AN AGENT-BASED SIMULATION MODEL OF WESTERN CANADIAN PRAIRIE AGRICULTURAL STRUCTURAL CHANGE

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Abstract

Western Canadian prairie farms are commonly stereotyped as large-scale grain farms located on flat lands that stretch to the horizon, but this misrepresents the diversity of farm operators, the landscape and the prairie ecosystem. This diversity has a profound impact on farm structure and competitiveness. Of particular interest are economically transitional or marginal lands between use in annual crops, forage and pasture. The primary objective of this research is to assess transitional land use, beef cow numbers, farm structure and performance under alternative price scenarios. Individual and sector performance is simulated over a period of 30 years using an agent based simulation model (ABSM). A "synthetic" farm population of 600 individual farming agents is constructed based on statistical data and located on an existing landscape of 341,530 hectares. Important model features are 1) segmented farmland auctions consisting of a primary farmland purchase market and a secondary leasing market; 2) a formalized business and farm expansion model that takes into account farm size, asset lumpiness, machinery technology and replacement policy; 3) individual agent expectations based on prior experience and risk aversion; 4) two basic farm types: grain farms and "mixed grain-cow" farms and 5) farm succession. Individual farming agent land use, success or failure in farmland markets and business prosperity are tracked over 30 years and through 100 different price and yield time paths. These are consolidated into a database and sector population statistics and farm structure are analyzed. Past economic trends such as declining farm numbers and increasing farm size are projected to continue; these trends are robust as they are generated under many different time paths and scenarios. Beef cow numbers depend upon land use which is sensitive to agent farm type preferences and wheat-beef price ratios. Large grain price increases have a more dramatic impact on industry structure by creating large structural shifts towards more grain and eventually fewer mixed farms. However, large changes in livestock prices generate smaller structural shifts over time because of the many lags and difficulties in expanding beef cow production.

Keywords: farm structure; Agent based simulation model

1. Introduction

Western Canadian prairie farms are commonly stereotyped as large-scale grain farms located on a flat landscape that stretches from horizon to horizon. However, this image misrepresents the diversity of farm operators, the actual landscape and the prairie ecosystem. Western Canadian prairie farms consist of numerous individuals with diverse financial and demographic characteristics located on a highly heterogeneous landscape. Of particular interest are lower quality and transitional soils representing about 43% of Canadian Prairie farm land. These lands are of con-

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siderable environment concern and are "transitional" in that they are at the economic "margin" between annual crops and forage/pasture. Much of forage and pasture land is generally used in beef cow production (or dairy) and not directly marketed; hence, transitional land use is ultimately tied to the comparative profitability of livestock over grains. Further, land conversion from one use to the other is a longer run decision and is subject to farm operator preferences/aversion to livestock. The latter is particularly important as it means that shifts in marginal land use generally occur only when land changes hands. This is inherently complex because of the cascading effect of internally generated land rents into subsequent land purchase and leasing decisions which ultimately affect farm survival and succession.

In the following sections, an agent based simulation model (ABSM) of a grain and mixed grain-beef cows farm population is developed for an existing farming region. Farm level production of grain and beef is subsequently tracked over 30 simulated years. Two alternative price scenarios are formulated and farm structure is re-simulated in order to evaluate the effect of price shifts on regional production. We conclude by examining longer run structural impacts of changing grain-beef calf prices.

2. An ABSM of grain and mixed grain-beef cow farms

Because of the nature of the farms in our study area, we do not incorporate as explicit a bio-economic model of land-pasture-cow-manger interaction as Gross et al (2006) and McAllister et al (2006), but emphasize more of the whole farm business and financial management, more in the style of the AgriPoliS model (Happe, Balmann, Kellermann, 2004), Freeman (2005) and Anderson (2012). We build on the Freeman model by introducing: 1) a more formalized model of machinery investment lumpiness; 2) a more explicit relationship between farm size, machinery technology and replacement policy; 3) the inclusion of beef cows and "mixed farms" with associated lower farmland quality; 4) a segmented purchase and leasing farmland market with the inclusion of non-farmer investors; and 5) spatial diseconomies with farm size (Stolniuk, 2007).

