Evaluating the Consequences of Second Generation Bioenergy Crops on a Grain/Livestock Economy: An Example of the Canadian Prairies

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Abstract

Biofuels are used as renewable alternatives to traditional fossil fuels. Government agricultural policies are currently focused on the production and use of so-called first-generation biofuels (FGB). Partly because of the success of many FGB programs, concerns about food and water security have become important considerations in the policy arena. These considerations have led to the development of so-called second-generation biofuel (SGB) technologies, based on relatively low value feedstocks that thrive on marginal land. This changes the competitive environment for biofuels, as SGB's do not need to compete directly with relatively high-value annual crops. To examine consequences of this situation on the future of mixed farming, we develop an agent based simulation model (ABSM) for the analysis of economic situations characterized by large numbers of dynamically interacting individuals located on a heterogeneous landscape. Like most policies designed with good societal intentions, we find that SGB crops may lead to significant and possibly unwanted trade-offs in agricultural economies. If energy prices become high enough, the model indicates that structural changes in the farming sector will be significant, resulting in a very different agricultural landscape than we see today.

1. Introduction

Biofuels are used as renewable alternatives to traditional fossil fuels for reducing greenhouse gas (GHG) emissions. Most government agricultural policies around the globe are focused on so-called first-generation biofuels (FGB), such as corn-based ethanol, as the primary solution to various environmental issues (Chen et al. 2009). However, partly because of the success of many FGB programs, other related concerns such as food and water security have become important additional considerations in the environmental policy arena (Becker 2008). These considerations have led to the development of so-called second-generation biofuel (SGB) technologies that are based on relatively low value feedstocks such as woody plants or tall grasses that can grow on marginal land. This changes the competitive environment of SGB as they do not need to compete directly with relatively high-value annual crops. However, this does bring them into direct competition with both pasture and hay, and in many cases, with grazing animals. And although not all of the almost 5 million acres of seeded pasture in western Canada (Statistics Canada, 2006) are necessarily good candidates for SGB (since some acreage lies too far north) there is still considerable potential that if commonly grown, SGBs could disrupt the entire beef chain by reducing the approximately 3 million beef cows now in the region, while curtailing beef production (Statistics Canada). Accordingly, future policy incentives towards SGB's must be examined carefully in a much broader context of regional land-use as well as sustainability, GHG emissions and SGB competitiveness.

2. Review of Agricultural and Regional Land Use Models

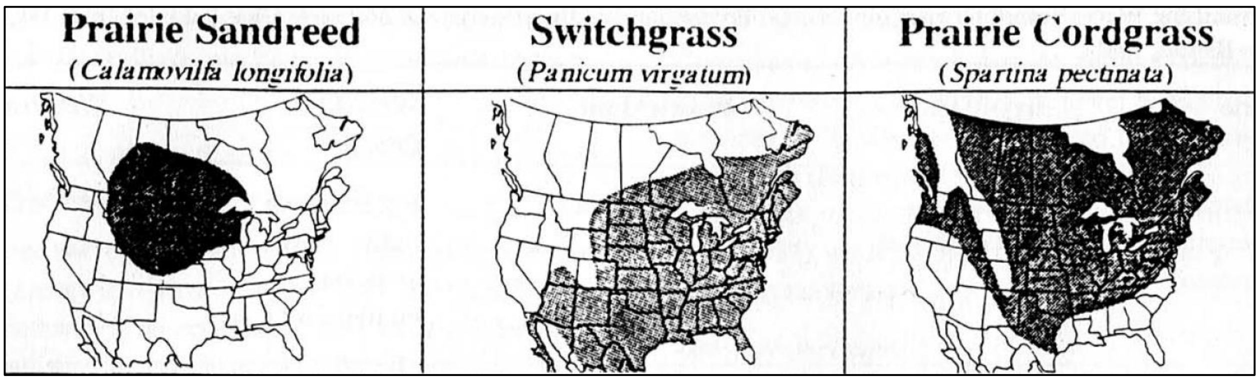
Key to the widespread adoption of SGB crops on the western Canadian prairie is their competitiveness with existing crops at the farm level, where considerable heterogeneity in farm type, size, and soil quality and operator characteristics exists. In addition, the very different agronomic characteristics of SGB crops means that a shift to them in the region will also affect existing equipment use patterns and plant utilization (Sims et al., 2010**)**. The result is that a decision to shift to these crops will ultimately be a long run decision that carries important farm size and scale considerations, among other spatial components. Given regional heterogeneity in farm type, resource endowment and quality, traditional methods of farm level analysis (like the analysis of a few case farms) is not likely to be a reliable guide for policy. Moreover because of the long run nature of the issue and the potential for significant farm reorganization in response to widespread crop adoption, there is likely to be a relatively unstable transition period in the sector.

In this light, we develop an agent based simulation model (ABSM) designed for the analysis of situations characterized by large numbers of dynamically interacting individuals located across a heterogeneous landscape. ABSM accounts for actions between individuals and also aggregates individual agent decisions up to an area or regional level, which avoids aggregation bias inherent in most traditional regional agricultural models. Much of the feedback within the modeled agricultural system occurs through the market for farmland, where farmer agents transact using a simulated land auction process.

Related literature on this important topic is limited, but growing. For example, Gross et al (2006) used ABSM to study Australian grazing and pasture management systems. Their primary concern was to study the effect weather dynamics and markets had on individual agent learning, as well as the importance of business management in evaluating rangeland systems and behavior. In subsequent work, McAllister et al (2006) updated this model in order to evaluate the consolidation problem of grazing and pasture units over time. While beef cows are an important consideration in our study, we do not develop as detailed a model of land-pasture-cow-manger interaction as McAllister et al., but instead we emphasize the whole farm business and financial management associated with the potential adoption of a new crop and concurrent farm reorganization. The latter focus is more in the style of the well-known AgriPoliS agricultural model (Happe et al. 2008), as well as the work of Freeman et al. (2009), Stolniuk (2008) and Stolniuk et al. (2013). Freeman et al. constructed an ABSM projecting structural agricultural change in Saskatchewan over 30 years, generating estimates of farm numbers, farm size and distribution, production characteristics, demographic characteristics, resource ownership and finances. The subsequent Stolniuk (2008, 2013) simulation research was an extension of the Freeman et al. work to include beef cow operations, hay and pasture lands and improved farmland auction bid equations. Since the latter model was designed to account for transitional forage lands, indeed it provides a starting point for assessing SGB production in the current context.

Candidate energy crops will likely be based on a variety of perennial grasses and woody trees using conventional agronomic practices. The SGB crops considered in this research are willow (short-rotation woody crops) and Prairie Sandreed (a tall perennial grass). Willows are an ideal SGB crop because of their high yield growth in a short-time period and their ability to re-grow after multiple harvests (Volk et al. 2006). In addition, willow grows well in northern temperate areas like Saskatchewan and is suitable for marginal lands not appropriate for annual crop production (Konecsni 2010; Volk et al. 2006). Switchgrass and Miscanthus are dominant tall grass species native to North America and have been the focus of other SGB energy crop studies (Scheffran and BenDor 2009; Walsh et al. 2003). However, because of Saskatchewan's harsh climate these crops are not the energy crop of choice for this assessment of SGB production (refer to Figure 1). Instead, we base perennial grass in the model on grasses (like Prairie Sandreed) that are compatible with cooler growing regions (Samson et al. 2001; Jannasch et al. 2001).

Figure 1. Native Range of Warm Season Grasses



Source: Samson and Omielan 1992 (pp 256); Thirteenth North American Prairie Conference.

