and turning points accurately and is therefore functioning well as a simulation exercise.

Chapter 6
Results

6.0 Introduction

This chapter presents the results of potential structural change that can occur within the Base Scenario. In addition to the Base Scenario, two alternative scenarios are identified and the structural outcomes evaluated.

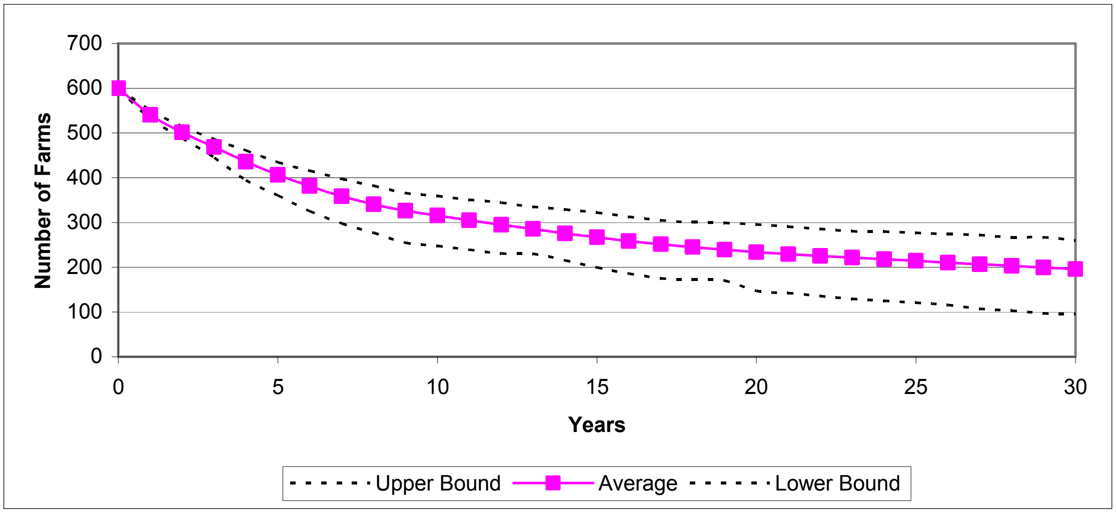
6.1 Simulation Results: Base Scenario

Under the Base Scenario, 100 price and yield time paths are simulated, as outlined in Chapter 4. Each time path consists of 30 simulated years of production, management decisions, and land markets, and each has a unique price and yield time path based on the process described in section 5.2.

6.1.1 Farm Numbers, Type, and Average Size

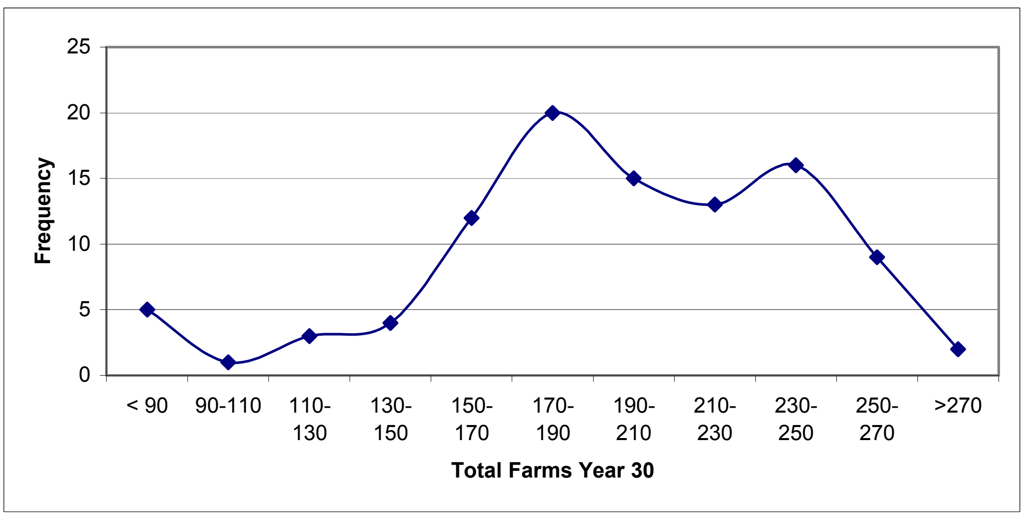
Historically, farm numbers have declined over time, leading to fewer but larger farms. In this simulation, these trends are projected to continue into the future as farm numbers decrease at a decreasing rate (figure 6.1). Averaging the 100 time paths shows that 196 farms remain; this is a 67% reduction and represents a 3.67% annual decline in farm numbers. The 90% confidence interval (CI90) for farm numbers expands through time passes because the price and yield time paths have a major impact on the number of farms that remain in the industry. At the end of the 30 year period, the lower bound of the CI90 is 95 and the upper bound 260 farms, corresponding to an annual decrease of 5.96% and 2.75%, respectively.

Figure 6.1: Simulated Farm Numbers (Base Scenario)



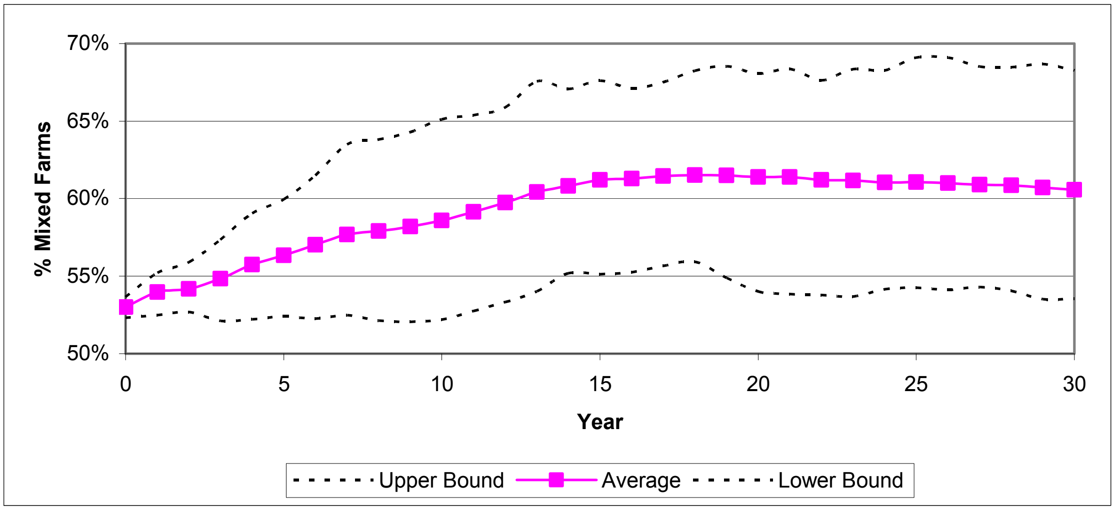
At the end of the simulation, 76 time paths result in total farm numbers between 150 and 250 farmers. There are 11 time paths that result in total farm numbers greater than 250 and 13 time paths that have fewer than 150 farms.

Figure 6.2: Simulated Distribution of Final Farm Numbers (Base Scenario)



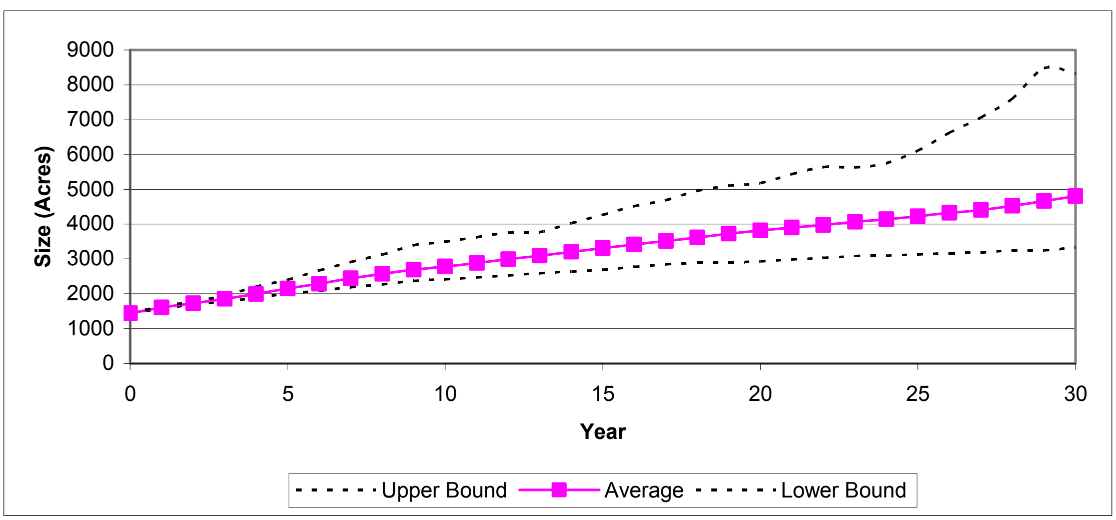
Mixed farms use all the land available to them in the highest and best use, therefore increasing the likelihood of their survival relative to grain farms (figure 6.3). This is evidenced in the simulation by the increasing proportion of mixed farms over time. On average, the proportion of mixed farms in the simulated sample increases from 54% to 61% by year 14, after which it remains relatively constant.

Figure 6.3: Simulated Proportion of Mixed Farms (Base Scenario)



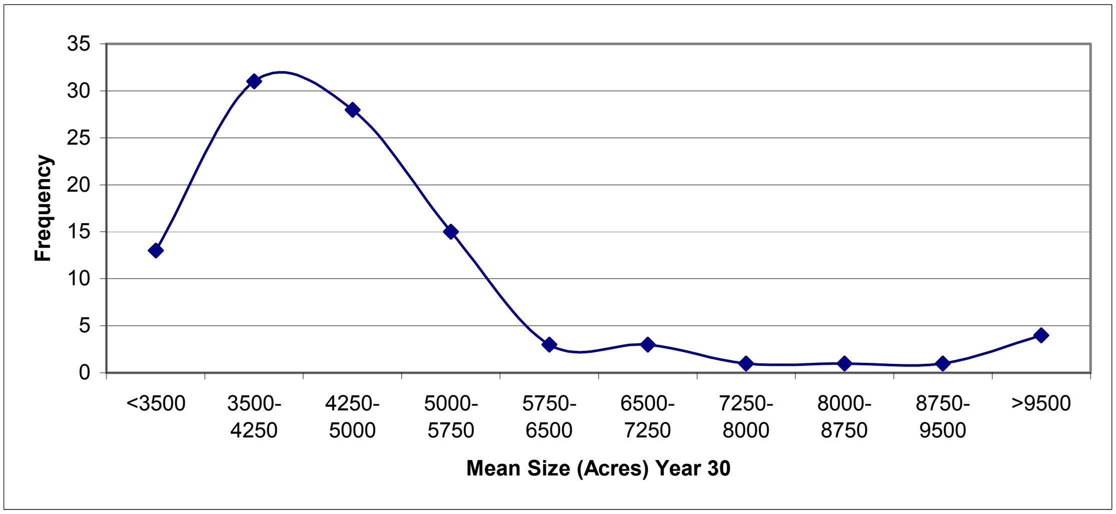
Land from the exiting farms is acquired by the remaining farmers, increasing average farm size (figure 6.4). At the end of the simulation, the mean farm size increases approximately 3.3 times more than the initial mean size, farm of 1,445 to 4,805 acres. Again, the CI90 broadens over time. At the end of the simulated period the CI90 upper and lower bounds are 8,324 and 3,336 acres, respectively.

Figure 6.4: Simulated Mean Farm Size (Base Scenario)



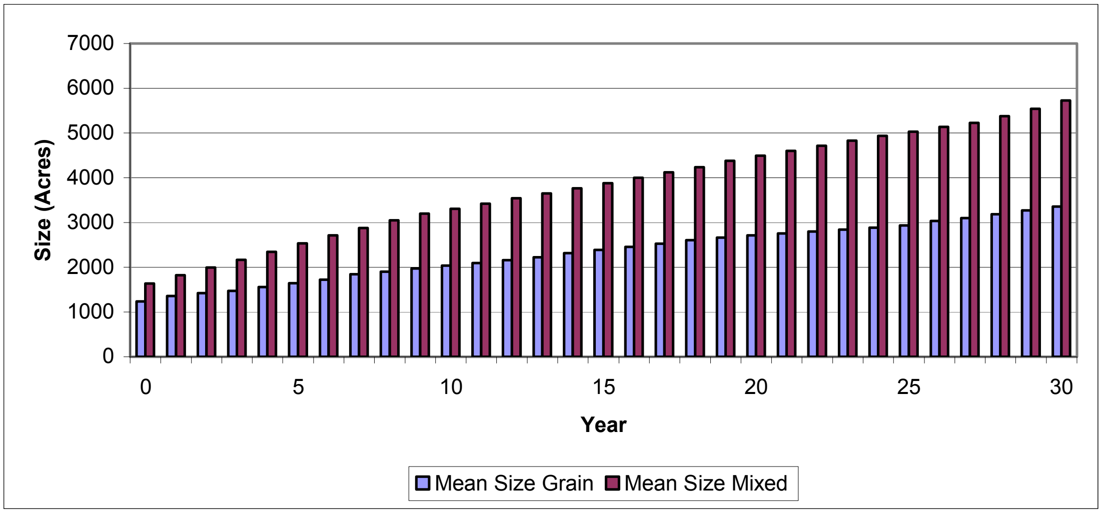
The distribution of final mean farm size has a long tail, with 74 time paths resulting in a mean farm size between 3,500 and 5,750 acres. There are 13 time paths that end with mean farm size less than 3,500 acres. The remaining 13 have a final mean farm size greater than 5,750 acres.

Figure 6.5: Simulated Distribution of Final Mean Farm Size (Base Scenario)



On average, mixed farms are more likely to expand than crop farms (figure 6.6). Mixed farms have a distinct bidding advantage on land due to the heterogeneous nature of many plots. The relatively large plot size used in the simulation means that many plots will contain some amount of non-arable land. This gives mixed farms a comparative advantage in that beef cows can best use non-arable portions. On average, mixed farms increased 3.5 times in size from 1,633 acres at initialization to 5,727 acres, while crop farms increased 2.7 times in size from 1,235 to 3,358 acres by the end of the simulation.

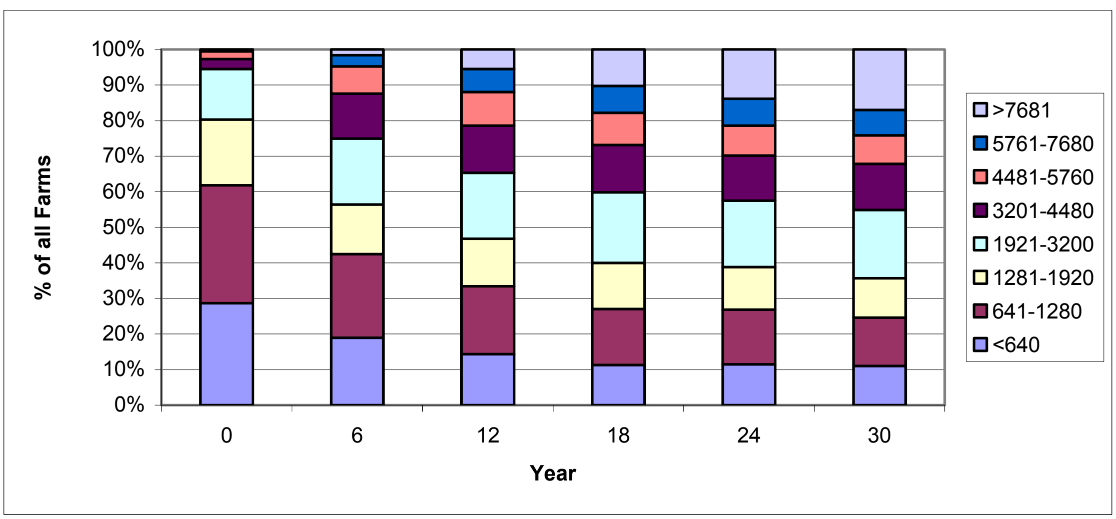
Figure 6.6: Simulated Mean Farm Size by Farm Type (Base Scenario)



6.1.2 Distribution of Farm Sizes

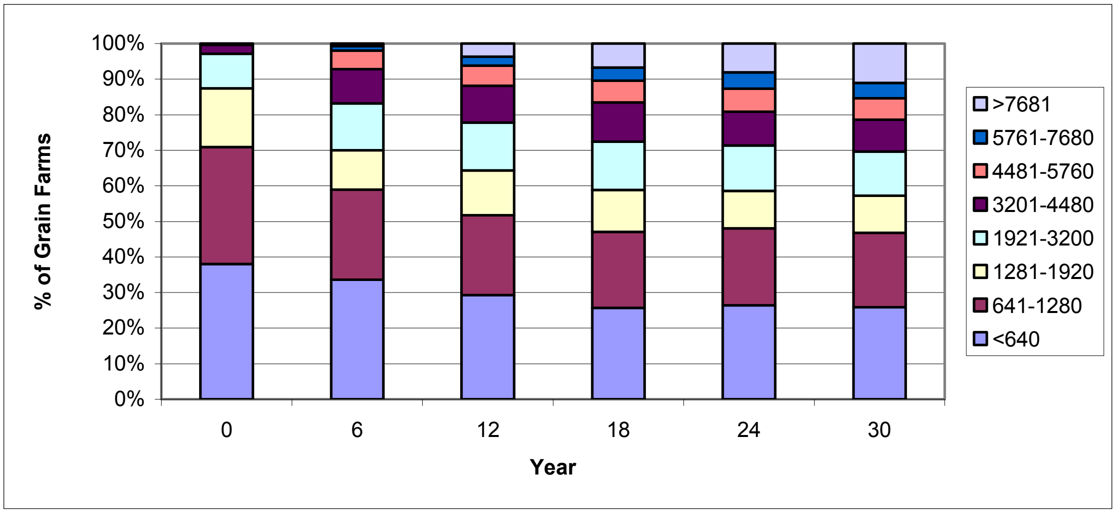
Farm size distribution changes considerably throughout the simulation period. At initialization, 62% of all farms comprise less than 1,280 acres; this amount decreased to an average of 25% by the end of the simulated period. The proportion of farms in the size category 1,281-3,200 acres remained relatively constant, changing from 33% at initialization to 30% at the end of the simulated period. However, there was a large change in the portion of farms greater than 3,200 acres, going from 6% to a final value of 45%.

Figure 6.7: Simulated Distribution of All Farm Sizes (Base Scenario)



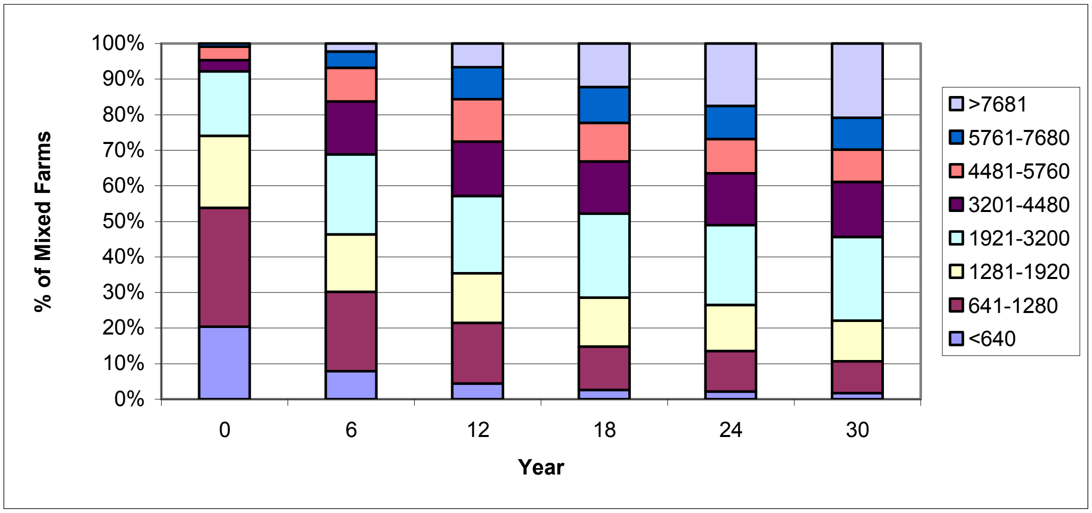
Grain farms distribution follows a similar trend to that of all farms, with the small farms ultimately being squeezed out of the industry, with the proportion of large farms increasing. At initialization, 71% of grain farms used less than 1,280 acres compared to 47% by the end of the simulated period. The proportion of farms greater than 3,200 acres increased from 3% to 30%, while mid sized grain farms fell slightly from 26% to 23% by the end of the simulated period.

Figure 6.8: Simulated Distribution of Grain Farm Sizes (Base Scenario)



Mixed farm distribution also follows a similar trend, with a change in the proportion of farms smaller than 1,280 acres in size decreasing dramatically from 54% at initialization to 11% by the end of the simulation. Farms greater than 3,200 acres in size became more dominant, increasing from 8% to 54%, while the proportion of mid size farms is relatively constant, decreasing from 38% to 35%.

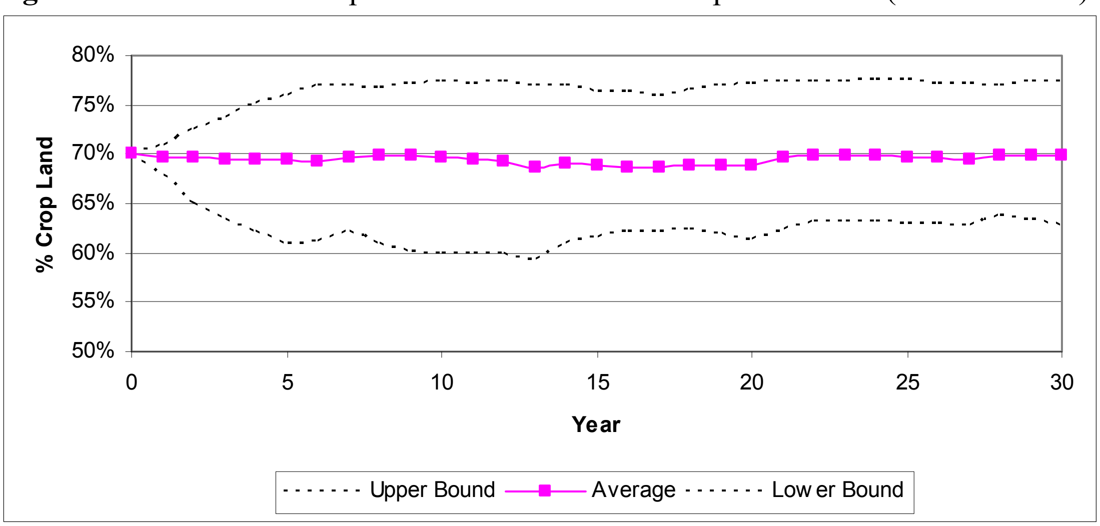
Figure 6.9: Simulated Distribution of Mixed Farm Sizes (Base Scenario)



6.1.3 Land Use, Total Livestock Numbers, and Average Herd Size

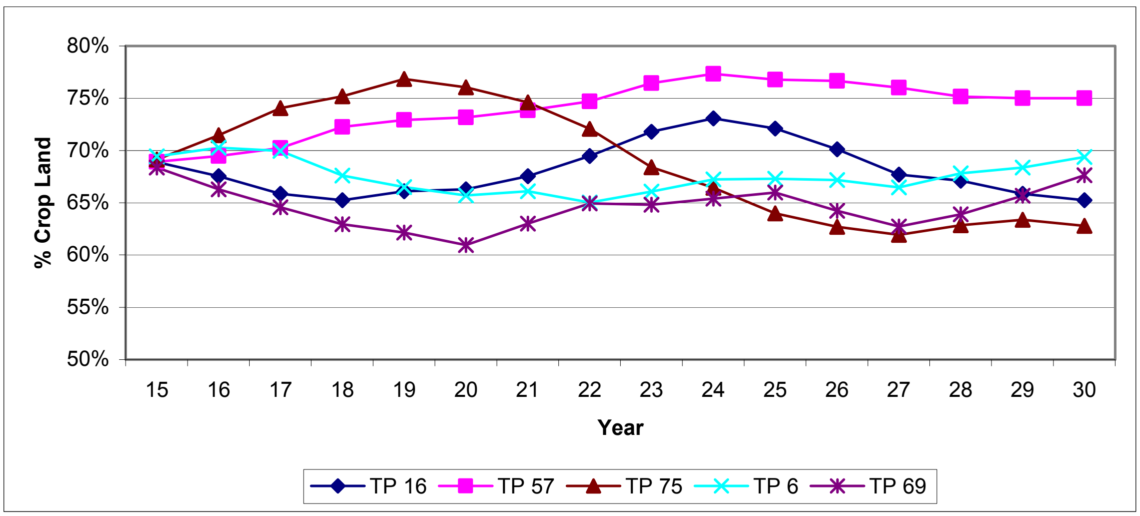
Land use is largely influenced by the time path of prices as well as the relative price between livestock and annual crops. As a result, the average percentage of land used in crop production remains relatively constant. There is a large band for the CI90, which emerges shortly after initialization and remains relatively flat throughout the simulation. The average proportion of land used in crop in the simulation is approximately 70%, while there is a 16% difference between the upper and lower bound for most of the simulated period.

Figure 6.10: Simulated Proportion of Land Used in Crop Production (Base Scenario)



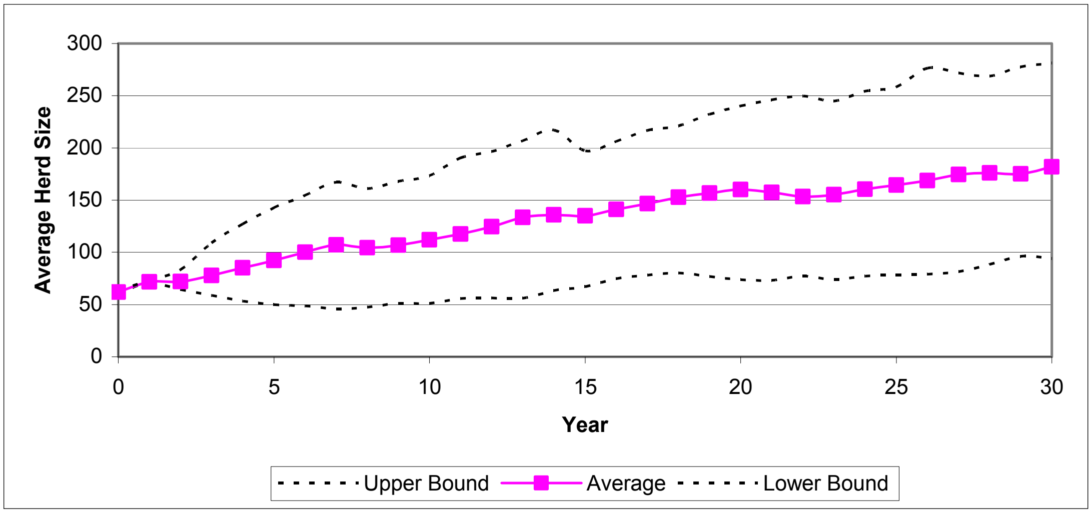
Over time the CI90 was expected to become larger, however as generated it remains relatively constant. To examine this situation further and see if the land use has reached an equilibrium value for each individual time path, 5 simulated time paths that contain approximately the same land use by year 15 are identified and plotted. In figure 6.11, note that the land use illustrated in each time path is not at equilibrium, but is in the process of adjusting to the current market conditions, i.e. the relative price of livestock to annual crops. This demonstrates that the bounds of CI90 for land use do not follow the same time path, but instead select from a different time path at different points in time.

Figure 6.11: 5 Simulated Time Paths of Proportion of Land Used in Crop Production (Base Scenario)



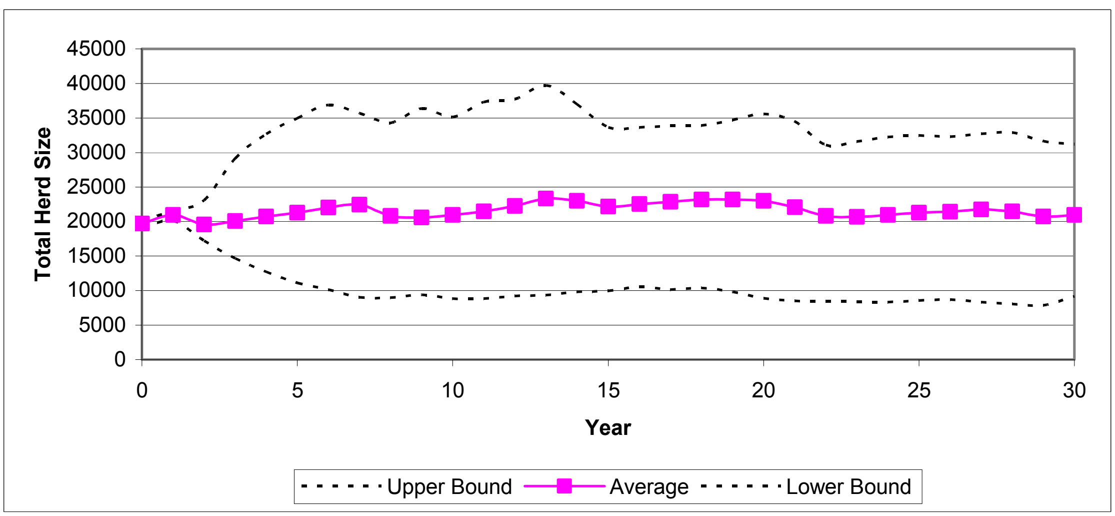
Next, the mean herd size of mixed farms in the simulation increases at a relatively constant rate from 62 to 182 head by the end of the time period. However, there is considerable variability caused by movements in the relative prices of livestock to annual crops. At the end of the simulation, the upper and lower bounds are found to be 281 and 94 head, respectively.

Figure 6.12: Simulated Mean Mixed Farm Herd Size (Base Scenario)



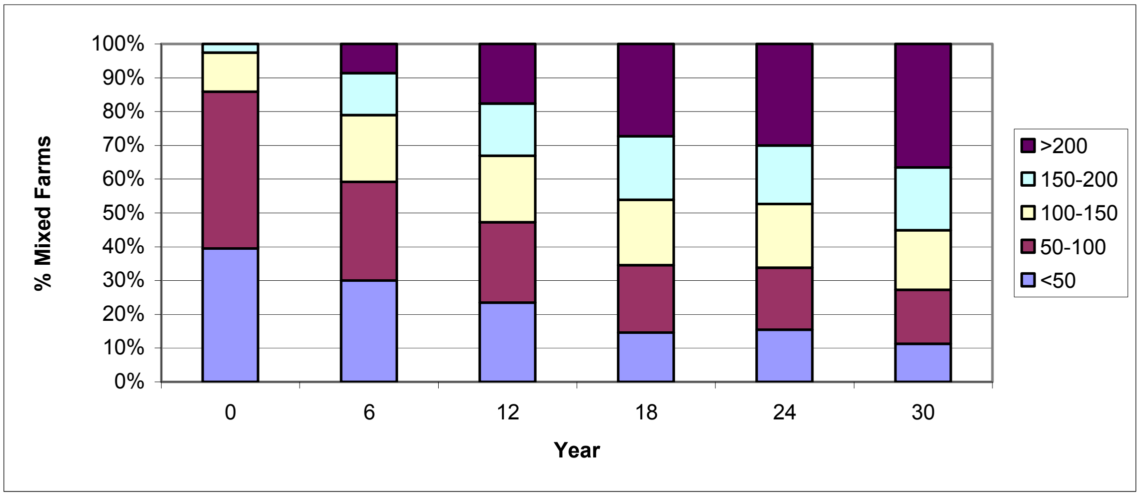
However, total mean cow numbers remain relatively constant, at approximately 20,000 head. The CI90 is large with a maximum simulated upper bound of 39,705 head and a minimum lower bound of 7,888 head. This is due to the proportion of land used in crop or pasture, and is therefore strongly dependent on the relative prices of livestock to annual crops.

Figure 6.13: Simulated Total Cow Herd Size (Base Scenario)



Herd size distribution follows a similar pattern to that of farm size. The proportion of large livestock herds (greater than 200 head) increased from zero at initialization to 37% at the simulation end. The proportion of mid sized herds (100-200 head) increased rapidly in the first 6 years from 14% to 32%, where after it remained relatively constant at approximately 35% of all livestock herds. The proportion of small sized herds (less than 100 head) decreased from 86% at initialization to 27% at the end of the simulation.