In brief overview, regional agricultural structure is a complex evolving system consisting of a heterogeneous population of farmer agents, each seeking to grow and prosper. These agents are located on a heterogeneous farm landscape and these agents interact with each other in farmland auctions over a geographical space dominated by yield and price uncertainty. Within a farmer age bracket and under certain financial conditions, the inherent desire of farmers to grow and prosper compels them to expand their operations. This leads farm agents to compete in land purchase and leasing auctions by tendering bids based on their own expectations as to future farm profitability for farmland that varies in land quality and location. Innate but differing levels of risk aversion, random price and yield events and errors in bid formulation lead to differing bid values in land auctions. Farmer agents who bid and end up paying too much for farmland can find themselves in financial stress, and subsequently be forced to downsize or to exit. Farmer agents who consistently bid too little will be unable to expand, making them progressively less competitive, leading to stagnation and over a lifetime, unable to generate sufficient equity to pass their farm on to the next generation.

Farmland pricing information generated by our auctions generates a "balance sheet effect" feedback loop where increased/decreased asset value based on current auction value, increase/decrease a farm's ability to secure additional credit. This effect is further enhanced by financial leverage. Farmland pricing is also used to set lessors' expectations as to "fair market" cash leases. Accordingly, regional structure over several generations is determined by the personal and business characteristics of the remaining farmer agents. In the next sections, we discuss the landscape, as well as our synthetic agent population and their characteristics and farmland auctions.

The simulated landscape is based on Census Agricultural Region (CAR) 7B, located in the dark-brown soil zone of west-central Saskatchewan, a province in western Canada. CAR 7B has a total of 1,740 farms and 1.3 million hectares of land in farms (2006 Agriculture Census of Canada). The CAR is divided into 259 h (640 acre) plots, each plot having a unique land use profile consisting of 1) tillable, 2) hay, 3) improved pasture, 4) natural pasture, and 5) non-agricultural land and associated crop yields. Tilled land can be used as improved pasture, hay, or annual crop production. Hay lands are used as hay (typically first cutting) or pastured if there is a projected surplus of hay. Improved pasture can be used for first cutting hay if there is a projected forage deficit, but more typically it is pastured. Natural or unimproved pasture is used only as pasture land, while non-agricultural land is unsuitable for agricultural use. Individual plot potential land use, pasture animal unit carrying capacity and productivity are derived from Saskatchewan Assessment and Management Agency (SAMA) assessment and Saskatchewan Government Crop Insurance data (Saskatchewan Agriculture and Food, 2010). Finally, plot location is important as it determines land quality and it affects transportation costs from the field to the farmstead.

There are four types of agents: 1) farmer-operators, 2) retired farmer landlords, 3) non-farming landlords, and 4) an auctioneer. Farmers purchase and rent land for grain and livestock production while non-farming land owners hold land solely as an investment. The auctioneer coordinates land markets between the sellers and individual bidders. Farming agents are endowed with different resources, abilities, and demographic characteristics. Farm business resources include capital, land, and labor and are used by farm agents to generate income and wealth. Agents also vary in their risk and livestock production preferences/aversion.

There are two types of farmer agents according to their preferences/aversion to livestock: grain farms and mixed grain beef-cow farms. Grain farmers have an innate strong aversion to beef cows and they cannot be induced to switch into beef production. These farms tend to have more annual crop land, and because of their relatively greater size have achieved greater economies of size than mixed farms in grain production. Grain farmers seek out better cropland as much as possible; on the poorer quality land they sell hay or lease out pasture land and incur transaction costs associated with forage transportation and marketing. A “mixed” farm has both grain production and beef cows and can expand towards either enterprise. When a mixed farm increases livestock numbers, there are no additional fixed costs as the existing plant is assumed to be capable of handling larger herds. Mixed farms do not incur costs in selling hay or leasing out pasture as they use forage lands for their own livestock production. Therefore, they have a competitive advantage in bidding for poorer quality and transitional land. Conversely, grain farms have a competitive advantage in bidding for better quality land which has little hay or pasture because of their size advantages.

