FROM THE GROUND UP:
AN AGENT-BASED MODEL OF
REGIONAL STRUCTURAL CHANGE

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by
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ABSTRACT

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The Saskatchewan farm sector is a dynamic system that is faced with the reality of farm consolidation and other structural adjustments. While structural adjustment may result in increased productivity at the farm-level, the declining farm population has a direct impact on rural regions. Given the economic difficulties now inherent in many rural regions, there has never been a more important time to improve our understanding of the structural dynamics of the farm sector.

By utilizing agent-based methods, competition that exists between farm households in land markets is modelled in a dynamic framework. By modeling land markets in this manner, structural adjustments that occur due to the re-allocation of land among farm household becomes endogenous to the model. The farming simulation was validated by evaluating its ability to replicate actual structural shifts that occurred during the period of 1960-2000. The results obtained from the simulation were found to mirror historic shifts, which gives the author confidence that the parsimonious assumptions made are robust, yet still characteristic of farm level behaviour in the region. Other scenarios were simulated in order to estimate a counterfactual structural evolution of the modelled region, in the absence of government stabilization and support programs. Significant deviations are observed between the base and zero transfer scenarios with regards to the consolidation of farm assets among a declining number of farm households. Most significantly, the decline in farm numbers accelerated significantly in the late 1980's in the zero transfer scenario compared to the base simulations.

The application of an agent-based framework allowed for the study of regional structure with an emphasis on the behaviour and actions of the primary decisions makers within the system. While structural change is driven by a number of factors, the ability of a farm household to fully employ their labour resource was an important factor in the simulations. This contrasts with the finding that productive efficiency, and purchasing and market power at the farm level is not a necessary condition for the observed consolidation of farm assets.

ACKNOWLEDGEMENTS

As I look back on the occasionally random path that has lead me to this point, I realize the substantial number of people that have played an important role in helping keep me on course. A great debt of gratitude is owed to you all.

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CHAPTER ONE

INTRODUCTION

1.0 Introduction

Significant structural change is occurring at the farm level in Saskatchewan. While not well understood, these changes appear to be due to a number of factors that are both endogenous and exogenous to farming and agriculture – including industrial decline and consolidation, demographics, entrepreneurial behaviour, rural migration, implementation of the WTO and the removal of many farming subsidies. There has never been a more important time to improve our understanding of regional issues and the farm sector.

Agriculture is a multi-layered economic system comprising numerous individual agents. These agents compete for limited resources, including land, against a constantly changing backdrop of agricultural policies, technologies, markets and natural events. Farm characteristics like operator age, land tenure, farm type, farm size, debt level and motivation vary widely across Canada. Changes in these factors underlie farm industry structure, and this issue is of perennial interest to agricultural policy makers. The desire to understand farm structure has led to the development of a number of well documented farm-level models, including FLIPSIM in the U.S. and CRAM (Canadian Regional Agricultural Model) in Canada (Klein and Narayanan 1992).

I argue that adaptive farm models based on individual interactions are necessary to help unravel the intricate interplay among natural and economic developments in the farming sector. Part of the motivation in this research is the realization that farming behaviour possesses characteristics of a complex system in the computational sense, and complex systems often generate large-scale behaviour that cannot readily be predicted by simply examining components of the system. In the complexity literature, such large-scale phenomena are referred to as "emergent" if they require new categories or methods of description, categories that were not required to explain the actions of the underlying agents (Gilbert and Troitszch 2002). To their credit, the previous generation of farm-level models were not designed to capture complexity or emergent behaviour, yet complexity is arguably one of the most crucial characteristics of any economic system. It is the potential to reveal emergent farm level behaviour that will distinguish new generation behavioural models from the older generation of atomistic farm level policy models.

At the micro level, there are many potential drivers for rural structural change. These include 1) the presence of economies of size and scale, 2) technological change and 3) changing lifestyle expectations and income. Another underlying driver that has not been fully explored in this context is the fundamental and intrinsic difference in farming "management style". Considerable anecdotal evidence exists among agricultural professionals as to how differences in decision making lead to a management style (Jensen 1977). While there are many possible management attributes, management style should encompass: 1) a willingness to accept/or reject the current situation or status quo, 2) a willingness/unwillingness to act or respond under incomplete information and to accept risk (entrepreneurship), and 3) a view of farming as a business/life style. These particular attributes are not necessarily independent and may be in turn influenced by a number of demographic variables. I will explore each of these alternative explanations of rural structural change in this thesis

1.1 Objectives

The focus of this thesis is to better capture the inter-relational dynamics of individual farm households/managerial units and to examine the resulting aggregate structure at the regional level. By building on an assumption that an agrarian region can be modelled as a complex system, issues concerning the limitations of farm-level modeling and policy analysis are re-examined using agent-based systems theory. In turn the aggregate outcome of historic market conditions as well as policies directed at the farm-level is analyzed by focusing on decisions made at the level of the individual farm household/managerial unit. These decisions become the underlying driver of regional structure.

I also seek to improve upon the limited predictive ability of previous farm-level modeling methodologies. Through the application of agent-based modeling techniques, and their inherent flexibility, the potential of including structural change as an endogenous factor to farm-level models will be illustrated. First, the structural evolution of a proto-typical rural municipality (RM) in the dark brown soil zone of Saskatchewan for the period of 1960-2000 will be simulated in the agent framework. By comparing the simulated and actual structural adjustments, the validity of the simulation can be evaluated. Subsequently, initializing the simulation model with alternative distributions of managerial characteristics allows the sensitivity of the model to variations in the initial farm population management profile to be evaluated. This also permits an analysis of the role of individual farm household/managerial units' management style as a driver of structural change. The latter has never been done before in the farm-level modeling literature, and represents a major contribution of this thesis.

Ultimately, a set of hypothetical or counterfactual scenarios will be simulated to assess the impact of historic farm stabilization and support programs on the structural evolution of the region. I call these zero-transfer scenarios. By directly comparing the results from both the validated base and hypothetical zero transfer scenarios, I can directly assess the impact of government transfers to the farm household on the structural evolution of the studied region.

1.2 Motivation for Study

Agent-based modeling is a newly emerging tool for the study of agricultural and resource management issues. Agent-based models serve as laboratories (or artificial societies) where competing hypotheses and theories of individual and social behaviour and rules can be tested in an empirical manner (Gumerman et al 2002). The use of agent-based models for creating artificial societies ranges from the development of abstract worlds[1] to recreating historic societies (Rauch 2002). Within the field of natural resource management there is a growing use of agent-based methods for the study of property rights, externalities (Parker 2000) and the use of common pool resources (Deadman 1999; Rouchier et al 2001).

The use of agent-based methods to study agricultural issues is limited but expanding. Some agricultural economists have begun to utilize these methods to study a number of important agricultural issues, ranging from regional structural change (Balmann 1997), EU farm policy-reform (Happe 2004), technology diffusion and resource use (Berger 2001) and land-use management (Polhill et al 2001). There is a need to

[1] A good example is the Sugarscape model. The simplest version of the Sugarscape artificial world consists of a single population of agents gathering a renewable resource (sugar) from the environment (a two dimensional lattice), and is used to investigate the distribution of wealth that arises (Epstein and Axtell 1996).

further develop these models in order to gain insight into structural change associated with the unique properties of Saskatchewan agriculture. And as there are still some concerns surrounding the use of agent-based methodologies, especially among economists, these concerns need to be acknowledged before these models are applied to study structural change in the farm sector.

1.3 Thesis Organization

This thesis is composed of six chapters. A brief review of the literature pertaining to the relevant issues of structural change in the agricultural sector and the role of farm management and entrepreneurial behaviour is found in chapter two. Within chapter three, the strengths and limitations of a number of farm-level modeling methodologies are outlined. As well, a substantial portion of chapter three discusses complexity theory and how it relates and leads to the use of agent-based systems and modeling. The structural logic, assumptions and initial characteristics of the simulated regional model of farming activity are laid out in chapter four in significant detail. The fifth chapter includes a presentation and discussion of the model results within the context of the issues and questions raised in chapters two and three. Finally, a summary and conclusion is presented in the final chapter, along with a discussion of model limitations and suggestions for further research.

CHAPTER TWO

TRENDS AND FACTORS OF STRUCTURAL CHANGE

2.0 Introduction

Farming and farm policy is faced with the reality of structural change. The underlying characteristics of the agricultural industry may change from the time a policy is introduced and the time its full impact is realized. As a result, policy makers are faced with the unenviable task of formulating and enacting policy that not only meets the short term objectives, but ultimately has a net positive impact on the long term sustainability of the industry. In order to assist policy makers, farm-level models for forecasting have been developed to help assess and predict the impact of policies, including its collateral or second order effects. Assessment and prediction becomes a significant challenge when policies have long term impacts that are difficult to capture in a model without explicitly endogenizing structural change. In order to improve the assessment and predictive ability of farm-level models, structure change needs to be made endogenous to these models. In order to achieve this, a thorough understanding of the factors contributing to rural structural change is required.

2.1 What is Structural Change?

Significant structural change occurs at all levels of the agriculture industry. A number of authors have categorized structural shifts in the agricultural sector under the rubric of the "industrialization of agriculture" and the consolidation and integration of production on larger operations (Sofranko et al 1999). The majority of academic and mass media publications describing structural change within Canadian agriculture have focused on the declining number of farms and the trend towards larger economic units although other issues related to increased capital assets, reduced labour requirements and part-time farming have also generated significant interest (Jones and Buckley 1980). Structural change in the sector is defined by Goddard et al (1993) as "changes in the essential characteristics of productive activities". As a result, structural change encompasses not only characteristics describing the number and size of farm units, but also the demographic and economic characteristics of the farm operators, the methods of production and the mix of products produced by industry participants. Simply stated, structural change in agriculture encompasses shifts in what is produced, how it is produced and where and by whom it is produced.

2.2 Trends and Patterns of Structural Change in Saskatchewan Agriculture

The long term structural transformation of agriculture has been well documented within the Canadian industry (Bollman, Whitener and Tung 1995). The focus of this brief discussion on structural change trends will be on the region of interest for this study, the Canadian province of Saskatchewan. Foremost, structural shifts in Saskatchewan agriculture center on a declining number of farms, shifts in the crop portfolio and cultivation practices, and an increased integration between the farm and non-farm sectors of the rural and urban regional economies.

The dominant trend in Saskatchewan agriculture has been the consolidation of production and control of a relatively fixed land resource among a declining number of farms. The number of farms within the province has been declining steadily since the late 1930's. Farm numbers declined from 93,924 in 1960 to 50,598 as of 2000 (Saskatchewan Agriculture, Food and Rural Revitalization 2004). The relatively constant area of land employed in provincial agricultural production dictates that mean farm size is inversely related to the number of farms. Mean farm size increased at a rate approximately equivalent to the rate of decline in farm numbers over the same period (figure 2.1).

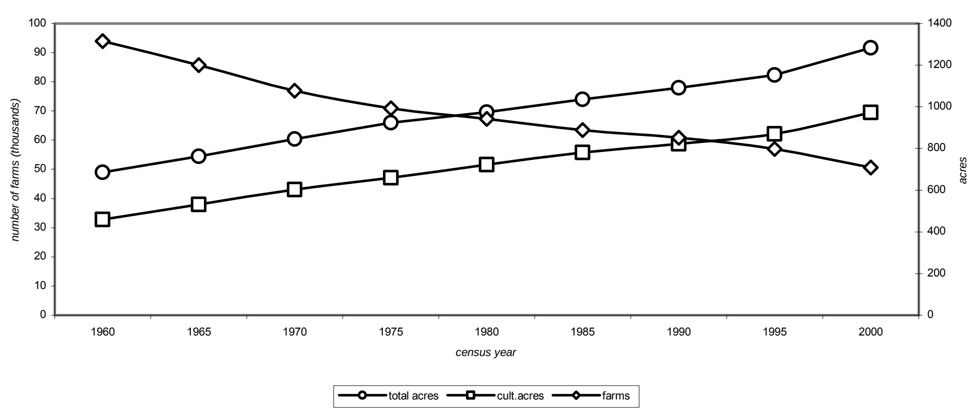

Figure 2.1: Saskatchewan Farms Numbers and Mean Acreage 1960-2000
Source: Saskatchewan Agriculture Food and Rural Revitalization 2004

The number of farms, and mean farm size, which are generally well published figures in the popular press, are only summary statistics and fail to portray key aspects of underlying change in the distribution of farm size. For example, while mean farm size approximately doubled between 1960 and 2000 (figure 2.1) the proportion of farms managing less than 400 acres remained relatively constant (figure 2.2).

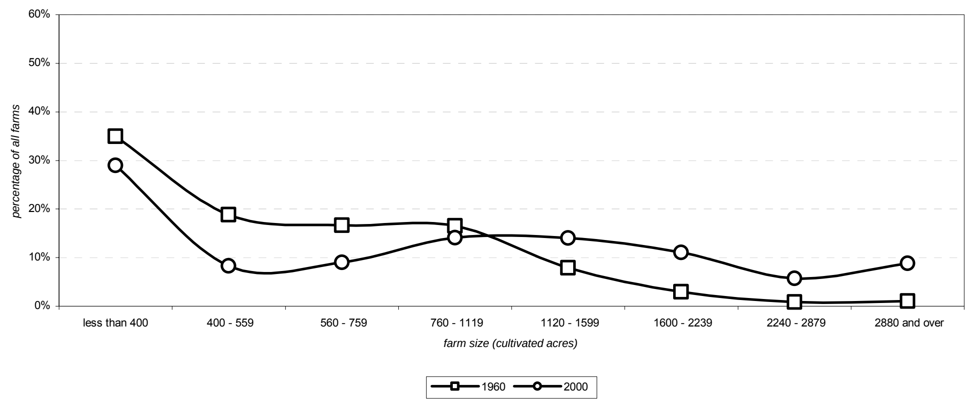

Figure 2.2: Distribution of Farm Acreage (Saskatchewan) 1960 and 2000
Source: Census of Canada: Agriculture: Saskatchewan

In addition to the persistence of small farm operations, the contrast between the distributions of farm size for the 1960 and 2000 periods highlights the growing heterogeneity between individual farms. In 1960 farms managing less than 1120 acres accounted for approximately 87% of all farms, whereas by 2000 this had fallen to 60% of all farms (figure 2.2).

Methods of crop production and the portfolio of crops produced by Saskatchewan farmers have also shifted over the past 30 years (figure 2.3). One of the most dramatic changes in production methods has been the reduction in soil cultivation and in particular the practice of leaving crop land in fallow. Summer fallowing farm land was a common practice for the majority of crop producers in the 1970’s. Throughout the 1970’s close to 40% of Saskatchewan’s crop producing land was fallowed in a given year (figure 2.3), while over the following decades the proportion of crop land in annual fallow declined steadily, accounting for less than 20% of crop land in 2000 (figure 2.3).

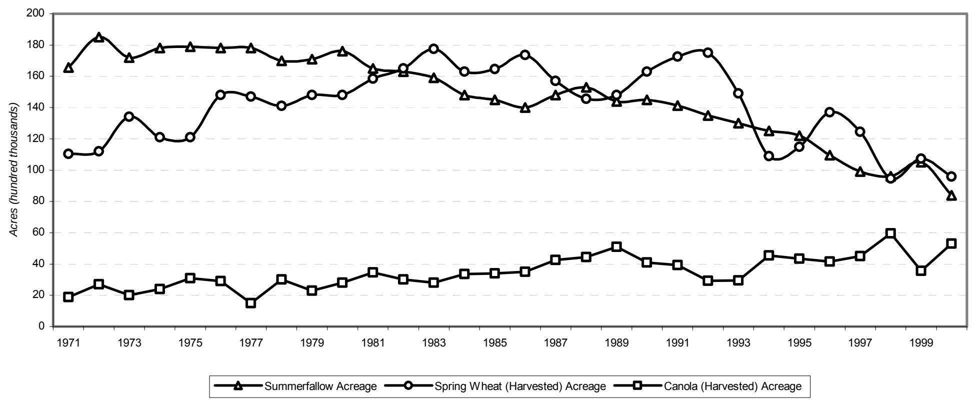

Figure 2.3: Saskatchewan Spring Wheat, Canola and Summer Fallow Acreage 1971-2000
Source: Saskatchewan Agriculture Food and Rural Revitalization 2004

The importance of spring wheat production also declined significantly over the same period. Spring wheat production accounted for approximately one-half of the harvested crop acres as recently as the early 1990's (Saskatchewan Agriculture, Food and Rural Revitalization 2004). Spring wheat production has declined in the past ten years to a level representing approximately 30% of the harvested crop acres annually (Saskatchewan Agriculture, Food and Rural Revitalization 2004). Reductions in the relative proportion of farm output represented by spring wheat have been offset by the increasing acreage of alternative crops, including canola (figure 2.3) and pulse crops. In fact, the number of Saskatchewan farms classified as wheat type[2] has declined from 64% to less than 20% of all farms over the period 1971-2000 (Statistics Canada).

At the production level, one of the most significant, but least understood, structural adjustments occurring in the industry is the substitution of capital assets for labour input. An increased proportion of farm equity tied up in capital assets and increasing levels of debt financing (figure 2.4) has had a significant impact on the aggregate behaviour of the farm sector. This aspect of structural adjustment needs to be properly analyzed.

The growth of part-time farming and off-farm income are closely related to the trend of farm capitalization and the high cost of labour relative to capital. The structure of the farm household has shifted dramatically

[2]Defined as a farm on which potential wheat sales account for at least 51% of the total farm receipts (Statistics Canada).

from the ideals of independence and self-reliance (Raup 1972), to the current reality where most farm households earn more money from off-farm sources than from agricultural production (Short 2004).

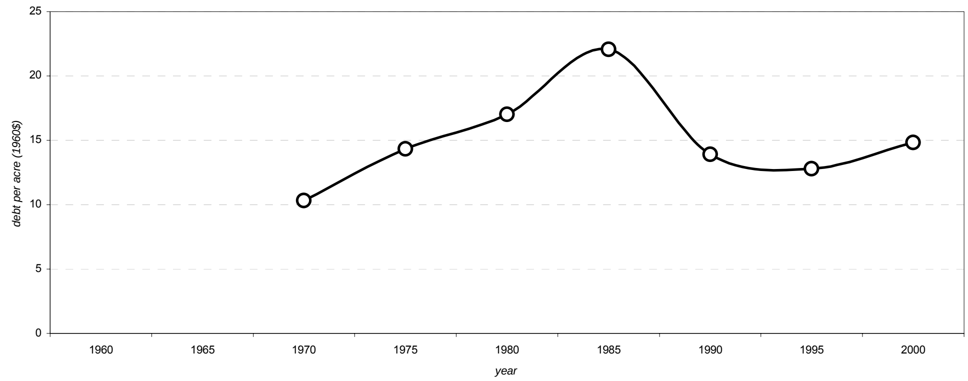

Figure 2.4: Saskatchewan Farm Debt per Cultivated Acre (in constant 1960s dollars) 1960-2000
Source: Saskatchewan Agriculture Food and Rural Revitalization 2004

In addition to the increasing capital intensity of crop production, and the related increase in farm debt, the importance of capital associated with non-farming land owners has increased over the 1960-2000 period. With the exception of the early 1960s, the percentage of farm land owned by non-farming individual and organizations, and subsequently leased[3] to farm operators, has increased (figure 2.5).

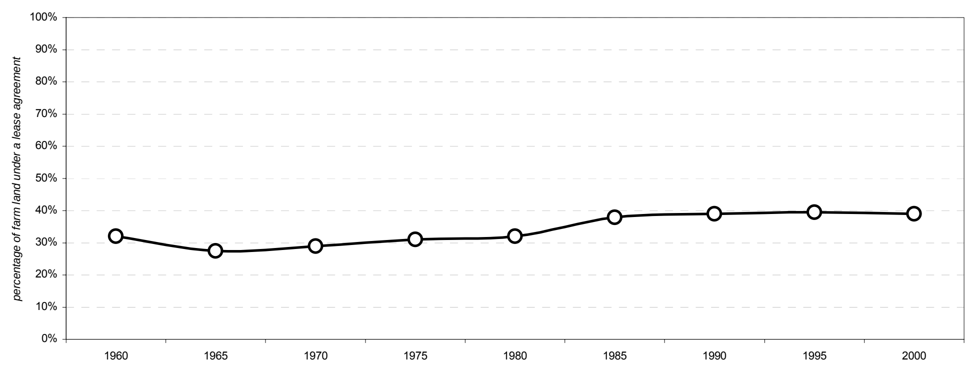

Figure 2.5: Proportion of Land under Lease Agreement (Saskatchewan) 1960-2000
Source: Census of Canada: Agriculture: Saskatchewan

The prevalence of land leases increased significantly in the first part of the 1980s, with an approximately 6% increase between 1980 and 1985 (figure 2.5). A significant adjustment in the proportion of farm land

[3] Lease arrangements consist of two general types: cash leases and crop share leases.

operated under leases can be expected to have a number of potential consequences that may alter both aggregate and individual behaviours.

The market value of farmland is determined by a number of factors, including regional supply and demand. The demand for farm land in this model is a function of its productive capacity, and the number of potential bidders. The latter is determined, at least in part, by the financial characteristics, cost structures and geographic location of individual farm operations. The supply of farm land is also a function of the characteristics of individual farm operations. If land is the residual earner of farm profits, all of the characteristics of structural change discussed are indirectly captured in land values or cash leases. In addition, it is through land markets that land control is obtained and transferred[4]. Accordingly a model that attempts to capture the underlying farm structural dynamics must play close attention to the underlying characteristics of the farmland market and land values.

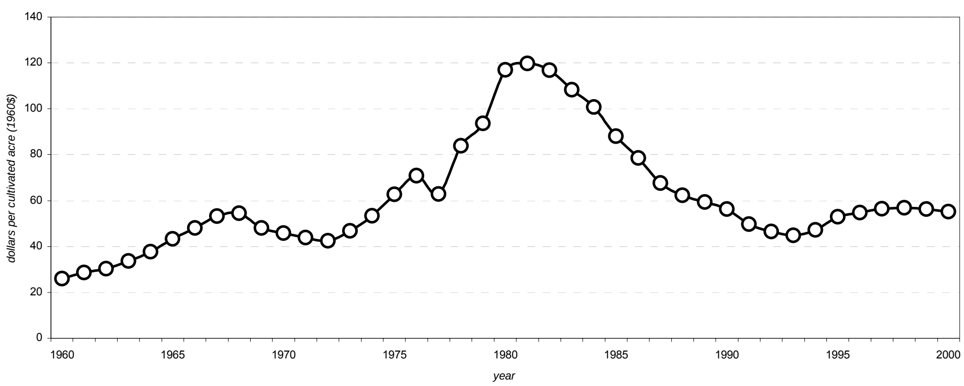

Figure 2.6: Saskatchewan Land Values per Acre (in constant 1960s dollars) 1960-2000
Source: Saskatchewan Agriculture, Food and Rural Revitalization 2004

Saskatchewan land values grew rapidly during the 1970s period and reached a peak of approximately $120 (1960$) in 1981 (figure 2.6). This period of rapid inflation in land values was followed by an equally dramatic downward adjustment in prices which resulted in land values returning to their pre-rally levels by the early 1990s (figure 2.6).

[4] This ignores the importance of inter-family land transfers.

2.3 Forces Driving Structural Change

While effort has been exerted on understanding the dynamics of structural change, research conclusions have not been consistent, and have lead to strikingly varied conclusions and policy recommendations (Harrington and Reinsel 1995). Figure 2.7 highlights eight major causative factors of structural change identified by Goddard et al (1993). The remainder of this section will be dedicated to a brief discussion about those key drivers of structural change within the Saskatchewan and western Canadian crop production sector.

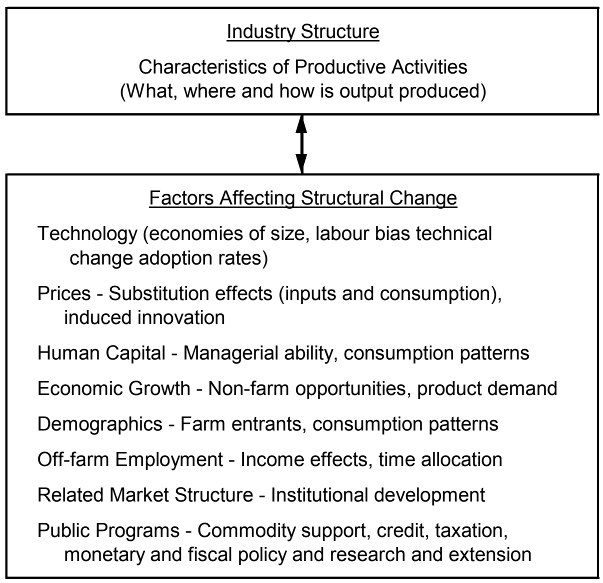

Figure 2.7: Dimensions of Structural Change: Industry Structure and Casual Factors (Goddard et al 1993).

2.3.1 Technology and Relative Factor Prices

Technological innovation is an important factor in the constantly evolving structure of Saskatchewan agriculture. Cochrane's (1958) "technological treadmill" is a well-known theory of structural change that is based on the incentives of individual producer's to adopt new technology. The typical producer, who is unable to individually influence market prices but has the ability to control production costs, has a strong incentive to search for cost reducing (output increasing) innovations (Cochrane 1958). Early adopters benefit in the short run, but diffusion of the innovation increases the industry output and results in lower commodity prices. Subsequently, a reduction in farm revenue forces other farmers to either adopt the new technology to maintain farm revenue at the level realized prior to the introduction of the innovation, or to exit the industry and transfer resources to the innovating producers (Harrington and Reinsel 1995). The consolidation of resource ownership is further accelerated when technological innovations are embodied in capital goods that require a minimum production size to be profitably adopted by producers. Technology embodied in capital assets result in larger farmers being better positioned to innovate and capture the benefits of early adoption (Harrington and Reinsel 1995). However, in contrast to these *a priori* supporting arguments, Giannakas et al (2001) found no clear relationship between farm size and technical efficiency among wheat producers in the province of Saskatchewan.

Technological innovation involving the mechanization of agriculture has resulted due to the price of capital falling relative to the price of labour. Producers respond to changes in relative prices by seeking out technology that saves the relatively more expensive factor of production (Karagiannis and Furtan 1990). As a result of changes in the relative prices of capital and labour, producers have incentive to replace labour inputs with capital inputs.

Others observe that technological change results in more than a simple alteration of the mix of inputs employed to produce a given level of output. It can also give rise to increases in economies of scale, requiring the producer to employ greater units of input (specifically land) in order to utilize labour inputs efficiently (Helmberger 1972). The presence of increasing returns to scale at low or moderate output levels suggests that farms within this size range will either exit the industry or expand to a size that is consistent with minimum long run average cost. Consequently, growth in farm size is consistent with economies of scale (Goddard et al 1993). Meanwhile, others have suggested that observed increases in farm scale are the result of farms attempting to garner higher total returns to bridge the gap between farm and non-farm returns to labour. This line of thinking postulates that it is not the presence of economies of scale, but rather the non-existence of significant diseconomies of scale that is driving farm growth (Goddard et al 1993). Both hypotheses are consistent with empirical evidence suggesting that agricultural production is characterized by either a steep L-shaped or a lazy U-shaped cost curve (Schoney 1997).

2.3.2 Labour Mobility and Non-Farm Opportunities

Kislev and Peterson (1982) focus their explanation of farm size growth on the assumption of perfect labour mobility between farm and non-farm sectors. A rise in non-farm incomes provides a strong incentive for producers to leave the farm to obtain higher returns to their labour, thus freeing resources for the remaining producers to decrease the urban-rural income gap. Kislev and Peterson (1982) hypothesize that the out-migration of farm labour and the growth in farm size are two aspects of a single economic process. Goetz and Debertin (2001) apply a similar idea to explain an individual's decision to quit or to remain farming (or start). Individual producers compare the utility they expect to derive from operating a farm to the utility derived from off-farm opportunities. A farm family, earning an opportunity wage on their labour, must increase in size as the real off-farm wage increases to maintain equilibrium between farm and non-farm returns to labour (Huffman and Evenson 2001). Thus, as the non-farm wage rate declines relative to farm returns to labour, this theory would suggest that the number of farms would increase.[5]

An increase in non-farm wages results in an increased opportunity cost for the farm family's labour input. The increasing cost of labour lowers the relative cost of capital and will result in an increase in the optimal capital-labour ratio (Kislev and Peterson 1982). The farm family is forced to either expand the farming operation to fully employ their labour input, or employ their excess labour in alternative markets. Both scenarios have a profound effect on the structure of the agricultural sector. The decision made by the individual farm family will be constrained by the opportunities that are available in both the farm and non-farm sectors.

2.3.3 Capital Immobility

The asset fixity or capital immobility argument also provides a rational basis for the observed diversity of farm size and technology adoption (Harrington and Reinsel 1995). Johnson (1972) argued that capital investments become fixed over a wide range of rates of returns between the acquisition cost of expanding capacity and the salvage value of reducing capacity. A resource becomes fixed for a given farm if its earning power is too low to justify the purchase of more of the resource at the market (acquisition) value,

[5] The economy wide depression of the 1930's was characterized by an increasing number of farm operators which may be at least partially explained by the lack of non-farm employment opportunities, and the resulting lower expected non-farm labour returns.

yet too high to justify selling the asset at its salvage value (Johnson 1972). The direct result is that in the short run, farm structure can be characterized by significant diversity of farm size and technology.

2.3.4 Demographics and the Life-Cycle Hypothesis

Demography is a powerful and often under-utilized factor in understanding economic activity. Foot (1996) argues that it is not possible to do any accurate economic forecasting without knowledge of demographics. Demographic characteristics of a population play an important role in both public policy and business analysis in the long run. Demand for education and health care services are two prime examples where public policy and demographics interact.

Extant demographic characteristics of a population are the best predictor of the future demographic structure of an economy. As a simple example of the power of demographics for educational policy analysis, consider that the number of births in a school district in 2004 constitutes a highly accurate forecast of the number of children entering the first grade in 2010. By failing to understanding the obvious future consequences of current demographic characteristics, the task of developing a forecast is needlessly complicated (Foot 1996).

One of the most useful statistics for predicting general economic behaviour is the age composition of a population (Foot 1996). While humans make decisions independently, individuals in the same age cohort generally engage in similar activities as their peers. In fact, highly similar patterns of behaviour are observed among age cohorts over time. Some observe that this behaviour can only be marginally altered by economic conditions, government programs, or external shocks (Harrington and Reinsel 1995). In most instances the participation rates of various age groups in different activities are relatively stable over the medium run. For instance, it is highly likely that a 45 year old in 2014 will behave the same as a 45 year old in 2004; chances are also good that an individual will move out of their parent's home, buy their first car, and get married about the same age as peers (Foot 1996). This basic life-cycle model of economic activity can have important impacts on the aggregate economy as the population ages[6] and the age composition of the population shifts and alters the number of individuals in each stage of the life cycle.

[6] "Population aging" refers to the basic fact that each year every individual is one year older, and should not be confused with an "aging population" which is generally characterized by an increase in the average age of the population.

A basic farm life cycle model will explicitly recognize the various life stages as well as management objectives an operator experiences. The operational ladder typically followed by a farm operator in Canada is to enter the industry by renting farm assets, add additional rented land for part of their lives while progressively acquiring ownership of land and capital assets throughout a growth phase, and finally relinquishing control of leased and owned assets as they exit from farming (Harrington and Reinsel 1995). Ultimately, structural change is the result of micro-level dynamics of entry, growth and exit. Some offer that government policies, economic conditions, and technological change may only marginally affect the incentives and opportunities within the life cycle of the farm operator (Harrington and Reinsel 1995).

Demographics imply are that while operator ability and hard work are important factors in farming, the timing of start up and initial capital stock may play a significant role in determining the success of a farm operation. Operators who have inherited substantial farm assets, or who operate established farms with a significant level of equity, are better positioned to withstand extended downturns in the farm economy that may bankrupt equally able and efficient operations. As a result, it is important to incorporate family and farm life cycles when analysing current and future farm survival and structural shifts (Barlett 1984)

In an industry where the bulk of the entry occurs from a relatively young age cohort (i.e. between 20-30; Harrington and Reinsel 1995), a reduction in the number of farmers, as well as young people raised on farms, has implications for the future of the food production sector (Goddard et al 1993). A declining number of young people raised on farms, who historically have accounted for the majority of new farm entrants, will lead to a further decline in farm entry. This in turn signals a shift away from the traditional single owner-operator farm arrangement (Goddard et al 1993).

2.3.5 Productive Heterogeneity

The changing structure of agricultural production is thought by some agricultural economists to be a consequence of the heterogeneous nature of productive efficiency. The existence of varied levels of productive efficiency among farm operations might also explain the consolidation of farm assets among fewer operators (Harrington and Reinsel 1995). Deferring to a mechanism similar to Cochrane’s (1958) “technology treadmill”, some have argued that efficient producers will earn economic profit, while the inefficient farms will incur losses. Facing a downward sloping demand, this cumulative process will result in the transfer of land and capital assets from the inefficient farms to the efficient farms. Increases in production resulting from the efficient use of these resources will increase aggregate supply, further leading to relatively low market prices and still more pressure on the net incomes of less efficient farms (Harrington and Reinsel 1995).

2.4 Farm Management/Entrepreneurship

At the farm level, there are many potential drivers for rural structural change. But one possible underlying driver that has not been fully explored in the literature is the fundamental and intrinsic difference in farming "management style." Much anecdotal evidence exists among agricultural professionals as to how differences in decision making lead to a management style (Jensen 1977). While there are many possible management attributes, management style should encompass; 1) a willingness to accept/or reject the current situation or status quo, 2) a willingness/unwillingness to act or respond under incomplete information and to accept risk (entrepreneurship), and 3) a view of farming as a business/life style. Clearly, these attributes are not necessarily independent and may be in turn influenced by a number of demographic variables.

Agricultural and rural structure is related to the ownership and control of agricultural land. The past, present and future ownership and/or control of the land resource are directly linked to the relative bidding potential of land market participants (Harris and Nehring 1976). A number of economic factors, including net income, income variability, wealth, marginal tax rate and interest rate, have a direct impact on the land bidding behaviour of an individual (Harris and Nehring 1976). Which farms are best suited for future growth and will gain the most from expanding their farm acreage? In turn, this leads to a second, potentially more important, question of the growth willingness of the farm manager/entrepreneur (Welter 2002).

The growth aspirations/willingness of the individual farm agents may have a profound effect on the final allocation of land. While theoretically growth is initially desirable to achieve a sustainable scale of production, personal growth ambitions play a significant role in shaping a farm's growth path (Welter 2002). A farm agent with a higher bidding potential and thus having more to gain from farm growth may ultimately end up being outbid by another farm manager with a lower bidding potential due to the agent's lower growth aspiration. In fact, the individual farm entrepreneur's growth ambition can be incorporated into their land market bidding behaviour in a number of ways, including the incorporation of a degree of risk aversion when forming a land bid (see Harris and Nehring 1976) as well as the simple choice of entering the land market or remaining on the sidelines. A general pattern of land market participation behaviour can be observed based on the age of the farm manager and the corresponding business phase. Studies have shown that participation is typically limited to established farms still in the growth phase, as farm managers nearing retirement typically refrain from participating in the land market as buyers. In addition, young farmers still in the entry/establishment phase are typically blocked from entering due to high debt-levels (Olson 2004).

The growth of a farm operation is directly linked with the underlying management style of the farm household. Within the literature, a rather consistent categorization of farm management styles has emerged (Taylor et al 1998). The business-oriented style of management encompasses the entrepreneur (Olsson 1988), dedicated producer (Fairweather and Keating 1994), and the efficient operator (Walker 1989). In contrast the lifestyle approach to farm management is typically characterized by strategic caution (Olsson 1988) and sufficing behaviour (Fairweather and Keating 1994). A number of researchers (Bennett 1982; Fairweather and Keating 1994) suggest that farm management styles are largely influenced by the life-cycle of the enterprise and may vary as time progresses. Ultimately, different approaches to farm management exist, and the distribution of management styles among a relevant farm population may have an effect on the aggregate agricultural structure of a region.

2.5 Summary

The literature on structural change in agriculture suggests a number of factors that may be driving the transformation of agriculture and in general, the composition of the farming sector in Saskatchewan in particular. The factors considered and highlighted here include technology, labour mobility, capital immobility, demographics and productive heterogeneity. While a diverse literature, a consensus has emerged that at the aggregate level, structural change results from transformations occurring at the individual farm level. Thus, theories concerning the sources of structural change have in common the importance of the individual farm household as the significant decision making unit in agriculture. This buttresses the need to establish the individual farm operation or household as the primary unit of analysis in a study of aggregate farming behaviour.

CHAPTER THREE

FARM LEVEL MODELING

3.0 Introduction

General policy analysis in agriculture often uses computational farm-level models. Early versions of these traditional models were designed by government and universities beginning in the 1960's to better understand the farming sector and the overall impact of policy change. Even today, the vast majority of farming models are founded on one of either representative producer, input/output or computational general equilibrium (CGE) methods. The first method is not statistically defensible when the population is highly diverse. The latter two types of models offer macro predictions based on structural equation parameters estimated from highly aggregated data. One of the inherent limitations of all of these traditional farm-level models is that due to hysteresis, they are often unable to accurately forecast behaviour very far beyond those years from which the model parameters were derived. This situation is a major impediment to formulating sound agricultural policy in an ever-changing economic environment.

This inherent limitation of the traditional models for understanding and predictive purposes has led to research into a new generation of farm-level models. General advancements in computer simulation environments have sparked the development of detailed, microscopic computational approaches to simulate the behaviour of human systems (Parker et al 2003). While these models are now widely used in some fields of research, there has been limited application so far to agriculture. Great potential exists for this kind of simulation modeling to better assess and forecast the major structural change now happening in Saskatchewan agriculture. The appropriateness and application of these new computing and simulation tools to the issues of farm-level modeling, agricultural production and land use will be the focus of this thesis.