Figure 6.14: Simulated Distribution of Mixed Farm Herd Sizes (Base Scenario)



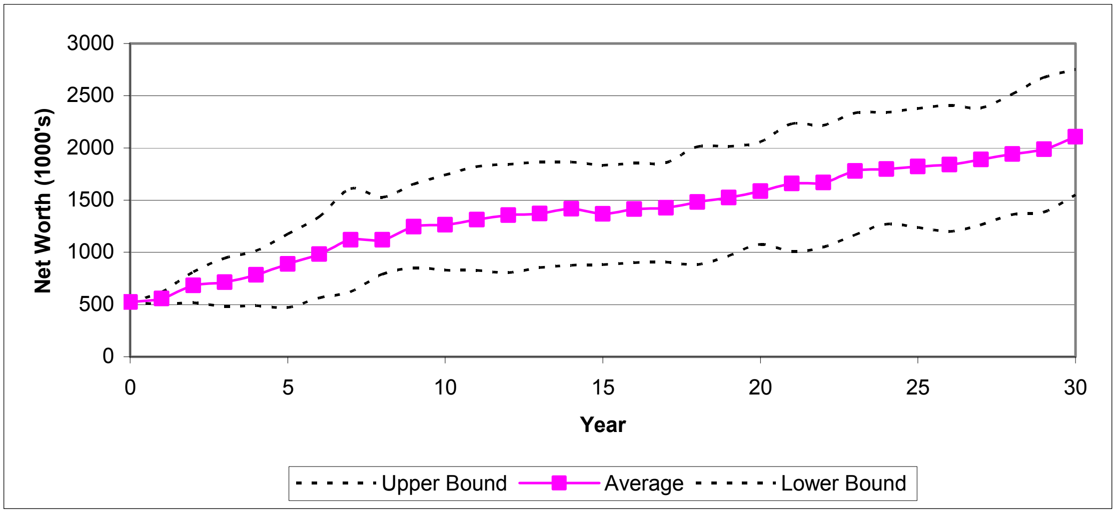
6.1.4 Financial Characteristics

The financial characteristics of the simulated farming agents are presented in the following section.

6.1.4.1 Farm Financial Characteristics

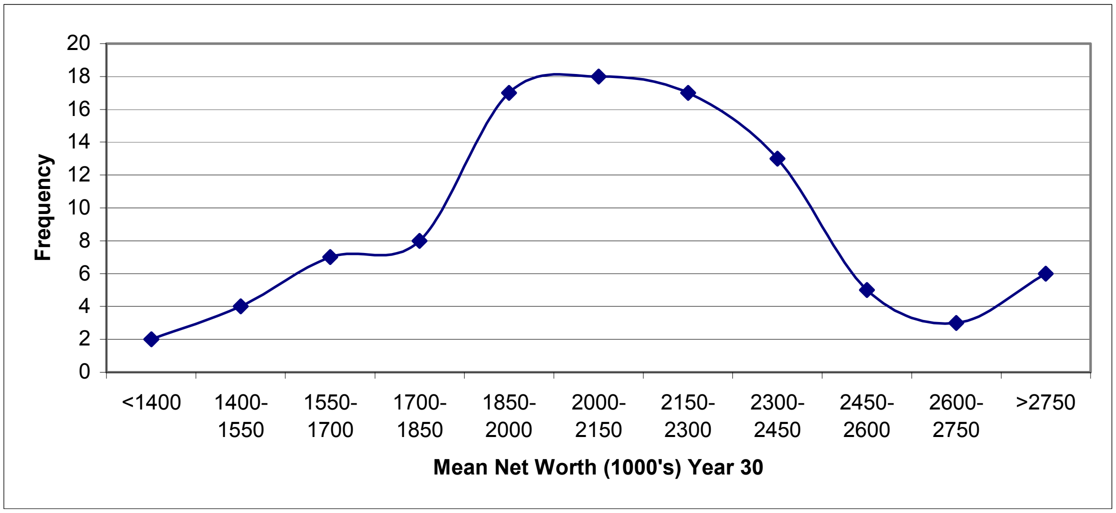
Mean farm net worth increased over time from a starting value of $523,000, to a final value of $2.107 million, with a CI90 of $1.203 million at simulation end. This is approximately a 4.75% annual increase. Variability is due to 1) variation in annual income from various prices and yields, 2) the indirect effect of income on farmland values, and 3) variations in farm size.

Figure 6.15: Simulated Mean Net Worth (Base Scenario)



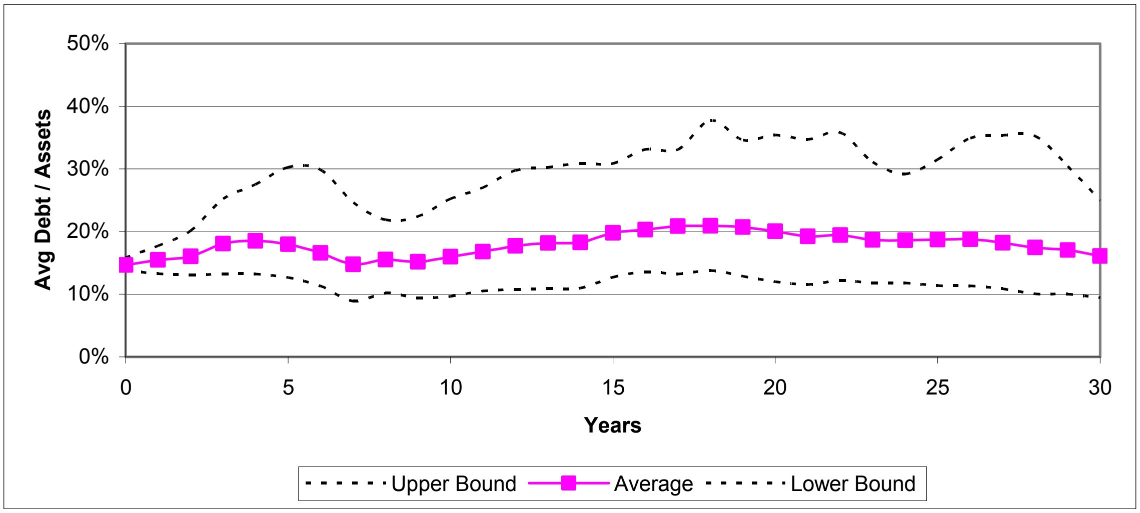
Mean net worth falls between $1.85 and $2.30 million in 52% of time paths. 21% of time paths end with a mean net worth below $1.85 million and 27% end at a value above $2.30 million.

Figure 6.16: Simulated Distribution of Final Mean Net Worth (Base Scenario)



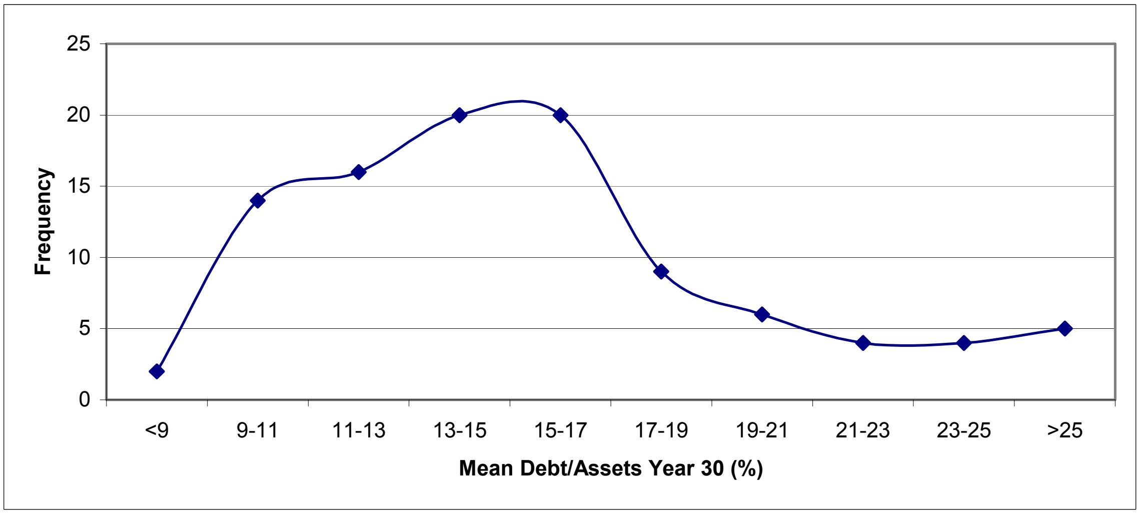
The mean farm debt to asset ratio (D/A) increased from 15% at year 0 to a level of 21% by year 17, where it then fell to a final value of 16%. It is likely that the initial increase is the result of increased borrowing for expansion by the remaining individuals as many farmers exit the industry in the early years. As observed with the other simulated variables, there is considerable variation in the average D/A, represented by a large CI90. This is again a result of the actual variation in land values and annual farm income.

Figure 6.17: Simulated Mean Debt to Assets (Base Scenario)



Mean D/A at the end of the simulation falls between 9% and 17% in 70 time paths. Final mean D/A has a long tail and is greater than 17% in 28 time paths, and less than 9% in only 2 time paths.

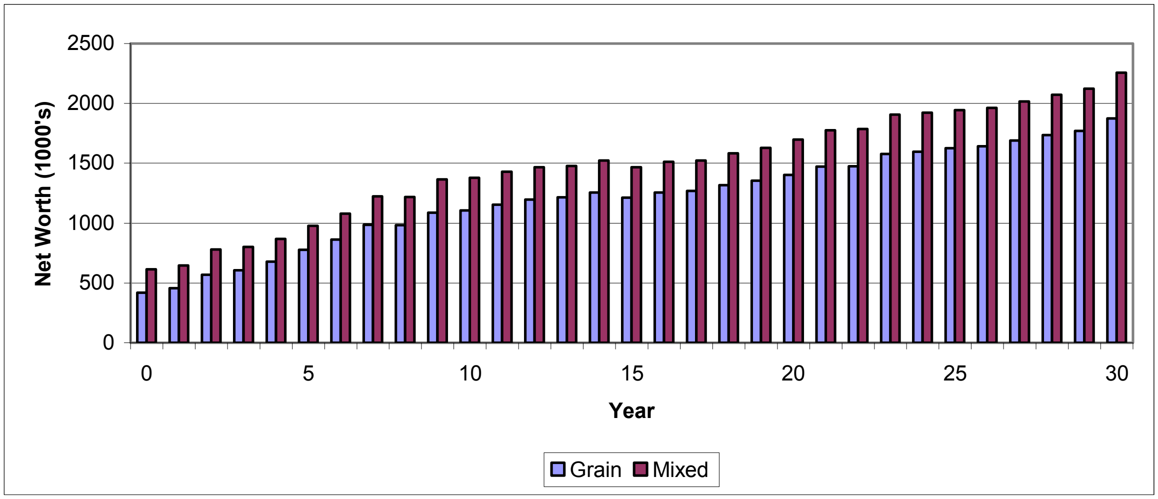
Figure 6.18: Simulated Distribution of Final Mean Debt to Assets (Base Scenario)



6.1.4.2 Financial Characteristics by Farm Type

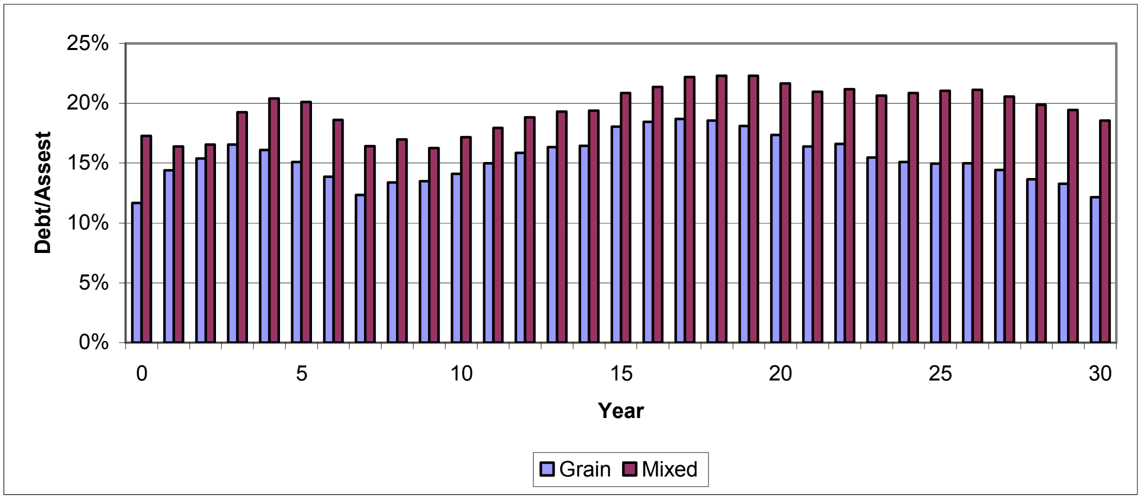
The simulated mean net worth for both mixed and grain farms follow the same trend, with mixed farmers always having a larger net worth. This is likely the result of these individuals using their land in the highest and best use, but is also due to their bidding advantage in land markets allowing their farms to expand at a more rapid pace.

Figure 6.19: Simulated Mean Net Worth by Farm Type (Base Scenario)



Again, the mean D/A follow the same trend for both farm types, with mixed farms always having a larger average D/A. This is again likely the result of mixed farms having a bidding advantage and therefore they are more likely to expand.

Figure 6.20: Simulated Mean Debt to Assets by Farm Type (Base Scenario)



6.1.5 Land Markets

Land markets are the main source of agent interaction. Land supply in the simulation comes from exiting farms and non-farming investors. Farm exits, land prices and lease rates, land tenure, and unmanaged land are explored in the following section.

6.1.5.1 Farm Exits

The farm exits decision occurs endogenously within the model and the majority of exits are the result of retirement and equity erosion from prolonged periods of negative cash flow. Retirement is the cause of an average of 47% of the farm exits. On average, equity erosion is the second largest cause of farm exits, generating 31% of the total exits. The least likely cause of farm exits is bankruptcy, leading to 22% of total exits.

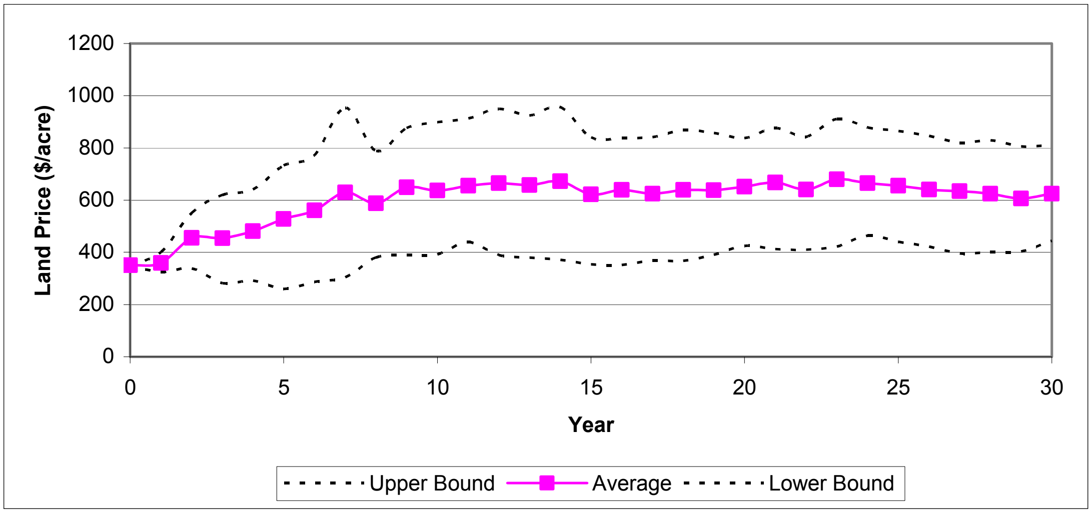
Table 6.1: Farm Exits by Exit Type (Base Scenario)

	Exit Type		
	Bankrupt	Equity Erosion	Retirement
Mean percentage of all exits	22.3%	30.5%	47.3%

6.1.5.2 Land Price and Lease Rate

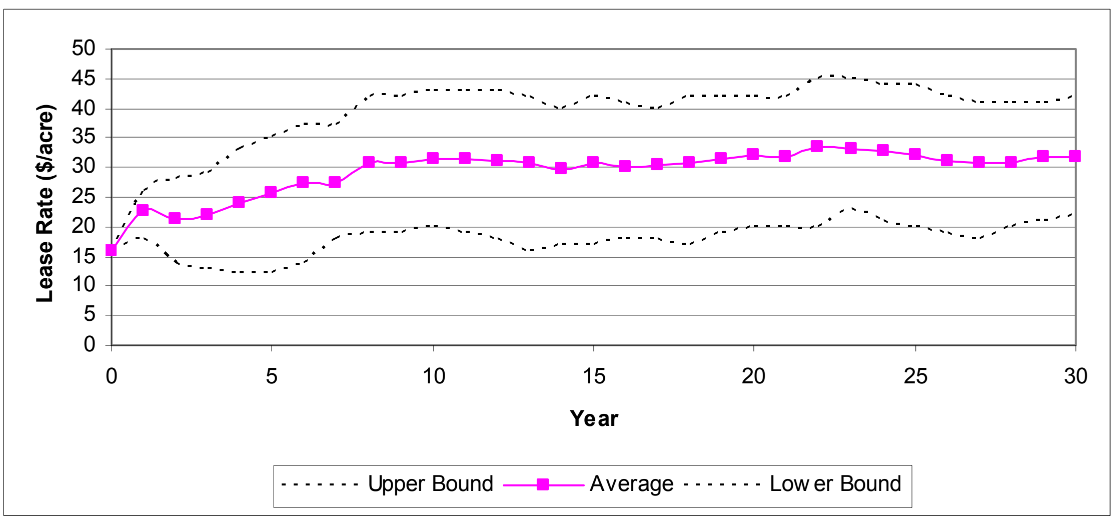
Land price varies noticeably depending on the price and yield time paths, and therefore has a large CI90. However, in the simulation on average land prices increase until year 7, and remain relatively constant afterwards at approximately $600 to $700 per acre. The CI90 range is $259 per acre to $956 per acre.

Figure 6.21: Simulated Land Price (Base Scenario)



The average lease rate follows the same trend and has a similar wide variation as land price. The average lease rate increases for 8 years in the base scenario and then remains relatively constant between approximately $30 and $35 per acre. The CI90 ranges from $12 per acre and to $45 per acre.

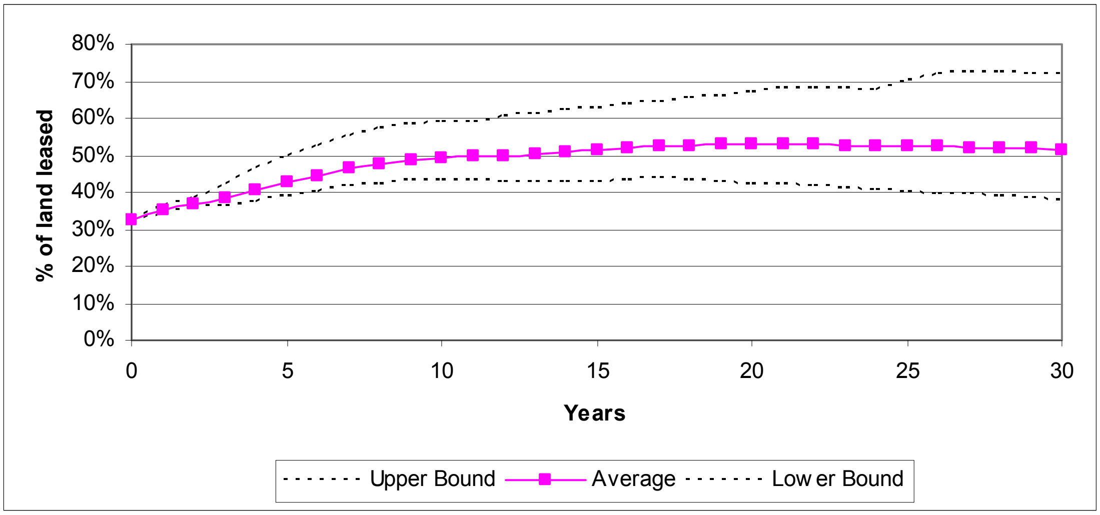
Figure 6.22: Simulated Land Lease Rate (Base Scenario)



6.1.5.3 Land Tenure

On average, the proportion of land leased increases for the first 18 years to approximately 53% and then remains relatively constant. There is however a large variation in the proportion of land under a lease agreement depending on the price and yield time path that occurs. At the end of the 30 year period, the CI90 has a range with an upper and lower bound of 72% and 38% leased land.

Figure 6.23: Simulated Proportion of Leased Land (Base Scenario)



6.1.5.4 Unfarmed Land

In 11 runs of the base simulations, at least one or more periods contained unfarmed land. This was predominantly the result of poor prices or yields, resulting in a large number of exits, while the remaining farmers where unable or unwilling absorb the exiting farmer's land. In 6 runs, the average portion of unfarmed land per year is less than 1% of all land. There is 1 run with an average portion of unfarmed land per year in each of the following groups: 1-2%, 2-3%, 7-8%, 12-13% and greater than 13%. The maximum average unfarmed land per year is 25.6%.

Table 6.2: Average Percentage of Unfarmed Land Per Year (Base Scenario)

Group	Runs
0%	89
0-1%	6
1-2%	1
2-3%	1
7-8%	1
12-13%	1
>13%	1

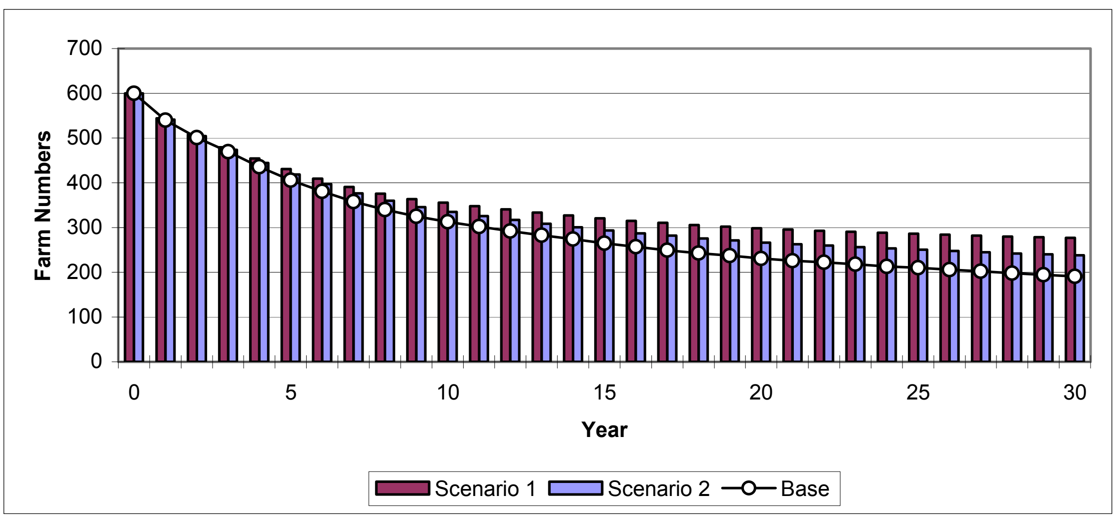
6.2 Simulation Results: Alternative Scenarios

Two alternative scenarios were simulated in addition to the Base Scenario. The first scenario represents a permanent structural shift in the grain markets (i.e. the introduction of biofuels), leading to a 25% increase in grain prices over the base. The second scenario represents a permanent shift in livestock markets resulting in a 25% increase in calf prices over the base. For each scenario, the appropriate prices are adjusted and the 100 yield and price time paths are simulated with all other elements of the model remaining unchanged.

6.2.1 Farm Numbers, Type, and Average Size

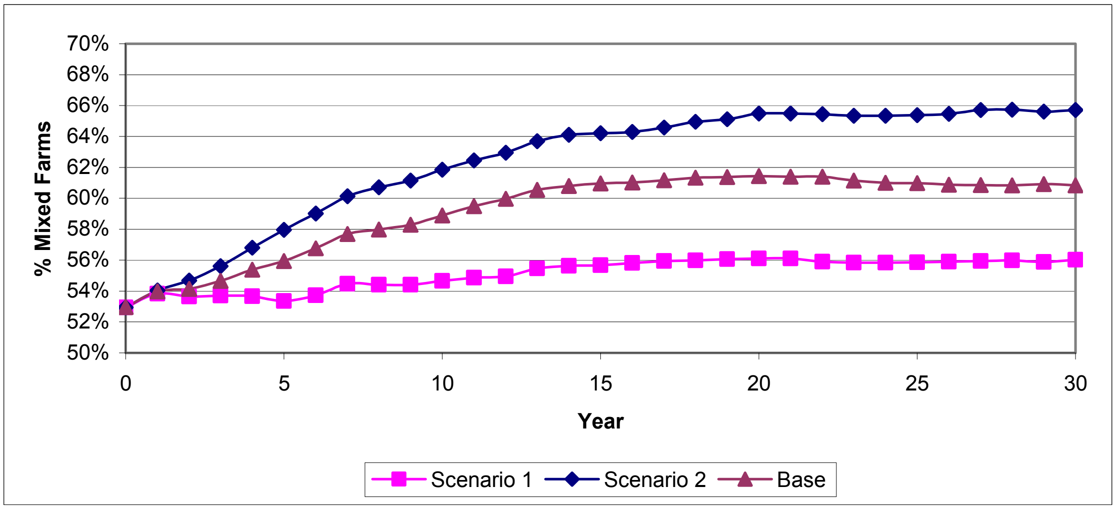
In both scenarios, farm numbers decline in a similar fashion as the Base Scenario. However, the rate of decline is lower as a direct result of increased annual income in both scenarios. Scenario 1 (grain prices are increased) resulted in the largest mean number of farms at the end of the 30 year period with an average of 277 compared to 238 in scenario 2 (livestock prices increased). The annual rate of decline under scenario 1 is 2.55% and for scenario 2 is 3.04%, both lower than the 3.67% generated in the Base Scenario.

Figure 6.24: Simulated Farm Numbers (All Scenarios)



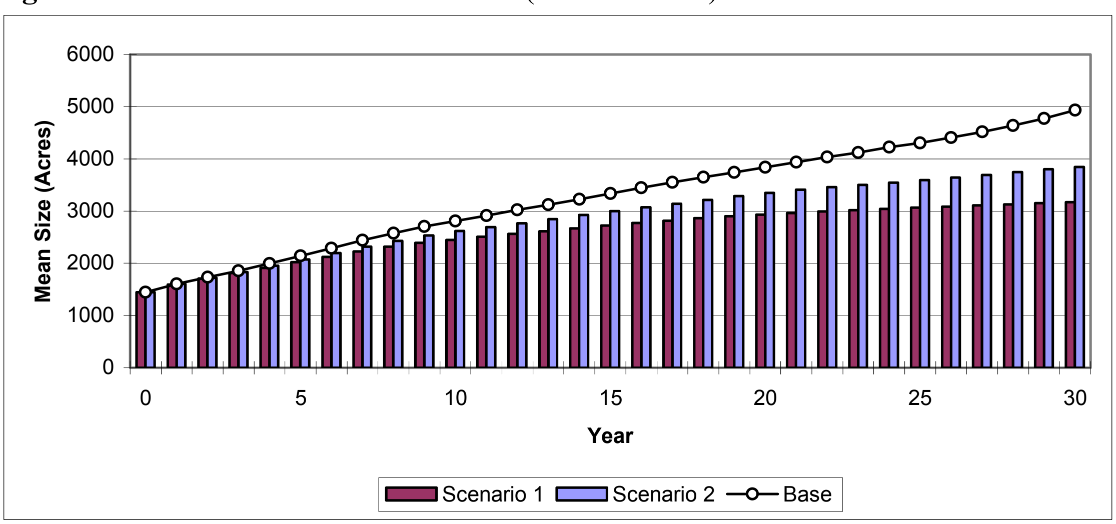
Once again, the proportion of mixed farms varies considerably depending on the relative price of grain to livestock. When grain prices are high relative to livestock (scenario 1) the proportion of mixed farms, on average, remains approximately constant at about 56%. The situation is very different when livestock prices are high relative to grain prices (scenario 2). The proportion of mixed farms, on average, increases to 65%, where after this it remains relatively constant.

Figure 6.25: Simulated Proportion of Mixed Farms (All Scenarios)



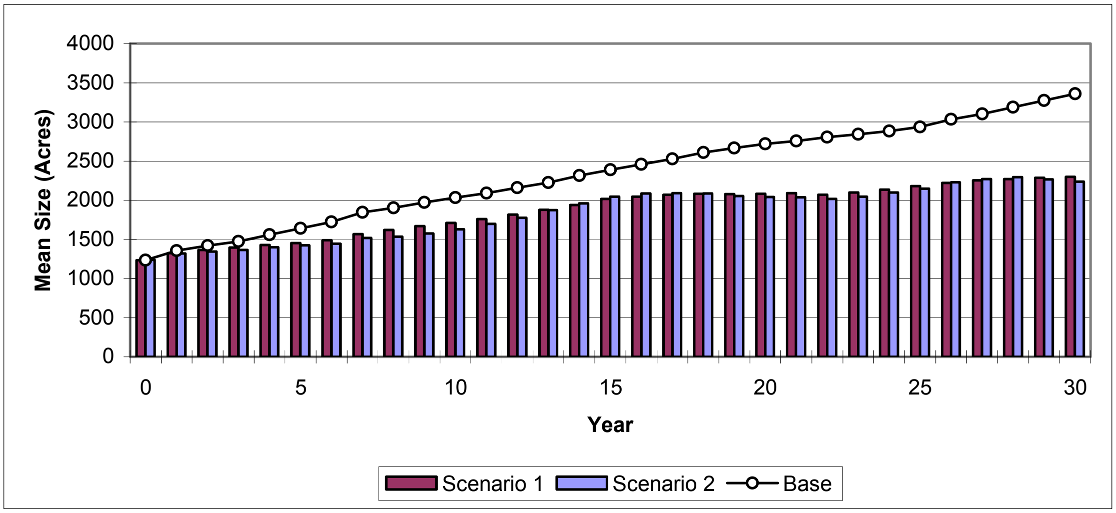
Average farm size is noticeably lower in the two scenarios relative to the Base Scenario. With higher grain prices, the mean farm size increased by 2.19 versus the size at initialization to an average of 3,172 acres, a value 64% the size found in the Base Scenario. The increase in livestock prices resulted in an average mean farm size increase of 2.66 times to 3,846 acres, which is 78% of the mean final farm size of the Base Scenario.

Figure 6.26: Simulated Mean Farm Size (All Scenarios)



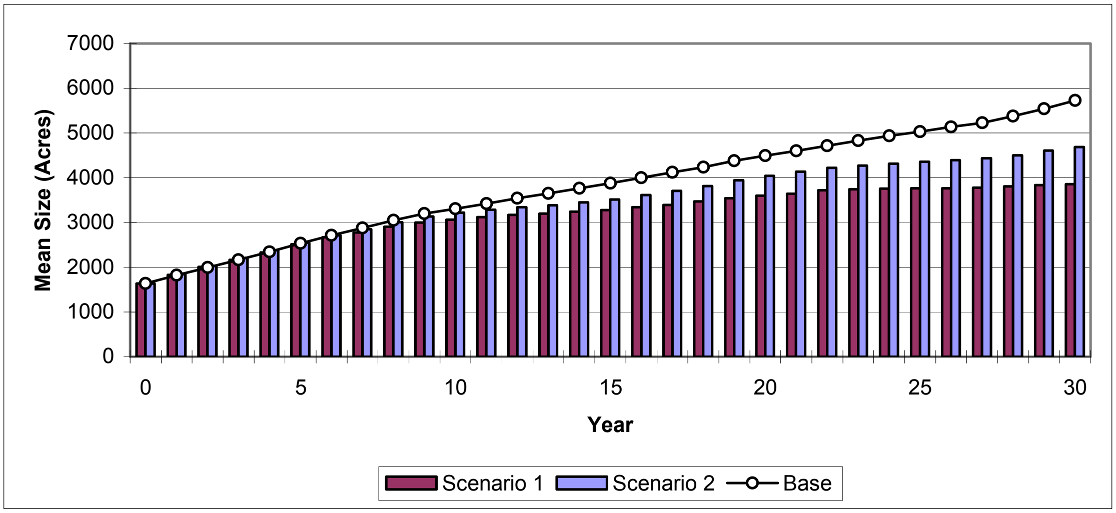
Mean grain farm size increased at almost the same rate under both scenarios, and both were lower than under the Base Scenario. With increased grain prices, mean grain farm size increased 186% over the initial value to 2,296 acres. When the livestock price was increased, the mean crop farm size increased 1.81 times to 3,358 acres. The final mean farm size for Scenario 1 and Scenario 2 were 68% and 66% of the Base Scenario mean farm size, respectively.