Farmgate energy prices in dollars per gigajoule as received by farmers for biomass production is a crucial component of this research. In prior literature, Walsh et al. (2003) used the POLYSYS model to examine energy crop production in the U.S. and discover that at energy prices between $1.83/GJ and $2.44/GJ, farmers earn higher profits than with traditional land uses. The Biomass Research and Development Board (2008) based in the U.S. also found that the farmgate price for willow necessary for farmers to earn a profit would fall in the range of $1.42/GJ to $2.50/GJ. These prior findings are incorporated into our model to evaluate various price levels for biofuels that might induce farmers in the simulation to switch over to these crops in their rotations.

3. The Agricultural Simulation Environment - MIXFARM

MIXFARM is an ABSM developed by the authors to simulate a regional agricultural economy over a 30 year period. The core model was written using Java code in the agent oriented Repast© software. Additional linear and integer programming algorithms needed to perform farm level optimization, including the revised simplex method (LP) as well as branch-and-bound methods (MIP) for solving integer programs, were completed within the core model using *lp_solve* software.[1] [2]

The synthetic population is characterized by four distinct types of agricultural agents operating operate in the study region. Based on the current situation in the industry, these agents are: 1) farmer agents, 2) retired-farmer agent landlords, and 3) non-farming investor agent landlords, and 4) an auctioneer agent. Farmer agents can own and/or lease crop and pasture land. Retired farmer agents and investor agent landlords hold land as an investment and lease their land out to farming agents. Land is critical since all farm agents are assumed to want to expand their operations if it is financially beneficial to do so. The land auctioneer agent controls the land market and effectively acts as a *deus ex machina* type of agent in the simulation, overseeing the critical land market. The auctioneer processes all land market bids, and matching the highest bids with the highest land quality in the simulated land auction process.

[1] Repast© is a free and open-source modeling platform designed for agent based simulation modeling. Repast© stands for Recursive Porous Agent Simulation Toolkit and was developed by team members at the University of Chicago and the Argonne National Laboratory (Collier et al. 2003). The version used here is Repast© © Simphony.

[2]The free and open-source software lpsolve program was developed by Michel Berkelaar at the Eindhoven University of Technology. The version of lpsolve used in this model is version 5.5.0.15. However lpsolve is not object oriented, and had to be called via a library in order to be accessible to Java. The so-called Java wrapper was created by J. Ebert (University of Koblenz-Landau, Germany) and allows Repast© to access the lpsolve library.

3.1 Agent behavior: Farming decisions

The synthetic farm agent population varies according to demographic and business characteristics, but each agent shares a common set of behavioural, accounting, and decision making rules along with an intrinsic desire to prosper and thrive over time. In order to do so, they must strive for cost efficiency, they must generate both sufficient family income and be successful in the farmland purchase and lease markets.

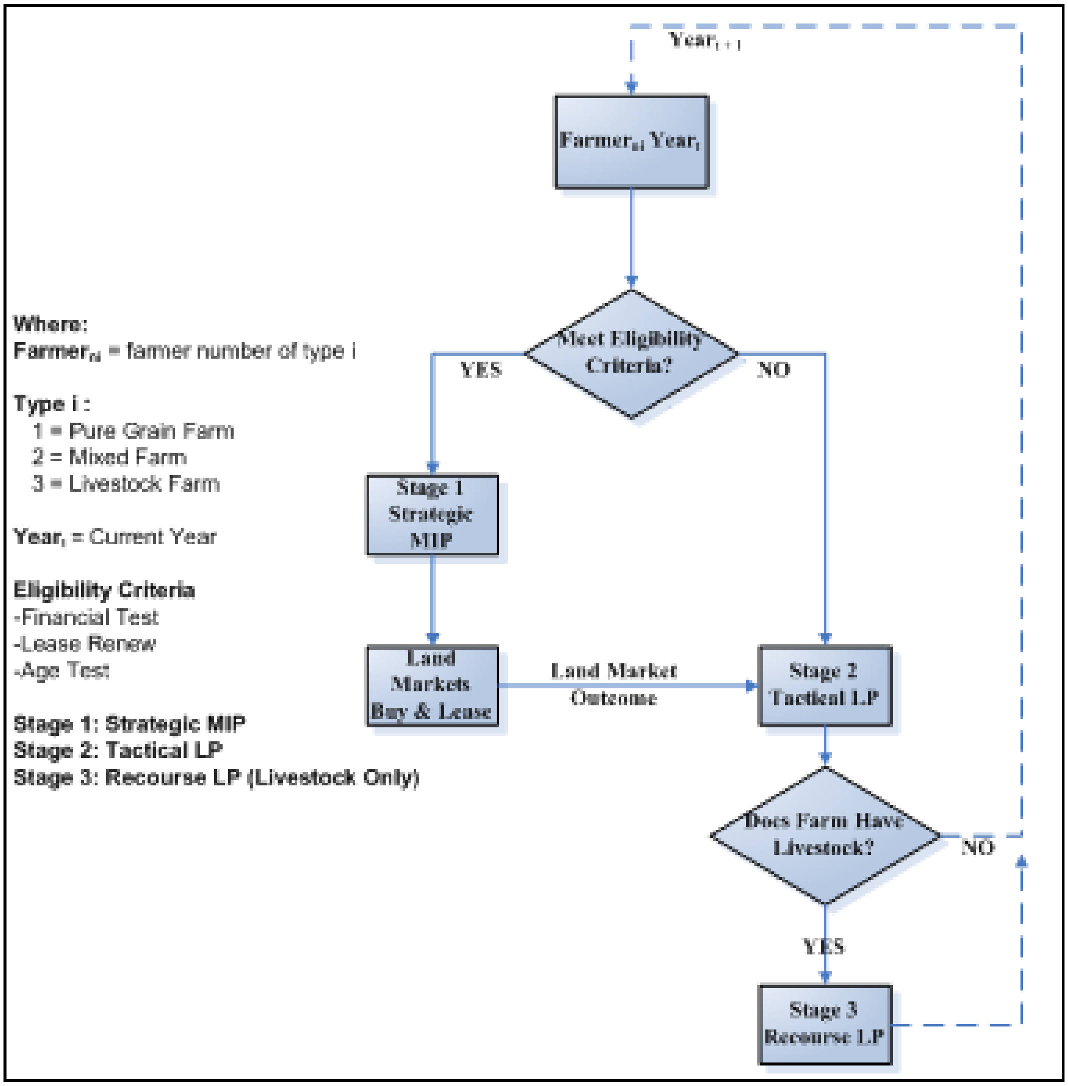
Each farm agent in the simulation is programmed with an individual level of risk aversion that affects his/her crop price and yield expectations. Next, each agent is located on farmland of varying quality and location, with differing transportation costs. Finally, each agent has differing financial circumstances and ability to borrow. These characteristics generate diverse land auction bids from various individuals, even when bidding for the same parcel of land. In the simulation, farm success and sustainability ultimately depends on obtaining the appropriate amount of farmland by lease or purchase that maintains or improves farming efficiency. Farmer agents who overpay for farmland can become strained financially and subsequently be forced to downsize or to exit farming. Farmer agents who consistently underbid may be unable to expand operations, likely leading to decreased efficiency and competiveness. Over a simulated lifetime, the latter individuals may be unable to generate sufficient equity to pass their farm on to the next generation.