3.1 An Alternative to the Neoclassical Economic "Toolkit"

Neoclassical economics has been the dominant paradigm in both economic research and teaching since the 1940's (Happe and Balmann 2003). This has resulted in the widespread acceptance of modeling economic problems and individual behaviour using the mathematical optimization 'toolkit'. The widespread use of optimization techniques to represent individual behaviour has resulted in some confusion regarding the fundamental economic concept of individual rationality. Rationality is often confused as a technique, the optimization technique, rather than a concept (Vriend 1996). Rationality, in economic terms, simply refers to an individual selecting the option, from their perceived opportunity set, believed to be in their best interest (Vriend 1996). Mathematical models are simply one way of representing an individual's selection process, but they should not be understood as an economic principle in spite of their widespread use. Alternative models of individual behaviour may result in the selection of different 'optimal' choices under assumptions using equivalent information, without violating economic rationality.

The concept of bounded-rationality in economics is defined as situations where limited resources constrain fully rational decision-making and this can also be described as ignorance. Bounded information is the direct result of economic search costs, and should not be confused with rationality, which is unaffected by economic factors (Vriend 1996). Modeling bounded-rationality presents two problems - modeling ignorance and modeling rationality. While agent-based modeling facilitates the development of a tractable model of individual learning and ignorance, some authors argue it is the second issue that will ultimately lead to its widespread acceptance as a new economic modeling 'toolkit' (Arthur 1994).

Agent-based systems are generally defined by a set of autonomous entities, or agents, which have limited knowledge and computational abilities (Berger 2001). As the name suggests, individual agents are the primary component of any agent-based model. Of primary interest to social scientists is the interaction and information exchange between agents that occurs in a decentralized and "somewhat social" manner within the simulation environment (Berger 2001). I will argue that the technique maps well onto farming and farm behaviour, especially the paradigm of interacting yet autonomous decision-makers conducting their business on a physical landscape.

The unit of analysis in an agent based system model is the individual actor or agent behaving as a result of autonomous decisions. Many systems are not controlled by a central planner; rather, stability or equilibrium in these models is generated via the decisions and actions of multiple individual agents, coupled with their interactions with other agents and the environment (Schelling, 1978). One advantage of the de-centralized decision making inherent in agent based modeling is that many well specified models generate unpredicted ('emergent'[7]) patterns of behaviour at the macro level (Bonfanti et al, 1998). Today, the agent-based literature is firm about the simulation algorithm - once initial conditions are set, all future events in these virtual worlds are initiated and driven by agent-agent and agent-environment interactions, with no further intervention by the modeller required or permitted (Tesfatsion, 2000).

The path to widespread acceptance of agent-based modeling methodologies is expected to parallel the development of the field of experimental economics from its pseudo-science status in the early 1960's. Experimental economics gained acceptance with the development of new equilibrium concepts (e.g. Nash equilibrium, and the core) in the late 1960's, and primarily as a methodology for choosing between alternative theories of behaviour (Friedman and Sunder 1994). The development of alternative equilibrium theories resulted in the focus of behavioural economics expanding from causal propositions in the form of "If x then y" under the existence of a single rationality theory to actual testing of the suitability of alternative theories based on experimental data (Friedman and Sunder 1994).

The development of alternative models of human behaviour to compete with the "economic man" paradigm has resulted in a need for methodologies to accommodate appropriate individual behaviour. It has also been argued that agent-based models have the ability to serve as a "social laboratory" for testing the plausibility of various behavioural models (Casti 1999). Furthermore, agent-based modeling can provide the researcher with a method that allows the modeling and testing of alternative models of individual behaviour that have been previously neglected due to tractability and complexity issues.

[7] Emergence is the property that a system is not simply equal to the sum of its individual parts. Phenomena at the macro level cannot always be explained by observing the properties of the system in isolation. Macro level structures are rather the result of interactions of the individual components of the system (Happe and Balmann 2003).

3.2 Current Farm-Level/Land-Use Modeling Methodologies

Research within the multidisciplinary fields of agricultural production and land-use has resulted in the application of a variety of model building methodologies. The appropriate modeling methodology must be based on the structure of the underlying system and the objectives of the research project. As a result the focus of this section will be to briefly examine the strengths and weaknesses of a number of broadly categorized alternative methodologies.

Agarwal et al (2002) identified three general components that are important for the evaluation of land-use models including space, time and human decision making. These three axioms form the basis for a discussion on alternative modeling methodologies. These authors argue that in order to adequately capture all relevant dynamics within a system characterized by a strong human-environment relationship, the interactions between the temporal and spatial environments and human choice must be explicitly incorporated into the model system.

3.2.1 Farm Budgeting/Planning Models

Initial modeling efforts at the farm-level are best described as farm management tools that were developed to study financial problems at the individual farm level. These early farm models consisted of simple partial budgets to predict the outcomes of alternative production scenarios, along with case studies of successful farms to determine common characteristics of successful producers (Klein and Narayanan, 1992).

While individual producers remain key factors in any agricultural system, the increasingly heterogeneous profile of remaining producers and the farm specific nature of these types of models limit their use for policy analysis as stand alone models. That is not to say that these simple partial budget and case studies are useless to the development and analysis of future policy tools. In fact they may help lead to a solution for the problem identified by Simon (1955), replacing the “economic man” model of human action based on global rationality with a model consistent with the computational capacity and access to information actually possessed by human actors in an economic system. The successful development of future farm level policy models within an increasingly complex and heterogeneous industry will require a better understanding of the characteristics that drive individual farm management decisions.

3.2.2 Equation Driven Models

Equation driven (quantitative) models have traditionally played an important role in the development and analysis of agricultural policy. The structure of these models has generally taken either a macro-perspective or a micro-perspective of the system under analysis. Attempts were made at developing classical spatial equilibrium models of agriculture, but they were inherently complex, difficult to solve and led to poor forecasts (Takayama and Labys, 1986). In addition, by focusing on either the macro level (country, province or region) or the individual farm (micro perspective), a number of significant issues that are functionally situated in between these extreme perspectives, such as structural and distributional effects, are effectively lost (Happe and Balmann 2003).

Micro-level models generally select a typical farm to represent a relatively homogenous group. The representative farm incorporates detailed micro data and is most often used to simulate adjustment to a policy change (Happe and Balmann 2003). The method of modeling each individual solution and then aggregating the results to determine the macro effects of a policy is referred to in the literature as microprogramming (Fisher and Kelley 1982). Modeling each individual farm is costly, and in many cases the solutions are non-feasible (Kelley and Fisher 1982). This problem is usually solved by aggregating similar producers and building so-called 'representative' farms. The development of the CRAM model (Canadian Regional Agricultural Model) of the Canadian agricultural sector and the REPFARM model of the U.S. sector are examples of behavioural farm-level models (Klein and Narayanan 1992) that focus on a limited number of representative farms which in turn are assumed to exist in isolation with no allowance for explicit inter-farm interactions.

In addition, analysis of the results generated through the aggregation of representative farms is subject to aggregation bias and error due to the difficulty in developing artificial farms that are truly representative of the entire group. As far back as the 1960s, Day (1963) argued that even though it is theoretically possible to achieve exact aggregation in economic models under certain conditions, developing satisfactory criterion remains a major problem.

Significant advancements in computational capacity allow researchers to avoid aggregation issues by facilitating much more disaggregate micro-programming. While decreasing computer processing costs may avoid the classic aggregation problem, current microprogramming methodologies are still hindered by a second aggregation bias identified by Happe and Balmann (2003). The simple arithmetical aggregation of individual farm models, solved independently to represent an industry or a region, completely omits any interactions and dynamical effects that can occur between individual farms and the subsequent macro level phenomena that emerge from these interactions (Happe and Balmann 2003). Berger (2001) compared the inability to capture interactions between farm-households to the assumption that no transaction or information costs exist. A second criticism of mathematical programming based on simulation models identified by Berger (2001) is the inadequate representation of the important spatial dimensions of agricultural activities. As a result, the role of internal transport costs and the immobility of land are often ignored in traditional farm-level models – an effect that can be likened to the assumption of zero transaction costs (Berger, 2001).

Through the 1970s, the growing importance of world markets and the cost of commodity based support programs resulted in a shift in farm modeling towards aggregate supply response of the industry (Klein and Narayanan 1992). However, a macro-level approach ignores the heterogeneity in behaviour and resource endowment among individual producers that form the aggregate response (Happe and Balmann 2003). The lack of understanding about the effects of policy at the individual producer level is the major point of criticism directed at macro-level modeling. Predictions generated from macro-level models are based on extrapolation from historic aggregate data patterns, with minimal attention paid to the behaviour of individual economic agents (Stoker, 1993). The use of macro-level modeling techniques not only masks the distributional effects of a policy change, it also fails to capture the important linkage between response at the individual level and the aggregate response. A relatively small shift in individual producer incentives or a change in the profile of producers in the region, resulting from a policy change, can potentially result in a significant impact on the aggregate response. The latter is not something macro-level models based on historical data can easily incorporate.

The inability of current farm-level models to readily adapt to shifts in individual responses also limits long-run predictive ability. If policy issues, such as structural change, are in fact path dependent[8] (Balmann

[8] See page 28 for a definition of path dependency

1997), the current models lack the ability, due to their limitations for long-run prediction, to fully assess the impacts of a policy option. Policy makers using these models must be careful to ensure that those policies intended to have a positive impact in the short-run do not have an unwanted and damaging impact on the long-run performance of the sector.

3.3 Agent-Based Systems: A New Farm-Level Modeling Paradigm

The use of agent-based or multi-agent systems originated in computer science through the field of distributive artificial intelligence. Today, the use of agent-based systems is a growing multidisciplinary research tool. Unfortunately, a degree of uncertainty still exists concerning the precise definition of an agent. The definition adopted by individual researchers varies depending on the area of study. However, a minimal common definition, as proposed by Ferber (1999), is as follows:

> An agent is a physical or virtual entity;
>
> - which is capable of acting in an environment
> - which can communicate directly with other agents
> - which is driven by a set of tendencies (in the form of individual objectives)
> - which possesses its own resources
> - which is capable of perceiving its environment (to a limited extent)

Balmann (2000) offers a more succinct definition, which captures Ferber's - agents are reactive, autonomous and goal orientated entities with the ability to sense their environment and, in particular cases the ability to communicate, learn and be mobile.

A number of concepts and issues associated with agent-based systems draw from the related field of complexity theory. While a detailed description of complexity theory (Manson 2001) is outside the scope of this thesis, it is worth briefly exploring the relationship between agent-based modeling and complexity. Complexity theory covers a variety of analytical concepts and is inherently a multidisciplinary field of research. It is important to note a fundamental difference between complexity theory, which is often concerned with non-linear relationships, and the linear relationships defined by stocks and flows in general systems theory (Manson 2001).

No concrete definition of complexity theory exists. Rather, complexity research is founded on a common concern for understanding how a system can be characterized with reference to its individual components in a non-reductionist manner (Manson 2001). Further, complexity theory is concerned with the evolution of system behaviour as a result of the interactions between constantly changing individuals, as opposed to the parameterization of entity interactions under the assumption of equilibrium that is implicit in general systems models (Manson 2001). Thus, agent-based models are often used to describe or explain social situations characterized by complexity.

In sum, agent-based models are founded on the idea that aggregate or system characteristics are the result of the actions of the system's underlying sub-components. In turn, these are affected by feedback from the aggregate system (figure 3.1). While traditional "top down" modeling approaches are focused on developing models that capture the outcome of individual actions, "bottom up" approaches explicitly model the individual actions and behaviours that likely generate the given outcome.

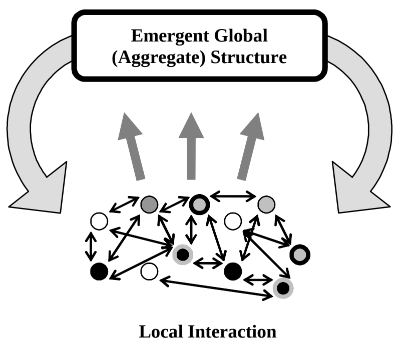

Figure 3.1: "Bottom Up" Modeling Logic (Lewin 2000)

Complexity theory and agent-based modeling broaden our understanding of economic phenomena as the emergence of order out of complexity. The direct interaction of economic agents is the foundation of economic complexity, and has been previously explored by some authors (Holland and Miller 1991; Day 1994; Arthur 1999). This conceptualization is significantly different from the majority of economic models in which individuals only interact through market clearing prices (Durlauf 1998). The value of incorporating ideas from complexity theory within the field of economics lies in its potential to enrich our understanding of the relationship between individual decisions and aggregate outcomes (Durlauf 1998). A modeling approach that consistently combines individual behaviour and interaction with aggregate phenomena is lacking within the mainstream economic literature. Agent-based systems offer the potential to remedy this issue by explicitly acknowledging the contribution of each individual in the system under analysis to outcomes at the aggregated level (Happe and Balmann 2003).

3.3.1 Why Agent-Based Methods?

There are a number of well-developed techniques of farm-level modeling for the purpose of policy analysis. However, each of these modeling methodologies has significant limitations. Equation-based spatial and aspatial models are generally only able to capture a limited degree of realism due to analytical and computational tractability issues (Takayama and Labys, 1986). And while analytical models can provide some insight on the impact of heterogeneity and neighbour effects in spatial modeling, they are generally limited to representing average and not extreme effects (Parker et al 2003). Due to the multitude of potential spatial and social interactions that may occur within a complex system, these analytical techniques can be inadequate for assessing issues that are guided by these interactions.

If formulated correctly, agent-based systems provide the researcher with the ability to overcome these and other limitations. The capability of agent-based systems to evolve solutions to phenomena that are regarded as systems of autonomous interacting components, like a farm economy, provide the motivation for increasing interest in ABS research in the social sciences (Sycara, 1998).

3.3.1.1 Flexibility and Complexity

Agent-based modeling is characterized as a “bottom up” approach, in that it is not driven by central coordinating mechanisms. “Bottom up” modeling approaches do not rely on exogenously imposed assumptions, including fixed decision rules, global rationality, representative agents or market equilibrium constraints, all of which are generally required within “top down” approaches such as computational general equilibrium models (Happe and Balmann 2003). In equilibrium models, the inclusion of these assumptions is usually required in order to analytically determine a solution, while solutions quickly become intractable as the level of system complexity increases. As a direct result of the comparatively less restrictive assumptions required for iterating a solution within an agent-based model, the researcher can endow individual agents with a more complete and realistic spectrum of properties and behavioural rules.

Ultimately, the attraction of traditional analytical economic models is their ability to yield stable, equilibrium solutions. However, many solutions fail to provide the researcher with an adequate understanding of the transition period between equilibrium states (Nelson 1995). Mathematicians and economists now recognize that it may not be the case that an economic system will always reach a stable equilibrium. For instance, frequent internal and external shocks may hinder identifying the equilibrium. The existence of a fixed or moving economic equilibrium needs to be viewed as an attractor[9], or desired state, rather than a description of the system state (Nelson 1995). In contrast, agent-based models permit quasi-equilibrium sinks or states to evolve from the interactions of individual actors without explicitly incorporating restrictive equilibrium constraints. This not only provides improved understanding of the transition period between equilibrium states, it also leaves open the opportunity for the equilibrium state to be altered prior to the system fully adjusting.

3.3.1.2 Emergent Characteristics

Emergent properties in systems analysis are those characteristics of a dynamic system (in equilibrium or not) that could not readily have been predicted before the experiment or simulation (Parker et al., 2003). Furthermore, emergent properties are the direct result of synergism between individual system components and are not simply additive affects of the system components (Manson 2001). The notion of aggregate system characteristics emerging from the interactions of individual actors is deeply embedded within traditional economic theory. Economists have long regarded market processes as being the result of unguided interactions between rational individuals, including most notability the Smithian “invisible hand” paradigm used to describe self-coordination within a market economy (Happe and Balmann 2003).

Parker et al (2003) argue that emergent phenomenon can only be practically modeled with computational tools such as agent-based models. This is due to the difficulty of constructing analytical spatial equilibrium models that can incorporate all relevant microscopic interactions. To date, a number of researchers have identified useful examples of emergent system properties in dynamic models in this context. These include land use patterns (Parker and Meretsky 2004) and the overall distribution of farm sizes in Europe (Balmann

[9] An equilibrium state can be thought of as an attractor in the sense that it is the state the system will reach if it is allowed to fully adjust, but full adjustment may not necessarily occur due to a number of internal and external factors.

1997) both of which are best described as emergent properties of systems of individuals interacting within a spatial market.

3.3.1.3 The Importance of Time and Space

The primary importance of time and space within any human driven system can be summarized by two undeniable physical truths for all matter, save for sub-atomic particles - 1) it is impossible for matter to be in two places at a single point in time and 2) time is irreversible. Past actions cannot be undone, and only their long term outcome can be altered by current and future decisions (Happe and Balmann 2003). Balmann (1999) among others calls this notion "path dependence", and refers to the phenomena that in a stochastic world, the current state depends upon previous actions and events. In such a case, agents operating within the same system may differ in their actions, even if the same information set is available to all agents, as past actions and observations affect their opportunity set and perceptions of the world. As an example of this, two farmers may be aware of a new technology that will potentially improve profitability, but a one may opt not to adopt the new technology due to financial constraints that were caused by an earlier action.

In many ways human perception of the world is largely shaped by space and geography (Fellmann et al 1999). For geographers, the importance of location and the influence of neighbours parallel the economist's reliance on theories of constrained (by resource or budget) utility maximization (Nelson 2002). The importance of modeling an agricultural system in a spatially explicit manner becomes increasingly evident when one considers the importance of space and location in a number of agricultural decisions. For example, an important factor in farm growth is the cost of internal transportation and the increased cost of farming geographically scattered units of land. As a result, producers with a desire for farm growth are generally limited to competing with their neighbours for additional units of land (Berger 2001).

3.3.1.4 The Importance of Heterogeneous Producers

The individual producer is ultimately the driving force behind and the recipient of the eventual outcomes of any agricultural policy. If agricultural policy makers do not understand the importance of individual management and behavioural characteristics, it becomes difficult to design policies to achieve a desired outcome. Furthermore, there are challenges solving any system involving dynamic, independent and intelligent actors with free will. At present, with only 39% of Canadian farmers self-described as business focused and 50% as lifestyle farmers (Short 2004), the development of effective agricultural policy must depend in part on understanding the varied management strategies that exist between and within these two drastically different groups. Thus, even under the assumption that all individuals are pursuing the same goals (i.e. utility maximization), a large variance in individual behaviour will result unless all individuals have identical information, computational abilities, and utility functions.

Within the framework of agent-based modeling, individual agents must be assumed to act according to some model of cognition (Parker et al 2003). At the most basic level, individual agents must also have the ability to react to their environment in a manner that is compatible with their individual perceptions of the world and their goals. This somewhat extends the notion of traditional economic theory, based on the idea of an "economic man" presumed to behave rationally under the assumption of perfect information (Simon 1955). While rational choice models developed under the assumptions of the "economic man" provide significant explanatory power, they may fail to accurately predict behaviour under realistic assumptions of imperfect information (Parker et al, 2003). Simon (1955) and others argue that even under assumptions of imperfect information, the "economic man" paradigm overstates the computational capacities actually possessed by many individuals.

The primary advantage agent-based models offer over traditional economic modeling approaches with regard to modeling human behaviour is the ability to readily incorporate a significant degree of individualism in the decision making process. The ability to design a multitude of individual agents also allows the researcher to incorporate a number of varied decision making models. And while not followed in this thesis, the researcher is not actually limited to assuming that all individuals follow the same decision making process. In fact, agent models can de designed to endow each individual with a unique decision making algorithm.

3.3.2 Challenges and Limitations

Economic models are designed to understand issues as part of a more complex economic system. Agent-based models have a unique characteristic in that their flexibility of specification and design is both a great advantage and a potential problem (Parker et al 2003). As these models become increasingly more realistic, they also increase rapidly in complexity, which can result in the loss of an ability to draw direct cause and effect conclusions (Happe and Balmann 2003). The inability to assign a direct causal link may pose a significant problem for theoretical research, but the point may be less important for policy analysis based on simulation models that are developed using empirically grounded assumptions. In addition, model verification and validation[10] become increasingly more difficult as the level of complexity increases (Kelton et al 2004). Kelton et al (2004) concede that it is "almost impossible to verify totally a model for a complex system" and it seems the only option is to rigorously test the simulation model under multiple scenarios to verify that it behaves correctly for a reasonable set of potential scenarios.

In addition, to move beyond replicative and predictive validity[11] based on comparing simulated and observed data is rather difficult. This is often accomplished in a qualitative context by agreement of participating stakeholders that the modeled behaviour is an acceptable theory that cannot be rejected based on current knowledge. Note that this is not a situation unique to agent-based modelling, as the scientific method is based on rejecting false hypothesis and theories rather than directly accepting true ones.

The wider acceptance of agent-based models as a tool for economic and policy analysis is currently hindered by a number of concerns that must be overcome. The greatest challenge facing researchers in this emerging field is the communication of model constructs and results without a standardized toolkit or a common base of knowledge. The lack of a standardized toolkit is further aggravated by the complex nature of agent-based problems, which often require long and detailed documentation. In contrast, while possibly misleading, agricultural models that have been widely accepted as tools for policy analysis seem to be appealing due to their reliance on neoclassical economic theory (Happe and Balmann 2003). Researchers must be aware that additional time and resources are currently required to outline underlying model assumptions and theories compared to researchers engaged in traditional economic research.

A number of the challenges and limitations identified within this section are not inherent to agent-based methods themselves, but rather result from a lack of understanding about underlying system dynamics.

[10] Verification ensures that the encoded model accurately represents the researcher's abstraction from the real world, while validation is concerned with comparing the model results to real world data and expectations (Parker et al 2003).
[11] Troitzsch (2004) identifies three types of validity; 1) *Replicative Validity:* the model matches data already acquired from the real system; 2) *Predictive Validity:* the model matches data before data are acquired from the real system; 3) *Structural Validity:* the model represents the manner in which the real system operates to produce the behaviour.

This point becomes increasingly obvious when attempting to model the behaviour of individual agents, while standard economic analysis has generally sidestepped issues related to the mechanisms used by agents to make choices in a perpetually novel world (Holland and Miller 1991). Current models of individual behaviour based on optimization techniques are often justified by postulating that adaptive, market driven, mechanisms result in agents acting 'as if' they are optimizing (Holland and Miller 1991). While this may in fact be a valid argument, it does little to address the structural behaviours driving the broader economy. Applications of the agent-based 'toolkit' stretch the boundaries of existing economic models and have the potential to dramatically alter the discipline of economics and the related field of farm-level modeling.

3.4 Summary

In any field of research, it is important to re-examine the methods of study from an alternative viewpoint or theoretical base. Agent-based simulations, combined with spatially explicit behavioural models, provide researchers interested in agricultural policy analysis the opportunity to view social and economic processes from an alternative perspective (Balmann 2000). Researchers must be aware of the advantages, as well as the limitations, of emerging research methods such as agent-based modeling when evaluating the available strategies for assessing both new and old issues and problems.

The modeling paradigm selected by a researcher must be driven by the objectives of the study and characteristics of the system under study. Systems that can be characterized as complex may be well suited for the application of agent-based methodologies. The ability of agent-based models to explicitly capture the complexity and emergent characteristics of economic systems in turn gives its application to farm-level modeling the potential to overcome the limitations of the previous generation of farm-level analysis.

The importance of understanding the limitations of any modeling paradigm should not be overlooked, particularly in the case of an emerging field. Without a standardized toolkit or knowledge base available, researchers utilizing agent-based models and complexity theory must ensure that all model assumptions and constructs are carefully documented and empirically and/or theoretically justified. While it is clear that the use of agent-based models results in some validity and verification problems, these problems can usually be distilled as problems associated with the specific research question rather than the methodology (Balmann

2000). The use of agent-based models also provides a significant degree of flexibility, particularly through incorporating individual behaviour and decision making characteristics. Like any new methodology that questions existing theories and ideas, agent-based modeling faces a number of challenges, but recent developments within the field should encourage other researchers interested in this newly emerging field of study.

CHAPTER FOUR

MODEL FRAMEWORK

4.0 Introduction

In the previous chapter, I argued that agent-based models are suitable for analyzing the structure of complex economic systems. In this light, there are now several agent-based models in the economics literature that have incorporated market-based agent interactions (Happe, Kellerman and Balmann 2004). The economic landscape of an agrarian region can be modeled as a result of local interactions between three primary components of agriculture: farms, land and markets (for products and land) (figure 4.1).

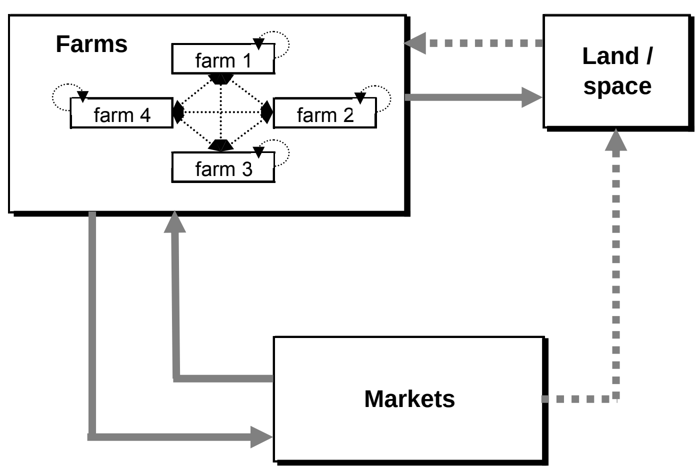

Figure 4.1: Conceptual Model of a Regional Agricultural System (Happe, Kellerman & Balmann 2004)

This representation of a regional agricultural system as an agent based model is appealing for two additional reasons. Rule based interpretation of farms as individually acting agents is a primary strength of agent based modeling methodologies. And a spatial issue like the allocation of a scarce and immobile resource, such as agricultural land, among a geographically dispersed set of farms can be dealt with in a relatively tractable manner in the agent framework.

4.1 Central Model Assumptions

Independent farming operations evolve based on the opportunities and constraints presented by their constantly changing environment. In this thesis, the farmer is considered to be engaged in two related but separate activities - producing and marketing field crops, and investing in agricultural assets. In the former, farms are essentially independent and annual production and marketing decisions are not directly constrained by the actions of neighbouring farms. In contrast, a farm's ability to increase asset investment, specifically in land, is directly constrained by the actions of all farms within a limited geographical area. The inability of a farm to produce output independently from the scarce land resource results in direct competition between farms for agricultural land.

Competition for agricultural land is organized in this model through the assignment of property rights and the continued functioning of well-defined agricultural land markets. An individual farm's production is constrained by the availability of additional crop land which is affected directly by the collective actions of all farms in the local land market. It is assumed that the farm manager's ability to acquire additional land for a price that is not in excess of its true future return is the key to the long term profitability of the farm operation.

A number of non-farming individuals, including retired farmers and speculators, are also assumed to be active within the agricultural land market. In fact, it is the presence of non-farming land owners in the land market that leads to the establishment of a lease market. It is assumed that the non-farming land owner will sell land when the return from selling outweighs the expected return from owning land, and will purchase land if the market price is less than the present value of the expected lease return.

In order to assess the impact of agricultural stabilization and support programs of the past few decades in Canada, the spatial and producer profile is initialized to represent an agricultural region typical of one that would be found in the dark brown soil zone of Saskatchewan in the year 1960. In addition all farms are assumed to be limited by the crop production technology of the initial time period for the duration of the model. In order to adjust for this assumption of constant technology, real commodity prices and production costs are also de-trended. Non-land capital investment stocks are assumed to be constant over farm size and between individual farms. Farms require a constant investment stock of machinery and equipment per acre for crop production. By assuming that technology and non-land capital stocks are constant, the role of managerial attributes on the evolution of regional agricultural structure can be studied in isolation from the effects of non-land capital variability and technological advancement.

Finally, the effect of income and property taxation over time is ignored and is not explicitly modelled. Income taxation is an important consideration for farm planning and cash flow, and can be assumed to be implicitly modelled as part of the annual farm household living/managerial withdrawal. Property tax is incorporated into the farm agents land bid value. The exclusion of property taxes results in a higher expected land rent (return to land) which results in a higher bid value compared to scenarios including property taxes.

4.2 Netlogo© Platform

NetLogo© is one of the several software packages that is currently available to facilitate the study of agent based systems research and model development. The NetLogo© software package was developed and is continually updated by the Center for Connected Learning and Computer-Based Modeling in the Dept. of Computer Science at Northwestern University in Evanston, Illinois. Its flexibility means that NetLogo© has a wide range of applications as both a research and a teaching tool. The program is useful to researchers because it contains a modeling environment suitable for simulating complex natural and social phenomena. The NetLogo© software readily permits the representation of thousands of independent agents all acting and interacting contemporaneously in a spatial environment. It is flexible and powerful enough to enable detailed study of the relationships that emerge from these individual actions and interactions, both at the micro and macro level (Wilensky 1999).

The Netlogo© 'world' is composed of multiple agents, each with the ability to carry out individual instructions and activity in a simultaneous manner. Within the software package, three general classes of agents are used (Wilensky 1999):

- "Turtles" - are a class of agent that can move around the environment
- "Patches" - each patch represents a piece of 'ground' over which the turtle agents move
- "Observer" - the observer is a 'god-like' agent, controlling all other classes of agents

Within the context of this model, individual farm operators are represented by the turtle agent class, while the patch class of agents is utilized to represent individual units of agricultural land used for crop production. Finally, the observer class of agents can be thought of as representing government and institutional agencies, which administer farm activities such as financial constraints, market mechanisms and government transfers. The observer class of agents also controls the timing of all activities within the model that are not directly controlled by individual turtle or patch class agents.

4.3 Model Logic and Organization

The basic logic of the simulation model is summarized in figure 4.2. The NetLogo© simulation consists of two phases: an initialization phase, and a simulation phase. In the initialization phase, the model structure, including all farm agents and land plots, is created. The initial attributes of all farm agents and land plots are also assigned during this phase.

Following the completion of the initialization phase, the simulation phase begins by initiating the crop production module. Following crop production, the observer agent effectively surveys all farm agents to sum up the gross revenue (determined in the crop production module) from all plots they currently control, while deducting all expenses in order to determine current financial state (farm results). Prior to initiating the land auctions, all farm agents are asked by the model to make management adjustments, which may include exiting the industry or transferring the farm to a new generation. The observer agent then proceeds to allocate available land to the remaining farm agents - initially through the purchase auction and any remaining land through the rental auction. Once both auctions are completed, the farm agents are again queried to make any addition capital investment requirements or divest of excess capital stocks. The simulation phase is repeated until a specific number of time periods are completed.

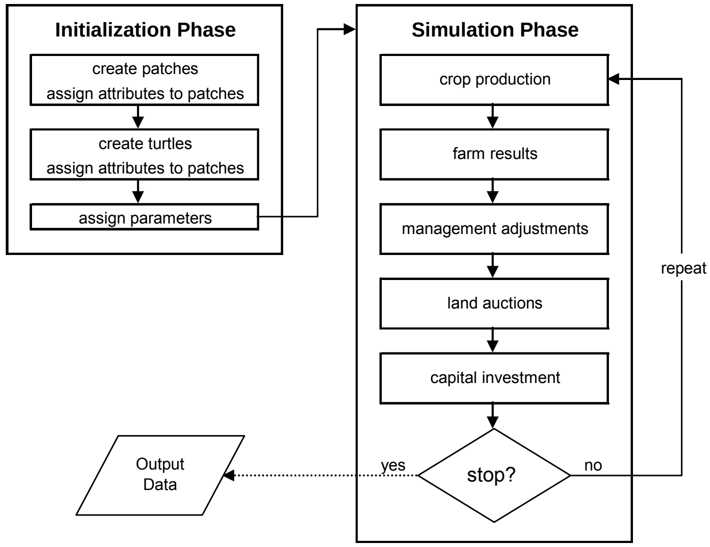

Figure 4.2: General Model Procedure Flow Chart (adapted from Happe, Kellermann and Balmann 2004)

4.4 Production Factors

The individual farm agent requires land, labour and capital inputs for annual crop production. Like the popular perspective of farming on the Canadian Prairies, it is assumed in this model that field crop production dominates the farming landscape. The importance of land as an input cannot be understated in a region characterised by field crop production as the sole form of agricultural activity.

4.4.1 Land

The spatial representation of the model utilizes the patch class of agents. A single patch agent represents an individual 160-acre plot of agricultural land. Note that just as in reality, total acres suitable for crop production on a given plot may be less than the total plot acreage. The simulated region used here consists of 1296 individual plots, and is equivalent to an idealized Rural Municipality in the province of Saskatchewan. Plots differ in three respects: productivity, land-use, and ownership. While this 'world' appears as a single two-dimensional grid in the model, the underlying characteristics and data structure can be simplified by separating the grid into multiple data and algorithmic layers (figure 4.3). The combination of five critical layers and their underlying characteristics form the physical and institutional spatial environment where the farm agents co-exist and alter their production decisions.

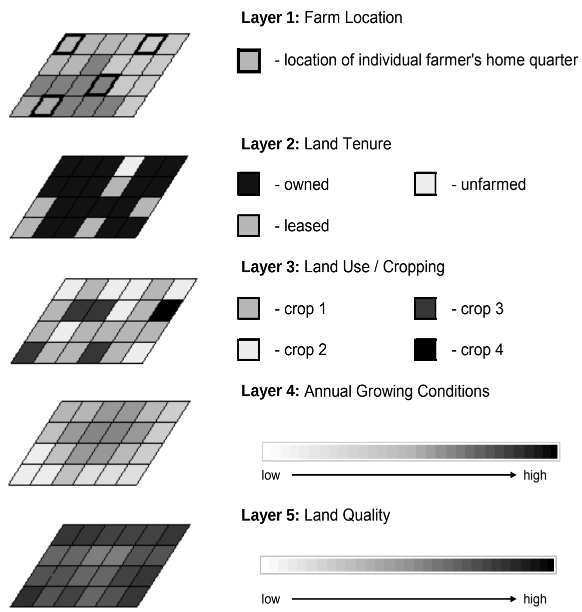

Figure 4.3: Spatial Data and Characteristics of the Simulation

The top two layers control institutional characteristics with respect to land control and tenure. Layer 1 maps out the spatial location of all agricultural plots available to an individual farm agent for productive activities. Note that the initial location of a given farm agent is determined randomly through each replication of the model. The second layer is essentially a regional map that identifies the owner and/or lessee (in the case of a non-farming land owner) of each individual plot of land, which is initially allocated based on the location of the farm agents. With respect to the top two layers, a given plot of land may exist in the following set of states:

- Plot is owned by farm agent *k*;
- Plot is leased by farm agent *k*;
- Plot is a farmstead;
- Plot is currently not managed (idle).

The land use/crop cover layer (layer 3) captures a producer's annual production decisions, and is the model equivalent of an aerial photograph of the region. Related research on the dynamics of land use and cover change utilizing the ABS framework typically focuses on this layer (Parker et al 2001). Annual crop production achieved from an individual unit of land is dependent on a number of exogenous factors, including soil productivity and annual weather patterns. The model algorithm incorporates these factors in a parsimonious way, yet the model consistently captures many of the subtleties of crop production. The impact of annual weather patterns and soil productivity are captured within layers 4 and 5, respectively. While overall weather conditions can differ dramatically between growing seasons, soil quality tends to be relatively constant over the relatively short geologic time period considered in the simulations. Therefore, soil quality is assumed to be stable within the simulation. Annual weather patterns and constant soil productivity are captured by a simple index value, where a value of unity corresponds to the average. Thus, a plot of land with average soil productivity and annual weather patterns (corresponding to index values of unity) realizes an average level of production. The exact meaning of an "average level of production" will be discussed again in section 4.6.1.1, which focuses directly on crop production.

4.4.2 Farm Labour and Capital

Farm agents are assumed to supply the majority, but not all, of the required labour for the farm operation. In turn, labour costs consist of both a family/managerial withdrawal and a charge for hired labour/custom work[12]. In addition, it is assumed that equipment and facilities inputs are fixed in constant proportions relative to the land input[13]. As a result, a farm agent who desires to double their farm acreage would also be required to double his/her equipment and facilities investment value.

4.5 Risk Preference/Entrepreneurial Classification/Farm Goals

A farm business deals with three primary types of risk – production/marketing, financial and asset risk. In this model, the farm manager's willingness to assume risk has a well defined impact on both annual crop production and long-term growth decisions.

Willingness of a farm manager to assume risk is a function of a number of factors, including personal goals/objectives, coupled with the entrepreneurial characteristics of the individual. I assume here that the life cycle of a farm business means operating in one of three life phases, where each phase is characterized by different levels of risk aversion: an entry and establishment phase, a development and growth phase, and an exit and retirement phase (Keatings and Munro 1989). The objectives of the farm business evolve as the

[12] The per acre cost of hiring additional non-family labour and/or custom work is assumed to be characterised as a logistic growth function and will be discussed further in chapter 5.
[13] While it is noted that farm machinery investments are often characterized as 'lumpy inputs', the existence of well functioning markets for machinery rental and custom operators will result in relatively constant economies of scale with regard to equipment and facility investment.

farm progresses through the three phases, while a farms' progression through the phases is strongly correlated with the age of the farm manager (Bennet and Kohl 1982). Throughout the development and growth stage, the farm manager will be primarily concerned with farm growth[14] and thus will be less risk averse than a farm manager in the exit and retirement phase, a time when equity protection and avoiding risk become the primary objectives (Olson 2004).