Figure 6.27: Simulated Mean Grain Farm Size (All Scenarios)



Under both alternate scenarios, average mixed farm size increased, again at a lower rate than under the Base Scenario. With an increase in grain prices, the mean final mixed farm size increased 2.36 times to 3,859 acres, and an increase in livestock prices increased the mean farm size 2.87 times to 4,683 acres. These figures represent 67% and 81% of the average final mixed farm size under the Base Scenario for Scenario 1 and Scenario 2, respectively. Under all scenarios, mixed farms are larger in size than grain farms.

Figure 6.28: Simulated Mean Mixed Farm Size (All Scenarios)



6.2.2 Distribution of Farm Sizes

Average farm size distributions under an increase in the grain price for all farm types are presented in figure 6.28. The proportion of farms smaller than 1,280 acres decreased 16% from 62% at initialization to an ending value of 46% of all farms. There are considerably more farms is this category than the Base Scenario, where at the end of the simulated period only 24% of farms were in this size category. There was a greater decrease in the proportion of mid sized farms (between 1,280 and 3,200 acres) than in the Base Scenario; only 25% of farms falling into this category under Scenario 1 versus 30% with the Base Scenario at the end of the simulation period. Similarly to the Base Scenario, there was growth in the larger sized farms (greater than 3,200 acres) to make up 29% of farms at the end of the simulation.

Figure 6.29: Simulated Distribution of All Farm Sizes (Scenario 1)

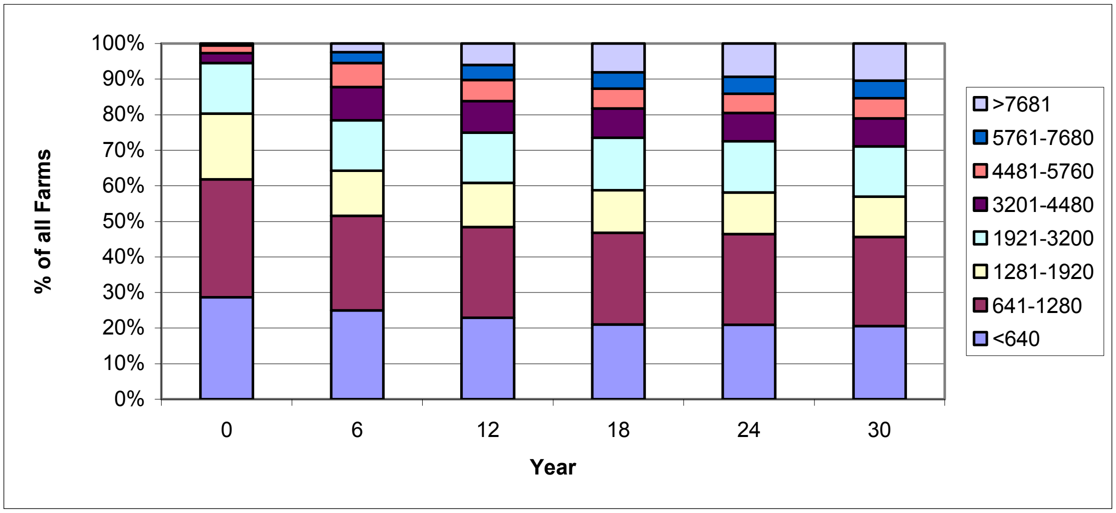
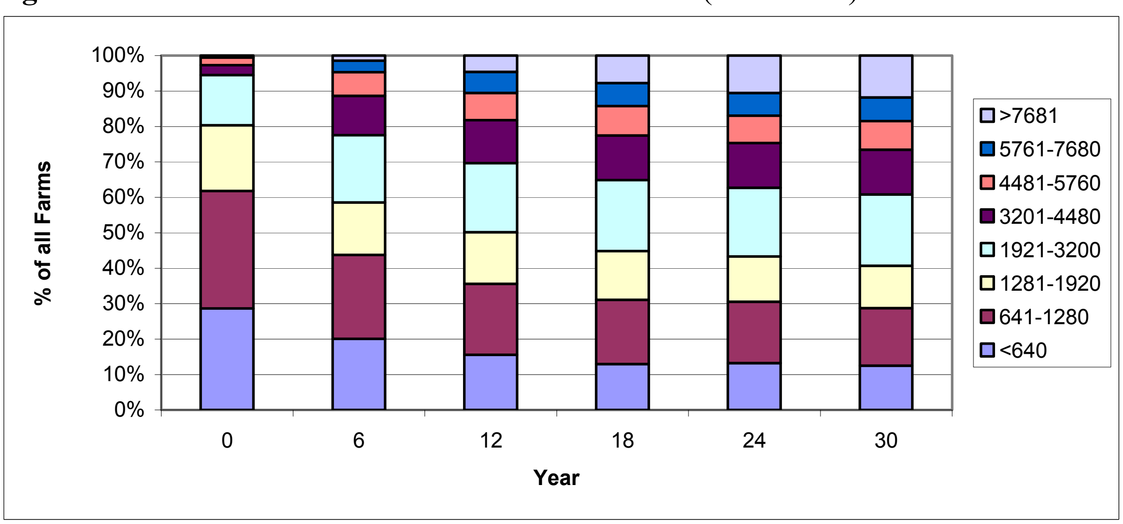


Figure 6.29 presents Scenario 2's average distribution of farm sizes, for all farm types. The distribution of farm sizes is similar to that under the Base Scenario, with a large decline in the smaller farms, a constant proportion of mid sized farms, and a large increase in the large sized farms. The proportion of farms with less than 1,280 acres decreased from 62% to 29% of all remaining farms at the end of the simulation. The proportion of farms of size between 1,280 and 3,200 acres decreased from 33% to 32% of all farms and farms larger than 3,200 acres increased from 6% to 39% of all farms at the end of the simulation.

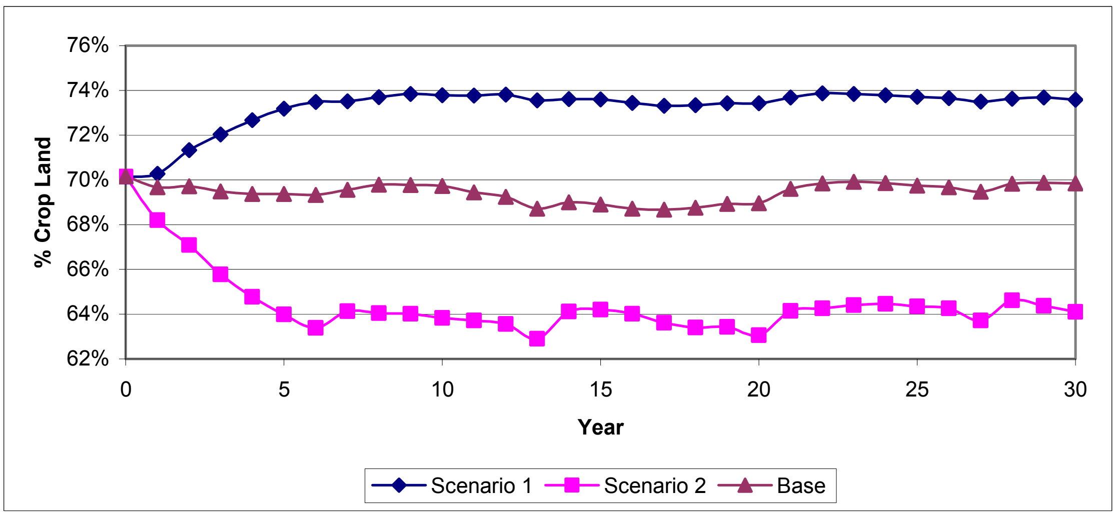
Figure 6.30: Simulated Distribution of All Farm Sizes (Scenario 2)



6.2.3 Land Use, Livestock Numbers, and Herd Size

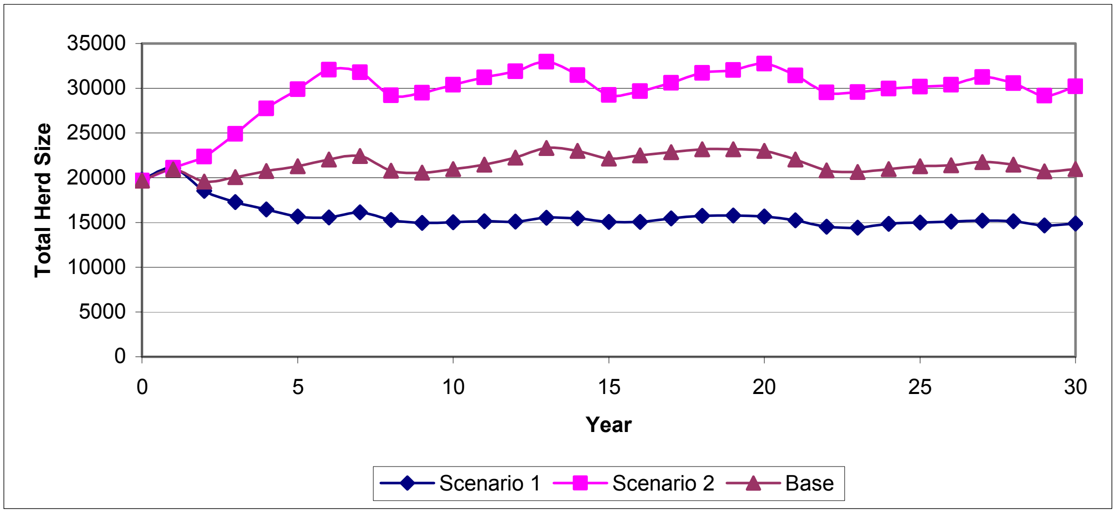
Land use is determined by the relative prices of grain to livestock and therefore it would be expected to vary considerably between the different scenarios. When grain prices increase, the average proportion of land used in crop production also increases and subsequently remained relatively constant at approximately 74%. When livestock prices increase, the average proportion of land used in crop decreases to approximately 64% and then remains relatively constant. Thus land use change shifts relatively quickly, within approximately 7 periods, and after this time it appears to have reached its highest and best use.

Figure 6.31: Simulated Proportion of Land Used in Crop Production (All Scenarios)



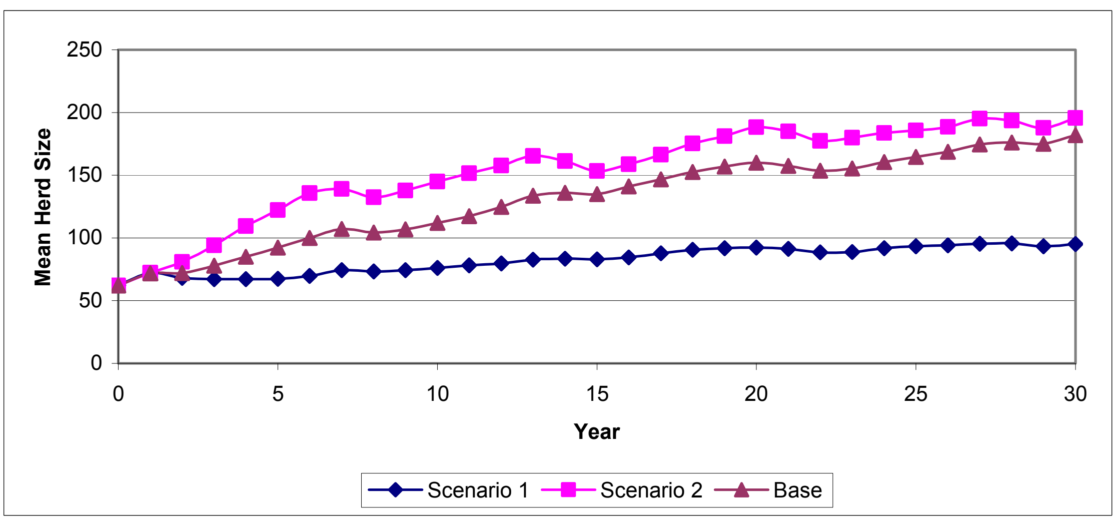
Mean total livestock herd size follows a similar, but mirrored pattern to land used in crop production. Under Scenario 1, mean total herd size decreases for the first few periods and then remains relatively constant. The opposite happens in Scenario 2: the mean total herd size increased for the first few periods and then remains relatively constant.

Figure 6.32: Simulated Mean Total Cow Herd Size (All Scenarios)



Although land use and livestock numbers remain relatively constant after only a few periods, the average herd size increases because there are fewer mixed farms. Under Scenario 1, average herd size increases over time but at a much slower pace compared to the Base Scenario. Under Scenario 2, more land is used as pasture, increasing the mean herd size at a slightly more rapid pace than the Base Scenario; the final mean herd size is 196 and 182 head per mixed farm in Scenario 2 and the Base Scenario, respectively.

Figure 6.33: Simulated Mean Mixed Farm Herd Size (All Scenarios)



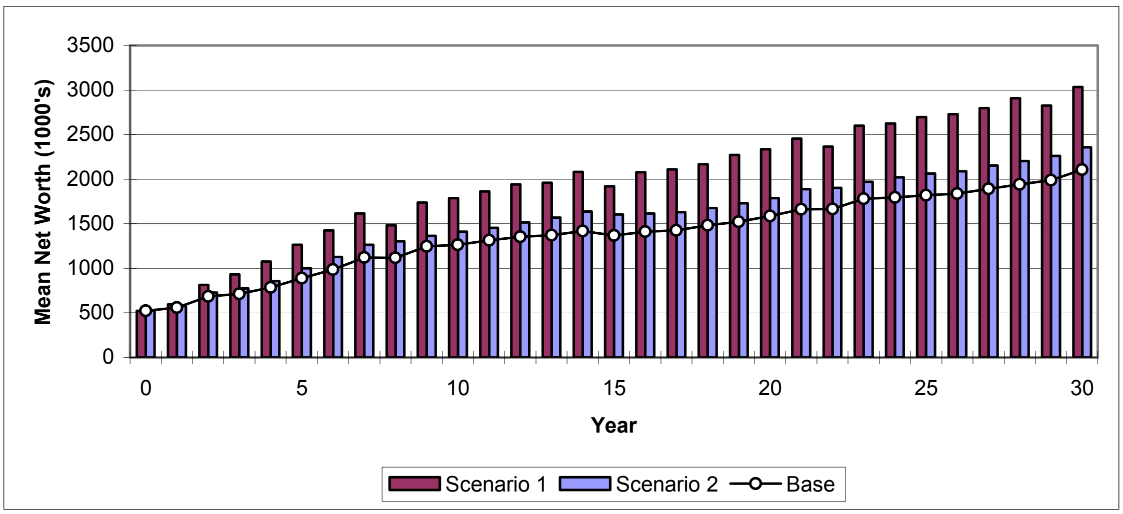
6.2.4 Financial Characteristics

In this section, the financial characteristics of farm all farm agents are presented for all scenarios and financial characteristics are compared by farm type.

6.2.4.1 All Farms Financial Characteristics

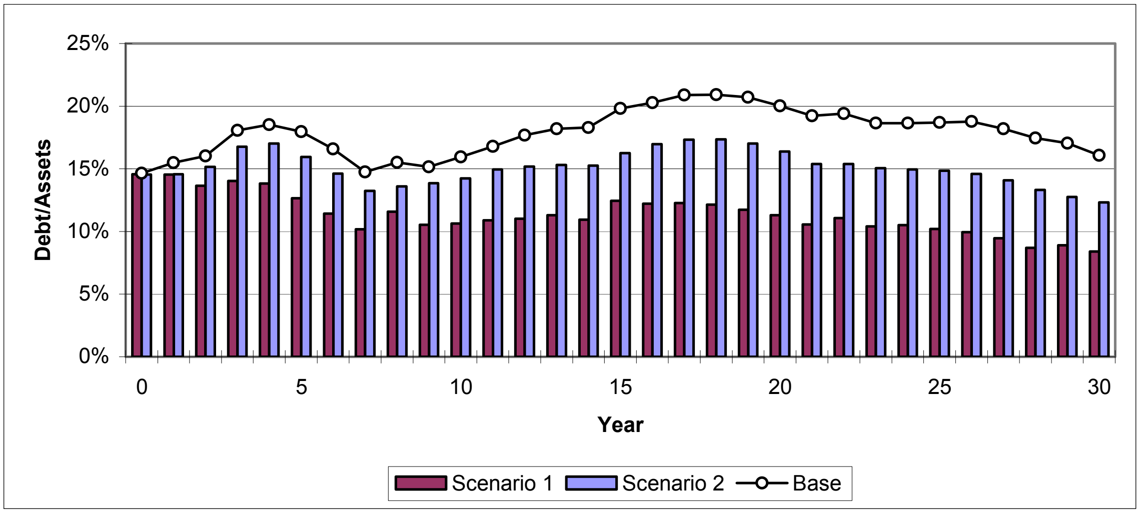
The mean net worth is greater under Scenario 1, high grain price, then the Base Scenario and Scenario 2. Scenario 1 has an final mean net worth of $3.03 million which is 1.43 times the final net worth under the Base Scenario. The final mean net worth when livestock prices are increased is slightly higher at $2.35 million, which is 1.12 times the Base Scenario.

Figure 6.34: Simulated Mean Net Worth (All Scenarios)



After a few years, the simulated average D/A is also considerably lower under Scenario 1 than the Base Scenario and Scenario 2. The lowest ending average D/A is Scenario 1 with 8%, followed by Scenario 2 with 12%, and the highest is the Base Scenario with 16%. This is the result of less opportunity for farm growth in Scenario 1 and 2, as well as an increase in annual income.

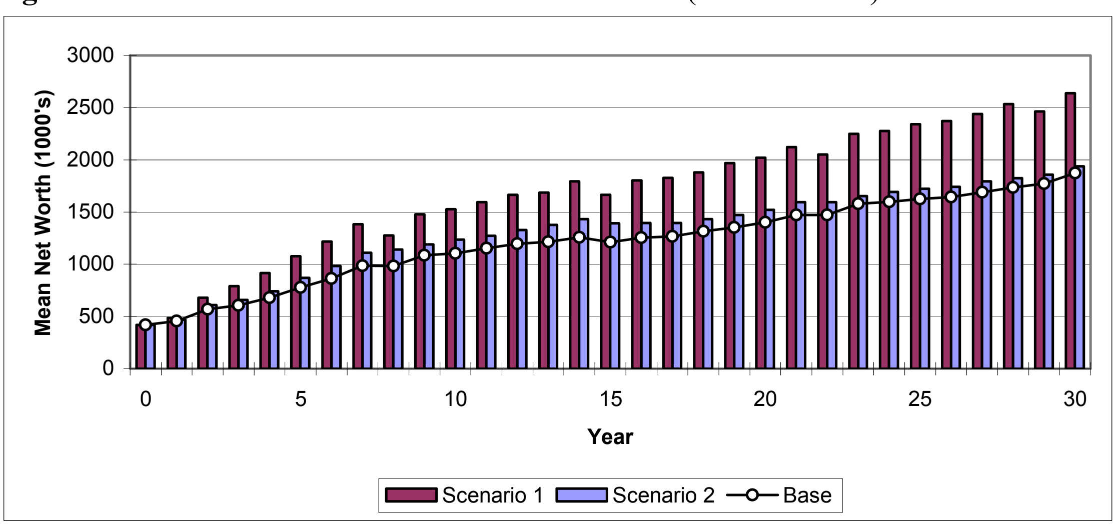
Figure 6.35: Simulated Average Debt to Assets (All Scenarios)



6.2.4.2 Comparison of Financial Characteristics by Farm Type

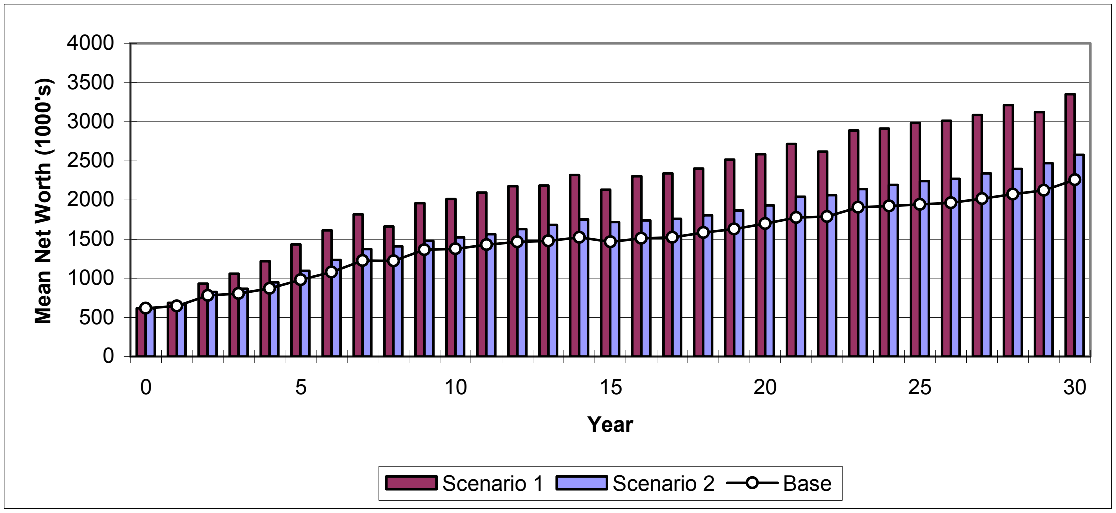
Grain farms average net worth increases across all Scenarios, but as expected has a large increase in Scenario 1. In Scenario 1, the average mean grain farm net worth increases to $2.63 million compared to $1.87 million in the Base Scenario and $1.93 million in Scenario 2. Mean grain farm net worth in Scenario 2 and the Base Scenario are marginally different, which is not surprising because the grain prices are equivalent and these farms are unable to capture the increase in livestock prices.

Figure 6.36: Simulated Mean Grain Farm Net Worth (All Scenarios)



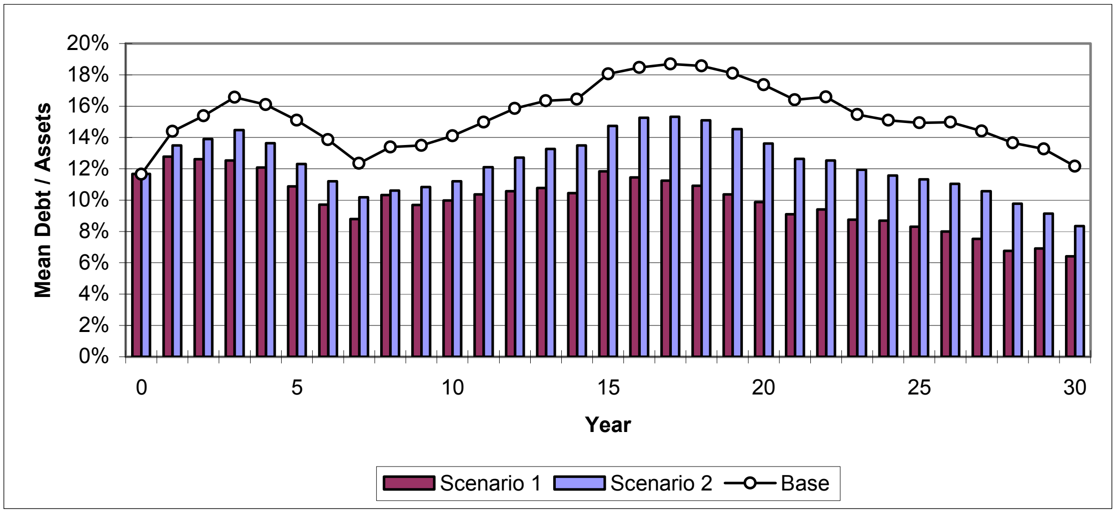
Mixed farms mean net worth also increases under all scenarios, however their net worth increased considerably when grain prices increased. In Scenario 1, the final mean net worth was $3.35 million compared to $2.575 under Scenario 2 and $2.25 million under the Base Scenario. Clearly, mixed farms have the ability to capture the increase in grain prices by using land in crop production if that is the highest and best use.

Figure 6.37: Simulated Mean Mixed Farm Net Worth (All Scenarios)



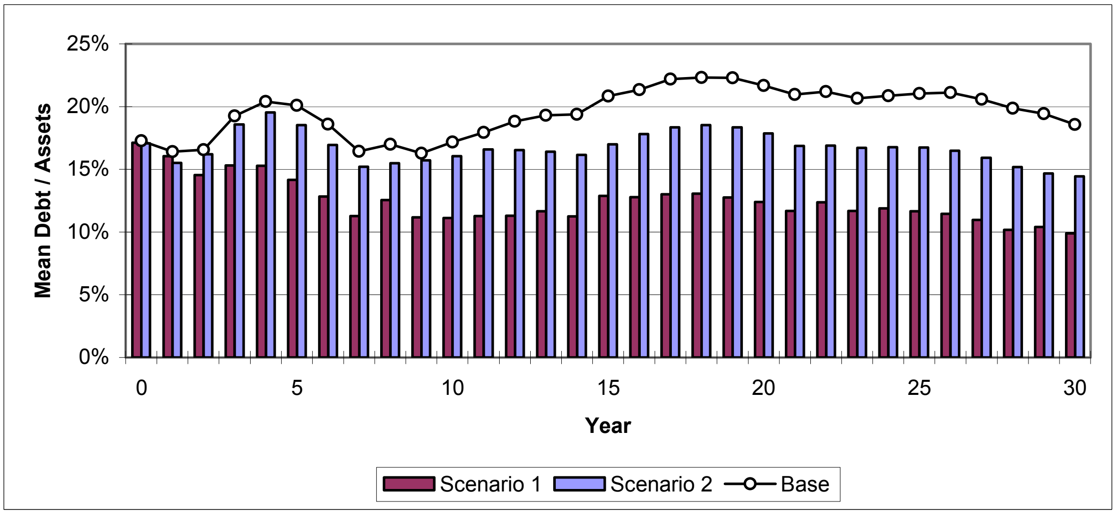
Grain farms mean D/A is the lowest in all periods in Scenario 1, followed by Scenario 2, and the highest in the Base Scenario. This is likely the result of the increase in the value of farmland. The final grain farms mean D/A in Scenario 1 is half that of the Base Scenario at 6% and in Scenario 2 ended with a value of 8%.

Figure 6.38: Simulated Mean Grain Farm Debt to Assets (All Scenarios)



Simulated mean D/A follows the same pattern for mixed farms as for grain farms with the lowest D/A occurring in Scenario 1, then Scenario 2, and the highest in the Base Scenario. The final value for mixed farms mean D/A was 10%, 14%, and 19% in Scenario 1, Scenario 2, and the Base Scenario, respectively.

Figure 6.39: Simulated Mean Mixed Farm Debt to Assets (All Scenarios)



6.2.5 Land Markets

This section will outline farm exits, land price and lease rate, and land tenure for all the simulated scenarios.

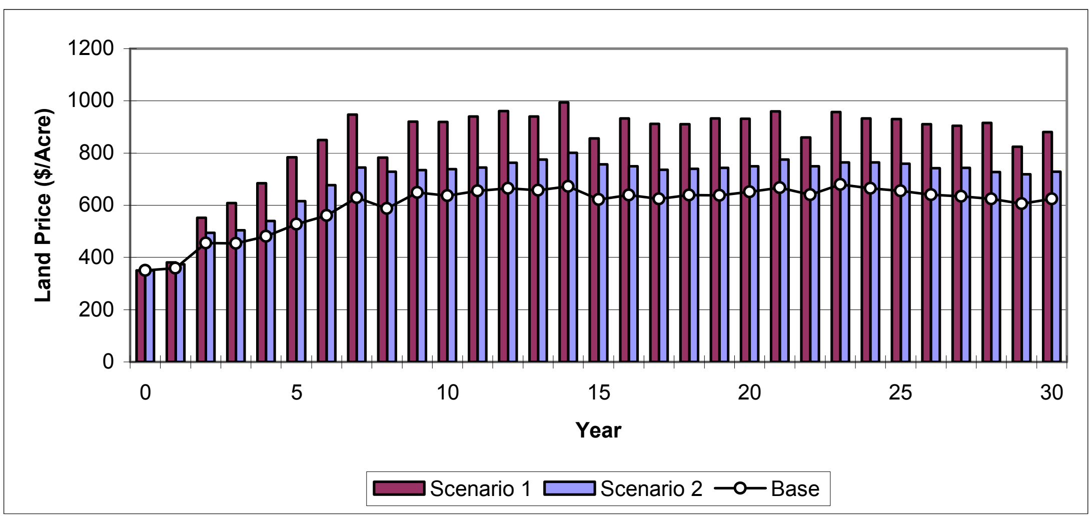
6.2.5.1 Farm Exits

The scenario chosen does not affect farm exits, as there is only a small variation in farm exits for each scenario. The majority of farm exits in all scenarios are the result of retirement, accounting for approximately 50% of exits in all scenarios. Equity erosion was the next largest exiting criteria in all scenarios, with a high of 30% in the Base Scenario and a low of 25% in Scenario 1. The least common exiting reason was bankruptcy with a high of 22% in the Base Scenario and a low of 20% in Scenario 1.

6.2.5.2 Land Price and Lease Rate

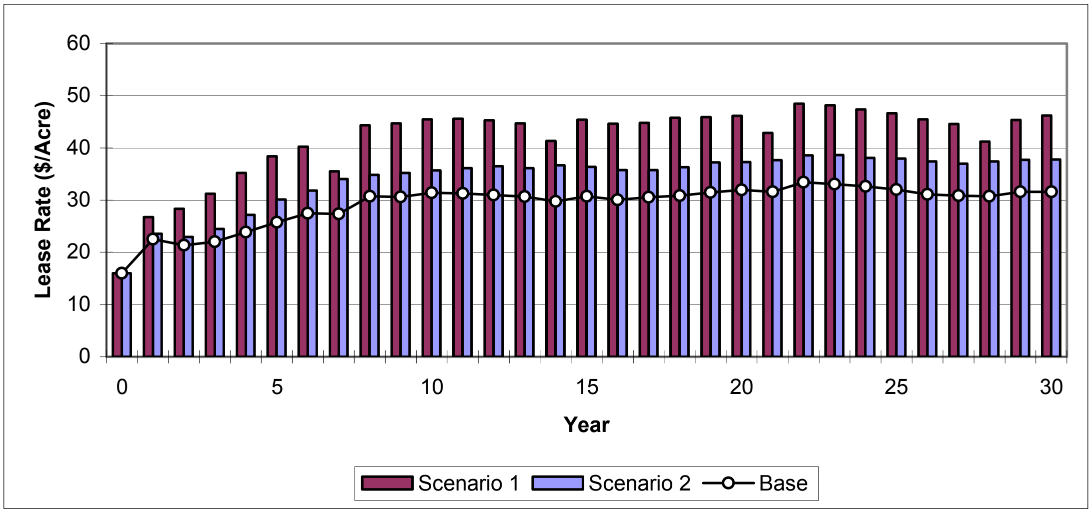
Land prices increased noticeably in the two alternate scenarios compared to the Base Scenario. The average land price over the 30 year period was $844, $694, and $600 per acre in Scenario 1, Scenario 2, and the Base Scenario, respectively. This represents a 41% increase in Scenario 1 and a 16% increase in Scenario 2 over the Base Scenario.

Figure 6.40: Simulated Land Price (All Scenarios)



Simulated lease rate has the same trend as land price. The highest average lease rate over the 30 year period is in Scenario 1, followed by Scenario 2, and the lowest is the Base Scenario. In Scenario 1 the average lease rate is 43% higher then the Base Scenario at $42 per acre and Scenario 2 is 17% higher then the Base Scenario at $34 per acre.

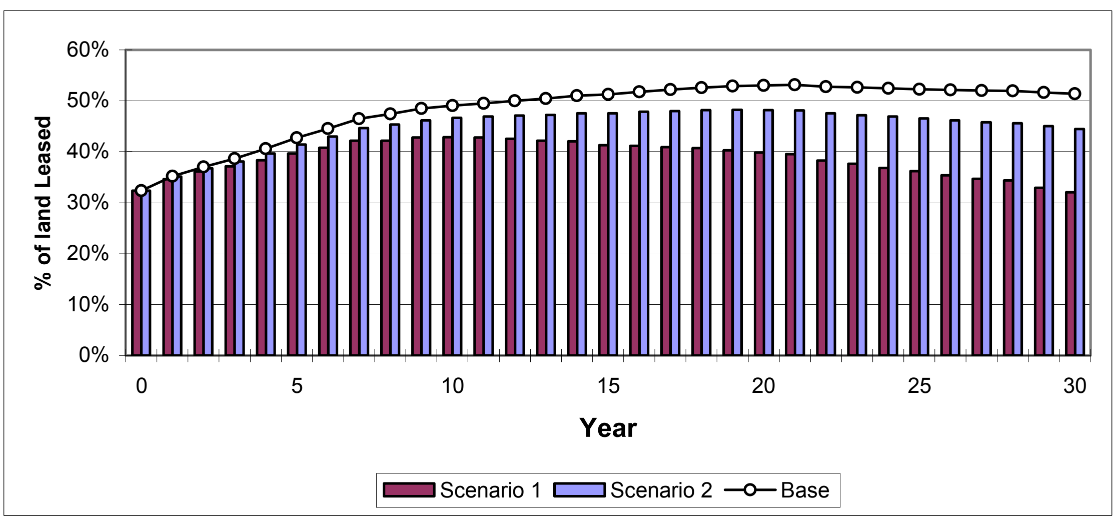
Figure 6.41: Simulated Land Lease Rate (All Scenarios)



6.2.5.3 Land Tenure

The increase in prices leads to more leased land. This is likely the result of increased land prices and the difficulty in meeting financial constraints. At the end of the 30 year simulated period, the proportion of leased land is 32% in Scenario 1, 44% in Scenario 2, and 51% in the Base Scenario.

