An Agent-Based Simulation of Wheat Based Ethanol Plant Location Decisions for Saskatchewan

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by
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ABSTRACT

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First generation ethanol production has experienced rapid expansion but is now at a crossroads facing impending industry transformation. While Saskatchewan's ethanol industry has benefited from demand and policy instruments that have guided substantial growth in recent years, changing policy and market dynamics present new challenges which are compelling the industry to adjust. This thesis examines three factors that are suspected to influence ethanol plant locational decisions. The development of an agent-based simulation model in this thesis will ascertain how transportation networks, market synergies, and subsidization influence location stability for an ethanol plant. The long term interaction of these factors is unknown, therefore do tradeoffs exist between these factors or is it conditional for all to be present?

Modeling factors that affect location stability through an agent-based approach creates a dynamic framework to understand how location attributes impact an ethanol agent's longevity. It was found that location stability is affected by an ethanol agent's distance to both primary transportation networks as well as product markets. Surprisingly, distance to DDGS (dried distillers grain with solubles) markets, a low value by-product of ethanol production, has a profound effect on location stability.

Policy instruments and industry subsidization are considered key ethanol development drivers and the surge in ethanol industry growth brought hopes of rural revitalization. In Saskatchewan, policy was developed to support small ethanol plants, those 25 Mmly (million litres per year) or smaller, aimed at increasing farmer investment and alternative markets for wheat. Measuring the effect of subsidization on location stability was fundamental to understanding how a post subsidized ethanol industry may look. The research found that subsidization of Saskatchewan's ethanol industry dramatically affected economies of scale and location decisions, which left ethanol agents unable to compete in an increasingly competitive ethanol industry.

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LIST OF ABBREVIATIONS

Abbreviation	Name	First Reference
CRFA	Canadian Renewable Fuels Association	1
Mmly	Millions of litres per year	1
MTBE	Methyl tertiary butyl ether	1
MGY	Millions of gallons per year	2
ABM	Agent-based modeling	4
DDGS	Dried distillers grains with solubles	4
GIS	Geographical information systems	5
WTO	World Trade Organization	14
FOB	Free on board	14
CIF	Cost in freight	14
US	United States	15
ABMS	Agent-based modeling and simulation	18
NPV	Net present value	33
KM	Kilometers	35
CAR	Census agricultural region	36
PV	Present value	40
MT	Metric tonne	47
EGP	Ethanol Grant Program	49
kg	Kilogram	51
LPM	Litres per minute	59
L	Litre	59
AVC	Average variable cost	71
CGC	Canadian Grain Commission	73
NIAT	Net income after taxes	98
WDG	Wet distillers grains	106

CHAPTER 1

INTRODUCTION

1.0 Introduction

Ethanol, a denatured alcohol used as a gasoline additive for its oxygen and octane content, is currently blended into all gasoline in Canada. It is considered to be a viable yet sustainable substitute for gasoline. Due to this, its market price should track closely with gasoline prices, providing that demand and supply in these markets are in concordance (Eathington and Swenson, 2007). However, to be a useful alternative to conventional gasoline ethanol should provide a net energy gain, hold environmental benefits, be economically competitive, and marketable in large enough quantities without affecting food supplies. To address the well-known food versus fuel debate and expand this industry, a number of ethanol production sources have emerged, including: biomass, cellulosic, wheat, milo (sorghum), corn, and municipal landfill waste. In Canada to date, ethanol is derived mostly from corn (73%), with wheat (17%), barley (3%), agricultural and forestry waste (7%) comprising the remainder of production (Viju, 2008).

As of August 17, 2009 the Canadian Renewable Fuels Association (CRFA) listed seven ethanol plants using wheat as a source material for production (Canadian Renewable Fuels Association, August 17, 2009). Those plants are located in Western Canada. One is in Manitoba, five are found in Saskatchewan and one in Alberta. If the province of Saskatchewan is considered by itself, the five wheat based ethanol plants there produce a total of 342 million litres per year (Mmly). The ethanol plants in Saskatchewan require approximately 1,026,000 tonnes of wheat feedstock per year. By way of comparison, a 100 Mmly wheat ethanol production plant requires approximately 300,000 tonnes of feedstock or an estimated 250,000 feedstock production acres, and would consume about 700 acres worth of production per day (Natural Resources Canada, February 12, 2011). Extrapolating, the five Saskatchewan ethanol plants require approximately 855,000 acres of farm land committed to wheat production to satisfy their current input demand.

1.1 Development of an Ethanol Market

There are a number of reasons for increasing the use of ethanol in fuel. These include restrictions on the use of methyl tertiary butyl ether (MTBE), high energy prices, reducing societal reliance on gasoline, social benefit of renewable fuels, gasoline alternatives, greater recognition of the environmental consequences of fossil fuels, rising oil prices, concerns about petroleum supplies, increasing energy imports, and political instability in the Middle East where the majority of crude oil is produced for gasoline (Solomon et al., 2007; Hill et al., 2006). These factors, when combined with increasing gasoline quality requirements, evolving clean air regulations, and a ban on the only other oxygen-enhancing additive, MTBE, are creating continued growth in demand for fuel ethanol. For example, the contamination of both ground and surface water from MTBE provided an initial push for more recent fuel ethanol industry growth (Russell et al., 2009).

Low and Isserman (2009) conclude that ethanol production, feedstock premiums, additional feedstock production, and potential livestock production increases are four possible effects a new ethanol plant may have on the local economy. Given the similarities between corn and wheat ethanol production, S&T^2 Consultants Inc. (2003) conclude that these findings would also provide similar impacts for a wheat ethanol plant, based on the caveat that location dependent analysis is required to confirm these impacts and profitability over time.

The most noticeable and positive opportunity for ethanol development in Western Canada is in providing a new economy for rural areas, furthering the government's desire for rural revitalization. The push for biofuels as an alternative energy source has revived the idea of rural revitalization and that rural areas may have a comparative advantage due to their access advantage to feedstock materials (Lambert et al., 2008). Both rural communities and farmers (producers) consider ethanol an attractive venture given its potential to offset rural out migration and unemployment, as it can provide sources of off-farm work and could increase farm income through backward linkages to local agricultural production (Lambert et al., 2008). New plants and plant extensions create new jobs, broaden the tax base of communities, and increase local incomes. For example, a 50 million gallon per year (mgy) ethanol plant employs approximately 36 individuals while a 100 mgy plant can provide 46 full time jobs, however this does not include indirect (suppliers) and induced jobs (due to household spending), which can range from 98 to 124 additional regional jobs (Eathington and Swenson, 2007).

Ethanol use is growing, driven mainly by petroleum markets and mandated blend levels. As surface and ground water contamination concerns were confirmed regarding MTBE, the demand for a safe antiknock[1] agent intensified. Combining this event with an environmental push for clean and renewable burning fuels and political drive to reduce oil dependence on other countries led to the dramatic increase of ethanol production. Government programs offered industry support and many were aimed at reducing rural out migration with the hope of revitalizing rural communities. Research supporting job growth and investment in rural areas as a result of ethanol projects varies greatly but the end result appears to be positive for selected communities.

1.2 Research Objective

There is sparse research regarding the location of ethanol plants in the Canadian context and much of the current research revolves around the basic economics of plant operations. The Canadian industry uses a variety of feedstocks to produce ethanol with locations commonly found in rural areas. Location is pushed by a need to minimize transportation costs, and given the weight losing nature of the industry where large quantities of feedstock are required, firms will tend to locate near areas of production to minimize costs (Huang and Levinson, 2008). Locational effects must also consider changing transportation networks, policy direction, and synergies with end users. Given this, it is imperative that locations be optimally chosen based on sound research to avoid high expenses or premature plant shutdown.

A simulated rural landscape has been developed in this research in order to generate insight into the interaction of multiple factors in plant location, as well as showing how a small change in a certain factor can dramatically affect locational decisions. In fact, the following analysis of the interaction between ethanol plants and the landscape has shown that initial considerations about the industry in this regard are not always correct. Agent-based simulations yield results that may not be uncovered using static economic analysis. It is these results that potentially hold unnoticed insights and solutions to key industry decisions.

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[1] An antiknock agent is a gasoline additive designed for internal combustion engines to prevent early ignition of gasoline (engine knock).

1.3 Research question

As the ethanol industry continues to mature, there are a number of barriers that will need to be overcome to ensure success and sustainability. These hurdles include market demand, policy, feedstock competition, and aging transportation infrastructure. How the current and future industry players respond and plan for these factors will have significant effects on the size and financial health of their operations.

The following research seeks to uncover what factors influence ethanol plant location in the province of Saskatchewan, and whether those locations can remain stable overtime. Specifically, the following three primary locational factors are considered in this analysis:

- transportation network
    - proximity to reliable and efficient transportation is essential for stable locations
- market synergies
    - proximity to both ethanol and dried distillers grains with solubles (DDGS) markets is important
- policy effects
    - current policy initiatives have predisposed the industry to smaller ethanol plants and limited economies of scale necessary for efficiency and competitiveness

This thesis utilizes an agent-based simulation to reveal the importance and effects these factors have on ethanol plant locational decisions in this region. Due to the nature of the problem and the method of analysis, the potential for emergent or unanticipated results exists and such outcomes may play an important role in understanding the nature of a sustainable or stable ethanol plant location.

1.4 Motivation for Study

Agent-based modeling (ABM) is increasingly being utilized in the social sciences to understand the decision making process and interactions found in social systems. ABM opens the opportunity to understand how complex systems evolve through agent interaction and move dynamically towards equilibria. The dynamic economic assumption of change in the movement towards equilibrium contrasts traditional static economic assumption of uniformity at a specific equilibrium (Kuznets, 1930). Hilletofth et al. (2009) offer that ABM is a new paradigm especially suited for complex and dynamic systems distributed in time and space. It is this characteristic that would seem well suited to identifying potentially stable locations for ethanol plants in the study region.

Broadly, agent-based models and specifically the NetLogo© software used in this thesis have been utilized recently to study a variety of related issues. These include the analysis of optimal supply chain configurations (Kawa and Golinska, 2010), land use (Lechner et al., 2004), the use of seaport container terminals (Vidal and Huynh, 2010), and traffic congestion (Hirankitti and Krohkaw, 2007). Agent-based models are also gaining acceptance and have already contributed to related literature in agricultural economics. Research areas that have benefited include the study of regional structural change (Happe, 2004; Freeman, 2005; Stolniuk, 2008), agricultural policy impacts at the farm and regional scale (Happe et al., 2006), farmland auctions (Hailu and Thoyer, 2007; Arsenault, 2007), and technology diffusion or adoption patterns (Berger, 2001). However, as of this writing, almost no research using this methodology has been applied to study locational issues in the growing ethanol industry.

Some of the growing literature on the ethanol industry rely upon linear programming methods to identify the optimal number, location, and size of cellulose ethanol plants in North Dakota (Taylor and Koo, 2010), while others use geographical information systems (GIS) software to determine the optimal placement of new ethanol plants based on feedstock availability within a geographic area (Eathington and Swenson, 2007). Others studies use traditional top down empirical analysis to study localized feasibility and economic impacts of ethanol plants (Low and Isserman, 2009; Herbst et al., 2003). In fact, spatial aspects of the ethanol industry have also been examined, including analysis of spatial pricing options on industry organization (Graubner et al., 2011 and Sarmiento and Wilson, 2007), market welfare impacts (Van Wart and Perrin, 2009), as well as effects on local corn prices (Katchova, 2009). However, the inclusion and analysis of individual ethanol plant interactions within a simulated landscape in a situation where more than one stable equilibrium might exist has not yet been addressed to the knowledge of this author.

This thesis contributes to the ethanol related literature by extending the research on ethanol plant location in a situation where heterogeneous plants try to stabilize their location decisions over time. This work uses the NetLogo© software in a novel manner in order to develop a better understanding of the ethanol industry in the region, as well as assist with future planning issues. Since the model assumptions are based on information and decision parameters that reflect real world behavior, this research also provides an opportunity to simulate future spatial organizational structures in the industry as key parameters are varied.

1.5 Thesis Overview

The agent-based simulation that has been developed within this thesis is slightly different from other agent-based models of spatial or locational issues. In most of these simulations, the expectation is that the agents (in this case, ethanol plants) would gradually emerge on an initially empty landscape because of changing market conditions over time. Given the research question, it was more instructive to combine together a basic optimization framework within an agent-based simulation. On one level, what this implies is that a standard locational optimization method like linear programming would have difficulty identifying solutions due to the scale of the problem under consideration. However, when optimization heuristics are linked with an agent-based simulation approach, it was discovered that finding good or stable solutions is more manageable.

The nature of discovering what one would call ‘stable’ ethanol plant locations is not a simple optimization problem as any number of spatial interactions and associated consequences could generate more than one stable location set. During model operation, the landscape is initially populated with many ethanol plants that are gradually eliminated through simulated time by a number of effects. This process of elimination eventually leads to the identification of the most stable plant locations in the region or space under consideration. In fact, these stable locations or solutions represent multiple equilibria in the model. The spatial aspect of these identified stable locations will provide insight not only about the actual physical location of the ethanol plant, but also those local factors that lead to locational stability.

1.6 Thesis Organization

This thesis is divided into seven chapters. Chapter One introduces the research issue and provides general background information on the ethanol industry. Current location, transportation, and ethanol industry organization literature is reviewed in Chapter Two, while Chapter Three discusses and reviews agent-based models and their application in the literature. Development of the agent-based simulation model, the underlying structure of the simulation environment and its construction within the NetLogo© software is described in Chapter Four. Chapter Five outlines parameter settings and initialization of the base location model, as well as a description of the counterfactual simulation. Chapter Six discusses the simulation results and how they inform the location question for potential future ethanol plants across a vast Western Canadian landscape. Lastly, Chapter Seven concludes by discussing study limitations as well as areas of further research.

CHAPTER 2

Review of the Ethanol Industry

2.0 Introduction

The main factors driving the current growth in ethanol demand include policy objectives, clean air regulations, and methyl tert butyl ether restrictions. However, its primary use as an antiknock agent in gasoline leaves ethanol pricing tied to petroleum market pricing, thus creating considerable price volatility in the current ethanol market. Price volatility combined with typical market contracts of short duration (six to twelve months) can lead to financial uncertainty in ethanol production and a high likelihood of industry instability in this regard.

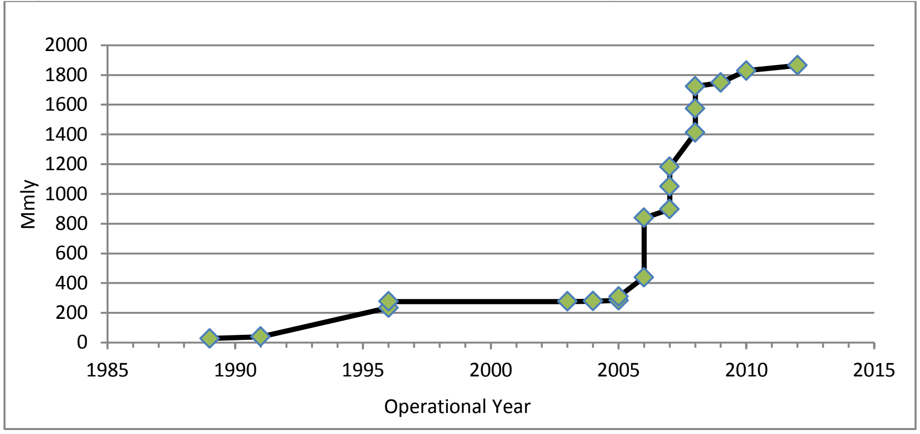
These effects of price volatility can be mitigated if ethanol plants are able to take advantage of economies of scale. Traditionally, larger plants in this industry have been able to outperform smaller plants given their lower average costs and the ability to obtain a larger number of sales contracts. The latter aids in spreading risk, thereby, reducing the potential effects of price volatility. Given these obstacles, the ethanol industry continues to grow in Canada, but how these factors may influence future industry structure remains to be seen.

2.1 Industry Organization

Canada’s policy objectives for expanding the biofuel industry include reducing greenhouse gas emissions, raise and stabilize farm incomes by increasing the demand for farm commodities, and promote rural development and diversification by encouraging biofuel plants in rural communities (Le Roy and Klein, 2007). The recent growth in ethanol production has been driven by both small and large scale producers. Many of the small ethanol producers in Canada have entered the market using direct subsidies and policy objectives aimed at rural revitalization. Some of the small ethanol producers have also organized as cooperative or producer (farmer) owned ventures, but these plants are typically under 25 Mmly and thus fail to exploit economies of scale present in plants that typically produce over 100 Mmly (Olar et al., 2004).

From 2005, a set of policy, environmental, and industry changes have allowed ethanol production to increase dramatically. Data obtained from the CRFA illustrates the rise of industry production capacity as shown in Figure 1. The dramatic increase in production capacity coincides with provincial mandates, policy and subsidy programs, consumer demand, and anticipation of the federal renewable fuels strategy (Canadian Renewable Fuels Association, 2010).