While our landscape is based on actual provincial land characteristics, our farm population of 600 farmer agents is synthesized based on the Whole Farm Survey for CAR 7B (Statistics Canada, 2007) and the 2006 Canadian Census of Agriculture. Important farm agent business characteristics include farm type (“grain” or “mixed”), farm size, tenure, relative debt, land value and livestock numbers. Important farm agent personal characteristics include age, grain/livestock preferences and off farm income. Individual agents and their associated businesses are matched to approximately 4500 actual farmland plots of 259 h (640 acres) according to their relative land value per hectare and relative amount of pasture. In the case of mixed farms, herd numbers are set by the associated cow carrying capacity of their individual land. Individual land tenure is based on their business characteristics.

Initial individual farm size is important as it sets the subsequent appropriate tillage technologies and machinery replacement patterns described in the following sections. Initial farm assets are based on farm size and the corresponding machinery technology and land is valued at current fair market value; farm debt is based on total farm assets times the relative debt level. Age and off farm employment income are assigned using a similar method.

3. Simulation procedure

Farmland auctions and farm structure are simulated using Version 3.1.4. of the NetLogo© simulation software (Wilensky, U. 1999). Netlogo is a widely used platform for ABSM research (Railsback, Lytinen, Jackson 2006). For tractability, only a 32% sample and corresponding land plots are randomly selected from the total population. Our sample consists of 600 farmers located on 341,530 hectares with an average farm size of 585 hectares, and an average farm operator age of 52 years.

A total of 100 different price and yield 30-year time paths are created using a bootstrap style procedure based on historic detrended yield and prices. Three key scenarios are examined. The first scenario or base scenario is based on historic prices and yields. The second scenario (HiCropPrice) represents a permanent structural shift in the grain markets leading to a 25% increase in grain prices over the base. The third scenario (HiCalfPrice) represents a permanent shift in livestock markets resulting in a 25% increase in calf prices over the base.

4. Model validation

It is inherently difficult to validate certain ABSM simulations, particularly those that simulate future longer run trends. Farmland pricing is chosen as our primary validation variable as it incorporates most of the fundamental economic and accounting relationships, and because farmland prices are completely endogenous and a result of the individual agent bidding formulation and the subsequent auction process. Because historic CAR 7B farmland prices are unavailable; validation is based on comparisons of simulated 1975 to 2004 CAR 7B farmland values to historical provincial farmland value averages. In order to check their goodness of fit, simulated values are regressed on the corresponding provincial farmland value using a simple linear model and ordinary least

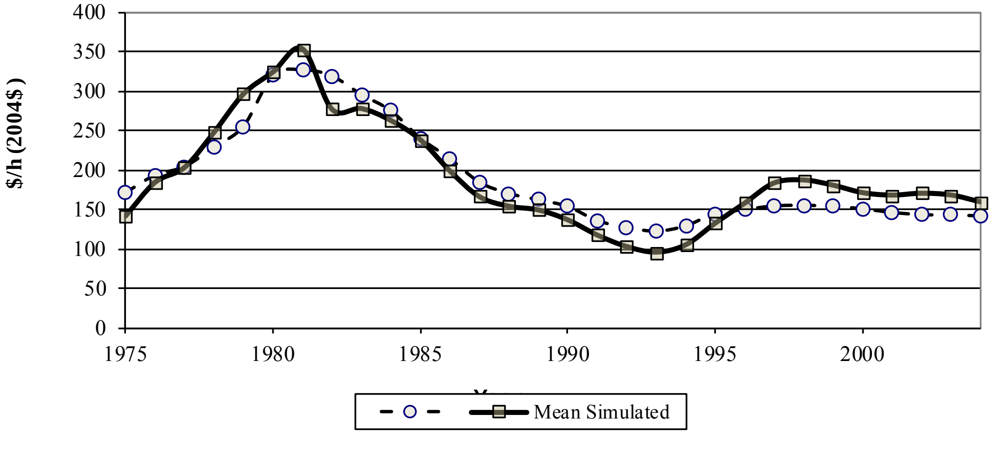

Figure 1. Comparison of Normalized Mean Simulated to Historic Land Prices

squares. Simulated farmland prices compare reasonably well: the adjusted *r* square is 0.88. The estimated coefficients with their *t* values in parenthesis are for the intercept: \$2.75 (0.184) and the β estimate: 1.088 (14.556). Thus, the intercept is not statistically significant from zero but the β estimate is highly significant from zero. Note that comparisons are based on different geographic areas, so that it would not be expected that the β estimate would be equal to 1.