Figure 6.42: Simulated Proportion of Leased Land (All Scenario)



6.3 Summary

Due to the computational requirements of the model, a limited number of runs and scenarios where ran. The results of the simulation indicate that many of the same trends exist under the different time paths and also the different scenarios, such as the declining farm numbers, increasing farm size, distribution of farm sizes, and increasing net worth. The rate of change that occurs is largely affected by the various time paths that occur, which is indicated by the large confidence intervals, and also the scenario. The distribution of farms size shows the proportion of large farms increasing, while the smaller farms are squeezed out of the industry. The simulation also identifies that mixed farms are more likely to grow in size and net worth, due to their willingness to use land in the highest and best use. Land use, livestock numbers, land prices, and land tenure depend considerably on the time path that occurs. Large shifts in grain prices have a more dramatic impact on the industry structure by creating large shifts in structure for both the grain and mixed farms. A large change in livestock prices has a smaller effect on farm structure because this shift in prices does not change the profitability of grain farming.

Chapter 7
Summary and Conclusions

7.1 Summary

Economic models built upon a few representative individuals, while potentially rich in detail, are very often unlikely to capture the heterogeneity commonly found among agricultural producers and the agricultural landscape. Moreover, so-called representative farms are usually treated as autonomous individuals and hence, traditional models ignore individual interactions and competition in farmland markets. At the other end of the modeling spectrum, equation based models such as computable general equilibrium models are frequently unable to accurately predict the effects of large structural shifts because they use parameters estimated from historical data. In this light, agent-based models offer a useful alternative to these agricultural modeling approaches in that they incorporate by design both complexity and diversity within an economic system. However, there are challenges associated with the design and operation of agent-based models. For example, they require detailed behavioural data, data that are largely unavailable. And even with modern software and increases in computing power, incorporating heterogeneity and feedback between numerous economic agents renders it difficult to keep even small models tractable. These problems are exacerbated when agent population size and geographic area is expanded in an effort to capture reality.

In this thesis, an agent-based simulation model is developed in order to capture individual heterogeneity and farm level interactions within a representative Saskatchewan agricultural sector. Subsequently, the model is used to forecast regional structural change 30 years into the future. This research contributes to existing AbM models on structural change by incorporating a synthetic farm population located on an existing landscape. While a large part of the work of Freeman (2005) is used as a starting point, important additions and modifications include; 1) a large and important livestock sector, with accompanying complexity in land use decisions; 2) lumpy machinery investments and resulting economies of size; and 3) land purchase and lease bid values based on land use while constrained by financial rules and machinery capacity. While Freeman's model was calibrated with historic land use (so that actual price and yields were used), the forward looking capability of the current model means that numerous different time paths are generated. Accordingly, a bootstrap statistical procedure using historic price and yield data is used to generate 100 different price and yield time paths.

In addition to the base model, two alterative scenarios are simulated; 1) a permanent increase in grain prices; and 2) a permanent increase in livestock prices. Under the base scenario, farm numbers are projected to decline at an annual rate of 3.67%, with a 2.55% decline under an increase in grain prices, and a 3.04% decline with an increase in livestock prices. The simulated proportion of small farms decreased under all scenarios, while the proportion of large farms increased and mid sized farms remained relatively constant. Interestingly, the proportion of mixed farms increased under the base model from 54% to 61% of all farms at the end of the 30 year period. Under increased livestock prices, the proportion of mixed farms increased slightly to 65%, but under increased grain prices, this decreased slightly to 56% of farms.

7.2 Conclusions

The main drivers of structural change modeled in this research are individual grain/mixed farm preferences along with the various levels of cost efficiency associated with machine technology and size. Livestock production preference/aversion has a significant impact on farm structure. Individuals willing to produce livestock are able to better adapt to changing market conditions and exploit heterogeneous land in its highest and best use, increasing the likelihood of farm growth and survival.

Although the total mix of available technology is held constant, cost efficiency varies from conventional tillage to a no-till system, with the no-till system being considerably more cost efficient. Also incorporating lumpy machinery investments create economies of size. However, the benefits of switching to a no-till system or exploiting the economies of size is captured by land owners through increases in land bid values as a result of increases in farm profits. In this light, the results of this research lend support to Cochrane's technology treadmill theory where individuals who do not adopt new technology are eventually forced out of an industry.

Structural change in agriculture results in both winners and losers. Inefficient farmers are forced to exit, leaving their land resources to the remaining more efficient producers. This leads to a gain for society. On the negative side, small rural towns become de-populated with relocation of exiting farmers, reducing demand for infrastructure and services, which is a concern for the remaining population. The outcome of more efficient agricultural production generates increases in land bid values and greater wealth for land owners comprising both farmers and non-farming investors. The latter makes it difficult for small farms to compete in land markets and expand.

7.3 Limitations

As noted earlier, one challenge developing agent-based simulations is the large quantity of behavioral data required to correctly capture individual heterogeneity. Although many equations in the model are based on well established accounting and behavioral equations, some necessarily include parameters specific to individuals.

The use of large 640 acre plots in the simulation likely has a significant effect on the results. Large plot sizes lead to farms purchasing land less frequently because of the large capital requirements of buying a plot along with supporting machinery and livestock. Also, plots of this size favor the expansion of mixed farms because many plots in the study region include land that is not tillable and grain farms are unable to efficiently utilize this portion of land. Although plots of this size are postulated to have a non-trivial effect on the results, it is believed that this choice of plot size is, in fact, close to what occurs in reality. When individuals sell land in this region, they generally sell all of their land and typically possess a land base greater than 640 acres.

The objective function of small farms in the study is likely a limitation of this research. It is assumed that all farms, both large and small, have the common goal of increasing wealth. In reality many small farms exist as hobby farms, where the farm operator takes enjoyment in the farming activities and lifestyle. The goals of these farms are not purely driven by wealth maximization. In this case, the assumed objective to grow and increase wealth is not likely to be accurate.

7.4 Suggestions for Further Study

This research includes the use of two types of technology and this is postulated to have a considerable effect on the structure of the industry. Including technology that is continually evolving and changing would exacerbate the treadmill effect and have a dramatic impact on the rate of structural change. This would intensify competition in land markets, meaning that the slow adopters of technology would likely be forced to exit more quickly. Also, including the means by which new technology adoption spreads from the first individuals to widespread use would be a major step forward in capturing the essence of agricultural structural change.

There is a need to better formulate the objective functions of small farms in the simulation to include non-monetary aspects of farm life. Such changes would help to ensure that small farms are not under represented in a model of structural change.

Finally, as in Freeman (2005), this model needs to incorporate government support payments and crop insurance. This would improve its ability to forecast agriculture structure. Although government support payments are continually changing and often short lived, it’s believed that they would have a considerable effect on the rate of structural change in the region.

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Appendix A
Quantity of Cows and Expected Hay Purchases or Sales

Livestock production requires an adequate quantity of pasture in early summer and late summer as well as hay for the winter months. With the ability to purchase and sell hay, farm operators set their cow herd to match their pasture production and will adjust hay sales and purchases.

The slow growth of pasture late in the summer often results in shortage of pasture late in the year. If this is expected to occur, a farmer can delay early pasture grazing for use later in the summer when there is a shortage of pasture production. To determine the quantity of early pasture that is delayed for late pasture grazing the available feed in each period divided by the energy required must be equivalent (equation 1.1).

$$\frac{(1-D)\cdot TE_1}{E_1}\cdot SR_p = \frac{D\cdot(1-L)\cdot TE_1 + TE_2}{E_2}\cdot SR_p \qquad 1.1$$

Where: D = the proportion of early pasture delayed for late pasture
TE_1 = the total energy of early pasture available
SR_p = the stocking rate of pasture
L = the loss due to delayed grazing
TE_2 = the total energy of late pasture available
E_2 = energy required per cow in late summer

From this equation the proportion of the early summer pasture that is delayed and not used until late summer can be calculated as:

$$D = \frac{TE_1\cdot E_2 - TE_2\cdot E_1}{TE_1\cdot E_2 + (1-L)\cdot TE_1\cdot E_1} \qquad 1.2$$

Late pasture cannot be shifted to early pasture and therefore the value of the proportion of early pasture delayed for late pasture must be greater than zero. From the previous equation, the total available early pasture production can be calculated as:

$$TAE_1 = TE_1\cdot(1-D) \qquad 1.3$$

Where: TAE_1 = total available early pasture energy

The expected quantity of cows for both hay and pasture production is calculated as:

$$E(C_i) = \frac{TAE_i}{E_i} \cdot SR_i \qquad 1.4$$

Where: C_i = cows for forage production i (hay or pasture)
TAE_i = total energy of i available
E_i = energy required per cow of i
SR_i = the stocking rate of i

To determine how many additional cows will be added with land converted to forage or gaining control of new land, the expected number of cows are calculated before the conversion to forage or new land included and after. The difference is the increase in total cows.

The farm agent will set the quantity of cows at a level that their pasture land can support and will sell/buy the excess/deficit of hay. The excess/deficit hay a farmer produces is:

$$SH = \frac{\left(E(C_H) - E(C_P)\right) \cdot E_H}{E_H^{ton}} \qquad 1.5$$

Where: SH = excess/deficit hay (if negative deficit) in tons
CH = cows based on hay production
Cp = cows based on pasture production
E_H = energy required as hay per cow
E_H^{ton} = energy in a ton of hay

Appendix B

Allocating Hay and Pasture Acres

If a farm operator has extra hay acres, they will shift some of the hay land to pasture production until the quantity of cows from hay production matches the quantity of cows from pasture production. An extra acre of hay land is calculated as:

$$EA_{hay} = \frac{\left(E(C_h) - E(C_p)\right) \cdot E_H}{E(Y_H) \cdot E_H^{ton}} \qquad 1.1$$

Where: EA_{hay} = extra hay acres
C_h = cows for hay production
C_p = cows for pasture production
E_h = hay energy required for a cow
Y_h = hay yield
E_H^{ton} = energy per ton of hay

The additional hay acres are allocated so the energy from all other acres for early pasture and the additional hay acres used as pasture result in the same quantity of cows as the energy from the existing hay acres, and the energy from the extra hay acres that will be used for hay (equation 1.2).

$$\frac{A_{P1} \cdot Y_1 \cdot E_{past}^{ton} + TAE_{P1}^{O}}{E_1} \cdot SR_p = \frac{A_H \cdot Y_H \cdot E_{hay}^{ton} + TAE_H^{O}}{E_H} \qquad 1.2$$

Where: A_{P1} = acres of early pasture
Y_1 = yield in energy units of plot per acre
TAE_{P1}^{O} = total available early pasture energy of all other acres
E_1 = energy required per cow in early summer
A_H = acres of early pasture
Y_H = yield in energy units of plot per acre
TAE_H^{O} = total hay energy of all other acres
E_H = energy required per cow in winter

The acres of early pasture and hay must add up to the extra hay acres and therefore the acres of early pasture can be solved as:

$$A_{P1} = \frac{TAE_H^{O} - TAE_{P1}^{O} \cdot E_H \cdot SR_p + EA_{hay} \cdot Y_h \cdot E_{hay}^{ton} \cdot E_1}{Y_1 \cdot E_{past}^{ton} \cdot E_H \cdot SR_p + Y_H \cdot E_{hay}^{ton} \cdot E_1} \qquad 1.3$$

Once the acres of pasture are determined, the total hay acres are the extra acres of hay less the acres used as pasture.

Appendix C
Forage Yields

Forage yields increase linearly with soil quality until they reach a maximum, after which they remain constant. The yield of early forage, which can be used for hay or early pasture is:

$$Y_1 = \frac{PR}{PR^{Max}} \cdot \left(Y_1^{\max} - Y_1^{\min}\right) + Y_1^{\min} \qquad 1.1$$

Where: Y_1 = yield of early forage
PR = productivity rating of the land category
PR^{max} = productivity rating where the maximum yield occurs
$Y_1^{\max}$ = maximum early yield of forage
$Y_1^{\min}$ = minimum early forage yield

It is assumed that no land qualities will have an early forage yield less than the minimum forage yield. The late forage growth that can only be used for late pasture grazing is calculated similarly, with the exception that there is no minimum yield.

$$Y_2 = \frac{PR}{PR^{Max}} \cdot Y_2^{\max} \qquad 1.2$$

Where: Y_2 = yield of late forage
$Y_2^{\max}$ = maximum late forage yield

Appendix D
Machinery Options

The machinery options for farm production are made up of four components: tractor, seeder, combine, and a combine header. There are 3 different combine and header combinations and 4 different tractor and seeder combinations. The available machinery, capacity of the machinery, work rate, and labour required are shown in the table.

Combine and Header Combinations											
Combines	Combine Cost	Draper Header (Ft)	Header Cost	Speed	Field Efficiency	Work Rate (Acre/hr)	Total Cost	Harvest Days	Hrs/ Day	Capacity (Acres)	Labours (per unit)
Class 5	$ 193,022	20	$ 30,588	5	0.8	9.70	$ 223,610	23	10	2230	2
Class 7	$ 245,281	30	$ 39,218	5	0.8	14.55	$ 284,499	23	10	3345	2
Class 7+	$ 272,417	36	$ 42,766	5	0.8	17.45	$ 315,183	23	10	4015	2
Tractor and Conventional Seeding Option											
Conventional size (ft)	Seeder Cost	Tractor	Tractor Cost	Speed	Field Efficiency	Work Rate (Acre/hr)	Total Cost	Seeding Days	Hrs/ Day	Capacity	Labours (per unit)
30	$ 82,080	170HP 2WD	$ 124,654	4.5	0.8	13.09	$ 206,734	15	10	1964	1.5
Tractor and Direct Seeding Combinations											
Direct Seeder (size Ft)	Seeder Cost	Tractor	Tractor Cost	Speed	Field Efficiency	Work Rate (Acre/hr)	Total Cost	Seeding Days	Hrs/ Day	Capacity (Acres)	Labours (per unit)
40	$ 97,710	275HP 4WD	$ 159,557	4.5	0.8	17.45	$ 257,267	15	10	2618	1.5
50	$ 124,175	350HP 4WD	$ 201,365	4.5	0.8	21.82	$ 325,539	15	10	3273	1.5
60	$ 152,558	425HP 4WD	$ 220,254	4.5	0.8	26.18	$ 372,812	15	10	3927	1.5

Source: Saskatchewan Agriculture and Food 2006b and Author's calculation

From these different combinations a 5 machinery options are available: 1) no machinery and all work custom hired, 2) used conventional seeding, 3) used direct seeding, 4) two sizes of new direct seeding. All other larger capacity machine options are a multiple of the largest new direct seeding option.

Machine Option 2 Used Conventional								
			Labour Required	Work Rate (acres/hr)	Max Acres	Passes	Min Model Acres	Max Model Acres
Seeding Equipment Description	30Ft Conventional	170HP 2WD	1.5	13.09	1964	2	500	982
Seeding Equipment Value	$ 82,080	$ 124,654						
Harvest Equipment Discription	Class 5	20Ft						
Harvest Equipment Value	$ 193,022	$ 30,588	2.5	9.70	2230	1		
Total New Value	$ 430,345							
Age of Machinery	10							
Used Value	$ 143,838							

Machine Option 3 Direct Seed Used								
			Labour Required	Work Rate (acres/hr)	Max Acres	Passes	Min Model Acres	Max Model Acres
Seeding Equipment	40 Ft Direct	275HP 4WD	1.5	17.45	2618	1	982	2000
Seeding Equipment Value	$ 97,710	$ 159,557						
Harvest Equipment	Class 5	20Ft						
Harvest Equipment Value	$ 193,022	$ 30,588	2.5	9.70	2230	1		
Total New Value	$ 480,878							
Age of Machinery	5							
Used Value	$ 270,687							

Machine Option 4 New Direct Seed								
			Labour Required	Work Rate (acres/hr)	Max Acres	Passes	Min Model Acres	Max Model Acres
Seeding Equipment	50 Ft Direct	350HP 4WD	1.5	21.82	3273	1	2000	3200
Seeding Equipment Value	$ 124,175	$ 201,365						
Harvest Equipment	Class 7	30Ft						
Harvest Equipment Value	$ 245,281	$ 39,218	2.5	14.55	3345	1		
Total New Value	$ 610,039							

Machine Option 5 New Direct Seed								
			Labour Required	Work Rate (acres/hr)	Max Acres	Passes	Min Model Acres	Max Model Acres
Seeding Equipment	60 Ft Direct	425HP 4WD	1.5	26.18	3927	1	3200	3900
Seeding Equipment Value	$ 152,558	$ 220,254						
Harvest Equipment	Class 7+	60Ft						
Harvest Equipment Value	$ 272,417	$ 42,766	2.5	17.45	4015	1		
Total New Value	$ 687,995							