Figure 1: Canadian Ethanol Production Capacity[2]



The majority of new ethanol plants are standalone operations. In fact, very little vertical integration has been seen in the North American market. Price volatility in the ethanol market may keep some blenders and petroleum producers from backward integrating as margins are thin and financial risk is high (Low and Isserman, 2008; Chan and Reiner, 2011). Also, ethanol is only one of the many inputs in the production of gasoline, so based on economic analysis it may be inefficient for petroleum producers to invest in ethanol technology. Likewise, ethanol producers may find it ineffective to forward integrate given the high capital cost and market domination found in the petroleum refining market. But as the ethanol market continues to evolve it may move towards larger plants, more efficient technologies, vertically integrated companies, and along with consolidation could drive out local inefficient plants (Low and Isserman, 2008).

2.2 Location Theory

Rural areas typically have not supported extensive industrialization. Kilkenny (1998) suggests that four factors work against rural development: 1) transport costs to market; 2) economies of

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[2] Canadian Renewable Fuels Association, Accessed August 17, 2009 and March 8, 2012; http://www.greenfuels.org/en.aspx.

scale; 3) product differentiation; and 4) positive general equilibrium feedback due to economies of agglomeration. However, her conclusions may not apply to all industries because standard spatial location theories such as those of Hotelling, von Thünen, and Weber offer evidence that under certain conditions, rural locations may actually be conducive to specific industries (Aguilar, 2009; Asami and Isard, 1989).

The ethanol industry is typically classified as an input or supply oriented industry, where the total cost structure is dominated by a single input, so that locating near this dominant input is required to effectively minimize procurement costs (Lambert et al., 2008). But uncertainty over feedstock prices and its effects on variable cost raises the importance of electrical, water, and natural gas access, access to dried distillers grains with solubles markets, and provincial and federal incentives and policy in the Canadian case (Lambert et al., 2008; Gallagher et al., 2005; Kenkel and Holcomb, 2006).

Ethanol plants by nature are idiosyncratic site-specific investments where the next best use is limited and may only be within the industry. Therefore, the need to identify stable locations is essential to efficient and profitable operations. Lambert et al. (2008) discuss locational factors that influence manufacturing firms and offer that given the numerous similarities between food production and grain-based ethanol production, previous food manufacturing location studies can provide some understanding about factors that affect location decisions of ethanol producers. In any case, proximity to product markets, infrastructure, and labour market characteristics are generally primary location determinants for food manufactures (Lambert et al., 2008).

In 1929 Hotelling modeled firm location decisions as being uniformly distributed among demanders (consumers), permitting consumers to ultimately choose the firm that minimized their transportation costs (Huang and Levinson, 2008, Carlton and Perloff, 2005). Translated to the ethanol problem, it may be the case that an ethanol plant locates where it is centrally located among its dispersed primary input, thereby avoiding direct competition with other plants and also minimizing procurement costs. This allows the primary input supplier (farmers) to deliver to the ethanol plant or agent that minimizes delivery cost. However, in the absence of some form of vertical integration, input suppliers would prefer more than one ethanol plant to choose from to make their deliveries, while ethanol plants would prefer minimal or no competition from other ethanol plants.

Weber characterized location theory as a process whereby the plant or firm seeks to maximize profits through minimization of total transport costs (Emerson, 1973). Firms can then be classified based on location with respect to their input and output markets. In this light, Weber distinguished between two categories of products in a physical sense, weight gaining and weight losing. If a product is weight gaining then the raw materials procured weigh less than the final product produced so that the optimal plant location is close to the goods market. However, if the product is weight losing then the raw materials procured weigh more than the final product, so that the optimal location will be near to where the raw material is produced (Huang and Levinson, 2008). Thus the modern ethanol industry would be classified as weight losing given that the primary input, feedstock, is heavy, bulky, and required in large quantities. All else being equal, ethanol agents should tend to locate near areas of feedstock production in order to minimize procurement (transportation) costs.

Finally, Krugman (1996) suggests that firms are geographically balanced based on a basic physics model, what he refers to as centripetal and centrifugal forces (Huang and Levinson, 2008). Centripetal forces cause firms to cluster and include natural advantages to a specific site, backward (access to markets) and forward (access to products) linkages, and external economies such as knowledge or information spillovers. Centrifugal forces cause firms to scatter and include the need to reduce costs as part of any negative effects associated with industrial clustering, market competition, increased competition for primary inputs, and other negative spillovers (Huang and Levinson, 2008). Interpreted in this context, centrifugal forces are strong in the ethanol industry, with the large demand for diffuse feedstock driving firms to spread out, avoiding procurement area competition and urban areas. This leads to greater transactional and input costs, including labour and utilities, along with reduced access to final markets.

Given these competing theories of industrial location, the majority of the literature on ethanol supports the notion that production costs are minimized when an ethanol plant locates near feedstock production areas as well as avoids procurement area competition. Ultimately, transportation costs play a significant role in these location decisions and these must be balanced against other production costs to ensure a stable location is selected.

2.3 Transportation Considerations

Transportation and logistical efficiency in agriculture is a spatial and temporal issue that includes numerous ‘what if’ scenarios requiring model flexibility. Flexibility allows inclusion of necessary factors needed to solve these large and complex models. The ability to address both spatial and or temporal dimensions, in addition to capturing details of transport and marketing systems, is an important concern for transportation costing (Fuller and Shanmugham, 1978). Linear programming models typically use network structures particularly applicable to agricultural transportation and these have been successfully applied by the industry to identify minimum cost transportation solutions.

The development of linear programming optimization models are constrained by the size and level of operational complexity that can be incorporated. The challenge to optimization models is that configuring the problem often goes beyond finding the optimal cost and quickly becomes complex as time and structural stability is considered (Akanle and Zhang, 2008). Akanle and Zhang (2008) state that the application of artificial intelligence and simulation methods to solve these problems can help avoid the pitfalls of the aforementioned analytical methods applied to complex and dynamic supply chains. In addition, the layers of, and flow of, materials and information across and within supply chains can be more realistically represented through simulations (Akanle and Zhang, 2008). This is an important consideration not fully addressed in many linear programming models of supply chains. Lastly, the heterogeneous nature of space means that transportation costs will vary over the landscape for an optimizing firm because their inputs and outputs must be transported at positive cost (Emerson, 1973; Kilkenny and Thisse, 1999). The latter adds computational complexity and when combined with other location factors that must be considered by the firm, leads to simulation being a more efficient way to identify a solution for this type of multi-layered decision-making.

2.4 Policy and Welfare Implications

Low and Isserman (2008) examine four ways in which an ethanol plant can directly affect a local or rural economy: 1) the production of ethanol which entails purchasing labour and other inputs locally; 2) paying a premium for feedstock which can increase income for landowners; 3) drawing additional land into feedstock production; and 4) encouraging increased cattle production. Plant location can also buttress the local tax base, grow or stabilize off-farm incomes by increasing demand for feedstock, and promote rural development and diversification (Le Roy and Klein, 2007).

A recent study by Van Wart and Perrin (2009) indicates that regional welfare benefits from an ethanol plant will vary depending on feedstock densities and spatial proximity to feedlots and other ethanol plants. Van Wart and Perrin (2009) find that producers benefit very little from the location of an individual plant, as the plant is able to attract sufficient quantities of corn with a very small premium (0.3%). If an ethanol plant is able to locate in an area with high feedstock and feedlot densities and no competing ethanol plants, then that particular ethanol plant will maximize its own welfare benefit. This acknowledges access to federal, provincial, and municipal subsidies, but the use of government subsidies to promote the ethanol industry can also create less than optimal situations when not properly implemented.

Freeze and Peters (1999) discuss the commercial viability of the ethanol industry, pointing out that a number of studies and opinions suggest that without government support the industry would not exist, and that the promise of environmental and community development benefits have been used to promote it. Hill et al. (2006) state that given prices and technology in 2005, ethanol was not cost competitive with petroleum-based fuel without the aid of subsidies. But as average petroleum prices rose above 2005 levels the cost competitiveness of ethanol increased, but it still remains profitable only due to large subsidies (Hill et al., 2006). Another important factor to consider is the social welfare effects of biofuels. The environmental costs of fossil and biofuel energy are not currently captured in market prices, so whether there is actually a net gain to society from ethanol use depends on both cost competitiveness and environmental costs (Hill et al., 2006).

Even though government intervention in markets is intended to increase overall social welfare, subsidization of the ethanol industry has created an environment in which it is not clear if this is the case. In fact, many of the current policies and subsidies used to support the biofuel industry are subject to change as they are considered actionable with respect to trade agreements, particularly under Part III of the World Trade Organization's (WTO) Agreement on Subsidies and Countervailing Measures (Kerr and Loppacher, 2005). When combined with the current Canadian government mindset of spending reductions, there exists a very real potential for negative effects on both ethanol production and exports. While trade effects regarding ethanol import and export markets are beyond the scope of this thesis, it is another area that could potentially alter the industry organization.

2.5 Pricing and Contract Options

When purchasing feedstock, ethanol plants typically engage in one of two pricing strategies. These are known as mill pricing and discriminatory pricing. Mill pricing or free on board (FOB) pricing, sets a fixed price with the farmer for each unit of product delivered regardless of the incurred transportation costs. Discriminatory pricing or cost in freight (CIF) pricing, sets a pre-determined price with the farmer at the point of supply, plus the estimated transportation costs that will be incurred (Noon et al., 2002). In spatial analysis the acknowledgement and use of mill or FOB pricing in the model is commonly accepted without further validation required (Van Wart and Perrin, 2009; Graubner et al., 2011) and within this thesis FOB pricing is the pricing strategy employed by the ethanol plants.

The sale of ethanol usually follows one of two types of marketing arrangements. These are direct sales to customers or movements to a strategic location. Most ethanol producers contract out the sale of their ethanol to marketing firms. Typically, 90 to 95% of ethanol is sold under contracts of 6 to 12 months between the ethanol producer or marketing firms and the petroleum companies (Low and Isserman, 2009). Little ethanol is sold on the spot market and most contacts are a fixed price or tied to gasoline prices with neither practice being standard (Low and Isserman, 2009).

Most blenders (buyers of ethanol) prefer to buy in large volumes of 50 to 180 million gallons (189 to 680 Mmly) and deal with a firm that produces over 500 million gallons per year (1,890

Mmly) (Dunn et al., 2005). Marketers work to reduce search, negotiation, and monitoring costs by consolidating ethanol production from a number of producers into lot sizes required by blenders, thereby providing contractual safeguards and reducing the number of transactions required by the blender. In the United States (US) there are approximately six buyers and six marketers of ethanol, and within these two groups each buyer and seller trades with one another (Dunn et al., 2005). Within the group, information regarding ethanol price is collectively robust (Dunn et al., 2005), however the arrangement carries the potential for collusion, a situation which could negatively affect both forward and backward linkages in the ethanol supply chain. The US ethanol market is comparatively more active than the Canadian ethanol market which is limited to a few buyers and sellers, but is expected to resemble the US market as it continues to grow ($S\&T^2$ Consultants Inc. and Meyers Norris Penny LLP., 2004).

DDGS pricing and marketing is very similar with respect to the number of buyers and sellers, but is more localized (Dunn et al., 2005). Boaitey (2010) found long-run price similarities between corn and wheat distillers grains, and that the US corn market indirectly affects DDGS prices. Within the local DDGS markets, price volatility is based on supply and demand considerations given the inverse relationship between livestock density and DDGS prices. Current wheat DDGS supply in Western Canada is estimated at 389,000 metric tonnes while the potential market demand is estimated at two million metric tonnes (Boaitey, 2010). Therefore, imports play a large role in the Western Canadian DDGS market, specifically in the province of Alberta due to the large concentration of feedlots. Thus there exists a potential DDGS market in Alberta given its close proximity to Saskatchewan.

2.6 Summary

The ethanol industry continues to grow and meet demand based on mandated use in gasoline, as well as environmental policy objectives, rural revitalization, and consumer demand. These factors combined with federal, provincial, and municipal subsidies in Canada have created substantial growth since 2005. However, this growth may not be sustainable given that economies of scale are not being realized in a number of ethanol operations. Potential changes or even an end to subsidies may force a number of small ethanol producers from the market place as competitive forces start to favour those with lower operating costs realized through a combination of good location choice and economies of scale.

Spatial economic theory implies that input or supply oriented industries should locate near the source of their primary input. However, this solution may not be ideal in all situations as particular rural locations can limit access to efficient transportation, viable labour markets, and access to sufficient utility services. Various optimization models have been used to study the ethanol industry and some have found that current plant locations may not be sustainable or optimal given their lack of transportation access or high operating costs. Combining these factors with the propensity for ethanol buyers to reduce their search, negotiation, and transaction costs through the purchase of large long term contracts from high volume sellers may limit market access for small ethanol producers. Clearly the industry is at a crossroads. This research seeks to identify the most critical factors that will help the industry improve location decisions as the industry matures in Canada.

CHAPTER 3

Agent-Based Modeling - Description and Literature Review

3.0 Introduction

Traditional economic research typically relies on static analysis of endogenous variables at a single equilibrium point in time, and usually assumes as well that the parameters do not change. Under this set of assumptions along with individual homogeneity, model parameters should generate the same equilibrium every period (Binger and Hoffman, 1998). Comparative static analysis allows economic change to be evaluated, but this only compares the change between two equilibrium points of an economic variable, given the change in one parameter (Binger and Hoffman, 1998). These standard methods do not offer any insight to understand how various potentially heterogeneous factors interact simultaneously to attain stability over time. Recently, this issue has been addressed by agent-based simulation models. These models are now used across physical, biological, social, and management sciences (Macal and North, 2010) and while these models are still relatively new to the science of economics, their use and recognition is increasing.

Bonabeau (2002) identifies three key benefits stemming from agent-based models over other modeling techniques: 1) ABM captures emergent phenomena that result from the interactions of individual entities; 2) ABM provides a natural description of a system, bringing a model composed of behavioural entities closer to reality; and 3) ABM is flexible in the ability to change the level of aggregation and description of agents within a single model, allowing easy modeling of multiple dimensions. These advantages work to overcome the simplifying assumptions found in many traditional economic models, allowing standard assumptions from classical economics to be relaxed so that transient, non-equilibrium states encountered along the way can be investigated (Macal and North, 2010). And with these simulations, once the initial attributes of the agents and decision rules are in place the modeler no longer interferes with the model and allows it to evolve over time (Tesfatsion, 2002).

3.1 What is Agent-Based Modeling and Simulation?

Gilbert (2008) defines agent-based modeling as a computational method that enables researchers to create, analyze, and experiment with simulation models comprised of agents that interact within an environment. The use of computer programmed models allow a simplified representation of reality to be constructed where the computer program and code represents the processes of that reality (Gilbert, 2008). Within these models, each agent individually assesses its own situation and makes decisions based on the programmed rules governing behavior. From these decisions, aggregate behaviour begins to emerge in the system coupled with information about the dynamic interactions taking place as the model attempts to emulate the real world being considered (Bonabeau, 2002). The interaction of in-silico[3] agents within the simulated environment allows information to be transferred from one agent to another, enabling learning processes and providing insight into behavioural aspects of the agents when individual heterogeneity, incomplete information, and bounded rationality are present. These are the main reasons that computational agent-based simulation is making strides in the field of behavioral and applied economics.

The use of agent-based modeling and simulation (ABMS) can refer to both dynamic and time dependent ABM processes but also includes general numerical simulations that are designed mostly for optimization purposes (Macal and North, 2010). To date, ABMs have been applied in urban location models, opinion dynamics, consumer behaviour, industrial networks, supply chain management, electricity markets, and participative and companion modeling (Gilbert, 2008). The bottom-up (or individually-based) approach of ABM allows the observed aggregate behaviour to be generated by the interactions of the individual agents that comprise the model. This contrasts with the top down approach taken by traditional economic models, which rely on broadly placed high-level rules within the economic system (Miller and Page, 2007). The agent-based simulation methodology provides an effective way to observe and explore the dynamics, heterogeneity, and interacting components of economic systems. Axelrod (1997) describes aggregation in these models as the organization of a system into patterns bringing highly compatible elements together and pushing less compatible elements apart. It is the actions and consequences of individual agents that can lead to unforeseen or complex macro-level behaviour or aggregate interaction within these models (Berger, 2001).

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[3] The use of a computer simulated or virtual environment to study behaviours of interest. See: Francesco, Luna and Perrone, Alessandro. (2002). *Agent-Based Methods in Economics and Finance: Simulations in Swarm.* Kluwer Academic Publishers.

3.1.1 Agents

Typically agent-based simulations are most applicable when: 1) agent interaction can dramatically alter the behaviour of another agent(s), hence interactions are complex, nonlinear, discontinuous, or discrete; 2) positions of economic agents are not fixed and space is germane to the model; 3) there is a heterogeneous agent population; 4) the interaction topology is heterogeneous and complex; and 5) the agents learn and adapt, creating ever more complex behaviour (Bonabeau, 2002). Specifically, Macal and North (2010) describe three elements of a typical agent-based model: 1) a particular set of agents with defined attributes and behaviours; 2) methods of interaction and relationships between the agents; and 3) a simulated environment within which the agents interact.

Gilbert (2008) describes agents as characteristically endowed with perception, performance, memory, and policy, all of which dictate how they will interact with their environment while providing capacity to decide future actions based on past experiences. The computational agents that are part of a typical ABM generally possess features of autonomy, social ability, reactivity, and proactivity. These features allow them to complete their programmed actions, interact with other agents, react appropriately to environmental stimuli, and also to pursue goals of their own initiative (Gilbert, 2008). However, other than autonomy, others argue that no universal agreement exists within the literature regarding the precise definition of an agent in this context (Macal and North, 2010).