There are three farm types: i) pure grain farm; ii) mixed crop and beef cow farm; and iii) pure beef cow farm. However, associated with each farm type is an aversion or preference towards livestock. For example, grain farms have no desire to invest in beef cows and thus will not bid on marginal farmland that is unsuitable for grain farming. But with the introduction of new farming alternatives such as SGB crops, grain farmers' behaviour towards bidding on marginal land may change. Grain farms typically use greater annual crop acres than other farm types and therefore achieve greater economies of scale than mixed farms. Since a mixed farm includes both grain and beef cows, this kind of farm can expand towards either enterprise, which gives them an advantage in bidding for marginal land. Conversely, grain farms have a competitive advantage in bidding for better quality land (which has little hay or pasture) because of their inherent size advantages.

There are two particularly important dynamic feedback mechanisms contributing to the complexity of this simulation environment. First, individual farm size is strongly driven by various feedback elements. Farm size effectively sets appropriate tillage technologies and machinery replacement options and also determines potential cost efficiencies (which may or may not be fully realized), depending upon individual success in expanding operations through farmland markets. Success in farmland markets can result in increased efficiency, which further enhances an agent's ability to better compete in future land markets. The second key feedback mechanism comes through what we call the "balance sheet effect". In this case, land market values established through farmland purchase auctions feed back to the balance sheets of all farm agents in the simulation holding land. In times with growing farm land values, increased agent equity relaxes some financial constraints, potentially allowing them to borrow more. Conversely, in times of falling land values, decreased equity further constrains ability to borrow and could result in downsizing or a forced exit.

Over several generations, the complex interaction of the farming agents through land purchases determines regional structure by determining the 1) number, 2) type, 3) size and 4) business characteristics of the remaining farms and farmer agents. The flow diagram below (see Figure 2) illustrates the three decision stages common to all agents in the simulation. These are - Stage 1: long-run strategic planning; Stage 2: short-run tactical annual production decisions; and Stage 3: short run recourse decisions. Each of the stages are characterized by somewhat different farm optimization problems within the simulation.

Figure 2. An Overview of the Farmer Agent Decision Making Process



Long-run strategic planning decisions are triggered by either the necessity through the past inability to obtain more land; forced downsizing or the new ability to increased farm size through agent's improved financial situation. Each year, all farmer agents are screened for borrowing ability and life stage. For instance, if an agent is less than approximately fifty-five years of age and able to meet the requisite financial criteria, this agent enters into the long-run strategic planning stage. Otherwise, they bypass this stage and continue their previous strategic plan and go to Stage 2 decisions.

The primary purpose of the programmed Stage 1 strategic mixed integer programming (MIP) problem (1), Z^1, is to determine optimal farm and herd size and associated lumpy investment requirements, given current farm resources. The Z^1 sizing decisions are critical in that as farmer agents attempt to "jump" to the next efficient size, correct machinery choices are essential to their overall farm success as well as an important tool in achieving cost efficiency. In the optimization problem, land use decision variables include acreage (X) in annual, forage, crops and energy crops. Additional decision variables include plots (Q=integer) rented in or out; acres of machine operation (X_j^{Jm}), and ownership (M=integer)); forage feeds sold or purchased (T), herd numbers (L) and changes in herd size (ΔL), amount of feed fed (Fd), herd facility capital requirements (K=integer) and borrowing (B). Activity coefficients include gross margins or costs (C), land rents (R), variable machine operating costs (V), annualized machine ownership costs (F^J), herd gross margins exclusive of feed costs (C^L) but including expansion/contraction costs ($C^{\Delta L}$), net forage sales/returns (D), costs of feeding (C^{Fd}), annualized costs of new herd facilities (F^L) and the real cost of capital (r). Collecting terms, this information generates the following optimization problem for Stage 1 farmers;

(1) $\max_{X,T,L,B,Fd;integer:Q,M,K} Z^1 = CX - RQ - VX_j^{Jm} - F^J M + C^L L + C^{\Delta L}\Delta L + DT - C^{Fd}Fd - F^L K - rB$

subject to:

(2) $X - Q^+ \leq Owned$

(3) $\sum_{j=1}^{n}(X_j^J - X_j^{Jm}) \leq 0$

(4) $\sum_{j=1}^{n}(X_j^{Jm} - \beta^m M_j^{Jm}) \leq 0$

(5) $-T + Fd \leq 0$

(6) $-McalFd + Mcal(\Delta L + L) \leq 0$

(7) $L - \Delta L^+ + \Delta L^- \leq Cows$

(8) $-\partial K^L + (\Delta L + L) \leq F$

(9) $CF - B \leq cash$

(10) $\delta\left(I + R + \left(F_m^J M_m^J\right) + L + F^L K^L\right) + B \leq Equity$

As a mixed integer linear program, this problem has nine basic constraints. The first constraint (2) means that total acres farmed (X) must be less than or equal to the sum of all rented and owned land (Q^+). In addition, all annual crops (J) require an acre of machinery capacity (X_j^J) which can be met by a machinery set, *m*, (X_j^{Jm}) (constraint 3) incurring an operating cost, V. However, the operation of *m* is limited by the associated package of acreage capacity, β^m times the number of packages (X_j^{Jm}).The latter constraint is captured in (4).

A feeding transfer constraint (5) is represented by (-T), the amount of tonnes either produced or purchased, while Fd is the amount of tonnes fed to livestock. The feed ration requirements for livestock (constraint 6) are based on the mega calories available from feed (-*McalFD*) and must be greater than the mega calories required (*Mcal*(L)) to maintain the beef herd. Constraint 7 is the livestock herd constraint, while L, represents non-feed, herd operating costs of the starting herd. Changes in livestock herd size (Δ) are generated by expansion (Δ+) or contraction (Δ-). Expansion has an associated acquisition cost greater than contraction revenues associated with culled animals (Δ-). Note that Δ+ also includes an operation cost. Ultimately, the combination of the three must be less than or equal to the current herd size (cows). The beef cow herd facility capital requirement (constraint 8) is similar to the annual crop machinery capacity constraint (constraint 4) except that instead of capacity in acres, capacity is in beef cows. We assume that an additional labourer, plus associated machinery and handling systems are required per 300 cows, as represented by ∂. Given this, the initial facility endowment in the simulation, F, is set at 300 cows.

Each of these activities has an associated cash inflow/outflow (CF) that may be different from the annualized economic costs in the objective criterion. For example, investment variables generate cash flow requirements associated with the investment decision, while divestment decisions such as herd downsizing generate cash inflows. Cash outflows in excess of available cash must be financed with borrowing activities (B, constraint 9). In the debt to asset ratio constraint (10), the critical debt to asset ratio is represented by δ; this is often the most binding constraint as additional investments can be made when relaxed. Major investment cash outflows include I, the initial investment in energy crops, where R represents farmland, F^J is the cost of machinery and M_m^J is the number of machine units (an integer) associated with annual cropping, F^L is the fixed costs of the beef cow machinery handling and labour package while K^L is the number of units (an integer) of the beef cow machinery, handling and labour package.

If land expansion emerges as an optimal strategy from Stage 1, then the next step is to determine whether to purchase or to lease land, and then bid in appropriate land auctions. In order to participate in a land purchase auction, the agent is first screened for sufficient equity and ability to manage cash flows. The final assumed bid value, $Bid_{purchase}$ is the minimum of the three potential bid values unique to the individual. These include a possible bid based on income generating ability and future resale value (Bid_{income}), a possible bid based on available cash (Bid_{cash}) and a maximum bid based on maintaining a critical debt to asset ratio ($Bid_{D/A}$):

(11) $$Bid_{Purchase} = Min(Bid_{income}, Bid_{cash,} Bid_{\frac{d}{a}})$$

The income based bid, (Bid_{income}) is the net present value of the certainty equivalent of future income earning ability (R_t) and the final land value (EV_n) using r, the risk-free discount rate;

(12) $$Bid_{income} = \sum_{t=1}^{n}\left(\frac{E\left[CE\left(R_t\right)\right]}{(1+r)^t}\right) + \frac{E[CE(EV)]}{(1+r)^n}$$

Expected income comes from the objective function in the MIP solution. This is calculated by using the annual contribution margins, less variable and fixed costs for machinery and labour variable costs, as well as costs associated with additional land acquisitions less expected income for taxes and family living.