While it is possible to predict general patterns of behaviour based on age and other demographic characteristics (Foot 1996), the behaviour of individuals within a demographic group may still vary significantly. It would be naive to assume that all farms in the same business phase would have the same willingness to assume risk, and it can be expected that the risk profile will vary significantly among producers. Yet on aggregate, there are observable consistencies in risk behaviour. Tractability and data limitations mean that for my purposes, farm managers are segregated into four distinct managerial classes with correspondingly different (but equal within each category) risk preferences:

- *Exit and Retirement phase* manager (most risk averse)
- *Lifestyle farm* manager
- *Cautious expanding farm* manager
- *Expanding farm* manager (least risk averse)

All farm agents are assumed to enter the *Exit and Retirement phase* at a pre-determined age, after which they will no longer place bids on additional farm land[15]. During this phase, retirement planning and asset protection replace farm growth as the farms primary objective. Prior to shifting into the *Exit and Retirement phase*, farm agents belong to one of the three alternative classes for the entire farm development and growth phase[16].

Farm agents are assumed here to be concerned with farm expansion and will attempt to increase the number of plots managed throughout the growth and development phase. The farm agent's willingness to assume risk corresponds directly with their risk aversion factor. In this model, a risk neutral farm agent would have

[14] Farm growth includes both growth in the size of the farm through land acquisition and the growth of farm equity.
[15] The farm agent will still attempt to renew previous lease agreements
[16] The farm growth period occurs from the age the farm agent begins managing the farm to the age when the farm manager enters the exit and retirement phase.

a risk aversion factor set to unity and values land based on their undiscounted land rent expectations. Alternately, risk averse farm agents discount their land rent expectations with a risk aversion factor less than one, meaning the probability of purchasing land at a price that overestimates its true earning potential is reduced. And an increase in the level of risk aversion will lead to a reduction in a farms' land valuation (Harris and Nehring 1976). The less risk averse a farm agent is, the greater their risk aversion factor is, and the less their land rent expectations are discounted.

4.6 The Farm Agent - Farm Actions

Over the course of a single simulation year cycle, a farm agent engages in a number of distinct activities as shown in figure 4.4.

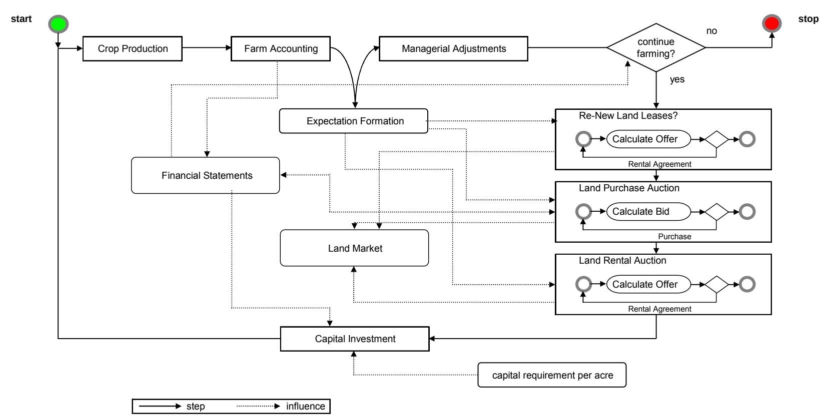

Figure 4.4: Individual Farm Agent Flowchart of Activities (based on Balmann 1997)

The activities undertaken by a farm agent include producing and marketing field crops, farm accounting, management decisions, renewing existing leases and acquiring control over additional land and capital assets.

4.6.1 Crop Production

Sale of crops produced generates gross cash income and variable cash expenses which becomes part of cash flows. Additional cash outflows include fixed production expenses and family living and managerial withdrawals.

4.6.1.1 Gross Crop Revenue

Annual crop production is characterised by gross revenue uncertainty, which can be separated into yield and price risks. The stochastic nature of annual crop production and commodity prices results in a varying short term profit and long term viability of each individual farm operation. Randomness within price and crop yield is composed of both global and local effects. On a global scale, commodity price is affected by world supply and demand dynamics - individual producers can have no impact on prices. However at the local level, individual producers may choose to market their crops at different times or to different locations, a strategy that may generate a price different from that of a neighbours' identical crop. Crop yields are determined by both global weather patterns applied to the region as well as local variations within the region of study. As an example, a drought will reduce the crop yields for all producers in the region, but localized weather patterns and other agronomic factors within the region determine the degree of yield reduction for individual plots of land.

The variability inherent in average annual world prices is exogenous to the simulation and is captured by an array of crop prices for all crops in a given year. Local variation among farmers is not permitted in this model, meaning that all producers receive the annual average world price for their production[17]. The global variability of crop yields is captured in the same manner as the global commodity prices. While the global price refers to a world market price, the global yield refers to the general yield pattern of the region.

Within the simulation, varied weather patterns and soil productivity lead to variation in the individual plots' actual crop yield. The relative production yield of an individual plot is determined by both fixed productivity factors such as soil quality, and annual productivity factors including weather. This combination of both fixed soil productivity and annual growing conditions determines the relative yield of the plot (see figure 4.5).

[17] This is probably not an onerous oversight. Local revenue effects will likely average out over the entire region, making this a rent-seeking issue, not a productivity issue.

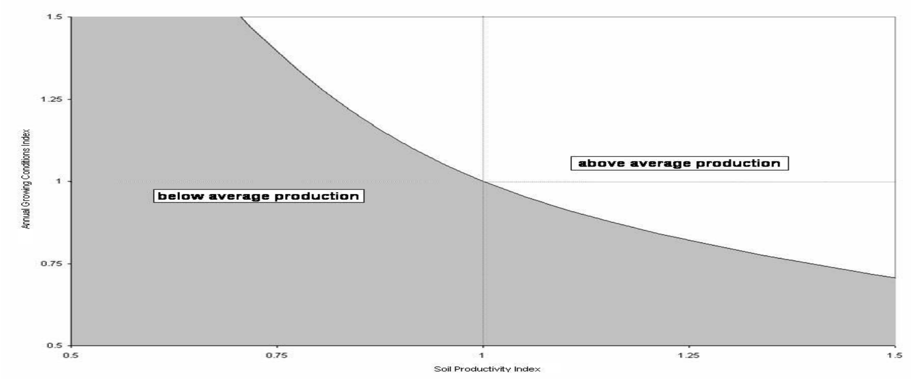

Figure 4.5: Relative crop yield, soil productivity, and annual growing conditions

A plot with soil productivity and annual growing condition index values both equal to 1 would produce a crop yield equivalent to the mean yield value for the current production period. Plots with a higher soil productivity index value have a higher probability of realizing a crop yield above the annual regional average crop yield than a plot with a lower soil productivity index value. A plot of land possessing a less than average soil productivity value (< 1) would require annual growing conditions exceeding the regional average growing conditions in order to produce a crop above the regional yield average for the same period.

The farm agent's realized gross revenue from crop production is a function of the global variability of commodity prices/yields and local yield variability. Global commodity prices and yields are input into the simulation as an array of values for each crop year, remaining consistent over all model replications[18]. Simply, the gross revenue of an individual farm agent is equal to the summation of the revenue generated by all crops grown on land controlled by the farm agent (equation 4.1).

$$GR = \sum_{i=1}^{I} GR_i \tag{4.1}$$

where GR = gross revenue of farm agent k
GR_i = gross revenue from crop i

[18]For example if the price of wheat is set at $2/bushel for crop year 1, and $3/bushel for crop year 2, these values would remain constant for all replications of the model.

Crop revenue is computed based on the global commodity price and yield, which are the same for all farm agents, as well as the individual farm agent's adjustment factor and the area of land allocated to production of the crop in question (equation 4.2).

$$GR_i = \overline{P_i} \cdot \overline{Y_i} \cdot PF \cdot A_i \tag{4.2}$$

where $\overline{P_i}$ = mean price of crop i
$\overline{Y_i}$ = mean yield of crop i
PF = productivity factor of farm agent k
A_i = area (acres) of crop i seeded/harvested by farm agent k

The productivity factor for each farm agent is the mean value of the productivity index (soil productivity index multiplied by annual growing conditions index) of all owned and leased plots weighted by the number of cultivated acres (equation 4.3).

$$PF = \sum \left(PI_{xy} \cdot \frac{K_{xy}}{K} \right) \tag{4.3}$$

where PI_{xy} = productivity index of plot_{xy}
K_{xy} = crop acres of plot_{xy}
K = crop acres managed by farm agent k

By computing the gross revenue in this manner, it is further assumed that each farm agent produces the same crop mix on all plots they manage.

4.6.1.2 Variable Production Costs

Variable crop production costs are dependent on both the area of cultivated land and the production level. For example, the cost of seed and fuel for planting and tillage operations are independent of the production level realized[19], but the cost of harvesting is related to the volume of production. In order to capture these cost relationships, the variable crop production costs are modelled as a function of both realized production level and the area of land employed. The total variable crop production costs for the farm agent are the sum of variable costs for all crops grown in the current period and the total non-family labour cost (equation 4.4).

[19] The possibilities that a farm agent may reduce input use when the production level is expected to be poor are ignored.

$$VC = \sum_{i=1}^{I} \left(A_i \cdot \left(VC_i^{acre} + W \right) + V_i \cdot VC_i^{vol} \right) \tag{4.4}$$

where VC = variable production costs of farm agent k
VC_i^{acre} = variable production costs per acre of crop i
W = non-family labour cost per acre of farm agent k
V_i = production volume of crop i
VC_i^{vol} = variable production costs per volume of crop i

Crop production costs are also dependent on distance, due to the cost of transporting farm products and machinery. Thus, holding all other factors constant, the cost of producing a crop on a given plot of land increases as the distance from the farm agent's farmstead increases. The relationship between production costs and distance can be expressed by the cost of transporting machinery[20] and the cost of transporting farm product by truck. Therefore, this model assumes that all crop production is marketed from the farmstead, with no farmstead-to-deliver-point freight variability between farm agents. As a result, the cost of transporting farm production is just the cost of moving product from the field to the managing farm agent's farmstead.

The total transportation cost of a farm agent is simply the sum of transportation costs of all plots currently managed. In turn the annual transportation cost for an individual plot of land is dependent on the distance[21] to the managing farm agent's farmstead and the volume of production realized (equation 4.5).

$$TE_{xy} = D_{xy} \cdot \left(Travel + V_{xy} \cdot Truck \right) \tag{4.5}$$

where TE_{xy} = transportation costs associated with $plot_{xy}$
D_{xy} = distance between $plot_{xy}$ and managing farm agent's farmstead
$Travel$ = annual cost of transporting farm equipment per unit of distance
V_{xy} = production volume (all crops) of $plot_{xy}$
$Truck$ = annual cost of transporting crop production per unit of distance

4.6.1.3 Fixed Production Costs

Fixed production costs include the two categories of fixed inputs used in the simulation – machinery/equipment, and land. Total annual fixed costs are composed of machinery and equipment replacement charges and land lease payments (equation 4.6).

[20] The cost of transporting machinery consists of machinery operating expenses (fuel, depreciation), and the opportunity cost of travel time.
[21] Distance is measured as the summation of the east-west and north-south distances between the farmstead and the plot.

$$FC = C^{replace} + LP \tag{4.6}$$

where FC = fixed production costs of farm agent k
$C^{replace}$ = machinery and building replacement charge of farm agent k
LP = land lease payment cost of farm agent k

Machinery and equipment replacement charges are assumed to equal annual economic depreciation. This implies each farm agent makes an annual cash investment in machinery and equipment equivalent to the annual reduction in machinery and equipment value due to economic depreciation. The net result is a constant machinery and equipment value per crop acre over time. Annual land lease expense is calculated as the sum of the annual per acre lease payment multiplied by the number of crop acres of all farm plots leased by the farm agent.

4.6.1.4 Family/Management Withdrawal

The farm agent requires a minimum level of "cash" that must be withdrawn annually for family living and managerial expenses[22]. All farm agents are given the same minimum withdrawal requirement and marginal propensity to consume from gross revenue. Annual withdrawals increase with farm size due to the additional labour and managerial requirements of producing on additional plots. When the farm agent's annual cash flow is unable to meet the producer's withdrawal value, the deficiency is made up by the equity built up in previous periods (or initially endowed). The annual withdrawal is evaluated as:

$$WD = WD^{\min} + \beta \cdot GR + \sigma \cdot K \tag{4.7}$$

where WD = family/management withdrawal of farm agent k
WD^{min} = minimum family/management withdrawal amount
β = marginal propensity to consume from gross revenue
σ = management cost adjustment factor for an additional acre of crop land managed

[22] While it is noted that off-farm income currently may be used to meet a significant portion of the family living requirement of many farm households, this was historically not the case. In order to remain consistent with the assumptions of constant technology and purchasing power and a 1960's base period in these simulations the farm household's farm/non farm labour allocation decision is ignored.

4.6.2 Farm Accounting

Like their real world counterparts, many of the decisions made by producers within the simulation are influenced by financial constraints. In order to fully capture reality, a set of basic accounting rules and data structures are implemented. While some producers may be unaware of the true financial state of their farming operation and may sometimes make decisions that are not conducive to financial success, large capital and land purchases are ultimately constrained by credit availability. This in turn is based on the financial solvency of the producer. As a result of the large investments required to expand a given farm, and the general requirement of credit procurement by individual producers, producer decisions can be influenced by financial constraints even in cases where producers are unaware of their true financial health.

Farm agents are concerned with both their short-run profitability and the long-run growth of equity in the farm operation. In the short-run, a farm must be able to generate cash flow levels capable of covering all production costs and family living withdrawals. This coverage ensures the long term sustainability and growth of the farm. The long-term financial health of each agent in the simulation is tracked continuously via a simplified balance sheet (figure 4.6).

Smith Farm
Balance Sheet
December 31, 1960

Assets			**Liabilities**		
Cash [a]		$5,000	Debt # 1		
Crop Inventories [b]		$0	payments remaining	15	
			annual payment	$463	
Land			Principal balance		$4,500
adjusted acres [c]	310				
average market value	$45		Debt # 2		
Land Value		$13,950	payments remaining	18	
			annual payment	$462	
Machinery/Equipment		$4,800	Principal balance		$5,000
			Total Liabilities		$9,500
			Equity		$14,250
Total Assets		$23,750	Liabilities + Equity		$23,750

[a] Cash includes all non-land and machinery/building assets
[b] crop production is assumed to be sold in the same period it is produced, resulting in zero inventories at year end
[c] cultivated acres pro-rated by soil productivity (i.e. 1 acre with a soil productivity index value of 0.85 = 0.85 adjusted acres)

Figure 4.6: Representative producer balance sheet

The cash account can be thought of as a residual account that tracks the accumulated annual net cash flow of the farm. The land assets are valued at market levels, which is equivalent in the simulations to the average selling price (adjusted for soil productivity) from the most recent period in which at least one plot of land was purchased through the land auction[23]. Machinery and equipment assets are also valued at their market value. Due to the assumption that annual replacement expense is equivalent to annual economic depreciation, this is calculated simply as the product of the total number of crop acres managed by the farm agent and the required per acre capital investment value.

In addition to the farm agent's long run financial indicators, annual net cash flow is also tracked within the model. Net cash flow is determined as the farm agent's net increment to their cash account after all farm and family living expenses, including investment and financing flows, have been calculated (equation 4.8).

$$NCF = GR + Gov - VC - TE - FC - WD + NCF^{INVEST} + NCF^{FINANCE} \quad (4.8)$$

where NCF = net cash flow of farm agent k
Gov = net government transfers received by farm agent k
TE = annual transportation cost of farm agent k
NCF^{INVEST} = equipment and facilities sale proceeds less purchases of farm agent k
$NCF^{FINANCE}$ = new borrowing less principal and interest payments

While an individual farm agent has the ability to cover negative annual cash flow with built up equity in the operation, prolonged periods of negative cash flow will erode the equity of the farm and may result in the farm agent eventually exiting the industry. At a minimum, in the simulation a prolonged period of negative cash flow and an erosion of farm equity will limit the future credit availability and land purchasing ability of a farm agent.

4.6.3 Expectation Formation

Individual farm agents make a number of important managerial decisions based on their expectations of future production margins. Land and family labour/management are modelled as the residual claimants of farm profit; as a result a farm manager's willingness to pay for addition farm land (rent) is a direct function of both future production margin expectations and family/managerial withdrawal requirements (figure 4.7).

[23] Only land sold through the land market is used to evaluate the market value of land. This eliminates "non arms-length" sales between family members that result when farms are transferred to a new generation. In the scenario where no farm agents purchase farm land the minimum acceptable land bid is used; when no land is available for sale in a period, and thus no land bids are calculated, the value from the previous period is used.

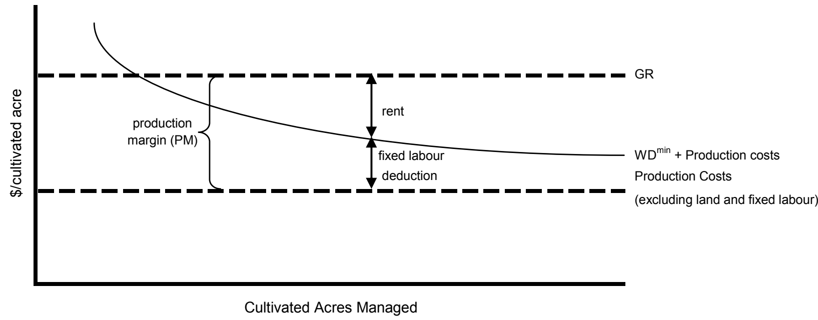

Figure 4.7: Production Margin, Fixed Labour Allowance and Rent

Farm agents form individual production margin expectations in this model based on a simple adaptive expectations scheme. This is defined as a weighted average of prior expectations and the production margin, adjusted for soil productivity, from the previous crop year (equation 4.9).

$$E[PM_t] = (1-\lambda)\cdot E[PM_{t-1}] + \lambda \cdot PM_{t-l} \tag{4.9}$$

where λ = expectation weight
PM = production margin (per acre) of farm agent k

The production margin of farm agent *k* is:

$$PM = \left[\frac{GR}{Q} - VC - \left(WD - WD^{\min}\right)\right] \div K - d \cdot CR \tag{4.10}$$

where *Q* = mean soil productivity of all plots managed by farm agent k
d = annual rate of economic depreciation on machinery and buildings
CR = machinery and buildings stock requirement per crop acre

The evaluated production margin is based upon land located at the farmstead, and soil productivity having an index value of one.

Farm agents are also required to form production volume expectations in order to estimate transportation cost when bidding on plots of land. The production volume expectations are formed using the same adaptive expectations weighting. The annual production volume per acre is evaluated as total production volume, adjusted for soil productivity, divided by total crop acres.

4.6.4 Farm Management

Farm management in the context of this research refers to the farm agent's decision to exit the industry or to continue farming and select a crop mix for the next production period. The decision to quit farming is the most drastic management adjustment any farm agent can make. In reality, it can be the result of a number of factors, including financial and family pressures.

4.6.4.1 Farm Exits

Farm exits are triggered as either an early forced exit due to financial factors or a more orderly exit due to old-age retirement/succession. In the case of forced exits, operations cease and all farm assets are released when either of the early shutdown conditions is met:

- Insolvency (forced exit)
  $$\textit{farm liabilities} \geq 0.9 \cdot \textit{farm assets} \tag{4.11}$$ [24]
- Prolonged Equity Erosion (voluntary exit)
  $$NCF < 0 \text{ for 5 continuous periods} \tag{4.12}$$ [25]

Farming is typically a lifetime commitment, and exits from farming are often less responsive to market conditions than many non-farm industries (Gale 1996). As a result, a farm manager will likely continue to operate, in the short-term, even if the full value of their labour input is not realised (see equation 4.12).

The farm agent's probability of a voluntary exit due to old-age retirement increases as the farm agent ages[26] and is based on probabilities common to all farm agents. When the decision to discontinue farming is made as part of an old-age retirement/succession plan, the farm has the potential to be transferred to an heir of the current farm agent as a transaction between family members. The possibility of a transfer of the complete farm to a non- family member is ignored here since most farms in North America have historically been transferred from parent to child (Bennet & Kohl 1982). The decision of the next generation to continue the operation of the farm is captured as a likelihood occurring at the time of retirement of the original farm

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[24] A farm is deemed to be insolvent when total liabilities exceed total assets, but in general a farm is vulnerable when their debt to asset ratio exceeds 0.7:1 (Olson 2004).

[25] While it is unrealistic to assume that all farmers will exit after exactly 5 continuous years of negative cash flow, on average the assumption of five years seems reasonable and tends to fit real data with reasonable accuracy.

[26] The probability of retirement increases as the farm agent moves into a new 5 year age bracket and remains constant while in the same bracket.

agent. All farms operated by farm agents that are exiting due to old-age retirement and have a strong current net worth, with a debt to asset ratio no greater than 0.4:1 (Olson 2004), have the same probability (a parameter value between 0 and 1) of being taken over by the next generation. The new farm agent is assumed to gain control over all existing farm assets, including all lease agreements. The new agent is also assumed to "buyout" the original farm agent by assuming all existing liabilities and a cash buyout of a proportion of the equity value of the farm (equation 4.13).

$$\textit{buyout value} = \textit{farm liabilities} + \alpha \cdot \textit{farm equity} \tag{4.13}$$

where α = proportion of farm equity debt financed when farm is transferred to new generation

The next generation farm agent is assumed to finance the purchase of farm equity by financing over a twenty-year amortization period[27]. In a situation where the farm is not transferred to a new generation, all land assets are released for other farm agents to acquire through the land market.

4.6.4.2 Crop Mix Adjustment

Farm agents select their annual crop mix from a discrete set of available crop alternatives. Producers are assumed to maximize their total expected utility ($E[U]$) based on the simple summation of the expected utility of the individual crops ($E[U_i]$) that are included in the selected crop mix, subject to land and agronomic constraints (equation 4.14).

$$Max \;\; E[U] = \sum_{i=1}^{I} E[U(\Pi_i)] \cdot a_i \tag{4.14}$$

s.t.

$$\sum_{i=1}^{I} a_i = 1$$

$$a_i \le b_i$$

where a_i = proportion of farm agent k's crop acres allotted to production of crop i
b_i = maximum proportion of farm agent k's crop acres allotted to production of crop i

[27] A twenty year amortization period corresponds with Farm Credit Canada's (FCC) general lending terms (Guide to Farm Practice in Saskatchewan 1960).

The expected utility of an individual crop is evaluated as a linear function of mean crop return[28] and the variance of crop return (Selley 1984), where each is computed based on the five previous production periods. The individual crop options can then be ranked based on an expected utility value, evaluated as:

$$E[U(\Pi_i)] = \Pi_i - \frac{1}{2}(1-\Phi)\sigma^2_{\Pi_i} \qquad (4.15)$$

where $\prod_i$ = mean crop return (GR - VC) of crop i
Φ = risk aversion factor of farm agent k
$\sigma^2_{\Pi_i}$ = variance of crop return of crop i

As a net result of the computed individual crop utility values, crop options can be ranked in an ordinal manner. The farm agent will then proceed to allocate his total crop acres in a manner that maximizes the production of crops with the highest rankings, subject to agronomic constraints. Note that while the functional form of the farmer's expected utility function ignores the covariance between the returns of crop alternatives, it significantly reduces the complexity of this part of the model. Due to the limited number of crops commonly produced in the study region and the strong correlations of crop returns[29], this is not likely an onerous over-simplification.

A risk neutral agent (Φ = 1) would behave in a pure profit maximizing manner and would select a crop mix that maximizes their expected total crop return. The risk averse (Φ < 1) farm agent will evaluate the individual crops based on a trade off between expected returns and variances. The more risk averse an individual farm agent is the lower the value of the risk parameter (Φ) will be. Intuitively this would mean that a more risk averse farmer would require a greater expected crop return than a less risk averse farm to take on the same level of risk (Hadar & Russell 1969).

4.6.5 Farmland Market

Farm agents can expand either by purchasing or leasing additional land, and they compete in two segmented farmland markets. All farmland tracts are based on a fixed plot size, and this defines the smallest unit by which farm acreage can change. In each period, land available for sale and leases are

[28] Crop return (π) = P x Y - VC (fixed costs are equivalent across all crops and are ignored in the analysis).
[29] The covariances of returns for the four crop alternatives modelled all exceed 0.7. This simplification may need to be revisited if the modelled crop alternatives are expanded in subsequent research.

allocated to farms through two separate iterative auctions,[30] with the lease auction occurring subsequent to the purchase auction. The order of the two land auctions attempts to capture the belief that farm agents have a strict preference for purchasing relative to leasing additional land.

Land becomes available for sale/lease when a farm agent exits (forced or voluntary) from the industry or continuing farm agents do not renew existing lease agreements. The manner in which land becomes available for re-allocation directly determines the land market in which the plot becomes available for farm agents to bid on. Available land is re-allocated based on the following rules:

- Forced Exit - Land owned by the exiting farm agent enters the 'for sale' market; land leased by the exiting farm agent enters the 'for lease' market.
- Voluntary Exit - Land owned by the exiting farm agent enters the 'for lease' market; land leased by the exiting farm agent enters the 'for lease' market.
- Non-Renewed Lease - Land enters the 'for sale' market.
- No Buyer Found - Land failing to find a buyer in the 'for sale' market enters the 'for lease' market.

In order to participate in either of the land markets, an individual farm agent must meet certain eligibility requirements. In this simulation, the requirements for purchasing land are more restrictive compared to the land lease market. In order to purchase additional farm plots, a producer requires debt financing and must be deemed credit worthy. Credit worthiness is tracked via a simplified credit scorecard. Credit can only be obtained if the farm agent meets each of the following requirements:

- Liquidity Cash > ($\Lambda \cdot K + K_{xy} \cdot P^L \cdot \Omega$) (4.16)
- Solvency Debt to Asset Ratio < 0.4: 1 (Olson 2004) (4.17)
- Repayment[31] $\frac{E[PM] \cdot K - WD^{\min}}{LP + DP} > 1$ (4.18)

where Λ = minimum cash balance per acre
P^L = mean price of land per crop acre (adjusted to reflect unitary soil productivity)
Ω = proportion of new investment equity financed (required down payment)

[30] The iterative auction algorithm is based on the algorithm developed in Balmann (1997)
[31] Equation 4.18 is approximately equivalent to the formula ((gross revenue – cash expenses + inventory change – family labour + interest)/annual debt payment) (Olson 2004).

Liquidity refers to the ability of the farm to meet short term liabilities using short term assets. The farm is financially vulnerable when the value of current liabilities exceeds the value of short term assets (Olson 2004). In the simulation, a farm agent is in a liquid financial position provided that their short term assets (cash value) are greater than their current liabilities, which include an allowance for covering the cash production costs for a single production period ($\Lambda \cdot K$) and the expected cash outlay required for the purchase of an additional plot of land ($K_{xy} \cdot P^L \cdot \Omega$). Second, an upper limit is placed on the total amount of debt. Finally, the last constraint restricts credit to farm agents whose current debt and lease payments can be serviced based on current land rent expectations and minimum living deductions (see figure 4.7). Repayment capacity is concerned with the ability of a farm to generate an annual cash flow capable of covering the annual debt payment (principal + interest).

Farm agents are also screened before participating in the land lease auction based on the first restriction on the credit scorecard, minus the cash down payment portion. A second requirement restricts bidding to those farm agents whose expected land rent is positive.

The next stage in both land allocation procedures requires all eligible farm agents to determine which available plot of land they have the greatest interest in managing. The mechanism for determining the optimal plot of land available is identical for both land auctions, but the evaluated set of plots is different. Farm agents select land to bid on by computing the highest expected annual land rent (equation 4.19).

$$E\left[rent_{xy}\right] = E\left[PM\right] \cdot Q_{xy} + E\left[Gov\right] - E\left[TE_{xy}\right] \cdot D_{xy} - \frac{WD^{\min}}{K + K_{xy}} \qquad (4.19)$$

where $rent_{xy}$ = rent value for of $plot_{xy}$ in subset A (available land)
Q_{xy} = soil productivity of $plot_{xy}$

Due to uncertainty that is present surrounding government transfer payments to western Canadian grain producers, the expected government transfer is assumed here to be zero[32] (equation 4.20). Note that while it is assumed that farm agents have no expectation of future government transfers, this does not rule out actual payments occurring.

[32] While it is unlikely that future government transfer expectations are in fact zero, this assumption is a reasonable starting point.

$$E\left[rent_{xy}\right] = E\left[PM\right]\cdot Q_{xy} - E\left[TE_{xy}\right]\cdot D_{xy} - \frac{WD^{\min}}{K + K_{xy}} \qquad (4.20)$$

Farm agents determine their individual land bid value based on expected annual rent and the value of the optimal plot at the end of the planning period (N). The bid is formulated by capitalizing the expected land rents, adjusted by a risk aversion factor, as the present value of an ordinary annuity plus the present value of the expected land value at the end of the planning period (equation 4.21). A risk averse farm agent ($\Phi < 1$) will discount the expected annual land rent, resulting in a lower bid than a risk neutral farm agent ($\Phi = 1$), all else equal.

$$Bid_{xy} = \Phi \cdot E\left[rent^*_{xy}\right]\cdot\left(\frac{1-(1+r)^{-n}}{r}\right) + E\left[\left(\frac{V_N}{(1+r)^n}\right)\right] \qquad (4.21)$$

where Bid_{xy} = bid value (per acre) of farm agent k on $plot_{xy}$
$rent^*_{xy}$ = return to land (per acre) of optimal plot in subset A
r = capitalization/interest rate
n = number of years (planning period)
V_N = value of $plot_{xy}$ (per acre) at period N

Future farmland values are inherently difficult to predict resulting in a significant level of asset risk for land purchasers. Due to the importance of meeting annual cash flow requirements, the farm agent is assumed here to set their bid value at the minimum of equation 4.21 and the present value of expected annual cash flows over the planning period (leading to equation 4.22)

$$Bid_{xy} = \Phi \cdot E\left[rent^*_{xy}\right]\cdot\left(\frac{1-(1+r)^{-n}}{r}\right) \qquad (4.22)$$

The land auctioneer agent determines successful bids in the land purchase market. In addition, the land auctioneer agent adjusts all land bids to an equivalent set of bids with plots of mean soil productivity. This adjustment allows the auctioneer to compare bids on land with varied soil productivity (equation 4.23).

$$Adjusted\ Bid_{xy} = Bid_{xy} \div Q_{xy} \qquad (4.23)$$

The land auctioneer sorts all current adjusted bid values and allocates the unit of land selected by the farm agent with the maximum adjusted bid value, provided the maximum bid is greater than a minimum value. The minimum bid for a single representative landlord agent is set as the weighted value of leasing out the land at the current mean lease rate and the mean value of current period purchase bids (equation 4.24). The value to the landlord of leasing out farmland is evaluated using an income capitalization method (Olson 2004).

$$Minimum\ \ Bid = \Psi \cdot \sqrt{\overline{Bid} \cdot \left(\frac{\overline{lease}}{r} \right)} \tag{4.24}$$

where Ψ = risk aversion factor of representative non-farming agent
$\overline{Bid}$ = mean bids in current land auction
$\overline{lease}$ = mean annual lease payment for all plots currently leased

As constructed, a risk neutral landlord agent (with $\Psi = 1$) would accept a bid that is equivalent to the expected return from leasing out the land at their current weighted land valuation. A risk averse landlord agent (with $\Psi < 1$) would accept a land bid that was less than the expected return from leasing out the land.

The final price paid by the successful farm agent in the land purchase auction does not correspond directly with their evaluated bid value. Farm agents are assumed to adjust their bids based on the best available land market information available to them, namely the mean value of all current period land bids[33]. Bids are adjusted to represent an equal weighting of the current periods mean land bid and the farm agent's individual land valuation[34] (equation 4.25).

$$price_{xy} = \sqrt{Bid_{xy} \cdot \overline{Bid} \cdot Q_{xy}} \tag{4.25}$$

where $price_{xy}$ = final price paid for $plot_{xy}$ by purchasing/leasing farm agent

The down payment proportion of the land purchase is deducted directly from the farm agent's cash account, while the balance is debt financed based on the same amortization period and interest rate utilized to calculate the bid.

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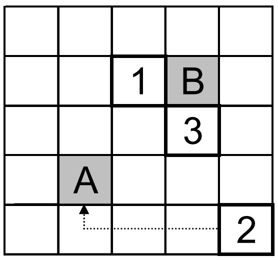
[33] The mean bid, is the same value for all participating farm agents and is only set during the first auction iteration and remains constant for the remainder of the current period.
[34] The bid adjustment is similar to Happe, Balmann and Kellermann (2004). The mean bid is set separately for the purchase and lease auction, and is set only during the first iteration of the two auctions and remains constant, in the respective auctions, until the next model year.

The dynamics of the individual farm agents and the land auctioneer agent are illustrated below through a simple example with 3 farms and 2 available plots, with average soil productivity (figure 4.8).

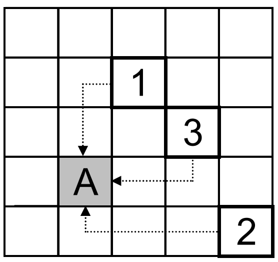
3-farm Land Auction Iteration # 1



Farmer	Land Bid On	$E[RL^*_{xy}]$	Valuation Factor	Bid [a]	Purchase Price [c]
# 1	B	$3.00/acre	0.90	$30.97 / acre	$30.39/acre
# 2	A	$2.90/acre	0.85	$28.27 / acre	$29.03/acre
# 3	B	$3.10/acre	0.85	$30.22 / acre	30.02/acre

Minimum Bid: $29.49/acre [b]
High Bid: $30.97/acre (farmer # 1 on land B)
Outcome: Farmer # 1 purchases land unit B for $30.39/acre

3-farm Land Auction Iteration # 2



Farmer	Land Bid On	$E[RL^*_{xy}]$	Valuation Factor	Bid [a]	Purchase Price [c]
# 1	A	$2.75/acre	0.90	$28.38/acre	$29.09/acre
# 2	A	$2.90/acre	0.85	$28.27/acre	$29.03/acre
# 3	A	$2.85/acre	0.85	$27.79/acre	$28.79/acre

Minimum Bid: $29.47/acre [b]
High Bid: $28.38/acre (farmer # 1 on land A)
Outcome: High bid rejected, Land A enters lease market

[a] bid values based on r = 6%, n = 20 years
[b] Minimum bid base on mean lease rate = $1.75 / acre and Ψ = 1 (land seller is risk neutral)
[c] purchase price if bid is successful; based on an mean land bid $29.82/acre

Figure 4.8: 3-person, 2 available plots land auction

In the example, note that in the second iteration of the land auction, farmer # 1 is the high bidder but is unsuccessful in purchasing land unit A due to the bid being less than the reservation price. Due to utilization of this iterative auction algorithm, individual bids compete against all land bidders and not only against those bids on the same unit of land.

Rental auction bid formation follows the same structure as the purchase price bid. Farm agents are assumed to be willing to pay an annual lease rate equivalent to 80% of annual debt payment they would accept if they were bidding to purchase the same plot of land[35]. The successful farm agent will be entered in a lease agreement at an annual lease rate equivalent to their bid value and for an upper-bound random lease period. In the example, assuming that the three farmers represent all producers in the lease market,

[35] Based on a 20 year planning horizon and a 6% discount (interest) rate the farm agent's annual cash lease bid is equivalent to approximately 7% of their individual land valuation. A reasonable cash lease for farmland is estimated at 6-8% of the land's value plus the cost of property taxes which are ignored in the simulation (Guide to Farm Practice in Saskatchewan 1960).

and land unit A is the only unit of land available for lease, farmer # 1 would sign a lease agreement to rent the plot for an annual lease payment of $1.97/acre[36].

At the expiration of all land leases, the farm agent is assumed to attempt to retain control of the land by negotiating a new lease agreement. The farm agent calculates a new rental bid for the appropriate plot of land utilizing current "rent" expectations. If the new lease bid is accepted by the land owner, a new lease agreement is signed. The landlord agent determines if a new lease bid is acceptable by comparing the lease offer, which is valued using an income capitalization method, to the expected value the land would generate in the land purchase market. The new lease rate is deemed to be acceptable if:

$$\Phi \cdot \left(\frac{E\left[RL_{xy}\right]}{r} \right) \geq \frac{\sqrt{\overline{Bid} \cdot P^{L} \cdot Q_{xy}}}{\Psi} \tag{4.26}$$

The more risk averse the landlord agent is, the higher the minimum acceptable bid value. The landlord agent will only continue to hold the risky land asset if the farm agent offers some premium over the landlord's expected return from selling the risky asset.

4.6.6 Non-Land Capital Investment

Non-land capital investment by the farm agent concerns the purchase of farm machinery and facilities required for crop production. In reality, individual farms have significant variability in the value of capital per acre of cultivated land. Part of this variability can potentially be explained by 1) differences in their machinery lifecycle (replacement timing) and 2) differences in machinery replacement. While controlling non-land capital investments is a key factor in financial success, in this model the process is simplified in order to keep the model computationally tractable.

Since differences in capital levels are not central to the objective of the research, capital requirements are computed as a simple linear function of the total cultivated plots of the farm agent land base. Thus all individual farm agents are assumed to require a fixed capital investment per plot of cultivated land. Investment in farm capital can be separated into two categories - replacement of existing capital and

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$$\$1.97 = 0.80 \cdot \sqrt{2.75 \cdot 0.90 \cdot 2.45}$$

$$2.45 = \frac{2.75 \cdot 0.90 + 2.90 \cdot 0.85 + 2.85 \cdot 0.85}{3}$$

investment in additional capital. Replacement of existing capital stocks is discussed further in section 4.6.1.3 and is covered by the assumptions made in the depreciation model. New investment in non-land capital only occurs when the farm agent has expanded their land base either by purchasing or leasing additional land. New non-land capital investment is equal to the fixed per plot non-land capital requirement multiplied by the total new cultivated plots acquired. In turn, all new non-land capital expenditures are assumed to be financed with a 25% cash down payment and a 5 year amortization period[37]. The net new non-land capital investment calculation of a farm agent is:

$$NCI = CR \cdot (C_t - C_{t-1}) \qquad (4.27)$$

where NCI = net investment in machinery and buildings of farm agent k
C = stock of machinery and buildings of farm agent k

Non-land capital is assumed to be perfectly mobile, meaning that the full per plot non-land capital investment is recovered when the farm agent's total acreage is reduced. In the event of a net reduction in the farm agent's land base, the net non-land capital investment is negative and the producer will receive a cash payment.