3.1.1.1 Complexity

Traditional economic models seek stable analytical solutions which minimize mathematical complexity and potentially ignore quasi-equilibrium solutions. Such top down approaches are typically linear (Durlauf, 1998), based on fixed decision rules (Tesfatsion, 2002), and bounded by assumptions where the primary interest is long run equilibrium using representative, completely rational, and homogeneous agents (Macal and North, 2010). In fact, these constraints are required to ensure analytical tractability (Macal and North, 2010) and to provide a stable equilibrium solution. However, the ease of computing stable equilibrium solutions in this case overlooks quasi-equilibrium states and the potential impact that short run decisions and shocks can have on long run or stable (if actually achievable) equilibrium states. Assumptions used for top down analytical techniques often predict outcomes that only hold for special cases, while others argue that the inclusion of spatial considerations with emergent outcomes cannot be solved analytically nor for a unique equilibrium in almost all cases (Parker et al., 2003).

Modeling complex systems often requires flexibility in design and experimental execution, highlighting the advantages of simulation models compared to closed form analytical equilibrium models (Parker et al., 2003). However this flexibility requires caution when developing model assumptions. The ability to relax and fashion assumptions specific to the problem is a stark contrast to standard top down approaches that require consistency between micro-and macro-level theory, hence additional care is required on the part of the agent-based modeler. Happe (2004) states a possible guideline for making agent-based modeling assumptions is that they be well founded in theory, justified, reasonable, and documented. Following these guidelines will lend credibility to both the model and results.

Accounting for system complexity and assessing its potential effects on economic models requires an alternative methodological approach. Many authors argue that a bottom up approach, a characteristic of agent-based models, is an efficient way to model complex systems. Inherent complexity often exhibits recognizable patterns of organization across spatial and temporal scales (Parker et al., 2003). Interdependencies, heterogeneity, and nested hierarchies between agents and their environment also structurally characterize these systems (Parker et al., 2003). More formally, Durlauf (1998) defines a system to be complex when it exhibits some type of order as a result of the interactions of many heterogeneous agents.

3.1.1.2 Emergence

By definition, the phenomenon of emergence is the consequence of micro-level agent interactions that are not readily predictable a priori. Parker et al. (2003) describe emergence as the “aggregate outcomes that cannot be predicted by examining the elements of a system in isolation” (p. 323). Emergent behaviours and properties in this literature are often surprising to the researcher as they are not anticipated; emergence frequently results from generated agent interactions within the model that were not directly programmed as agent behaviours (Durlauf, 1998; Gilbert and Troitzsch, 2005; North and Macal, 2007).

Emergence may also result from endogenous change, a property known as self-organization where the individual parts of the system interact to produce structures without external influence (Happe, 2004). The new structures may cause small or large deviations, such as a change in path dependence. As defined, path dependence is determined by historical factors and essentially its existence locks a system into a particular steady state or development path (Durlauf, 1998; Happe, 2004). But path dependence can be altered by changes in innovation or policy leading to system reorganization, of which both innovation and policy have the potential to dramatically affect the future ethanol industry. Thus analyzing potential scenarios through agent-based modeling could assist public and private groups to successfully navigate potential future industry changes.

3.1.1.3 Agent Heterogeneity

Traditionally a typical ‘agent’ in economic models is assumed to be representative of all individuals, but the assumption of homogeneity limits the ability of the model to generate important but abstract interactions as well as assess their effect on the economic system as a whole. Further, the simplifying assumption of agent homogeneity limits behavioural variability, leading to predictable macro-level behaviour that renders these models analytically tractable. In fact, the inclusion of heterogeneity within traditional economic models makes finding analytical solutions difficult (Parker et al., 2003). Relevant to this research, accounting for spatial considerations has been proven by some authors to be analytically intractable (Graubner et al., 2011 (b)).

Overall, the importance of modeling heterogeneous economic agents has gained attention in the economics literature. In the mid-1990s, estimating statistical parameters for individual agents in models became popular (Chen, 2012) while other developments began to consider the empirical significance of heterogeneous agents (Tesfatsion, 2000; Chen, 2012). Specific variance in experience, values, ability, and resources may be present in agents, and significant heterogeneity may exist in agents, the environment, as well as space and time (Parker et al., 2003). The recognition of heterogeneity and local interactions in economic systems is expanding the area of computational economics, encouraging new methods of analysis and increasing our understanding of individual and group behaviour caused by and within economic interactions.

3.1.1.4 Spatial Factors

The consideration of spatial and temporal aspects of economic systems is fundamentally important as time only moves forward (i.e. path dependence) and it is physically impossible for economic agents to be in two places at the same time. The spatial dimension of the research question relates location within a geographical distribution, the latter specifically concerned with access to feedstock, transportation networks, infrastructure, and final markets (Huang et al., 2010). Biofuel production costs related to feedstock, ethanol production, and transport are interdependent. Considering the entire supply chain during plant site analysis is the correct method of analysis, but this aspect is not widely adopted in the renewable energy planning literature due to tractability (Huang et al., 2010). In addition, the temporal dimension of the problem considers the long term planning of the biofuel system related to system transition and the effects that plant expansion over time will have on the ethanol production and distribution infrastructure (Huang et al., 2010).

In this system context, the term topology describes who transfers information to whom (Macal and North, 2010). Considering topology dynamics during the plant location planning process is likely to generate future system stability or at least mitigate the effects of transition states. Finding overall system effectiveness in this context requires consideration of the dynamics of system evolution on topology during planning, a situation that renders the conventional time-independent snapshot method of analysis lacking (Huang et al., 2010).

In the context of this research, spatial considerations are important for ethanol producers. Competition for feedstock occurs within a plants' procurement area. Input costs are likely to increase over time and space as well, since firms will offer higher prices for scarce resources or look farther afield to meet demand requirements. This process runs parallel to feedstock production densities, and as they increase so will the tendency for firms to locate. However, a fundamental tradeoff exists in that firms can locate in less dense production areas where they will face higher procurement costs, but avoid price competition (Graubner et al., 2011).

Ultimately, the explicit inclusion of space when modeling such agricultural systems should be carefully considered, given the potential negative consequences of ignoring it. On a practical level, some argue that firms with similar strategies that choose to ignore this will find it harder to maintain market share and profitability as competition for critical resources increases (Ross and Westgren, 2009).

3.2 Relevant Applications of Computational Economics

Versions of agent-based simulation models have been used to investigate social phenomena in the fields of economics, sociology, anthropology, and cognitive science (Macal and North, 2010). In turn, agricultural economists have long recognized the importance of space ever since the work of von Thünen and Ricardo (Runge, 2006). There has been a more recent realization of the potential agent-based models can play in understanding dependencies between individual and collective behaviours (Happe, 2004). The field of supply chain management has made great strides in developing and employing agent-based approaches to the problems of location and spatial interdependence. Applications of supply chain management in this regard will help shed light on the transfer of not only the main raw material feedstock, but also ethanol and how these movements affect location decisions within defined transportation corridors and market locations.

Supply chain management research uses agent-based models on a number of platforms to gain insight into complex factors such as clustering, information flows, and optimal spatial configuration. For example, Huang and Levinson (2009) investigate retail location in a market of two complementary goods and find that retailers of complementary goods tend to co-locate at supplier sites to reduce transportation costs while trying to avoid direct competition. This also leads to an increased customer base since consumers also consider transportation costs of having to buy both complementary goods (Huang and Levinson, 2009). Gjerdrum et al. (2001) develop a combined optimization and agent-based approach to determine the optimal manufacturing schedule of each factory in a supply chain based on the decisions being made by other agents within the system. Their focus was to investigate various inventory replenishment strategies characterized by different control parameters with the objective to reduce operating costs while maintaining a high level of customer order fulfillment. Their findings reveal a combination of order lead time along with reorder point and quantity affects the use of external orders and system operation in the supply chain. Akanle and Zhang (2008) propose an approach that can cope with future customer demand while optimizing the configuration of the dynamic supply chain. Their simplified example found that differing resource combinations can be optimized for individual orders and that group orders can be clustered to create balance between various demands.

Optimal configuration of modern supply chains strives to increase efficiency while reducing system costs. These are but a sampling of the relevant agent-based studies available, but they show the importance of simulation analysis and how it can be applied in a number of areas to increase our understanding of economic interactions.

Agent-based models within the field of agricultural economics cover topics like the evolution of land-use decisions; evaluating agricultural value chains and the effects of agent interaction on system and firm performance; measuring potential structural change in farming and the effects of land scarcity, scale efficiencies, and policy impacts; and conducting adaptive ecosystem management measuring how land values and crop returns interact to determine land investment or disinvestment decisions (Nolan et al., 2009).

Within the emerging biofuel industry, agent-based model development is growing with a number of studies coming out. Although ongoing, Scheffran et al. (2007) have developed an agent-based model to understand the optimal spatial arrangement of crops (both food and fuel) in the state of Illinois. Interestingly, their future work will include the effects of subsidies, fluctuating transportation costs and crop demands, and how new ethanol production facilities impact the industry.

Graubner et al. (2011) develop an agent-based simulation to simultaneously identify an ethanol producer’s location as well as its price strategy in a spatial input market. Traditionally either location or price is considered endogenous but the authors allow both to be endogenous under a number of scenarios. They find that market structure, transport costs, and border effects all influence the degree of spatial competition.

With respect to other related ethanol industry studies that rely on alternative computational techniques, Taylor and Koo (2010) use a heuristic approach in combination with a mathematical optimization model to determine the optimal size, number, and location of biomass plants in North Dakota. While their model does account for spatial access to inputs and transportation it does not allow costs to vary between regions or for time to affect the optimal number of plants.

Eathington and Swenson (2007) employ geographical information system software to locate potential ethanol plant locations in the state of Iowa. Locations are constrained by the existing transportation network, corn production, and competing uses for corn. Their approach highlights the importance of space when identifying stable ethanol plant locations and that there are clear and knowable limits to the size and distribution of the industry (Eathington and Swenson, 2007).

Finally, Huang et al. (2010) built a multistage mixed integer linear program model that includes spatial and temporal dimensions to minimize total system cost throughout the planning horizon for bioethanol in California. They find that full chain optimization strategy is required to understand the many tradeoffs involved in both temporal and spatial dimensions.

The above references highlight the increasing role computational methods are taking in understanding the spatial nature of agricultural industries and markets. Consideration of the entire ethanol supply chain along with spatial and temporal effects on location and firm operations should prove beneficial to optimizing linkages, anticipating future events, and planning appropriate responses in this growing industry.

3.3 Challenges and Limitations

Although the use of computational agent-based models continues to be developed and applied in economic research, a number of issues must still be addressed before the method will be considered in the mainstream of economic methodology. Foremost, the irreducibility of emergent properties is a major issue in developing techniques to understand how system components and model outcomes are related. Until sorted, this ambiguity will certainly affect acceptance in the broader scientific community (Parker et al., 2003; Heckbert, 2009). On a practical level, the very nature of modeling complex economic systems poses unique challenges and limitations regarding model communication and data needs, as well as model calibration, verification, and validation (Nolan et al., 2009). These issues will be sorted eventually, but the newness of the method means that research conduct and standards still vary widely.

3.3.1 Model Communication

Agent-based models use computer software and often require significant programming efforts. Similar to the situation 50 years ago with the field of econometrics, this situation leads to a number of difficulties in fostering acceptance. First, learning and understanding a modern object-oriented computer programming language can be a significant barrier to entry for many social science researchers; second, a reliance on heuristics rather than formal mathematical relationships challenges the author to concisely communicate model rules and mechanisms (Nolan et al., 2009); and lastly, the space requirements to document and explain model rules and mechanisms is substantial but a costly endeavor for scientific journal editors (Parker et al., 2003). Therefore, defining the experimental frame that will guide research efforts within the spatial, temporal, and institutional system under study along with the degree of abstraction and endogenous factors (Parker et al., 2003) must be as precise as possible to ensure efficient communication. To this end, development of a common language that is standard and comprehensive for ABMs (Parker et al., 2003; Nolan et al., 2009) such as the Unified Modeling Language may help alleviate the current communication gap allowing cross-fertilization and comparisons between projects (Parker et al., 2003) where current custom in much of economics dictates the inclusion of formal mathematical models (Nolan et al., 2009).

3.3.2 Data Needs

A direct relationship exists between the number of micro simulations and data requirements in agent-based models. In order to parameterize decisions in agent-based models, fine-resolution individual data is generally required but this can lead to confidentiality concerns (Parker et al., 2003) as well as potential confusion around model technique and theory application. Therefore, while computing power has advanced along with sophisticated analysis tools, there continues to be a lag in developing methods that link models to data (Parker et al., 2003). Overall, to ensure success, data requirements in these models should be identified based on model design. Once data that meets these requirements has been identified, it should be evaluated and a decision made whether to accept it as is, or if further data refinement is required (North and Macal, 2007).

3.3.3 Calibration, Verification, and Validation

If available, calibration of model parameters can be done using parameter estimates from real world cases (North and Macal, 2007). However, the flexibility of agent-based models can make calibration difficult given the number of plausible parameters, leaving wide parameter ranges difficult to restrict based on empirical data (Heckbert, 2009). Agent-based models can be left with excessive degrees of freedom as well as the possibility that the model may reflect the modeler's specific perspective rather than a broader understanding of the specific interests, beliefs, and scales of perception (Heckbert, 2009).

Verification tests the model to ensure it works as intended, both conceptually and technically (Parker et al., 2003; Happe, 2004; North and Macal, 2007; and Nolan et al., 2009). This process strikes a balance between theory and data which reduces the associated flexibility concerns and evaluates the structure and rules employed in the simulation (Parker et al., 2003). Varying model parameters and configurations ensures the model does not contain programming errors, oversights, or bugs, ensures algorithms are properly implemented, and that incremental input changes are justifiable against model outputs (Parker et al., 2003; North and Macal, 2007).

Validation tests how well model outputs compare to real world data or represent real system behaviours (Parker et al., 2003; Happe, 2004; North and Macal, 2007; and Nolan et al., 2009). Agent-based models are most frequently associated with situations of mathematical complexity and non-linear relationships, two factors that increase validation difficulty. However, these factors do not serve as excuses for any results that cannot be explained (Parker et al., 2003; Happe, 2004). So while there is no standard validation procedure in the simulation literature, Happe (2004) suggests comparing outcomes to a number of benchmarks. Alternatively, North and Macal (2007) suggest that if the model works as intended by addressing the intended problem and provides accurate information about the system being modeled, then the validation process has been successful.

3.4 NetLogo© Simulation Software

NetLogo© is a programmable multi-agent modeling language that was developed to simulate natural and social phenomena. It is particularly well suited to modeling complex systems that evolve over time (Wilensky, 1999). It is a flexible modeling medium that has become widely accepted with applications in both educational and research settings (Lechner et al., 2004). It was originally developed and is currently upgraded by the Center for Connected Learning and Computer-Based Modeling at Northwestern University.

The NetLogo© platform allows modelers to concurrently program hundreds or thousands of agents independently with their own user defined variables, allowing micro-level behaviours and macro-level patterns to be observed and explored as they emerge from the multitude of simultaneous agent interactions (Wilensky, 1999; Sakellariou et al., 2008). Formally, NetLogo© is comprised of four classes of agents – known as ‘patches’, ‘turtles’, ‘links’, and ‘the observer’ (Wilensky, 1999). Turtles are mobile agents that navigate and interact within the landscape or artificial world. In contrast, patches are stationary and divide a landscape into a spatial or geographic grid over which the turtles move. Links are agents that connect turtles, while the observer, who does not have a physical location, oversees the programmed system and gives instructions to the agents (turtles, patches, and links; Wilensky, 1999). The agent-based simulation presented in this thesis includes individual farmers and ethanol plants, represented by the turtle agents. Agricultural land used for crop production is represented by patches. Other patches include transportation and utility networks. The observer represents the various institutions and administers system activities such as market mechanisms, government policy changes, and financial constraints. Lastly, it must be noted that links are not incorporated since the turtles programmed within the simulation are considered to be independent of one another.

3.4.1 NetLogo© Limitations

While there are many benefits to using NetLogo© to conduct simulation research, currently the software has specific limitations that can prevent accurate simulation of really large or highly complex models. For example, the NetLogo© engine design is single-threaded, allowing only one task to be completed at a time (Tissue and Wilensky, 2004). In addition, when turtles receive a command, the single-thread means that only one move can take place at a time. Thus, turtle agents do not actually move simultaneously, like they would in many real economic environments (Tissue and Wilensky, 2004). To compensate for these issues, the NetLogo© engine moves from agent to agent after each of them has performed some minimal amount of its programmed action, called a turn. This process is called context switching and means that overall model behaviour remains deterministic because the timing of context switching is also deterministic (Tisue and Wilensky, 2004). While the model runs, visually the illusion of simultaneous action or resolution is present but only because the visual interface is updated after all agents have completed their turn. As an example, when all turtles in a simulation are asked to move 10 steps forward, in Netlogo© all turtles effectively move one step at time which prevents any one turtle from gaining an unfair advantage through the full turn.