A bid using available cash (Bid_{cash}) is based on the cash flow needed to maintain a positive cash balance for the expansion phase. A definition of total available cash is based on Stolniuk (2008), and includes minimum cash per acre and per cow for all farm enterprises and down payments for new capital investments. The available cash formula is:

(13) $Cash_{Avail} = Cash - \ min_{cash} - \ min_{cow} - min_{fam} - \propto (Cap_{Value}) - \ Cash_{res}$

where: Min_{cash} is the minimum cash per acre for each farm enterprise

Min_{cow} is the minimum cash per cow required

Min_{fam} is the minimum family withdrawal expense

α is the down payment percent required on new borrowing

Cap_{Value} is the new land asset value

$Cash_{Res}$ is the cash reserves required of the farm

Finally, the maximum debt-to-asset ratio bid ratio ($Bid_{D/A}$) is calculated as follows:

(14) $Bid_{d/a} = \frac{\gamma*(Assets_{new} + Land_{Value}) - Debt_{new}}{\gamma*(\alpha+(1-\alpha))}$

where: γ is the maximum debt-to-asset ratio allowed

α is the down-payment

$Assets_{new}$ is the new assets required (plus old assets)

$Land_{Value}$ is the market value of the land being bid on

$Debt_{new}$ is the new debt (plus old debt) of the new assets being financed

If an agent cannot pass the land purchase credibility test or is unsuccessful in the land purchase auction, the agent then proceeds to the land rental market. Agent rental bid value is based on the Stage 1 expected income, less family living expenses divided by the total crop acres, and then multiplied by a risk parameter.

After the Stage 1 strategic investment decisions have been made or continued, and the total farm land area is known, farmer agents then enter our Stage 2 “tactical” linear program (Z^2) where they maximize short-run expected annual crop returns over variable cost (15), subject to available cropland and agronomic rotations (16);

(15) $$\max_{X} Z^2 = CX_j^{Jm}$$

subject to;

(16) $$X_j^{Jm} \leq total\ cropland$$

Individual gross margins are based on agent expectations of short-run yields and prices in the Stage 2 tactical program or LP. We assume that annual crop rotations have upper and lower limits for crops including pulses, cereals and oilseeds that vary according to the type of tillage.

The final Stage 3 "recourse" optimization problem (17), Z^3, effectively occurs in the fall after hay and pasture yields are known. The third stage uses a linear program to manage feed inventories and sales/purchases subject to herd nutrient requirements:

(17) $$\max_{t,Fd} z^3 = DT - C^{Fd}Fd$$

subject to:

(18) $$-T + Fd \leq 0$$

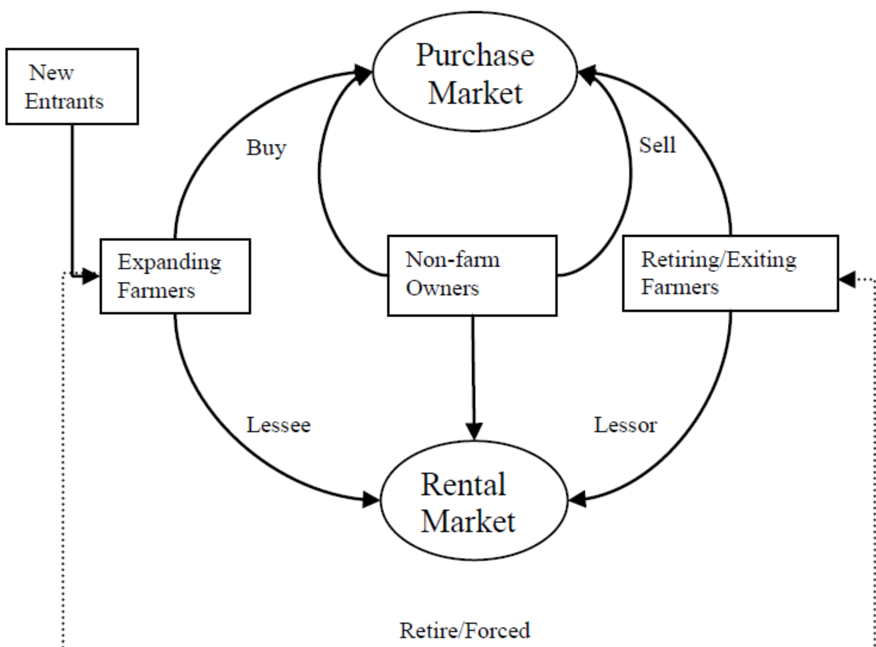
(19) $$-McalFd \leq Mcal(\Delta L + L)$$

The feed transfer constraint (18) consists of –T, the amount of tonnes produced or purchased, while (Fd) is the amount of feed fed to livestock in tonnes. The herd energy requirement constraint (19) requires that mega calories fed to the herd (-*McalFD*) must be greater than the mega calories required (*Mcal*(L)) times the current herd size (ΔL+L).

3.2 Agent behavior: farmland auctions for land purchase or lease

A visual representation of the farmland market is presented in Figure 3 below. Demand for farmland comes from farm agents wishing to expand farm size, and also from non-farm investors. Farmers who can meet cash flow and financial criteria submit land bids for purchase and lease markets based upon their own individual price and yield expectations, as well as associated variable production costs, subject to credit restraints and borrowing limits.

Figure 3. The Simulated Farmland Market



Source: Stolniuk (2008), pp 21.

Supply of farmland comes from the following; 1) farmers who either exit the industry voluntarily; or 2) are forced to exit; and 3) from non-farming land investment owners. Forced farming exits will automatically result in land being available on the purchase market, whereas a voluntary exit will enter either a purchase or lease market, which in the simulation is assigned a likelihood. In this land auction market, each parcel is auctioned separately and consecutively. In the purchase market, the highest bid value wins if it is greater than the seller reservation price. Any unsold land becomes available for leasing in the secondary auction lease market, and there are no reservation prices in the land lease market. However, if no lessor is identified the land becomes idle for the subsequent period.

After the land auctions and third stage farm optimization problem, individual farmer financial statements are updated. This information is linked back to the farm agents, while additional financing may be needed to meet any cash flow deficits. If an agent is unable to maintain sufficient cash flow and their financial position erodes, they may voluntary exit or in extreme cases actually be forced to exit.

All land sales and leases are conducted through auctions. Building again on the work of Stolniuk (2008), our land markets are divided into two types for auction: cropland and marginal land. It is through the ABSM land markets where the majority of the interaction between the farmer and non-farmer agents occurs (Freeman et al., 2009). Subject to the financial and age eligibility criteria, farmers first try to acquire their most desired plots of land through the purchase market, and if unsuccessful, then enter the leasing market since we assume farmers prefer to own land over leasing or renting it.

With respect the behavior of non-farming investor in the land market, we assume that they submit bids on available plots in the land purchase market randomly, and do so in 10% of the auctions. Following Stolniuk (2008) and in lieu of actual data, we assume that 25% of the land that enters the purchase market has an amplified urgency to sell for various reasons. The reasons for urgency might include agent death, divorce or other personal circumstances. In these cases, we further assume the minimum acceptable selling price is reduced by a little over half (65 percent reduced).