4.7 Initializing the Model

Thus far, this chapter has outlined and described the encoded model algorithms and assumptions while avoiding a discussion of the initial spatial and population profile and production data utilized in the simulations. The following section contains a detailed summary of the initial profiles and production data. In order to initialize the model with a population of farm agents consistent with a 1960's profile, farm agents are assigned a number of attributes based on available census and survey data. The attributes include 1) age, 2) farm size, 3) tenure status, 4) finances, and 5) management. The success of individual farms is partially dependent on the boom-bust cycle of gross crop returns. As a result, crop yield and market price data are important considerations. Due to the small level of production in the studied region relative to the world market, commodity prices are modelled as exogenous to the model and are equivalent to real de-trended values for the 1955-2000 crop years. In addition, to remain consistent with the constant technology assumption, variable and fixed production costs and family living/management withdrawals are

[37] The assumed loan terms are consistent with the maximum lending terms (75% of asset value and 10 year repayment period) for chattel offered by Farm Credit Corporation for the 1960 period (Guide to Farm Practice in Saskatchewan 1960).

based on real 1960 values. In this manner, individual farm agent behaviour and actions play an important role in the evolution of the region. Behavioural data is required in three primary areas, including 1) crop mix selection, 2) land valuation and 3) retirement and farm transfer.

4.7.1 Initial Farm Population Profile

Delineating the demographic characteristics of the relevant farm population is a critical step in the simulation process because demographic characteristics are one of the key predictors of the future structure of industry (Foot 1996). Further, the age composition of the initial farm population appears to be the best predictor of the number and timing of voluntary farm exits and the resulting transfer of farm assets (Gale 2003). Ultimately, an initial population with low farm equity will most likely result in tight credit markets, and this will have consequences for future land markets.

4.7.1.1 Operator Age and Farm Acreage

The initial distribution of farm operators is classified by age and total acreage in table 4.1, and is based on data from the 1961 census of agriculture for the province of Saskatchewan. The simulation is initialized with a farm population of 310 primary farm operators with a median age of 46 and an average farm size of approximately 4 plots (640 acres).

Table 4.1: Initial Distribution of Farm Agents by Age and Plots Managed

	plots farmed (1 plot = 160 acres)									
	1	2	3	4	5-7	8-10	11-14	15-18	19 & over	total
under 25 years	2	3	2	2	1	0	0	0	0	10
25-34 years	5	11	10	9	9	4	1	0	0	49
35-44 years	7	16	15	15	16	8	3	1	1	82
45-54 years	8	17	15	14	15	8	3	1	1	82
55-59 years	4	8	6	5	5	2	1	0	0	31
60-64 years	4	6	5	3	3	1	0	0	0	22
65-69 years	3	5	3	3	2	1	0	0	0	17
70 years and over	4	5	3	2	2	1	0	0	0	17

Source: Author based on Census of Canada: Agriculture: Saskatchewan (1961)

While the distribution of age profile is approximately normal across the age groups, the age profile of the initial farm population is assumed to be uniformly distributed within the census age classifications. A minimum operator age of 20 and a maximum age of 80 years are also assumed.

4.7.1.2 Land Tenure

The model is initialized with approximately 30% of all farm land under cash lease agreements. This total corresponds to the proportion of Saskatchewan farm land under either a cash lease or crop share agreement as of 1960 (Statistics Canada). Based on available census data, farm tenure is classified into three categories (table 4.2).

Table 4.2: Initial Distribution of Farms by Tenure

	Provincial Level (census)					Rural Municipality Level (author)				
	all farms	owner	tenant	owner / tenant	manager	all farms	owner	tenant	owner / tenant	manager
under 25 years	3.6%	1.1%	1.5%	0.9%	0.0%	3.2%	1.0%	1.3%	1.0%	0.0%
25-34 years	15.7%	5.4%	3.2%	6.9%	0.1%	15.8%	5.5%	3.2%	7.1%	0.0%
35-44 years	25.9%	11.2%	2.7%	11.8%	0.1%	26.5%	11.3%	2.9%	12.3%	0.0%
45-54 years	25.8%	13.7%	1.5%	10.5%	0.1%	26.5%	14.2%	1.6%	10.6%	0.0%
55-59 years	10.3%	6.6%	0.4%	3.3%	0.0%	10.0%	6.5%	0.3%	3.2%	0.0%
60-64 years	7.5%	5.1%	0.3%	2.1%	0.0%	7.1%	4.8%	0.3%	1.9%	0.0%
65-69 years	5.7%	4.0%	0.2%	1.4%	0.0%	5.5%	3.9%	0.3%	1.3%	0.0%
70 years and over	5.5%	4.3%	0.2%	1.0%	0.0%	5.5%	4.2%	0.3%	1.0%	0.0%
total	100.0%	51.5%	10.1%	38.0%	0.4%	100.0%	51.3%	10.3%	38.4%	0.0%

Source: Census of Canada: Agriculture: Saskatchewan (1961) and author.

A farm operator is classified as an owner if the operator owns all land used for crop production. A farm operator is classified as a tenant if all land used for crop production is leased, with the exception of the farmstead [38]. A farm characterized by crop production on both leased and owned land is classified as an owner/tenant [39].

4.7.1.3 Assets and Debt

The initial asset value of a farm agent is the sum total of the value of machinery and equipment, owned farm land and their residual cash account. Machinery and equipment investment stocks are initialized at $15 per cultivated acre (see table 4.3) and remain at this level for the duration of the simulation. Land with a soil productivity index of one is initially valued at $30 per acre (table 4.3). The cash account is initialized as $15 per cultivated acre.

[38] The Census definition does not include the farmstead restriction.
[39] To be classified as an owner/tenant the farm operator must own land in addition to their farmstead.

Table 4.3: Value of Farm Assets 1960

	Census of Canada	Farm Business Review	Simulation Model
geographic region	Saskatchewan	Dark Brown Soil Zone	Rural Municipality
Machinery & Equipment Investment (per cult.acre)	$15.93	$13.57	$15.00
Land (per cult. Acre)	$26.00	$44.68[a]	$30.00
Total	$41.93	$58.25	$45.00

[a] includes the value of farm buildings

Sources: Census of Canada: Agriculture: Saskatchewan (1961). Saskatchewan Agriculture: Farm Business Review 1961

Mean farm indebtedness starts at approximately $3400 per farm operator, in accordance with survey results for the period 1960-64 for the province of Saskatchewan (Ragush 1966). The total initial outstanding farm debt in the simulation of approximately $1.05M is allocated among the initial farm agents based on operator age and farm size attributes (table 4.4). The farm agent's ability to take on further debt is limited by credit restrictions which limit the amount of borrowed capital.

Table 4.4: Farm Debt of Grain Farms by Age of Operator and Size in the Prairie Region of Saskatchewan

n = 350	no debt	$1 - $9,999	$10,000 - $19,999	$20,000 and over
under 34 years	17.0%	68.1%	12.8%	2.1%
34-49 years	37.2%	54.4%	5.1%	3.3%
50 years and over	55.3%	39.9%	2.4%	2.4%
medium size grain farms (480-600 acres)	42.2%	52.9%	2.0%	2.9%
large size grain farms (800-1400 acres)	47.4%	41.2%	7.2%	4.2%

Source: Ragush 1966.

4.7.1.4 Risk Attitude/Entrepreneurial Classification/Farm Goals

Managerial attributes that dictate the farm manager's behaviour in both land auctions and cropping decisions are modeled by the assignment of farm agents to one of four managerial classes and a corresponding risk aversion factor (table 4.5). The risk aversion factor is thought to be an important parameter in the farm agent's land bid valuation and crop mix selection decision[40].

[40] Sensitivity analysis was conducted on risk aversion factor values and model results were found to not be significantly different even under assumptions of a 0.25 difference between the expanding and lifestyle farm risk aversion factors.

Table 4.5: Managerial Classification and Risk Aversion Factor

Managerial Classification	description	risk aversion factor (Φ)
expanding farm	least risk averse	0.95
cautious expanding farm	intermediate risk aversion	0.90
lifestyle farm	most risk averse	0.85
exit and retirement farm	includes all farm agents with age ≥ 55	0.85 [a]

[a] risk aversion factor used only in crop mix selection

Source: Author

In reality, the exit and retirement phase generally begins relatively early, when the farm manager is in his/her early fifties (Keating & Munro 1989). All farm agents here are moved into the *Exit and Retirement phase* when they reach the age of 55 and will remain in that managerial class for the rest of their farming career. Due to uncertainty of the actual composition of managerial classes, a set of five alternative distributions are implemented at various times in the simulation runs (see Table 4.6).

Table 4.6: Simulated Managerial Distributions

scenario	proportion of all farms		
	expanding	cautious expanding	lifestyle
uniform	33.2%	33.2%	33.6%
normal	15.8%	68.4%	15.8%
skew	10.0%	30.0%	60.0%
all 1	100.0%	0.0%	0.0%
all 3	0.0%	0.0%	100.0%

Source: Author

4.7.2 Production Data

Production data is required to generate annual cash flow for individual farm agents. A separate yield and price value is required for each individual crop option for each year of the simulation. Under the assumptions of the base scenario, production costs are estimated for the initial period only and are held constant throughout the duration of the simulation.

4.7.2.1 Crop Yields and Price

Yield and price arrays for the crops included in the simulation are based on Saskatchewan Agriculture Food and Rural Revitalization data for the period 1955-2002, which have been adjusted to represent 1960 technology[41] and purchasing power[42]. As a direct result of these adjustments, the long term crop yield and real price trends are flat. Crop prices are based on data at the provincial level, while yields are based on data for a representative rural municipality (RM)[43] in the dark brown soil zone. The yield and price data utilized within the simulation are presented in table 4.7.

Table 4.7: Detrended Crop Yield and Price 1955-2002

	wheat		oats		barley		flaxseed	
year	yield (bu/acre)	price ($/acre)	yield (bu/acre)	price ($/acre)	yield (bu/acre)	price ($/acre)	yield (bu/acre)	price ($/acre)
1955	23	1.42	37	0.64	30	0.90	12	2.80
1956	25	1.27	44	0.50	33	0.80	15	2.58
1957	18	1.28	36	0.49	24	0.76	6	2.52
1958	16	1.32	26	0.54	21	0.73	9	2.58
1959	12	1.30	30	0.62	25	0.74	6	3.06
1960	23	1.57	28	0.59	29	0.79	10	2.76
1961	8	1.66	13	0.64	12	1.05	5	3.37
1962	21	1.64	38	0.59	32	0.92	9	3.12
1963	27	1.76	56	0.55	40	0.95	14	2.98
1964	17	1.59	27	0.63	27	1.01	6	2.96
1965	23	1.67	45	0.68	37	1.02	13	2.75
1966	27	1.69	48	0.65	42	1.01	11	2.72
1967	16	1.54	26	0.62	23	0.81	7	2.97
1968	20	1.26	31	0.47	30	0.74	7	2.78
1969	26	1.21	52	0.49	37	0.64	10	2.46
1970	27	1.34	50	0.49	41	0.72	14	2.16
1971	27	1.25	54	0.48	46	0.19	12	2.17
1972	17	1.47	29	0.73	29	1.02	9	3.40
1973	21	3.15	55	1.09	43	1.82	11	6.66
1974	16	2.72	42	0.98	36	1.46	8	6.33
1975	17	2.18	37	0.86	27	1.42	6	4.26
1976	32	1.76	51	0.68	50	1.16	11	4.19
1977	27	1.46	50	0.51	40	0.86	14	2.96
1978	26	2.04	43	0.57	42	0.98	14	3.93
1979	18	2.28	27	0.69	27	1.18	8	3.89
1980	18	2.41	31	0.81	35	1.37	10	4.04
1981	27	2.06	42	0.69	42	1.15	11	3.62
1982	31	1.80	44	0.56	52	0.92	12	2.87
1983	29	1.79	46	0.61	39	1.00	12	3.31
1984	17	1.74	23	0.61	29	0.99	3	3.21
1985	24	1.44	35	0.54	38	0.88	9	2.83
1986	27	1.24	40	0.50	39	0.74	17	2.29
1987	27	1.29	51	0.59	46	0.73	16	2.47
1988	4	1.69	2	0.73	8	0.95	6	3.32
1989	13	1.48	15	0.51	14	0.89	3	3.21
1990	20	1.27	23	0.44	29	0.74	3	2.41
1991	25	1.24	52	0.49	22	0.77	9	2.22
1992	24	1.29	35	0.53	36	0.42	12	2.52
1993	20	1.30	62	0.52	48	0.73	20	2.61
1994	21	1.56	56	0.54	24	0.87	12	2.87
1995	18	1.79	50	0.67	36	1.08	9	3.01
1996	20	1.53	52	0.63	38	0.92	8	3.19
1997	19	1.49	18	0.63	29	0.91	10	3.25
1998	23	1.51	35	0.56	36	0.84	14	3.11
1999	27	1.60	47	0.54	35	0.87	12	2.75
2000	25	1.48	43	0.55	33	0.90	10	2.89
2001	9	1.60	24	0.74	15	0.98	5	3.23
2002	14	1.66	22	0.76	17	1.02	5	3.49
mean	21.3	1.66	38.4	0.62	33.3	0.94	9.9	3.20
trend value[a]	0.190	-0.022	0.560	-0.001	0.312	-0.001	0.239	-0.049

[a] annual rate of inflation/deflation in crop yield/price

Source: Author's calculations based on data from Saskatchewan Agriculture, Food and Rural Revitalization (2004).

[41] Crop yields were adjusted to remove yield inflation due to technological advancements. Yield inflation was assumed to be constant over time, but varied between crops. The effects of technology on crop prices were handled in a similar manner.
[42] Crop prices are evaluated in constant 1960 dollars based on Statistics Canada CPI data.
[43] Rural Municipality of Wood Creek (#281)

4.7.2.2 Variable Costs

Variable costs include all cash production and transportation expenses. Due to data availability, all production costs are assumed to be dependent on crop acreage, with no adjustment for realized crop production volume (i.e. the cost of producing a crop does not increase with yield). In addition, the increased cost of farming plots at a greater distance from the farmstead is assumed to be captured through grain transportation costs alone[44]. The cost of transporting grain produced on individual plots of farm land to the farmstead of the managing farm agent is based on a flat per tonne/mile charge of $0.10[45]. As a result larger farms generally have a higher per acre transportation costs due to the need to farm land at a greater distance from the farmstead than small farms.

Due to a lack of crop enterprise level data, whole farm data for the period 1961-1964 (see table 4.8) for the dark brown soil zone of Saskatchewan are utilized to estimate variable crop production costs for the four major field crops used in the model.

Table 4.8: Whole Farm Data, Dark Brown Soil Zone, Saskatchewan, 1961-1964

n	year	acres			gross revenue ($/acre)						yield [a] (bushels/acre)				price ($/bushel)				crop production expenditures (CPE) [b]	Labour (operator and family)
		crop	seeded	fallow	wheat	oats	barley	flaxseed	other	total	wheat	oats	barley	flaxseed	wheat	oats	barley	flaxseed		
1	1961	342	205	137	1091	112	234	0	979	2416	8	14	12	5	1.60	0.65	0.80	3.25	1948	2241
2	1961	635	345	290	5182	266	303	153	680	6584	8	14	12	5	1.60	0.65	0.80	3.25	1483	2689
3	1961	941	522	419	8368	662	510	1518	906	11964	8	14	12	5	1.60	0.65	0.80	3.25	3472	3269
4	1961	1210	654	556	9336	497	401	2347	973	13554	8	14	12	5	1.60	0.65	0.80	3.25	4209	3993
5	1961	1741	917	824	18043	142	374	2061	661	21281	8	14	12	5	1.60	0.65	0.80	3.25	7734	4562
6	1962	411	277	134	5875	1625	742	434	1370	10046	21	39	33	9	1.60	0.60	0.95	3.10	1881	2773
7	1962	610	328	282	7778	391	156	363	880	9568	21	39	33	9	1.60	0.60	0.95	3.10	2138	3212
8	1962	950	525	425	12296	703	614	663	1411	15687	21	39	33	9	1.60	0.60	0.95	3.10	4024	3780
9	1962	1225	671	554	22126	1109	674	1559	1748	27216	21	39	33	9	1.60	0.60	0.95	3.10	4387	4981
10	1962	1822	948	874	34496	252	1140	0	945	36833	21	39	33	9	1.60	0.60	0.95	3.10	7953	6384
11	1963	409	257	152	8415	995	360	1755	719	12244	28	58	41	15	1.65	0.55	0.90	2.95	2507	3254
12	1963	642	368	274	14987	1202	830	319	540	17878	28	58	41	15	1.65	0.55	0.90	2.95	2397	3564
13	1963	953	516	437	22607	899	1430	552	647	26135	28	58	41	15	1.65	0.55	0.90	2.95	4005	4179
14	1963	1231	714	517	28357	697	930	3027	2081	35092	28	58	41	15	1.65	0.55	0.90	2.95	5128	5180
15	1963	1938	1097	841	49723	478	1395	5918	536	58050	28	58	41	15	1.65	0.55	0.90	2.95	11146	7367
16	1964	385	242	143	4190	296	0	1262	1470	7218	18	29	28	7	1.60	0.55	0.90	2.95	2533	2815
17	1964	657	387	270	12307	395	81	76	632	13491	18	29	28	7	1.60	0.55	0.90	2.95	2794	3449
18	1964	940	509	431	12764	268	166	728	1735	15661	18	29	28	7	1.60	0.55	0.90	2.95	4769	3770
19	1964	1185	686	499	20519	145	577	1206	1922	24369	18	29	28	7	1.60	0.55	0.90	2.95	6080	4469
20	1964	2118	1167	951	35407	164	539	2734	543	39387	18	29	28	7	1.60	0.55	0.90	2.95	12159	6178

[a] Rural Municipality # 281

[b] crop production expenditure = cash operating expenditure - $5 x fallow acres

Source: Farm Business Review (various years) and Saskatchewan Agriculture, Food and Rural Revitalization (2004; 2005)

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[44] The cost of transporting machinery between plots of land is assumed to be negligible.

[45] A study by John R. Meyer for the United states for the period 1952-55 estimated the long-run marginal cost of truck transportation to be 8.80¢ (USD) per ton-mile, or 9.70¢ per tonne-mile (Purdy 1972). Glaeser and Kohlhase (2004) estimate the real cost of truck transportation remained constant at approximately 38¢ (in 2001 USD) per ton-mile, or 41.89¢ per tonne-mile. In 1960 Canadian dollars (1 USD = 0.91 CDN), the cost of truck transportation is approximately equivalent to 7.25-10.66¢ per tonne-mile.

The variable production costs for the four individual crops are proportional to the weighted mean variable production cost per seeded acre, based on the values reported in table 4.9.

$$VC_i = \overline{VC} \cdot \hat{R}_i \tag{4.28}$$

where $\overline{VC}$ = estimated weighted mean variable production costs per seeded acre 1961-1964
$\hat{R}_i$ = estimated relative production cost of crop i

$$\overline{VC} = \frac{\sum_{n=1}^{20}(CPE)}{\sum_{n=1}^{20}\left[\sum_i \left(acres_i \cdot \hat{R}_i\right)\right]} \tag{4.29}$$

where *CPE* = crop production expenditures, 1961-1964
$acres_i$ = estimated acreage of crop i, 1961-1964

$$acres_i = \frac{GR \ / \hat{P}_i \hat{Y}_i}{\sum_i \left(GR \ / \hat{P}_i \hat{Y}_i\right)} \cdot seeded \tag{4.30}$$

where $\hat{P}_i$ = estimated price of crop i, 1961-1964
$\hat{Y}_i$ = estimated yield of crop I, 1961-1964
seeded = total seeded acres of all crops, 1961-1964

Due to a lack of data, the relative variable production costs ($\hat{R}_i$) for the individual crops were estimated based on crop enterprise data for the dark brown soil zone of Saskatchewan for the period 1994-2004[46] (Table 4.9).

Table 4.9: Estimated Crop Production Variable Costs (excluding non-family labour)

	$\hat{R}_i$ [a]	variable production cost (per acre)
wheat	1.00	$8.00
oats	0.85	$6.80
barley	0.95	$7.60
flaxseed	1.05	$8.40
fallow		$5.00

[a] based on Saskatchewan Agriculture Food & Rural Revitalization crop planning guides dark brown soil zone (1994-2004).

Source: Author

[46] It is assumed that technological development has been crop neutral and has not altered relative crop production expenditures among the four modeled cropping options.

The estimated variable production costs are reasonably close to the reported mean variable production cost of $7.50 per acre for fallow seeded crops (Guide to Farm Practice in Saskatchewan 1960). And the annual cost of leaving a plot in fallow is estimated at $5.00/acre (Guide to Farm Practice in Saskatchewan 1960).

In addition to the variable production costs per acre outlined in table 4.9, farm agents are faced with cost of hiring non-family labour and/or custom work. The cost of non-family labour is assumed here to be characterized by a logistic growth function, with increasing per acre costs as farm acreage increases up to a maximum cost per acre at a minimum acreage threshold. The logistic function was selected due to the reality that small farms are able to supply the majority of the required labour, while the non-family labour requirement increases drastically as the farm expands up to a size where the majority of labour is non-family. The per acre cost of non-family labour for an individual farm agent was estimated utilizing equation 4.31.

$$W = 0.03 + \frac{0.8}{1 + 14500 \cdot e^{-0.009 \cdot K}} \tag{4.31}$$

$$R^2 = 0.95$$

The maximum cost of non-family labour is $0.83 per acre and is incurred by all farms that manage a total land base in excess of approximately 1800-1900 cultivated acres. While it is recognized that non-family labour requirements are likely correlated with operator age[47], data restrictions make it difficult to estimate such a relationship.

4.7.2.3 Fixed Costs and Debt Servicing

Fixed costs include farm machinery and equipment replacement costs and land lease payments. Due to the assumption that total machinery and equipment investment remain constant per cultivated acre, the annual machinery and equipment replacement charge is computed as $15 multiplied by the rate of economic depreciation. The base scenario of chapter five assumes a fixed annual rate of economic depreciation of 10%[48]. The annual machinery and equipment replacement charge of $1.50 per cultivated acre is in line

[47] The supply of family labour will decline as the farm agent ages due to both 1) offspring leaving the household and 2) the physical abilities of the agent declining over time.
[48] Based on a 10 year useful life, the salvage value is approximately 35% of the purchase price which is consistent with American Society of Agricultural Engineers estimates of 36% for farm tractors (ASEA 2003).

with actual depreciation expenditures estimates for the period (Saskatchewan Agriculture, various years). Annual lease payments are determined within the model through the land lease auction, with the exception of land under a lease agreement at the initial period. Land leases are initialized with an annual lease payment of $2.25 per cultivated acre[49] multiplied by the soil productivity index of the plot in question. The initial cash lease payment is in line with a reasonable cash lease allowance of 6%-8% of the current land value (Guide to Farm Practice in Saskatchewan 1960).

The annual debt servicing cost of individual farm agents is determined by their initial level of debt and any new debt acquired over the duration of the study period. Farm agents are assumed to finance new land purchases with a 25% cash down payment, with a 20 year amortization period. Interest is assumed to accrue at a rate of 6.0%[50], compounded annually, on all outstanding principal balances.

4.7.2.4 Family/Managerial Withdrawal

The family living and managerial deduction from farm revenue is based on data in Table 4.8 and was estimated as:

$$WD = 1882 + 0.068 \cdot GR + 0.834 \cdot K \quad (4.32)$$

[51]

$R^2 = 0.98$

The family living and managerial deductions are characterized by an L-shaped cost curve; indicative of significant economies of scale.

4.7.3 Behavioural Data

Setting agent behavioural parameters is one of the most important and challenging aspects of agent based models. Within this framework, farm operator agents are assumed to make three primary types of managerial decisions: they select a crop mix, determine a value for farm land, and decide when to exit the industry.

[49] $2.25 = $30.00 x 7.5%.
[50] 7.5% (mean Bank of Canada rate 1960-2000) - 3.0% (inflation adjustment) + 1.5% = 6.0%
[51] T-statistics available upon request.

4.7.3.1 Crop Mix

Farm agents here are restricted to the production of four field crops, wheat[52], oats, barley and flaxseed. These four field crops represent the major production options available to Saskatchewan grain producers located within the dark brown soil zone in the 1960's (Table 4.10). It should be noted that rapeseed (canola), which is now an important crop, was not recommended for production in the dark brown soil zone, due to its low drought tolerance (Guide to Farm Practice in Saskatchewan 1960).

Table 4.10: Crop Acreages (percent of total), Saskatchewan, 1960-1964

	all wheat	oats	barley	rye	flaxseed	rapeseed	fallow
1960	40.6%	6.5%	6.3%	0.7%	3.1%	1.4%	41.4%
1961	42.2%	3.9%	4.8%	0.6%	2.5%	1.0%	45.0%
1962	43.8%	6.8%	4.1%	0.7%	1.0%	0.4%	43.1%
1963	44.8%	5.5%	4.8%	0.8%	1.3%	0.5%	42.2%
1964	48.0%	3.7%	3.5%	0.8%	1.3%	0.8%	42.0%
mean	43.9%	5.3%	4.7%	0.7%	1.8%	0.8%	42.7%
max	48.0%	6.8%	6.3%	0.8%	3.1%	1.4%	45.0%
min	40.6%	3.7%	3.5%	0.6%	1.0%	0.4%	41.4%

note: percentages are based on harvested acres of included field crops and fallow acres

Source: Saskatchewan Agriculture Food and Rural Revitalization (2004)

Based on relative production acreages of the four primary field crops (see table 4.10), all farms in the simulation are assumed to determine their annual crop mix based on the following cropping constraints:

- Fallow acres = 0.40 x cultivated acreage
- Wheat acres $\leq$ 0.55 x cultivated acreage
- Oat acre $\leq$ 0.10 x cultivated acreage
- Barley acres $\leq$ 0.10 x cultivated acreage
- Flaxseed acres $\leq$ 0.05 x cultivated acreage

4.7.3.2 Land Valuation

Interaction through the land auctions requires all farm agents to form individual valuations of available plots of agricultural land. In turn a farm agent's land valuation is dependent on two factors; the agent's expectations of rent generated from a given plot of land, and their level of risk aversion. A farm agent's expectations are based on both their prior expectations and the most recent realized rent from land. The

[52] For simplicity all wheat (including spring, winter and durum) is classed as a single crop alternative.

farm agent is also assumed to place a greater weight on their prior expectations than their recent outcome ($\lambda = 0.1$). As a result expectations cannot be significantly altered by a single time period of production.

Agents with a greater level of risk aversion possess a greater risk discount value when bidding on additional plots of farm land. A risk neutral agent would have a risk discount of zero and would value a plot of land based on its full expected return. Risk averse agents have a positive discount value and their land rent expectations are weighted using a value less than one when valuing land (see table 4.11).

Table 4.11: Land Valuation and Management Classification

Managerial Classification	Risk Aversion Factor (Φ)	Expected Production Margin
expanding farm	0.95	$8.25
cautious expanding farm	0.90	$8.25
lifestyle farm	0.85	$8.25
exit and retirement farm	0.00	$8.25
landlord	1.00	$2.25 [a]

[a] initial lease payment

Source: Author

A farm agent that is part of the *exit and -retirement* manager class is assumed to no longer be interested in controlling additional land resources. This corresponds to a full discount of their land rent expectations. A farm agent in the *exit and retirement* managerial class will still attempt to renew land leases when the current agreements expire. In turn, they will evaluate the current value of the plots based on their prior managerial classification and their corresponding risk aversion factor.

4.7.3.3 Retirement and Intergenerational Transfers

Farm agents are assumed to be able to voluntarily exit the industry (for non-financial reasons) only after they have reached a minimum age of 55 years. Prior to this point, all exits, either forced or voluntary, are restricted to be due to financial considerations. Old-age retirements are modeled as a simple function of age and random chance. The simulation is designed so that the probability of a farm agent retiring increases as the farm agent moves into a new age class (table 4.12).

Table 4.12: Net Exit of Farm Operators by Age Cohort (1961-1986)

	5-years period	Annual Probability of Exit
55-59 years	25%	6%
60-64 years	40%	10%
65-69 years	64%	18%
70 years & over		30% [a]
80 years		100% [a]

[a] author's estimate

Source: Author's calculations. Census of Canada: Agriculture: Saskatchewan

The net exit of farm operators within an age cohort is calculated as the net change in the number of farms in an age cohort over a five year period[53] relative to the initial age cohort size (equation 4.34).

$$net\ \ exit\ \ 55-59\ \ years = 1 - \left[\frac{no.farms\ \ 60-64_{t+5}}{no.farms\ \ 55-59_{t}} \right] \tag{4.34}$$

When a farm agent voluntarily exits from the industry, it is assumed that the farm will continue to be operated with the next generation[54] taking over as the farm manager. The new generation is in turn assumed to buyout the exiting generation by assuming all existing farm assets and debts and purchasing 40%[55] of the existing farm equity with additional debt financing.

4.7.4 Using the Model: Assessing the Impact of Farm Stabilization and Support Programs

Government intervention, with goals of stabilizing and supporting the farm sector, has played a significant role in the evolution of farm structure in Canada. Fulton et al. (1989) argue that without these farm programs the health of the prairie economy and farm sector would have been significantly worse since 1985. Beginning in the late 1950's, and reaching its peak in the mid-1980s, significant transfer payments have come from federal and provincial governments to agricultural producers. Over the duration of the period of study selected for simulation, a number of significant programs and payments to Saskatchewan

[53]i.e. farms in the 55-59 age cohort in the current time period will make up the 60-64 age cohort in five years.

[54] The model assumes a 30 year age gap between generations (i.e. if the retiring farm agent is 60 years old the new farm agent will have an initial age of 30 years.

[55] Due to the private and often complex nature of intra-family farm transfers, a crude estimate of the buyout rate had to be used. Based on the survey data of Ragush (1966), the debt carried by the successor is on average approximately double that of the retiring farm agent. A transfer price based on new debt financing of 40% of the equity capital (all existing debt is also assumed), and the injection of new equity capital equal to 25% of the total transfer price by the successor, results in the farm assets being transferred for 53-85¢ on the dollar. After the transfer, the farms total debt is increased to a level that is 1.6–4.6 (0.4:1– 0.1:1 debt to asset ratio) times the pre-transfer debt level.

producers have occurred. While not all transfers occurring over the 1960-200 period are included within this simulation, an effort was made to incorporate all the major programs and transfers in the base scenario of chapter five (see figure 4.9).

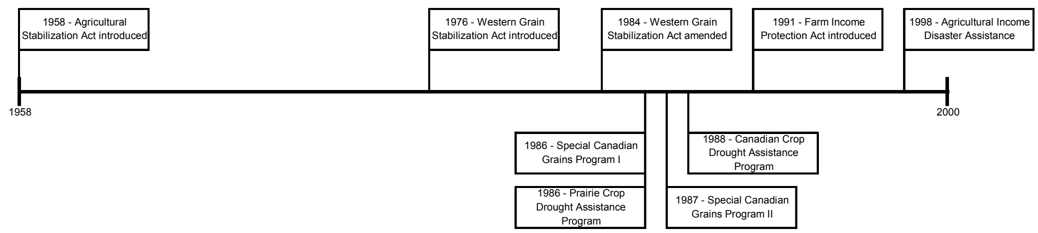

Figure 4.9: Agricultural Stabilization and Support Programs 1958-2000.

4.7.4.1 The Agricultural Stabilization Act

In 1958 the federal government implemented the Agricultural Stabilization Act, and introduced the first significant program aimed at stabilizing the Canadian farm sector (Schmitz et al. 2002). The program was designed with the primary objective of stabilizing the prices of specific farm commodities including those grains typically grown on the prairies. Under the Agricultural Stabilization Act, farmers where guaranteed 90 percent of a three-year moving-average commodity price. In the event that the market price fell below the guaranteed price, farmers received a per-unit subsidy payment equivalent to the price deficiency (Schmitz at al. 2002). Western grains were removed from the Agricultural Stabilization Act in 1976 with the introduction of the Western Grains Stabilization Act.

4.7.4.2 Western Grain Stabilization Act

Unlike the Agricultural Stabilization Act, which focused on stabilizing commodity price, the Western Grains Stabilization Act (WGSA) aimed to stabilize the net cash flow from the major grain and oilseed crops on the Prairies (Fulton et al. 1989). Individual producers voluntarily entered into the program, which was funded through both producer levies and government contributions. Participating farmers contributed a percentage of their gross sales[56] to the stabilization fund, an amount that was matched by the federal government in addition to a further contribution equivalent to 2 percent of gross sales (Fulton et al. 1989).

[56] The producer levy ranged between 1 an 4 percent of gross sale depending on the balance of the stabilization fund (Fulton et al 1989).

Payments to producers under the WGSA where triggered when net cash flow from the major grains grown in the Prairie region fell below 90 percent of the previous five-year average net cash flow (Fulton et al. 1989). In response to criticism directed at the program, Bill C-33 was passed to amend the WGSA. The amendment was intended to make the program more responsive to crop production volume changes (Schmitz et al. 2002). Under this program, when a payment was triggered, individual producers received a payout proportional to their contributions to the stabilization fund in the current and two previous program periods (Fulton et al. 1989).

Within the simulation, all farm agents are assumed to be enrolled in the WGSA. A farm agent's net annual cash flow from the WGSA program is evaluated as the difference between program payments received and levy contributions to the stabilization fund (equation 4.35).

$$NCF_k^{WGSA} = Payment_k^{WGSA} - Levy_k^{WGSA} \tag{4.35}$$

where NCF_k^{WGSA} = net cash flow from WGSA to farm agent k
$Payment_k^{WGSA}$ = gross WGSA payment to farm agent k
$Levy_k^{WGSA}$ = total WGSA levy paid by farm agent k

$$Levy_k^{WGSA} = 0.02 \cdot GR_k \tag{4.36}$$

As a result of the program's design, the payouts received by individual producers are based on the aggregate net cash flow of the entire region. The total payout received within the region is based on the aggregate net cash flow of all farms (equation 4.37).

$$Payout^{WGSA} = \begin{pmatrix} if\ 1977 \le t \le 1983\ \ Max\left[0, PAYMENT\ \ 1\right] \\ \\ if\ 1984 \le t \le 1990\ \ Max\left[0, PAYMENT\ \ 1, PAYMENT\ \ 2\right] \end{pmatrix} \tag{4.37}$$

where $Payout^{WGSA}$ = Total WGSA payments made to the aggregate region

$$PAYMENT\ \ 1 = \overline{NGP} - NGP_t \tag{4.38}$$

$$NGP_t = \sum^{K} \left(GR_k - VC_k \right)$$

$$\overline{NGP_t} = \sum_{p=1}^{5} \left(NGP_{t-p} / 5 \right)$$

where NGP = net grain proceeds (all farms) in current production period
$\overline{NGP}$ = 5-year moving average net grain proceeds

$$PAYMENT\ \ 2 = \left(\overline{NGPT} - NGPT_t \right) \cdot \sum^{K} tonnes_k \tag{4.39}$$

$$NGPT_t = \sum^{K} \left[\left(GR_k - VC_k \right)\ / tonnes_k \right]$$

$$\overline{NGPT_t} = \sum_{p=1}^{5} \left(NGPT_{t-p} / 5 \right)$$

where $NGPT$ = net grain proceeds per tonne (all farms) in current production period
$\overline{NGPT}$ = 5-year moving average net grain proceeds per tonne
$tonnes_k$ = total grain production (all crops) by volume of farm agent k

Once the aggregate regional payment has been determined, it is allocated among all farm agents in direct proportion to their current and historic contributions to the stabilization fund through producer levies (equation 4.40).

$$Payment_k^{WGSA} = Payout^{WGSA} \cdot \left(\frac{\sum_{p=0}^{2} Levy_{k(t-p)}^{WGSA}}{\sum^{K} \left[\sum_{p=0}^{2} Levy_{k(t-p)}^{WGSA} \right]} \right) \tag{4.40}$$

4.7.4.3 Special Canadian Grains and Drought Assistance Programs

In 1986 the government of Canada paid out $1 billion to grain producers under the Special Canadian Grains Program (SCGP) to cushion the impact of the subsidy war between the United States and the European Economic Community (Agriculture Canada 1986a). Additional payments were made in the subsequent crop year, bringing the total assistance to just over $2 billion (in nominal dollars). Payments to individual producers were based on seeded acreages of eligible crops, regional yields, and assistance rates[57]. The payment received by an individual farm agent in the model is the sum of acres seeded to eligible commodities multiplied by the subsidy rate (equation 4.41). In addition, payments to individual producers are capped at $25,000 ($5,500 in 1960$).

$$Payment_k^{SCGP} = \min\left[5500,\ \sum_{i=1}^{4}\left(A_i \cdot Subs_i^{acre}\right)\right] \tag{4.41}$$

where $Payment_k^{SCGP}$ = SCGP payment to farm agent k
$Subs_i^{acre}$ = SCGP assistance rate per acre of crop i

In the simulation, the assistance rates are set at: wheat $0.11, oats $0.04, barley $0.06 and flax $0.11[58] for both crop periods (1986, 1987) covered by the program.