In order to better evaluate the two series, the simulated data are normalized to give the same mean as the provincial data and turning points and trends assessed (Figure 1). Overall, we find that the simulated land values tend to overreact, which might be caused by comparing a local market to a much larger overall provincial market.

5. Results

5.1. Base scenario

Farm structural characteristics such farm size and numbers are displayed by farm type in Figure 2 and summarized in Tables 1 and 2. In the base scenario, land use as measured by the percentage of land cropped does not change much, remaining at a constant 70% (Table 1). In addition, the base scenario displays the familiar patterns found in Canada of continued diminishing farm numbers and a corresponding increase in farm size. However, the simulated annual decrease in farm numbers of 3.7% (Table 1) is higher than a recent measured rate of 2.6% (Saskatchewan Agriculture and Food, 2010), although this annual rate has been accelerating over the last 35 years. The reason for a projected greater rate of decrease is that we project greater difficulties in farm succession as it will be progressively more difficult for families to accumulate sufficient farm equity to allow another member of the family to start farming, yet allow sufficient remaining equity for the parents for retirement living.

Table 1. Change in Mean Farm Type, Land Cropped and Herd Structural Characteristics

Structural Statistic	Farm		Proportion of mixed farms		Land cropped		Total beef cows		Farm herd size	
	numbers	% change	%	% change	%	% change	head	% change	head	% change
Beginning	600		53%		70%		19,682		62	
Ending by Scenario										
Base	191	-3.7%	61%	0.5%	70%	0.0%	20,957	0.2%	182	3.7%
HiCropPrice	277	-2.5%	56%	0.2%	74%	0.2%	14,880	-0.9%	95	1.4%
HiCalfPrice	238	-3.0%	66%	0.7%	64%	-0.3%	30,207	1.4%	196	3.9%

Note: HiCropPricesis based on a 25% increase in crop prices and HiCalfPrice in based on a 25% increase in beef feeder calf prices, % change is the average annual compounded rate of change

Total herd size is a function of land use and since land use is almost constant, herd numbers are also nearly constant, increasing at an annual rate of 0.2%. However because farm size is increasing in the simulation, mean herd size increases at a rather constant annual rate from 65 to 182 head due to fewer farms. While farms grew rapidly, much of the expansion came through additional leased land rather than purchased land. In the initial simulated farm population, 32% of farmland was leased. At the end of 30 years, mean leased lands increased to 51% (Table 2).

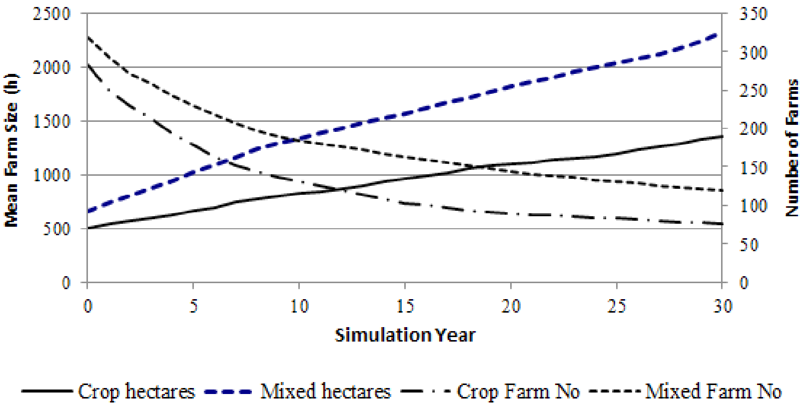

Figure 2. Patterns in farm size and numbers by farm type

Table 2. Mean Farm Business Performance Characteristics and Land Tenure

Structural Statistic	Farm Size		Net Worth		Farmland Value		Debt/Asset Ratio		Leased Land	
	hectares	% change	(x1000)	% change	($/h)	% change	%	% change	%	% change
Beginning	585		523		865		15%		32%	
Ending by Scenario										
Base	1996	4.2%	2,108	4.8%	1,544	2.0%	16%	0.3%	51%	1.6%
HiCropPrice	1284	2.7%	3,033	6.0%	2,175	3.1%	8%	-1.8%	32%	0.0%
HiCalfPrice	1556	3.3%	2,359	5.1%	1,801	2.5%	12%	-0.6%	44%	1.1%