In sum, all land up for sale enters the auction process with some minimum acceptable selling price. Minimum acceptable prices for the owners are calculated based on the capitalized expected lease rate. Here, the capitalized lease rate is calculated using the last updated lease rate and the expected change in the lease rate for the coming year based on price expectations for all commodities;

$$(20)\ E(Cap_{Lease}) = L_{r_{t-1}} + \sum_{i=1}^{2} \frac{\left(E(P_{t,i}) - E(P_{t-1,i})\right)}{E(P_{t-1,i})} * L_{r_{t-1}}$$

Where: $E(Cap_{Lease})$ is the expected capitalized lease rate

L_{rt-1} is the lease rate from last year

$E(P_{t,i})$ is the expected price of commodity i

$E(P_{t-1,i})$ is the expected price of commodity i last year

The minimum accepted price for land then becomes:

$$(21)\ \ Min_{accept} = \frac{Risk_{Owner} * Cap_{Lease} * (1 - Adm_{Fee})}{r}$$

Where: $Risk_{Owner}$ is the risk level of the current owner based on random probability

Cap_{Lease} is the adjusted lease of the capitalized lease rate

Adm_{Fee} is the management fee for the auction process

r is the discount rate

The land rental market is also determined based on results from the strategic Stage 1 MIP model. The rental bid value is income based and is calculated from after-tax expected income, less family living, divided by the total crop acres and multiplied by a risk parameter. This equation is written as follows:

$$(22) Rent\ Bid_{income} = \frac{AI}{TCA}\ \alpha$$

Where: *AI* is the after-tax expected Income

TCA is total crop acres

α is the risk parameter of the farmer

Farmland markets for both beef cows and energy crops are conducted in a similar manner, with the exception that the sizing decision is not as critical a component in determining efficient size as it is with annual crop production.

For land purchase, all farmers and investors submit bids to the auctioneer agent. The auctioneer agent inspects all farmland for sale and sorts it according to its productivity rating. This separates land into either cropland or marginal land markets, while in each market, the best quality farmland sells first. The auctioneer agent matches the farmland with the highest productivity rating with the highest bid from a farmer agent or an investor agent. The highest bidder is the purchaser of the plot to be sold, but only if the bid exceeds the computed minimum acceptable price. In turn, if a bid is from a farmer, their bid is adjusted so as to equal the average of the minimum acceptable bid and their actual bid. This adjustment is done to prevent a "winners curse"[3] situation (Besanko and Braeutigam, 2008) for farmers participating in the auction. Farmers who have unsuccessfully bid to acquire additional land in the purchase market, or do not meet financial criterion, then enter

[3] Winner's curse in this market is a situation where the highest bidder gains the purchase or lease, but as a result goes bankrupt due to overbidding relative to other bidders. Since the highest bid is always the winner in our auction, overvaluing land in this manner is a real concern, so our adjusted bid process minimizes the chances of winner's curse.

the land rental market. The lease market follows the same process as the purchase market where farmer agents submit lease bids to the auctioneer agent. However unlike the purchase market, the lease market possesses no land reservation price. If the auctioneer agent receives no bids for the land, the auctioneer declares the farmland unmanaged and the plot remains idle until the next year's land auction starts the process all over again.

Land leases are renegotiated based upon a farmer's age, and follow the same randomized process that is used to determine farm retirement probabilities (Freeman et al, 2009). In effect, if a randomly generated number is greater than the associated lease renewal probability, the leased plot is renewed at that time for a specified period. But if the randomly generated number is less than the renewal probability, the farmer agent does not renew their lease and the land parcel enters the purchase market. In addition, lease values are readjusted to prevailing market lease values if they have either increased or decreased by 20% since the last adjustment to the lease. This is done to better reflect current market conditions for longer term leases in the simulation.

Table 1. Assumed Farmer Retirement Probability

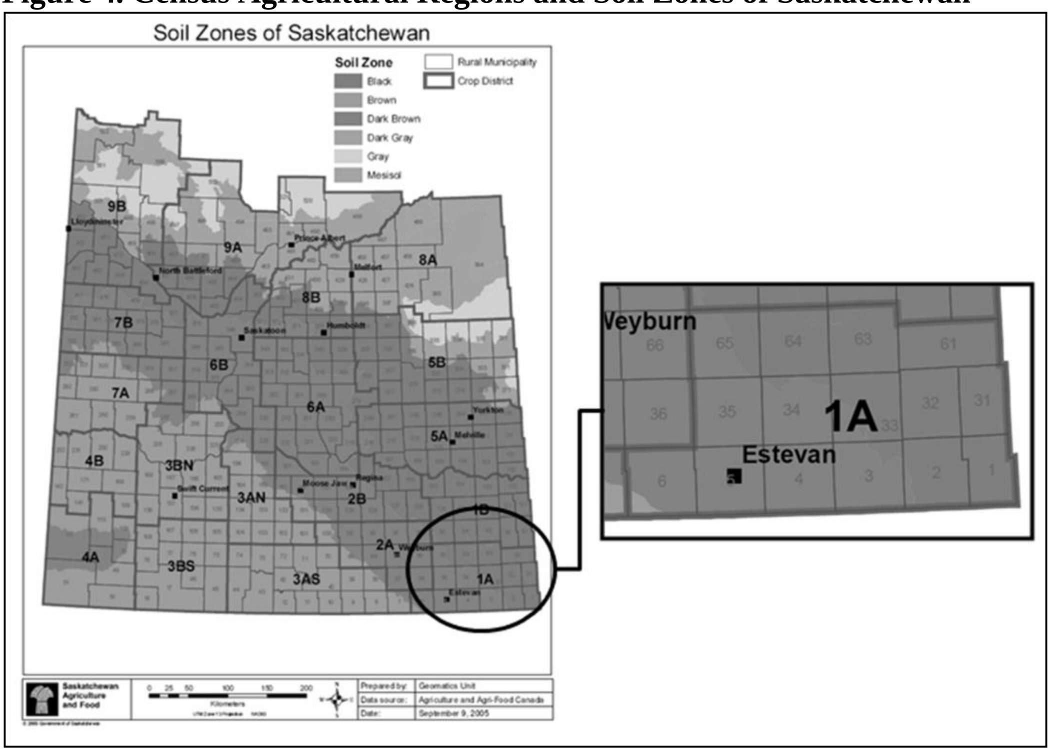
Age	Probability of Exiting
55 - 59	6%
60 - 64	10%
65 - 69	18%
70 - 79	30%
> 80	100%

Source: Freeman et al. (2009)

4.1 The Agricultural Landscape of Southern Saskatchewan

The study landscape consists of Census Agricultural Region (CAR) 1A, located in the southeast corner of the Canadian province of Saskatchewan (Figure 4). In 2006, CAR 1A had a total of 2.1 and 2.7 million acres of cultivated and total farm acres, respectively. It also features 337,732 acres of lower quality land of marginal land used for hay, improved pasture and unimproved pasture. There were a total of 1,823 farms in this region, with an average farm size of 1,474 acres. These where mostly grain farms (1,017) but a considerable number of farms had had beef cows (557), while only a few (less than 50) raised hogs, dairy, and goats (Statistics Canada, 2006). The region is somewhat unique in that it includes both black and dark brown soils in the province, representing a relatively wide range of soil productivity and land use.