Concurrency also affects the elemental inputs from the user interface, which when enacted can initiate code execution. When an input is received from the user interface, a ‘job’ is created and submitted to the NetLogo© engine. Since a job represents a thread or process, NetLogo© must choose and switch between the agents within a job, a process driven by its single-thread design (Tissue and Wilensky, 2004). Specifically, the coding rule for jobs is to switch from job to job once every agent in the first job has had a turn (Tissue and Wilensky, 2004). On a design level, these issues continue to be an active area of concern within NetLogo© and work continues to refine the software into a more realistic modeling environment.

3.5 Summary

Since the early 1960s, agricultural economists have recognized that many agricultural systems are actually complex dynamic systems in a mathematical sense (Happe, 2004). To this end, computational simulation and agent-based models are increasingly being used to study and understand how variables interact and evolve within these complex agricultural systems, thus offering alternative insights when compared to traditional static models. Through the use of individual interacting agents, the effects of individual heterogeneity, incomplete information, and bounded rationality within an economic system can be better understood while buttressing our understanding of complexity, emergence, and path dependence in economic systems. Modeling aspects such as calibration, verification, and validation still need standardization so as to increase acceptance in the broader economic research community. A first step towards acceptance is developing a framework to design, test, and analyze bottom up agent-based models which are justifiable while emphasizing the nature of the results.

Development and application of agent-based models through more user friendly software such as NetLogo© is growing. The ability to independently program numerous individual agents and examine their interactions allows a progression from micro-level behaviour to macro-level patterns to be explored as part of the simulation environment. Model limitations in the software are continually being addressed to improve NetLogo's© overall simulation environment.

CHAPTER 4

The Simulation Model

4.0 Introduction

This chapter outlines and discusses the conceptual model underlying this agent-based simulation of ethanol plant location. An overview of the model and its underlying assumptions will be described along with a description of the individual agents, including behavioural and structural equations used that pertain to the areas of transportation, market synergies, and policy effects.

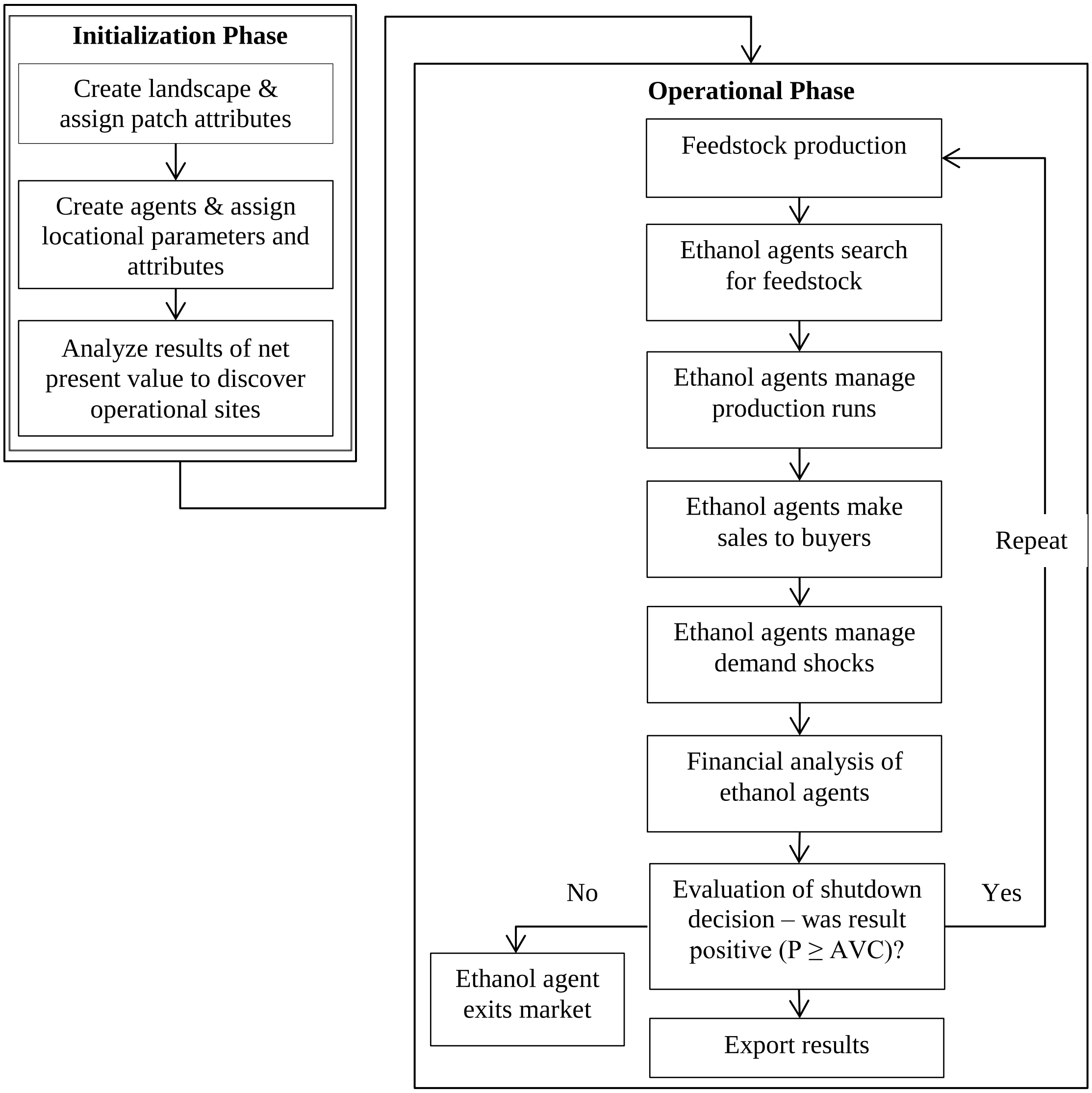
An agent-based model was developed used to gain a better understanding of how decision and system variables specific to the ethanol industry interact over time. In turn, these variables have been recognized in the ethanol literature to affect both locational and operational factors within the industry. An agent-based simulation of location decisions allows a number of scenarios to be evaluated, bringing to light those variables which significantly affect ethanol plant location. Analyzing system dynamics using simulation will facilitate understanding of how changing initial parameters and variables affect agent decisions.

Ethanol plants as agents form the core of the model and the agents perform actions based on heuristics and formal equations in order to find a sustainable or stable location within the simulated landscape. Their goals are to maintain adequate access to feedstock, as well as gain proximity to transportation and final product markets. In essence, these factors place financial constraints on the agents and also can limit their ability to maintain and grow their plant operation. The critical variables are discussed in Chapter 4, while a discussion of the remaining variables is contained in Appendix A. This distinction allows for greater attention to the variables that are germane to the simulation and also permits discussion of supporting data and inputs.

4.1 Model Overview

Heuristics and algorithms within the model permit ethanol plant agents to make choices that generate a stable or economically sustainable location. The simulation environment provides the opportunity to better understand locational decisions at both a micro-and macro-level. Diagram 1 displays the simulation model sequence and also serves as a basic overview of the modeling process.

Diagram 1: Model Simulation Sequence (See Section 4.1)



The model initializes such that an ethanol agent has the opportunity to begin operations on the site (patch) on which they are situated within the simulated landscape. Exceptions are those model patches committed instead to transportation networks, towns, cities, feedlots, and blenders. Initialization takes place at year zero, a point where each patch is endowed with a specified production value that is harvested once per time period (year). Each patch is programmed to compute site specific criteria used by the ethanol plant agent to determine if operations are viable during that time.

During initialization, discussed in Sections 4.5 and 4.6, one ethanol plant agent is placed on each patch and each agent calculates a net present value (NPV) of operations for that specific location to determine if that site is suitable for future operation and generates profitability. After calculating this site specific NPV, the ethanol agent then decides if it will start operations on that site. The heuristic assumed here for starting plant operations is simply that NPV ≥ 0, and if NPV < 0 then the ethanol agent is removed from the site.

The operation phase, discussed in Section 4.7, allows all remaining ethanol plants to begin daily operations. Ethanol agents must meet specific financial, feedstock access, plant utilization levels, and operation criteria to continue operating on the landscape. In essence, high cost plants are removed from the landscape through various heuristics, favoring ethanol agents with the lowest operation costs, allowing these plants to potentially expand as demand shocks hit the system.

Profit maximization drives an ethanol agent's decision regarding site viability in the model. As shown below, the profit maximization equation within the operation phase of the simulation model is only applied when an ethanol agent successfully satisfies the NPV constraint. This constraint is satisfied when the locational site in consideration returns a net present value greater than or equal to zero during the initialization stage.

The profit maximization problem is as follows:

$$\max_{s.t. NPV \geq 0} \pi = R + FPS - VC - FC - CL - DP - T$$

Where: *π is profit*
R is revenue (ethanol and DDGS sales)
FPS is federal and provincial subsidies
VC is variable cost
FC is fixed cost
CL is capital loan principle payment
DP is depreciation on capital assets
T is corporate tax
NPV is net present value of the investment at t = 0

As discussed above, an ethanol agent's ability to profit maximize is subject to the following constraint, $NPV \geq 0$, which is required before operational procedures can begin. The NPV equation utilized in this model is based on the standard NPV equation presented in Ross et al. (1996); please see Section 4.6.1 for further discussion.

The net present value equation is as follows:

$$NPV = (-U_0 + SE_0 + \sum_{t=1}^{v} \left[\frac{R_t + FPS_t - VC_t - FC_t - CL_t - DP_t - T_t}{(1+df)^t} \right] + \frac{S_v}{(1+df)^v}) \geq 0$$

Where: U_0 *is the investment capital outlay at t = 0*

SE_0 *is shareholder equity at t = 0*
R_t *is revenue (ethanol and DDGS sales)*
FPS_t *is federal and provincial subsidies*
VC_t *is variable cost*
FC_t *is fixed cost*
CL_t *is capital loan principle payment*
DP_t *is depreciation on capital assets*
T_t *is corporate tax*
S_v *is salvage value of capital assets*
v *is the planning horizon*
df *is discount factor (opportunity cost of capital)*

These criteria provide the overarching rational for the ethanol agents in the simulation model and will be subsequently discussed in greater detail.

4.2 Agent Overview

As stated above, the model is comprised of farming, ethanol, blending, and feedlot agents. For instance, farm agents harvest and store any unsold feedstock in inventory and ship it to what are referred to as 'calling' ethanol plants. These latter agents are separately placed on patches during initialization that contain feedstock production and remain there for the duration of the model run. Farm agents also keep track of feedstock trucking costs, the number of shipments, and the identity of the ethanol agent receiving their feedstock production.

Blender (ethanol buyers) and feedlot (DDGS buyers) agents are randomly placed on the landscape when the model initializes. These agents accept deliveries from the ethanol agents based on market demand for the product and will not accept deliveries that exceed demand limits which are discussed in Section 5.5. Excess ethanol and DDGS production must be stored by the ethanol agent and sold at a later date. Further, it is assumed that both blender and feedlot agents share the cost of transportation with the ethanol agent, where this cost is based on a mix of contract types currently used in ethanol and DDGS markets. For example, a Chicago Board of Trade ethanol futures contract is based on delivery to a designated delivery point at the buyer's terminal (Funk et al., 2008). However, ethanol companies may sell either FOB or CIF depending on negotiating strategy of the spot market or long term contract (Outlook Market Research and Consulting Ltd., 2008). Given that only very broad contractual market place transportation terms are known at this time, it is assumed here that transportation costs for ethanol and DDGS contracts are split in a 50-50 equal share between the buyer and seller within the model.

Ethanol agents seek inputs from the simulated landscape to produce ethanol and DDGS during model operation. During the initialization phase each ethanol agent checks the patch it is sitting on to see if it is suitable for operations. The initialization period also sets the number of ethanol agents that will begin operations when the model starts, while the initialization code generates and reviews the main cost factors that affect site selection. Site selection factors include access to utility services (water, natural gas, and electricity), to feedstock, to transportation networks (primary highways and railways), as well as distance to ethanol and DDGS markets and competing feedstock users (TDI Projects Inc., 2004).

4.3 Landscape Overview

The simulation model attempts to replicate a major wheat producing area, with the main focus in this case being the province of Saskatchewan. However, flexibility has been designed into the model allowing the simulation to be altered to fit any wheat or even corn producing agricultural region. As coded, each patch is considered to be one Saskatchewan township (36 sections of land) with a total area of 9.6 kilometers^2 (KM). Currently in the model there are 1,369 patches (a 37 x 37 grid) which represent the 13.2 million hectares of seeded land in Saskatchewan (Statistics Canada, 2000). In turn, patches are assigned a productivity value based on the three main soil zones in Saskatchewan; black, dark brown, and brown. The value of productivity in each soil zone is based on average wheat production per Census Agricultural Region (CAR) provincial data from 1976 to 2006 (Statistics Canada, Crops – Historical Data, 1976 – 2006).

When the average 30 year production figures are compared to specific CAR locations within the three main soil zones, it was found that wheat production is relatively uniform across the province. Average production in each of the three soil zones was split approximately as follows: black 33%, dark brown 34%, and brown 33%. Therefore, differences in production values based on soil zone classification are deemed to be negligible and assumed not to affect the location of any wheat based ethanol plant. But one caveat to this finding is that nine of the 20 CARs have production figures above overall average production (Statistics Canada, 2006). In fact, the area of census agricultural regions with above average wheat production centers roughly on the middle of Saskatchewan's grain growing region. Higher than average production levels in this area may prove to be more suitable for ethanol plant locations in reality, but this remains to be seen given other key factors. Additional information pertaining to the soil zones of the province is presented in Appendix A.

4.4 Ethanol Production

Ethanol is produced using a number of inputs. Given the weight losing nature of production in this industry, plants will choose to locate near their primary input, feedstock. But other high use production inputs can also affect location. These include inputs such as natural gas, electricity, and water. Thus not only production costs must be considered, but also initial fixed utility servicing costs for a potential production site.

Ultimately, it is considered that during the planning stages of a proposed ethanol site that the following should be considered: average wheat production both within and surrounding a given procurement area; competitive operations; proximity to DDGS and ethanol markets; water, electrical, and natural gas supply; and type and distance to transportation system(s) (TDI Projects Inc., 2004). Other considerations would include environmental impact studies, local subsidies, and land zoning (TDI Projects Inc., 2004). To this end, local subsidies to the industry are typically considered site specific and may include tax concessions, education programs, or upgrades to water treatment facilities that are completed to entice an ethanol plant to locate. The site specific nature of local subsidies and lack of traceability creates another level of complexity that precludes them from being included in this model. Therefore, only Canadian provincial and federal subsidies have been considered in this simulation.

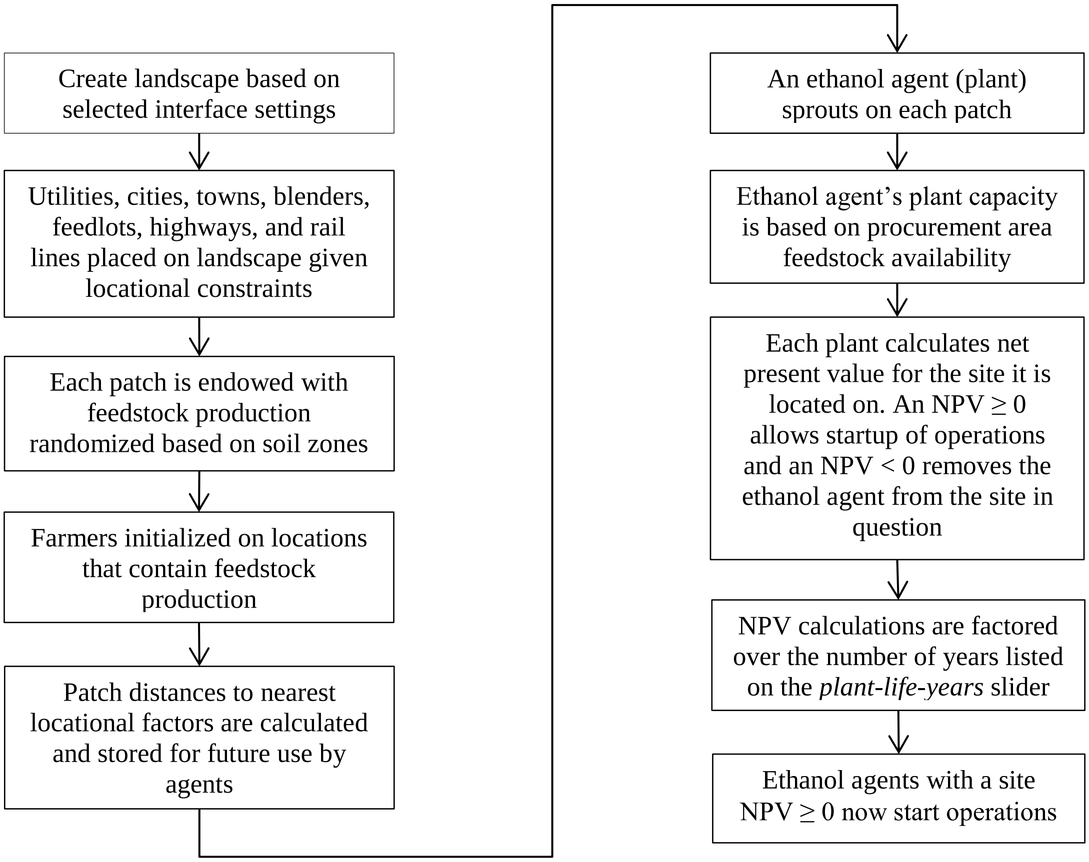
4.4.1 Conversion and Contracting

In the model, conversion of feedstock to ethanol and DDGS takes place once ethanol agents have taken delivery of all called feedstock. Each unit of feedstock is considered to weigh one metric tonne, and this produces 372 litres of ethanol and 295 kilograms of DDGS (Bonnardeaux, 2007). Relevant costs associated with producing ethanol here include feedstock purchase, freight for inputs (which does not include feedstock delivery costs), marketing, chemicals, denaturants, maintenance, insurance, property tax, and labour costs. Including inflationary effects, these costs are calculated using the same formulas and parameters utilized in both the initialization and operation procedures. The primary difference between initialization and operation phases is that variable costs in operation phase are based on actual ethanol production as opposed to the initialization assumption that ethanol agents operate continually at maximum capacity. Further discussion of how these variables are calculated can be found in Appendix A.