Appendix E

NetLogo© Source Code

Version 3.1.4

```
globals
[
avg-lease
scenario
total-farmers
crop-mach-new-value-list            ;; value of new machinery options for crop
crop-mach-purchase-value-list        ;; purchase value of crop machinery options
crop-capacity-list                  ;; capacity of the different crop machinery options
crop-pt-hired-labour-list           ;; part time hired labour list based on machinery options in Hrs. per acre crop
crop-ft-hired-labour-list           ;; full time hired labour list based on machinery opiton in labours all year
total-rented                        ;; total land rented
total-owned                         ;; total land owned
avg-cash                            ;; average cash at end of year for farmers
avg-debt
avg-assets
avg-net-worth
avg-size                            ;; average size of all farms at the end of the year
farmers-bidding                     ;; identifies the number of farmers bidding on a plot
current-plot-on-market              ;; the current plot that is up for sale in the land markets
bid-list                            ;; list of bids on the current-plot
land-price-list                     ;; list of all land sales that are adjusted to represent average quality
land-price                          ;; land price at the end of the year
buyer                               ;; buyer of the plot currenlty on the market
plots-sold-farmers                  ;; counts number of plots sold to farmers in year
plots-sold-investor                 ;; counts number of plots sold to investors in year
land-lease-list                     ;; tracks all lease agreements including renewed leases adjusted to represent average quality
lease-rate                          ;; lease rate for the year
hay-needed                          ;; need 6.000 thousand mcals for winter feed
pasture-1-needed                    ;; need 3.157 thousand mcals for may - july summer months actual pasture needed
pasture-2-needed                    ;; need 2.426 thousand mcals for  august,septmeber and october actual pasture needed
stocking-pasture-1-needed           ;; this value includes waste and stocking rate (used in decisions)
stocking-pasture-2-needed           ;; this is the values used to detemine the expected carrying capactiy of grass (so farmers do not stock to the
                                       capacity)
mcals-ton-np                        ;; 1933 mcals in ton of natural pasture
mcals-ton-ip                        ;; 2196 mcals in ton of improved pasture
mcals-ton-hay                       ;; 2196 mcals in ton of hay
e-yield-1                           ;; expected yield of canola on stubble for the region
e-yield-2                           ;; expected yield of wheat on stubble for the region
e-yield-3                           ;; expected yield of barley on stubble for the region
mean-patch-quality
crop-1-price-list                   ;; farm level crop price of crop in $ per bu actual price used in simulation
crop-2-price-list
crop-3-price-list
crop-1-yield-list                   ;; average yield of crop in bu for all years in the simulation
crop-2-yield-list
crop-3-yield-list
hay-yield-list                      ;; forage yield in tons for each year
hay-price-list
calf-price-list                     ;; value of a calf after expenses except labour and feed
yield-1                             ;; current years yield
yield-2
yield-3
hay-yield-1
max-hay-yield-1                     ;; max yield of hay in ton
max-hay-yield-2
price-1
price-2
price-3                             ;; current years price in $/bu
price-hay                           ;; current years price in tons
price-calf                          ;; current years price resid to labour and feed
hay-price                           ;; market price in $ per ton
last-5-years-price-1                ;; the last 5 years of prices used in the to develope expectations
last-5-years-price-2
```

```
last-5-years-price-3
last-5-years-price-hay
last-5-years-price-calf
cashflow                    ;; total farmers exiting because of negative cash flows
bankrupt                    ;; total farmers exiting because of debt exceeding their assets
transfers                   ;; total farms that have been transfered to the next generation
oldage                      ;; farmers retiring without transfering
year                        ;; is used to calculate expectations and retrive prices and yields
expected-price-list         ;; list wieghted price for the previous 5 years (canola, wheat, barley,calf, ton of forage)
year-20-factor              ;; discount value back 20 years
pv-annuity-land             ;; used to calculate pv of 20 years income
loan-factor-payment-20      ;; used to calculate loan payment for 20 year loan
loan-factor-payment-25
loan-factor-payment-5       ;; used to calculate loan payment for 5 year loan
run-number                  ;; currnet run of the simulation
total-cows
%-crop
%-hay
%-np
%-ip
%-crop-sf
total-avg-hay-q
tractor-value-list          ;; used to determine repairs
seeder-value-list           ;; used to determine repairs
combine-value-list          ;; used to determine repairs
header-value-list           ;; used to determine repairs
seeder-width-list           ;; used to determine repairs
seeder-rate-list            ;; used to determine repairs
harvest-rate-list           ;; used to determine repairs
exp-lease
max-distance
last-year-exp-list          ;; list of the last years expected prices
initial-farmers
unmanaged
]


patches-own
[
gross-income-crop
need-sell
plot-income-crop            ;; actual crop income from the plot
patch-leased                ;; used to determine if patch is initally leased
patch-id                    ;; number specific to that plot of land
current-farmer              ;; identifies the farmer currently in control of the patch
owner                       ;; the current owner of the plot
renter                      ;; the current renter of the plot
sama-hay                    ;; land use acres of each category from sama
sama-ip
sama-tilled
sama-np
sama-hay-quality            ;; quality of each category of land based on sama data
sama-tilled-quality
sama-np-quality
sama-ip-quality
barley-yield-index          ;; yield of each crop on tilled portion of land relavtive to average yields on stubble
canola-yield-index          ;; based on sask crop insurance data
wheat-yield-index
wheat-sf-yield-index        ;; yield index for wheat on fallow (adjust wheat on stubble yield to reflect wheat on fallow for the plot)
avg-yield-index             ;; average of all crop on stubble yield indexs for the tilled plot
fallow                      ;; acres of fallow on the plot
pasture-1-prod-mcals        ;; total pasture period 1 mcals from plot
pasture-2-prod-mcals        ;; total pasture period 2 mcals from plot
hay-prod-mcals              ;; total hay produciton in mcals from plot
e-pasture-1-prod-mcals
e-pasture-2-prod-mcals      ;; total pasture period 2 mcals expected from plot
e-hay-prod-mcals
distance-to-farm            ;; distance to the homestead of the current farmer
lease-payment               ;; annual lease payment of the plot of land
lease-term                  ;; years on current lease agreement expires at 7
```

```
avg-prod-patch                  ;; average productivity rating of the plot based on SAMA data wighted for acres in each use
for-sale?                       ;; the plot is currently for sale
for-rent?                       ;; the plot is currently available for rent
e-np-yield-1                    ;; expected forage yield on each category of land for the plot type of land
e-np-yield-2
e-ip-yield-1
e-ip-yield-2
e-hay-forage-yield-1
e-hay-forage-yield-2
e-tilled-forage-yield-1
e-tilled-forage-yield-2
vc-hay                          ;; total variable cost for hay production on the plot
hay-trans-cost                  ;; transportation cost for hay (only for those farmers producing cows)
tilled-hay                      ;; acres of tilled land in hay production on the plot
tilled-crop                     ;; acres of tilled land in crop production on the plot
tilled-pasture                  ;; acres of tilled land in pasture production on the plot
hay-hay                         ;; acres of hay land in hay on the plot
hay-pasture                     ;; acres of hay land in pasture on the plot
acres                           ;; total usable acres on the plot
hay-acres                       ;; total hay acres on the plot
years-in-grass                  ;; years that the tilled land has been in a forage rotation
use-change                      ;; idintifies if the plot should be evaluated to take land out of forage and use it for crop
can-change                      ;; identifies if the plot can be switched to forage (do not allow leased plots to change after 3 years into lease)
net-income-crop                 ;; the expected net income from crop production on the plot
additional-cow-income           ;; additional income from cows if plot is used in forages
additional-income-grass         ;; total additional income if plot is used in forages
hay-income-sell                 ;; income if hay is sold from the plot
proportion-of-p1-delayed        ;; amount of early pasture delayed for late pasture in the land use decision
new-other-mcals-pasture-1       ;; identifies the total of all other plots farmed by this farmers production of forages
new-other-mcals-pasture-2       ;; used in switching hay land to pasture land
new-other-mcals-hay
new-tilled-acres-pasture-1      ;; acres of each land use for different land categories if a switch in use occurs
new-hay-acres-pasture-1
new-hay-hay
new-tilled-hay
new-cows-pasture-1              ;; new cows based on forage produced in that period if switch would occur
new-cows-pasture-2
new-cows-hay
lost-cow-income-plot            ;; the lost income that results if the patch is cultivated instead of used in crop production
came-from-bid                   ;; to determine if the land came from bid creation in the land markets or annual land use
came-from-year-1                ;; to determine if the land came from initalization stage or annual land use
income-pasture-hay-land-bid     ;; used to detemine the value of the hay and pasture land on a plot if the best use is crop for the tilled acres
e-total-plot-income-crop        ;; total-value of a plot when it is used in crop (includes natural pasture and hay)
e-cows-if-patch-bought
net-hay-inc                     ;; net income from changes in hay sold or purchased
crop-acres-bid                  ;; acres that would be in crop production if the land was purchased
break-grass-tilled              ;; used to determine how much grass is broke
avg-hay-q
bidders
last-adj-lease-rate
]


turtles-own
[
cows-pasture-1                  ;; cows that the farmer can have for the differnt forage produciton
cows-pasture-2
cows-hay
plots-needed                    ;; farmers initial land allocation
begin-patch-id                  ;; needed to lable patches
age                             ;; age of the farm operator
crop-mix                        ;; proportion of crop or summerfallow on each acre used in crop production
total-plots-owned               ;; total plot the farmer owns
total-plots-leased              ;; total plots the farmer rents
total-acres-owned               ;;total acres owned by farmer
total-acres-farmed              ;; total of all acres farmed by the farmer
total-acres-leased              ;; total acres rented
total-hay                       ;; total acres of hay
```

```
total-improved-pasture          ;; total acres of improved pasture
total-natural-pasture           ;; total acres of natural pasture
total-crop-acres                ;; total acres used for crop production
id                              ;; number used to identify the farmer
generation                      ;; family generation of farm agent
total-crop-income               ;; crop income less vc tonne, vc acre, and transportation cost
total-cow-inc                   ;; total income from cows in the period
total-vc-hay                    ;; total variable cost of hay produciton in the period
total-hay-trans-cost            ;; transportation cost of hay (only for the farmers who produce cows)
debt-list                       ;; tracks each debt seperately [payments remaining, annual payment, prinicpal balance]
debt-payment                    ;; summation of the individual annual payments of all outstanding debts
debt                            ;; summation of the individual principal balance on all outstanding debts
ncfbi                           ;; net cash flow  before investment
assets                          ;; total current value of assets
equity                          ;; asset less debt
cash                            ;; cash available to the farm
hired-labour                    ;; total cost of hired labour
family-living                   ;; family living withdrawal of the farmer
off-farm-employ                 ;; if the farm has off farm employment
off-farm-inc                    ;; how much income the farm earns from off farm income
total-land-lease-payment        ;; summation of all lease payments of farmer on rented land
land-value                      ;; current value of land
capital-value                   ;; current value of machinery
cow-value                       ;; current value of cows
years-neg-cash                  ;; consecutive years that net cash flow before investment is negative
price-exp-list                  ;; individual farmers price expectation list
total-hay-inc                   ;; income from hay sold
total-pasture-inc               ;; pasture income from rented pasture
total-hay-purchase-cost         ;; total cost of hay purchases for the year
will-cows                       ;; identifies if the farmer currently produces cows
adjusted-cult-to-hay            ;; used to determine if they still need to adjust land to hay (starts with lowest quality land)
n-cows                          ;; actual number of cows the have
e-n-cows                        ;; expected number of cows that can be produced
e-total-hay-mcals               ;; expected production of hay energy of the farmer
e-total-pasture-1-mcals         ;; expected production of early pasture energy of the farmer
e-total-pasture-2-mcals         ;; expected production of late pasture energy of the farmer
total-hay-mcals                 ;; acutal hay production in the period
e-hay-bought                    ;; expected quantity of hay purchaed
e-hay-sold                      ;; expected quantity of hay sales
hay-for-sale                    ;; actual hay sold in the period
buy-hay                         ;; actal hay purchased in the period
tons-hay-short                  ;; quantity of hay the farmer expects to be short
tons-hay-extra                  ;; quantity of hay the farmer expects to be extra
hay-reserves                    ;; current hay reservest of the farmer in tons
can-bid                         ;; farmer can bid in general
can-bid-on-plot                 ;; farmer can bid on the current plot on the market
e-income-plot-acre              ;; expected annual income from the plot
current-bid                     ;; farmers current bid on the specific plot in the land markets
new-machienry-inv               ;; machienry invetment that will need to occur in order to purchase land
risk-parameter                  ;; risk parameter of the farmer (value less than or equal to 1)
buy-cows                        ;; how many cows the farmer must purchase
sell-cows                       ;; how many cows the farmer must sell
cows-pasture-1-after            ;; used in land markets to determine how many cows a farmer would have if they gained control of the plot
cows-hay-after                  ;; used in land markets to determine how many cows a farmer would have if they gained control of the plot
e-hay-bought-change             ;; the expected cahnge in hay purchases if a plot was purchased
e-hay-sold-change               ;; the expected cahnge in hay sales if a plot was purchased
crop-machine-option             ;; current crop machinery package of the farmer
crop-machine-value              ;; current value of crop machinery
crop-machine-age                ;; current age of crop machinery
crop-machine-inv                ;; investment required in crop machinery when bidding on additional land (if they purchase the plot)
crop-option-needed              ;; crop machiery package needed if get plot they are bidding on
custom-crop                     ;; cost of custom work for farmers with no crop machinery
yield-mult                      ;; adjusts yields up for no till
bid-finances                    ;; maximum bid based on available cash and max debt to asset ratio
breaking-grass                  ;; total cost for breaking grass in the period
seed-grass                      ;; total cost for seeding grass in the period
fuel                            ;; fuel cost per crop acre of farmer
total-crop-hired-labour
total-combine-hrs               ;; used to calculate the repair costs of the farmer
total-acres-seeding             ;; used to calculate the repair costs of the farmer
```

```
total-repairs                 ;; total cost of repairs in the year
exp-cf
last-years-pasture-crop-acres
last-adjust-inc-acre
why-exit
transfer-value
transfer-borrow
total-gross-crop-inc
total-gross-cow-inc
total-gross-hay-inc
total-annual-gross-inc
]

breed [farmers farmer]

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to initialization-phase

ca
set run-number start-run-number
set scenario start-sim-scenario
setup

end

to setup

import-data
initialize-farm-agents
create-plots
set-farmers-values
set year 0
export-data
do-plots
intial-values
show "complete"
end



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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Create Farm Agents;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to initialize-farm-agents

set-border
setup-land
setup-farmers
assign-patch-id

end

to set-border

ask n-of patches-not-needed patches with [pycor = max-pycor] [set patch-id "border"
                                              set pcolor 7
                                              set for-sale? "na"
                                              set for-rent? "na"]

end

to setup-land

ask n-of agents patches with [patch-id != "border"] [sprout 1 [set breed farmers
                                               set color red]
```

```
                                        ]

ask patches  [set owner "na"
          set current-farmer "na"
          set renter "na"
          set for-sale? true
          set for-rent? true
          if (patch-id = "border")[set for-sale? false
                          set for-rent? false]
          ]
end

to setup-farmers

file-open "Farmer info.txt"
let all-info file-read
file-close

ask farmers [let farmer-info item (who) all-info
          set ID item 0 farmer-info
          set plots-needed item 1 farmer-info
          set begin-patch-id item 2 farmer-info
          set age item 3 farmer-info
          set will-cows false
          if (item 4 farmer-info = 1) [set will-cows true]
          set debt item 6 farmer-info
          set off-farm-inc item 7 farmer-info
          if (off-farm-inc > 0)[set off-farm-employ true]
          set generation 1
          set why-exit "na"
          let risk-att random 3 + 1
          if (risk-att = 1) [set risk-parameter .7]
          if (risk-att = 2) [set risk-parameter .6]
          if (risk-att = 3)[set risk-parameter .5]
           ]

ask farmers [if (plots-needed = 0) [die]]

ask farmers [set xcor pxcor-of patch-at 0 0
          set ycor pycor-of patch-at 0 0
          set current-farmer-of (patch-at 0 0) who
          set owner-of (patch-at 0 0) who
          find-land
          ]

set initial-farmers count farmers

end

to find-land

  if (count patches with [current-farmer = who-of myself] < plots-needed)
                                          [choose-land]

end

to choose-land

  without-interruption [ask min-one-of patches with [current-farmer = "na" and patch-id != "border"]
                                    [distancexy (xcor-of myself) (ycor-of myself) ]
                                       [set current-farmer who-of myself
                                        set owner who-of myself
                                        set distance-to-farm (round distancexy (value-from turtle (current-farmer)[xcor])
                                                            (value-from turtle (current-farmer)[ycor]))
                                        set for-sale? false
                                        set for-rent? false
                                         ]]

  if ((count patches with [current-farmer = who-of myself])  < plots-needed)
                                       [choose-land]
```

```
end

to assign-patch-id

let counter 1
ask farmers [without-interruption [set counter begin-patch-id
                    ask patches with [current-farmer = who-of myself]
                        [without-interruption [set patch-id counter
                                        set counter counter + 1]
                        ]]]

end

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to create-plots

assing-patch-info
move-farmers-to-owned-land
set-total-land
set-quality-acres-tenure
set-land-use


end

to assing-patch-info

file-open "Patch Info.txt"
let all-patch-info file-read
file-close


ask patches with [patch-id != "border"] [let patch-info item (patch-id - 1) all-patch-info
        set sama-tilled-quality item 2 patch-info
        set sama-tilled item 3 patch-info
        set sama-hay-quality item 4 patch-info
        set sama-hay item 5 patch-info
        set sama-ip-quality item 6 patch-info
        set sama-ip item 7 patch-info
        set sama-np-quality item 8 patch-info
        set sama-np item 9 patch-info
        set patch-leased item 10 patch-info
       if (patch-leased = 640) [set renter current-farmer
                           set owner "na"]
       set barley-yield-index item 13 patch-info
       set canola-yield-index item 14 patch-info
       set wheat-yield-index item 16 patch-info
       set wheat-sf-yield-index item 17 patch-info
       set avg-yield-index (barley-yield-index + canola-yield-index + wheat-yield-index) / 3
       if (barley-yield-index = 0) [ set barley-yield-index "na"
                               set canola-yield-index "na"
                               set wheat-sf-yield-index "na"
                               set wheat-yield-index "na"]]

ask patches [if (renter = "na") [ set pcolor blue]
        if (owner = "na") [set pcolor green]
        if (patch-id = "border") [set pcolor 7]]

end

to move-farmers-to-owned-land

ask farmers [if (renter-of patch-at 0 0 = who and any? patches with [owner = who-of myself])
       [let new-home one-of patches with [owner = who-of myself]
       setxy pxcor-of new-home pycor-of new-home]]
```

```
end

to set-total-land

ask farmers [set total-plots-owned count patches with [owner = who-of myself]
          set total-plots-leased count patches with [renter = who-of myself]]
end


to set-quality-acres-tenure

ask patches with [current-farmer != "na"]
         [ set for-sale? false
          set for-rent? false
          let total-acres-plot sama-hay + sama-np + sama-ip + sama-tilled
          set avg-prod-patch (sama-hay * sama-hay-quality + sama-tilled * sama-tilled-quality + sama-np * sama-np-quality + sama-ip * sama-ip-
quality) / total-acres-plot
         ]
         set mean-patch-quality mean values-from patches [avg-prod-patch]

ask patches with [renter != "na"][set lease-term random 7 + 1
                         set lease-payment initial-lease-rate *  avg-prod-patch / mean-patch-quality
                         set last-adj-lease-rate initial-lease-rate]

end

to set-land-use

ask patches with [current-farmer != "na"]
           [if (sama-tilled-quality < 30 and sama-tilled > 0)[set sama-ip-quality (sama-ip * sama-ip-quality + sama-tilled * sama-tilled-quality) /
(sama-tilled + sama-ip)
                                set sama-ip sama-ip + sama-tilled
                                  set sama-tilled 0
                                  set sama-tilled-quality 0]

            if (sama-hay-quality < 30 and sama-hay > 0)[set sama-ip-quality (sama-ip * sama-ip-quality + sama-hay * sama-hay-quality) / (sama-hay
+ sama-ip)
                                set sama-ip sama-ip + sama-hay
                               set sama-hay 0
                               set sama-hay-quality 0]

             if (sama-tilled-quality < 40 and sama-tilled > 0)[set sama-hay-quality (sama-hay * sama-hay-quality + sama-tilled * sama-tilled-quality)
/ (sama-hay + sama-tilled)
                                set sama-hay sama-tilled + sama-hay
                              set sama-tilled 0
                               set sama-tilled-quality 0]

            if (sama-tilled < 10 and sama-tilled > 0) [set sama-hay-quality (sama-hay * sama-hay-quality + sama-tilled * sama-tilled-quality) /
(sama-hay + sama-tilled)
                          set sama-hay sama-tilled + sama-hay
                          set sama-tilled 0
                          set sama-tilled-quality 0]

            set hay-hay sama-hay
            set tilled-crop sama-tilled
            set acres sama-hay + sama-tilled + sama-np + sama-ip]

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Adjust Farm Assets and Land Use=;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to set-farmers-values

ask farmers [update-acres]
ask farmers [set-debt]
machinery-investment
set-crop-mix
```

```
initial-land-use
ask farmers [update-acres]
ask farmers [without-interruption [if(will-cows = true)[buy-sell-cows]]]
ask farmers [if (n-cows = 0) [set will-cows false]]
machinery-investment
adjust-machinery-value
set-total-accumulated-repairs
set-assets
set-crop-mix
ask farmers [set years-neg-cash random 3]
set-avg-hay-land-q

end


to set-debt

let loan-factor-payment-10 (interest-rate / (1 - (1 / ((1 + interest-rate)^ 10))))
set debt-list []
set debt precision (debt * total-acres-farmed)0
let payment precision (debt * loan-factor-payment-10)0
set debt-list fput (list 10 payment debt) debt-list
set debt-payment payment

end

to set-assets

set land-price initial-land-price
set lease-rate initial-lease-rate

ask farmers [ if (total-plots-owned > 0) [set land-value precision (sum values-from patches with [owner = who-of myself]
                                           [avg-prod-patch / mean-patch-quality * land-price * acres])0 ]
        set capital-value precision (crop-machine-value)0
        set cow-value precision (n-cows * cow-price)0
        let random-cash min-inital-cash + random 5
        set cash precision ((total-crop-acres) * random-cash)0
        set cash precision (cash + n-cows * 4 * random-cash)0
        set assets precision (land-value + capital-value + cash + cow-value)0
        set equity precision (assets - debt)0]

end

to initial-land-use

set-parameters
set-expcted-forage-yields
ask patches with [current-farmer != "na"][adjust-production-mcals]
ask patches [set can-change true]
land-use
ask patches [set years-in-grass random 5 + 1]

end


to set-parameters

set hay-needed 6.000 / (1 - hay-waste)                        ;; need 6.000 mcals for winter feed in thousands
set pasture-1-needed 3.157 / (1 - pasture-waste)              ;; need 3.157 mcals for may june july summer months in thousands
set pasture-2-needed 2.426 / (1 - pasture-waste)              ;; need 2.426 mcals for august,septmeber and october in thousands

set stocking-pasture-1-needed precision (pasture-1-needed / stocking-rate) 3     ;; stocing rate is the maximum pecentage they will have on
pasture adjust the cows per pasture
set stocking-pasture-2-needed precision (pasture-2-needed / stocking-rate)3

set mcals-ton-np 1.933        ;; 1.933 mcals in ton of np in thousands
set mcals-ton-ip 2.196        ;; 2.196 mcals in ton of ip in thousands
set mcals-ton-hay 2.196       ;; 2.196 mcals in ton of ip in thousands
```

```
set last-5-years-price-1 [       6.26    7.91    8.49    7.18    5.49    ]    ;; new prices
set last-5-years-price-2 [       3.08    4.27    4.79    4.41    3.70    ]
set last-5-years-price-3 [2.09   2.64    3.31    3.02    2.52    ]
set last-5-years-price-hay [     65.34   80.78   113.61  79.13   61.16   ]
set last-5-years-price-calf [    1.05    1.28    1.40    1.74    1.85]

set-wieghted-avg

ask farmers [set price-exp-list expected-price-list
        let calf-value precision ((item 3 price-exp-list * 495) - vc-cow)2
        set price-exp-list replace-item 3 price-exp-list calf-value ]


set e-yield-1 21.88
set e-yield-2 28.46
set e-yield-3 42.54

end

to set-expcted-forage-yields

ask patches with [current-farmer != "na" ]
        [let pr-rating 0
        ifelse (sama-np-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-np-quality]
        set e-np-yield-1 precision ((pr-rating / pr-max-hay-yield * (max-hay-1 - threshold-hay-1) + threshold-hay-1) )2
        set e-np-yield-2 precision (pr-rating / pr-max-hay-yield * max-hay-2)2
        ifelse (sama-ip-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-ip-quality]
        set e-ip-yield-1 precision (pr-rating / pr-max-hay-yield * (max-hay-1 - threshold-hay-1) + threshold-hay-1) 2
        set e-ip-yield-2 precision (pr-rating / pr-max-hay-yield * max-hay-2)2
        ifelse (sama-hay-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-hay-quality]
        set e-hay-forage-yield-1 precision (pr-rating / pr-max-hay-yield * (max-hay-1 - threshold-hay-1) + threshold-hay-1) 2
        set e-hay-forage-yield-2 precision (pr-rating / pr-max-hay-yield * max-hay-2)2
        ifelse (sama-tilled-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-tilled-quality]
        set e-tilled-forage-yield-1 precision (pr-rating / pr-max-hay-yield * (max-hay-1 - threshold-hay-1) + threshold-hay-1) 2
        set e-tilled-forage-yield-2 precision (pr-rating / pr-max-hay-yield * max-hay-2)2
        ]

end

to adjust-machinery-value

ask farmers [let random-age random 2
        if (crop-machine-option = 1) [set crop-machine-age 10 + random-age]
        if (crop-machine-option = 2) [set crop-machine-age 5 + random-age]
        if (crop-machine-option > 2) [set crop-machine-age random-age]
        let new-value item (crop-machine-option ) crop-mach-new-value-list
        set crop-machine-value precision (new-value * .948 * (.901 ^ crop-machine-age))0
       ]
end

to set-total-accumulated-repairs

ask farmers [set total-acres-seeding precision (crop-machine-age * item (crop-machine-option) seeder-rate-list * 250)0
        set total-combine-hrs precision (crop-machine-age * 150)0
         ]
end

to set-crop-mix

ask farmers [set yield-mult 1]
ask farmers [if (crop-machine-option <= 1)[set crop-mix [.1 0 0.2 .35 .35]
                                 set yield-mult 1
                                 set fuel 12.47]
        if (crop-machine-option > 1)[set crop-mix [.3 .4 .3 0 0 ]
                                set yield-mult (1 + increase-no-till)
                                set fuel 8.73]
       if (crop-machine-option = 0)[set fuel 0]]

end
```

```
to do-plots

set-current-plot "Land Price"
set-current-plot-pen "price"
plot land-price


set-current-plot "Lease Rate"
set-current-plot-pen "price"
plot lease-rate

end


to set-avg-hay-land-q

ask patches with [tilled-hay + hay-hay > 0] [set avg-hay-q (tilled-hay * sama-tilled-quality + hay-hay * sama-hay-quality) / (tilled-hay + hay-hay)
]
set total-avg-hay-q sum values-from patches [avg-hay-q * (tilled-hay + hay-hay)] / sum values-from patches [tilled-hay + hay-hay]

end

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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Import Data;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to import-data

set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Inputs"

file-open "Canola Price.txt"
let all-data file-read
set crop-1-price-list item (run-number - 1) all-data
file-close

file-open "Canola Yield.txt"
set all-data file-read
set crop-1-yield-list item (run-number - 1) all-data
file-close

file-open "Wheat Price.txt"
set all-data file-read
set crop-2-price-list item (run-number - 1) all-data
file-close

file-open "Wheat Yield.txt"
set all-data file-read
set crop-2-yield-list item (run-number - 1) all-data
file-close

file-open "Barley Price.txt"
set all-data file-read
set crop-3-price-list item (run-number - 1) all-data
file-close

file-open "Barley Yield.txt"
set all-data file-read
set crop-3-yield-list item (run-number - 1) all-data
file-close

file-open "Hay Price.txt"
set all-data file-read
set hay-price-list item (start-run-number - 1) all-data
file-close

file-open "Hay Yield.txt"
```

```
set all-data file-read
set hay-yield-list item (run-number - 1) all-data
file-close

file-open "Calf Price.txt"
set all-data file-read
set calf-price-list item (run-number - 1) all-data
file-close

set  crop-mach-new-value-list [0  430345  480878  610039  687995  1375991  2063986  2751982  3439977  4127972  4815968
        5503963]
set crop-mach-purchase-value-list [0  143838  270687  610039  687995  1375991  2063986  2751982  3439977  4127972
        4815968   5503963]
set crop-capacity-list [500  982  2000  3200  3900  7800  11700  15600  19500  23400  27300
        31200]
set crop-pt-hired-labour-list [0  0.103  0.103  0.069  0.000  0.081  0.089  0.117  0.115  0.129  0.139
        0.147]
set crop-ft-hired-labour-list [0 0  0  0  1  1  2  2  3  3 3 3]

set tractor-value-list [0  124654  159557  201365  220254  440509  660763  881018  1101272  1321527  1541781
        1762035]
set seeder-value-list [0  82080  97710  124175  152558  305115  457673  610230  762788  915346  1067903
        1220461]
set combine-value-list [0  193022  193022  245281  272417  544835  817252  1089670  1362087  1634505  1906922
        2179339]
set header-value-list [0  30588  30588  39218  42766  85532  128298  171064  213830  256596  299362
        342128]
set seeder-width-list [0  30  40  50  60  120  180  240  300  360  420
        480]
set seeder-rate-list [0  13.09  15.27  21.82  26.18  52.36  78.55  104.73  130.91  157.09  183.27  209.45]
set harvest-rate-list [0 9.70  9.70  14.55  17.45  34.91  52.36  69.82  87.27  104.73  122.18  139.64]

end


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to simulation-phase

if (run-number = 1 and year = 0) [reset-timer]
update-parameters
production
fixed-costs
expecation-formulation
land-use
ask farmers with [will-cows = true] [without-interruption   [buy-sell-cows]]
simulate-depreciation
farm-accounting
continue-farming
update-lease
ask farmers[without-interruption [set-expected-income]]
set-exp-lease-investor
land-markets
ask farmers with [will-cows = true] [without-interruption   [buy-sell-cows]]
machinery-investment
set-crop-mix
postive-cash
export-data
do-plots
if (continues = true)[if (year < sim-length) [simulation-phase]]
set run-number run-number + 1
if (run-number <= total-runs)[clear-model
                         setup
                         simulation-phase
                        import-data]
set scenario scenario + 1
if (scenario <= end-sim-scenario)[set run-number start-run-number
                          clear-model
```

```
                    setup
                    simulation-phase
                    import-data]

show (list "time in seconds" timer)

end


to update-parameters

set year year + 1
ask farmers [set age age + 1]
set max-hay-yield-2 max-hay-yield-1 * .3
set year-20-factor (1 + discount-rate)^(-20)
set pv-annuity-land ((1 - (1 / ((1 + discount-rate)^ 20))) / discount-rate)
set loan-factor-payment-20 (interest-rate / (1 - (1 / ((1 + interest-rate)^ 20))))
set loan-factor-payment-25 (interest-rate / (1 - (1 / ((1 + interest-rate)^ 25))))
set loan-factor-payment-5 (interest-rate / (1 - (1 / ((1 + interest-rate)^ 5))))
if (year = 1) [set max-distance start-max-distance]
let %-initial-farmers count farmers / initial-farmers
let dist-inc 1
if (%-initial-farmers < 0.9 and max-distance = start-max-distance )[set max-distance max-distance + dist-inc]
if (%-initial-farmers < 0.8 and max-distance = start-max-distance + dist-inc)[set max-distance max-distance +  (2 * dist-inc)]
if (%-initial-farmers < 0.7 and max-distance = start-max-distance +(2 * dist-inc))[set max-distance max-distance +  (3 * dist-inc)]
if (%-initial-farmers < 0.6 and max-distance = start-max-distance +(3 * dist-inc))[set max-distance max-distance +  (4 * dist-inc)]
if (%-initial-farmers < 0.5 and max-distance = start-max-distance +(4 * dist-inc))[set max-distance max-distance +  (5 * dist-inc)]
if (%-initial-farmers < 0.4 and max-distance = start-max-distance +(5 * dist-inc))[set max-distance max-distance +  (6 * dist-inc)]
if (%-initial-farmers < 0.3 and max-distance = start-max-distance +(6 * dist-inc))[set max-distance max-distance +  (7 * dist-inc)]
if (%-initial-farmers < 0.2 and max-distance = start-max-distance +(7 * dist-inc))[set max-distance max-distance +  (8 * dist-inc)]

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Production;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to production

update-prices-and-yields
crop-production
forage-production
livestock-income
hay-income
pasture-income
seeding-breaking-grass


end


to update-prices-and-yields

ask patches [set need-sell false]
set yield-1 item (year - 1) crop-1-yield-list
set yield-2 item (year - 1) crop-2-yield-list
set yield-3 item (year - 1) crop-3-yield-list
set hay-yield-1 item (year - 1) hay-yield-list
set max-hay-yield-1 hay-yield-1 * pr-max-hay-yield / 50          ;; assumes average productivity of hay is on land with PR rating of 50
set max-hay-yield-2 .2 * max-hay-yield-1

set price-1 item (year - 1) crop-1-price-list
set price-2 item (year - 1) crop-2-price-list
set price-3 item (year - 1) crop-3-price-list
set price-hay item (year - 1) hay-price-list
set price-calf item (year - 1) calf-price-list

adjust-price-scenario
```

```
set last-5-years-price-1 fput price-1 last-5-years-price-1
set last-5-years-price-2 fput price-2 last-5-years-price-2
set last-5-years-price-3 fput price-3 last-5-years-price-3
set last-5-years-price-hay fput price-hay last-5-years-price-hay
set last-5-years-price-calf fput price-calf last-5-years-price-calf

set last-5-years-price-1 remove-item 5 last-5-years-price-1
set last-5-years-price-2 remove-item 5 last-5-years-price-2
set last-5-years-price-3 remove-item 5 last-5-years-price-3
set last-5-years-price-hay remove-item 5 last-5-years-price-hay
set last-5-years-price-calf remove-item 5 last-5-years-price-calf

end

to adjust-price-scenario

if (scenario = 2)[set price-1 price-1 * 1.25
                set price-2 price-2 * 1.25
                set price-3 price-3 * 1.25]

if (scenario = 3)[set price-calf price-calf * 1.25]

end


to crop-production

ask patches with [current-farmer != "na"]
        [without-interruption [ifelse (tilled-crop > 0)[