Figure 4. Census Agricultural Regions and Soil Zones of Saskatchewan



Source: Saskatchewan Agriculture and Food, 2005

4.2 The synthetic beef cow and grain farm population

A synthetic population is constructed to match the three agent farm types: pure grain farm; mixed crop and beef cow farm and the pure beef cow farm. In addition, it is assumed that the hobby farms here defined as consisting of 640 acres or less can excluded as their personal objectives are unlikely to match those of a commercial farmer.[4] The resulting sub-population consisted of 717 farms with a total farm acreage of 1,247,121 acres or about 46% of the total CAR 1A acreage. The synthetic farm population was constructed to closely represent the actual farm subpopulation in terms of individual farm size, number of cows, assets and debt level, farmer age, land value and off-farm income, based on data from the 2006 *Whole Farm Survey* of CAR 1A (Statistics Canada, 2006).

An initial distribution of farm sizes by farm type was generated according to the known number of farms in each farm size classification. Operator characteristics such as age and farm income, resource endowments including farm capital and relative debt levels and herd size, were assigned according to the class average plus a random term capturing dispersion within that group. In Saskatchewan, since actual land parcels of 640 acres are assigned to each farm, farms must be rescaled to match the integer number of parcels within a farm. This actual assignment is based on a simple ranking heuristic. First, crop and mixed farms with the highest per acre farmland are assigned to the parcels with the highest known property tax assessments for bare land (SAMA,

[4] This also has an important advantage in reducing the total number of patches but not the acreage. Using a patch size of less than 640 acres makes our simulation solution times unrealistically long.

2009).[5] Next, beef cow farms are assigned parcels so those with highest number of cows per acre were matched to remaining farmland parcels with the greatest amount of pasture.

5. ABSM Verification and Validation and the Benchmark Scenario

Verification and validation of the simulation model are important steps in ABSM development. These actions should always be performed when developing economic simulation models (Parker et al. 2001). Verification refers to the method of checking a model to ensure it is "built right" as well as verifying that internal equations are free of errors so that the model conforms to specification (Gilbert, 2008; Balci, 1998).

Verification is essential in monitoring input data used for (in our case) the synthetic farm population, the land base and the (bootstrapped) prices and yields. Both the integer and linear programming farming models were verified by first solving smaller representative examples using the Microsoft Excel©Solver© add-in to ensure no errors were present either in model logic and formulation, along with checking constraints on the coefficients (Anderson, 2012)[6] [7]. In this model, the latter is an important step because it would be easy to mistakenly sign a particular coefficient incorrectly. Other key relationships and equations in the model were verified by comparing simulated output values with calculated values from regional farm data.

[5] All farmland in Saskatchewan has a corresponding classification and productivity quality rating index. In terms of arable land, productivity is determined based on a soil classification system based on historical wheat-yields. The heterogeneity of soil quality and wheat yields on cropland is correlated, allowing for different productivity ratings for corresponding parcels of land. In terms of marginal land, the productivity rating is based on potential beef cow carrying capacity and forage production yields.

[6] Because the IP and LP problems often have to be solved for each farmer agent and each year, in fact there can be over 2,000 IP and LP problems per year in the simulation.

[7] Refer to section 3.2.1.6. in Anderson (2012) for applicable integer and linear programming examples.

Validation answers the question “are we building the right model?” (Balci, 1998). This tells the researcher whether the model can be relied on to accurately represent the real world. Performance measures in this regard are generally based on comparing simulated results to real world data (Gilbert, 2008; North and Macal, 2007). Validation seeks to guarantee that the results generated endogenously are correct and the model performs accurately. Model complexity and stochasticity associated make it extremely difficult to validate our results in a typical fashion. Direct comparisons to regional statistical averages are also complicated in that the synthetic population is a subset of the entire population: small farms of less than 640 acres and other livestock farms are excluded and hence comparisons can only be approximate. In fact, three endogenously generated values in the model are validated - annual crop acres, beef cow numbers and farmland purchase values.

First, annual crop acres are endogenously determined so they can be used to validate the crop module. Individual agent land use is the result of Stage 1 optimization based on the maximization of gross margins (Eq 15), subject to land quality and rotation constraints (Eq 16). Even though 2008 yields and prices were set at their actual values in the bootstrapping process, individual commodity prices may still vary because of differing agent expectations and risk attitudes, while actual farm yields also vary according to the individual farmland productivity, so that individual agent gross margins may also vary. Simulated regional land use is based on the mean of aggregate results for 50 replicates of the first year. Because our synthetic agent population is a subpopulation with a lower total acreage, aggregate acreage estimates are not directly comparable between the simulated acreages and actual CAR1A acres, so comparisons are based on crop mix percentages. In fact, the simulated aggregate crop mix tended to overestimate peas and, canola and barley and underestimated spring wheat percentages. This is likely due to the omission of small farms that seed more traditional mixes that favour hard red spring wheat and fallow and exclude canola and field peas (see Table 3). So while not an exact match to all of the real data, for the purpose of our objectives most of the simulated crop estimates are close enough by comparison that we accept the overall reliability of our crop mix module.

Table 3. Comparison of Actual 2008 and Simulated Crop Production Mix, CAR 1A[8]

Source	Fallow	Hard Red Spring Wheat	Durum Wheat	Field Peas	Flax	Canola	Spring Barley	Lentils	Total
Simulated	0.0%	4.6%	16.7%	27.2%	5.3%	29.2%	16.0%	0.0%	99.0%
Actual	9.1%	23.2%	11.3%	8.3%	10.7%	23.7%	11.8%	1.9%	100.0%
Difference	-9.1%	-18.6%	5.4%	18.9%	-5.4%	5.5%	4.2%	-1.9%	-1.0%

Source: Actual yields: Saskatchewan Ministry of Agriculture

The last and most powerful overall validation test is to compare average 2008 simulated bid values to the actual farmland prices paid in CAR1A. In effect, this tests all of the model subsystems. The simulated land transactions from the various auctions averaged $453 per acre for 2008, a level comparing very favorably to the average farmland price sold of $426/acre based on a weighted average of land parcels over 40 acres (Farm Credit Canada, 2010).

While the model subsystems for the base simulation can be compared to real world data, this cannot be the case with the SGB and energy price scenarios as they are currently beyond historical experience. Hence, they can only be qualitatively assessed against expert knowledge and experience gathered through research and consultation.[9]

[8] The actual percentages are only based upon crops used in this model and exclude other minor crops grown in CAR 1A. The simulated percentage does not total 100% because of rounding errors.

[9] Research was based on information obtained in a literature search, as well as consultation with professionals in the

Three different simulated scenarios were evaluated. We start with a base scenario without energy crops, and then simulate two different energy price scenarios. The base scenario excludes energy crops from farm decisions while the two alternate scenarios model the possibility of planting energy crops, examining farmer reactions to different energy crop prices. Each scenario was simulated for 30 years using identical crop price and yield time paths through the simulation period. In turn, this allowed us to generate 50 different time paths using a bootstrap type procedure on the simulated data.[10]

6. Simulated Long-run Farming Structure with SGB Crops

In addition to the base scenario that excluded energy crops, two additional scenarios are simulated: 1) inclusion of energy crops at a constant price of $2/GJ; and 2) inclusion of energy crops at a constant price of $4/GJ[11]. Following Stolniuk (2008), farm structure, sector performance and energy crop adoption is simulated for each scenario using 50 identical (bootstrapped) price and yield 30-year time paths. In the following sections, important simulation results are presented about the sector and region. Specifically, we detail the rate of energy crop adaptation among farms as well as the evolution of farm financial structure.

willow and tall grass industry.

[10] The various yield and price time paths use a bootstrap procedure as described in section 4.2.3 of Anderson (2012).

[11] Unless otherwise specified all prices used in this model are listed in Canadian dollars.

6.1 Trends in the adoption of SGB energy crops

For ease of exposition, simulated energy crop acres are displayed for the years 2008, 2014, 2021, 2029 and 2037 in Tables 4 and 5. These years were chosen to better illustrate changes in farm acreage over the simulated time interval.