In addition to the payments made under the Special Canadian Grains programs, prairie producers also received significant direct payments from the federal government for drought assistance (DAP) in 1986 and 1988 (Agriculture Canada 1986b, 1988). The payment received by individual farmers under these programs is evaluated as:

$$Payment_k^{DAP} = Subs^{acre} \cdot \sum_{i=1}^{4} A_i \tag{4.42}$$

where $Payment_k^{DAP}$ = DAP to farm agent k
$Subs^{acre}$ = DAP assistance rate per seeded acre

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[57] Commodity specific assistance rates are proportional to the relative price decline attributed to the subsidy war (Agriculture Canada 1986a)

[58] Payouts in 1960$ based on reported rates of: wheat $0.48, oats $0.18, barley $0.06 and flax $0.50 (Agriculture Canada 1986a).

Under the Prairie Crop Drought Assistance Program, farmers in areas worst hit by drought conditions received $15 ($3.30 in 1960$) per seeded acre. In 1988, prairie farmers received an additional $40 ($8.80 in 1960$) under the Canadian Crop Drought Assistance Program.

4.7.4.4 Farm Income Protection Act

As a result of a sharp decline in world grain prices in 1985 and the subsequent large payout, the WGSA program was in a significant deficit position and only offered farmers limited income support by the closing years of the 1980's (Schmitz et al. 2002). As a result new federal legislation, entitled the Farm Income Protection Act, was passed in 1991 to replace the WGSA. In addition to crop insurance[59], the Farm Income Protection Act encompassed two farm stabilization programs: the Gross Revenue Insurance Plan (GRIP) and the Net Income Stabilization Account (NISA) programs (Schmitz et al. 2002).

The short lived GRIP provided farmers with revenue protection through guaranteed per-acre gross returns. Within 18 months of its implementation, the government of Saskatchewan significantly altered the program and by 1992 withdrew completely from GRIP (Schmitz et al. 2002). Under the GRIP a farm agent's net program annual cash flow is evaluated as:

$$NCF_k^{GRIP} = Payment_k^{GRIP} - Indem_k^{GRIP} \tag{4.43}$$

where NCF_k^{GRIP} = net cash flow from GRIP to farm agent k
$Payment_k^{GRIP}$ = gross GRIP payment to farm agent k
$Indem_k^{GRIP}$ = total GRIP indemnity paid by farm agent k

GRIP payments and indemnity costs are calculated based on the long term average yields (LTAY) for the individual crops reported in table 4.7. The guaranteed price under the GRIP was set as a 15-year indexed moving average price (IMAP), lagged by two crop production periods[60]. Under the revised Saskatchewan GRIP, introduced for the 1991-92 crop production period, the payouts received and premiums paid by an individual producer were based on their risk area and its corresponding premium rate and per acre payment. Under the revised program the payouts and premiums were based on total seeded acres with no individual crop differentiation at the farm level.

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[59] While crop insurance programs may offer participating producer's a significant source of income stabilization, due to the complexity of modelling the individual nature of coverage and premiums, it has been omitted from simulation. Due to the historic levels of relatively low participation rates in the program, its omission is likely trivial.

[60] Under the GRIP program, individual IMAP were set for each of the eligible crops as an average from the previous fifteen years, lagged by two years, indexed by a farm input price index (Schmitz et al. 2002). Due to the fixed variable costs assumption of the simulation, the simulation does not index the historic crop prices and uses a simple arithmetic mean price.

$$Payment_k^{GRIP} = \begin{pmatrix} if \;\; t = 1991, \;\; \sum_{i=1}^{4} \left(\max\left[\left(\overline{P}_i \cdot prodn_i - IMAP_i \cdot LTAY_i \cdot A_i \cdot Q \right), 0 \right) \right] \\ if \;\; t = 1992, \;\; \dfrac{\sum^{K} \sum_{i=1}^{4} \left(A_i \cdot LTAY_i \cdot Q \cdot \left(IMAP_i - \overline{P}_i \right) \right)}{\sum^{K} \sum_{i=1}^{4} A_i} \cdot \sum_{i=4}^{4} A_i \end{pmatrix} \tag{4.44}$$

where $prodn_i$ = total production (volume) of crop i on land managed by farm agent k
$IMAP_i$ = indexed moving average price of crop i
$LTAY_i$ = long term average yield of crop i

The farmer was responsible for one-third of the total GRIP premium, with the balance paid by the provincial and federal government (Schmitz et al. 2002). The total indemnity costs are based on indemnity rates[61] published by Agriculture Canada for the 1991-92 program year.

$$Indem_k^{GRIP} = \begin{pmatrix} if \;\; t = 1991, \;\; \frac{1}{3} \cdot \sum_{i=1}^{4} \left(IMAP_i \cdot LTAY_i \cdot Q \cdot A_i \cdot Indem\%_i \right) \\ if \;\; t = 1992, \;\; \frac{1}{3} \cdot \dfrac{\sum^{K} \sum_{i=1}^{4} \left(IMAP_i \cdot LTAY_i \cdot Q \cdot A_i \cdot Indem\%_i \right)}{\sum^{K} \sum_{i=1}^{4} A_i} \cdot \sum_{i=1}^{4} A_i \end{pmatrix} \tag{4.45}$$

where $Indem\%_i$ = indemnity rate of crop i

The Net Income Stabilization Account (NISA) program was introduced along with GRIP in 1991, and unlike the latter, remained as the major stabilization program for many Canadian producers through the year 2001 (Schmitz et al. 2002). The basic mechanism of the NISA program was the establishment of a government matched savings account from which producers where able to withdraw funds during period of decreased farm income. Individual producers voluntarily joined the NISA program by opening up a NISA

[61] Wheat 18.55%, Oats 11.26%, Barley 16.51% and Flaxseed 18.42% (Agriculture Canada 1992)

account (Fund 1) into which they had the ability to deposit up to 3%[62] of their annual eligible net sales (Schmitz et al 2002). In addition to the producer's deposit, a matching deposit, a cost shared by the provincial and federal governments, was made into a separate account (Fund 2). The balance of the combined NISA accounts was capped at three-times the three-year moving average eligible net sales. Producers earned a rate of interest equal to the rate on a short-term deposit[63] on the combined balance, as well as an additional 3% on the balance of Fund 1. For the purpose of the simulation, all farm agents are assumed to maximize their matching deposit by depositing a cash amount equivalent to 3% of their gross revenue into Fund 1.

Under the program, producers were able to withdraw funds from their NISA account if farm income fell below 70 percent of the previous three year average[64] (Schmitz et al. 2002). When a withdrawal is triggered, the producer was able to withdraw funds[65] to bring farm income up to the 70 percent of the three year average, provided their NISA account did not go into a deficit position. In this model, the maximum annual withdrawal an individual farm agent can make from their NISA account is determined by their annual and historic farm income and combined NISA balance (equation 4.46).

$$TWD^{NISA} = \min\left[\left(\overline{NI}^{NISA} - NI^{NISA}\right), \left(Fund\ 1 + Fund\ 2\right)\right] \qquad (4.46)$$

$$NI^{NISA} = GR - VC$$

$$\overline{NI}^{NISA} = \sum_{p=1}^{3} NI_{t-p}^{NISA} / 3$$

where TWD^{NISA} = maximum triggered withdrawal from NISA account for farm agent k
NI^{NISA} = net income for NISA program of farm agent k
$\overline{NI}^{NISA}$ = 3-year moving average net income for NISA program of farm agent k
Fund 1 = balance of NISA fund 1 of farm agent k
Fund 2 = balance of NISA fund 2 of farm agent k

As in reality, farm agents are able to manage their NISA accounts individually, and may not always withdrawal NISA funds up to the maximum allowable level. All farm agents are assumed to manage their

[62] The Saskatchewan NISA program falls under the enhanced NISA guidelines which allows for government matching deposits of 3% of eligible net sales versus the standard NISA maximum of 2%. Individual producers were able to make addition deposits over and above the 3% level, but additional deposits were not matched by the government.
[63] For the purpose of the simulation, the short term rate has been set as one-half the interest rate charged on debt capital.
[64] In addition to this withdrawal trigger, a withdrawal is also triggered if farm net income falls below $10,000 (increased to $20,000 in 1999) (Schmitz et al. 2002).
[65] Withdrawals must first be made from Fund 2 (government deposits), as withdrawals from this fund are taxable. Due to the assumption of a tax-free region this separation is not significant, but has been included to aid in future model extensions.

NISA accounts using a simple rule based on meeting annual cash flow requirements. Farm agents can only withdraw NISA funds when two conditions are met: 1) a withdrawal has been triggered and 2) annual net cash flow, prior to additional land investment, is negative. The farm agent will withdraw funds up to the level where either net cash flow is zero, or the total triggered withdrawal is made (equation 4.47).

$$WD^{NISA} = \max\left[TWD^{NISA},\ -NCF\right] \tag{4.47}$$

where WD^{NISA} = actual withdrawal from NISA account of farm agent k

4.7.4.5 Agricultural Income Disaster Assistance

In 1998 the federal government unveiled the Agricultural Income Disaster Assistance (AIDA) program, a new support program structured according to WTO guidelines (Schmitz et al. 2002). AIDA remained in place until 2001 when it was replaced by the Canadian Farm Income Program (CFIP). Producers became eligible for a payout from AIDA when their net income (not including depreciation) fell below 70 percent of their reference net income (Schmitz et al. 2002). The farm agent's payout here is calculated as 70 percent of their three-year average net income less current net income (equation 4.48).

$$Payment_k^{AIDA} = Max\left[0,\ \left(0.7\cdot\overline{NI}^{AIDA} - NI^{AIDA}\right)\right] \tag{4.48}$$

where $Payment_k^{AIDA}$ = AIDA payment to farm agent k
$\overline{NI}^{AIDA}$ = 3-year moving average net income for AIDA program of farm agent k
NI^{AIDA} = net income for AIDA program of farm agent k

A farm agent's net income is calculated for AIDA as their gross revenue (GR) less variable production costs (VC). The farm agent's reference net income is equivalent to the arithmetic mean of the farm agent's net income from the previous three production periods.

4.8 Summary

Regional structural change is dependent on not only the independent actions of individual farm households, but also the interaction of the same through land and product markets. The application of agent based methods to study such changes is intuitively attractive, as it allows for the development of models that incorporate both the heterogeneity of the farm household, or decision making unit, and the inherent interactions that exist between individual farms. In turn, the farm household is assumed to be engaged in the two related, but separate, activities of producing and marketing field crops and investing in agricultural assets. It is the second activity, namely investment in farmland, which incorporates the interactions between individual farm households through the assignment of property rights and well-defined land markets.

This regional model of farming activity is initialized with a base scenario representative of the 1960-2000 time period. Farm agents are endowed with a number of attributes including 1) age, 2) farm size, 3) tenure, 4) finance and 5) management, based on available census and survey data. Production costs correspond with 1960 cost levels and are held constant throughout the model duration. In addition, real commodity prices and yields are de-trended to a 1960 base period to adjust for constant production technology and practices. Finally, transfer payments from the federal and provincial government beginning in the late 1950's, and reaching a peak in the mid-1980's have played a prominent role in the annual cash flow of many farm households. In order to replicate and assess the impact of government intervention into the farming sector, the most significant farm stabilization and support programs are modelled as part of the base simulation framework.

CHAPTER FIVE

DISCUSSION OF RESULTS

5.0 Introduction

A profile of 310 farms is initialized to represent a proto-typical RM in the dark brown soil zone of Saskatchewan. The profile contains the following structural farm characteristics: 1) age, 2) farm size, 3) tenure, 4) finance and 5) management. Farm costs and returns are set up to represent those of the 1960 time period. This agent based model simulates farm expansion and contraction in the region through farmland ownership and leasing markets. The model starts in the year 1960 and runs to the year 2000; each scenario is replicated 200 times to achieve statistically useful results. In addition to the base scenarios described earlier, zero government transfer scenarios are also simulated. The first set of scenarios test the sensitivity of the final structural predictions to initial assumptions as to the distribution of varied managerial classes. The second set of counterfactual scenarios examines the impact of removing government programs on structural change in the region. The simulation environment was implemented using NetLogo © version 2.1 on a Windows XP platform[66].

The model results reported illustrate a limited number of structural characteristics of the study region including: 1) the number of farm units, 2) mean farm size, 3) the distribution of farm size, 4) land values, 5) proportion of farm land leased from non farming owners, and 6) farm debt. The results presented in this chapter provide evidence of the ability of agent-based models to generate patterns and trends that closely mirror the historic structural evolution of a Saskatchewan region dominated by crop production agriculture. Model validity has been tested through direct comparison to available census and survey data. While model validation of results is important when dealing with "proof of concept" issues, it also allows the researcher to draw conclusions from the model that can be used to improve understanding of the system of

[66] A copy of the NetLogo © source code is included in Appendix C

study. To move beyond the scope of simply validating model results based on direct comparisons to actual data, a number of the drivers of structural changed discussed in chapter two are revisited and discussed in the context of the simulation results.

5.1 Simulation Results: Base Scenario

Under the base scenario, the model is executed as outlined in chapter 4. Two hundred replications are simulated for each of the 5 managerial distributions outlined in table 4.6. The base scenario results are evaluated based on their ability to mirror historic structural adjustments over the study period of 1960-2000.

5.1.1 Number and Mean Size of Farms

The trend towards fewer and larger farm units has a number of important implications for agricultural policy. As farm production becomes more consolidated, the aggregate response of the sector may also shift in a significant manner. The simulated consolidation of farm land among a declining number of farm agents are compared to actual farm numbers and mean farm size data (figures 5.1 and 5.2).

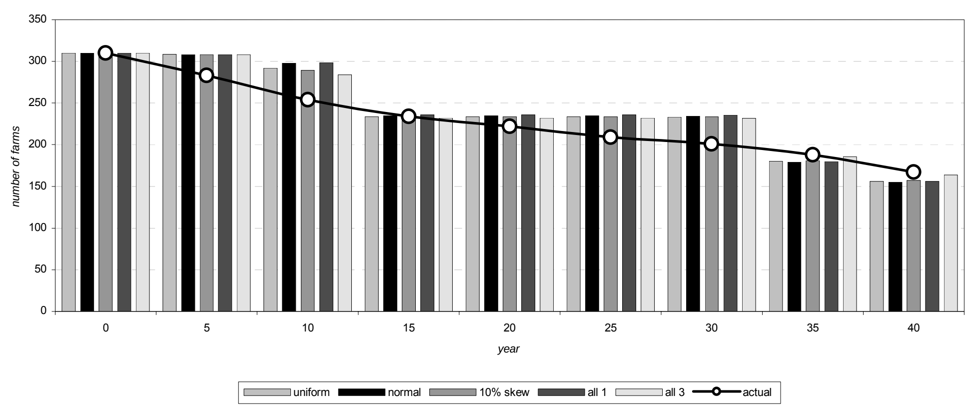

Figure 5.1: Simulation Results (base scenario) - Number of Farm Agents

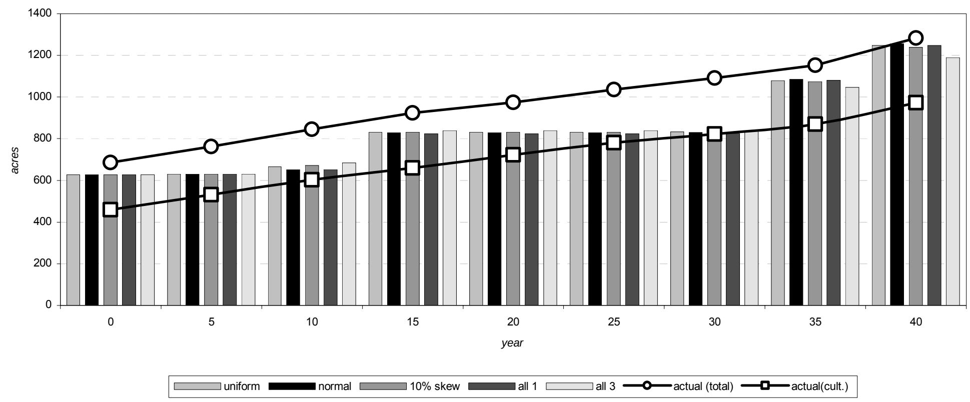

Figure 5.2: Simulation Results (base scenario) - Mean Farm Size (cultivated acres)

Over the simulated period, the number of farms decreased at an annualized rate between 1.59 - 1.72%, as compared to an actual rate of 1.53%. The corresponding mean farm size increased at an annualized rate of between 1.61 - 1.76%, as compared to an actual rate of 1.58%. While the model closely approximates overall trends, a more interesting comparison occurs with respect to sub-periods. There are five distinct periods of simulated farm numbers and mean size observations: 1960-1970, 1970-1972, 1972-1992, 1992-1997 and 1997-2000. Prior to 1970, the model under-estimates the rate of consolidation with an annualized decline in farm numbers ranging from 0.38 - 0.86% (1.97% actual) and the rate of growth in farm size ranging from 0.38 - 0.88% (2.11% actual). During the 1970-72 period, the simulation makes an over adjustment resulting in a two period annual rate of decline of farms of 9.64 - 11.26% (1.39% actual) and a growth of 10.61 - 12.70% (1.78% actual) in mean farm size. For the combined 1960-1972 period, the model results estimate a 2.25 - 2.39% (1.88% actual) annual decline in farm numbers and a 2.39 - 2.45% (2.05% actual) increase in farm size. For the period of 1972-1992, the number of farms is relatively constant with an estimated annual rate of decline between 0.06 - 0.09% (1.15% actual) and annual growth in farm size of 0.06 - 0.16% (1.16% actual). The simulated period 1992-2000 is characterised by an annual decline in farms of 4.12 - 4.88% (1.96% actual) and an annual increase in farm size of 4.31 - 5.14% (1.77% actual). Like the previous time period, this latter period is characterized by rapid consolidation followed by a period of relatively little restructuring. The number of farms declined rapidly during the period 1992-1997 with an annual rate of decline between 5.89 - 7.20% (1.77% actual) and a corresponding increase in mean farm size of 6.28 - 7.80% (1.53% actual). The rate of decline slows significantly for all managerial classification distributions evaluated for the final period (1997-2000). The annual rate of farm decline is estimated at 0.76 - 1.09% (2.34% actual) and growth in mean farm size is estimated at 0.77 - 1.09% (2.18% actual). And all five distributions of managerial characteristics tested returned results that closely replicate the actual decline in farm operators (figure 5.1) and increase in farm size (figure 5.2) over the study period.

5.1.2 Distribution of Farm Size

The changing distribution of farm size is of greater importance than summary characteristics such as mean farm size. Over the course of the period under study, the relative amount of farms smaller than 400 acres remained relatively constant, ranging from a high of 35% of all farms in 1960 (Census of Canada: Agriculture: Saskatchewan 1961) to 29% in 2000 (Census of Canada: Agriculture: Saskatchewan 2001). In direct contrast, the proportion of farms occupying the largest size class (≥ 2880 acres) has increased significantly from 1% in 1960 to 9% of all farms in 2000. Over this same period, the distribution of farm size has flattened compared to the situation in 1960, where 87% of all farms operated less than 1120 acres. By 2000 this had fallen to only 60%.

After a simulation period of 10 years, the proportion of farms operating less than 400 acres is over estimated by the model at 49 - 51% of all farms (27% actual) under all the assumed initial distributions of the managerial types (see table 4.6). While not as well defined as in the actual distribution, a small bulge in the distribution begins to emerge in the simulated 760-1119 acre size class (see figure 5.3).

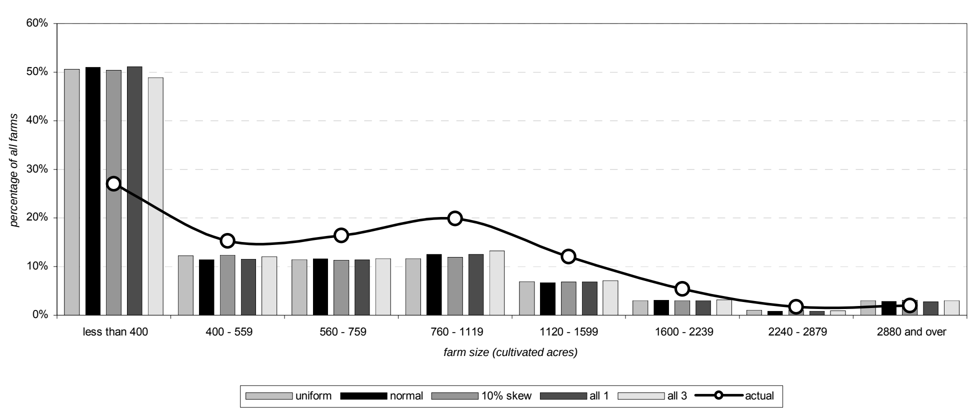

Figure 5.3: Simulation Results (base scenario) - Distribution of Farm Size (year 10)

After 20 years, while the simulation still over represents the less than 400 acre size class, the results appear to be converging closer to census data. Here 38 - 39% (figure 5.4) of all farms are contained in this size class (26% actual). In addition, the bulge of farms in the 760-1119 acres class continues to become more prevalent and accounts for 14 - 16% of all farms (20% actual). The model results also over estimate the proportion of farms in the 2880 acres and over class at 4% of all farms (3% actual).

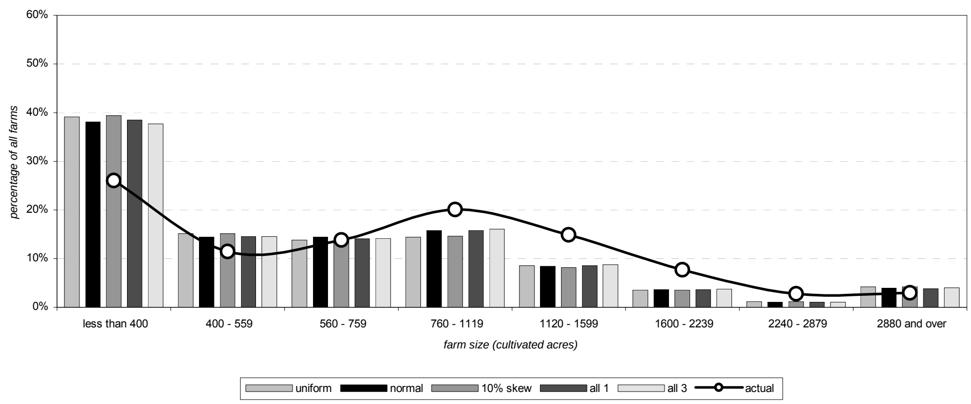

Figure 5.4: Simulation Results (base scenario) - Distribution of Farm Size (year 20)

The number of farms operating farms less than 760 acres are over estimated after 30 years, and farms of size 1120 - 2879 acres are under estimated, while farms of a size 2880 acres and over are over represented in the simulation (see figure 5.5). The small bulge of farms in the 760 - 1119 acre class continues to show representing 14 - 16% of all farms (19% actual).

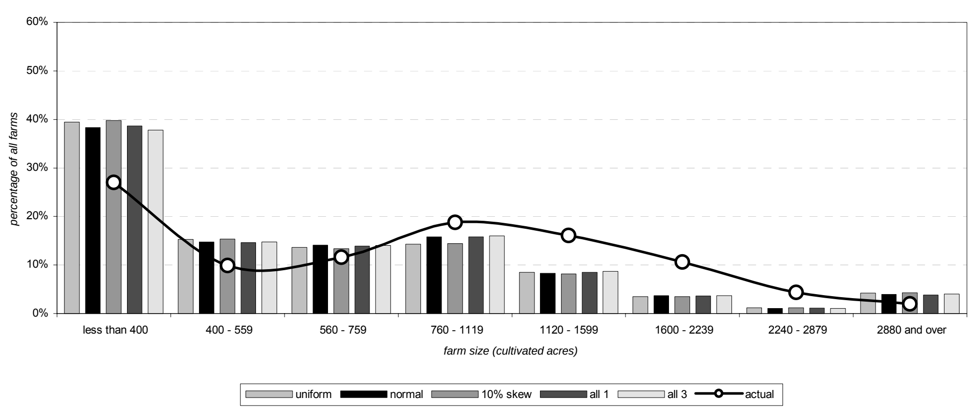

Figure 5.5: Simulation Results (base scenario) - Distribution of Farm Size (year 30)

After 40 years (figure 5.6), corresponding to the end of the time period studied, the proportion of farms occupying the less than 400 acre class has adjusted to a level (20 - 22% of all farms) that under estimates the census data observation for the period (29%). The model results for all five managerial distributions estimate the proportion of farms managing a land holding of 400-1119 cultivated acres at 53 - 55% (31% actual) of all farms. The proportion of farms managing 1120-2879 acres is estimated to be 18-19% (31% actual) of all farms.

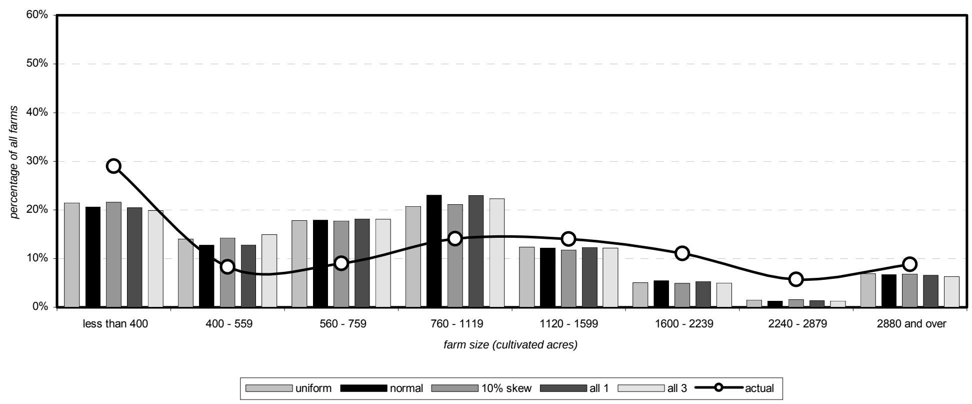

Figure 5.6: Simulation Results (base scenario) - Distribution of Farm Size (year 40)

The result shown here show that in spite of the inherent limitations within the simulation environment, the model closely replicates the dynamic distribution of farm size actually observed during the relevant timeframe[67]. This gives confidence that the assumptions made to conduct this simulation are a parsimonious, yet robust, characterization of individual level behaviour in Saskatchewan agriculture

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5.1.3 The Land Market

Farmers interact in this agent based environment and land is allocated among individual farm operators and absentee land owners through direct competition in land market auctions. This interaction and the bidding behaviour of agents results in varying value for farmland and the proportion of farmland owned by non-farming individuals. All farmland values reported here are listed in constant 1960s dollars.

[67] The simulated distributions were tested against the actual distribution using a non-parametric Kruskal-Wallis test statistic with K-1 degrees of freedom. The null hypothesis, that all of the all of the tested distributions are equivalent, could not be reject with a critical region of 0.05 for years 10 and 40 and a critical region of 0.01 for years 20 and 30.

Farmland prices fluctuated significantly from a low of $26 in 1960 to a high of $120 in 1981 (see figure 5.7). The model correctly replicates the trend of increasing farmland values from 1960 through 1968, with a total growth in farmland value of $16.84 - 25.27 per acre ($28.46 actual). With the exception of an increase in 1970, the model also correctly replicates the trend of decreasing farmland values over the 1968-1972 period, with land values decreasing by $5.07 - 6.56 per acre ($11.96 actual). From 1972 through 1981, farmland values increased at a rapid rate, resulting in a $78 per acre increase in a nine year period (Saskatchewan Agriculture, Food and Rural Revitalization 2004). While the model does capture this rapid increase in farmland value, the simulated peak lags by four years the actual peak. As well, simulated farmland values increased by $42.81 - 50.15 per acre over a 13 year period, an amount somewhat less than reality. This actual rapid growth in farmland values was followed by a period of rapidly declining farmland values compared to their peak in 1981 through to 1993. Over this period farmland values declined by $75 per acre, thereby returning farmland values to their earlier levels. The simulation replicates this rapid decline in farmland values, again lagged by four years, with farmland values falling by $31.47 - 49.05 per acre through 1998.

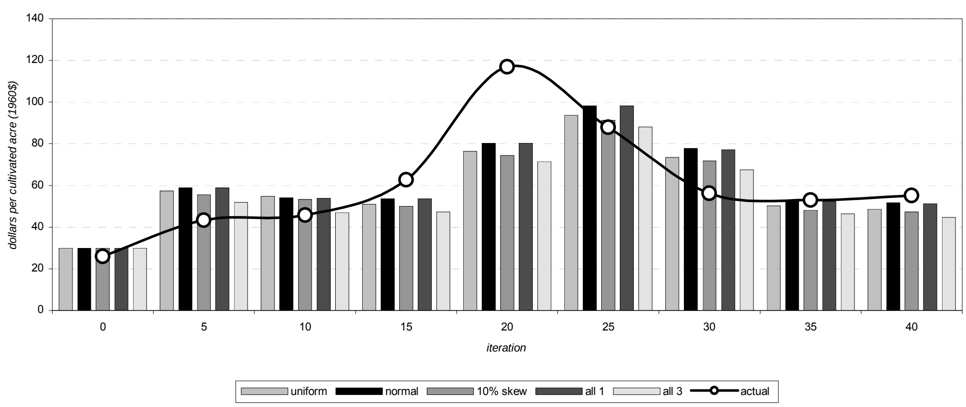

Figure 5.7: Simulation Results (base scenario) - Land Value per Cultivated Acre

All replications are initiated with less leased farmland (27.6%) relative to the actual proportion of farmland under a cash or crop share lease agreement (32%) at the provincial level in Saskatchewan. Throughout all simulations, the level of leased farmland remains below the proportion observed in the census of agriculture (figure 5.8). As a result, the absolute level of leased land can not be directly compared. The change from one census year to the next (5 year intervals) is of greater importance in evaluating the model's ability to capture historic shifts.

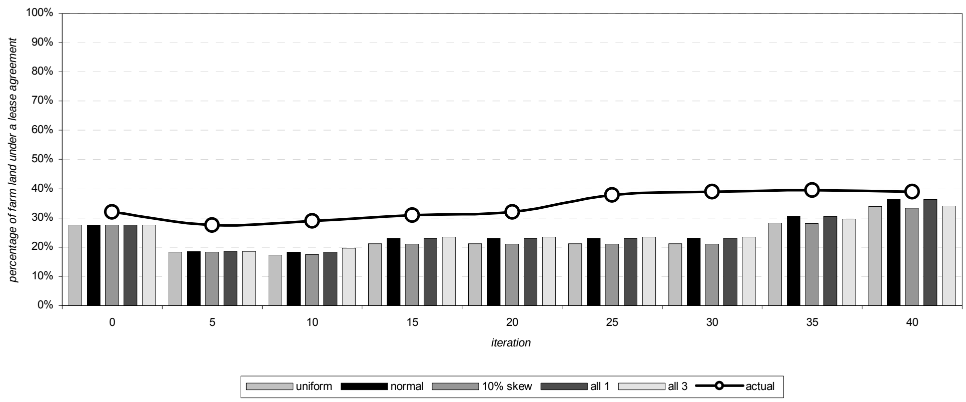

Figure 5.8: Simulation Results (base scenario) - Proportion of Land under Lease Agreement

Under all initial distributions of the managerial types, the model correctly replicates the trend in the proportion of farmland leased from 1960 to 1965. However, it over estimates the actual reduction in leased land -leased land is estimated to decline by 9.01 - 9.32% compared to an actual reduction of only 4.5%. From 1965 to 1970, the actual level of leased farmland increased by 1.5% as compared to a simulated change in leased land between -0.25 - 1.02%. Only the "all 3" distribution of managerial attributes replicated the increase in leased land during the period. During the period 1970-1975, the simulated proportion of leased land increased by 3.86 - 4.72% as compared to an actual increase of 2.0%. In the subsequent 1975-1990 period, simulated land tenure is relatively stable (leased land increasing by only 0.01 - 0.03%), in sharp contrast to actual increases of 8.54%. The rapid growth in leased farmland (5.90%) that occurred between 1980 and 1985 does not show up in any of the simulations until the period 1990-1995, when the proportion of leased land increases by 6.12 - 7.48%. The trend of an increasing level of leased farm land continues for the final 1995-2000 period with the proportion of leased farm land increasing by an additional 4.50 - 5.83%.

5.1.4 Farm Debt

The level of farm debt is an important factor in the financial health of the farm sector. A significant proportion of a farm's revenue must be used to service debt principal and interest payments. From 1970 to 1985, actual total farm debt more than doubled, from \$10.32 to \$22.06 per acre (Saskatchewan Agriculture, Food and Rural Revitalization 2004).

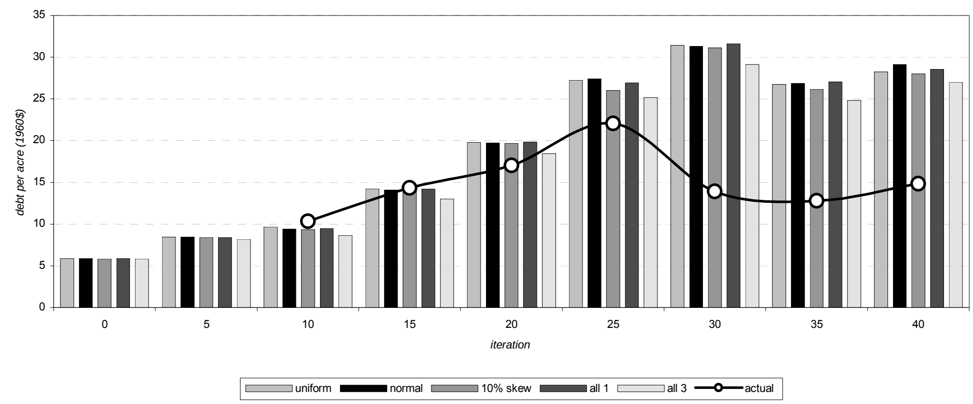

Figure 5.9: Simulation Results (base scenario) - Farm Debt per Cultivated Acre

Under all initial distributions of the managerial types, the model correctly replicates the trend of increasing total farm debt from 1970 to 1985, with simulated total farm debt increasing from \$8.65 - 9.68 to \$25.17 - 27.44. In contrast, the actual reduction in farm debt to \$12.79 per acre by 1990 is not replicated by any of the simulations; in fact simulated farm debt continues to grow during this period reaching a peak of \$29.14 - 31.60 per acre. Simulated farm debt declines from 1990 to 1995, but remains substantially above the actual observed levels (see figure 5.9). The actual increase in farm debt that occurred between 1995 and 2000 (2.03%) is replicated by all simulations with farm debt increasing by 1.50 - 2.24% over the same period. However, farm debt is estimated by simulation to be approximately double the actual level (see figure 5.9).

5.1.5 Farm Exits

One of the outcomes from the consolidation of farm production on a declining number of farms is the exodus of farm families. Policy makers need to concern themselves with the distribution effects of structural adjustments and the varied impacts these shifts have on the farm population. The agent based results generated shed light on a number of these distributional issues with regard to the characteristics of farm closure over the duration of the period studied.

Policy makers concerned with the rate of decline in farm numbers need to understand the reasons individual farm operations cease production. In the simulation, the significant majority (97.7%) of all farms that ceased operating did so due to a prolonged period of equity erosion and cash flow short fall. Only a small proportion of farms exited when the current manager retired (0.3%). While intuitively correct, this result suggests that the intergenerational farm transfer algorithm incorporated into the model needs to be developed and extended in further research.

Table 5.1: Simulation Results (Base Scenario) - Farm Exits by Exit Type

	exit type		
	Equity Erosion (eq 4.12)	Insolvency (eq 4.11)	Old-Age Retirement[a]
mean percentage of all exits	97.7%	2.0%	0.3%

[a] farms transferred to a new generation are not counted as exits

One of the more interesting results that emerges from the simulations concerns the farm agent's managerial attribute and the probability of an individual farm discontinuing production over the course of the period studied. A farm agent in the *Lifestyle* managerial class is 2.6% more likely to exit when compared to an *Expanding* farm agent (table 5.2).

Table 5.2: Simulation Results (Base Scenario) - Farm Exits by Managerial Class

	managerial class			
	Lifestyle	Cautious Expanding	Expanding	All
probability of farm exit[a]	49.0%	48.6%	46.4%	48.7%

[a] probability of farm exit = exits / initial number of farms

Balmann (1997) argued that the success of an individual farm depends, at least partially, on their initial state. These results add some support to this statement by examining the initial endowment of agricultural land among farms. While the average farm was initialized with approximately 4 (640 total acres) plots of farm land, farms that ceased operation during the period of study possessed, on average, an initial endowment of just over 2 plots (table 5.3).

Table 5.3: Simulation Results (Base Scenario) - Farm Exits and Initial Farm Attributes

	initial farm characteristic	
	Exit Farms[a]	All Farms
farm size (cult. acres)	357	627
debt (per cult. acre)	5.50	5.45

[a] Farms that discontinue farm operations during the simulation period

Farm agents initialized with less than average land holdings are at a significant bidding disadvantage as compared to farms operating on a larger scale, due to the need to generate greater cash flow per acre to cover fixed family living costs (see equation 4.32). This results in a disproportionate number of small farms exiting during prolonged periods of tightening production margins (table 5.4).

Table 5.4: Simulation Results (Base Scenario) - Farm Exits by Farm Size

Farm Size (cult. acres)	mean percentage of all exits
less than 400	89.92%
400-559	7.80%
560-759	1.88%
760-1119	0.13%
1120-1599	0.09%
1600-2239	0.02%
2240-2879	0.02%
2880 and over	0.04%

5.2 Simulation Results: Zero Transfer Scenario

Building on the results obtained from the base scenario, the model is then utilized to estimate the net impact of the historic package of agricultural stabilization programs and payments made over the study period (figure 5.10). Simulations are re-estimated assuming zero transfer payments to farm agents, for each of the five managerial distributions. These results and are compared to the base scenario in the next sections.