 let tonnes-crop-1 value-from farmer (current-farmer) [item 0 crop-mix * yield-mult ] * canola-yield-index * yield-1 / 44.09
 let tonnes-crop-2 value-from farmer (current-farmer) [item 1 crop-mix * yield-mult ] * wheat-yield-index * yield-2 / 36.74
 let tonnes-crop-3 value-from farmer (current-farmer) [item 2 crop-mix *  yield-mult ] * barley-yield-index * yield-3  / 45.93
 let tonnes-crop-4 value-from farmer (current-farmer) [item 3 crop-mix * yield-mult ] * wheat-sf-yield-index * yield-2  / 36.74

let gross-crop-inc tonnes-crop-1 * 44.09 * price-1 + tonnes-crop-2 * 36.74 * price-2 + tonnes-crop-3 * 45.93 * price-3 + tonnes-crop-4 * 36.74 *
price-2

let vc-acre value-from farmer (current-farmer) [item 0 crop-mix] * (per-acre-vc-1 + value-from farmer (current-farmer) [fuel]) +
          value-from farmer (current-farmer) [item 1 crop-mix] * (per-acre-vc-2 + value-from farmer (current-farmer) [fuel]) +
          value-from farmer (current-farmer) [item 2 crop-mix] * (per-acre-vc-3 + value-from farmer (current-farmer) [fuel]) +
          value-from farmer (current-farmer) [item 3 crop-mix] * (per-acre-vc-4 + value-from farmer (current-farmer) [fuel]) +
          value-from farmer (current-farmer) [item 4 crop-mix] * per-acre-vc-sf

let vc-tonne tonnes-crop-1 * per-tonne-vc-1 + tonnes-crop-2 * per-tonne-vc-2 + tonnes-crop-3 * per-tonne-vc-3 + tonnes-crop-4 * per-tonne-vc-4

let bu (tonnes-crop-1 * 44.09  + tonnes-crop-2 * 36.74  + tonnes-crop-3 * 45.93 + tonnes-crop-4 * 36.74 )

let trans-cost-crop bu * trans-rate-crop-mile-1 + (distance-to-farm - 1) * trans-rate-crop-mile

set plot-income-crop precision ((gross-crop-inc - vc-acre - vc-tonne - trans-cost-crop)* tilled-crop) 2

set gross-income-crop gross-crop-inc * tilled-crop          ]
          [set plot-income-crop 0
          set gross-income-crop 0]
          ] ]

ask farmers [set total-crop-income precision (sum values-from patches with [current-farmer = who-of myself][plot-income-crop])0
           set total-gross-crop-inc precision (sum values-from patches with [current-farmer = who-of myself][gross-income-crop])0 ]

ask patches with [current-farmer != "na"]  [set fallow  value-from farmer (current-farmer) [item 4 crop-mix] * tilled-crop]

end

to forage-production

ask patches with [current-farmer != "na"  ]
           [let pr-rating 0
           ifelse (sama-np-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-np-quality]
```

```
    let np-yield-1 (pr-rating / pr-max-hay-yield * (max-hay-yield-1 - threshold-hay-1) + threshold-hay-1)
    let np-yield-2 (pr-rating / pr-max-hay-yield * max-hay-yield-2)

    ifelse (sama-ip-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-ip-quality]

    let ip-yield-1 (pr-rating / pr-max-hay-yield * (max-hay-yield-1 - threshold-hay-1) + threshold-hay-1)
    let ip-yield-2 (pr-rating / pr-max-hay-yield * max-hay-yield-2)

    let np-prod-1 np-yield-1 * sama-np * mcals-ton-np
    let np-prod-2 np-yield-2 * sama-np * mcals-ton-np
    let ip-prod-1 ip-yield-1 * sama-ip * mcals-ton-ip
    let ip-prod-2 ip-yield-2 * sama-ip * mcals-ton-ip

    ifelse (sama-hay-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-hay-quality]

    let hay-forage-prod-1 (pr-rating / pr-max-hay-yield * (max-hay-yield-1 - threshold-hay-1) + threshold-hay-1)
    let hay-forage-prod-2 (pr-rating / pr-max-hay-yield) * (max-hay-yield-2)

    let hay-hay-prod hay-forage-prod-1 * hay-hay * mcals-ton-hay

    let hay-pasture-1-prod hay-forage-prod-1 * hay-pasture * mcals-ton-ip
    let hay-pasture-2-prod (hay-hay + hay-pasture) * hay-forage-prod-2 *  mcals-ton-ip

    ifelse (sama-tilled-quality > pr-max-hay-yield)[set pr-rating pr-max-hay-yield][set pr-rating sama-tilled-quality]

    let tilled-forage-yield-1 (pr-rating / pr-max-hay-yield * (max-hay-yield-1 - threshold-hay-1) + threshold-hay-1)
    let tilled-forage-yield-2 (pr-rating / pr-max-hay-yield) * (max-hay-yield-2)

    let tilled-hay-prod tilled-forage-yield-1 * tilled-hay * mcals-ton-hay
    let tilled-pasture-1-prod  tilled-forage-yield-1 * tilled-pasture * mcals-ton-ip
    let tilled-pasture-2-prod (tilled-hay + tilled-pasture ) * tilled-forage-yield-2 * mcals-ton-ip

    set hay-prod-mcals hay-hay-prod + tilled-hay-prod
    set pasture-1-prod-mcals ip-prod-1 + np-prod-1 + hay-pasture-1-prod + tilled-pasture-1-prod
    set pasture-2-prod-mcals  ip-prod-2  + np-prod-2 + hay-pasture-2-prod + tilled-pasture-2-prod

    let total-hay-prod-tons hay-prod-mcals / mcals-ton-hay

    set vc-hay precision ((tilled-hay + hay-hay) * cost-hay-acre + total-hay-prod-tons * cost-hay-ton )2

    if (value-from farmer (current-farmer) [will-cows = true]) [set hay-trans-cost total-hay-prod-tons * trans-rate-hay-mile-1 +  total-hay-prod-
tons * (distance-to-farm - 1) * trans-rate-ton-hay-mile]

    if (years-in-grass = 1)[set hay-prod-mcals 0
                set pasture-1-prod-mcals 0
                set pasture-2-prod-mcals 0
                set vc-hay 0
                set hay-trans-cost 0]
    ]


ask farmers [set hay-reserves hay-reserves * (1 - loss-hay-storage)
    let extra-pasture-1-mcals 0
    let short-pasture-1-mcals 0
    let short-pasture-2-mcals 0

    let total-pasture-1-mcals sum values-from patches with [current-farmer = who-of myself][pasture-1-prod-mcals]
    let total-pasture-2-mcals sum values-from patches with [current-farmer = who-of myself][pasture-2-prod-mcals]
    set total-hay-mcals sum values-from patches with [current-farmer = who-of myself][hay-prod-mcals]

    let mcals-pasture-1-needed n-cows *  pasture-1-needed
    ifelse (mcals-pasture-1-needed < total-pasture-1-mcals) [set extra-pasture-1-mcals total-pasture-1-mcals - mcals-pasture-1-needed]
                        [set short-pasture-1-mcals mcals-pasture-1-needed - total-pasture-1-mcals]

    let transfered-to-p2 extra-pasture-1-mcals * ( 1 - loss-delayed-graze)

    set total-pasture-1-mcals total-pasture-1-mcals + transfered-to-p2

    let mcals-pasture-2-needed n-cows *  pasture-2-needed
```

```
          ifelse (mcals-pasture-2-needed < total-pasture-2-mcals) [set short-pasture-2-mcals 0]
                                          [set short-pasture-2-mcals mcals-pasture-2-needed - total-pasture-2-mcals]

          let pasture-mcals-short short-pasture-1-mcals + short-pasture-2-mcals

          set pasture-mcals-short pasture-mcals-short * (1 - pasture-waste)                                    ;;; adjusts back to the acutal
mcals needed not including pasture waste

          let mcals-hay-needed n-cows *  hay-needed + pasture-mcals-short
          ifelse(mcals-hay-needed > total-hay-mcals) [set tons-hay-short precision ((mcals-hay-needed - total-hay-mcals) / mcals-ton-hay)2
                              set tons-hay-extra 0]
                              [set tons-hay-short 0
                              set tons-hay-extra precision ((total-hay-mcals - mcals-hay-needed) / mcals-ton-hay)2]

          if (tons-hay-extra > 0) [set hay-reserves hay-reserves + tons-hay-extra]
          if (tons-hay-short > 0) [set hay-reserves hay-reserves - tons-hay-short]

          set total-vc-hay precision (sum values-from patches with [current-farmer = who-of myself][vc-hay]) 2
          set total-hay-trans-cost precision (sum values-from patches with [current-farmer = who-of myself][hay-trans-cost]) 2
            ]

end


to livestock-income

let calf-value (price-calf * 495) - vc-cow

ask farmers [set total-cow-inc precision (n-cows * calf-value) 2
          set total-gross-cow-inc precision (n-cows * price-calf * 495) 2 ]

end

to hay-income

ask farmers with [n-cows > 0]
         [ set hay-for-sale 0
         set buy-hay 0
         let annual-tons-hay-needed precision (n-cows * hay-needed / mcals-ton-hay)2
         let target-reserves .15 * annual-tons-hay-needed
         let min-reserves .05 * annual-tons-hay-needed
         let max-reserves .3 * annual-tons-hay-needed
         if (hay-reserves < min-reserves)[set buy-hay precision (min-reserves - hay-reserves)2]
                                                  ;only buy hay to the minium reserves required (try build reserves yourself)

         if (hay-reserves > max-reserves)[set hay-for-sale precision (hay-reserves - target-reserves)2]          ;;sell hay to the target reserves level

          set hay-reserves precision (hay-reserves + buy-hay - hay-for-sale)2
          ]

ask farmers with [n-cows = 0][set hay-for-sale tons-hay-extra
                    set hay-reserves precision (hay-reserves + buy-hay - hay-for-sale)2]

ask farmers [set total-hay-inc precision (hay-for-sale * (price-hay - transaction-fee-hay))2
          set total-hay-purchase-cost precision (buy-hay * price-hay)2
          set total-gross-hay-inc total-hay-inc]

end


to pasture-income

ask farmers [if (n-cows = 0) [set total-pasture-inc total-natural-pasture * np-rental + total-improved-pasture * ip-rental]]

end


to seeding-breaking-grass
```

```
ask farmers [set breaking-grass 0
           set seed-grass  sum values-from patches with [current-farmer = who-of myself and (tilled-hay > 0 or tilled-pasture > 0) and years-in-grass
= 1][sama-tilled * seed-grass-cost]
          ]

ask patches with [owner != "na" and current-farmer != "na"][without-interruption [if (years-in-grass + 1 = 7 and (tilled-pasture > 0 or tilled-hay >
0))
                        [ask farmer (current-farmer)[set breaking-grass breaking-grass + sama-tilled * break-grass-cost]]]]

ask patches with [renter != "na" and current-farmer != "na"][without-interruption [if ((years-in-grass + 1 = 7 or lease-term + 1 = 7)and (tilled-
pasture > 0 or tilled-hay > 0))
                        [ask farmer (current-farmer)[set breaking-grass breaking-grass + sama-tilled * break-grass-cost]]]]

ask farmers [set last-years-pasture-crop-acres total-crop-acres + total-improved-pasture + total-natural-pasture]

end


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to custom-work

ask farmers [if (crop-machine-option = 0)[set custom-crop total-crop-acres * (1 - item 4 crop-mix) * custom-crop-cost]
           ]

end


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to fixed-costs
ask farmers [debt-service]
simulate-land-lease-payment


end

to debt-service

    let result2 add debt-list                                                   ;;; calculates annual debt payment
    set debt-payment result2

    let list-index 0
    foreach debt-list [
                   set debt-list replace-item list-index debt-list list (item 0 ? - 1) (item 1 ?)         ;;; reduces years left on debt
                   set list-index list-index + 1]


   set debt-list filter [first ? != 0] debt-list                                   ;;; remove paid off debt
   set list-index 0
   foreach debt-list [
                  if item 0 ? = 0 [set debt-list remove (item list-index debt-list) debt-list]
                  set list-index list-index + 1
                 ]

      set list-index 0                                                          ;;; calculate principal balance of each loan
    foreach debt-list [
                   set debt-list replace-item list-index debt-list (list (item 0 ?)(item 1 ?)
                   (precision (item 1 ? * ((1 - ( 1 / (1 + interest-rate)^ item 0 ?))/ interest-rate))0))
                   set list-index list-index + 1]

     let result3 add2 debt-list                                                 ;;; update total debt-value (principal remaining for all debts)
    set debt result3

 end
```

```
;;; CALCULATORS

 to-report add [lst]
   let result 0
   foreach lst [set result result + item 1 ?]
   report result
 end

 to-report add2 [lst]
   let result 0
   foreach lst [set result result + item 2 ?]
   report result
 end


to simulate-land-lease-payment

ask farmers [set total-land-lease-payment precision ((sum values-from patches with [current-farmer = who-of myself][lease-payment * acres]))0]

end


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to simulate-depreciation

ask farmers [set crop-machine-age crop-machine-age + 1
        let new-value item (crop-machine-option ) crop-mach-new-value-list
        set crop-machine-value precision (new-value * .948 * (.901 ^ crop-machine-age))0
        ]

end

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to farm-accounting

simulate-hired-labour
ask farmers [set total-repairs 0
        if (crop-machine-option > 0) [without-interruption [simulate-repairs]]]
cash-flow
ask farmers [without-interruption [balance-sheet]]
ask farmers [refinance-loans?]
postive-cash
ask farmers [without-interruption [balance-sheet]]

end

to simulate-hired-labour

ask farmers [let full-time-workers item crop-machine-option crop-ft-hired-labour-list
        let full-time-crop-cost full-time-workers * full-time-salary
        let pt-hired-labour-hrs item crop-machine-option crop-pt-hired-labour-list
        let pt-crop-cost pt-hired-labour-hrs * total-crop-acres * pt-labour-cost
        set total-crop-hired-labour pt-crop-cost + full-time-crop-cost
        let cow-labour 0
        if (n-cows > 300)[set cow-labour 1]
        if (n-cows > 600)[set cow-labour 2]
        if (n-cows > 900)[set cow-labour 2]
        if (n-cows > 1200)[set cow-labour 4]
        if (n-cows > 1500)[set cow-labour 5]

        let cow-labour-hours cow-labour * 60 * 10
        let total-cow-hired-labour cow-labour-hours * pt-labour-cost
        set hired-labour precision (total-crop-hired-labour + total-cow-hired-labour)0]
```

```
end


to simulate-repairs

let acres-seeded total-crop-acres
if (crop-machine-option = 1)[set acres-seeded acres-seeded * 2]          ;; this is to account for 2 passes with conventional seeding

let new-hrs-seed acres-seeded / item (crop-machine-option) seeder-rate-list
let new-hrs-harvest (total-crop-acres * (1 - item 4 crop-mix)) / item (crop-machine-option) harvest-rate-list

let old-hrs-tractor total-acres-seeding / item (crop-machine-option) seeder-rate-list

let a 1.5
let b 0.12
let c .007

if (crop-machine-option > 1)[set b 0.1]

let old-accum-repair-tractor item (crop-machine-option) tractor-value-list / 100 * b * (c * old-hrs-tractor)^ a
set old-hrs-tractor old-hrs-tractor + new-hrs-seed
let new-accum-repair-tractor item (crop-machine-option) tractor-value-list / 100 * b * (c * old-hrs-tractor)^ a

let tractor-repairs new-accum-repair-tractor - old-accum-repair-tractor

set a 1.3
set b 0.301
set c 0.018

let old-accum-repair-seeder item (crop-machine-option) seeder-value-list / 100 * b *
                        (c * (total-acres-seeding / item (crop-machine-option) seeder-width-list))^ a

set total-acres-seeding total-acres-seeding + acres-seeded
let new-accum-repair-seeder item (crop-machine-option) seeder-value-list / 100 * b *
                        (c * (total-acres-seeding / item (crop-machine-option) seeder-width-list))^ a

let seeder-repairs new-accum-repair-seeder - old-accum-repair-seeder

set a 1.4
set b 0.096
set c 0.013

let old-accum-repair-combine item (crop-machine-option) combine-value-list / 100 * b * (c * total-combine-hrs)^ a
let new-combine-hrs total-combine-hrs + new-hrs-harvest
let new-accum-repair-combine item (crop-machine-option) combine-value-list / 100 * b * (c * new-combine-hrs)^ a

let combine-repairs new-accum-repair-combine - old-accum-repair-combine

set a 1.4
set b 0.159
set c 0.025

let old-accum-repair-header item (crop-machine-option) header-value-list / 100 * b * (c * total-combine-hrs)^ a
set total-combine-hrs total-combine-hrs + new-hrs-harvest
let new-accum-repair-header item (crop-machine-option) header-value-list / 100 * b * (c * total-combine-hrs)^ a

let header-repairs new-accum-repair-header - old-accum-repair-header

set total-repairs precision (tractor-repairs + seeder-repairs + combine-repairs + header-repairs)0

end


to cash-flow

ask farmers [set total-annual-gross-inc total-gross-crop-inc + total-gross-cow-inc + total-gross-hay-inc

            set ncfbi precision (total-crop-income +  total-cow-inc - total-vc-hay + total-hay-inc - total-hay-trans-cost - total-hay-purchase-cost +
total-pasture-inc
```

```
        - hired-labour  + off-farm-inc - custom-crop - seed-grass - breaking-grass - total-repairs )0

     set ncfbi precision (ncfbi - debt-payment - total-land-lease-payment)0

    let fl-profits 0
     if (ncfbi > 0) [set fl-profits precision (family-living-profits * ncfbi)0]
     set family-living max (list min-family-withdrawal  fl-profits)
     if (family-living >  max-family-withdrawal)[set family-living max-family-withdrawal]
     set ncfbi precision (ncfbi - family-living )0
     set cash precision (cash + ncfbi)0
    ]

ask farmers [ifelse (NCFBI  < 0)
     [set years-neg-cash years-neg-cash + 1][set years-neg-cash 0]]


end


to refinance-loans?

 if (debt > (0.75 * (assets - cash)) and cash > (debt - 0.75 * (assets - cash)))                    ;; if debt is greater than 75% of assets
without cash
  [set cash cash - (debt - 0.75 * (assets - cash))                          ;; reduce debt to 75% by paying it down with
cash and
   let payment precision((0.75 * (assets - cash)) * loan-factor-payment-20 )2          ;; update-debt list
   set debt-list []
   set debt-list fput(list 20 payment (precision (0.75 * (assets - cash))0))debt-list
   update-debt]

end


to postive-cash

ask farmers [if (cash < 0) [let payment precision((-1 * cash) * loan-factor-payment-5 )2
            set debt-list fput (list 5 payment (precision (-1 * cash)0)) debt-list
            update-debt
            set cash 0 ]
           ]

end


to update-debt

   let result2 add debt-list                                   ;;; calculates annual debt payment
   set debt-payment result2

      let list-index 0
   foreach debt-list [
          set debt-list replace-item list-index debt-list (list (item 0 ?)(item 1 ?)          ;;; calculate principal balance of each loan
          (precision (item 1 ? * ((1 - ( 1 / (1 + interest-rate)^ item 0 ?))/ interest-rate))0))
          set list-index list-index + 1]

   let result3 add2 debt-list                                  ;;; update total debt-value (principal remaining for all debts)
   set debt result3

 end


to balance-sheet

let all-patches-avg-prod mean values-from patches with [patch-id != "border"] [avg-prod-patch]
if (total-plots-owned > 0) [let avg-land-q mean values-from patches with [owner = who-of myself] [avg-prod-patch]
            set land-value precision (land-price * avg-land-q / all-patches-avg-prod * total-acres-owned)0 ]

set cow-value precision (n-cows * cow-price)0
set capital-value precision (crop-machine-value)0
set assets precision (land-value + capital-value  + cash + cow-value)0
```

```
set equity precision (assets - debt)0

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Continue Farming;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to continue-farming

exit-industry

end

to exit-industry

  ask farmers [without-interruption[if (years-neg-cash =  5 and random 101 / 100 < .15)[determine-sell-rent
                                                    set cashflow cashflow + 1
                                                    set why-exit "cash flow"
                                                    without-interruption [export-exits]
                                                       die]
                    if (years-neg-cash =  6 and random 101 / 100 < .2)[determine-sell-rent
                                                    set cashflow cashflow + 1
                                                    set why-exit "cash flow"
                                                    without-interruption [export-exits]
                                                       die]

                    if (years-neg-cash =  7 and random 101 / 100 < .3)[determine-sell-rent
                                                    set cashflow cashflow + 1
                                                    set why-exit "cash flow"
                                                    without-interruption [export-exits]
                                                       die]
                   if (years-neg-cash =  8 and random 101 / 100 < .4)[determine-sell-rent
                                                    set cashflow cashflow + 1
                                                    set why-exit "cash flow"
                                                    without-interruption [export-exits]
                                                       die]

                   if (years-neg-cash =  9) [determine-sell-rent
                                 set cashflow cashflow + 1
                                 set why-exit "cash flow"
                                 without-interruption [export-exits]
                                 die]

                                                    ]]



  ask farmers [without-interruption[if ((debt) > (0.9 * assets) or assets = 0)[
     ask patches with [owner = who-of myself][
        set owner "na" set current-farmer "na" set for-sale? true set need-sell true]
     ask patches with [renter = who-of myself][set renter "na" set current-farmer "na" set for-sale? true]

        set bankrupt bankrupt + 1
       set why-exit "bankrupt"
       without-interruption [export-exits]
       die
        ]]]

  ask farmers with [(age >= 55) and (age < 60)][without-interruption [if (random 101 < retirement-tendency-55-59 * 100)  [retire]]   ]
  ask farmers with [(age >= 60) and (age < 65)][without-interruption[if (random 101 < retirement-tendency-60-64 * 100)  [retire]]]
  ask farmers with [(age >= 65) and (age < 70)][without-interruption[if (random 101 < retirement-tendency-65-69 * 100)  [retire]]]
  ask farmers with [age >= 70]                [without-interruption[if (random 101 < retirement-tendency-70-over * 100)[retire]]]
  ask farmers with [age >= 80]                 [without-interruption                                   [retire]]

end
```

```
to retire

 ifelse (random 101 < transfer-prob * 100) [without-interruption [transfer]]
                              [determine-sell-rent
                              set oldage oldage + 1
                              set why-exit "retire"
                              without-interruption [export-exits]
                              die]
end


to determine-sell-rent

ifelse (random 101 >= sell-prob-retired * 100) [ask patches with [owner = who-of myself]
                                              [set owner "na" set current-farmer "na" set for-sale? true]
                                          ask patches with [renter = who-of myself]
                                              [set renter "na" set current-farmer "na"
                                              set for-sale? true]]

                                  [ask patches with [owner = who-of myself]
                                              [set owner "na" set current-farmer "na" set for-rent? true]
                                   ask patches with [renter = who-of myself]
                                              [set renter "na" set current-farmer "na"
                                             set for-sale? true]]
end


to transfer

without-interruption [

let old-equity equity
let old-cash cash
let old-assets assets

let buy-value precision (min-cash-retire + transfer-rate * (equity -  min-cash-retire))0

if (equity - min-cash-retire < 0) [set buy-value precision (assets - cash)0
                               set cash 0]

set cash precision (cash - buy-value)0

let borrow precision (-1 * cash)0
ifelse (borrow < 0) [set cash precision (-1 * borrow)0
                  set borrow 0]
                 [set cash 0]

let payment precision(borrow * loan-factor-payment-25 )2
set debt-list []
set debt-list fput (list 25 payment (precision (borrow)0)) debt-list
set debt-payment payment
set debt borrow
without-interruption [update-debt]

set-off-farm-inc

without-interruption [set-expected-income]

let full-time-workers item crop-machine-option crop-ft-hired-labour-list
let full-time-crop-cost full-time-workers * full-time-salary
let pt-hired-labour-hrs item crop-machine-option crop-pt-hired-labour-list
let pt-crop-cost pt-hired-labour-hrs * total-crop-acres * pt-labour-cost           ;; used to maintain same family living withdrawal
                                                                       ;; Hired labour is deducted when they creat their bid
 let cow-labour 0
 if (n-cows > 300)[set cow-labour 1]
 if (n-cows > 600)[set cow-labour 2]
 if (n-cows > 900)[set cow-labour 2]
 if (n-cows > 1200)[set cow-labour 4]
 if (n-cows > 1500)[set cow-labour 5]
```

```
let cow-labour-hours cow-labour * 60 * 10
let total-cow-hired-labour cow-labour-hours * pt-labour-cost

let exp-hired-labour pt-crop-cost + full-time-crop-cost + total-cow-hired-labour

let exp-net-cf exp-cf - exp-hired-labour

ifelse (exp-net-cf > debt-payment) [
                        set cash precision (cash + random-normal 50000 10000)0
                        balance-sheet
                         ifelse (debt / assets < .6)[set transfer-value buy-value
                                      set transfer-borrow borrow
                                      set age age - 30
                                      set transfers transfers + 1
                                      set generation generation + 1

                                      without-interruption [export-transfer]
                                      ]

                                      [determine-sell-rent
                                       set oldage oldage + 1
                                       set why-exit "retire"
                                       without-interruption [export-exits]
                                       die
                                      ]

                        ]

                        [determine-sell-rent
                          set oldage oldage + 1
                         set why-exit "retire"
                          without-interruption [export-exits]
                          die]
  ]

end

to set-off-farm-inc

if(total-acres-farmed < 640)[set off-farm-employ true]

if(total-acres-farmed > 640 and total-acres-farmed < 1280)[without-interruption [ifelse (random 101 < off-farm-employment-640-1280 * 100) [set
off-farm-employ true]
                                                                                                    [set off-farm-employ false]]]

if(total-acres-farmed > 1280 and total-acres-farmed < 1920)[without-interruption [ifelse (random 101 < off-farm-employment-1280-1920 * 100)
[set off-farm-employ true]
                                                                                                    [set off-farm-employ false]]]

if(total-acres-farmed > 1920 and total-acres-farmed < 3200)[without-interruption [ifelse (random 101 < off-farm-employment-1920-3200 * 100)
[set off-farm-employ true]
                                                                                                    [set off-farm-employ false]]]

if(total-acres-farmed > 3200)[without-interruption [ifelse (random 101 < off-farm-employment-greater-3200 * 100) [set off-farm-employ true]
                                                                                [set off-farm-employ false]]]
if(off-farm-employ = false)[set off-farm-inc 0]

if (off-farm-employ = true) [set off-farm-inc random-normal 50943 36493]

if (off-farm-inc < 0) [set off-farm-inc 0]

end

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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Expectation Formulation;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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;;notes
;;the wieghted average of all expectations is the same for all farmers and is later differentiated by a random error term
;;each farmer an error in price expectation that is the same for all prices of crops and different for forage
```

```
to expecation-formulation

set-wieghted-avg
set-individual

end

to set-wieghted-avg

if (year > 0)[set last-year-exp-list expected-price-list]

let exp-crop-1 precision (5 / 15 * item (0) last-5-years-price-1 + 4 / 15 * item (1) last-5-years-price-1 + 3 / 15 * item (2) last-5-years-price-1 +
                         2 / 15 * item (3) last-5-years-price-1 + 1 / 15 * item (4) last-5-years-price-1)2

let exp-crop-2 precision (5 / 15 * item (0) last-5-years-price-2 + 4 / 15 * item (1) last-5-years-price-2 + 3 / 15 * item (2) last-5-years-price-2 +
                         2 / 15 * item (3) last-5-years-price-2 + 1 / 15 * item (4) last-5-years-price-2)2

let exp-crop-3  precision (5 / 15 * item (0) last-5-years-price-3 + 4 / 15 * item (1) last-5-years-price-3 + 3 / 15 * item (2) last-5-years-price-3 +
                         2 / 15 * item (3) last-5-years-price-3 + 1 / 15 * item (4) last-5-years-price-3)2


let exp-hay precision (5 / 15 * item (0) last-5-years-price-hay + 4 / 15 * item (1) last-5-years-price-hay + 3 / 15 * item (2) last-5-years-price-hay +
                         2 / 15 * item (3) last-5-years-price-hay + 1 / 15 * item (4) last-5-years-price-hay)2

let exp-calf-value precision (5 / 15 * item (0) last-5-years-price-calf + 4 / 15 * item (1) last-5-years-price-calf + 3 / 15 * item (2) last-5-years-
price-calf +
                         2 / 15 * item (3) last-5-years-price-calf + 1 / 15 * item (4) last-5-years-price-calf)2

set expected-price-list (list (exp-crop-1) (exp-crop-2) (exp-crop-3) (exp-calf-value) (exp-hay))

end

to set-individual

ask farmers [ without-interruption [let error (1 + (random 11 - 5) / 100)
      set price-exp-list expected-price-list
      set price-exp-list replace-item 0 price-exp-list precision (item 0 price-exp-list * error)2
      set price-exp-list replace-item 1 price-exp-list precision (item 1 price-exp-list * error)2
      set price-exp-list replace-item 2 price-exp-list precision (item 2 price-exp-list * error)2

      set error (1 + (random 11 - 5) / 100)

      set price-exp-list replace-item 4 price-exp-list precision (item 4 price-exp-list * error)2     ;; market price forage

      set error (1 + (random 11 - 5) / 100)

      let calf-value precision ((item 3 price-exp-list * error * 495) - vc-cow)2
      set price-exp-list replace-item 3 price-exp-list calf-value                ;sets expected value of calf
       ]]


end

to set-exp-lease-investor

let e-change-1 (item 0 expected-price-list - item 0 last-year-exp-list) / item 0 last-year-exp-list         ;; % change in canola price
let e-change-2 (item 1 expected-price-list - item 1 last-year-exp-list) / item 1 last-year-exp-list         ;; % change in wheat price
let e-change-3 (item 2 expected-price-list - item 2 last-year-exp-list) / item 2 last-year-exp-list         ;; % change in barley price

let e-change-calf (item 3 expected-price-list - item 3 last-year-exp-list) / item 3 last-year-exp-list         ;; % change in calf price

let e-grain-change .3 * e-change-1 + .4 * e-change-2 + .3 * e-change-3

let wieght-grain  (sum values-from patches [tilled-crop] / sum values-from patches [tilled-crop + tilled-hay + hay-hay + sama-np + tilled-pasture +
hay-pasture + sama-ip])
let wieght-calf (1 - wieght-grain)
```

```
set exp-lease lease-rate + wieght-grain * adjustment-lease-prices * e-grain-change * lease-rate + wieght-calf *  adjustment-lease-prices * e-change-calf * lease-rate

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Update Leases ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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;;;;need to include fixed costs and opportunity on investment



to update-lease

ask patches with [renter != "na"] [set lease-term lease-term + 1

                        if (lease-term = 7)[without-interruption[
                                    set for-sale? true
                                    let old-farmer current-farmer
                                    set current-farmer "na"
                                    set renter "na"
                                    ask farmer (old-farmer)[adjust-farmer-mcals]]]
                                    ]

ask farmers [update-acres]

let all-patches-avg-prod mean values-from patches with [patch-id != "border"] [avg-prod-patch]
set avg-lease mean values-from patches with [renter != "na"][lease-payment *  all-patches-avg-prod / avg-prod-patch ]

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Land Use;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to land-use

ask patches [set net-income-crop 0
          set additional-income-grass 0
          set additional-cow-income 0
          set came-from-bid false]

if (year = 0) [adjust-hay]

if (year > 0)[ask patches [set years-in-grass years-in-grass + 1
                    set break-grass-tilled false
                    if (years-in-grass = 7 and (tilled-pasture > 0 or tilled-hay > 0)) [set break-grass-tilled true
                                                            set tilled-crop sama-tilled
                                                            set tilled-hay 0
                                                            set tilled-pasture 0]
                   set can-change true
                   if (renter != "na" and lease-term > 2)
                             [set can-change false]
             ]  ]

ask farmers [ifelse (total-crop-acres > 0)[set adjusted-cult-to-hay  true][set adjusted-cult-to-hay  false]
         ]

ask farmers  [if (will-cows = true) [without-interruption [adjust-cult-to-grass-cows]]
           if (will-cows = false) [without-interruption[adjust-cult-to-grass-sell]]]

ask farmers [if any? patches with [current-farmer = who-of myself][without-interruption [ask one-of patches with [current-farmer = who-of myself][adjust-production-mcals]]]]

ask farmers [update-acres]

end
```

```
to adjust-hay

ask farmers with [will-cows = true][if( cows-hay > cows-pasture-1 and any? patches with [current-farmer = who-of myself and hay-hay > 0 ] )
                                            [without-interruption [ask min-one-of patches with [current-farmer = who-of myself and hay-hay > 0 ]
[sama-hay-quality]
                                               [without-interruption [set-total-mcals-others
                                                                set came-from-year-1 true
                                                                 switch-hay-land-to-pasture
                                                                adjust-production-mcals
                                                                set came-from-year-1 false]]]]

                                           if (cows-hay - cows-pasture-1 > 15 and any? patches with [current-farmer = who-of myself and hay-hay > 0
])[ adjust-hay]
                                               ]

end

to adjust-cult-to-grass-cows

if (adjusted-cult-to-hay = true and any? patches with [current-farmer = who-of myself and tilled-crop > 10 and can-change = true])
                         [without-interruption [ask min-one-of patches with [current-farmer = who-of myself and tilled-crop > 10 and can-change =
true ] [avg-yield-index]

                                                                  [without-interruption [ set-crop-income
                                                                   if (tilled-crop > 0 and value-from farmer (current-farmer) [adjusted-cult-to-hay = true])
[set-cow-income-tilled]]]

                                           ]
                            adjust-cult-to-grass-cows

                            ]

end

to set-crop-income

 let tonnes-crop-1 value-from farmer (current-farmer) [item 0 crop-mix *  yield-mult] * canola-yield-index * e-yield-1  / 44.09
 let tonnes-crop-2 value-from farmer (current-farmer) [item 1 crop-mix * yield-mult] * wheat-yield-index * e-yield-2  / 36.74
 let tonnes-crop-3 value-from farmer (current-farmer) [item 2 crop-mix * yield-mult] * barley-yield-index * e-yield-3   / 45.93
 let tonnes-crop-4 value-from farmer (current-farmer) [item 3 crop-mix * yield-mult] * wheat-sf-yield-index * e-yield-2  / 36.74


let e-crop-inc tonnes-crop-1 * 44.09 * value-from farmer (current-farmer) [item 0 price-exp-list]
          + tonnes-crop-2 * 36.74 * value-from farmer (current-farmer) [item 1 price-exp-list]
          + tonnes-crop-3 * 45.93 * value-from farmer (current-farmer) [item 2 price-exp-list]
          + tonnes-crop-4 * 36.74 * value-from farmer (current-farmer) [item 1 price-exp-list]

let vc-acre value-from farmer (current-farmer) [item 0 crop-mix] * (per-acre-vc-1 + value-from farmer (current-farmer) [fuel]) +
         value-from farmer (current-farmer) [item 1 crop-mix] * (per-acre-vc-2 + value-from farmer (current-farmer) [fuel]) +
         value-from farmer (current-farmer) [item 2 crop-mix] * (per-acre-vc-3 + value-from farmer (current-farmer) [fuel]) +
         value-from farmer (current-farmer) [item 3 crop-mix] * (per-acre-vc-4 + value-from farmer (current-farmer) [fuel]) +
         value-from farmer (current-farmer) [item 4 crop-mix] * per-acre-vc-sf

let vc-tonne tonnes-crop-1 * per-tonne-vc-1 + tonnes-crop-2 * per-tonne-vc-2 + tonnes-crop-3 * per-tonne-vc-3 + tonnes-crop-4 * per-tonne-vc-4

let bu (tonnes-crop-1 * 44.09  + tonnes-crop-2 * 36.74  + tonnes-crop-3 * 45.93 + tonnes-crop-4 * 36.74 )

let trans-cost-crop bu * trans-rate-crop-mile-1 + (distance-to-farm - 1) * trans-rate-crop-mile

let custom 0
if (value-from farmer (current-farmer) [crop-machine-option] = 0 and came-from-bid = false)  [set custom custom-crop-cost * (1 - value-from
farmer (current-farmer) [item 4 crop-mix]) ]

set net-income-crop precision (e-crop-inc - vc-acre - vc-tonne - trans-cost-crop - custom) 2

end

to set-cow-income-tilled
```

```
adjust-production-mcals
set-total-mcals-others
if (hay-hay > 0)[switch-hay-land-to-pasture]
set-crop-land
set-new-cows-and-income

end


to set-total-mcals-others

let my-farmer value-from farmer (current-farmer)[who]
set new-other-mcals-hay precision (sum values-from patches with [current-farmer = my-farmer] [e-hay-prod-mcals] )0
set new-other-mcals-pasture-1 precision (sum values-from patches with [current-farmer = my-farmer][e-pasture-1-prod-mcals])0
set new-other-mcals-pasture-2 precision (sum values-from patches with [current-farmer = my-farmer] [e-pasture-2-prod-mcals])0

end


to switch-hay-land-to-pasture

let e-tilled-hay-mcals e-tilled-forage-yield-1 * mcals-ton-hay * tilled-crop
let e-tilled-pasture-2-mcals e-tilled-forage-yield-2 * mcals-ton-ip * tilled-crop

if (came-from-year-1 = true)[set e-tilled-hay-mcals 0
                    set e-tilled-pasture-2-mcals 0]

let new-pasture-2-mcals 0
let new-hay-mcals 0

set new-hay-hay 0

set new-other-mcals-pasture-2 precision (new-other-mcals-pasture-2 + e-tilled-pasture-2-mcals)0          ;; total mcals of each with all tilled in hay
set new-other-mcals-hay precision (new-other-mcals-hay + e-tilled-hay-mcals)0

let hay-hay-mcals precision (e-hay-forage-yield-1 * mcals-ton-hay * hay-hay)0

set new-other-mcals-hay precision (new-other-mcals-hay - hay-hay-mcals )0
                                                                 ;;sets the total mcals of all other plots for hay without the hay land in