With the introduction of energy crops, farmer agents immediately responded by planting them under both the $2/GJ and $4/GJ price scenarios. In the $2/GJ scenario, planting starts off in 2008 with 160,597 acres of energy crops, of which 139,997 acres is devoted to willow. In all of the simulations and in accordance with expert opinion, willow plantations seem to be the choice amongst our farmer agents as these are the most profitable of the considered SGB alternatives[12]. Note as well that for the $4/GJ scenario, farmers increase their use of energy crops by approximately 2% more acres, up to 163,943 acres.

In both energy crop scenarios, energy crops shift into pasture lands first, followed by hay land. Since energy crops yields are similar for these two land types, this effect was expected. Total energy crop acres reach approximately 80% of marginal lands by years 2014 and 2020 in the energy price scenarios, and approximately 86% of the marginal acres by 2020 in the $4/GJ scenario[13].

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[12] In earlier simulation models hybrid poplar trees were incorporated but the code for poplar was subsequently turned off in this simulation. We decided to turn off poplar trees in this simulation because they always generated a lower expected contribution margin than willows and as result no acres of hybrid poplar were generated from the MIP. Poplar was assumed to be harvested on the same rotation as willows; in future simulations longer poplar stands might produce different results. excluded in this

[13] The percent of marginal land in Tables 1.0 and 1.1 refers to the total energy crop acres out of a total of 246,547 marginal acres.

Table 4 Simulated Total Average Energy Crop Acres, $2/GJ Scenario

Total Energy Crop Acres - $2/GJ Scenario									
Year	Willows Natural Pasture	Willows Improved Pasture	Willows Hayland Pasture	Prairie Sandreed Natural Pasture	Prairie Sandreed Improved Pasture	Prairie Sandreed Hayland Pasture	Total Energy Crop Acres	Energy Crop Percent of Marginal Land	Total Hay and Pasture
2008	67,469	31,880	40,648	6,008	4,970	9,623	160,597	66%	84,347
2014	79,369	43,619	52,381	5,388	5,155	10,336	196,248	80%	48,022
2020	82,947	49,813	62,283	1,708	1,855	4,077	202,683	83%	40,714
2021	83,351	50,576	63,957	1,631	1,703	3,803	205,020	84%	39,787
2029	84,056	49,566	63,514	1,180	1,291	3,058	202,664	83%	42,598
2037	84,294	46,595	57,972	1,006	1,036	2,548	193,451	79%	52,082

Table 5 Simulated Total Average Energy Crop Acres, $4/GJ Scenario

Total Energy Crop Acres - $4/GJ Scenario									
Year	Willows Natural Pasture	Willows Improved Pasture	Willows Hayland Pasture	Prairie Sandreed Natural Pasture	Prairie Sandreed Improved Pasture	Prairie Sandreed Hayland Pasture	Total Energy Crop Acres	Energy Crop Percent of Marginal Land	Total Hay and Pasture
2008	70,975	32,916	42,485	5,852	4,356	7,358	163,943	67%	81,065
2014	79,654	48,596	58,454	5,628	4,433	7,978	204,744	82%	43,789
2020	83,404	55,235	68,327	1,688	1,687	3,071	213,411	86%	35,002
2021	83,624	55,613	68,539	1,475	1,341	2,805	213,396	86%	34,806
2029	84,257	52,601	65,138	1,063	949	2,258	206,267	83%	41,057
2037	84,492	51,352	63,119	896	834	1,931	202,624	82%	44,217

Over time, energy crop acres planted in prairie sandreed shrink dramatically as land area gradually shifts into willow production. Initially in the simulations, Prairie sandreed was adopted by farmers because of high investment costs associated with willow production under credit constraints. But as that initial prairie sandreed grass came to the end of its life-cycle in the simulation, marginal acres were all converted to willow production.

Initially, beef cattle farms are the dominant farm type adopting energy crops. They account for 74.3% of the energy acres, while mixed farms and crop farms initially account for 15.4% and

10.4% of these acres respectively. The reason for this is simple - beef farms operate on most of the marginal land in the region. Over time, both grain and mixed farms include more energy crops in their rotations (see Table 6). At the end of the simulation, mean energy crop shares are 10.9%, 23.4%, and 65.0% respectively, for grain, mixed farms and beef cow farms in the \$2/GJ scenario. Similarly, the \$4/GJ scenario generates mean crop shares of 10.4%, 23.9% and 65.3% for grain, mixed and beef cow farms. Mixed farms increase their energy acres relatively more than the others as they have the greatest flexibility in utilizing all land types.

Table 6 Simulated Mean Energy Crop Acres by Farm Type

Scenario \$/GJ	Year	Grain Farmer Agent	Mixed Farmer Agent	Livestock Farmer Agent
\$2/GJ	2008	49	169	533
	2037	95	373	1003
\$4/GJ	2008	52	177	538
	2037	96	396	1009

Total energy crop acres grown by farm classification are shown in Table 7. Beef cow farms grow the majority of energy crops with 119,944 and 121,059 acres initially, for the \$2/GJ and \$4/GJ scenarios respectively. Mixed farms generate the greatest increase in energy crop acres with 45,351 and 48,487 for each of the \$2/GJ and \$4/GJ scenarios by the year 2037. The average annual increase in these acres for mixed farms is approximately 2.2%, while the grain and livestock farms both had an average annual increase of less than one percent in both energy price scenarios.

Table 7 Simulated Total Energy Crop Acres by Farm Types

Scenario	Year	Grain Farms	Mixed Farms	Beef Cow Farms
$2/GJ	2008	16,365	24,284	119,944
	2037	21,000	45,351	125,656
$4/GJ	2008	17,367	25,517	121,059
	2037	21,086	48,487	132,311

6.2 Farm financial structure and performance

Assessing total sectoral well-being using typical static economic measures like producer welfare or surplus is difficult in this instance because of the dynamic nature of the simulation, including on-going investment decisions, cash flows, off-farm income and taxes. Accordingly, sectoral well-being and vitality is appraised by comparing simulated to actual farm financial structure. To gauge farm financial viability and long-run growth with respect to net worth, financial characteristics in the model are tracked using a balance sheet approach, similar to that done in Stolniuk et al. (2013). In this context, measures of sector well-being used in the simulation include total sector income, equity and structural change associated with farm numbers, farm transfers, bankruptcies, cash flow exits and retirements. The latter are included in farm financial structure because they are directly related to the overall financial solvency and liquidity of each farm.

The base case scenario generates a final farm equity average increase of 3.66% per year over the 30 years, terminating with a final value of just over $2.3 billion (Table 8). The first energy crop scenario equity at $2/GJ is only slightly higher than the base scenario at $2.53 billion with an average annual increase of 3.93%, meaning the latter is close to a break-even situation. In fact, total sector equity is the greatest under the $4/GJ energy crop scenario at $3.57 billion, a total generated by an average annual increase of 5.12%.