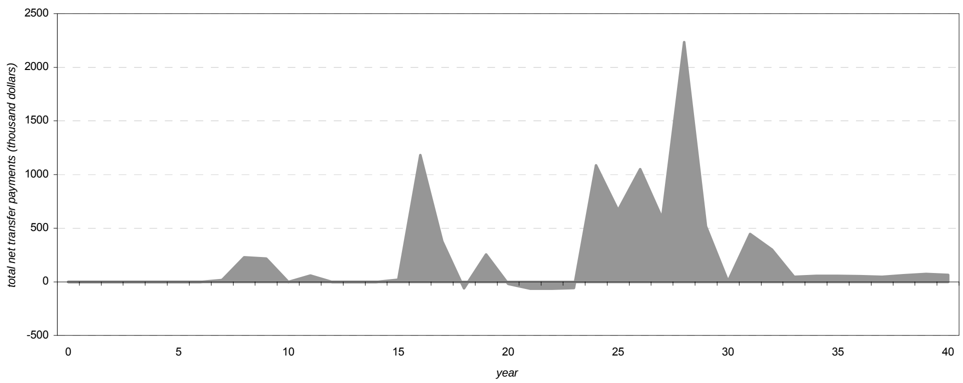

Figure 5.10: Simulation Results (base scenario) - Net Aggregate Stabilization Transfers

The zero transfer scenario simulates the structural evolution of the idealized study region in the absence of any government intervention through stabilization programs and ad-hoc stabilization payments.

5.2.1 Number and Mean Size of Farms

With regards to the number of farm agents populating the study region and government transfer payments, two critical time periods are identified: 1960-1987 and 1987-2000 (year 0-27 and 27-40). Prior to the year 1987, there is no significant difference between the number of farm agents in either the base or zero transfer scenarios (figure 5.11).

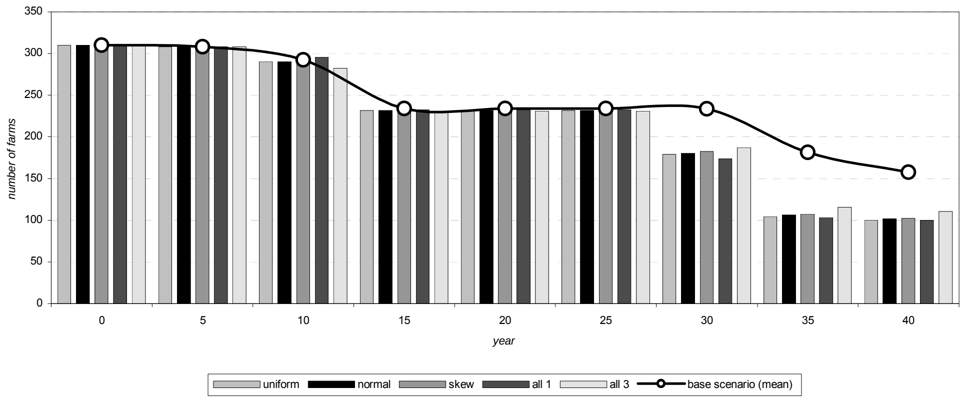

Figure 5.11: Simulation Results (zero transfer scenario) - Number of Farm Agents

While the 1960-1987 period does not exhibit any significant difference in the rate of farm decline over the base scenario, in contrast the 1987-2000 period is characterized by a significant increase in the rate of farm consolidation. By the end of the simulated time period, the number of farms declined to a level of 64 - 68% of the base scenario results (figure 5.11). Both the base and zero transfer scenarios exhibit a period of rapid farm consolidation after 1987. Under the zero transfer assumption, the number of farm agents in the region undergoes a period of rapid decline from 1987-1993, with an annualized rate of decline of 11.02 - 12.80%. This period of decline is followed by a period of moderate decline (1.15 - 1.51% annual drop for the period 1987-2000). In contrast, the base scenario exhibits a period of rapid decline (mean annual rate of 6.78%) from 1992-1997 which is preceded and followed by periods of relatively constant farm numbers.

The growth rate in farm size is inversely related to the fall in farm numbers. As a result the rate of change in mean farm size in the simulations is observed to be approximately proportional to the rate of decline in farm numbers. Like the observed trends obtained concerning farm numbers in the simulations, the rate of growth in mean farm size is not observed to be significantly different from the base scenario prior to 1987. In addition, the delayed period of farm decline found in the base scenario compared to the zero transfer scenario is mirrored by the varied periods of rapid growth in farm size.

5.2.2 Distribution of Farm Size

The distribution of farms by size (cultivated acres) is not found to be significantly different from the base scenario results for two initial observation periods (year 10 and 20). It is only by the third observation period (year 30) that the distribution of farm size diverges from the base scenario results[68] (figure 5.12).

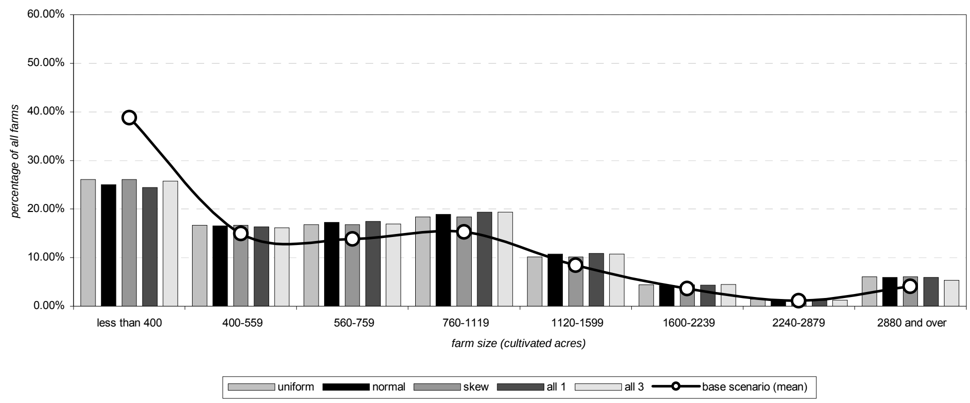

Figure 5.12: Simulation Results (zero transfer scenario) - Distribution of Farm Size (year 30)

Under the zero transfer scenario, the number of farms managing less than 400 cultivated acres is considerably less after thirty years, accounting for 24.16 - 26.10% of all farms (vs. 38.80% in the mean base scenario). As a result of significant reductions in the smallest size class, all other classes are estimated to account for a greater proportion of farms over the base scenario. Farms managing 400-1119 cultivated acres make up 51.47 - 53.50% of all farms (vs. 44.02% in the mean base scenario) while those managing 1120-2879 acres account for 15.56 - 16.79% (vs. 13.11% in the mean base scenario). Farms in the largest size class are also estimated to account for a greater proportion of farms at 5.36 - 6.05% (vs. 4.07% in the mean base scenario).

By the end of the zero transfer simulation (year 40) the distribution of farms by cultivated acres converges back to the distribution generated in the base scenario (figure 5.13). Farms in the largest size class (2880 acres and over) comprise a greater proportion of farms (8.24 - 9.00%) compared to the base scenario (6.68%). With a single exception[69], the proportions of farms in all other size classes are, on average, only marginally less than their base scenario values.

[68] Note that it is only after year 27 (1987), when the decline in farm agents increases over the base scenario results.

[69] Farms in the 400-559 acres class account for 13.84 - 14.76% of all farms (13.77% mean base scenario). The values for all other classes are(mean base scenario in parentheses): less than 400 acres; 19.93 - 20.59% (20.80), 560-759 acres; 17.13 - 18.06 (17.96),

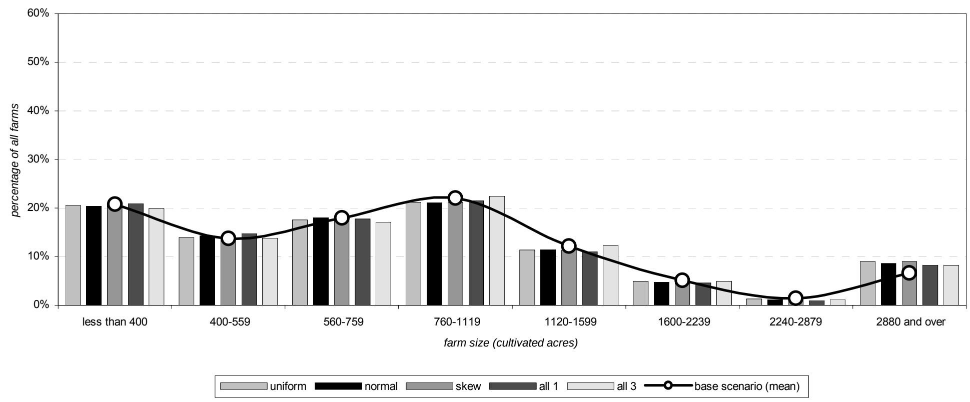

Figure 5.13: Simulation Results (zero transfer scenario) - Distribution of Farm Size (year 40)

5.2.3 The Land Market

The effects on the land markets of the package of stabilization programs and ad-hoc payments are measured by comparing farmland values and the proportion of land under a lease agreement for both the base and zero transfer scenarios. The effect of government transfers on farmland values are reported as either a premium or discount over the base scenario values based on mean values over five year periods (figure 5.14). Prior to the 1986-1990 (year 26-30), government transfers do not result in either a significant premium or discount in the farmland market.

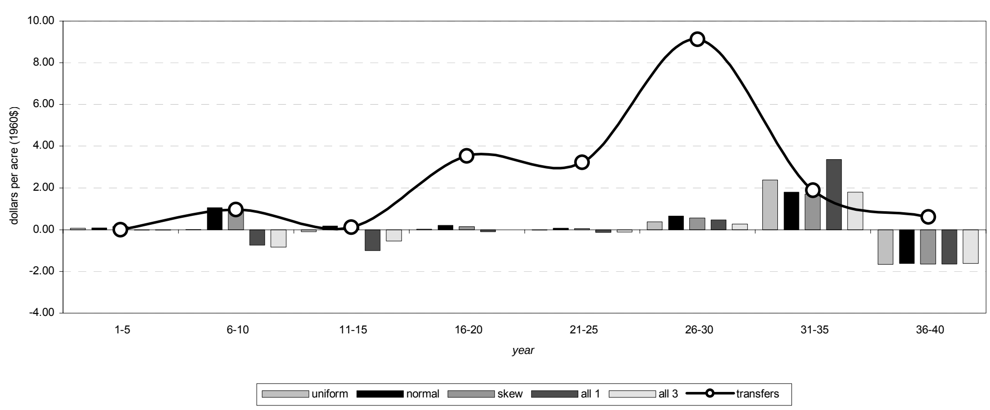

Figure 5.14: Simulation Results (zero transfer scenario) - Net Transfer Payments and Land Premiums

Over the 1986-1990 period, farmland values are estimated to be at a $0.27 - $0.65 per cultivated acre premium over the base scenario values. Farmland continues to be valued at a premium ($1.70 - $3.30) over

760-1119 acres; 21.19-22.43% (22.06%), 1120-1599 acres; 11.10-12.29% (12.18%), 1600-2239 acres; 4.61-4.95% (5.15%), 2240-2879 acres; 0.97-1.35% (1.42%).

the base scenario during the 1991-1995 (year 31-35). During the final five year time period (year 36-40) land values are on average discounted over the base scenario by between $1.62 - $1.66 per cultivated acre.

Like the other structural characteristics, land tenure under zero transfer does not show significant divergence from the base scenario prior to year 27 (figure 5.15). Under zero transfer, the proportion of farmland under a lease agreement increases both earlier and more rapidly than the base scenario.

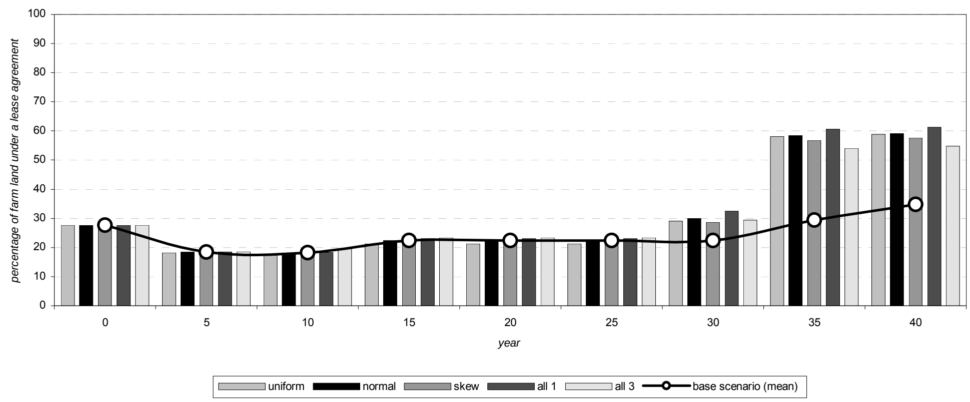

Figure 5.15: Simulation Results (zero transfers scenario) - Proportion of Land under Lease Agreement

Over the 1987-1991 (year 27-31) period, the proportion of farm land under lease agreement increases at an annualized rate of 7.26 - 10.55% (vs. 0.12% in the mean base scenario). Under the base scenario, the number of lease agreements increases rapidly at a mean annual rate of 7.41%, but this is substantially less than the 20.43 - 23.60% annual growth estimated within the zero transfer scenario. Unlike the base case (3.79% mean) the prevalence of lease agreements increases only marginally (0.16 - 0.23%) for the duration of the simulation.

5.2.4 Farm Debt

As might be expected, the level of farm debt per acre does not show any significant variation from the base scenario prior to 1987 (figure 5.16). Under the zero transfer scenario, farm debt per acre does not reach the same peak level ($31.27 mean in 1991) as the base scenario and is estimated to $3.91 - $4.64 per acre less in 1990 (iteration 30). Farm debt per acre remains less than the base scenario after year 35 ($4.54 - $5.47

per acre), but converges to the base scenario level after year 40, with debt levels only marginally less per acre ($0.32 - $1.68).

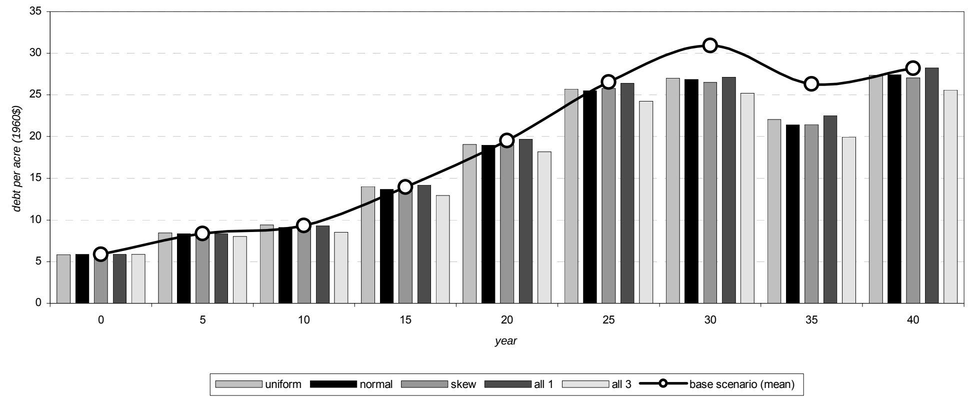

Figure 5.16: Simulation Results (zero transfers scenario) - Farm Debt per Cultivated Acre

5.3 Model Drivers and Structural Change

The forces driving structural adjustment in the farm sector have generated significant debate and research within the field of agricultural and regional economics. While a significant amount of time and effort has been exerted on understanding the drivers of structural change, no general consensus has been achieved and a strikingly varied number of explanations and policy recommendations exist. A number of the driving forces of structural change outlined in chapter two are revisited next and briefly discussed within the context of the simulation framework. The drivers on which I will focus include 1) entrepreneurial behaviour and farm household expectations, 2) cost of production and productive efficiency, 3) path dependency and the farm life-cycle and 4) government transfers.

5.3.1 Entrepreneurial Behaviour and Farm Household Expectations

Underlying differences between farm household management strategies and styles has been suggested as a potential driver of structural change. It seems that the fundamental and intrinsic difference between management styles could have a measurable impact on the behaviour of individual farm households. While it was implicitly assumed that all farm households held the same fundamental goal about farm growth, they were classified into three management classes. This affected their behaviour in both land markets and crop mix selection. It is interesting to note that even though the simulations were set up so that all farm households had an inherent desire for farm growth, a significantly skewed distribution of farm size still emerged. While growth aspirations seem to be a necessary condition for an increase in farm size, land and credit resource constraints appear to play a much greater role at the individual farm level. The simulation results suggest that while the probability of a given farm exiting increases marginally with an increased level of risk aversion (table 5.2), resource and personal constraints play a more significant role.

The farm household labour input is an important factor determining the sustainability of the farm operation. A number of studies (Kislev and Peterson 1982; Goetz and Debertin 2001; Huffman and Evenson 2001) focused on the mobility of labour between farm and non-farm industries, along with the relative wage rate as important factors in the consolidation of farm assets. While this model framework ignores the labour market, the researcher found that the farm household's required return to labour is an important factor for the sustainability of individual farms and the aggregate regional structure. This is due to the fact that within the simulation, farm households are assumed to require a minimum annual living/management withdrawal from the farm operation. And the farm household's withdrawal is assumed to increase as the farm grows, as a result of the increased labour and management costs of operating on a larger scale. As a direct result, the total annual living/management withdrawal increases with farm size, but the required withdrawal per acre decreases with farm size (figure 5.17).

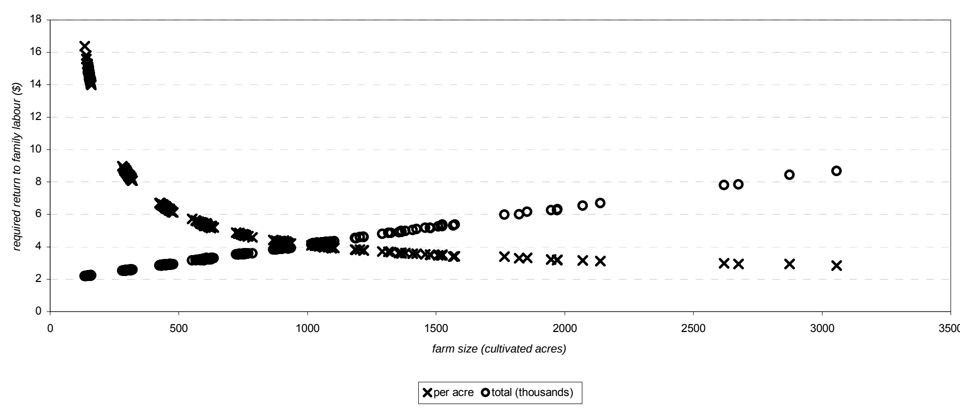

Figure 5.17: Farm Agent Family Labour Costs

Farms operating on a small scale of production (less than 400 cultivated acres) require relatively high crop revenues to meet their annual withdrawal requirements. As a direct result of a high per acre return to family labour inputs, small farms are unable to withstand prolonged periods of low crop revenue. The inability of small farms in the simulation to consistently meet their annual withdrawal requirements is an important driver of structural change. Periods of low crop revenue result in the transfer of farm assets from small farms to larger operators who are able to meet their withdrawal requirements more consistently.

5.3.2 Cost of Production and Productive Efficiency

The changing structure of the farming sector is often thought to be the consequence of heterogeneous production efficiency among farms. The argument is that the most efficient farms acquire the assets of the less efficient producers, resulting in the consolidation of farm assets among the most efficient (Harrington and Reinsel 1995). Economists often acknowledge the relationship between economies of scale in purchasing inputs and marketing output and the consolidation of farm assets. It is often assumed that by expanding the area of production, the farm can benefit from economies of scale. While economies of scale in purchase inputs and marketing products may in fact be a sufficient condition to explain the structural shifts that have occurred, this study finds they are not necessary. This series of simulations explicitly assumes that farms operate with constant economies of scale with respect to non-labour costs of producing a crop (before transportation costs). When non-family labour is included, small farms actually have a cost advantage over large farms that are required to hire a greater level of non-family labour (figure 5.18).

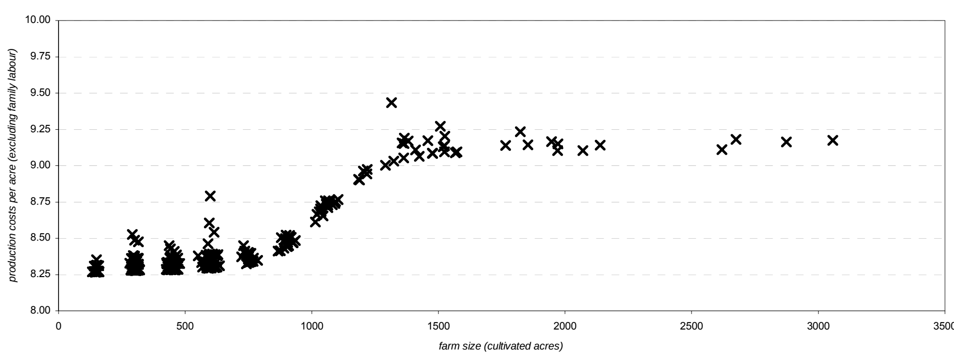

Figure 5.18: Farm Agent Production Costs (excluding Family Labour)

The observed variation in production costs in the simulation among farms of the same size (figure 5.18) is the direct result of transportation costs. Farms with land spread out over a larger area have higher production costs, attributable to the incremental cost of moving crop production to the farmstead to be marketed. In general, larger farms are found to have a higher transportation cost per acre compared to small farms. Larger farms must farm land at a greater distance from their farmstead than small farms.

Ultimately, it can be concluded that the distribution of farm size that emerged in the simulations under the assumption of constant (decreasing) returns to scale for crop production undermines the traditional argument that economies of scale and producer efficiency are the only significant drivers in the observed consolidation of farm assets in this chapter.

5.3.3 Path Dependency and the Farm Life-Cycle

Structural change at the individual farm level is affected not only by the economic situation faced by individual farms, but also the interdependencies between farms (Balmann 1999). Farms wanting to expand are faced with the reality of competing with neighbouring farms for the control of limited resources. As a direct result, the spatial location of a farm may be a key factor in the long term sustainability of a given farm. The ability of any farm to expand is directly related to the availability of land within a reasonable distance from an existing land base. In addition, the ability of a given farm to acquire an available plot of land is affected by the actions of other farms within the same general geographic region. This situation is defined by Balmann (1999) in the farming context as path dependence, whereby, in a stochastic world, the current state of a system is directly dependent on historic actions and events. Given the results obtained here, in particular the consistency with regard to changes in distributions of management classes and the marginal variation between exit rates among the three management classes considered, factors other than varied risk preference must be important in determining the growth path of individual farms.

In this light, it is found that one of the most important factors in determining the sustainability of a given farm appears to be its initial land base. The mean initial size (cultivated acres) of farms that discontinued production during the simulation period was found to be approximately one-half that of the mean initial size of all farms. Based on simulation results, the study found that farms which declined over a five year period managed, on average, a total land base of only 76% (std dev = 28%) of the average for the region. In direct contrast, those farms that expanded over a given 5 year interval operated on a scale that was significantly greater, with a mean size advantage of approximately 450% (std dev =270%) over the regional average. Thus while farms operating on a large scale have significant advantages in the land market, this is not a guarantee of growth in a given time period. Farms that experienced zero growth over a given five year interval had an average scale of production of 94% (std dev = 91%) of the regional average, with approximately 7% of this group operating on a scale at least three times the regional average.

On average, a farm operation in the simulation with an initial land holding greater than the regional mean is significantly more likely to realize their growth aspirations. In addition, due to the spreading of the family/management withdrawal over a greater number of acres, the large farm is better able to withstand periods of reduced crop revenues. Finally, while operating on a large scale effectively reduces the risk of continued operation, it is not a guarantee of success. On average 4% of the total exits over the simulated period were by farms operating within the largest size classification measured (see table 5.4).

5.3.4 Government Transfers and Regional Structure

Government policies and support programs are commonly discussed concurrently with issues of structural change and the resulting reallocation of resources (Fulton et al 1989). In fact it is prudent that policy makers understand the relationship between stabilization/support programs and structural change. Goddard et al (1993) identified public programs as one the eight factors affecting structural change in the agriculture sector. In the simulations, it is found that prior to the rapid decline in farm land values throughout the late 1980's, simulated government transfers aimed at stabilizing the income of farm agents played no significant role in the evolution of regional farm structure. In fact, prior to the mid 1980's, no significant difference is found between the base and zero transfer scenarios.

The period that overlaps the late 1980's and early 1990's is characterized in the simulations by a rapid downward trend in farmland values and an increased rate of consolidation. Fulton et al's (1989) supposition that without the significant transfers farmers received from stabilization and support programs, the rate of decline in the farm population would have been significantly greater is supported by the results obtained in this research. A significant level of divergence occurs for the observed farm number trends between the base and zero transfer scenarios. It is also interesting to note that while the number of farms declined at a significantly faster rate in the zero transfer scenario, the distribution of farms by cultivated acres at the end of the simulation did not differ significantly from the base scenario. Thus, the ability of governments to alter the rate of structural change must not be dismissed. But, whether the increased rate of consolidation that would surely have occurred in the absence of direct government transfers in Canadian agriculture would have led to a more productive agricultural sector in the long run is still open for debate.

5.4 Summary

The application of an agent-based framework to study structural change at the regional level allows the issue to be analyzed with a focus on the decisions made at the individual or farm level. The drivers of structural change discussed in chapter two all focus on the incentives and decisions of farms at this level. As a result, a study of structural change at the regional level is well suited for the application of this new modeling paradigm.

The simulation environment was designed to attempt to replicate the actual structural shifts that occurred in Saskatchewan agriculture over the period from1960 to 2000, under the assumption that technology and farming practices remained constant throughout the simulated period. To do this, five distributions of farms among three primary managerial classes are simulated. Relatively consistent results are obtained from all distributions. All five distributions closely replicate the trend of declining farm numbers and increasing farm size. The distribution of farms by number of acres managed generated by all our simulations closely replicate the actual distribution observed over the time period. In addition, the simulations replicate the sharp increase in farmland values during the 1970's as well as the subsequent decline throughout the 1980's, albeit with a time lag. The decline in the proportion of farmland managed under a lease agreement that occurred between the 1961 and 1966 census periods, as well as the later trend of increased farm land owned by non-farming individuals, is correctly replicated by all simulations.

A second simulation scenario was run to estimate the structural evolution of the region under the assumption of zero government stabilization transfers. By comparing the results estimated for both the base and zero transfer scenarios, the net results of the package of stabilization programs and ad-hoc payments can be estimated. The package of stabilization programs and payments do not show a significant impact on the regional structural characteristics in the simulation prior to 1987. However, significant divergence begins to emerge between the base and zero transfer scenarios in the post 1987 time period. In the absence of government transfers to grain operations, the simulated number of farms is significantly reduced by the end of the simulation compared to the base scenario. This result is consistent with the earlier findings of Fulton et al (1989) and the post 1985 impact of government farm programs. As a direct result, the mean area cultivated by individual farm agents increased substantially without transfers, but interestingly, we found that the distribution of farms does not vary significantly from the base scenario. I conclude that while transfers have certainly had an effect on the agricultural sector, the consequences of transfers have not necessarily transpired as originally intended by policymakers. The simulations show that transfers tend to have minor impacts on the small farm, and instead have contributed to the growth of the larger farms in the region.

In the sense described in Chapter 3, a number of key insights about agriculture in this region emerged from this research. For example, while economies of scale in purchasing inputs and marketing production may work in reality for larger producers, they are not necessary to replicate the structural shifts that occurred over the period studied. Instead, the ability of the farm agent to fully employ their labour and management input emerges as an important factor in the sustainability and growth of an individual farm. Those farm agents that were unable to expand their farm to a sustainable scale are found to be incapable of consistently meeting their annual living/management withdrawal requirements during periods of depressed crop returns. Finally, it appears that opportunity and luck often play a more important role than individual ability. In fact, it is possible that a less productive farm agent may succeed while a more productive farm agent may fail, and this is due to the immobility of farmland.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

6.1 Summary

The Saskatchewan farm sector continues to be a dynamic industry, faced with the reality of significant structural adjustment. While structural adjustment can result in more efficient production, the consolidation of farm assets among a decreasing number of farm operations also has a significant impact on the population base of rural regions. Structural change continues to one of the most important issues for both the farm sector and rural regions, but the process and its underlying drivers continue to be weakly understood. Farm characteristics like operator age, land tenure, farm type, farm size, debt level and motivation vary widely across Canada (Statistics Canada), and it is clear that these factors are key drivers of farm industry structure. Given the economic difficulties now inherent in rural Saskatchewan, there has never been a more important time to improve our understanding of the structural dynamics of the farming sector.

The desire to understand farming and farm structure has led to the development of a number of well documented farm-level models, including FLIPSIM in the U.S. and CRAM (Canadian Regional Agricultural Model) in Canada (Klein and Narayanan 1992). To their credit, the previous generation of farm-level models were not designed to capture complexity or emergent behaviour, yet complexity is arguably one of the most important characteristics of any dynamic economic system. It is argued that adaptive farm models based on individual interactions are necessary to help unravel the intricate interplay among natural and economic developments in the farming sector. Part of the motivation for this research is the realization that farming behaviour possesses characteristics of a complex system in the computational sense, and complex systems often generate large-scale behaviour that cannot readily be predicted by simply examining components of the system. It is the potential to reveal emergent farm level behaviour that distinguishes new generation behavioural farm models from the older generation of atomistic farm level policy models.

The rigidity that generally characterizes previous farm-level modeling methodologies limited their ability to incorporate and predict structural change. Through the application of an agent-based simulation framework, the potential of incorporating structural change as an endogenous factor to the farm model can be realized. The developed model of an idealized agricultural region in the Canadian province of Saskatchewan was then evaluated on its ability to replicate historic structural shifts for the period 1960-2000.

6.2 Conclusions

Agent-based methods exhibit a strong potential to overcome one of the major limitations of current farm level modeling frameworks. The highly heterogeneous nature of agricultural production is in sharp contrast to the general assumption of a homogenous population required for traditional farm-level models. The highly flexible nature of agent-based models, due to their focus on a building system from the 'ground up', allows the researcher/policymaker an improved understanding of the interplay between aggregate level behaviour and patterns and the underlying characteristics of the individuals that constitute the system of study.

I offer that the demonstrated ability of this agent based model of a rural region, characterized by annual crop production, to mirror the actual structural adjustments that played out over the study period can be at a minimum regarded as a strong "proof of concept". The research and model development discussed in this thesis offers the potential to provide a fundamental framework for future research focused on structural dynamics and policy analysis.

While significant discussion in agricultural and regional economics has been concerned with the importance of producer efficiency and economies of scale, the results generated here suggest that this is not a necessary condition for structural change. The ability of a farm household to fully employ their labour resource is found to play a far greater role in determining the continued existence of a given farm than the ability to produce a crop efficiently. As a result, I find that a less efficient producer[70] operating on a large scale is more likely to remain in the industry than a small, yet more efficient producer. While a non-farm labour market for the farm household's excess labour was not explicitly considered here, I offer that it is highly unlikely that its inclusion would significantly alter the simulation results.

Varied management styles were also incorporated into the simulations, and they only marginally improved the mean survival rate of the least risk averse relative to the most risk averse farm households. While, all else constant, the least risk averse farm household has a greater probability of achieving their aspiration for farm growth, simple opportunity and timing appear to play a more significant role in the long term profitability and sustainability of a given farm.

6.3 Limitations

Agent-based methodologies provide the agricultural researcher with a highly flexible and adaptable toolkit for studying complex physical/social interactions and networks. One of the greatest challenges faced when developing the simulation model utilized in this thesis, a challenge faced by all who undertake this type of research, was trying to find an appropriate balance between model realism and tractability. It is a relatively simple task to highlight a number of areas in which the model abstracts significantly from reality. But given the multitude of layers of reality that could potentially be incorporated within the basic framework, the selection of those key drivers and structures to incorporate was a time consuming and difficult process. This study is not unique in making this assessment about agent based simulations (see Robinson 2003).

It is not the purpose of this section to outline all areas where the simulation model abstracts from the target system modeled, but rather to highlight those key areas the reader needs to be aware of when interpreting the results and conclusions presented. First, due to the nature of the methodology selected and the individual and behavioural level data requirements, data availability proved to be a significant limitation. While great care was taken to track down the required data/parameter values, in a number of situations an approximation of the actual value was the only viable option. Significant care has been taken to ensure that all approximations are clearly stated and explained. Second, due to the long standing tradition in economic research to focus on the outcome of individual behaviour (i.e. individuals behave "as if" they are

[70] Producer efficiency refers to cost of producing a crop excluding the family/management withdrawal.

profit/utility maximizing), rather than the underlying behavioural rules being utilized, the modeling of sound behavioural rules is a rather daunting task.

Thus, while the level of realism incorporated into the model is an appropriate abstraction from the true system, three key areas where the model differs significantly from reality should be noted. The first significant variation deals with the assumption of constant 1960's farm practices and technology, as well as de-trended crop yields and market prices. Secondly, a lack of an explicit non-farm labour market and potential the use of off-farm income to subsidize the farm operation likely resulted in an under-estimation of the number of small farms in the final simulated distribution. The relatively small proportion of farm agents who retire due to old age without a new generation continuing to operate the farm also suggests that a more realistic algorithm is required to model the intergenerational transfer of farm assets.

6.4 Suggestions for Further Study

One of the underlying objectives of this research was to develop a relatively simple framework on which to base future farming model developments. Of primary importance in this framework is the conceptualization of the farmland markets. While the farmland market mechanisms incorporated within the model are justifiable and defendable, it would be interesting to test alternative specifications against the results obtained in this study. Ultimately, due to the flexibility of the toolkit utilized, it is possible to outline an almost unlimited number of potential model extensions and improvements. In an attempt to sidestep listing multiple potential model extension, it should be noted that new developments will need to be driven by the research problems tackled in the future. It is not the coding of model constructs that will limit future research[71], but rather the ability to understand what to code.

In order to improve future research utilizing the agent based model framework, regardless of the issue to be studied, research needs to be focused on two inter-related aspects. There is a stark need to develop an improved understanding of the behaviour of individuals and the varied behavioural patterns that exist among the relevant agent populations. This is an area economists have traditionally ignored and would benefit substantially form an interdisciplinary approach to future research. Economists interested in

[71] While the author may be nearing the upper limits of his programming skills, it is assumed that more skilled programmers are available.

utilizing agent-based methodologies may need to seek out collaborators from other academic disciplines. In particular for this research considerable efforts need to be made to collect and compile survey data describing the managerial and behavioural characteristics of farm decision making units. By improving our understanding of the underlying behavioural and managerial decisions of the farm household, a number of the limitations outlined in the previous section can be overcome.