question
delay-p1

let actual-other-mcals-pasture-2 new-other-mcals-pasture-2 + proportion-of-p1-delayed * new-other-mcals-pasture-1 * (1 - loss-delayed-graze)
;; sets how much of the pasture 1 needs to be delayed therefore setting p1 and p2

let actual-other-mcals-pasture-1 (1 - proportion-of-p1-delayed) * new-other-mcals-pasture-1

set new-hay-acres-pasture-1 precision ((new-other-mcals-hay * stocking-pasture-1-needed - actual-other-mcals-pasture-1 * hay-needed + hay-hay
* e-hay-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed) /
                (e-hay-forage-yield-1 * mcals-ton-ip * hay-needed +  e-hay-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed)) 0

if (new-hay-acres-pasture-1 > hay-hay) [set new-hay-acres-pasture-1 hay-hay]
if (new-hay-acres-pasture-1 < 0) [set new-hay-acres-pasture-1 0]

set new-hay-hay hay-hay - new-hay-acres-pasture-1

if (came-from-year-1 = true)[set hay-hay new-hay-hay
                    set hay-pasture sama-hay - hay-hay
                    ]

ifelse (came-from-year-1 != true)[set new-other-mcals-pasture-1 precision (new-other-mcals-pasture-1 + new-hay-acres-pasture-1 * e-hay-forage-
yield-1 * mcals-ton-ip)0
                      set new-other-mcals-pasture-2 precision (new-other-mcals-pasture-2 )0
                      set new-other-mcals-hay precision (new-other-mcals-hay + new-hay-hay * e-hay-forage-yield-1 * mcals-ton-hay - hay-hay-
mcals - e-tilled-hay-mcals )0]

                      [set new-other-mcals-pasture-1 precision (new-other-mcals-pasture-1 + hay-pasture * e-hay-forage-yield-1 * mcals-ton-ip)0
                      set new-other-mcals-pasture-2 precision (new-other-mcals-pasture-2 + hay-pasture * e-hay-forage-yield-2 * mcals-ton-ip +
hay-hay * e-hay-forage-yield-2 * mcals-ton-ip)0
```

```
set new-other-mcals-hay precision (new-other-mcals-hay + hay-hay * e-hay-forage-yield-1 * mcals-ton-hay )0]

end


to delay-p1

set proportion-of-p1-delayed 0

if (new-other-mcals-pasture-1 > 0)
    [set proportion-of-p1-delayed ((new-other-mcals-pasture-1 * stocking-pasture-2-needed - new-other-mcals-pasture-2 * stocking-pasture-1-needed) /
                    (new-other-mcals-pasture-1 * stocking-pasture-2-needed + (1 - loss-delayed-graze) * new-other-mcals-pasture-1 * stocking-pasture-1-needed))]

if (proportion-of-p1-delayed < 0)[set proportion-of-p1-delayed 0]

end



to set-crop-land
delay-p1

let actual-other-mcals-pasture-2 new-other-mcals-pasture-2 + proportion-of-p1-delayed * new-other-mcals-pasture-1 * (1 - loss-delayed-graze)
;; sets how much of the pasture 1 needs to be delayed therefore setting p1 and p2

let actual-other-mcals-pasture-1 (1 - proportion-of-p1-delayed) * new-other-mcals-pasture-1

set new-tilled-acres-pasture-1 precision ((new-other-mcals-hay * stocking-pasture-1-needed - actual-other-mcals-pasture-1 * hay-needed + tilled-crop * e-tilled-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed) /
        (e-tilled-forage-yield-1 * mcals-ton-ip * hay-needed +  e-tilled-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed)) 0

if (new-tilled-acres-pasture-1 > tilled-crop) [set new-tilled-acres-pasture-1 tilled-crop]
if (new-tilled-acres-pasture-1 < 0) [set new-tilled-acres-pasture-1 0]
set new-tilled-hay tilled-crop - new-tilled-acres-pasture-1

set new-other-mcals-pasture-1 precision (new-other-mcals-pasture-1 + new-tilled-acres-pasture-1 * e-tilled-forage-yield-1 * mcals-ton-ip)0
set new-other-mcals-pasture-2 precision (new-other-mcals-pasture-2 + (new-tilled-acres-pasture-1 + new-tilled-hay) * e-tilled-forage-yield-2 * mcals-ton-ip)0
set new-other-mcals-hay precision (new-other-mcals-hay + new-tilled-hay * e-tilled-forage-yield-1 * mcals-ton-hay)0

delay-p1

adjust-extra-hay

end

to adjust-extra-hay

let actual-other-mcals-pasture-2 new-other-mcals-pasture-2 + proportion-of-p1-delayed * new-other-mcals-pasture-1 * (1 - loss-delayed-graze)
;; sets how much of the pasture 1 needs to be delayed therefore setting p1 and p2

let actual-other-mcals-pasture-1 (1 - proportion-of-p1-delayed) * new-other-mcals-pasture-1

set new-cows-pasture-1 int (actual-other-mcals-pasture-1 / stocking-pasture-1-needed)
set new-cows-pasture-2 int (actual-other-mcals-pasture-2 / stocking-pasture-2-needed)
set new-cows-hay int (new-other-mcals-hay / hay-needed)

if (abs (new-cows-pasture-1 - new-cows-hay) > 5 and new-tilled-hay > 0 and new-tilled-hay < tilled-crop)
;; only makes the adjustment if the difference between cows is greater than 10

      [let extra-mcals-hay (new-cows-hay - new-cows-pasture-1) * hay-needed
       let extra-acres-hay precision (extra-mcals-hay / (e-tilled-forage-yield-1 * mcals-ton-hay))0

       let actual-hay-mcals new-other-mcals-hay - extra-acres-hay * e-tilled-forage-yield-1 * mcals-ton-hay

       let extra-tilled-acres-pasture-1 precision ((actual-hay-mcals * stocking-pasture-1-needed - actual-other-mcals-pasture-1 * hay-needed + extra-acres-hay * e-tilled-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed) /
```

```
                    (e-tilled-forage-yield-1 * mcals-ton-ip * hay-needed +  e-tilled-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed))
0

          let previous-pasture new-tilled-acres-pasture-1

          set new-tilled-acres-pasture-1 new-tilled-acres-pasture-1 + extra-tilled-acres-pasture-1

          let changed-pasture extra-tilled-acres-pasture-1

          if (new-tilled-acres-pasture-1 > tilled-crop) [set changed-pasture tilled-crop - previous-pasture
                                      set new-tilled-acres-pasture-1 tilled-crop]

          if (new-tilled-acres-pasture-1 < 0) [set changed-pasture previous-pasture * -1
                                 set new-tilled-acres-pasture-1 0]

          set new-tilled-hay tilled-crop - new-tilled-acres-pasture-1

          set new-other-mcals-pasture-1 precision (new-other-mcals-pasture-1 + changed-pasture * e-tilled-forage-yield-1 * mcals-ton-ip)0

          set new-other-mcals-hay precision (new-other-mcals-hay - (changed-pasture) * e-tilled-forage-yield-1 * mcals-ton-hay)0

          delay-p1

          adjust-extra-hay
          ]

end


to set-new-cows-and-income

let market-value-hay value-from farmer (current-farmer) [item 4 price-exp-list]
let new-cows new-cows-pasture-1
let new-cows-hay-after new-cows-hay

ask farmer (current-farmer) [set cows-pasture-1-after new-cows
              set cows-hay-after new-cows-hay-after ]
set-change-in-hay-buy

let additional-cows new-cows - value-from farmer (current-farmer) [e-n-cows]

set additional-cow-income precision (additional-cows * value-from farmer (current-farmer) [item 3 price-exp-list]) 2

let new-hay-ton new-other-mcals-hay / mcals-ton-hay

let total-new-hay-acres new-tilled-hay + new-hay-hay - hay-hay

let new-vc-hay total-new-hay-acres * cost-hay-acre + new-hay-ton * cost-hay-ton

let e-hay-trans-cost  new-hay-ton * trans-rate-hay-mile-1 + trans-rate-ton-hay-mile * (distance-to-farm - 1)* new-hay-ton

set additional-income-grass  precision( (additional-cow-income + net-hay-inc - new-vc-hay - e-hay-trans-cost  ) )2

if (came-from-bid = false)[let pv-annual-income additional-income-grass * (1 - (1 + discount-rate)^ (-1 * (forage-years - 1))) / discount-rate   ;;
present value of annual net income have income all years except 1
            let pv-seed seed-grass-cost * tilled-crop
            let pv-break break-grass-cost * tilled-crop * (1 + discount-rate)^ (-1 * (forage-years - 1)) ;; starts at time 0 not 1
            let pv-forage pv-annual-income - pv-seed - pv-break
            let annualized-income pv-forage * discount-rate / (1 - (1 + discount-rate)^ (-1 * (forage-years)))
            set annualized-income annualized-income * (1 + discount-rate)^ (-1)                    ;; discounts to time 0
            set additional-income-grass annualized-income]

if (came-from-bid = true)[let additional-inc-tilled-forage additional-income-grass - income-pasture-hay-land-bid
            let pv-annual-income additional-inc-tilled-forage * (1 - (1 + discount-rate)^ (-1 * (forage-years - 1))) / discount-rate    ;; present
value of annual net income have income all years except 1
            let pv-seed seed-grass-cost * tilled-crop
            let pv-break break-grass-cost * tilled-crop * (1 + discount-rate)^ (-1 * (forage-years - 1))
            let pv-forage pv-annual-income - pv-seed - pv-break
            let annualized-income pv-forage * discount-rate / (1 - (1 + discount-rate)^ (-1 * (forage-years)))
            set annualized-income annualized-income * (1 + discount-rate)^ (-1)                    ;; discounts to time 0
```

```
                        set additional-income-grass annualized-income]

if (came-from-bid = false)[set additional-income-grass precision(additional-income-grass / tilled-crop )2

          ifelse (additional-income-grass > net-income-crop) [
                                        set tilled-hay new-tilled-hay
                                        set tilled-pasture tilled-crop - new-tilled-hay
                                        set tilled-crop 0
                                        set hay-hay new-hay-hay
                                        set hay-pasture sama-hay - hay-hay
                                        adjust-production-mcals
                                        set years-in-grass 1
                                       ]

                                        [set tilled-hay 0
                                        set tilled-pasture 0
                                        set tilled-crop sama-tilled
                                        ask farmer (current-farmer) [set adjusted-cult-to-hay false]
                                        ]
                                  ]


if (came-from-bid = true)[let adjusted-crop-income net-income-crop * tilled-crop + income-pasture-hay-land-bid
                                                                                    ;adjusts crop income to include the value of pasture and hay
                      ifelse (additional-income-grass > adjusted-crop-income) [set e-cows-if-patch-bought new-cows-pasture-1
                                                                   set crop-acres-bid 0
                                                                   ]
                                                                  [set crop-acres-bid tilled-crop]
                      ]

end


to adjust-production-mcals

set-patch-mcals
ask farmer (current-farmer) [without-interruption [adjust-farmer-mcals]]

end


to set-patch-mcals

set e-hay-prod-mcals hay-hay * e-hay-forage-yield-1 * mcals-ton-hay + tilled-hay  * e-tilled-forage-yield-1 * mcals-ton-hay

let e-pasture-2-from-hay hay-hay * e-hay-forage-yield-2 * mcals-ton-ip + tilled-hay * e-tilled-forage-yield-2 * mcals-ton-ip

let e-np-prod-1 precision (e-np-yield-1 * sama-np * mcals-ton-np)2
let e-np-prod-2 precision (e-np-yield-2 * sama-np * mcals-ton-np)2
let e-ip-prod-1 precision (e-ip-yield-1 * sama-ip * mcals-ton-ip)2
let e-ip-prod-2 precision (e-ip-yield-2 * sama-ip * mcals-ton-ip)2

let e-hay-pasture-1 hay-pasture * e-hay-forage-yield-1 * mcals-ton-ip
let e-hay-pasture-2 hay-pasture * e-hay-forage-yield-2 * mcals-ton-ip

let e-tilled-pasture-1 tilled-pasture * e-tilled-forage-yield-1 * mcals-ton-ip
let e-tilled-pasture-2 tilled-pasture * e-tilled-forage-yield-2 * mcals-ton-ip

set e-pasture-1-prod-mcals e-ip-prod-1 + e-np-prod-1 + e-hay-pasture-1 + e-tilled-pasture-1
set e-pasture-2-prod-mcals e-ip-prod-2  + e-np-prod-2 + e-pasture-2-from-hay + e-hay-pasture-2 + e-tilled-pasture-2

end

to adjust-farmer-mcals

set e-total-pasture-1-mcals sum values-from patches with [current-farmer = who-of myself][e-pasture-1-prod-mcals]
set e-total-pasture-2-mcals sum values-from patches with [current-farmer = who-of myself][e-pasture-2-prod-mcals]
set e-total-hay-mcals sum values-from patches with [current-farmer = who-of myself][e-hay-prod-mcals]

set proportion-of-p1-delayed 0
```

```
if (e-total-pasture-1-mcals > 0)
[set proportion-of-p1-delayed ((e-total-pasture-1-mcals * stocking-pasture-2-needed - e-total-pasture-2-mcals * stocking-pasture-1-needed) /
                        (e-total-pasture-1-mcals * stocking-pasture-2-needed + (1 - loss-delayed-graze) * e-total-pasture-1-mcals * stocking-pasture-1-
needed))]

if (proportion-of-p1-delayed < 0)[set proportion-of-p1-delayed 0]

let actual-e-total-pasture-2-mcals e-total-pasture-2-mcals + proportion-of-p1-delayed * e-total-pasture-1-mcals * (1 - loss-delayed-graze)

let actual-e-total-pasture-1-mcals (1 - proportion-of-p1-delayed) * e-total-pasture-1-mcals

ifelse (will-cows = true)[set cows-pasture-1 int ( actual-e-total-pasture-1-mcals / stocking-pasture-1-needed)
                    set cows-pasture-2 int (actual-e-total-pasture-2-mcals / stocking-pasture-2-needed)
                    set cows-hay int (e-total-hay-mcals / hay-needed )
                    let cows-list (list cows-pasture-1 cows-pasture-2)
                    set e-n-cows min cows-list

                     set e-hay-bought (e-n-cows - cows-hay) * hay-needed / mcals-ton-hay
                     ifelse (e-hay-bought < 0) [set e-hay-sold -1 * e-hay-bought
                                   set e-hay-bought 0]
                                   [set e-hay-sold 0]  ]

                     [set e-hay-sold e-total-hay-mcals / mcals-ton-hay
                      set e-n-cows 0]

end



to adjust-cult-to-grass-sell

if (adjusted-cult-to-hay = true and any? patches with [current-farmer = who-of myself and tilled-crop > 0 and can-change = true ])
                        [without-interruption    [ask min-one-of patches with [current-farmer = who-of myself and tilled-crop > 0 and can-change =
true] [avg-yield-index]
                          [set-crop-income
                          set-hay-sell-income
                          ]]

                          adjust-cult-to-grass-sell
                           ]
end


to set-hay-sell-income

set hay-income-sell precision (e-tilled-forage-yield-1 * (value-from farmer (current-farmer) [item 4 price-exp-list] - transaction-fee-hay) - cost-
hay-acre - e-tilled-forage-yield-1 * cost-hay-ton ) 2          ;; there is no transportation fee because it is sold from the field

let pv-annual-income hay-income-sell * (1 - (1 + discount-rate)^ (-1 * (forage-years - 1))) / discount-rate * (1 + discount-rate)^ (-1)
                                                                        ;; present value of annual net income have income all years except 1
let pv-seed seed-grass-cost
let pv-break break-grass-cost * (1 + discount-rate)^ (-1 * (forage-years - 1)) ;; starts at time 0 not 1
let pv-forage pv-annual-income - pv-seed - pv-break
let annualized-income pv-forage * discount-rate / (1 - (1 + discount-rate)^ (-1 * (forage-years)))
set annualized-income annualized-income * (1 + discount-rate)^ (-1)                              ;; discounts to time 0
set hay-income-sell annualized-income

if (no-cows-no-hay = true and came-from-bid = false)
                                   [ifelse(net-income-crop > 0)[ask farmer (current-farmer) [set adjusted-cult-to-hay false]
                                                 set tilled-crop sama-tilled
                                                  set hay-hay sama-hay
                                                  set hay-pasture sama-hay - hay-hay
                                                 set tilled-hay 0
                                                  set tilled-pasture 0]

                                        [ifelse (hay-income-sell > net-income-crop)
                                              [set tilled-hay sama-tilled
                                                 set tilled-crop 0
                                                 set hay-hay sama-hay
```

```
                                             set hay-pasture sama-hay - hay-hay
                                             set years-in-grass 1
                                            ]

                                            [ask farmer (current-farmer) [set adjusted-cult-to-hay false]
                                             set tilled-crop sama-tilled
                                              set hay-hay sama-hay
                                              set hay-pasture sama-hay - hay-hay
                                             set tilled-hay 0
                                              set tilled-pasture 0]]
                              ]


if (no-cows-no-hay = false and came-from-bid = false)[ifelse (hay-income-sell > net-income-crop)[set tilled-hay sama-tilled
                                             set tilled-crop 0
                                             set hay-hay sama-hay
                                             set hay-pasture sama-hay - hay-hay
                                             set years-in-grass 1
                                            ]

                                            [ask farmer (current-farmer) [set adjusted-cult-to-hay false]
                                             set tilled-crop sama-tilled
                                              set hay-hay sama-hay
                                              set hay-pasture sama-hay - hay-hay
                                             set tilled-hay 0
                                              set tilled-pasture 0]
                                 ]

end


to adjust-production-mcals-before

adjust-patch-mcals-before
ask farmer (current-farmer) [adjust-farmer-mcals-before]
adjust-hay-before

end

;;this will set the stuff before a change is made
;; only needed for bid stuff

to adjust-patch-mcals-before

set e-hay-prod-mcals hay-hay * e-hay-forage-yield-1 * mcals-ton-hay + tilled-hay  * e-tilled-forage-yield-1 * mcals-ton-hay

let e-pasture-2-from-hay hay-hay * e-hay-forage-yield-2 * mcals-ton-ip + tilled-hay * e-tilled-forage-yield-2 * mcals-ton-ip

let e-np-prod-1 precision (e-np-yield-1 * sama-np * mcals-ton-np)2
let e-np-prod-2 precision (e-np-yield-2 * sama-np * mcals-ton-np)2
let e-ip-prod-1 precision (e-ip-yield-1 * sama-ip * mcals-ton-ip)2
let e-ip-prod-2 precision (e-ip-yield-2 * sama-ip * mcals-ton-ip)2


let e-hay-pasture-1 hay-pasture * e-hay-forage-yield-1 * mcals-ton-ip
let e-hay-pasture-2 hay-pasture * e-hay-forage-yield-2 * mcals-ton-ip

let e-tilled-pasture-1 tilled-pasture * e-tilled-forage-yield-1 * mcals-ton-ip
let e-tilled-pasture-2 tilled-pasture * e-tilled-forage-yield-2 * mcals-ton-ip

set e-pasture-1-prod-mcals e-ip-prod-1 + e-np-prod-1 + e-hay-pasture-1 + e-tilled-pasture-1
set e-pasture-2-prod-mcals e-ip-prod-2  + e-np-prod-2 + e-pasture-2-from-hay + e-hay-pasture-2 + e-tilled-pasture-2


end

to adjust-farmer-mcals-before

let additional-cows 0
let cow-pasture-after-1 0
```

```
set e-total-pasture-1-mcals sum values-from patches with [current-farmer = who-of myself][e-pasture-1-prod-mcals]
set e-total-pasture-2-mcals sum values-from patches with [current-farmer = who-of myself][e-pasture-2-prod-mcals]
set e-total-hay-mcals sum values-from patches with [current-farmer = who-of myself][e-hay-prod-mcals]

 set proportion-of-p1-delayed 0

if (e-total-pasture-1-mcals > 0)
        [set proportion-of-p1-delayed ((e-total-pasture-1-mcals * stocking-pasture-2-needed - e-total-pasture-2-mcals * stocking-pasture-1-
needed) /
                        (e-total-pasture-1-mcals * stocking-pasture-2-needed + (1 - loss-delayed-graze) * e-total-pasture-1-mcals * stocking-pasture-
1-needed))]

if (proportion-of-p1-delayed < 0)[set proportion-of-p1-delayed 0]

let actual-e-total-pasture-2-mcals e-total-pasture-2-mcals + proportion-of-p1-delayed * e-total-pasture-1-mcals * (1 - loss-delayed-graze)

let actual-e-total-pasture-1-mcals (1 - proportion-of-p1-delayed) * e-total-pasture-1-mcals

set cows-pasture-1-after int ( actual-e-total-pasture-1-mcals / stocking-pasture-1-needed)
let cows-pasture-2-after int (actual-e-total-pasture-2-mcals / stocking-pasture-2-needed)
set cows-hay-after int (e-total-hay-mcals / hay-needed )

set additional-cows cows-pasture-1-after - e-n-cows

set cow-pasture-after-1 cows-pasture-1-after

ask one-of patches with [patch-id = current-plot-on-market][set e-cows-if-patch-bought additional-cows
                                        set new-cows-pasture-1 cow-pasture-after-1 ]

end

to adjust-hay-before

set new-other-mcals-pasture-1 value-from farmer (current-farmer) [e-total-pasture-1-mcals]
set new-other-mcals-pasture-2 value-from farmer (current-farmer) [e-total-pasture-2-mcals]
set new-other-mcals-hay value-from farmer (current-farmer) [e-total-hay-mcals]

let new-pasture-2-mcals 0
let new-hay-mcals 0

set new-hay-hay 0

let hay-hay-mcals precision (e-hay-forage-yield-1 * mcals-ton-hay * hay-hay)0

set new-other-mcals-hay precision (new-other-mcals-hay - hay-hay-mcals )0

delay-p1

let actual-other-mcals-pasture-2 new-other-mcals-pasture-2 + proportion-of-p1-delayed * new-other-mcals-pasture-1 * (1 - loss-delayed-graze)
;; sets how much of the pasture 1 needs to be delayed therefore setting p1 and p2

let actual-other-mcals-pasture-1 (1 - proportion-of-p1-delayed) * new-other-mcals-pasture-1

set new-hay-acres-pasture-1 precision ((new-other-mcals-hay * stocking-pasture-1-needed - actual-other-mcals-pasture-1 * hay-needed + hay-hay
* e-hay-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed) /
                (e-hay-forage-yield-1 * mcals-ton-ip * hay-needed +  e-hay-forage-yield-1 * mcals-ton-hay * stocking-pasture-1-needed)) 0

if (new-hay-acres-pasture-1 > hay-hay) [set new-hay-acres-pasture-1 hay-hay]
if (new-hay-acres-pasture-1 < 0) [set new-hay-acres-pasture-1 0]

set new-hay-hay hay-hay - new-hay-acres-pasture-1

set hay-hay new-hay-hay
set hay-pasture sama-hay - hay-hay

adjust-patch-mcals-before
ask farmer (current-farmer) [adjust-farmer-mcals-before]
```

```
end


to set-change-in-hay-buy

ask farmer (current-farmer) [set e-hay-bought-change (cows-pasture-1-after - cows-hay-after ) * hay-needed / mcals-ton-hay
                             ifelse (e-hay-bought-change < 0) [set e-hay-sold-change -1 * e-hay-bought-change
                                                                 ;the amount of hay bought or sold if a change occurs
                                        set e-hay-bought-change 0]
                                         [set e-hay-sold-change 0]
            ]

let market-value-hay value-from farmer (current-farmer) [item 4 price-exp-list]

let new-hay-buy value-from farmer (current-farmer) [ e-hay-bought-change]
let new-hay-sell value-from farmer (current-farmer) [ e-hay-sold-change]

let change-tons-hay-will-buy precision  (new-hay-buy - value-from farmer (current-farmer) [e-hay-bought] )2

let change-tons-hay-will-sell precision  (value-from farmer (current-farmer) [e-hay-sold] - new-hay-sell)2

let hay-not-bought 0
let extra-hay-bought 0

ifelse  (change-tons-hay-will-buy < 0)[set hay-not-bought change-tons-hay-will-buy * -1]
                  [set extra-hay-bought change-tons-hay-will-buy]

let lost-hay-sale 0
let extra-hay-sale 0

ifelse ( change-tons-hay-will-sell > 0)[set lost-hay-sale change-tons-hay-will-sell ]
                  [set extra-hay-sale change-tons-hay-will-sell * -1]

let saving-hay-not-bought hay-not-bought * market-value-hay
let cost-addititonal-hay-bought extra-hay-bought * market-value-hay

let lost-hay-sold-income lost-hay-sale * (market-value-hay - transaction-fee-hay)
let addititonal-hay-sold-income extra-hay-sale * (market-value-hay - transaction-fee-hay)

set net-hay-inc saving-hay-not-bought -  cost-addititonal-hay-bought + addititonal-hay-sold-income - lost-hay-sold-income

end


to update-acres

set total-crop-acres sum values-from patches with [current-farmer = who-of myself][tilled-crop]
set total-hay sum values-from patches with [current-farmer = who-of myself][tilled-hay + hay-hay]
set total-improved-pasture sum values-from patches with [current-farmer = who-of myself][tilled-pasture + hay-pasture + sama-ip ]
set total-natural-pasture sum values-from patches with [current-farmer = who-of myself][sama-np]
set total-acres-farmed total-crop-acres +  total-hay + total-improved-pasture + total-natural-pasture

set total-acres-owned sum values-from patches with [owner = who-of myself][acres]
set total-plots-owned count patches with [owner = who-of myself]
set total-acres-leased sum values-from patches with [renter = who-of myself][acres]
set total-plots-leased count patches with [renter = who-of myself]

end


to set-expected-income


ask patches with [current-farmer = who-of myself and tilled-crop > 0][set-crop-income

                             ]

let exp-crop-income precision( sum values-from patches with [current-farmer = who-of myself and tilled-crop > 0] [ net-income-crop * tilled-
crop])0
```

```
let exp-cow-inc precision (e-n-cows * item 3 price-exp-list)0

let hay-prod sum values-from patches with [current-farmer = who-of myself][ hay-hay * e-hay-forage-yield-1  + tilled-hay  * e-tilled-forage-yield-
1 ]
let farmer-hay-acres sum values-from patches with [current-farmer = who-of myself][ hay-hay + tilled-hay]
let hay-trans 0

if (will-cows = true)[
set hay-trans sum values-from patches with [current-farmer = who-of myself][ (hay-hay * e-hay-forage-yield-1  + tilled-hay  * e-tilled-forage-
yield-1 )* trans-rate-hay-mile-1 +
                                                    (hay-hay * e-hay-forage-yield-1  + tilled-hay  * e-tilled-forage-yield-1 )* (distance-to-farm - 1) *
trans-rate-ton-hay-mile]
              ]

let farmer-vc-hay precision ( hay-prod * cost-hay-ton +  farmer-hay-acres * cost-hay-acre + hay-trans)0

let sell-hay-inc e-hay-sold * (item 4 price-exp-list - transaction-fee-hay)
let buy-hay-cost e-hay-bought * item 4 price-exp-list

let pasture-inc 0
if (will-cows = false)[set pasture-inc sum values-from patches with [current-farmer = who-of myself][sama-np * np-rental + sama-ip * ip-rental]]

let total-exp-income precision(exp-crop-income + exp-cow-inc + sell-hay-inc - buy-hay-cost - farmer-vc-hay + pasture-inc + off-farm-inc)2

let lease-payments sum values-from patches with [current-farmer = who-of myself][lease-payment]

let full-time-workers item crop-machine-option crop-ft-hired-labour-list
let full-time-crop-cost full-time-workers * full-time-salary
let pt-hired-labour-hrs item crop-machine-option crop-pt-hired-labour-list
let pt-crop-cost pt-hired-labour-hrs * total-crop-acres * pt-labour-cost           ;; used to maintain same family living withdrawal
                                                                                    ;; Hired labour is deducted when they creat their bid
 let cow-labour 0
 if (n-cows > 300)[set cow-labour 1]
 if (n-cows > 600)[set cow-labour 2]
 if (n-cows > 900)[set cow-labour 2]
 if (n-cows > 1200)[set cow-labour 4]
 if (n-cows > 1500)[set cow-labour 5]

let cow-labour-hours cow-labour * 60 * 10
let total-cow-hired-labour cow-labour-hours * pt-labour-cost

let exp-hired-labour pt-crop-cost + full-time-crop-cost + total-cow-hired-labour

let exp-net-cf  total-exp-income - debt-payment - lease-payments - exp-hired-labour

let exp-fl max (list (exp-net-cf * family-living-profits)  min-family-withdrawal)
if (exp-fl > max-family-withdrawal)[set exp-fl max-family-withdrawal]

set exp-cf total-exp-income - lease-payments - debt-payment - exp-fl

end


;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Land Markets;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to land-markets

set land-price-list []
set land-lease-list []
set plots-sold-farmers  0
set plots-sold-investor 0
if any? patches with [for-sale? = true] [farmland-purchase-market]
farmland-lease-market
end


to farmland-purchase-market
```

```
select-plot
initial-screen-farmers
without-interruption [create-bid]

ifelse (bid-list != [])[sell-land]
                    [ask one-of patches with [patch-id = current-plot-on-market] [set for-sale? false
                                                                    set for-rent? true]]

if any? patches with [for-sale? = true] [farmland-purchase-market]


if (land-price-list != [])[set land-price precision (mean land-price-list)0]

end


to select-plot

if any? patches with [for-sale? = true] [without-interruption [ask one-of patches with [for-sale? = true]
                                               [set current-plot-on-market patch-id
                                                 ask farmers [set can-bid-on-plot false]
                                                plot-screening]]]

end



to initial-screen-farmers

ask farmers [ifelse (age < pre-retirement-age) [set can-bid true]
                                       [set can-bid false]

           if ((debt / assets) > max-before-d/a-ratio)[set can-bid false]

           let min-cash total-crop-acres * min-cash-crop-acre + total-hay * min-cash-hay-acre

           if (cash < min-cash)[set can-bid false]
           ]

 end



to plot-screening

ask farmers with [can-bid = true]
                       [let distance-plot (round distancexy (value-from one-of patches with [patch-id = current-plot-on-market] [pxcor])
                                                         (value-from one-of patches with [patch-id = current-plot-on-market] [pycor]))

                         if (distance-plot < max-distance) [set can-bid-on-plot true]
                       ]

end


to create-bid

;;;; need to check cash flow bid
;;;; when bids are created it is assumed that the tilled land is cultivated
;;; will have to adjust bid value to inclue breaking if currently in grass

set bid-list []
ask farmers [set current-bid 0]

ask farmers with [can-bid-on-plot = true]

              [without-interruption [let income-list 0
                                ask one-of patches with [patch-id = current-plot-on-market]
                                              [without-interruption
                                                 [clear-parameters
```

```
                    set distance-to-farm (round distancexy (value-from turtle (current-farmer)[xcor])
                              (value-from turtle (current-farmer)[ycor]))


                    let plot-tilled sama-tilled
                    ask farmer (current-farmer) [if (crop-machine-option <= 1 and (total-crop-acres + sama-tilled) > 982)
                                                [set crop-mix [.3 .4 .3 0 0 ]
                                                 set yield-mult (1 + increase-no-till)
                                                 set fuel 12.47
                                                 set-expected-income]

                               if (total-crop-acres + sama-tilled < 500)[set fuel 0]]


                    if (tilled-crop > 0) [set-crop-income
                              ]


                    if (value-from farmer (current-farmer) [will-cows] = true)
                               [adjust-production-mcals-before
                                determine-new-cows-pasture-hay
                                set-total-value-used-in-crop
                                if (tilled-crop > 0) [income-tilled-forage-bid]
          ;;; sets the total additonal income if all tilled land is used in grass it is in additonal-income-grass (called additioal-income-
   grass)
                                ]

                    if (value-from farmer (current-farmer) [will-cows] = false)
                               [determine-value-pasture-hay-rent
                                set-total-value-used-in-crop
                                set-hay-sell-income
                                set-total-income-sell-hay
                                ]

                   set income-list (list additional-income-grass e-total-plot-income-crop)

                   ask farmer (current-farmer)[without-interruption
                              [set e-income-plot-acre max income-list /
                                    value-from one-of patches with [patch-id = current-plot-on-market][ acres]
                               if(no-cows-no-hay = true and will-cows = false)[set e-income-plot-acre item 1 income-list /
                                    value-from one-of patches with [patch-id = current-plot-on-market][ acres]]
                               update-machienry-fl
                               set-bid-value
                               finacial-bid
                               set bid-list lput current-bid bid-list]]

                   set bid-list filter [? != 0] bid-list

                   ask one-of patches with [patch-id = current-plot-on-market][set current-farmer "na"  ]]]
                    ]]

 ask farmers with [can-bid-on-plot = true] [without-interruption [ifelse any? patches with [current-farmer = who-of myself]
                          [ask one-of patches with [current-farmer = who-of myself][ adjust-production-mcals]]
                          [set e-n-cows 0
                           set e-hay-bought 0
                           set e-hay-sold 0]]
            ]
ask farmers with [can-bid-on-plot = true][without-interruption [if (crop-machine-option <= 1) [set crop-mix [.3 .4 .3 0 0 ]
                                 set yield-mult (1 + increase-no-till)
                                 set fuel 12.47
                                 set-expected-income]]]

set farmers-bidding count farmers with [current-bid > 0]

end


to clear-parameters
```

```
set net-income-crop 0
set income-pasture-hay-land-bid 0
set additional-income-grass 0
set came-from-bid true
set current-farmer who-of myself
set tilled-crop sama-tilled
set tilled-hay 0
set tilled-pasture 0
set hay-hay sama-hay
set hay-pasture 0
set e-cows-if-patch-bought 0

end


to determine-new-cows-pasture-hay

;;; this sets the value of the existing pasture and hay land on new plot.  It is added to the crop income when determining use and bid value.

let new-cows-pasture-hay  e-cows-if-patch-bought
let new-cows-income new-cows-pasture-hay * value-from farmer (current-farmer) [item 3 price-exp-list]

set-change-in-hay-buy

let new-vc-hay-hay hay-hay * cost-hay-acre + hay-hay * e-hay-forage-yield-1 * cost-hay-ton
set net-hay-inc net-hay-inc - new-vc-hay-hay

set income-pasture-hay-land-bid new-cows-income + net-hay-inc  - new-vc-hay-hay


end


to set-total-value-used-in-crop

set e-total-plot-income-crop net-income-crop * tilled-crop + income-pasture-hay-land-bid

end


to determine-value-pasture-hay-rent

let income-pasture  sama-np * 2 + sama-ip * 10
let hay-prod hay-hay * e-hay-forage-yield-1
let new-vc-hay-hay hay-hay * cost-hay-acre + hay-hay * e-hay-forage-yield-1 * cost-hay-ton
let hay-cost-trans   hay-prod  * trans-rate-hay-mile-1 + trans-rate-ton-hay-mile * (distance-to-farm - 1)* hay-prod
let market-value-hay value-from farmer (current-farmer) [item 4 price-exp-list]
let new-hay-income  (market-value-hay - transaction-fee-hay) * hay-prod - new-vc-hay-hay - hay-cost-trans
set income-pasture-hay-land-bid new-hay-income + income-pasture

end


to set-total-income-sell-hay

set additional-income-grass hay-income-sell * tilled-crop + income-pasture-hay-land-bid

ifelse (no-cows-no-hay = true)
   [set crop-acres-bid sama-tilled]

[ifelse (additional-income-grass > e-total-plot-income-crop) [set crop-acres-bid 0]
                                          [set crop-acres-bid sama-tilled]]

end


to income-tilled-forage-bid

set-patch-mcals
set-total-mcals-others
```

```
switch-hay-land-to-pasture
set-crop-land
set-new-cows-and-income

end



to update-machienry-fl

let machine-age 0
let new-value-mach 0
let end-age 0
let depr 0
let annualized-dep-value 0
let opportunity-invest 0
let capital-recovery 0
let fc-crop-acres 0
let inv-crop-mach-needed 0

let current-value-crop-machine crop-machine-value
set machine-age crop-machine-age

let new-crop-acres total-crop-acres + value-from one-of patches with [patch-id = current-plot-on-market][crop-acres-bid]

let capacity-current-mach item (crop-machine-option) crop-capacity-list

ifelse (new-crop-acres > capacity-current-mach) [set crop-option-needed crop-machine-option + 1]
                                    [set crop-option-needed crop-machine-option
                                    set capacity-current-mach item (crop-option-needed) crop-capacity-list ]

set new-value-mach item (crop-option-needed) crop-mach-new-value-list
                                                    ;; set the new value of the machine needed used to determine salvage value

if (crop-option-needed != crop-machine-option)[set inv-crop-mach-needed item (crop-option-needed) crop-mach-purchase-value-list - crop-
machine-value
                                                set current-value-crop-machine item (crop-option-needed) crop-mach-purchase-value-list
                                                if (crop-option-needed = 1) [set machine-age 10]
                                                if (crop-option-needed = 2) [set machine-age 5]
                                                if (crop-option-needed > 2) [set machine-age 0]
                                               ]                        ;;if investment in machinery required this sets inv amount, current value, and age


set end-age machine-age + 5                              ;;sets the age of machinery at the end of planning horizon (assumed 5 years for machine)


let end-crop-mach-value precision (new-value-mach * .948 * (.901 ^ end-age))0          ;sets salvage value of land
set depr current-value-crop-machine - end-crop-mach-value                    ;;set depreciation on machine
set annualized-dep-value depr * (interest-rate / (1 - ((1 + interest-rate)^ -5)))   ; assumes 5 year planning horizon
set opportunity-invest  end-crop-mach-value * interest-rate
set capital-recovery annualized-dep-value + opportunity-invest                ;;sets total captial recovery charge for all machienry used for crop

let fc-acre-crop capital-recovery / capacity-current-mach                    ;; sets cost per acre with new plot included (average cost pricing)

if (crop-option-needed = 0) [set fc-crop-acres custom-crop-cost]                    ;; if to small to buy equipment sets the cost per acre to a custom rate

set fc-crop-acres crop-acres-bid *  fc-acre-crop                   ;; sets total fixed for the crop acres on the plot

let ft-crop-labors item (crop-option-needed) crop-ft-hired-labour-list
let total-cost-ft-labours ft-crop-labors * full-time-salary
let ft-cost-crop-acre 0
if (total-crop-acres + crop-acres-bid > 0) [set ft-cost-crop-acre total-cost-ft-labours / (total-crop-acres + crop-acres-bid)]
let ft-cost-plot ft-cost-crop-acre * crop-acres-bid

let pt-hr-acre  item (crop-option-needed) crop-pt-hired-labour-list
let pt-cost-acre pt-hr-acre * pt-labour-cost * crop-acres-bid

let crop-hire-labour-acre (pt-cost-acre + ft-cost-crop-acre) / value-from one-of patches with [patch-id = current-plot-on-market] [acres]

let opportunity-cows e-cows-if-patch-bought * cow-price  * interest-rate
```

```