4.5 Model Initialization

Model initialization generates the landscape according to a number of user input variables displayed on the NetLogo© interface. Software input interfaces such as sliders, switches, input windows, and choosers (all part of the Netlogo© package) can be changed by the user to create various simulation configurations to be accessed by the model agents during the setup and operations portion of the model. In this case, the user adjustable settings can alter the location, length of time, or number of agents that materialize on the landscape (as a result of the initial NPV analysis). Diagram 2 displays an overview of the simulation model initialization period followed by a discussion of the initialization sequence.

Diagram 2: Model Initialization Sequence (See Sections 4.5 – 4.6.1)



As mentioned, creating the simulation landscape involves the setup of primary highways, main line railways, water sources (river), an electrical grid, a natural gas grid, towns, cities, feedlots, blenders, farmers, variables for nearest location factors, and feedstock production. The actual location of towns and cities in the province are approximated within the simulated landscape. On inspection, a map of Saskatchewan indicates that towns are typically located farther from primary highway and mainline rail than cities. The location assumptions made in the simulation are only of relative importance and have been made to reflect reality as much as possible while facilitating the design of the simulation model.

Ready access to transportation networks appears to be critical for feedlots to help minimize transportation costs associated with feed access and shipment of finished livestock (Carter and Schmitz, 1986). As well, convention dictates that feedlot proximity to reliable and clean water access is necessary as cattle consume up to eight gallons of water per day (TDI Projects Inc., 2004).

Blender location is driven by industrial location and market access. Cities are engines of growth where industry tends to locate because of access to transportation and markets (Ullman, 1941; Partridge et al., 2007). Thus it is postulated that stable locations for blenders will be near both transportation networks and cities granting centralized market access (TDI Projects Inc., 2004).

Each patch also stores distance and cost variables that are used to generate utility servicing cost, along with patch distance to blenders, feedlots, railways, and highways. These variables are accessed by ethanol agents when they evaluate a patch as a potential operations site. Appendix A discusses the statistical rationale for the nearest location variables and costs used in the simulation. Finally, during the simulation the precise location of cities, towns, feedlots, and blenders is not fixed but randomized within the specified parameters across each run.

During initialization, each patch is reviewed by an ethanol agent as a potential operational site. A formal net present value analysis is completed for the patch. If $NPV \geq$, 0 then a plant initializes at that location. If $NPV < 0$, the site or patch is left vacant. Investment factors[4] such as inflation, capital loan interest rate, capital loan finance life, plant life, corporate tax level, subsidies, shareholder equity, and NPV discount rate all enter into the NPV site analysis. Interaction of these factors can significantly affect the number of ethanol agents that initialize. These factors are discussed in detail in Section 4.8 and Appendix A.

Initialization of ethanol plant locations and reviews of potential sites are characterized by the following actions. First, the ethanol agent finds the potential nameplate capacity of a plant by multiplying the total production volume of the patches found in the immediate procurement area (as set by the slider on the simulation interface) by the number of litres of ethanol produced per metric tonne of feedstock (372; Bonnardeaux, 2007). The potential nameplate capacity is used in calculating capital building costs, salvage value, loan payments, interest, income, and expenses.

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[4] These factors are assumed to be determinants of location but are beyond the scope of this thesis and not analyzed beyond this point.

Variables such as plant finance life affect the amortization of capital loans, while interest rates affect the cost of borrowing. Lastly, the level of shareholder equity affects the size of the capital cost loan required. All these factors affect the number of plants that materialize on the landscape.

4.6 Net Present Value Calculations

Net present value calculations are based on the initial catchment area, as set by the catchment area input slider on the NetLogo© interface. Catchment areas in the current ethanol industry are typically in the 50 – 100 KM range (Eathington and Swenson, 2007; Sarmiento and Wilson, 2007), and this range is used for testing and operating the simulation model. During the NPV analysis, it is assumed the ethanol agents do not consider the effects of competition, meaning at early stages their only concern is determining site suitability for future operations. Competition effects are accounted for during the operations portion of the model. Finally, the potential ethanol agent's plant output capacity is based on the total available feedstock found in the catchment area, and it is this amount that is used in the remaining NPV calculations.

4.6.1 Present and Net Present Value Calculations

Present value (PV) and net present value calculations are completed during the final stages of initialization. The present value of a potential site measures the total generated net income after taxes as a function of salvage value, discount factor, and plant life. As is well known, present value is simply the current value of future cash flows, given the chosen discount factor (Ross et al., 1996). The discount factor is set via the *NPV-discount-factor* slider on the simulation interface and indicates the expected rate of return on the project. In their work, Holcomb and Kenkel (2008) used a 12% discount factor while Herbst et al. (2002) used an 8% discount factor. Here, the initial discount rate used will be 10% (as in Bain, 2007).

The formal present value calculation (Ross et al., 1996) is as follows:

$$PV = \left(\left(NRt * \left(\frac{1 - \left(\frac{1}{(1+df)^t}\right)}{df}\right)\right) + \left(\frac{S}{(1+df)^t}\right)\right)$$

Where: PV is present value
NRt is total net income after taxes for the life of the investment
df is the discount factor
S is the salvage value of the investment
t is the life of the plant (investment)

Once the PV is known, it is simple to calculate the NPV of a potential site. NPV measures the value created today due to making the investment, and is the difference between the market value and cost of the investment (Ross et al., 1996). Acceptance or rejection of investments here is based on the NPV, where a positive value suggests the investment should be undertaken while a negative value would suggest rejecting it. The criteria in this model states that investment to build a plant at a proposed site will occur only on those sites with an NPV greater than or equal to zero. If NPV is computed to be negative, the site remains empty and is not considered again by other ethanol agents.

The formal net present value calculation (Ross et al., 1996) is as follows:

$$NPV = (Ro + PV)$$

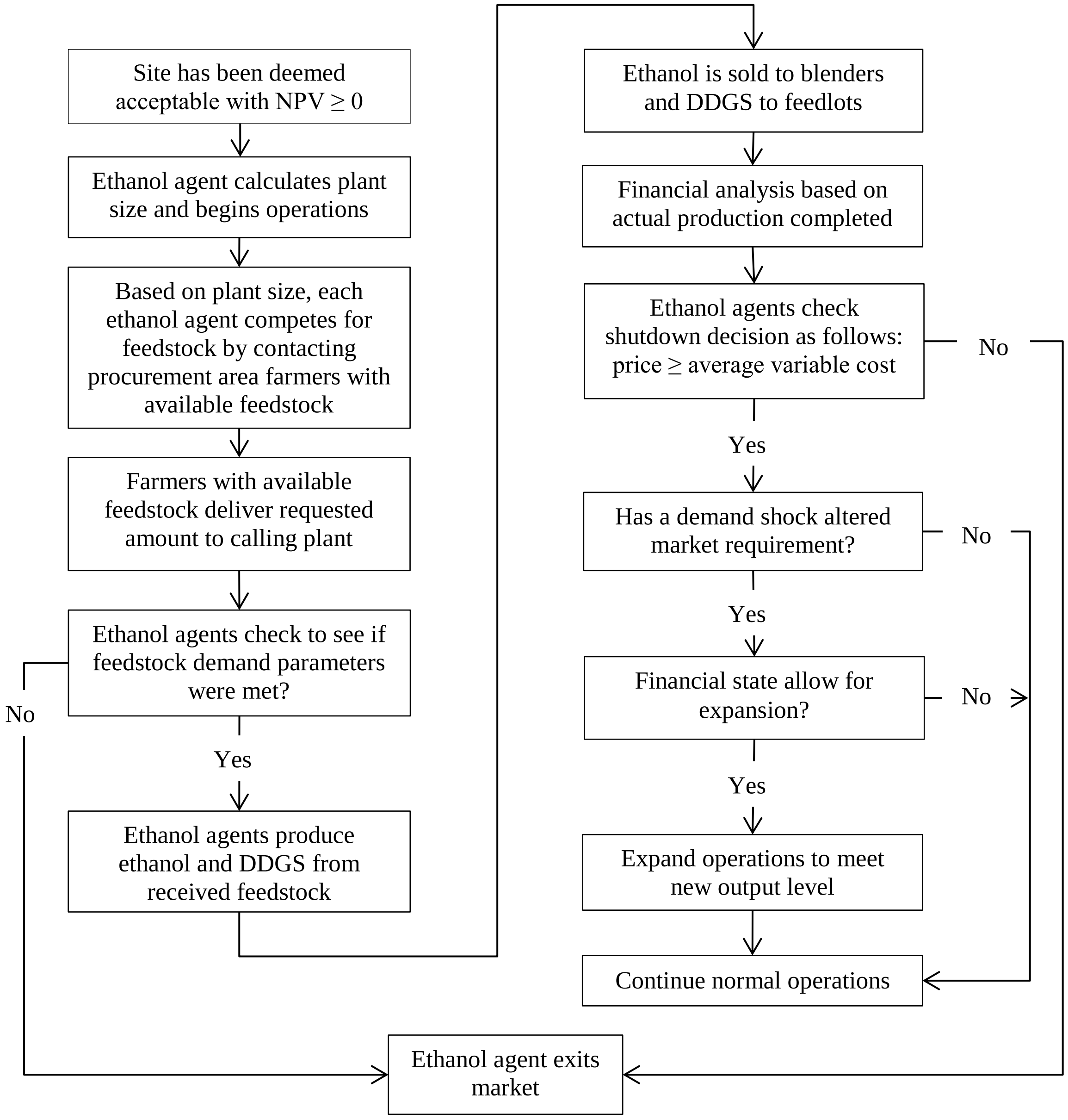
Where: NPV is net present value
Ro is capital cost, in this case, including utility access cost to site; this figure is negative to represent the initial cash outlay for the investment
PV is present value of the proposed site

All cost figures used here align very closely with USDA's 2002 Ethanol Cost of Production Survey as completed for the US dry mill ethanol industry (Shapouri and Gallagher, 2005). In addition, the figures fall within the numbers provided in this study for both small and large plants.

4.7 Operations Phase

During the operations phase, the ethanol agents who identify a NPV ≥ 0 begin operations. Here the plants must satisfy a number of constraints to remain viable, as illustrated in Diagram 3. These constraints include the need to maintain access to adequate feedstock, ensuring they are operating above their shutdown point, and can manage any demand shocks. If an ethanol agent is unable to successfully meet these constraints, the agent exits the landscape. From a system feedback perspective, when an ethanol agent exits in the simulation run the remaining ethanol agents then get an opportunity to increase their extant market share as a result of the industry ethanol supply decrease.

Diagram 3: Model Operation Sequence (See Sections 4.7 – 4.8.7 and Appendix A)



4.7.1 Operational Procedures

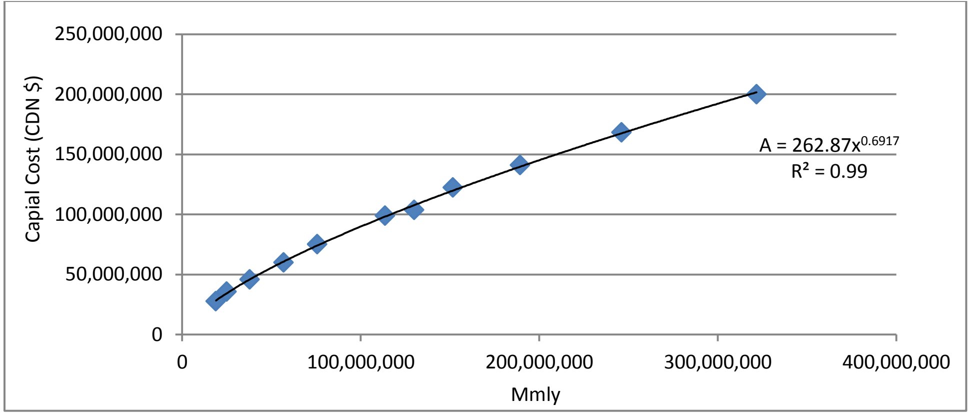
For ethanol agents which have identified locations with an NPV ≥ 0 at $t = 0$, the operational procedures in the simulation code now begin. Operational procedures regarding income and expense calculations are similar in structure to many of the initialization formulas. Ethanol agents use this phase to decide which locations are most likely to remain stable over the simulation given their proximity to transportation, utilities, feedstock, competitors, and ethanol and DDGS markets. Other mitigating factors such as subsidy levels, interest rates, demand shocks, shareholder equity, and inflation will also affect plant operations, creating an evolutionary environment where ethanol agents either thrive or fail over time.

4.8 Capital Costs

Capital building costs are defined as the cost to build the ethanol plant, but in fact other indirect costs must be included. Outlook Market Research and Consulting (2008) defines indirect costs as land, soft costs (business planning, market development, arranging strategic alliances), project contingency costs, interest during construction, taxes, and plant commissioning. They estimate indirect costs add an additional 22% to capital building costs (Outlook Market Research and Consulting, 2008). However, indirect costs do not include working capital costs, items such as inventory, accounts receivable, and margin accounts, which are estimated at 25% of capital building costs (Outlook Market Research and Consulting, 2008). Thus to ensure more accurate project planning and complete financial requirements, ethanol projects should also account for an additional 47% over direct capital costs. Other studies have found that indirect and working costs range from 39% to 60% based on the definitions above (Kansas State University, 2002 and National Renewable Energy Laboratory, 2011).

In creating a capital cost formula, several estimated ethanol plant building costs were compiled and graphed. The data presented in Herbst et al. (2002), TDI Projects Inc. (2004), Bain (2007), and Outlook Market Research and Consulting (2008) all showed very consistent results regarding ethanol plant capital costs. Graphing the data generated a representative capital cost curve by size of plant, shown in Figure 2. The cost curve used in the simulation does generate figures that are slightly above those applicable to corn ethanol capital costs. However, the research conducted by Outlook Market Research and Consulting (2008) shows that under foreseeable conditions, ethanol plants using wheat as a feedstock will have slightly higher building costs than those using corn feedstock. The most likely reason for this difference is that the corn ethanol industry is more developed than the wheat version of same and while this situation may change, without any other reason to change the assumption, this thesis uses the data as generated.

Figure 2: Capital Building Costs for Wheat Based Ethanol Plants



Other evidence supports a slightly concave (or power) relationship between capital cost and plant size as presented in Figure 2. For instance, Gallagher et al. (2005) state that it is well known that most industries follow the 0.6 factor rule, where a 1% expansion in processing capacity yields a smaller 0.6% increase in capital costs. Gallaher et al. (2005) also found that dry mill ethanol plants in fact have a power function for capital costs closer to 0.836, which is higher than average for processing plants. The data used in this research follows capital costs as outlined for several wheat ethanol plant capacities in Bain (2007) and Outlook Market Research and Consulting (2008). After an extensive review of their research, a detailed capital cost profile was defined and developed for plant capacities. Stemming from this, a capital cost power formula that accounts for both direct and indirect costs was derived and found to provide the best fit. The resulting discovery of a power factor for wheat ethanol plants of 0.6917 suggests that capital costs for wheat based ethanol plants are higher than most industries but lower than that found in Gallaher et al. (2005). Research by Bain (2007) supports these findings where a power cost factor of 0.7 for wheat ethanol analysis was utilized, further supporting the power cost factor of 0.6917 used in this research.