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APPENDIX A

List of Variable Names

Farm agent (k = 1,…,K)

GR	Gross revenue of farm agent k
PF	Productivity factor of farm agent k
K	Crop acres managed (owned or leased) by farm agent k
P	Number of plots managed by farm agent k
VC	Variable production expenses of farm agent k
TE	Transportation expense of farm agent k
Travel	Unit cost of transporting farm equipment of farm agent k
Truck	Unit cost of transporting farm production of farm agent k
FC	Fixed production expenses of farm agent k
$C^{replace}$	Machinery and building replacement expense of farm agent k
DS	Principal and Interest expense of farm agent k
*L*P	Land leasing expense of farm agent k
WD	Family living and managerial withdrawal of farm agent k
NCI	Net investment in additional equipment and facilities of farm agent k
NCF^{PRODN}	Net cash flow from crop production of farm agent k
NCF^{INVEST}	Equipment and facilities sale proceeds less purchases of farm agent k
$NCF^{FINANCE}$	New borrowing less principal and interest payments of farm agent k
NCF	Net cash flow of farm agent k
Gov	Net government transfers received by farm agent k
PM	Production Margin (per acre) of farm agent k
rent	Residual return to Land of farm agent k
Q	Mean soil productivity of all plots managed by farm agent k
Bid_{xy}	Bid of farm agent k on $plot_{xy}$
Φ	Land valuation / risk aversion parameter of farm agent k
C	Stock of machinery and buildings of farm agent k
W	Non-family labour costs per cultivated acre
Λ	Minimum cash balance per acre
NCF_k^{WGSA}	Net cash flow from WGSA of farm agent k
$Payment_k^{WGSA}$	Gross payment from WGSA to farm agent k
$Levy_k^{WGSA}$	Total levy paid under WGSA by farm agent k
$tonnes_k$	Total grain production by volume of farm agent k
$Payment_k^{SCGP}$	Gross payment from SCGP to farm agent k
A_i	Total acreage of crop i for farm agent k
$Payment_k^{DAP}$	Gross payment from DAP to farm agent k
NCF_k^{GRIP}	Net cash flow from GRIP of farm agent k
$Payment_k^{GRIP}$	Gross payment from GRIP to farm agent k
$Indem_k^{GRIP}$	Total indemnity paid under GRIP by farm agent k
$prodn_i$	Total production by volume of crop i by farm agent k
TWD^{NISA}	Maximum triggered withdrawal from NISA account for farm agent k
NI^{NISA}	Net income of farm agent k for NISA program
$\overline{NI}^{NISA}$	3- year moving average net income of farm agent k for NISA program
Fund 1	Balance of NISA account, fund 1, of farm agent k
Fund 2	Balance of NISA account, fund 2, of farm agent k
WD^{NISA}	Actual withdrawal from NISA account of farm agent k
$Payment_k^{AIDA}$	Gross payment from AIDA to farm agent k
NI^{AIDA}	Net income of farm agent k for AIDA program
$\overline{NI}^{AIDA}$	3-year moving average net income of farm agent k for AIDA program

$Plot_{xy}$ (x = x co-ordinate, y = y co-ordinate)

Q_{xy}	Fixed soil productivity value of $plot_{xy}$
R_{xy}	Annual growing conditions value of $plot_{xy}$
PI_{xy}	Productivity index of $plot_{xy}$
K_{xy}	Crop acres of $plot_{xy}$
TE_{xy}	Transportation expense of $plot_{xy}$
D_{xy}	Distance between $plot_{xy}$ and managing farm agent's farmstead
V_{xy}	Volume of total crop production on $plot_{xy}$
$rent_{xy}$	Rent value for $plot_{xy}$
V_N	Value of $plot_{xy}$ (per acre) at period N
$Price_{xy}$	Final price paid for $plot_{xy}$ by purchasing/leasing farm agent

Crop$_i$ (i = 1,…,I)

GR_i	Gross revenue of crop i
$\overline{P}_i$	Mean price of crop i
$\overline{Y}_i$	Mean yield of crop i
A_i	Area (acres) of crop i
V_i	Volume (bushels) of crop i
VC_i^{acre}	Variable production costs per acre of crop i
VC_i^{volume}	Variable production costs per volume of crop i
a_i	proportion of farm agent k's crop acres allotted to production of crop i
b_i	Maximum proportion of farm agent k's crop acres allotted to production of crop i
$\prod_i$	mean crop return (GR - VC) of crop i
$\sigma^2_{\Pi_i}$	crop return variance of crop i
VC_i	Variable production costs per acre of crop i
$\hat{R}_i$	Relative variable production costs of crop i
$\hat{P}_i$	*E*stimated price of crop i, 1961-1964
$\hat{Y}_i$	Estimated yield of crop i, 1961-1964
$Subs_i^{acre}$	Per acre subsidy rate of crop i (SCGP)
$Indem\%_i$	Indemnity rate if crop i

Global Parameters

WD^{min}	Minimum family and managerial withdrawal value
β	Marginal propensity to consume from gross revenue
CR	Equipment and facilities stock requirement per crop acre
d	Rate of economic depreciation of equipment and facility stocks
r	Interest rate
n	number of years (planning period)
P^L	Price of farm land per acre (for $Q_{xy} = 1$)
Ψ	Land valuation parameter of non-farming land owner
λ	expectation weighting
α	proportion of farm equity debt financed when farm is transferred
σ	labour cost adjustment factor to additional cultivated acre of land managed
Ω	proportion of total land purchase price that must be paid out of the cash account
$\overline{Bid}$	mean value of current land bids
$\overline{lease}$	mean lease rate
$\overline{VC}$	Mean variable cost per acre
CPE	Crop Production Expenditure, 1961-1964
$acres_i$	Estimated acreage of crop i, 1961-1964
$Seeded$	Seeded acres
$Payout^{WGSA}$	Total regional payout under WGSA
$PAYMENT\ 1$	Total regional payout under WGSA based on original trigger
$PAYMENT\ 2$	Total regional payout under WGSA based on second trigger
NGP	Net Grain Proceeds (WGSA)
$\overline{NGP}$	5-year moving average net grain proceeds (WGSA)
$NGPT$	Net Grain Proceeds per tonne
$\overline{NGPT}$	5-year moving average net grain proceeds (WGSA)
$Subs^{acre}$	Per acre subsidy rate (DAP)
$LTAY_i$	Long term average yield of crop i
$IMAP_i$	Indexed moving average price of crop i

APPENDIX B

Model Initial Values/Distributions

Name in Model	Name in Text	Description	Initial Value
yield-crop-1	$\overline{Y_i}$	mean wheat yield value	see Table 4.7
yield-crop-2	$\overline{Y_i}$	mean oats yield value	
yield-crop-3	$\overline{Y_i}$	mean barley yield value	
yield-crop-4	$\overline{Y_i}$	mean flaxseed yield value	
price-crop-1	$\overline{P_i}$	mean wheat price value	
price-crop-2	$\overline{P_i}$	mean oats price value	
price-crop-3	$\overline{P_i}$	mean barley price value	
price-crop-4	$\overline{P_i}$	mean flaxseed price value	
subsidy-ASA-crop-1		annual per bushel subsidy 1960-1975 (wheat)	see Table B.1
subsidy-ASA-crop-2		annual per bushel subsidy 1960-1975 (oats)	
subsidy-ASA-crop-3		annual per bushel subsidy 1960-1975 (barley)	
subsidy-ASA-crop-4		annual per bushel subsidy 1960-1975 (flaxseed)	
per-acre-vc-1	VC_i^{acre}	variable production expenses per acre (wheat)	$8.00
per-acre-vc-2	VC_i^{acre}	variable production expenses per acre (oats)	$6.80
per-acre-vc-3	VC_i^{acre}	variable production expenses per acre (barley)	$7.60
per-acre-vc-4	VC_i^{acre}	variable production expenses per acre (flaxseed)	$8.40
per-acre-vc-5	VC_i^{acre}	variable production expenses per acre (summerfallow)	$5.00
per-bu-vc-1	VC_i^{volume}	variable production expenses per bushel (wheat)	na
per-bu-vc-2	VC_i^{volume}	variable production expenses per bushel (oats)	na
per-bu-vc-3	VC_i^{volume}	variable production expenses per bushel (barley)	na
per-bu-vc-4	VC_i^{volume}	variable production expenses per bushel (flaxseed)	na
crop-1-list		historic production margin 1955-1959 (wheat)	(24.66, 23.75, 15.04, 13.12, 8.60)
crop-2-list		historic production margins 1955-1959 (oats)	(16.88, 15.20, 10.84, 7.24, 11.8)
crop-3-list		historic production margins 1955-1959 (barley)	(19.40, 18.80, 10.64, 7.73, 10.90)
crop-4-list		historic production margins 1955-1959 (flaxseed)	(25.20, 30.30, 6.72, 14.82, 9.96)
travel-adjustment	Travel	cost of transporting machinery between plots ($/mile)	na
trucking-rate	Truck	cost of transporting grain ($/tonne-mile)	$0.10
min-family-withdrawal	WD^{min}	mimimum level of cash withdrawn from farm for family and managerial expenses	$1,882
value embedded in code	β	marginal propensity to consume from gross farm revenue	0.068
value embedded in code	σ	labour cost adjustment for an additional cultivated acre of land managed	0.834

Name in Model	Name in Text	Description	Initial Value
lease-term		number of years a lease agreement is in effect	uniform distribution 1-5
rain	R_{xy}	annual growing conditions index	~N(1,0.02)
quality	Q_{xy}	fixed growing conditions index	~N(1,0.02)
K-acres	K_{xy}	crop acres on a given plot	~N(150,5.5), max 160
depreciation-rate	d	rate of economic depreciation of farm equipment and facilities	10%
interest-rate	r	rate of interest for borrowing capital	6%
expectation-weight	λ	weight of most recent observation in expectation formation	0.10
preretirement-age		age at which farm agents stop buying land	55
value embedded in code		proportion of debt to assets at which a farm is deemed insolvent	0.90
retirement-tendency-55-59		probability of a farm agent retiring each year when age is between 55 and 59	0.06
retirement-tendency-60-64		probability of a farm agent retiring each year when age is between 60 and 64	0.10
retirement-tendency-65-69		probability of a farm agent retiring each year when age is between 65 and 69	0.18
retirement-tendency-70-over		probability of a farm agent retiring each year when age is 70 or above	0.3
maximum-age		age at which farm agents are forced to retire	80
transfer-sell-rate	α	proportion of equity that must be refinanced when farm transferred	0.40
D-A-ratio		maximum ratio of debt to assets a farm agent can have in order to obtain credit	0.40
discount-value-1	Φ	land valuation factor of farm agents with attitude = 1	0.95
discount-value-2	Φ	land valuation factor of farm agents with attitude = 2	0.90
discount-value-3	Φ	land valuation factor of farm agents with attitude = 3	0.85
discount-value-NA	Ψ	land valuation factor of non-farming land owners	1.00
capital-per-acre	CR	value of machinery and buildings required per acre for crop production	$15
downpayment		land and equipment down payment requirement	25%
equipment-amor-period		amortization period for equipment purchases	5
land-amor-period		amortization period for land purchases	20
average-rent		intial mean lease payment value	$2.25/cultivated acre
land-price	P^L	initila mean land value	$30/cultivated acre
plots-leased-percent		proportion of plots leased	27.62%
farms		number of farmagents	310
age		age of farm agents	see Table 4.1
debt		initial value of farm agent debt	see Table 4.4

Name in Model	Name in Text	Description	Initial Value
cash		initial value of farm agent cash	$15/cultivated acre
plots-owned		intial number of plots owned by a farm agent	see Table 4.1 and Table 4.2
plots-leased		intitial number of plots leased by a farm agent	
crop-mix		proportion of total cultivated acres alloacted to each crop (wheat, oats, barley, flaxseed)	expanding (0.55, 0, 0, 0.05) cautious (0.55, 0, 0.05, 0) lifestyle (0.55, 0.05, 0, 0) farms 55+ (0.55, 0.05, 0, 0)
generation		current generation managing the farm	1
expected-return-to-land	Rent	initial expectation of residual return to land	$8.25/cultivated acre
expected-production-volume		initial expectation of crop production volume	0.58 tonnes/cultivate acre
attitude		managerial group	see Table 4.6

Table B.1: Agricultural Stabilization Act Crop Subsidies

	per bushel payment			
year	wheat	oats	barley	flaxseed
1960	0.00	0.00	0.00	0.00
1961	0.00	0.00	0.00	0.00
1962	0.00	0.00	0.00	0.00
1963	0.00	0.00	0.00	0.00
1964	0.00	0.00	0.00	0.00
1965	0.00	0.00	0.00	0.00
1966	0.00	0.00	0.10	0.00
1967	0.20	0.12	0.11	0.00
1968	0.14	0.03	0.13	0.08
1969	0.00	0.00	0.00	0.30
1970	0.00	0.00	0.44	0.05
1971	0.00	0.00	0.00	0.00
1972	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.00	0.00
1974	0.02	0.00	0.00	0.66
1975	0.66	0.20	0.25	0.99

Source: Author based on data from Saskatchewan Agriculture, Food and Rural Revitalization (2004)