                                                    ;;captial recovery for cow investment depreciation of cows is captured in the income

let total-fc-plot fc-crop-acres + opportunity-cows
let fc-acre-plot total-fc-plot / value-from one-of patches with [patch-id = current-plot-on-market] [acres]

let fl-acre-profits e-income-plot-acre * family-living-bid

set new-machienry-inv  inv-crop-mach-needed

set e-income-plot-acre e-income-plot-acre - fl-acre-profits - fc-acre-plot - crop-hire-labour-acre

end

to set-bid-value

let current-value-land avg-prod-patch / mean-patch-quality * land-price
let income-land-value e-income-plot-acre * pv-annuity-land
let end-value-land current-value-land * ((1 + land-inflate)^ 20) * year-20-factor
set current-bid (income-land-value + end-value-land ) *  risk-parameter

end

to finacial-bid


let capacity-current-mach item (crop-machine-option) crop-capacity-list

let acres-needed-efficient capacity-current-mach - total-crop-acres

let cow-invest (e-n-cows - n-cows + e-cows-if-patch-bought) * cow-price

let cash-reserve cash * cash-reserve-%

let patch-hay value-from one-of patches with [patch-id = current-plot-on-market][ new-tilled-hay + new-hay-hay]

let min-cash capacity-current-mach * min-cash-crop-acre + (total-hay + patch-hay) * min-cash-hay-acre

let capital-available cash - min-cash - down-payment * new-machienry-inv - down-payment * cow-invest
                                        - cash-reserve
set bid-finances capital-available / down-payment

let cash-avil precision (bid-finances)0
if (bid-finances < 0) [set bid-finances 0]

let new-debt debt + (1 - down-payment) * (new-machienry-inv + cow-invest)
let new-assets assets + new-machienry-inv + cow-invest - down-payment * (new-machienry-inv + cow-invest)

let market-value-land avg-prod-patch / mean-patch-quality * land-price

let max-debt-asset-bid precision ((d/a-ratio * new-assets + d/a-ratio * market-value-land - new-debt)
                        / (d/a-ratio * down-payment + (1 - down-payment)))0

if (max-debt-asset-bid < bid-finances) [set bid-finances max-debt-asset-bid]

let ft-crop-labors item (crop-option-needed) crop-ft-hired-labour-list
let total-cost-ft-labours ft-crop-labors * full-time-salary

let pt-hr-acre  item (crop-option-needed) crop-pt-hired-labour-list
let pt-cost pt-hr-acre * pt-labour-cost * (total-crop-acres + crop-acres-bid)

let hired-labour-cost total-cost-ft-labours + pt-cost

let exp-total-cf exp-cf +  e-income-plot-acre *   value-from one-of patches with [patch-id = current-plot-on-market][acres] - hired-labour-cost

let new-debt-pay-cow-mach  (1 - down-payment) * (new-machienry-inv + cow-invest) *  loan-factor-payment-5

let new-exp-cf (exp-total-cf - new-debt-pay-cow-mach )* max-%-cf

let max-cf-bid precision (new-exp-cf / interest-rate * (1 - (1 / (1 + interest-rate)^ 20)) / (1 - down-payment) )0
```

```
if (max-cf-bid < bid-finances) [set bid-finances max-cf-bid]

set bid-finances (bid-finances / value-from one-of patches with [patch-id = current-plot-on-market][acres]) *  risk-parameter

let inc-bid precision (current-bid * value-from one-of patches with [patch-id = current-plot-on-market][acres])0

if (bid-finances < current-bid)[set current-bid bid-finances ]

if (current-bid < 0 ) [set current-bid 0]


end

to sell-land

let market-value 0
let mean-bid 0
let adjusted-price 0
let adjusted-lease 0
let acres-purchased 0

ask one-of patches with [patch-id = current-plot-on-market][set market-value avg-prod-patch / mean-patch-quality * land-price
                                            set adjusted-lease avg-prod-patch / mean-patch-quality * exp-lease
                                           ]

let min-accept land-owner-risk * adjusted-lease * (1 - lease-man-fee-%) / .03


if (random 101 / 100 <= must-sell-prob)[ask one-of patches with [patch-id = current-plot-on-market ] [set need-sell true]]

let investor-bid 0
if (random 101 / 100 <= prob-investor-bid)[set investor-bid min-accept]                 ;; random investor bid (bid is the same as min accepted)

if (value-from one-of patches with [patch-id = current-plot-on-market ] [need-sell] = true) [set min-accept  must-sell-min * min-accept]


set bid-list sort-by [?1 > ?2] bid-list
let bid-2 0
if (length bid-list > 2)[set bid-2 item 1 bid-list]

let farmer-buyer value-from max-one-of farmers [current-bid][who]

let adjusted-bid 0

ask farmer farmer-buyer [if(bid-2 < investor-bid)[set bid-2 investor-bid]
                      ifelse (bid-2 > 0)[set adjusted-bid (bid-2 + current-bid ) / 2]
                                  [set adjusted-bid (current-bid )]                ;;; adjust bid for current information
                     if (adjusted-bid > bid-finances)[set adjusted-bid bid-finances]
                             ]

ifelse (adjusted-bid > min-accept and adjusted-bid > investor-bid)
          [ask farmer farmer-buyer
                        [set plots-sold-farmers  plots-sold-farmers  + 1
                         let price-paid (adjusted-bid + min-accept) / 2
                         without-interruption [ask one-of patches with [patch-id = current-plot-on-market]
                                              [set current-farmer who-of myself
                                               set owner who-of myself
                                               set acres-purchased acres
                                               set for-sale? false
                                               set lease-term 0
                                               set lease-payment 0
                                               set pcolor blue
                                               set distance-to-farm (round distancexy (value-from turtle (current-farmer)[xcor])
                                                                   (value-from turtle (current-farmer)[ycor]))
                                               set came-from-bid false
                                               adjust-production-mcals

                                               if (value-from farmer (current-farmer) [will-cows = true])
                                                          [if (sama-hay > 0)[
                                                                     set-total-mcals-others
```

```
                                                            set came-from-year-1 true
                                                            switch-hay-land-to-pasture
                                                            adjust-production-mcals
                                                            set came-from-year-1 false]

                                                    if (tilled-crop > 0) [set-crop-income                ;;; this sets the use
                                                              set-cow-income-tilled]
                                                              ]


                                                   if (value-from farmer (current-farmer) [will-cows = false])
                                                              [ if (tilled-crop > 0) [set-crop-income                ;;; this sets the use
                                                                          set-hay-sell-income]
                                                              ]


                                         set buyer who-of myself
                                         ]]

                           let total-price price-paid * acres-purchased
                           set cash precision (cash - down-payment *  total-price) 0
                           let payment precision ((1 - down-payment) * total-price * loan-factor-payment-20)0
                           set debt-list fput (list 20 payment (precision ((1 - down-payment) * total-price)0)) debt-list
                           set debt precision (debt + (1 - down-payment) * total-price)0
                           set debt-payment precision (debt-payment + payment)0

                           set adjusted-price precision (price-paid *  mean-patch-quality / (value-from one-of patches with [patch-id = current-plot-
on-market] [avg-prod-patch]))0

                           update-acres

                           buy-machine
                           if (will-cows = true)[buy-sell-cows]
                           set-crop-mix
                           set-expected-income
                           balance-sheet
                           initial-screen-farmers

                           set land-price-list fput adjusted-price land-price-list

                           ]]


    [if (investor-bid > 0)[let price ((investor-bid + min-accept) / 2)
                         set adjusted-price precision (price *  mean-patch-quality /
                                (value-from one-of patches with [patch-id = current-plot-on-market] [avg-prod-patch]))0

                         set land-price-list fput adjusted-price  land-price-list
                         set plots-sold-investor plots-sold-investor + 1]
     ask one-of patches with [patch-id = current-plot-on-market][set for-sale? false
                                              set for-rent? true]
    ]


end


to farmland-lease-market

select-lease-plot
initial-screen-farmers-lease
create-lease-bid
if any? patches with [for-rent? = true] [farmland-lease-market]
if (land-lease-list != [])[set lease-rate precision (mean land-lease-list)0]
set unmanaged count patches with [for-sale? = true]

ask patches with [lease-term = 0 and renter != "na"][set last-adj-lease-rate lease-rate]

adjust-lease
```

```
end

to select-lease-plot

if any? patches with [for-rent? = true] [without-interruption [ask one-of patches with [for-rent? = true]
                                        [set current-plot-on-market patch-id
                                        ask farmers [set can-bid-on-plot false]
                                         screen-farmers-plot]]]
end


to initial-screen-farmers-lease

ask farmers [ifelse (age < pre-retirement-age) [set can-bid true]
                                  [ifelse (total-crop-acres + value-from one-of patches with [current-plot-on-market = patch-id][sama-tilled] <
                                     item (crop-machine-option) crop-capacity-list)  [set can-bid true]
                                                                      [set can-bid false]]
         let min-cash total-crop-acres * min-cash-crop-acre + total-hay * min-cash-hay-acre

          if (cash < min-cash)[set can-bid false]
          ]

end

to screen-farmers-plot

ask farmers with [can-bid = true]
                   [let distance-plot (round distancexy (value-from one-of patches with [patch-id = current-plot-on-market] [pxcor])
                                              (value-from one-of patches with [patch-id = current-plot-on-market] [pycor]))

                     if (distance-plot < max-distance)  [set can-bid-on-plot true]
                   ]

end



to create-lease-bid


;;;; when bids are created it is assumed that the tilled land is cultivated
;;; will have to adjust bid value to inclue breaking if currently in grass


ask farmers [set current-bid 0]
set bid-list []

ask farmers with [can-bid-on-plot = true]

            [
            without-interruption [ask one-of patches with [patch-id = current-plot-on-market]
                                      [without-interruption
                                         [clear-parameters
                                           set distance-to-farm (round distancexy (value-from turtle (current-farmer)[xcor])
                                                          (value-from turtle (current-farmer)[ycor]))

                                          ask farmer (current-farmer) [if (crop-machine-option <= 1 and (total-crop-acres + sama-tilled) > 982)
                                                                 [set crop-mix [.3 .4 .3 0 0 ]
                                                                  set yield-mult (1 + increase-no-till)
                                                                  set fuel 12.47
                                                                  set-expected-income]

                                                      if (total-crop-acres + sama-tilled < 500)[set fuel 0]]


                                          if (tilled-crop > 0) [set-crop-income]

                                          if (value-from farmer (current-farmer) [will-cows] = true) [

                                                         adjust-production-mcals-before
```

```
                                   determine-new-cows-pasture-hay
                                   set-total-value-used-in-crop
                                   if (tilled-crop > 0) [income-tilled-forage-bid]
      ;;; sets the total additonal income if all tilled land is used in grass it is in additonal-income-grass (called additioal-income-grass)


                                   ]

                          if (value-from farmer (current-farmer) [will-cows] = false)[determine-value-pasture-hay-rent
                                          set-total-value-used-in-crop
                                          set-hay-sell-income
                                          set-total-income-sell-hay
                                          ]


                let income-list (list additional-income-grass e-total-plot-income-crop)

                ask farmer (current-farmer)[without-interruption
                 [ set e-income-plot-acre max income-list / value-from one-of patches with [patch-id = current-plot-on-market][ acres]
                  update-machienry-fl
                  lease-finacial-bid
                  set-lease-bid
                   ]]

                  ask one-of patches with [patch-id = current-plot-on-market][set current-farmer "na"]
                         ]
                       ]]]

ask farmers with [can-bid-on-plot = true]  [without-interruption [ifelse any? patches with [current-farmer = who-of myself]
                             [ask one-of patches with [current-farmer = who-of myself][ adjust-production-mcals]]
                             [set e-n-cows 0
                              set e-hay-bought 0
                              set e-hay-sold 0]]]

ask farmers with [can-bid-on-plot = true][without-interruption [if (crop-machine-option <= 1) [set crop-mix [.3 .4 .3 0 0 ]
                                    set yield-mult (1 + increase-no-till)
                                    set fuel 12.47
                                    set-expected-income]]]
sell-lease-land

end


to set-lease-bid

set current-bid e-income-plot-acre * risk-parameter

end


to lease-finacial-bid

let capacity-current-mach item (crop-option-needed) crop-capacity-list

let acres-needed-efficient capacity-current-mach - total-crop-acres

let cow-invest (e-n-cows - n-cows + e-cows-if-patch-bought) * cow-price

let cash-reserve cash * cash-reserve-%

let patch-hay value-from one-of patches with [patch-id = current-plot-on-market][ new-tilled-hay + new-hay-hay]

let min-cash capacity-current-mach * min-cash-crop-acre + (total-hay + patch-hay) * min-cash-hay-acre

let capital-available cash - min-cash - down-payment * new-machienry-inv - down-payment * cow-invest
                      - cash-reserve

if (capital-available  < 0) [set current-bid 0]
```

```
let new-debt debt + (1 - down-payment) * (new-machienry-inv + cow-invest)
let new-assets assets + new-machienry-inv + cow-invest - down-payment * (new-machienry-inv + cow-invest)

if ((new-debt / new-assets) > d/a-ratio)  [set current-bid 0]

let ft-crop-labors item (crop-option-needed) crop-ft-hired-labour-list
let total-cost-ft-labours ft-crop-labors * full-time-salary

let pt-hr-acre  item (crop-option-needed) crop-pt-hired-labour-list
let pt-cost pt-hr-acre * pt-labour-cost * (total-crop-acres + crop-acres-bid)

let hired-labour-cost total-cost-ft-labours + pt-cost

let exp-total-cf exp-cf +  e-income-plot-acre *   value-from one-of patches with [patch-id = current-plot-on-market][acres] - hired-labour-cost

let new-debt-pay-cow-mach  (1 - down-payment) * (new-machienry-inv + cow-invest) *  loan-factor-payment-5

let new-exp-cf (exp-total-cf - new-debt-pay-cow-mach) * max-%-cf

if (new-exp-cf < current-bid) [set current-bid new-exp-cf]

end

to sell-lease-land

ask farmers [without-interruption [set bid-list fput current-bid bid-list]]

let adjusted-lease-rate 0

let lease-value 0


set bid-list sort-by [?1 > ?2] bid-list
let bid-2 0
if (length bid-list > 2)[set bid-2 item 1 bid-list]

let plot-q value-from one-of patches with [patch-id = current-plot-on-market][avg-prod-patch]
let market-rate plot-q / mean-patch-quality * lease-rate



ifelse (max bid-list > 0)[
ask max-one-of farmers [current-bid][without-interruption [ifelse (bid-2 > 0) [set lease-value (current-bid + bid-2) / 2]
                                                  [set lease-value (current-bid )]
                                          ask one-of patches with [patch-id = current-plot-on-market]
                                             [set market-rate avg-prod-patch / mean-patch-quality * lease-rate
                                              set current-farmer who-of myself
                                             set renter who-of myself
                                             set for-rent? false
                                             set pcolor green
                                              set distance-to-farm (round distancexy (value-from turtle (current-farmer)[xcor])
                                                     (value-from turtle (current-farmer)[ycor]))
                                             set came-from-bid false
                                             adjust-production-mcals

                                              if (value-from farmer (current-farmer) [will-cows = true])
                                                                      [if (sama-hay > 0)[
                                                                              set-total-mcals-others
                                                                              set came-from-year-1 true
                                                                              switch-hay-land-to-pasture
                                                                              adjust-production-mcals
                                                                              set came-from-year-1 false]

                                                                       if (tilled-crop > 0) [set-crop-income              ;;; this sets the use
                                                                                set-cow-income-tilled]
                                                                      ]


                                             if (value-from farmer (current-farmer) [will-cows = false])
                                                                      [ if (tilled-crop > 0) [set-crop-income             ;;; this sets the use
```

```
                                                         set-hay-sell-income]
                                                  ]

                          set lease-payment lease-value
                          set lease-term 0



                          ]

              set adjusted-lease-rate precision (lease-value *  mean-patch-quality / (value-from one-of patches with [patch-id = current-
plot-on-market] [avg-prod-patch]))0

              update-acres
              buy-machine
              if (will-cows = true) [buy-sell-cows]
              set-expected-income
              set-crop-mix
              balance-sheet

               ]
               ]

set land-lease-list fput adjusted-lease-rate land-lease-list
              ]

              [ ask one-of patches with [patch-id = current-plot-on-market][set for-rent? false
                                      set for-sale? true
                                      set pcolor black
                                      set bidders count farmers with [can-bid-on-plot = true]]

              ]


end


to adjust-lease

ask patches with [renter != "na" and lease-term > 0][ let %-change lease-rate / last-adj-lease-rate
                    if (%-change < .08)[set lease-payment lease-payment * %-change
                           set last-adj-lease-rate lease-rate]
                    if (%-change > 1.2)[set lease-payment lease-payment * %-change
                           set last-adj-lease-rate lease-rate]
                   ]


end
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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Buy and Sell Cows;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to buy-sell-cows


let past-1 0
let past-2 0

    set past-1 sum values-from patches with [current-farmer = who-of myself and years-in-grass != 1]
               [  e-np-yield-1 * sama-np * mcals-ton-np + e-ip-yield-1 * sama-ip * mcals-ton-ip + hay-pasture * e-hay-forage-yield-1 *
mcals-ton-ip
                                   +  tilled-pasture * e-tilled-forage-yield-1 * mcals-ton-ip]

   set past-2 sum values-from patches with [current-farmer = who-of myself and years-in-grass != 1]
               [hay-hay * e-hay-forage-yield-2 * mcals-ton-ip + tilled-hay * e-tilled-forage-yield-2 * mcals-ton-ip
```

```
                                + e-np-yield-2 * sama-np * mcals-ton-np + e-ip-yield-2 * sama-ip * mcals-ton-ip + hay-pasture * e-hay-forage-yield-
2 * mcals-ton-ip
                                + tilled-pasture * e-tilled-forage-yield-2 * mcals-ton-ip]


   let extra-p1 sum values-from patches with [current-farmer = who-of myself and years-in-grass = 1]
                            [ e-np-yield-1 * sama-np * mcals-ton-np + e-ip-yield-1 * sama-ip * mcals-ton-ip + hay-pasture * e-hay-forage-yield-1 *
mcals-ton-ip]

    let extra-p2 sum values-from patches with [current-farmer = who-of myself and years-in-grass = 1]
                            [hay-hay * e-hay-forage-yield-2 * mcals-ton-ip +  e-np-yield-2 * sama-np * mcals-ton-np + e-ip-yield-2 * sama-ip * mcals-
ton-ip
                                    + hay-pasture * e-hay-forage-yield-2 * mcals-ton-ip]

   set past-1 past-1 + extra-p1
   set past-2 past-2 + extra-p2

   set proportion-of-p1-delayed 0
    if(past-1 > 0)[set proportion-of-p1-delayed ((past-1 * stocking-pasture-2-needed - past-2 * stocking-pasture-1-needed) /
                                        (past-1 * stocking-pasture-2-needed + (1 - loss-delayed-graze) * past-1 * stocking-pasture-1-needed))]
    if (proportion-of-p1-delayed < 0)[set proportion-of-p1-delayed 0]
    let actual-past-2-mcals past-2 + proportion-of-p1-delayed * past-1 * (1 - loss-delayed-graze)
    let actual-past-1 (1 - proportion-of-p1-delayed) * past-1
    let new-cows int ( actual-past-1 / stocking-pasture-1-needed)

    if (year = 0)[set n-cows new-cows]

  if (year > 0)[
    ifelse (new-cows > n-cows) [set buy-cows new-cows - n-cows
                            set sell-cows 0]
                          [set sell-cows n-cows - new-cows
                           set buy-cows 0]

       let cows-purchased-expense buy-cows * cow-price
       let cows-sold-inc sell-cows * cow-price
       let net-cow-inv cows-purchased-expense - cows-sold-inc

       ifelse (net-cow-inv > 0) [let payment precision ((1 - down-payment) * net-cow-inv * loan-factor-payment-5)0
                         set cash precision (cash - down-payment * net-cow-inv)0
                         set debt-list fput (list 5 payment (precision ((1 - down-payment) * net-cow-inv)0)) debt-list
                         set debt precision (debt + (1 - down-payment) * net-cow-inv)0
                         set debt-payment precision (debt-payment + payment)0]

                         [set cash cash - net-cow-inv]

       set n-cows n-cows + buy-cows - sell-cows]

      balance-sheet

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Machinery Investment;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to machinery-investment

ask farmers [
       without-interruption [buy-machine]
        balance-sheet
       ]


end


to buy-machine
```

```
set crop-machine-inv 0
let old-mach-value crop-machine-value
let old-mach-option crop-machine-option

      if(total-crop-acres <= 500)[set crop-machine-option 0]
      if(total-crop-acres > 500 and total-crop-acres <= 1300)[set crop-machine-option 1]
      if(total-crop-acres > 1300 and total-crop-acres <= 2000) [set crop-machine-option 2]
      if (total-crop-acres > 2000 and total-crop-acres <= 3200) [set crop-machine-option 3]
      if (total-crop-acres > 3200 and total-crop-acres <= 3900) [set crop-machine-option 4]
      if (total-crop-acres > 3900 and total-crop-acres <= 7800) [set crop-machine-option 5]
      if (total-crop-acres > 7800 and total-crop-acres <= 11700) [set crop-machine-option 6]
      if (total-crop-acres > 11700 and total-crop-acres <= 15600) [set crop-machine-option 7]
      if (total-crop-acres > 15600 and total-crop-acres <= 19500) [set crop-machine-option 8]
      if (total-crop-acres > 19500 and total-crop-acres <= 23400) [set crop-machine-option 9]

     if (crop-machine-option < old-mach-option)[set crop-machine-option old-mach-option]


     if(old-mach-option < crop-machine-option )
              [set crop-machine-inv item (crop-machine-option ) crop-mach-purchase-value-list - old-mach-value
               set crop-machine-value item (crop-machine-option ) crop-mach-purchase-value-list
               if (crop-machine-option = 1) [set crop-machine-age 10
                             set total-acres-seeding 32727
                             set total-combine-hrs 1500]

               if (crop-machine-option = 2)[set crop-machine-age 5
                             set total-acres-seeding 19091
                             set total-combine-hrs 750                    ]
               if (crop-machine-option > 2) [set crop-machine-age 0
                             set total-acres-seeding 0
                             set total-combine-hrs 0]
               ]

      if (crop-machine-option > 2 and crop-machine-age > 7)

      [

     let machine-inv-if-buy item (crop-machine-option ) crop-mach-purchase-value-list - old-mach-value

     let cash-reserve cash * cash-reserve-%
     let min-cash total-crop-acres * min-cash-crop-acre + total-hay * min-cash-hay-acre
     let capital-available cash - min-cash  - cash-reserve - down-payment * machine-inv-if-buy
     let new-debt (1 - down-payment) * machine-inv-if-buy
     let new-assets assets + machine-inv-if-buy - down-payment * machine-inv-if-buy

    let new-debt-pay-mach  (1 - down-payment) * machine-inv-if-buy *  loan-factor-payment-5

    let ft-crop-labors item (crop-machine-option) crop-ft-hired-labour-list
    let total-cost-ft-labours ft-crop-labors * full-time-salary

    let pt-hr-acre  item (crop-machine-option) crop-pt-hired-labour-list
    let pt-cost pt-hr-acre * pt-labour-cost * total-crop-acres

    let hired-labour-cost total-cost-ft-labours + pt-cost

     let new-exp-cf (exp-cf - new-debt-pay-mach - hired-labour-cost) * max-%-cf

     if ((new-debt / new-assets) < d/a-ratio and capital-available > 0 and new-exp-cf > 0)

        [

      set crop-machine-inv item (crop-machine-option ) crop-mach-purchase-value-list - old-mach-value
      set crop-machine-age 0
      set total-acres-seeding 0
      set total-combine-hrs 0

       ]]

if (year > 0 and crop-machine-inv > 0)[
       let net-machine-inv crop-machine-inv
```

```
                ifelse (net-machine-inv > 0) [let money-down down-payment * net-machine-inv
                                set cash cash - money-down
                                let payment precision ((1 - down-payment) * net-machine-inv  * loan-factor-payment-5 )0
                                set debt-list fput (list 5 payment (precision ((1 - down-payment) * net-machine-inv )0)) debt-list
                                set debt precision (debt + (1 - down-payment) * net-machine-inv )0
                                set debt-payment precision (debt-payment + payment)0]

                                [set cash cash - net-machine-inv]
                ]


if (crop-machine-option < old-mach-option)

        [let crop-machine-inc old-mach-value - item (crop-machine-option ) crop-mach-purchase-value-list
                set crop-machine-value item (crop-machine-option ) crop-mach-purchase-value-list
                if (crop-machine-option = 1) [set crop-machine-age 10
                                set total-acres-seeding 32727
                                set total-combine-hrs 1500]

                if (crop-machine-option = 2)[set crop-machine-age 5
                                set total-acres-seeding 19091
                                set total-combine-hrs 750                                    ]
                if (crop-machine-option > 2) [set crop-machine-age 0
                                set total-acres-seeding 0
                                set total-combine-hrs 0]
        set cash cash + crop-machine-inc
        ]


end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Export Data;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to intial-values

set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Initial Values"
let spacer ""
file-open "Inital Values.txt"
file-print (list spacer "Age" spacer "Total-Acres" spacer "Acres-Owned" spacer "Acres Leased" spacer "Debt" spacer "Cows" spacer "off farm
inc" spacer)
ask farmers [without-interruption [file-print (list spacer age spacer total-acres-farmed spacer total-acres-owned
                spacer total-acres-leased spacer debt spacer n-cows spacer off-farm-inc spacer)]]
file-close

end



to export-data
set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Output"

if (run-number = start-run-number and year = 0)[create-files]

set total-rented count patches with [renter != "na"]
set total-owned count patches with [owner != "na"]
set avg-cash mean values-from farmers [cash]
set avg-debt mean values-from farmers [debt]
set avg-net-worth mean values-from farmers [assets - debt]
set avg-assets mean values-from farmers [assets]
set avg-size mean values-from farmers[total-acres-farmed]
set total-cows sum values-from farmers [n-cows]
set %-crop 100 * (sum values-from patches [tilled-crop] / sum values-from patches [tilled-crop + tilled-hay + hay-hay + sama-np + tilled-pasture +
hay-pasture + sama-ip])
set %-hay 100 * (sum values-from patches [tilled-hay + hay-hay] / sum values-from patches [tilled-crop + tilled-hay + hay-hay + sama-np + tilled-
pasture + hay-pasture + sama-ip])
set %-np 100 * (sum values-from patches [sama-np] / sum values-from patches [tilled-crop + tilled-hay + hay-hay + sama-np + tilled-pasture +
hay-pasture + sama-ip])
```

```
set %-ip 100 * (sum values-from patches [tilled-pasture + hay-pasture + sama-ip] / sum values-from patches [tilled-crop + tilled-hay + hay-hay +
sama-np + tilled-pasture + hay-pasture + sama-ip])
set %-crop-sf 100 *(sum values-from patches [fallow] / sum values-from patches [tilled-crop])
set total-farmers count farmers

export-farmer
export-global

end


to create-files

let spacer ","
file-open "Farmer Output.csv"
file-print (list spacer "scenario" spacer "run-number" spacer "year" spacer "who" spacer "age" spacer "total-acres-farmed" spacer
            "total-plots-owned" spacer" total-plots-leased" spacer "total-acres-owned" spacer "total-acres-leased" spacer
            "total-hay" spacer "total-improved-pasture" spacer "total-natural-pasture" spacer "total-crop-acres" spacer
            "debt" spacer "assets" spacer "equity" spacer "cash" spacer "net-worth" spacer "hired-labour" spacer
            "family-living" spacer "ncfbi" spacer "off-farm-inc" spacer "generation" spacer "debt-payment" spacer "land-value" spacer
            "capital-value" spacer "cow-value" spacer "n-cows" spacer "hay-for-sale" spacer "buy-hay" spacer "hay-reserves" spacer
            "risk-parameter" spacer "crop-machine-age" spacer "will-cows" spacer "total-repairs" spacer "total-gross-crop-inc"
            spacer "total-gross-cow-inc" spacer "total-gross-hay-inc" spacer "total-annual-gross-inc" spacer )
file-close

file-open "Global Output.csv"
file-print (list spacer "scenario" spacer "run-number" spacer "year" spacer "land-price" spacer "lease-rate" spacer "price canola" spacer
        "price wheat" spacer "price barley" spacer "price hay" spacer "price calf" spacer "yield canola" spacer "yield wheat" spacer
         "yield barley" spacer "hay yield" spacer "total farmers" spacer "bankrupt" spacer "cash flow" spacer "retired" spacer "transfer" spacer
         "unmanaged" spacer "plots-sold-investor" spacer "plots-sold-farmers" spacer)
file-close

file-open "Exits.csv"
file-print (list spacer "scenario" spacer "run-number" spacer "year" spacer "who" spacer "why-exit" spacer "age" spacer "total-acres-farmed"
spacer
            "total-plots-owned" spacer" total-plots-leased" spacer "total-acres-owned" spacer "total-acres-leased" spacer
            "total-hay" spacer "total-improved-pasture" spacer "total-natural-pasture" spacer "total-crop-acres" spacer
            "debt" spacer "assets" spacer "equity" spacer "cash" spacer "net-worth" spacer "hired-labour" spacer
            "family-living" spacer "ncfbi" spacer "off-farm-inc" spacer "generation" spacer "debt-payment" spacer "land-value" spacer
            "capital-value" spacer "cow-value" spacer "n-cows" spacer "hay-for-sale" spacer "buy-hay" spacer "hay-reserves" spacer
            "risk-parameter" spacer "crop-machine-age" spacer "will-cows" spacer "total-repairs" spacer "total-gross-crop-inc"
            spacer "total-gross-cow-inc" spacer "total-gross-hay-inc" spacer "total-annual-gross-inc" spacer )

file-close

file-open "Transfer.csv"
file-print (list spacer "scenario" spacer "run-number" spacer "year" spacer "who" spacer "transfer-value" spacer "transfer-borrow" spacer "age"
spacer "total-acres-farmed" spacer
            "total-plots-owned" spacer" total-plots-leased" spacer "total-acres-owned" spacer "total-acres-leased" spacer
            "total-hay" spacer "total-improved-pasture" spacer "total-natural-pasture" spacer "total-crop-acres" spacer
            "debt" spacer "assets" spacer "equity" spacer "cash" spacer "net-worth" spacer "hired-labour" spacer
            "family-living" spacer "ncfbi" spacer "off-farm-inc" spacer "generation" spacer "debt-payment" spacer "land-value" spacer
            "capital-value" spacer "cow-value" spacer "n-cows" spacer "hay-for-sale" spacer "buy-hay" spacer "hay-reserves" spacer
            "risk-parameter" spacer "crop-machine-age" spacer "will-cows" spacer "total-repairs" spacer )

file-close

end

to export-farmer

let spacer ","

file-open "Farmer Output.csv"
ask farmers [without-interruption [file-print (list spacer scenario spacer run-number spacer year spacer who spacer age spacer total-acres-farmed
spacer
            total-plots-owned spacer total-plots-leased spacer total-acres-owned spacer total-acres-leased spacer
            total-hay spacer total-improved-pasture spacer total-natural-pasture spacer total-crop-acres spacer
            debt spacer assets spacer equity spacer cash spacer (assets - debt) spacer hired-labour spacer
            family-living spacer ncfbi spacer off-farm-inc spacer generation spacer debt-payment spacer land-value spacer
```

```
                   capital-value spacer cow-value spacer n-cows spacer hay-for-sale spacer buy-hay spacer hay-reserves spacer
                   risk-parameter spacer crop-machine-age spacer will-cows spacer total-repairs spacer
                   total-gross-crop-inc spacer total-gross-cow-inc spacer total-gross-hay-inc spacer total-annual-gross-inc spacer)]]
file-close


end

to export-global

let spacer ","
file-open "Global Output.csv"

file-print (list spacer scenario spacer run-number spacer year spacer land-price spacer lease-rate spacer price-1 spacer
            price-2 spacer price-3 spacer price-hay spacer price-calf spacer yield-1 spacer yield-2 spacer yield-3 spacer
            hay-yield-1 spacer total-farmers spacer bankrupt spacer cashflow spacer oldage spacer transfers spacer unmanaged spacer
            plots-sold-investor spacer plots-sold-farmers spacer)

file-close


end

to export-exits
set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Output"

let spacer ","
file-open "Exits.csv"
file-print (list spacer scenario spacer run-number spacer year spacer who spacer why-exit spacer age spacer total-acres-farmed spacer
         total-plots-owned spacer total-plots-leased spacer total-acres-owned spacer total-acres-leased spacer
         total-hay spacer total-improved-pasture spacer total-natural-pasture spacer total-crop-acres spacer
         debt spacer assets spacer equity spacer cash spacer (assets - debt) spacer hired-labour spacer
         family-living spacer ncfbi spacer off-farm-inc spacer generation spacer debt-payment spacer land-value spacer
         capital-value spacer cow-value spacer n-cows spacer hay-for-sale spacer buy-hay spacer hay-reserves spacer
         risk-parameter spacer crop-machine-age spacer will-cows spacer total-repairs spacer)
file-close

end

to export-transfer
set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Output"

let spacer ","
file-open "Transfer.csv"
file-print (list spacer scenario spacer run-number spacer year spacer who spacer transfer-value spacer transfer-borrow spacer age spacer total-
acres-farmed spacer
         total-plots-owned spacer total-plots-leased spacer total-acres-owned spacer total-acres-leased spacer
         total-hay spacer total-improved-pasture spacer total-natural-pasture spacer total-crop-acres spacer
         debt spacer assets spacer equity spacer cash spacer (assets - debt) spacer hired-labour spacer
         family-living spacer ncfbi spacer off-farm-inc spacer generation spacer debt-payment spacer land-value spacer
         capital-value spacer cow-value spacer n-cows spacer hay-for-sale spacer buy-hay spacer hay-reserves spacer
         risk-parameter spacer crop-machine-age spacer will-cows spacer total-repairs spacer)
file-close

end


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;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;Delete Files;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
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to delete-files
set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Initial Values"
file-delete "Inital Values.txt"

set-current-directory "C:\\Documents and Settings\\Peter\\My Documents\\Research\\Model\\Output"

file-delete "Farmer Output.csv"
```

```
file-delete "Global Output.csv"
file-delete "Exits.csv"
file-delete "Transfer.csv"

show "files deleted"
end

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to clear-model

clear-turtles
clear-patches
clear-all-plots
set cashflow 0
set bankrupt 0
set transfers 0
set oldage  0
set year  0
set unmanaged 0

end
```