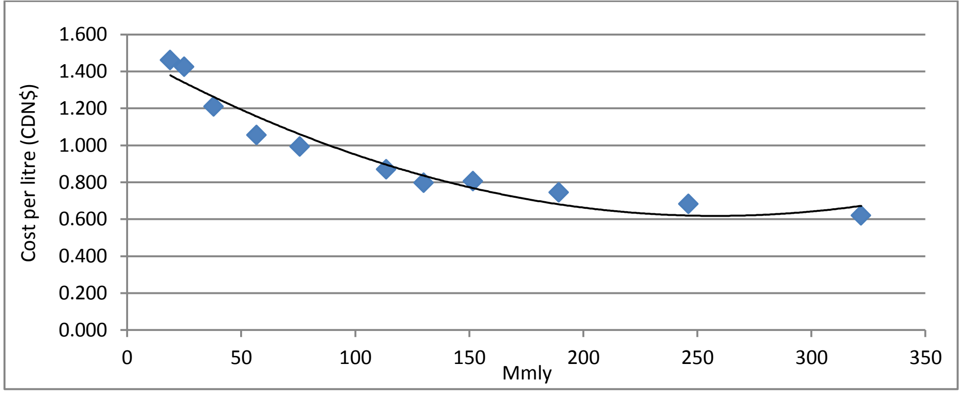
The capital cost formula for a wheat ethanol plant was estimated as:

$$A = 262.87x^{0.6917}$$
$$R^2 = 0.99$$

Where: *A* is total capital building costs, CDN$ (including indirect and working capital costs)
x is proposed plant size in millions of litres per year (Mmly)

If the capital building costs including direct and indirect costs as outlined above in Figure 2 are considered on a cost per litre basis related to plant size (Figure 3), it is concluded that optimal wheat ethanol plant size falls approximately between 240 and 275 Mmly. In turn, this suggests that decreasing capital costs are followed by a period of increasing capital costs past some level of minimum efficient scale. This aspect will be investigated later in the thesis to see if the assumption holds.

Figure 3: Wheat Ethanol Plant Capital Cost per Litre of Nameplate Capacity



Once the capital cost[5] of the proposed ethanol plant is known, factors such as salvage value, loan, and interest payments can also be calculated. Formally, salvage value is set at 10% of capital cost (Outlook Market Research and Consulting, 2008) and the model uses a fixed declining balance method for depreciation (Ross et al., 1996). Capital loan payments are a fixed amount based on the amortization period of the loan, with interest being charged on the remaining balance.

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[5] If shareholder equity is available then this amount reduces the required level of capital cost financing.

The capital loan payment formula (Ross et al., 1996) is as follows:

$$B = \frac{c}{\left(\frac{\left(1-\left(\frac{1}{\left(1+\left(\frac{i}{100}\right)\right)^{k}}\right)\right)}{\left(\frac{i}{100}\right)}\right)}$$

Where: *B* is capital loan payment; CDN$ per year
c is total capital cost of proposed ethanol plant
i is interest rate on capital loan
k is years loan is amortized (*plant-finance-life*)

Depreciation of capital assets considers salvage value, capital cost, and amortization period. Therefore, the depreciation rate will vary depending on the finance period length, as set by the *plant-finance-life* slider on the model interface. Depreciation accumulates over the amortized life of the capital loan. The depreciation rate (Ross et al., 1996) is calculated as follows:

$$C = \left(1-\left(\frac{s}{c}\right)^{k}\right)$$

Where: *C* is depreciation rate
s is salvage value
c is total capital cost of proposed ethanol plant
k is years loan is amortized (*plant-finance-life*)

4.8.1 Capital Cost for Operations

Capital cost is recalculated at the start of the operations phase for sites with NPV ≥ 0. In effect, the ethanol agents once again review production volume within the initial procurement area. From this figure they establish an initial plant size and then calculate capital building costs, salvage value, depreciation, loan, and interest payments based on model settings. The capital cost formula applied during the operations phase utilizes the power formula discussed in Section 4.8, but now the cost for utility servicing[6] must be included in the capital cost formula. This is estimated as:

$$D = 262.87x^{0.6917} + c$$

Where: D is total capital building costs; CDN$ (including indirect and working capital costs)
x is proposed plant size in millions of litres per year (Mmly)
c is the total cost to connect utility service to the site

Ethanol plants typically can produce 20% to 30% above their nameplate capacity if necessary (Swain, October 26, 2006). The ability to produce above nameplate does not affect capital cost, so the simulation endows ethanol agents with an additional 25% of capacity in year one. This flexibility also helps with model stability in the face of possible early demand shocks. Finally, ethanol agents set their period feedstock demand based on current feedstock and ethanol inventory, and this aids in preventing an oversupply of ethanol in the market.

4.8.2 Revenue Streams

Market prices for ethanol and DDGS were averaged out to help stabilize the simulation. Since limited price data is available for Canadian markets, South Dakota ethanol and DDGS price data were used, considering the proximity and similarity of the state to the province of Saskatchewan. Weekly price points from the Agricultural Marketing Resource Centre (Hofstrand and Johanns, 2011) were accessed for the period of March 30, 2007 to July 29, 2011 and converted[7] to Canadian dollars per litre for ethanol and metric tonnes (MT) for DDGS. The Canadian prices were then averaged over this sample period, yielding an overall average price of CDN$0.53/ L for ethanol and CDN$151.86/ MT for DDGS. This average ethanol price is similar to the TDI Projects Inc. (2004) forecasted ethanol price of CDN $0.50 per litre, which was computed based on a formula incorporating a number of factors, including gasoline markets. Figures 4 and 5 display the converted ethanol and DDGS prices for the sample period, while Figure 6 is the Bank of Canada's daily noon exchange rate, used for conversion of this data to Canadian dollars.

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[6] Further discussion regarding utility servicing can be found in the Appendix A.
[7] Ethanol was converted from gallons to litres and DDGS remained in MT. Daily noon exchange rates from the Bank of Canada were also applied.

Figure 4: Ethanol Prices (CDN$) March 30, 2007 – July 29, 2011

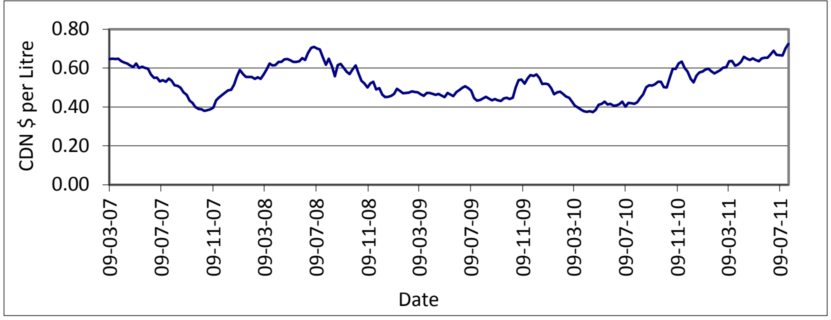


Figure 5: DDGS Prices (CDN$) March 30, 2007 – July 29, 2011

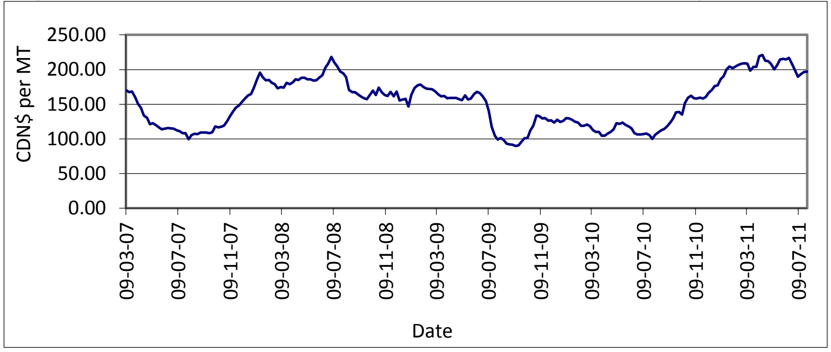
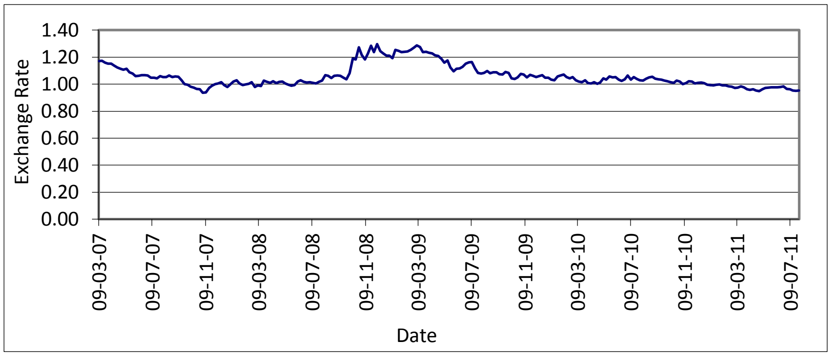


Figure 6: Bank of Canada Daily Noon CDN-USD Exchange Rate; March 30, 2007 – July 29, 2011



Subsidies are another potential source of revenue for ethanol agents since both provincial and federal subsidies in Canada are available to ethanol agents. Two important subsidy programs have been incorporated into the simulation model. These are the EcoEnergy and Ethanol Grant Program. EcoEnergy is a federal program that offers qualifying plants up to $0.10/ L for up to 7 years. This program uses a fixed declining rate per litre of production grant that is applicable to both ethanol and biodiesel. Table 1 shows the applicable rate per year for ethanol agents. Given the years remaining in the program, ethanol agents receive this grant for the full 7 years, based on operations starting in a simulated 2008 – 2009 year.

Table 1: EcoEnergy Program Incentive Rate for Ethanol Producers[8]

Incentive Rate ($ per L)									
Fiscal Year*	**2008 - 2009**	**2009 - 2010**	**2010 - 2011**	**2011 - 2012**	**2012 - 2013**	**2013 - 2014**	**2014 - 2015**	**2015 - 2016**	**2016 - 2017**
Renewable Alternatives to Gasoline	0.1	0.1	0.09	0.08	0.07	0.06	0.05	0.04	0.03
Renewable Alternatives to Diesel	0.26	0.24	0.2	0.18	0.14	0.1	0.08	0.06	0.04
* April 1 of a year to March 31 of the following year.									

The Ethanol Grant Program (EGP) subsidy is a Saskatchewan provincial program that is designed to encourage rural revitalization. Smaller ethanol plants (25 Mmly and less) must receive 30% of blender sales for ethanol sold and blended in Saskatchewan (Canadian Centre of Policy Alternatives – SK, 2008). Currently the mandated level of ethanol in Saskatchewan is 7.5%, meaning that based on gasoline consumption there is an ethanol market of approximately 135 Mmly. Therefore, 30% of this market, or 40.5Mmly (135 Mmly times 30%) is being given to these smaller ethanol plants. The program pays a subsidy of $0.15/ L up to the ethanol market limit of 135 Mmly (Canadian Centre of Policy Alternatives – SK, 2008). The EGP has a budget of approximately $23 million per year and is renewed on yearly basis.

In the agent-based simulation, the latter subsidy is received over the life of the plant during the initialization stage. However, once operations begin, options are programmed into the interface to limit the number of years this program can operate. During initialization the ethanol agents are split into two groups, those with proposed output capacities above 25 Mmly and those below 25 Mmly. The groups then share the EGP as follows; small plants (below 25 Mmly) receive 30% of the 135 Mmly ethanol market, while large plants receive the balance of funding (70% of the 135

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[8] Natural Resources Canada: http://oee.nrcan.gc.ca/transportation/alternative-fuels/programs/ecoenergy-biofuels/biofuels-incentive.cfm?attr=16.

Mmly ethanol market). This ensures equal access for all simulated ethanol agents to the provincial EGP subsidy.

4.8.3 Market Sales of Ethanol and DDGS

Sales of ethanol and DDGS are connected to the ethanol agents' operational size and market demand constraints, implying that total production at best should only slightly exceed the applicable demand. Therefore, each ethanol agent will only expand and produce to that level it can sell, thereby limiting its total market share to production capabilities. Based on this assumption, market share is computed as a percentage of an individual ethanol agent's production and inventory compared to total production and inventory of all ethanol agents. Should an ethanol agent's share of market demand exceed its production, then this demand is met by drawing from that agent's inventory, if available. But excess market demand also creates expansion opportunities for ethanol agents, a point discussed in more detail in Appendix A. Being a byproduct of ethanol production, DDGS market share is handled in the same manner as ethanol and is assumed to track the same demand changes found in the ethanol market.

Sales of ethanol and DDGS take place based on the allocated market share. Ethanol and DDGS prices are based on an average price derived from data in South Dakota. Prices are adjusted for the effects of inflation after year one, whereby inflationary effects can be further set by the *inflation-on-revenue* slider found on the NetLogo interface. Once sales have been calculated, corporate income taxes are applied to positive net income and the tax rate is set from the interface slider *corporate-tax-rate*.

4.8.4 Ethanol Breakeven Price Analysis

A breakeven ethanol price is calculated, which is the ethanol market price required for the ethanol agent to cover their average variable costs as computed. The ethanol breakeven price is driven by the price of ethanol and the breakeven decision is not affected by revenues from subsidies and DDGS. Removal of DDGS and subsidy revenue for each plant provides a more realistic snapshot of the agent's financial situation given that both DDGS revenue and subsidies are not guaranteed. As is well known, subsidies can be removed from the marketplace and DDGS revenue can be quite volatile given the number of alternative feed sources available.

Perrin et al. (2009) state that an ethanol plant would presumably shutdown when the price of ethanol falls below its variable average cost. Without considering the effect of corporate income tax and observing the work of Perrin et al. (2009), the ethanol breakeven price is calculated as follows:

$$P_e = OC + \left(\left(\frac{1}{EY}\right) P_w\right) - \left(DY * P_{ddgs}\right) - S$$

Where: P_e is ethanol breakeven price
OC is average variable cost per litre of ethanol produced (note that when corporate income tax is considered, it is added to average variable cost per litre)
EY is ethanol yield (litre) per kilogram (kg) of processed feedstock (0.372)[9]
P_w is the price of wheat per kg
DY is DDGS yield (kg) per kg of processed feedstock (0.793)[10]
P_{ddgs} is the price of DDGS per kg
S is total subsidies received by the ethanol agent per litre of ethanol production

Perrin et al. (2009) found that since corn and DDGS are essentially substitute feeds, the price of DDGS is closely related to the price of corn. Based on the assumption that wheat feedstock and DDGS produced from wheat based ethanol plants are also substitutes, the Perrin et al. (2009) findings are applied to this wheat ethanol market. Therefore, the price of DDGS is approximated as follows:

$$P_{ddgs} = \left(\frac{\overline{P_{ddgs}}}{\overline{P_w}}\right) P_w$$

Where: $\overline{P_{ddgs}}$ is the average price of DDGS per kg
$\overline{P_w}$ is the average price of wheat per kg
P_w is the price of wheat per kg

As stated, the average price of DDGS used in the model is \$151.86/ MT (Hofstrand and Johanns, 2011) or \$0.15186/ kg and the average price of wheat used is \$154.69 (Saskatchewan Ministry of Agriculture) or \$0.15469/ kg.

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[9] Ethanol production for one MT of wheat feedstock is 372 L or 0.372 L of ethanol per kg.

[10] DDGS production for 372 litres of ethanol is 295 kg or 0.793 kg of DDGS per litre.

4.8.5 Financial Analysis/ Operational Health

Given that the ethanol agents have calculated income and expenses, a number of other assessments are completed regarding the financial health of their operations. These assessments will help decide whether an ethanol agent will continue or discontinue its operations. And it is assumed that if an ethanol agent discontinues operations, any inventory levels belonging to that particular agent are removed from the marketplace. Operational efficiency and profitability are reviewed by assessing whether the ethanol agent has reasonable access to feedstock to meet plant capacity, and that the ethanol agent is able to meet its short and long term financial obligations.

The work of Outlook Market Research and Consulting Ltd. (2008) offers that it may take up to five years for ethanol production to stabilize after startup, but most studies consider a two year startup period for production to attain nameplate capacity (Herbst et al., 2003). During this time, access to feedstock is key to survival in this market. If procurement area competition limits access to feedstock, then an ethanol agent faces increasing costs, either by operating below capacity or through additional search costs incurred in order to acquire feedstock from greater distances. Therefore, feedstock requirements are slowly phased-in to reflect market reality and aid with model stability within the first few years of the simulation.

Staging feedstock access in the model during startup entailed numerous trials to ensure model stability while continuing to emulate market reality. Allowing the ethanol agents to initially secure feedstock requirements lower than their individual feedstock capacity constraint eased initial competition effects and promoted model reliability. Thus, the ethanol agent is only required to secure enough feedstock to meet 50% of their feedstock capacity constraint in year one, 60% in year 2, 70% in year 3, and for year 4 and beyond this constraint increases to a user setting between 80% and 100% of plant feedstock capacity, the latter being set by slider on the interface called *plant-size-variability*[11]. This process allowed the simulation to carefully assess the effects of competition and smoothly remove ethanol agents which were not able to meet their nameplate capacity levels.

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[11] The variable *plant-size-variability* was included to allow ethanol agents operational flexibility resulting from competition and demand shifts.

The remaining assessments focus on the financial strength of the ethanol agent. At specified time periods, the ethanol agent compares average income per litre of produced ethanol with average variable cost, average fixed cost, and total average cost. Each of these financial assessments is administered individually to ensure the ethanol agent continues to meet both their short and long term financial obligations. In other words, is the ethanol agent operating above their shutdown point in the short term and financially solvent in the long term? Should they be unable to meet their financial obligations then the plant immediately shuts down. Once an ethanol plant has shutdown, it is removed from the landscape[12].