Table 8 Simulated Farm Sector Equity, All Scenarios

	Year	Base	$2/GJ	$4/GJ
Initialization - Year 0	2007	$ 786,290,901	$ 797,152,874	$ 796,645,874
Year - 30	2037	$ 2,310,123,821	$ 2,531,337,181	$ 3,567,794,003
Average Annual Change		3.66%	3.93%	5.12%

Net farm income is an important component in generating farm equity. But note that in the first year of the simulation (2008) except for Prairie sandreed, energy crops have little effect as their generated income is necessarily delayed - total sector net income from energy crops runs from $118,655 to $366,444 respectively (see Table 9). The initial energy crop income generates returns of $5.76 and $20.86 per acre for Prairie sandreed in the $2/GJ and $4/GJ scenarios respectively. However, by the end of the simulation, mean energy crop net income ranges from $33.4 million to $104.3 million, respectively, for $2/GJ and $4/GJ scenarios. The $2/GJ energy crop net income represents a per acre return of approximately $173 per acre per year, or $518 per acre when the estimated majority of the biomass is harvested every three years. The return in the $4/GJ scenario corresponds to approximately $514 per acre per year or $1,545 per acre over three years, when the $104.3 million of gain is averaged over the 202,624 acres of energy crops.

Net crop income is minimally affected by the introduction of energy crops because they compete for different land qualities. However, we infer that there may be significant indirect effects on sector health as cash flow is improved, facilitating investments and thus potentially improving sector efficiency.

On beef cow farms, most if not all (at least in the later years of the simulation) hay production is transferred to the beef herd. Since internal transfer credits are not generated, net hay income is accordingly negative.[14] In the case of the base scenario, net hay income eventually becomes positive because of increasing hay sales, although it is still relatively small. Subsequently, net hay income drops over time in the energy crop scenarios compared to the base scenario, while this drop occurs because of the shift in acres to energy crops. From Table 9, we see that by the end of the simulation, mean sector net beef cow income decreases from the base scenario compared to the $2/GJ energy crop scenario by approximately $504,799, from $19.6 million to $19.1 million, despite the total beef cow herd size being just over 10,000 cows less. In addition, beef cow income also includes hay sales and in the base scenario it is likely that some farmer agents were losing money on their hay sales. In fact, the price of hay in the model was determined endogenously and we find that in some years when the hay contribution margin is high, significant hay is grown for resale. Ultimately, we also find that beef cow income decreases to $9.4 million in the $4/GJ price scenario.

[14] Net hay income is included as beef cow income for beef cow farmers because the costs associated with growing hay are difficult to separate when a proportion is sold and another is fed.

Table 9 Simulated Average Total Net Income, All Scenarios

Scenario	Year	Total Income	Energy Income	Crop Income	Hay Income	Beef Cow Income
Base	2008	$ 65,884,964	$ -	$ 56,492,402	-$ 16,798	$ 9,409,360
	2037	$119,668,633	$ -	$ 99,627,133	$ 428,893	$ 19,612,606
$2/GJ	2008	$ 67,153,155	$ 118,665	$ 57,719,646	-$ 16,793	$ 9,331,637
	2037	$158,987,397	$ 33,421,518	$ 106,431,835	$ 26,236	$ 19,107,807
$4/GJ	2008	$ 67,468,152	$ 366,444	$ 57,804,753	-$ 16,789	$ 9,313,744
	2037	$214,968,470	$ 104,317,938	$ 101,216,065	-$ 6,341	$ 9,440,807

6.3 Discussion and summary of results

The MIXFARM simulation was used to evaluate the consequences stemming from the introduction of certain energy crops into the agricultural economy of Canadian Census Agricultural Region 1A, an important agricultural region in the province of Saskatchewan. Key variables such as sector profitability, the number of beef cows and marginal land use were simulated and tracked over a 30 year period. Three scenarios are considered, consisting of a base scenario (with no energy crops), and two energy crop scenarios (energy prices of $2/GJ and $4/GJ, respectively). In turn, each scenario uses the same (bootstrapped) crop price and crop yield time paths. Finally, the synthetic population in the simulation is a subset of the total actual regional farm population since some real farms had to be excluded from the analysis.

This model was initially verified by examining integer and linear programming farm rotation optimization problems and comparing simulated values with calculated values. Subsequently, model validation was done by confirming that simulated farm accounts actually balance. This process illustrated internal model consistency and also ensured that the simulation results converged at the farm level. However, we understand that by definition our model verification is incomplete because of the speculative nature of the SGB simulations. But overall, we find that the MIXFARM-ABM model seems to mirror historical farm population statistics reasonably well, factoring in the likely differences between the synthetic subpopulation and the real populations in the region. We conclude that MIXFARM-ABM model performance is a reasonable representation of current reality as well as the foreseeable future of farming in the region.

In each of the scenarios and under most of the time paths used as input, a basic trend of both larger and fewer farms across the region continued into the long run. These broad results are consistent with prior related work of Freeman et al. (2009), Stolniuk (2008) and Stolniuk et al. (2013) who found that mixed farms tend to dominate farming in the region since they make the best use of both cropland and marginal land. Given this, the introduction of energy crops in the simulation generated smaller changes for grain farmers as compared to both mixed and beef cattle farms. In the energy crop scenarios, energy crops effectively pushed out beef cows and hay production, as well as reduced average total farm size and mean crop acreage. For the region, energy crops generated greater structural changes for beef cow and mixed farms than for grain farms.

Total farm sector equity and farm income improved under both energy scenarios. Energy crop production can be somewhat profitable even with low energy prices or very profitable at higher energy prices. By the end of the simulation, total agricultural farm sector equity grew to between \$200 million and \$1.2 billion, respectively, for the \$2/GJ and \$4/GJ energy crop scenarios. While farm financial structure as measured by outstanding debt showed only minor improvements over time under the \$2/GJ scenario, it did improve significantly at the \$4/GJ price, characterized by reduced bankruptcies and forced exits.

7. Summary and Conclusions

Agent based simulation models of farming behavior allow for evaluation of those issues associated with potential structural change, and are illustrated by simulated output on farm numbers, farm types and individual financial status. ABSM's allow for realistic heterogeneity in the landscape and in the farm population. They also readily incorporate dynamic aging and farm succession effects as well as allow farmer interaction in farmland purchase and leasing markets. Individual heterogeneity, interaction and the feedback of farm and land prices to the farm decision making process implies that farming is truly a complex economic system, one that cannot be accurately modeled by static or analytic models of farming.

Building upon an economic perspective on the issue, we assumed that farmers in this simulation will not necessarily adopt second generation energy crops simply because they are beneficial to the environment, but will only do so if they are profitable. Farmers maximize profit by using a combination of land, machinery, labour, inputs, management, and given their resource endowments, produce their optimal commodity mix. By each using an optimal combination of resources in production, farmers free up scarce resources allowing other farmers in the simulation to produce commodities that the marketplace deems valuable.

It is well understood that energy crops have the potential to change the structure of modern agriculture, but the simulation shows that this effect should occur primarily above the $2/GJ price threshold. The continued planting and harvesting of energy crops emerges within the simulation in both of the energy price scenarios, and we find that total farm sector equity and total sector net income is improved over the base (i.e. no energy crops) scenario. Farmers with significant quantities of marginal land experience the greatest change in their farm structure through the adoption of energy crops, if they choose to go down this path. However the spillover effects of this adoption will be felt throughout the entire regional beef industry as cattle numbers will be gradually reduced. Finally, the simulation results also indicate that all pure beef cow farmers are actually better off with the introduction of energy crops as compared to the base scenario, since energy crops stabilize and maintain farm income as average farm size decreases.

Like most policies designed with good societal intentions, we find that in fact the development and use of SGB's may lead to substantial and possibly unwanted trade-offs in agricultural economies. If energy prices become high enough, the model indicates that structural changes in the farming sector will be significant, eventually leaving a very different agricultural landscape than the one we see today. From an agricultural policy perspective, governments must remain aware that other critical agricultural sectors (in this case, beef) will almost surely be strongly affected by the introduction of second generation energy crops. How this latter situation will affect food supplies and prices for consumers will certainly become a crucial issue as the world struggles to both feed and power itself into the 22nd century.

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