Note: HiCropPricesis based on a 25% increase in crop prices and HiCalfPrice in based on a 25% increase in beef feeder calf prices, % change is the average annual compounded rate of change

We measure sector health by the growth in aggregate net worth, which in turn is a rough proxy for return on investment, and the debt/asset ratio, which is a measure of risk bearing ability (Table 2). Net worth in the simulation increased at an annual rate of 4.8% while the debt/asset ratio increased slightly from 15 to 16%. These figures would be considered relatively healthy by traditional farm management standards. Note the importance of increased farm land values in farm equity gains—farm land increased at an average annual rate of 2% over the period of the simulation; however, this further complicates farm succession.

5.2. Alternative price scenarios

Clearly, land use is affected by the relative price of grain to livestock. When grain prices increased (HiCropPrice Scenario), the average amount of land used in annual crop production also increased over the first seven years of the simulation and then increased very slowly to approximately 74% of total arable land. When livestock prices increased (HiCalfPrice Scenario), a mirror situation occurred: the average amount of land used in annual crops decreased over the first seven years and then stabilized to approximately 64%. These shifts are due to the nature of transitional land: it is at the economic margin between hay or annual crops. The price changes used here are close to so-called "tipping point" but change is not instantaneous as it takes time for actual prices to affect agent expectations and then be reflected in crop choices and farmland pricing decisions. In addition, the decision to decrease perennial forages is only made at the end of its normal stand and hence it takes a few years for all of the forage rotations to come up for profitability review. While the herd can be downsized relatively quickly, it takes longer to increase herd size. The subsequent, slower long- run changes are founded on the shift to/from grain mixed from/to grain-beef cow farms as land changes hands. In the case of the HiCropPrice scenario, the proportion of mixed grain-beef cow farms decreased from the base scenario of 61 to 56%; in the HiCalfPrice scenario the proportion increased to 66%.

In both of the increased price scenarios, as farm profitability increased, the rate of decrease in farm numbers slowed. The effect is most dramatic in the case of increased crop prices (HiCrop-Price). The shock of increased crop prices slowed the erosion in farm numbers from the base of 3.7 to 2.5%. Accompanying higher crop prices is increased annual growth in farmland values (2.0 to 3.1%), lowered debt-to-asset ratios (16 to 8%), decreased annual growth in farm size (4.2 to 2.7%) and decreased reliance on more leased land (1.6 to a 0.0% annual growth rate). Increasing farm equity and, in particular, non-land equity over time and reduction of farm debt enabled more farms to successfully transition from one generation to the next. In contrast to higher crop prices, higher calf prices only affect the livestock farms, and only that land which derives its value from the beef cow herd. This translates into a much lower impact on sector farm viability.

6. Conclusions

Agricultural structure in western Canada has been continually evolving since the days of homesteading, but in recent years, the causes underlying structural change have become so multi-dimensional and complex that little comprehensive research has been done to understand what changes are occurring and why. Using an agent-based simulation model of farming in Western Canada, we project that historical trends of declining farm numbers and increasing farm size will continue over the foreseeable future. These projections are remarkably robust since they are generated under many different time paths and alternative scenarios. Overall, increased grain profitability resulted in a quicker and more dramatic shift in land use than increased beef cow profitability because of 1) the lags in beef production associated with delays in expanding herd numbers; and 2) in the case of shifts from a grain only farm to a mixed farm, it is only at the time of transition from one type of farm operator to another that changes occur.

Simulated growth in farm size is subtle and is not generally due to forced exits, but instead is due to farm stagnation and/or the subsequent failure to generate sufficient equity to allow the next farm generation to enter. Historically, Canadian farm policy has tended to support the status quo, particularly through subsidizing small family farms. This has sustained many uneconomic farming operations that, under less supportive conditions, would not be able to survive the transition from one generation to the next. Our research suggests that structural change in the sector, characterized by fewer and larger farms, now appears to be inexorable. Former government goals and policies will thus be wasteful unless they are appropriately modified to the new regional economic reality.

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