Options built into the NetLogo© interface also allow the user to specify the time periods when revenue and average costs will be compared. In simulation runs, average variable costs can be checked every 0, 3, or 5 years and average costs can be checked every 0, 5, 10, 25, 35, 45, or 55 years. However, it was found that shorter durations between revenue/cost checks will severely limit the number of successful ethanol agents on the landscape, especially when demand shocks lead to plant expansions. Given the low margins found in general in the ethanol industry, it is observed that average cost should be checked every 25 years (preferably 35 years), allowing ethanol agents the opportunity to stabilize their operations and ultimately take advantage of economies of scale. Lastly, an overall profitably check is completed to see if an ethanol agent has been able to net out profits and losses. The year chosen for this check is set using an input box on the interface called *profitability-year-check*. For the simulation results shown in this thesis, this parameter was set at 50 years since this duration was found to offer the highest level of model stability in generating solutions. Additional discussion of these variables will be found in Section 5.6.

4.8.6 Feedstock Access

Given that plant capacity remains set at the limit found during the initialization phase, the effects of procurement area competition will start to be felt during the first year (or tick) of the simulation. Ethanol agents in the model are permitted to call deliveries from farmers outside their initially assigned procurement area, but this will increase feedstock transportation costs. In

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[12] Allowing inefficient (shutdown) plants to remain on the landscape for the purpose of starting at a later date or being acquired by another ethanol agent was considered beyond the scope of this research, given that the objective is to examine factors that promote stable locations over time.

turn, it is assumed in the model that farmers are responsible for the cost of feedstock delivery and that they are price takers, meaning that at even greater distances, there always exists a pool of farmers who would be willing to deliver[13].

4.8.7 Feedstock Delivery

As discussed in the literature review, there are simultaneity of computation limitations within NetLogo© which prevent actual concurrent agent actions. To mitigate this issue, the algorithm used for feedstock delivery (illustrated in Diagram 4) spreads the call for feedstock across farmers with inventory in a particular procurement area. This creates a situation that mimics actual farmer deliveries and more importantly prevents one buyer from dominating an area. In the author's real life experience, very few farmers deliver to only one buyer, rather they seek out various buyers based on price, distance, or loyalty for example. This supports competition within overlapping procurement areas of competing ethanol agents and also permits farming agents to have contracts with multiple buyers. However, a more detailed analysis of price competition in input procurement between ethanol agents is beyond the scope of this research.

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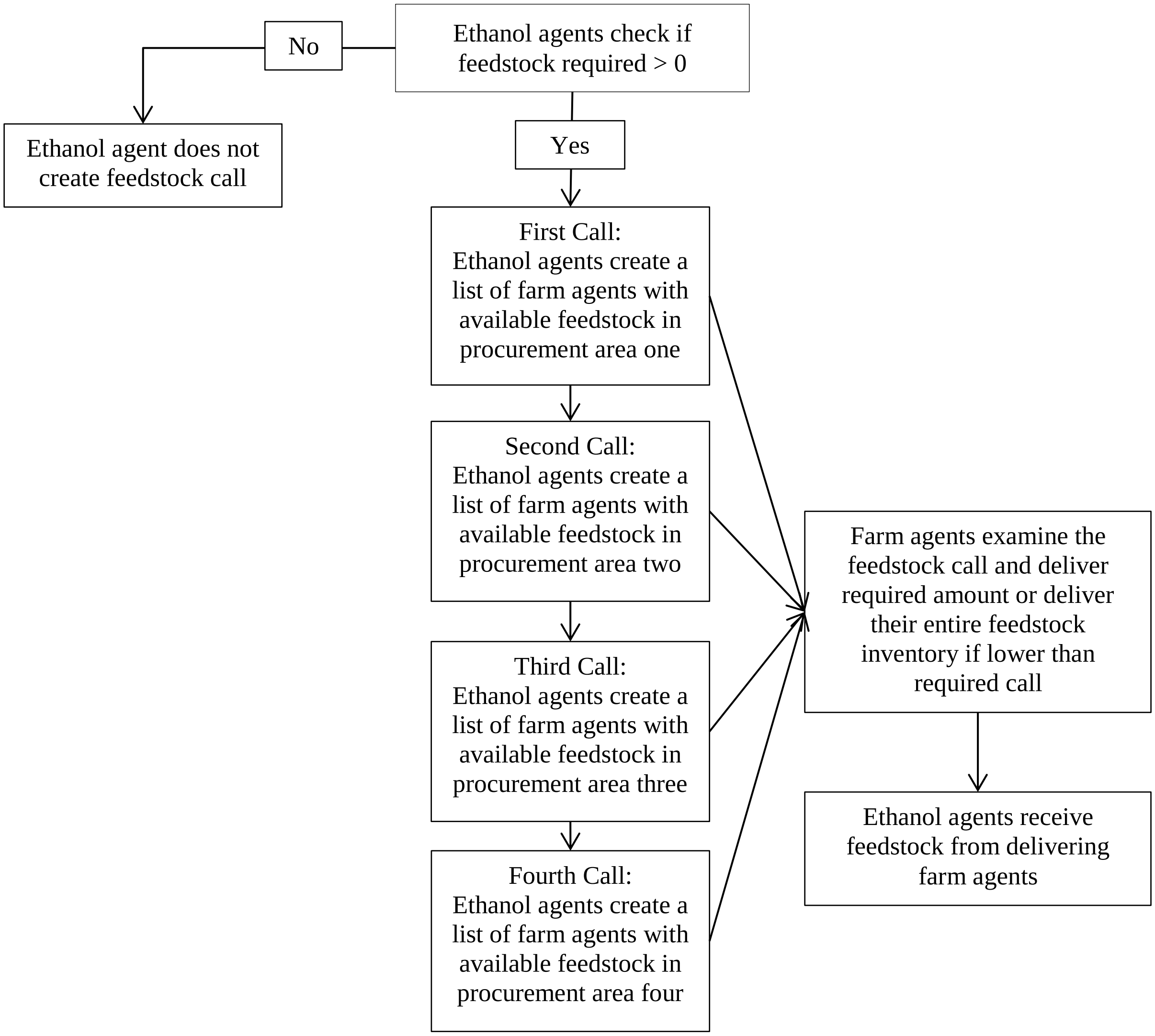
[13] Please see Appendix A for more details on bulk trucking rates and distances.

Diagram 4: Ethanol Agent Feedstock Delivery Algorithm (See Section 4.8.7)



The call for feedstock is comprised of four algorithms. Each call corresponds to a specific procurement area. The first feedstock call is comprised of farmers with feedstock inventory found in the first procurement area. The ethanol agent then creates of list of farmers with feedstock inventory and allocates its input demand among those farmer agents. It is assumed that a farmer agent only delivers what is called. However, if a farmer agent's inventory does not meet the specified call, then that farmer can only deliver their current feedstock inventory. Once a farmer agent has delivered their entire feedstock inventory, they are no longer contacted by ethanol agents for the remainder of that cycle. To reiterate, the model assumes FOB pricing to minimize the net cost of feedstock, where this is the amount paid for feedstock minus the amount received for DDGS byproduct (Van Wart and Perrin, 2009).

The ethanol agents then compare their feedstock inventory to required input demand. If additional feedstock is needed, they can move to a second call which is sent to farmers in the second procurement area. Feedstock calls to farmers in the second, third, and forth procurement areas follow the same procedure. Once an ethanol agent's feedstock requirement is met, no additional calls are made. During the call process it is possible, if competition is heavy, for an ethanol agent to be unable to meet their feedstock input demand. Should this happen, the ethanol agent operates below capacity through the remaining operation procedures. This will increase variable and fixed costs for the ethanol agent since they are not able to operate at maximum efficiency. Depending on their financial situation, this may lead to plant shutdown.

4.9 Nearest Location Factors

Within the simulation model there exist a number of heuristics specific to distance calculations. The measurement of the distance within a simulated landscape can either be based on a grid pattern typical of most transportation networks, often referred to as the Manhattan distance, or a more direct route where obstacles do not impede movement, often referred to as Euclidian or 'as the crow flies' distance. The grid based patch pattern found within NetLogo©, based off an (x, y) coordinate plane, can be used to mimic real transportation routes. This happens to be quite representative of Saskatchewan's actual rural transportation system, where both north/south and east/west movements are typically required to move between two points. Thus the Manhattan distance heuristic will be utilized in the simulation and is subsequently discussed.

4.9.1 Transportation Calculations

The value of the distance between two points is found using the absolute x and y coordinates of the first location, less the absolute x and y coordinates of the second location. Using an exact heuristic (with absolute values) means that the distance is the shortest grid path between two points and therefore the lowest transportation cost (Patel, 2012). The Manhattan distance heuristic is considered standard for square grids (Patel, 2012), and is a superior representation of transportation routes in Saskatchewan and most rural locations, since roadways in the province typically run in an east/west and north/south grid pattern. Manhattan distance also allows for travel around obstacles by following roadways, as compared to Euclidian distance which takes the shortest path across the landscape (Teahan, 2010). For example, in this simulation farm agents calculate distance from their location to the ‘calling’ ethanol plant using the following NetLogo© code:

```
set feedstock-truck-dist (abs ([xcor] of self - [xcor] of ethanol-delivered-too) +
                                    abs([ycor] of self - [ycor] of ethanol-delivered-too))
```

Within this Manhattan distance heuristic, the variable *feedstock-truck-dist* stores the calculated distance value which will later be used in subsequent transport cost calculations. Distance is calculated from the x and y coordinates of the farm agent, denoted by the command *of self*, to the absolute x and y coordinates of the ethanol plant, denoted by the variable *ethanol-delivered-too*. Subtracting the respective x and y distances and summing the absolute value of each produces the requested distance from each farm to an ethanol plant agent. Using the shortest grid path between the farmer and ethanol plant, the projected outcome is to source inputs with the lowest transportation cost. This distance value is then used to calculate other associated costs.

The Manhattan distance algorithm is also used to find nearest location variables which are held at the patch level. These variables are accessed by other agents within various procedures during model initialization and operations. Finding the distance between a fixed patch location and an agent follows a similar procedure as described above, only now the built in patch location variables *pxcor* and *pycor* are compared to the built in turtle location variables *xcor* and *ycor*. These patch variables hold the (x, y) coordinate location of the patch and remain constant throughout the simulation since patches cannot move. In contrast, turtle coordinate variables can change as the turtle moves over the landscape.

During the simulation, distances to site specific variables such as mainline railway, primary highway, feedlot, blender, water (river), electrical, and natural gas access must be calculated to allow an ethanol agent to efficiently evaluate a potential production location. Distances to these nearest locational factors for a particular site are calculated in NetLogo© using the Manhattan heuristic. By way of example, here is the NetLogo© code used in the simulation to find nearest location factors:

(abs([xcor] of nearest-location-factor - pxcor) + (abs([ycor] of nearest-location-factor - pycor)))

The term *nearest-location-factor* represents one of the site specific location factors used to evaluate the ethanol production potential of a location. As site distance to these location factors increase so does associated costs. For instance, as patch distance increases from location factors such as transportation networks, utilities, or markets the costs associated with those distances will have to be weighed against access to procurement area feedstock for example. These locational constraints are included to imitate fact within the simulation model. Ignoring these types of locational cost factors during site selection can have a dramatic effect on operational efficiency and costs.

4.9.2 Ethanol and DDGS Transloading Costs

Some well cited prior literature indicates that ethanol loading and transfer costs can be on average approximately US$0.05/ gallon (Low and Isserman, 2008). However, when additional US data on ethanol trucking costs were reviewed, loading costs actually averaged CDN$0.0122/ litre[14,15] (National Academy of Sciences, 2009). This rate includes cost per litre to load and unload, coupled with the time dependent cost of the truck driver. In turn, average time dependent cost of a truck driver is approximately CDN$33.73/ hour[14,15] (National Academy of Sciences, 2009), which includes labour and capital considerations when the truck is stationary. Distance rate on a per kilometer basis averages CDN$0.8516[14,15] (National Academy of Sciences, 2009), including fuel, insurance, maintenance, and acquiring permits. Pump volume for loading ethanol

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[14] All figures have been converted to metric from imperial using conversion figures of 3.7844 for gallons to litres and 1.609344 for miles to kilometers.

[15] Average dollar calculations have been adjusted with Bank of Canada Monthly Consumer Price Index over a 22 month time period and converted to CDN$ using Bank of Canada Monthly Exchange Rates. The period chosen coincides with and builds upon National Academy of Sciences (2009) research dates allowing current day prices to be generated using the Consumer Price Index and Exchange Rate.

averages out at 2,460[14] litres per min (lpm) and unloading pump volume is averaged at 1,514[14] lpm (Abengoa Bioenergy, 2003).

Product characteristics dictate that transloading costs are different for ethanol and DDGS. Ethanol transloading costs typically involve shipment loading and storage facility fees, and within the simulation model the following two cost factors were considered. The cost to load and unload at an ethanol facility (CDN$0.0056/ litre (L)) was used as a proxy for transloading, as well as a storage fee of CDN$0.002/ L (OECD, 2004). The storage fee covers the cost of holding ethanol until the volume required for a large order (or unit train, for example) is met. This leads to a total transloading cost per litre of CDN$0.0076/ L. To complete this process, under current conditions it was calculated that 3.75[16] tanker trucks are required to fill one tanker railcar. Therefore, each ethanol agent must consider additional shipping costs for rail movements when evaluating a location not directly adjacent to a rail line on the landscape. Finally, it is assumed that the cost to transload a truck shipment of DDGS is fixed rate at $398.00[17] (Informa Economics, 2007), while the ethanol agent must ship 2.28[18] DDGS truck shipments to fill one covered hopper railcar.

4.9.3 Ethanol Transportation Methods

The total cost of shipping ethanol by tanker truck is considered to be an increasing linear relationship (as shown in Figure 7), which translates into a declining per-unit cost as distance increases. An ethanol tanker truck in the simulation holds 30,275 litres[19], a figure converted from US tanker truck capacity of 8,000 gallons (National Academy of Sciences, 2009). Shipment cost is estimated as follows[20]:

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[16] One ethanol tanker truck carries 30,275 L and one ethanol rail tanker car carries 113,562 L, dividing 113,562 by 30,275 equates to 3.75, the number of tanker trucks required to load one rail tanker car.

[17] Rate quoted in USD $375.00, used an average exchange rate of 1.06, based on weekly exchange rates for the period March 2007 to July 2011 (Bank of Canada, www.bankofcanada.ca/rates/exchange/10-year-lookup/, accessed August 30, 2011.

[18] One DDGS bulk truck carries 24.9 MT of and one DDGS covered hopper railcar carries 56.74 MT, dividing 56.74 by 24.9 equates to 2.28, the number of bulk trucks required to load one covered railcar.

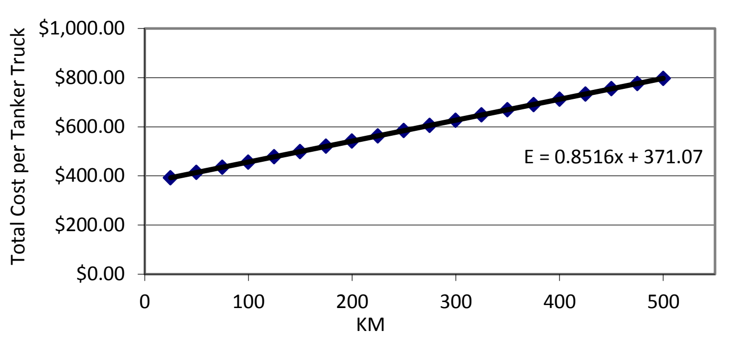
[19] All figures have been converted to metric from imperial using conversion figures of 3.7844 for gallons to litres and 1.609344 for miles to kilometers.

[20] The relationship of shipping ethanol by transport truck is deterministic ($R^2 = 1$) due to the use of flat (average per unit) costs (as outlined in section 4.9.2) for loading/unloading, labour (driver), and cost/KM (distance) figures, which only increase linearly with distance.

$$E = 0.8516x + 371.07$$

Where: E is total rate per loaded tanker truck; CDN\$
x is distance in kilometers

Figure 7: Ethanol Tanker Truck Transportation Cost



Rates for ethanol rail shipments are also set using an increasing linear relationship. Figure 8 graphs recent ethanol rail rates for Canadian National Railway[21] applicable to a loaded tanker car. Ethanol rail rates were calculated using CN's online Carload Tool, where a total of 25 routes were searched based on extant ethanol plant and market locations. The data generated was very similar to rail rates acquired from USDA Agricultural Marketing Service's Biofuel Transportation Database. Therefore, the choice to use the Canadian data was made given the similar results[22]. A simple relationship for ethanol rail shipping cost was estimated using this data. This produced the following relationship:

$$F = -0.0009x^2 + 4.0872x + 1441.90$$
$$R^2 = 0.91$$

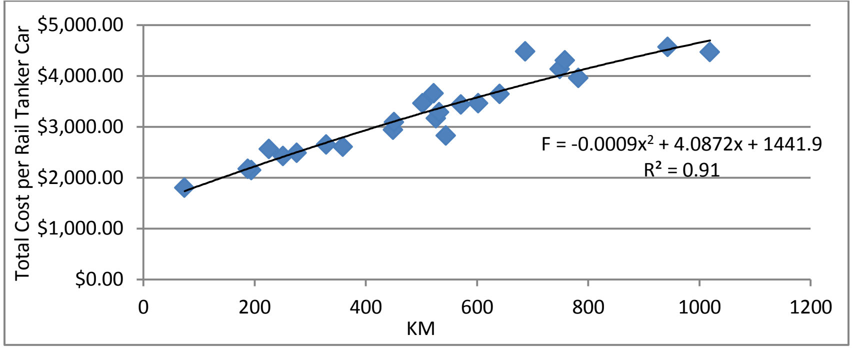
Where: F is total rate per loaded railcar; CDN\$
x is distance in kilometers

---

[21] CN Rail Rates are for shipping 4909159 (Ethanol (Alcohol Ethyl)), UN1170.