APPENDIX C

NetLogo© Source Code

```
globals
 [
 yield-crop-1                     ;; Array of wheat yields
 yield-crop-2                     ;; Array of oat yields
 yield-crop-3                     ;; Array of barley yields
 yield-crop-4                     ;; Array of flax yields
 price-crop-1                     ;; Array of wheat prices
 price-crop-2                     ;; Array of oat yields
 price-crop-3                     ;; Array of barley yields
 price-crop-4                     ;; Array of flax yields
 land-price                       ;; mean purchase price of land (adjusted for quality) sold in most recent auction
 bids                             ;; list of successful bids in current auction
 average-rent                     ;; mean lease rate of all plots currently leased
 land-unit-sold                   ;; tracking variable, holds ID value of the last plot sold
 land-unit-rented                 ;; tracking variable, holds ID value of the last plot leased
 year                             ;; tracks current simulation  time period
 plots-leased-percent             ;; number of plots leased divided by total number of plots
 plots-not-in-crop-prodn-percent  ;; number of plots not currently managed divided by total number of plots
 farms                            ;; total number of farm agents currently managing a minimum of 1 plot
 crop-1-rank                      ;; used in crop mix selection algorithm to track relative rank of wheat production
 crop-2-rank                      ;; used in crop mix selection algorithm to track relative rank of oat production
 crop-3-rank                      ;; used in crop mix selection algorithm to track relative rank of barley production
 crop-4-rank                      ;; used in crop mix selection algorithm to track relative rank of flax production
 crop-1-value                     ;; used in crop mix selection algorithm to rank crops (value for wheat)
 crop-2-value                     ;; used in crop mix selection algorithm to rank crops (value for oat)
 crop-3-value                     ;; used in crop mix selection algorithm to rank crops (value for barley)
 crop-4-value                     ;; used in crop mix selection algorithm to rank crops (value for flax)
 crop-1-list                      ;; holds five years of data on gross return (wheat)
 crop-2-list                      ;; holds five years of data on gross return (oats)
 crop-3-list                      ;; holds five years of data on gross return (barley)
 crop-4-list                      ;; holds five years of data on gross return (flax)
 mix                              ;; variable use in crop mix selection algorithm
 sold                             ;; number of plots sold in the current auction period
 bankrupt                         ;; total number of farm agents exiting due to bankruptcy condition
 cashflow                         ;; total number of farm agents exiting due to cash-flow condition
 oldage                           ;; total number of farm agents exiting, without an intergenerational transfer
 transfers                        ;; total number of farm agents exiting, with an intergenerational transfer
 tracking-number                  ;; variable used in GRIP algorithms
 equip-purchase-adjustment        ;; deduction from residual return to land and labour to cover the cost of equipment
 IMAP-1                           ;; GRIP indexed moving average price (wheat)
 IMAP-2                           ;; GRIP indexed moving average price (oats)
 IMAP-3                           ;; GRIP indexed moving average price (barley)
 IMAP-4                           ;; GRIP indexed moving average price (flax)
 mean-bid                         ;; mean bid value of all farm agents, active in the first iteration of the land auction
 WGSA-NCF-MA                      ;; WGSA program net cash flow moving average
 WGSA-NCFPT-MA                    ;; WGSA program net cash flow per tonne moving average
 WGSA-total-payout                ;; WGSA program total payment to the region
 WGSA-total-levy                  ;; WGSA program total levy amount collected from the region
 susidy-ASA-crop-1                ;; ASA program subsidy value per bushel of wheat
 subsidy-ASA-crop-2               ;; ASA program subsidy value per bushel of oats
 subsidy-ASA-crop-3               ;; ASA program subsidy value per bushel of barley
 subsidy-ASA-crop-4               ;; ASA program subsidy value per bushel of flax
 ]

patches-own
 [
 quality                          ;; relative index value (0-1) of soil productivity
 rain                             ;; relative index value (0-1) of annual growing conditions
 annual-multiplier                ;; quality * rain
 farmer                           ;; ID number of farm agent managing plot
 renter                           ;; ID number of farm agent leasing plot
 owner                            ;; ID number of farm agent who owns plot
 k-acres                          ;; total number of acres suitable for crop production
 distance-to-farmstead            ;; distance between plot and farmstead of managing farm agent
 prodn-volume                     ;; total crop production of plot
```

```
  lease-payment                   ;; annual lease payment per k-acre
  lease-term                      ;; number of years remaining on current lease agreement
  patch-id                        ;; unique ID number for each plot
  for-sale?                       ;; TRUE if land is available for sale, else FALSE
  for-rent?                       ;; TRUE if land is available for lease, else FALSE
  ]

turtles-own
  [
  age                             ;; age of farm agent
  generation                      ;; family generation of farm agent
  crop-revenue                    ;; gross crop revenue of farm agent
  average-multiplier              ;; mean value of annual multiplier values of all plots managed by farm agent
  average-soil-quality            ;; mean value of quality values of all plots managed by farm agent
  crop-mix                        ;; list of proportion of crops relative to total k-acres of farm agent
  acres-total-crop                ;; summation of all crop acres from all managed plots
  acres-crop-1                    ;; total acres of wheat production
  acres-crop-2                    ;; total acres of oats production
  acres-crop-3                    ;; total acres of barley production
  acres-crop-4                    ;; total acres of flax production
  acres-crop-5                    ;; total acres of fallow
  prodn-crop-total                ;; summation of all crop production from all managed plots
  prodn-crop-1                    ;; total production volume of wheat
  prodn-crop-2                    ;; total production volume of oats
  prodn-crop-3                    ;; total production volume of barley
  prodn-crop-4                    ;; total production volume of flax
  variable-prodn-costs            ;; total variable costs for farm agent in current production period
  hired-labour                    ;; total cost of hired labour for farm agent in current production period
  travel-cost                     ;; total cost of traveling, moving machinery between plots
  trucking-cost                   ;; total cost of transporting crop production from plots to farmstead
  capital-replacement-charge      ;; total cost of equipment replacement (assumed to equal economic depreciation)
  debt-list                       ;; tracks each debt separately [payments remaining, annual payment, principal balance]
  debt                            ;; summation of individual principal balances of all outstanding debts
  debt-payment                    ;; summation of individual annual payments of all outstanding debts
  cash                            ;; residual asset account
  capital-value                   ;; value of farm equipment and facilities
  land-value                      ;; market value of all land owned by farm agent
  asset-value                     ;; summation of land-value, capital-value, cash and NISA account
  equity-value                    ;; asset-value less debt
  total-lease-payment             ;; summation of annual lease-payment of all plots leased by farm agent
  family-withdrawal               ;; managerial and operator annual withdrawal
  NCFBI                           ;; Net CashFlow Before Investment (cashflow prior to purchasing additional land)
  plots-owned                     ;; number of plots owned by farm agent
  plots-leased                    ;; number of plots leased by farm agent
  residual-to-land-labor          ;; annual residual return to land and labour of farm agent
  residual-to-land-labor-exp      ;; expected residual return to land and labour of farm agent
  expected-production-volume      ;; expectation of crop production on an acre of crop land
  current-plot-bid-on             ;; used in auctions to track plot interesting in purchasing, leasing
  attitude                        ;; managerial attitude of farm agent
  current-bid                     ;; used in auctions to track current bid value of farm agent
  years-neg-cash                  ;; tracks number of years since farm realized a net positive cashflow
  prodn-conv-factor               ;; used to convert bushels to tonnes
  transfers-received              ;; tracks value of annual transfer payments to farm agent
  WGSA-levy                       ;; annual levy paid to WGSA program by farm agent
  WGSA-levy-list                  ;; list of levies paid to WGSA program by farm agent in previous periods
  NISA-MA                         ;; NISA program list of historic farm returns over variable costs
  NISA-ENS                        ;; NISA program list of historic farm eligible net sales in previous periods
  NISA-fund-1                     ;; NISA program balance in NISA account fund 1
  NISA-fund-2                     ;; NISA program balance in NISA account fund 2
  NISA-deposit                    ;; NISA program cash deposit into NISA account by farm agent
  NISA-withdrawal                 ;; NISA program maximum triggered withdrawal
  SCGP-transfer                   ;; SCGP program transfers received by farm agent
  AIDA-MA                         ;; AIDA program list of historic farm returns over variable costs
  AIDA-payment                    ;; AIDA program payment received by farm agent
]

 breeds
  [farmers]                       ;; farm agents
```

```
--------------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------- INITIALIZATION PHASE CONTROL ----------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------

to initialization-phase-control

if "yes" = (user-choice
               "Have Output Files Been Initialized?"
               ["no" "yes"])
  [ setup ]

end

to setup

  ca
  clear-output
  create-plots
  initialize-farm-agents
  import-crop-arrays
  export-data
  show "initialization complete"

end

--------------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------- CREATE PLOTS ----------------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------

to create-plots

  assign-patch-id
  clear-land-tenure
  set-quality-and-cultivated-acres
  set land-price initial-land-price
  set average-rent initial-lease-rate

end

to assign-patch-id

  locals [counter]

  ask patches with [pxcor = screen-edge-x][set patch-id "border"]
  ask patches with [pycor = screen-edge-y][set patch-id "border"]

  set counter 1
  ask patches with [patch-id != "border"][without-interruption [set patch-id counter set counter counter + 1]]
  ask patches with [patch-id = "border"][set pcolor 7]

end

to clear-land-tenure

  ask patches [set owner "NA"
                 set farmer "NA"
                 set renter "NA"]

  ask patches with [patch-id != "border"]
               [set for-sale? true
                set for-rent? true]

end

to set-quality-and-cultivated-acres

  ask patches [set quality random-normal 1 0.05]
```

```
    diffuse quality 0.75
  ask patches [set quality precision quality 2]
  ask patches with [patch-id = "border"][set quality 0]

  ask patches [set k-acres random-normal 150 15]
    diffuse k-acres .75
  ask patches [set k-acres precision k-acres 0]
  ask patches with [patch-id = "border"][set k-acres 0]
  ask patches with [patch-id != "border"][if k-acres > 160 [set k-acres 160]]

end

------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------- CREATE FARM AGENTS -------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------------------------

to initialize-farm-agents

   create-farm-agents
   assign-farm-agent-attributes

end

to create-farm-agents

   create-farmers 310
   ask farmers [set color red]
   ask farmers [set heading random 360]
   ask farmers [fd random 1000]
   ask farmers [if any? other-turtles-here
              or patch-id-of patch-at 0 0 = "border" [ find-new-spot ]]
   ask farmers [set xcor pxcor-of patch-at 0 0]
   ask farmers [set ycor pycor-of patch-at 0 0]
   ask farmers [set owner-of (patch-at 0 0) who]
   ask farmers [set farmer-of(patch-at 0 0) who]
   ask patches with [patch-id != "border" and farmer != "NA"][set for-sale? false set for-rent? false]

end

to assign-farm-agent-attributes

   ask farmers [set generation 1]

   file-open "age profile.txt"
   ask farmers [set age file-read]
   file-close

   file-open "plots-owned.txt"
   ask farmers [set plots-owned file-read]
   file-close

   file-open "plots-leased.txt"
   ask farmers [set plots-leased file-read]
   file-close

   ask farmers [own rent]

   file-open "debt-list.txt"
   ask farmers [set debt-list file-read]
   file-close

   file-open "initial-cash-value.txt"
   ask farmers [set cash file-read]
   file-close

   ask farmers [set attitude 3]
   ask random-n-of attitude-2-initial farmers with [attitude = 3][set attitude 2]
   ask random-n-of attitude-1-initial farmers with [attitude = 3][set attitude 1]

   ask farmers with [attitude = 1][set crop-mix (list 0.55 0.0 0.0 0.05)]
```

```
  ask farmers with [attitude = 2][set crop-mix (list 0.55 0.0 0.05 0.0)]
  ask farmers with [attitude = 3][set crop-mix (list 0.55 0.05 0.0 0.0)]
  ask farmers [if age > preretirement-age [set crop-mix (list 0.55 0.05 0.0 0.0)]]

  file-open "residual-to-land-labor.txt"
  ask farmers [set residual-to-land-labor-exp file-read]
  file-close

  file-open "expected-crop-volume.txt"
  ask farmers [set expected-production-volume file-read]
  file-close

  ask farmers [set acres-total-crop sum values-from patches with [farmer = who-of myself][k-acres]]
  ask farmers [set capital-value (capital-per-acre * acres-total-crop)]
  ask farmers [ifelse debt-list != [] [set debt item 2 item 0 debt-list][set debt 0]]
  ask farmers [set cash 15 * acres-total-crop]

  farm-accounting-module

  set equip-purchase-adjustment precision(capital-per-acre *(interest-rate / (1 - (1 / (1 + interest-rate)^ 20))))2

  set WGSA-NCF-MA []
  set WGSA-NCFPT-MA []

  ask farmers [set NISA-MA []]
  ask farmers [set NISA-ENS []]
  ask farmers [set AIDA-MA []]
  ask farmers [set WGSA-levy-list []]

end

to find-new-spot

 fd random 1000
 if any? other-turtles-here
 or patch-id-of patch-at 0 0 = "border"[ find-new-spot]

end

to own

 if ((count patches with [owner = who-of myself])
      < plots-owned)[find-land]

end

to find-land

 without-interruption [ask min-one-of patches with [for-sale? = true][(abs(pxcor - xcor-of myself) + abs(pycor - ycor-of myself))]
    [set farmer who-of myself
     set owner who-of myself
     set distance-to-farmstead abs((pxcor - value-from turtle (farmer)[xcor]))+
                         abs((pycor - value-from turtle (farmer)[ycor]))
     set for-sale? false
     set for-rent? false
     set pcolor blue
     ]]

 if ((count patches with [owner = who-of myself])
   < plots-owned)[find-land]

end

to rent

 if ((count patches with [renter = who-of myself])
   < plots-leased)[find-land-lease]

end
```

```
to find-land-lease

  without-interruption [ask min-one-of patches with [for-rent? = true][(abs(pxcor - xcor-of myself) + abs(pycor - ycor-of myself))]

      [set farmer who-of myself
       set renter who-of myself
       set lease-term random 5 + 1
       set lease-payment (initial-lease-rate * quality)
       set distance-to-farmstead abs((pxcor - value-from turtle (farmer)[xcor]))+
                             abs((pycor - value-from turtle (farmer)[ycor]))
       set for-sale? false
       set for-rent? false
       set pcolor green
       ]]

  if ((count patches with [renter = who-of myself])
    < plots-leased)[find-land-lease]

end

--------------------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------- ASSIGN PARAMETERS ----------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------------

to import-crop-arrays

  file-open "yield crop 1.txt"
  set yield-crop-1 file-read
  file-close

  file-open "yield crop 2.txt"
  set yield-crop-2 file-read
  file-close

  file-open "yield crop 3.txt"
  set yield-crop-3 file-read
  file-close

  file-open "yield crop 4.txt"
  set yield-crop-4 file-read
  file-close

  import-price-arrays

  if ASA = true[import-price-support]

  file-open "crop-1-list.txt"
  set crop-1-list file-read
  file-close

  file-open "crop-2-list.txt"
  set crop-2-list file-read
  file-close

  file-open "crop-3-list.txt"
  set crop-3-list file-read
  file-close

  file-open "crop-4-list.txt"
  set crop-4-list file-read
  file-close

end
```

```
to import-price-arrays

  file-open "price crop 1.txt"
  set price-crop-1 file-read
  file-close

  file-open "price crop 2.txt"
  set price-crop-2 file-read
  file-close

  file-open "price crop 3.txt"
  set price-crop-3 file-read
  file-close

  file-open "price crop 4.txt"
  set price-crop-4 file-read
  file-close

end

to import-price-support

  file-open "subsidy-crop-1-ASA.txt"
  set subsidy-ASA-crop-1 file-read
  file-close

  file-open "subsidy-crop-2-ASA.txt"
  set subsidy-ASA-crop-2 file-read
  file-close

  file-open "subsidy-crop-3-ASA.txt"
  set subsidy-ASA-crop-3 file-read
  file-close

  file-open "subsidy-crop-4-ASA.txt"
  set subsidy-ASA-crop-4 file-read
  file-close

end

----------------------------------------------------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------- SIMULATION PHASE CONTROL --------------------------------------------------------
----------------------------------------------------------------------------------------------------------------------------------------------------------------

to simulation-phase

  set year year + 1
  crop-production-module
  farm-accounting-module
  expectation-formation-module
  adjust-crop-mix
  continue-farming-module?
  update-land-leases
  land-purchase-auction-module
  land-lease-auction-module
  ask farmers [capital-expenditure-module]
  ask farmers [set age age + 1]
  export-data
  ask farmers [set cash cash * 1.02]
  if year < simulation-length [simulation-phase]
  show "complete"

end
```

```
-------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------ CROP PRODUCTION MODULE ------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------------------------------------------

to crop-production-module

  simulate-crop-revenue
  simulate-variable-prodn-costs
  simulate-hired-labour-cost
  simulate-transport-cost
  simulate-capital-replacement-charge
  ask farmers [simulate-debt-servicing]
  simulate-lease-payments
  ask farmers [set transfers-received 0]
  if ASA   = true [simulate-ASA-transfer]
  if NISA  = true [simulate-NISA-transfer]
  if WGSA  = true [simulate-WGSA-transfer]
  if GRIP  = true [simulate-GRIP-transfer]
  if SCGP  = true [simulate-SCGP-transfer]
  if CCDAP = true [simulate-CCDAP-transfer]
  if AIDA  = true [simulate-AIDA-transfer]
  set-net-cash-flow-before-investment
  simulate-living-deductions

end

to simulate-crop-revenue

  ask patches [set rain random-normal 1 0.05]
    diffuse rain 0.75
      ask patches [set rain precision rain 2]
      ask patches with [patch-id = "border"][set rain 0]

  ask patches with [patch-id != "border"][set annual-multiplier rain * quality]
  ask farmers [set acres-total-crop sum values-from patches with [farmer = who-of myself][k-acres]]
  ask farmers [set average-multiplier (sum values-from patches with [farmer = who-of myself]
                [annual-multiplier * k-acres]) / acres-total-crop]
  ask farmers [set average-soil-quality (sum values-from patches with [farmer = who-of myself][quality * k-acres]) / acres-total-crop]
  ask farmers [set acres-crop-1 (item 0 crop-mix) * acres-total-crop
                set acres-crop-2 (item 1 crop-mix) * acres-total-crop
                set acres-crop-3 (item 2 crop-mix) * acres-total-crop
                set acres-crop-4 (item 3 crop-mix) * acres-total-crop
                set acres-crop-5 (1 - (sum crop-mix)) * acres-total-crop]

  ask farmers [set prodn-crop-1 acres-crop-1 * average-multiplier * (item (year) yield-crop-1)
               set prodn-crop-2 acres-crop-2 * average-multiplier * (item (year) yield-crop-2)
               set prodn-crop-3 acres-crop-3 * average-multiplier * (item (year) yield-crop-3)
               set prodn-crop-4 acres-crop-4 * average-multiplier * (item (year) yield-crop-4)
               set prodn-crop-total prodn-crop-1 + prodn-crop-2 + prodn-crop-3 + prodn-crop-4  ]

  ask farmers [set crop-revenue prodn-crop-1 * (item (year) price-crop-1)
               + prodn-crop-2 * (item (year) price-crop-2)
               + prodn-crop-3 * (item (year) price-crop-3)
               + prodn-crop-4 * (item (year) price-crop-4)]

  ask farmers [ask patches with [farmer = who-of myself]
              [set prodn-volume (annual-multiplier / average-multiplier-of myself)
                          * (prodn-crop-total-of myself / acres-total-crop-of myself) * k-acres]]

end
```

```
to simulate-variable-prodn-costs

  ask farmers [set variable-prodn-costs precision (
                                acres-crop-1 * per-acre-vc-1 + prodn-crop-1 * per-bu-vc-1
                              + acres-crop-2 * per-acre-vc-2 + prodn-crop-2 * per-bu-vc-2
                              + acres-crop-3 * per-acre-vc-3 + prodn-crop-3 * per-bu-vc-3
                              + acres-crop-4 * per-acre-vc-4 + prodn-crop-4 * per-bu-vc-4
                              + acres-crop-5 * per-acre-vc-5)0]

end

to simulate-hired-labour-cost

  ask farmers [set hired-labour precision (((0.8 / (1 + 14500 * exp (-0.009 * acres-total-crop))) + 0.03) * acres-total-crop)0]

end

to simulate-transport-cost

  ask farmers [set prodn-conv-factor (item 0 crop-mix * 36.7437
                            + item 1 crop-mix * 64.8418
                            + item 2 crop-mix * 45.9296
                            + item 3 crop-mix * 39.3683)
                            / 0.6 ]

  ask farmers [set travel-cost (sum values-from patches with [farmer = who-of myself][distance-to-farmstead]) * travel-adjustment]
  ask farmers [set trucking-cost precision (sum values-from patches with [farmer = who-of myself]
        [prodn-volume * distance-to-farmstead] * trucking-rate / prodn-conv-factor)0]

end

to simulate-capital-replacement-charge

  ask farmers [set capital-replacement-charge capital-value * depreciation-rate]

end

to simulate-debt-servicing

    locals [result
        result2
        result3
        list-index
       ]

  set result2 add debt-list
  set debt-payment result2

  set list-index 0
  foreach debt-list [
                      set debt-list replace-item list-index debt-list list (item 0 ? - 1) (item 1 ?)
                      set list-index list-index + 1]

  set debt-list filter [first ? != 0] debt-list
  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
  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]

  set result3 add2 debt-list
  set debt result3

 end
```

```
----------------------------------------------
---------- CALCULATORS --------------
----------------------------------------------

          to-report product [lst]
            locals[result]
            set result 1
            foreach lst [set result result * ?]
            report result
          end

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

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

to simulate-lease-payments

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

end

to set-net-cash-flow-before-investment

  ask farmers [set NCFBI  crop-revenue
                + transfers-received
                - NISA-deposit
                - variable-prodn-costs
                - hired-labour
                - travel-cost
                - trucking-cost
                - capital-replacement-charge
                - debt-payment
                - total-lease-payment]

end

to simulate-living-deductions

  ask farmers [set family-withdrawal min-family-withdrawal + 0.068 * crop-revenue + 125 * (plots-owned + plots-leased)]

  ask farmers [set NCFBI precision (NCFBI - family-withdrawal)0]

  ask farmers [if (NCFBI < 0 and NISA-withdrawal > 0) [make-NISA-withdrawal]]

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

  ask farmers [set NISA-fund-1 precision (NISA-fund-1 + NISA-deposit)0]
  ask farmers [set NISA-fund-2 precision (NISA-fund-2 + NISA-deposit)0]

  ask farmers [set cash precision(cash + NCFBI)0]

end
```

```
to make-NISA-withdrawal

  if NISA-withdrawal > (-1 * NCFBI)[set NISA-withdrawal (-1 * NCFBI)]
  set NISA-fund-1 precision (NISA-fund-1 - NISA-withdrawal)0
  if NISA-fund-1 < 0 [set NISA-fund-2 precision (NISA-fund-2 + NISA-fund-1)0 set NISA-fund-1 0]
  set NCFBI NCFBI + NISA-withdrawal

end

-----------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------- ASA POLICY -----------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------------

to simulate-ASA-transfer

  if (year < 17 and ASA = true)[

  ask farmers  [set transfers-received prodn-crop-1 * (item (year) subsidy-ASA-crop-1)
                             + prodn-crop-2 * (item (year) subsidy-ASA-crop-2)
                             + prodn-crop-3 * (item (year) subsidy-ASA-crop-3)
                             + prodn-crop-4 * (item (year) subsidy-ASA-crop-4)]]

end

-----------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------  WGSA POLICY ----------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------------------------------------

to simulate-WGSA-transfer

  ask farmers [set WGSA-levy 0]
  if (year >= 12 and year <= 16)[start-track-NCF]
  if (year >= 14 and year <= 16)[start-levy-list]
  if (year >= 17 and year <= 24)[WGSA-I]
  if (year >= 20 and year <= 24)[start-track-NCFPT]
  if (year >= 25 and year <= 30)[WGSA-II]

end

to start-track-NCF

  set WGSA-NCF-MA fput (precision((sum values-from farmers [crop-revenue - variable-prodn-costs]))0) WGSA-NCF-MA

end

to start-levy-list

  ask farmers [set WGSA-levy-list fput (precision (crop-revenue * 0.02)0) WGSA-levy-list]

end

to WGSA-I

  set WGSA-total-payout precision (max list (0)
                                (mean WGSA-NCF-MA - (sum values-from farmers [crop-revenue - variable-prodn-costs]))
                                )0

  set WGSA-NCF-MA fput (precision(sum values-from farmers [crop-revenue - variable-prodn-costs])0) WGSA-NCF-MA
  set WGSA-NCF-MA remove-item 5 WGSA-NCF-MA

  ask farmers [set WGSA-levy precision (0.02 * crop-revenue)0]
  ask farmers [set WGSA-levy-list fput WGSA-levy WGSA-levy-list]
  ask farmers [set WGSA-levy-list remove-item 3 WGSA-levy-list]

  set WGSA-total-levy sum values-from farmers [mean WGSA-levy-list]

  ask farmers [set transfers-received precision (((mean WGSA-levy-list / WGSA-total-levy) * WGSA-total-payout)- WGSA-levy)0]

end
```

```
to start-track-NCFPT

  set WGSA-NCFPT-MA fput (precision(sum values-from farmers [(crop-revenue - variable-prodn-costs)]
                          /(sum values-from farmers [prodn-crop-total]))2) WGSA-NCFPT-MA

end

to WGSA-II

  set WGSA-total-payout precision (max (list (0)
                                  (mean WGSA-NCF-MA - (sum values-from farmers [crop-revenue - variable-prodn-costs]))
                                  ((mean WGSA-NCFPT-MA * (sum values-from farmers [prodn-crop-total]))
                                    - (sum values-from farmers [crop-revenue - variable-prodn-costs])))
                                  )0

  set WGSA-NCF-MA fput (precision(sum values-from farmers [crop-revenue - variable-prodn-costs])0) WGSA-NCF-MA
  set WGSA-NCF-MA remove-item 5 WGSA-NCF-MA

  set WGSA-NCFPT-MA fput (precision(sum values-from farmers [(crop-revenue - variable-prodn-costs)]
                          /(sum values-from farmers [prodn-crop-total]))2) WGSA-NCFPT-MA
  set WGSA-NCFPT-MA remove-item 5 WGSA-NCFPT-MA

  ask farmers [set WGSA-levy precision (0.02 * crop-revenue)0]
  ask farmers [set WGSA-levy-list fput WGSA-levy WGSA-levy-list]
  ask farmers [set WGSA-levy-list remove-item 3 WGSA-levy-list]

  set WGSA-total-levy sum values-from farmers [mean WGSA-levy-list]

  ask farmers [set transfers-received precision (((mean WGSA-levy-list / WGSA-total-levy) * WGSA-total-payout)- WGSA-levy)0]

end

--------------------------------------------------------------------------------------------------------------------------------------------------------
--------------------------------------------------------------------- GRIP POLICY -----------------------------------------------------------------
--------------------------------------------------------------------------------------------------------------------------------------------------------

to simulate-GRIP-transfer

  if (year >= 31 and year <= 32)[calculate-GRIP-transfer]

end

to calculate-GRIP-transfer

  set-IMAPs
  if year = 31 [GRIP-transfer-1]
  if year = 32 [GRIP-transfer-2]

end

to set-IMAPs

  set IMAP-1 0
  set tracking-number 3
  set-IMAP-1
  set IMAP-2 0
  set tracking-number 3
  set-IMAP-2
  set IMAP-3 0
  set tracking-number 3
  set-IMAP-3
  set IMAP-4 0
  set tracking-number 3
  set-IMAP-4

end
```

```
to set-IMAP-1

  set IMAP-1 IMAP-1 + item (year - tracking-number) price-crop-1
  set tracking-number tracking-number + 1
  ifelse tracking-number <= 17 [set-IMAP-1][set IMAP-1 IMAP-1 / 15]

end

to set-IMAP-2

  set IMAP-2 IMAP-2 + item (year - tracking-number) price-crop-2
  set tracking-number tracking-number + 1
  ifelse tracking-number <= 17 [set-IMAP-2][set IMAP-2 IMAP-2 / 15]

end

to set-IMAP-3

  set IMAP-3 IMAP-3 + item (year - tracking-number) price-crop-3
  set tracking-number tracking-number + 1
  ifelse tracking-number <= 17 [set-IMAP-3][set IMAP-3 IMAP-3 / 15]

end

to set-IMAP-4

  set IMAP-4 IMAP-4 + item (year - tracking-number) price-crop-4
  set tracking-number tracking-number + 1
  ifelse tracking-number <= 17 [set-IMAP-4][set IMAP-4 IMAP-4 / 15]

end

to GRIP-transfer-1

  ask farmers [set transfers-received transfers-received +
          (max list (0) ((IMAP-1 * 21.3 * average-soil-quality * acres-crop-1) - (prodn-crop-1 * item (year) price-crop-1)))
         +(max list (0) ((IMAP-2 * 38.4 * average-soil-quality * acres-crop-2) - (prodn-crop-2 * item (year) price-crop-2)))
         +(max list (0) ((IMAP-3 * 33.3 * average-soil-quality * acres-crop-3) - (prodn-crop-3 * item (year) price-crop-3)))
         +(max list (0) ((IMAP-4 * 9.90  * average-soil-quality * acres-crop-4) - (prodn-crop-4 * item (year) price-crop-4)))
                ]
  ask farmers [set transfers-received precision (transfers-received - (((IMAP-1 * 21.3 * 0.1855 * average-soil-quality * acres-crop-1)
                                      +(IMAP-2 * 38.4 * 0.1126 * average-soil-quality * acres-crop-2)
                                      +(IMAP-3 * 33.3 * 0.1651 * average-soil-quality * acres-crop-3)
                                      +(IMAP-4 * 9.9  * 0.1842 * average-soil-quality * acres-crop-4))
                                      * 1 / 3))0]

end

to GRIP-transfer-2

  locals [per-acre-transfer per-acre-premium]

  set per-acre-transfer (((sum values-from farmers [acres-crop-1] * 21.3 * (IMAP-1 - item (year) price-crop-1))
              +(sum values-from farmers [acres-crop-2] * 38.4 * (IMAP-2 - item (year) price-crop-2))
              +(sum values-from farmers [acres-crop-3] * 33.3 * (IMAP-3 - item (year) price-crop-3))
              +(sum values-from farmers [acres-crop-4] *  9.9 * (IMAP-4 - item (year) price-crop-4)))
             / (sum values-from farmers [acres-total-crop - acres-crop-5]))

  set per-acre-premium (((sum values-from farmers [acres-crop-1] * 21.3 * IMAP-1 * 0.1855)
             +(sum values-from farmers [acres-crop-2] * 38.4 * IMAP-2 * 0.1126)
             +(sum values-from farmers [acres-crop-3] * 33.3 * IMAP-3 * 0.1651)
             +(sum values-from farmers [acres-crop-4] *  9.9 * IMAP-4 * 0.1842))
             /(sum values-from farmers [acres-total-crop - acres-crop-5]))

  ask farmers [if per-acre-transfer > 0 [set transfers-received precision (transfers-received +
                                    ((acres-crop-1 + acres-crop-2 + acres-crop-3 + acres-crop-4)
                                    * average-soil-quality * (per-acre-transfer - per-acre-premium)))0]]

end
```

```
------------------------------------------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------ SCGP POLICY ------------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------------------------------

to simulate-SCGP-transfer

  ask farmers [set SCGP-transfer 0]
  if (year = 26)[SCGP-I]
  if (year = 27)[SCGP-II]

end

to SCGP-I

  ask farmers [set SCGP-transfer precision ((acres-crop-1 * 21.3 * 0.11)
                                    + (acres-crop-2 * 38.4 * 0.04)
                                    + (acres-crop-3 * 33.3 * 0.06)
                                    + (acres-crop-4 * 9.90 * 0.11))0]
  ask farmers [if SCGP-transfer > 5500 [set SCGP-transfer 5500]]
  ask farmers [set cash precision (cash + SCGP-transfer)0]
  ask farmers [set transfers-received precision (transfers-received + SCGP-transfer)0]

end

to SCGP-II

  SCGP-I

end

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------------------------------------------------------------------ CCDAP POLICY -----------------------------------------------------------------
------------------------------------------------------------------------------------------------------------------------------------------------------

to simulate-CCDAP-transfer

  if year = 26 [ask farmers [set transfers-received transfers-received + 3.3 * acres-total-crop * 0.6
                        set cash cash + 3.3 * acres-total-crop * 0.6]]

  if year = 28 [ask farmers [set transfers-received transfers-received + 8.8 * acres-total-crop * 0.6
                        set cash cash + 8.8 * acres-total-crop * 0.6]]

end

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------------------------------------------------------------------ NISA POLICY ------------------------------------------------------------------
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to simulate-NISA-transfer

  if (year >= 28 and year <= 30)[start-track-NISA]
  if (year >= 31 and year <= 41)[NISA-transfer]

end

to start-track-NISA

  ask farmers [set NISA-MA fput (precision (crop-revenue - variable-prodn-costs)0) NISA-MA]
  ask farmers [set NISA-ENS fput (precision (crop-revenue)0) NISA-ENS]

end

to NISA-transfer

  ask farmers [ifelse (NISA-fund-1 + NISA-fund-2) < ((mean NISA-ENS) * 1.5)
                              [set NISA-deposit 0.03 * crop-revenue][set NISA-deposit 0]]
  ask farmers [set NISA-fund-1 precision (NISA-fund-1 * (1 + 0.5 * interest-rate + 0.03))0]
  ask farmers [set NISA-fund-2 precision (NISA-fund-2 * (1 + 0.5 * interest-rate))0]
  ask farmers [set NISA-withdrawal precision (min list (mean NISA-MA - (crop-revenue - variable-prodn-costs))
              (NISA-fund-1 + NISA-fund-2))0]
```

```
  ask farmers [if NISA-withdrawal < 0 [set NISA-withdrawal 0]]
  ask farmers [set NISA-MA fput (precision(crop-revenue - variable-prodn-costs)0)NISA-MA]
  ask farmers [set NISA-MA remove-item 3 NISA-MA]
  ask farmers [set NISA-ENS fput (precision(crop-revenue)0) NISA-ENS]
  ask farmers [set NISA-ENS remove-item 3 NISA-ENS]

end

-----------------------------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------- AIDA POLICY --------------------------------------------------------------------
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to simulate-AIDA-transfer

   if (year >= 35 and year <= 37)[start-track-AIDA]
   if (year >= 38 and year <= 40)[AIDA-transfer]

end

to start-track-AIDA

  ask farmers [set AIDA-MA fput (precision (crop-revenue - variable-prodn-costs)0) AIDA-MA]

end

to AIDA-transfer

  ask farmers [set AIDA-payment (( 0.7 * mean AIDA-MA) - (crop-revenue - variable-prodn-costs))]
  ask farmers [if AIDA-payment < 0 [set AIDA-payment 0]]
  ask farmers [set cash cash + AIDA-payment]
  ask farmers [set transfers-received transfers-received + AIDA-payment]
  ask farmers [set AIDA-MA fput (precision (crop-revenue - variable-prodn-costs)0) AIDA-MA]
  ask farmers [set AIDA-MA remove-item 3 AIDA-MA]

end

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---------------------------------------------------- FARM ACCOUNTING MODULE -------------------------------------------------------------
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 ;; NOTES  i.   net cash flow before investment calculated in crop production section
 ;;             ii.  debt values updated in crop production section
 ;;            iii.  total cultivated acres updated in crop production section
 ;;            iv.  capital value updates in capital investment section


to farm-accounting-module

  ask farmers [determine-land-market-value]
  ask farmers [refinance-loans?]
  ask farmers [determine-asset-value]
  ask farmers [determine-equity-value]
  ask farmers [determine-land-tenure-state]

end

to determine-land-market-value

  set land-value precision((sum values-from patches with [owner = who-of myself ][k-acres * quality]) * land-price)0

end

to refinance-loans?

  locals [payment]

  if debt > (0.75 * (land-value + capital-value))
     [set cash cash - (debt - 0.75 * (land-value + capital-value))
      set payment precision((0.75 * (land-value + capital-value)) * ((interest-rate) / ( 1 - ( 1 / ((1 + interest-rate)^ 20)))))2
      set debt-list []
```

```
    set debt-list fput(list 20 payment (precision (0.75 * (land-value + capital-value))0))debt-list
    update-debt]

end

to determine-asset-value

  set asset-value precision( land-value + capital-value + cash + NISA-fund-1 + NISA-fund-2)0

end

to determine-equity-value

  set equity-value precision (asset-value - debt)0

end

to determine-land-tenure-state

   set plots-leased (count patches with [renter = who-of myself and lease-term != 0])
   set plots-owned (count patches with [owner = who-of myself])

end


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---------------------------------------------------------------EXPECTATION FORMATION ----------------------------------------------------------
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;; NOTES  i.   crop revenue is adjusted to represent soil quality of 1
;;        ii.  travel and trucking costs are removed (will be adjusted for when farmers place bids)
;;        iii. lease-payments and land debt payments are also removed because they are part of the return to land

to expectation-formation-module

  ask farmers [set residual-to-land-labor precision
               (((crop-revenue / average-soil-quality)
                 - variable-prodn-costs
                 - capital-replacement-charge
                 - (0.068 * crop-revenue)
                 - (125 * (plots-leased + plots-owned)))
                 / acres-total-crop)2]

  ask farmers [ifelse residual-to-land-labor >= residual-to-land-labor-exp
              [set residual-to-land-labor-exp (residual-to-land-labor-exp * (1 - expectation-weight)
                                  + (expectation-weight * residual-to-land-labor))]
              [set residual-to-land-labor-exp (residual-to-land-labor-exp * (1 - (1 * expectation-weight))
                                  + ((1 * expectation-weight) * residual-to-land-labor))]]

  ask farmers [set expected-production-volume precision
               ((expected-production-volume * (1 - expectation-weight))  +
                (prodn-crop-total / average-soil-quality / acres-total-crop / prodn-conv-factor)* expectation-weight)0]

end

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---------------------------------------------------  MANAGERIAL ADJUSTMENT MODULE ---------------------------------------------------
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to adjust-crop-mix

  expanding-farms-crop-mix-adjustment
  cautious-farms-crop-mix-adjustment
  lifestyle-farms-crop-mix-adjustment
  set-crop-lists

end
```

```
to expanding-farms-crop-mix-adjustment

  set-crop-value-expanding
  rank-crops
  set-crop-mix
  ask farmers with [attitude = 1 and age <= preretirement-age][set crop-mix mix]

end

to cautious-farms-crop-mix-adjustment

  set-crop-value-cautious
  rank-crops
  set-crop-mix
  ask farmers with [attitude = 2 and age <= preretirement-age][set crop-mix mix]

end

to lifestyle-farms-crop-mix-adjustment

  set-crop-value-lifestyle
  rank-crops
  set-crop-mix
  ask farmers with [attitude = 3 or age > preretirement-age][set crop-mix mix]

end

to set-crop-lists

  set crop-1-list remove-item 0 crop-1-list
  set crop-1-list lput (item (year) yield-crop-1 * item (year) price-crop-1
                - (per-acre-vc-1 + per-bu-vc-1 * item (year) yield-crop-1)) crop-1-list

  set crop-2-list remove-item 0 crop-2-list
  set crop-2-list lput (item (year) yield-crop-2 * item (year) price-crop-2
                - (per-acre-vc-2 + per-bu-vc-2 * item (year) yield-crop-2)) crop-2-list

  set crop-3-list remove-item 0 crop-3-list
  set crop-3-list lput (item (year) yield-crop-3 * item (year) price-crop-3
                - (per-acre-vc-3 + per-bu-vc-3 * item (year) yield-crop-3)) crop-3-list

  set crop-4-list remove-item 0 crop-4-list
  set crop-4-list lput (item (year) yield-crop-4 * item (year) price-crop-4
                - (per-acre-vc-4 + per-bu-vc-4 * item (year) yield-crop-4)) crop-4-list

end

to set-crop-value-expanding

  set crop-1-value ((mean crop-1-list) - (0.5 * (1 - discount-value-1) * (variance crop-1-list)))
  set crop-2-value ((mean crop-2-list) - (0.5 * (1 - discount-value-1) * (variance crop-2-list)))
  set crop-3-value ((mean crop-3-list) - (0.5 * (1 - discount-value-1) * (variance crop-3-list)))
  set crop-4-value ((mean crop-4-list) - (0.5 * (1 - discount-value-1) * (variance crop-4-list)))

end

to set-crop-value-cautious

  set crop-1-value ((mean crop-1-list) - (0.5 * (1 - discount-value-2) * (variance crop-1-list)))
  set crop-2-value ((mean crop-2-list) - (0.5 * (1 - discount-value-2) * (variance crop-2-list)))
  set crop-3-value ((mean crop-3-list) - (0.5 * (1 - discount-value-2) * (variance crop-3-list)))
  set crop-4-value ((mean crop-4-list) - (0.5 * (1 - discount-value-2) * (variance crop-4-list)))

end
```

```
to set-crop-value-lifestyle

  set crop-1-value ((mean crop-1-list) - (0.5 * (1 - discount-value-3) * (variance crop-1-list)))
  set crop-2-value ((mean crop-2-list) - (0.5 * (1 - discount-value-3) * (variance crop-2-list)))
  set crop-3-value ((mean crop-3-list) - (0.5 * (1 - discount-value-3) * (variance crop-3-list)))
  set crop-4-value ((mean crop-4-list) - (0.5 * (1 - discount-value-3) * (variance crop-4-list)))

end

to rank-crops

  set crop-1-rank 4
  set crop-2-rank 4
  set crop-3-rank 4
  set crop-4-rank 4

  if crop-1-value > crop-2-value [set crop-1-rank crop-1-rank - 1]
  if crop-1-value > crop-3-value [set crop-1-rank crop-1-rank - 1]
  if crop-1-value > crop-4-value [set crop-1-rank crop-1-rank - 1]

  if crop-2-value > crop-1-value [set crop-2-rank crop-2-rank - 1]
  if crop-2-value > crop-3-value [set crop-2-rank crop-2-rank - 1]
  if crop-2-value > crop-4-value [set crop-2-rank crop-2-rank - 1]

  if crop-3-value > crop-1-value [set crop-3-rank crop-3-rank - 1]
  if crop-3-value > crop-2-value [set crop-3-rank crop-3-rank - 1]
  if crop-3-value > crop-4-value [set crop-3-rank crop-3-rank - 1]

  if crop-4-value > crop-1-value [set crop-4-rank crop-4-rank - 1]
  if crop-4-value > crop-2-value [set crop-4-rank crop-4-rank - 1]
  if crop-4-value > crop-3-value [set crop-4-rank crop-4-rank - 1]


end

to set-crop-mix

  locals [list-acres max-acres]

  set mix [0 0 0 0]

  if crop-1-rank = 1 [set mix replace-item 0 mix 0.55]
  if crop-2-rank = 1 [set mix replace-item 1 mix 0.10]
  if crop-3-rank = 1 [set mix replace-item 2 mix 0.10]
  if crop-4-rank = 1 [set mix replace-item 3 mix 0.05]

  if crop-1-rank = 2 [set list-acres [0.55 0]
                    set list-acres replace-item 1 list-acres (precision (0.6 - (sum mix))2)
                    set mix replace-item 0 mix (min list-acres)]

  if crop-2-rank = 2 [set list-acres [0.10 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 1 mix (min list-acres)]

  if crop-3-rank = 2 [set list-acres [0.10 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 2 mix (min list-acres)]

  if crop-4-rank = 2 [set list-acres [0.05 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 3 mix (min list-acres)]

  if crop-1-rank = 3 [set list-acres [0.55 0]
                    set list-acres replace-item 1 list-acres (precision (0.6 - (sum mix))2)
                    set mix replace-item 0 mix (min list-acres)]

  if crop-2-rank = 3 [set list-acres [0.10 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 1 mix (min list-acres)]
```

```
  if crop-3-rank = 3 [set list-acres [0.10 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 2 mix (min list-acres)]

  if crop-4-rank = 3 [set list-acres [0.05 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 3 mix (min list-acres)]

  if crop-1-rank = 4 [set list-acres [0.55 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 0 mix (min list-acres)]

  if crop-2-rank = 4 [set list-acres [0.10 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 1 mix (min list-acres)]

  if crop-3-rank = 4 [set list-acres [0.10 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 2 mix (min list-acres)]

  if crop-4-rank = 4 [set list-acres [0.05 0]
                    set list-acres replace-item 1 list-acres (precision(0.6 - (sum mix))2)
                    set mix replace-item 3 mix (min list-acres)]

end



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------------------------------------------------------- CONTINUE FARMING MODULE?-----------------------------------------------------------
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to continue-farming-module?

  exit-industry

end

to exit-industry

  ask farmers [without-interruption[if years-neg-cash >=  5 [
    ask patches with [owner = who-of myself][
         set owner "NA" set renter "NA" set farmer "NA" set for-rent? true]
    ask patches with [renter = who-of myself][
         set renter "NA" set farmer "NA" set for-rent? true]
         set cashflow cashflow + 1
            die]]]

  ask farmers [without-interruption[if (debt) > (0.9 * asset-value)[
    ask patches with [owner = who-of myself][
         set owner "NA"  set renter "NA" set farmer "NA" set for-sale? true]
    ask patches with [renter = who-of myself][
         set renter "NA" set farmer "NA" set for-rent? true]
         set bankrupt bankrupt + 1
             die]]]

  ask farmers with [(age >= 55) and (age < 60)][if (random 100 < retirement-tendency-55-59 * 100)  [retire]]
  ask farmers with [(age >= 60) and (age < 65)][if (random 100 < retirement-tendency-60-64 * 100)  [retire]]
  ask farmers with [(age >= 65) and (age < 70)][if (random 100 < retirement-tendency-65-69 * 100)  [retire]]
  ask farmers with [age >= 70]               [if (random 100 < retirement-tendency-70-over * 100)[retire]]
  ask farmers with [age >= 80]                                                      [retire]

end
```

```
to retire

  locals [payment]

  ifelse (equity-value / asset-value > 0.6)
          [set age age - 30
           set transfers transfers + 1
           set preretirement-age 55
           set generation generation + 1
           set payment precision((transfer-sell-rate * equity-value) * ((interest-rate) / ( 1 - ( 1 / ((1 + interest-rate)^ 20)))))2
           set debt-list fput (list 20 payment (precision (transfer-sell-rate * equity-value)0)) debt-list
           update-debt
           determine-asset-value
           determine-equity-value]

           [ask patches with [owner = who-of myself]
              [set owner "NA" set renter "NA" set farmer "NA" set for-rent? true]
            ask patches with [renter = who-of myself]
              [set renter "NA" set farmer "NA" set for-rent? true]
              set oldage oldage + 1
                die]

end

to update-debt

  locals [result
           result2
           result3
           list-index
          ]

     set result2 add debt-list
     set debt-payment result2

  set list-index 0
  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]

  set result3 add2 debt-list
  set debt result3

end

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-------------------------------------------------------------- RE-NEW LAND LEASE MODULE -------------------------------------------------------
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to update-land-leases

  ask patches with [lease-term != 0 and patch-id != "border"][set lease-term lease-term - 1]
  ask patches with [lease-term = 0 and renter != "NA" and patch-id != "border"][set for-sale? true]
  ask farmers [set current-plot-bid-on "NA"]
  ask farmers [without-interruption [ ifelse (((cash > 10 * acres-total-crop + 150 * land-price * downpayment))
                  and ((debt / asset-value) < D-A-ratio)
                  and ((lease-payment + debt-payment + min-family-withdrawal) < (residual-to-land-labor-exp * acres-total-crop))
                  and (age <= preretirement-age) )

                     [select-land]
                     [set current-bid 0]]]

  set mean-bid (mean values-from farmers with [current-plot-bid-on != "NA"] [current-bid])

  ask farmers with [current-plot-bid-on != "NA"]
                  [set current-bid precision(((current-bid * mean-bid)^ 0.5) *
                  (value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]))2]

  ask farmers [set acres-total-crop acres-total-crop - 150]
```

```
 ask patches with [lease-term = 0 and renter != "NA" and patch-id != "border"][without-interruption [ask turtle (farmer)
                   [set current-plot-bid-on (patch-id-of myself) set-bid-rent
           set current-bid precision((current-bid * (mean-bid / (((1 - (1 / (1 + interest-rate))^ 20)) / interest-rate)))^ 0.5 *
                           (value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]))2

 ifelse (current-bid / interest-rate) >= ((((mean-bid * land-price)^ 0.5) * quality) / landlord-discount)
          [set lease-term-of myself 5
           set lease-payment-of myself current-bid
           set for-sale?-of myself false]
          [set renter-of myself "NA"
           set farmer-of myself "NA"]]]]

 ask farmers [set acres-total-crop sum values-from patches with [farmer = who-of myself][k-acres]
           set plots-leased count patches with [renter = who-of myself]]
 ask farmers [capital-expenditure-module]

 set average-rent mean values-from patches with [renter != "NA" and patch-id != "border"][lease-payment * quality]

end

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-------------------------------------------------------- LAND PURCHASE AUCTION MODULE ---------------------------------------------------
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to land-purchase-auction-module

 set bids []
 check-if-land-available-for-sale
 ifelse (bids != []) [set land-price mean bids]
                   [set land-price (average-rent * (((1 - (1 / (1 + interest-rate))^ 20)) / interest-rate))]

end

to check-if-land-available-for-sale

 ask farmers [set current-plot-bid-on "NA"]
 if (count patches with [for-sale? = true]) > 0 [screen-farmers]


end

to screen-farmers

 ask farmers [without-interruption [ ifelse ((cash > (10 * acres-total-crop + 150 * land-price * downpayment))
                   and ((debt / asset-value) < D-A-ratio)
                   and ((lease-payment + debt-payment + min-family-withdrawal) < (residual-to-land-labor-exp * acres-total-crop))
                   and (age <= preretirement-age) )

                      [select-land]
                      [set current-bid 0]]]

 set mean-bid (mean values-from farmers with [current-plot-bid-on != "NA"][current-bid])

 ask farmers with [current-plot-bid-on != "NA"]
                         [set current-bid precision((current-bid * (mean-bid)) ^ 0.5 *
                         (value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]))0]

 if (count farmers with [current-bid > 0] > 0)[auction-land]

end
```

```
to select-land

  set current-plot-bid-on value-from (max-one-of patches with [for-sale? = true]
       [((abs(pxcor - xcor-of myself) + abs(pycor - ycor-of myself)) * -1
       *((trucking-rate * expected-production-volume-of myself) + travel-adjustment / k-acres))
       + residual-to-land-labor-exp-of myself * quality])
       [patch-id]

  set-bid

end

to set-bid

  locals [expected-value-plot]

  set expected-value-plot ((abs((value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][pxcor]) - xcor)) +
                        (abs((value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][pycor]) - ycor)))
                       * ((trucking-rate * expected-production-volume) + (travel-adjustment
                       / (value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][k-acres]))) * -1
                       + value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]
                          * residual-to-land-labor-exp

  if attitude = 1 [set current-bid precision (((expected-value-plot - equip-purchase-adjustment -
                                         (min-family-withdrawal / (acres-total-crop + 150)) -
                                        ((0.8 / (1 + 14500 * exp (-0.009 * (acres-total-crop + 150)))) + 0.03))
                                        *  (discount-value-1 ))
                                        * (((1 - (1 / (1 + interest-rate))^ 20)) / interest-rate)) 2]

  if attitude = 2 [set current-bid precision (((expected-value-plot - equip-purchase-adjustment -
                                         (min-family-withdrawal / (acres-total-crop + 150)) -
                                        ((0.8 / (1 + 14500 * exp (-0.009 * (acres-total-crop + 150)))) + 0.03))
                                        *  (discount-value-2 ))
                                        * (((1 - (1 / (1 + interest-rate))^ 20)) / interest-rate)) 2]
  if attitude = 3 [set current-bid precision (((expected-value-plot - equip-purchase-adjustment -
                                         (min-family-withdrawal / (acres-total-crop + 150)) -
                                        ((0.8 / (1 + 14500 * exp (-0.009 * (acres-total-crop + 150)))) + 0.03))
                                        *  (discount-value-3 ))
                                        * (((1 - (1 / (1 + interest-rate))^ 20)) / interest-rate)) 2]

  if current-bid < 0 [set current-bid 0]

end

to auction-land

  locals [payment total-bid adjusted-bid counter]

  ask max-one-of farmers [current-bid][
                        set adjusted-bid (current-bid / value-from
                       (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality])
                        if adjusted-bid >= ((landlord-discount) * (mean-bid * (average-rent / interest-rate))^ 0.5)[
                        set owner-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself]) who
                        set farmer-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself]) who
                        set renter-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself]) "NA"
                        set total-bid (current-bid * k-acres-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself]))
                        set land-unit-sold current-plot-bid-on
                        set payment precision(((1 - downpayment) * total-bid)* (interest-rate / (1 - (1 / (1 + interest-rate)^ 20))))0
                        set cash precision(cash - (downpayment * total-bid))0
                        set debt-list fput (list 20 payment (precision (0.75 * total-bid)0)) debt-list
                        set for-sale?-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])false
                        set for-rent?-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])false
                        set pcolor-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])blue
                        set debt precision (debt + (0.75 * total-bid))0
                        set debt-payment precision(debt-payment + payment)0
                        set plots-owned plots-owned + 1
                        set acres-total-crop acres-total-crop +
                           value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][k-acres]
                        set distance-to-farmstead-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself])
                           abs((xcor - value-from random-one-of patches with[patch-id = current-plot-bid-on-of myself][pxcor]))+
```

```
                abs((ycor - value-from random-one-of patches with[patch-id = current-plot-bid-on-of myself][pycor]))

              set land-value land-value + total-bid
              set sold sold + 1
              capital-expenditure-module
              determine-asset-value
              determine-equity-value

  set bids lput adjusted-bid bids ]]

  ifelse adjusted-bid >= ((landlord-discount) * (mean-bid * (average-rent / interest-rate))^ 0.5)
              [check-if-more-land-available-for-sale]

              [set bids lput ((landlord-discount) * (mean-bid * (average-rent / interest-rate))^ 0.5) bids]

end

to check-if-more-land-available-for-sale

  if (count patches with [for-sale? = true]) > 0 [screen-farmers-bidding-on-sold-land]

end

to screen-farmers-bidding-on-sold-land

  ask farmers with [current-plot-bid-on = land-unit-sold][without-interruption
       [ifelse (    ((cash > 10 * acres-total-crop + 150 * land-price * downpayment))
            and ((debt / asset-value) < D-A-ratio)
            and ((lease-payment + debt-payment + min-family-withdrawal) < (residual-to-land-labor-exp * acres-total-crop))
            and (age <= preretirement-age) )
              [select-land]
              [set current-bid 0]]]

  ask farmers with [current-plot-bid-on = land-unit-sold]
         [set current-bid precision((current-bid * (mean-bid))^ 0.5 *
               (value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]))0]

  if (count farmers with [current-bid > 0] > 0)[auction-land]

end


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------------------------------------------------------- LAND LEASE AUCTION MODULE -------------------------------------------------------
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to land-lease-auction-module

  check-if-land-available-for-rent

end

to check-if-land-available-for-rent

  ask patches [if for-sale? = true [set for-rent? true]]
  ask farmers [set current-plot-bid-on "NA"]
  set units-for-sale (count patches with [for-rent? = true])
  if (count patches with [for-rent? = true]) > 0 [screen-farmers-rent]

end

to screen-farmers-rent

  ask farmers [without-interruption [ifelse ((cash > 10 * acres-total-crop)
            and (residual-to-land-labor-exp > 0)
            and (age <= preretirement-age) )
              [select-land-rent]
              [set current-bid 0]]]

  set mean-bid (mean values-from farmers with [current-plot-bid-on != "NA"] [current-bid])
```

```
  ask farmers with [current-plot-bid-on != "NA"]
                  [set current-bid precision((current-bid * (mean-bid))^ 0.5 *
                            (value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]))0]

  set buyers-in-market (count farmers with [current-bid > 0])
  if (count farmers with [current-bid > 0] > 0)[auction-land-rent]

end

to select-land-rent

  set current-plot-bid-on value-from (max-one-of patches with [for-rent? = true]
       [((abs(pxcor - xcor-of myself) + (pycor - ycor-of myself))) * -1 *
        ((trucking-rate * expected-production-volume-of myself) + travel-adjustment / k-acres)
       + residual-to-land-labor-exp-of myself * quality])
       [patch-id]

  set-bid-rent

end

to set-bid-rent

  locals [expected-value-plot]

  set expected-value-plot ((abs((value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][pxcor]) - xcor)) +
                        (abs((value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][pycor]) - ycor)))
                       * ((trucking-rate * expected-production-volume) + (travel-adjustment
                       / (value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][k-acres]))) * -1
                       + value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]
                       * residual-to-land-labor-exp * 0.80

  if attitude = 1 [set current-bid precision ((expected-value-plot - equip-purchase-adjustment
                                    - (min-family-withdrawal / (acres-total-crop + 150))
                                    - ((0.8 / (1 + 14500 * exp (-0.009 * (acres-total-crop + 150)))) + 0.03))
                                    * (discount-value-1 ))2]

  if attitude = 2 [set current-bid precision ((expected-value-plot - equip-purchase-adjustment
                                    - (min-family-withdrawal / (acres-total-crop + 150))
                                    - ((0.8 / (1 + 14500 * exp (-0.009 * (acres-total-crop + 150)))) + 0.03))
                                    * (discount-value-2 ))2]
  if attitude = 3 [set current-bid precision ((expected-value-plot - equip-purchase-adjustment
                                    - (min-family-withdrawal / (acres-total-crop + 150))
                                    - ((0.8 / (1 + 14500 * exp (-0.009 * (acres-total-crop + 150)))) + 0.03))
                                    * (discount-value-3 ))2]

  if current-bid < 0 [set current-bid 0]

end

to auction-land-rent

  locals [adjusted-bid]

  ask max-one-of farmers [current-bid][if current-bid > 0 [
                     set renter-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself]) who
                     set farmer-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself]) who
                     set adjusted-bid (current-bid / value-from
                        (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality])
                     ask (random-one-of patches with [patch-id = current-plot-bid-on-of myself])
                       [set lease-payment current-bid-of myself set lease-term random 5 + 1]
                     set land-unit-rented current-plot-bid-on
                     set for-rent?-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])false
                     set for-sale?-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])false
                     set pcolor-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])green
                     set plots-leased plots-leased + 1
                     set acres-total-crop acres-total-crop +
                           value-from random-one-of patches with [patch-id = current-plot-bid-on-of myself][k-acres]
                     set distance-to-farmstead-of(random-one-of patches with [patch-id = current-plot-bid-on-of myself])
```

```
                abs((xcor - value-from random-one-of patches with[patch-id = current-plot-bid-on-of myself][pxcor]))+
                abs((ycor - value-from random-one-of patches with[patch-id = current-plot-bid-on-of myself][pycor]))
            set total-lease-payment total-lease-payment + current-bid
                * k-acres-of (random-one-of patches with [patch-id = current-plot-bid-on-of myself])
            capital-expenditure-module
            determine-asset-value
            determine-equity-value
            ]]

  if adjusted-bid > 0 [check-if-more-land-available-for-rent]

end

to check-if-more-land-available-for-rent

  if (count patches with [for-rent? = true]) > 0 [screen-farmers-bidding-on-rented-land]

end

to screen-farmers-bidding-on-rented-land

  ask farmers with [current-plot-bid-on = land-unit-rented][without-interruption
        [ifelse (    (cash > 10 * acres-total-crop)
                and (residual-to-land-labor-exp > 0)
                and (age <= preretirement-age) )
                  [select-land-rent]
                  [set current-bid 0]]]

  ask farmers with [current-plot-bid-on = land-unit-rented]
            [set current-bid precision((current-bid * (mean-bid))^ 0.5 *
                    (value-from (random-one-of patches with [patch-id = current-plot-bid-on-of myself])[quality]))0]

  if (count farmers with [current-bid > 0] > 0)[auction-land-rent]

  set average-rent mean values-from patches with [renter != "NA" and patch-id != "border"][lease-payment * quality]

end


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---------------------------------------------------------- CAPITAL INVESTMENT MODULE -----------------------------------------------------
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to capital-expenditure-module

  locals [payment capital-purchase]

  set capital-purchase ((acres-total-crop * capital-per-acre) - capital-value)
  ifelse capital-purchase > 0 [set payment precision(((1 - downpayment) * capital-purchase)
    * (interest-rate / (1 - (1 / (1 + interest-rate) ^ 5))))0
  set cash precision(cash - (downpayment * capital-purchase))0
  set debt-list fput (list 5 payment (precision (0.75 * capital-purchase)0)) debt-list
  set debt precision (debt + (0.75 * capital-purchase))0
  set debt-payment precision(debt-payment + payment)0 ]
    [set cash precision(cash - capital-purchase)0]

  set capital-value (acres-total-crop * capital-per-acre)

  end
```

```
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-------------------------------------------------------------- UPDATE DATA AND PARAMETERS --------------------------------------------------
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to export-data

 let plots-total count patches with [patch-id != "border"]
 set plots-not-in-crop-prodn-percent ((count patches with [patch-id != "border" and farmer = "NA"]) / (plots-total) * 100)
 set plots-leased-percent ((count patches with [patch-id != "border" and renter != "NA"]) / (plots-total) * 100)
 set farms (count farmers)

 file-open "farms.txt"
 file-print farms
 file-close
 file-open "debt.txt"
 file-print (mean values-from farmers [debt])
 file-close
 file-open "debt per acre.txt"
 file-print (mean values-from farmers [debt / acres-total-crop])
 file-close
 file-open "mean size.txt"
 file-print (mean values-from farmers [acres-total-crop])
 file-close
 file-open "leased.txt"
 file-print plots-leased-percent
 file-close
 file-open "unmanaged.txt"
 file-print plots-not-in-crop-prodn-percent
 file-close
 file-open "land price.txt"
 file-print land-price
 file-close
 file-open "lease rate.txt"
 file-print average-rent
 file-close
 file-open "returns.txt"
 file-print (mean values-from farmers [residual-to-land-labor])
 file-close
 file-open "transfers.txt"
 file-print sum values-from farmers [transfers-received + NISA-deposit]
 file-close
 file-open "age.txt"
 file-print mean values-from farmers [age]
 file-close
 file-open "attitude-1.txt"
 file-print count farmers with [attitude = 1]
 file-close
 file-open "attitude-2.txt"
 file-print count farmers with [attitude = 2]
 file-close
 file-open "attitude-3.txt"
 file-print count farmers with [attitude = 3]
 file-close
 file-open "land-attitude-1.txt"
 file-print sum values-from farmers with [attitude = 1][acres-total-crop]
 file-close
 file-open "land-attitude-2.txt"
 file-print sum values-from farmers with [attitude = 2][acres-total-crop]
 file-close
 file-open "land-attitude-3.txt"
 file-print sum values-from farmers with [attitude = 3][acres-total-crop]
 file-close
 file-open "mean-size-attitude-1.txt"
 file-print mean values-from farmers with [attitude = 1][acres-total-crop]
 file-close
 file-open "mean-size-attitude-2.txt"
 file-print mean values-from farmers with [attitude = 2][acres-total-crop]
 file-close
 file-open "mean-size-attitude-3.txt"
 file-print mean values-from farmers with [attitude = 3][acres-total-crop]
```

```
  file-close
  file-open "mean-equity-attitude-1.txt"
  file-print mean values-from farmers with [attitude = 1][equity-value]
  file-close
  file-open "mean-equity-attitude-2.txt"
  file-print mean values-from farmers with [attitude = 2][equity-value]
  file-close
  file-open "mean-equity-attitude-3.txt"
  file-print mean values-from farmers with [attitude = 3][equity-value]
  file-close
  file-open "mean-equity.txt"
  file-print mean values-from farmers [equity-value]
  file-close
  file-open "acres-wheat.txt"
  file-print sum values-from farmers [acres-crop-1]
  file-close
  file-open "acres-oats.txt"
  file-print sum values-from farmers [acres-crop-2]
  file-close
  file-open "acres-barley.txt"
  file-print sum values-from farmers [acres-crop-3]
  file-close
  file-open "acres-flaxseed.txt"
  file-print sum values-from farmers [acres-crop-4]
  file-close
  export-size-distn

end

to export-size-distn

  file-open "size-1.txt"
  file-print (count farmers with [acres-total-crop < 400 ])
  file-close
  file-open "size-2.txt"
  file-print (count farmers with [acres-total-crop >= 400  and acres-total-crop < 560 ])
  file-close
  file-open "size-3.txt"
  file-print (count farmers with [acres-total-crop >= 560  and acres-total-crop < 760 ])
  file-close
  file-open "size-4.txt"
  file-print (count farmers with [acres-total-crop >= 760  and acres-total-crop < 1120])
  file-close
  file-open "size-5.txt"
  file-print (count farmers with [acres-total-crop >= 1120 and acres-total-crop < 1600])
  file-close
  file-open "size-6.txt"
  file-print (count farmers with [acres-total-crop >= 1600 and acres-total-crop < 2240])
  file-close
  file-open "size-7.txt"
  file-print (count farmers with [acres-total-crop >= 2240 and acres-total-crop < 2880])
  file-close
  file-open "size-8.txt"
  file-print (count farmers with [acres-total-crop >= 2880])
  file-close

end
```