[22] One outlier was removed from the dataset obtained from CN's Carload Tool. This point biased the results leading to what was found to be undervalued outcomes from the estimated relationship.

Figure 8: Ethanol Tanker Railcar Transportation Cost



Note that the movement of ethanol in the simulation is converted from litres to metric tonnes, and this was done to ease computation and maintain consistency for movements through the supply chain. By volume, one MT of ethanol is equivalent to 1,262 litres (Oak Ridge National Laboratory, 2008). Using this figure, a loaded tanker truck carries 23.99 MT (30,275 L divided by 1,262 L) while a tanker railcar carries 89.99 MT (113,562 L divided by 1,262 L).

4.9.4 DDGS Transportation Methods

DDGS shipments are treated in a very similar fashion to ethanol. Given that DDGS are moved in bulk shipments, freight costs for feedstock shipments were used as a proxy but altered slightly to reflect the lower haul weight - a bulk truckload of DDGS has been calculated to weigh 24.9 MT[23]. DDGS bulk truck shipping cost is shown in Figure 9 and was estimated as follows:

$G = -0.0009x^2 + 2.8246x + 251.58$
$R^2 = 0.99$[24]

Where: *G* is total rate per loaded bulk truck; CDN$
x is distance in kilometers

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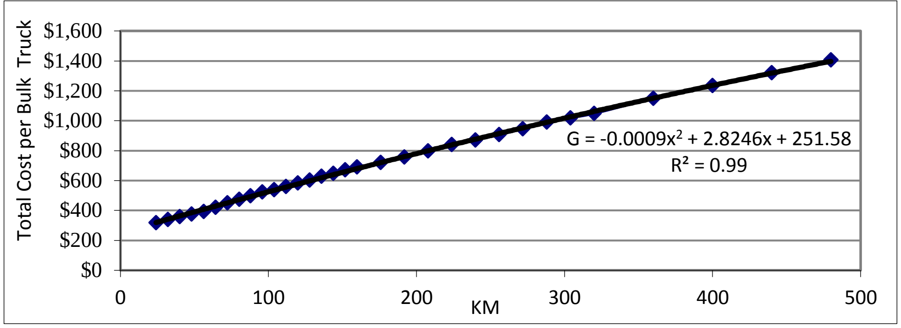
[23] Wheat has a bulk density of 48.18 lbs./cubic foot and DDGS 30lbs./cubic foot. Therefore, DDGS bulk density is 62.27% of wheat. A super B bulk transport truck is assumed to haul 40 MT of wheat. Therefore, the same bulk truck can haul 40 MT * 62.27% = 24.9 MT of DDGS. This assumption implies that the trucking rate for wheat will be the same for DDGS. Even though less weight is hauled, the available hauling volume is still being utilized, which leads to an increase cost per MT. A $1.10/ MT charge for shoveling has been included to further create an accurate cost estimate considering the problems of unloading DDGS at the final destination.

[24] Data for transport truck shipment of bulk DDGS was based on bulk grain shipping costs obtained from Weyburn Inland Terminal. These costs were adjusted to reflect the lower hauling weight of DDGS (24.9 MT) and to rationalize the known difficulties with unloading DDGS (such as bridging, where the DDGS product refuses to flow out at unload), an additional cost of $1.10 per MT was added for shoveling (a surchargeable cost listed for grain transport by Weyburn Inland Terminal).

Figure 9: DDGS Bulk Truck Transportation Cost

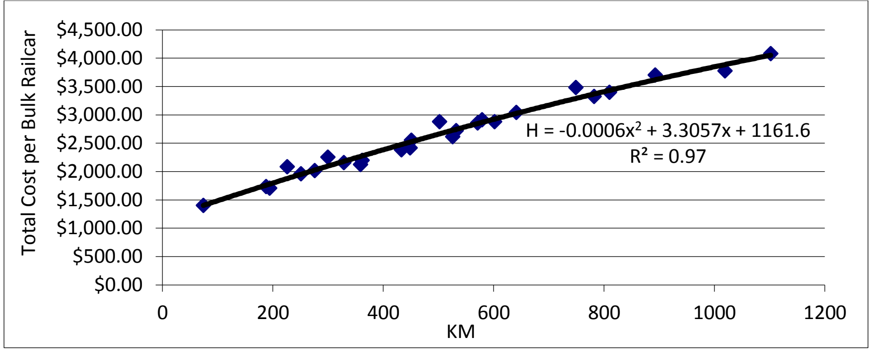


DDGS rail shipments (shown in Figure 10) were obtained once again from Canadian National Railway[25]. DDGS rail rates were calculated using CN's online Carload Tool, with a total of 25 routes searched based on current ethanol plant and DDGS market locations. Again, the data was very similar to DDGS rail rates acquired from USDA Agricultural Marketing Service's Biofuel Transportation Database. As with ethanol, the choice to use Canadian data was made given the similarity of the results[26]. One covered hopper railcar holds 56.74 MT (Ileleji, 2010) of DDGS, leading to the following estimates of rail costs:

$$H = -0.0006x^2 + 3.3057x + 1161.60$$
$$R^2 = 0.97$$

Where: H is total rate per loaded hopper railcar; CDN\$
x is distance in kilometers

Figure 10: DDGS Bulk Covered Hopper Railcar Cost



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[25] CN Rail Rates are for shipping 2085940 (Dist Mash (Spt)).

[26] Outliers for one destination were removed from the dataset obtained from CN's Carload Tool. This destination skewed the dataset leading to undervalued outcomes.

4.10 Summary

This chapter outlined the economic, financial, and transportation concepts used in the simulation model, as well as the key underlying heuristics and algorithms as coded into the software. The model is designed to simulate and evaluate location potential for ethanol plants, with the goal of identifying stable or sustainable ethanol plant locations on the representative landscape. The econometric relationships used in the model are estimated using applicable data and are also designed to help emulate actual decisions to locate ethanol plants in Saskatchewan, Canada. In the interest of continuity, discussion of any remaining variables and relationships used in the model but not specifically mentioned in this chapter are provided in Appendix A.

CHAPTER 5

Base Model Parameter Settings

5.0 Introduction

Next attention is given to the initial parameter settings used for what will be referred to as the base simulation model run. Ethanol agents perform the majority of interactions and decisions within this model, and the success of an agent is founded upon factors aimed at discovering stable or sustainable plant locations on the landscape. Factors influencing these decisions include the presence of economies of scale in production, feedstock production, procurement area competition, and government policy and subsidies.

During the net present value and operations phase of the simulation, a number of variables can be adjusted by the user to evaluate aspects of system dynamics. These variables include inflation, capital loan interest rate, capital loan finance life, plant life, corporate tax rate, subsidies, shareholder equity, discount rate (applies to NPV analysis only), and demand shocks. These variables will affect the number of ethanol agents that initialize in the simulation on locations with an $NPV \geq 0$, and during operations these variables can affect success or failure of plant location.

5.1 Base Run Parameterization

The base run is designed to reflect the current ethanol market in Canada, specifically applied to the province of Saskatchewan. The chosen parameters are an attempt to emulate a current market scenario and will be tested to see if a situation resembling the current market structure in this industry can be replicated within the simulation. The opportunity to perform additional model runs can help identify the effect of potential system shocks and help build a greater understanding of industry reaction over time as a result of these shocks. Most notable among these are the effect that government intervention through subsidies may have had on the organization of this industry. To this end, Tables 2 and 3 show the initial settings used in the model, including both adjustable and landscape parameters.

Table 2: Base Run Variable Settings

Variable	**Setting**	**Reference**	**Notes**
Plant-finance-life	20 years	Bain (2007)	Herbst et al. (2002) uses 10 years
Interest-rate	8%	Herbst et al. (2002)	Capital loan interest rate
Plant-life-years	60 years	Nilles (2006)	Range of 30 – 60 years
Expansion-plant-finance-life	10 years	Herbst et al. (2002)	Expansion loan, half of start up
Inflation-on-revenue	1.9%	Bain (2007)	Holcomb & Kenkel (2008) use 1%
Inflation-on-expenses	1.9%	Bain (2007)	Herbst et al. (2002) and Holcomb & Kenkel (2008) use 1%
Inflation-on-labour	2%	Holcomb & Kenkel (2008)	
NPV-discount-factor	10%	Bain (2007)	Herbst et al. (2002) use 8%; Holcomb & Kenkel (2008) use 12%
Corporate-tax-rate	30%	Herbst et al. (2002); Holcomb & Kenkel (2008) use 30%	S&T^2 Consultants Inc. (2004) suggest a rate of 32.12%
Plant-size-variability	90%		Slack variable to allow for intake variability
Shareholder-equity?	On		Switch (either on or off)
Level-shareholder-equity	50%	Herbst et al. (2002)	Literature suggests 25-100% shareholder equity with majority at 50% (Herbst et al. (2002); S&T^2 Consultants Inc. (2004); TDI Projects Inc. (2004))
Profitability-year-check	50 years	Model instability results if checked earlier when in expansion mode	Input window. With expansion, an early overall profitability check can cause model instability
Subsidy?	Yes		Switch: on = yes; off = no
Provincial-subsidy-years	60 years	Currently renewed each year, assume this will continue	Drop down chooser menu
Market-demand-on?	Yes		Switch: on = yes; off = no
Ethanol-market-demand	135 Mmly	Canadian Centre of Policy Alternatives – SK (2008)	Input window. Based on current Saskatchewan gasoline demand and mandated ethanol content level
Timed-demand-shock	5 years		Drop down chooser menu. Demand will increase every five years
Percent-increase-in-demand	10%	Adds 162 Mmly over 60 year life	Drop down chooser menu. Amount that demand will increase based on timed demand shock setting
AVC-year-check	3 years		Drop down chooser menu. Every three years average variable costs will be reviewed (shutdown point)
AFC-year-check	5 years		Drop down chooser menu. Check to see if average fixed costs are being

			covered
AC-year-check	35 years		Drop down chooser menu. Check to see if average costs are being covered. Earlier dates cause model instability in expansion mode

Table 3: Base Run Landscape Variable Settings

Landscape Variables	**Setting**	**Notes**
Procurement-area	10	Eathington & Swenson (2007); Sarmiento & Wilson (2008). Equates to a 100 km zone
Total-production	4,000,000 MT	Feedstock production – see discussion below; S&T^2 Consultants Inc. (2004)
Primary-road	8	Location on landscape
Main-rail	6	Location on landscape
Power-grid	6	Location on landscape
Natural-gas-grid	6	Location on landscape
River	7	Location on landscape
Number-of-towns	10	Number located on landscape
Number-of-cities	5	Number located on landscape
Number-of-feedlots	4	Number located on landscape
Number-of-blenders	2	Number located on landscape
Total-runs	1,000	Number of runs in base simulation

5.2 Endogenous and Exogenous Variable Effects

The variables or factors mentioned throughout this research are all postulated to have an effect on where and how an ethanol plant will locate within the landscape. Few of them are decisive elements on their own, but collectively they can influence what characterizes a sustainable or stable plant location. Many of these variables are considered exogenous to locational choices for ethanol plants and also generate a level of risk, given that no control over the variable can be exerted by the agent. Within this simulation, such exogenous variables include feedstock (wheat) price and production levels, ethanol and DDGS market prices, bank interest rate, inflation rate, subsidies, corporate tax rate, and mandated ethanol levels.

Endogenous variables are those that the ethanol plant can influence and potentially use to their advantage. Endogenous variables include nameplate capacity and production level, plant life, and ethanol contract type. These variables are considered influential within the model for the following reasons. During planning stages, there exists an opportunity to appropriately plan nameplate capacity within required input constraints, while the operations phase allows ethanol plants opportunities to choose maintenance schedules along with contract types and lengths that best suit their operation. Within this model, ethanol plants are able to choose nameplate capacity and output levels within predetermined constraints, but for tractability maintenance and ethanol contract types are fixed.

The inclusion of these endogenous and exogenous variables in the simulation will extend our understanding of how such variables can help decide sustainable or stable ethanol plant locations over both time and space. To reiterate, other studies including those by Noon et al. (2002), Freeze and Peters (1999), Tyner and Taheripour (2008), and Herbst et al. (2002) have also identified a number of these variables, again providing strong evidence of their importance to the decision-making process in this industry.

5.3 Financing

Financial requirements for ethanol agents must consider several factors. Typically, capital cost requirements in the industry are split evenly with 50% borrowed funds and 50% contributed equity or equity capital from perspective investors (Herbst et al., 2002). Herbst et al. (2002) state this ratio of borrowed to owned equity is an industry standard, with most lenders requiring borrowed equity to be split between three or four financial institutions to reduce risk. The base run simulation model assumes that 50% of required equity will be obtained through shareholders, where shareholder equity can take the form of local investors, primary producers, or private enterprises.

Financing term length for capital building costs will also affect an ethanol agent’s success in this model. For example, if the chosen term is too short, the ethanol plant may fail as it struggles with high debt servicing requirements. If it is too long, then inherently inefficient ethanol plant agents may be allowed to continue operations. The literature offers a number of suggestions about capital loan repayment periods. For example, Bain (2007) uses 20 years, which offers ethanol agents a lower principle payment amount, a factor that may help alleviate cash flow dilemmas during startup stages. Interest rates on borrowed equity range from 6% to 10% (Herbst et al., 2002; S&T^2 Consultants Inc., 2004; TDI Projects Inc., 2004; Bain, 2007; Holcomb & Kenkel, 2008; Hofstrand, 2011), while this base run scenario will use an interest rate of 8% (Herbst et al., 2002). The same rate will also apply to expansion loans, but here the repayment period is set at 10 years. Expansion costs are approximately 32% (Shapouri and Gallagher, 2005) of new capital building costs, and when combined with changing demand factors allows ethanol agents a better chance to respond to market opportunities while reducing loan carrying time. This translates to an increased number of expansion opportunities for successful ethanol agents within their simulated 60 year plant life.

Production life for an ethanol plant is continually shifting forward given the industry’s relative youthfulness. Nilles (2006) states that most experts suggest 30 to 60 years of useful life expectancy for dry-mill fuel ethanol facilities, while the low end of the range seems conservative with the industry now reaching its 30 year milestone. A quality and adaptable plant that follows manufacturer recommendations for maintenance, is likely to be the key to extended ethanol facility life past 50 years. An adaptable plant with a flexible design will allow future expansions to take advantage of new technologies and efficiencies, leading to greater competiveness while increasing industry knowledge regarding future plant design (Nilles, 2006).

5.4 Operating Cost Factors

Inflationary effects on variable operating costs and revenue must be included in any capital investment analysis. The long life of capital projects generally implies that price inflation or deflation will occur, and while it is possible that positive and negative inflationary effects on capital investment price levels may net to zero over time, this is not guaranteed (Ross et al., 1996). In the base model, inflation is set at 1.9% for operating costs and revenue (Bain, 2007), whereas other authors have suggested an inflation rate of 1% for the industry (Herbst et al., 2002; Holcomb & Kenkel, 2008). The higher rate used in the base model more accurately reflects the current inflation rate of approximately 2.6% (Bank of Canada, 2012). Holcomb & Kenkel (2008) suggest a wage inflation rate of 2% which reflects the additional costs associated with administering salary increases due to inflationary adjustments, an area that does not concern the current research but could be worth noting for future work given its financial effect on operations.

Income tax rates vary based on provincial boundaries and affect investor returns through lowered earnings. The simulation assumes a generic rather than a specific type of business structure in this regard, and while a specific business structure may provide a tax shield, building that into the current model is beyond the scope of this research. Related literature specifies that corporate tax rates are location dependent (Bain, 2007) which creates variability during site selection. However, the suggested tax rate for such analysis is 30% (Herbst et al., 2002; S&T^2 Consultants Inc., 2004; Holcomb & Kenkel, 2008). Therefore profits here will be taxed at 30%, an amount consistent with shareholders or partners paying taxes on their earnings (Herbst et al., 2002).

5.5 Market Demand

Ethanol market demand factors will affect the number of ethanol agents operating in the simulated landscape and influence future expansion plans. Ethanol facilities typically experience a production ramp up period where ethanol output is less than nameplate capacity. Herbst et al. (2002) suggest that plants follow a 50% operational capacity in the first year, followed by 100% capacity thereafter. Others have suggested that it takes up to five years to bring a new plant fully online. Within the simulation, *plant-size-variability* essentially functions as a kind of slack variable that facilitates model stability and allows agents to continue operations during cycles where they are unable to secure required feedstock to meet nameplate capacity output. In other words, this variable allows the plant to operate at less than efficient levels due to exogenous factors such as decreased ethanol demand or low feedstock supply, while taking into account current plant feedstock (delivered but not yet processed) and ethanol (unsold) inventory levels. In additional to operating below nameplate capacity, ethanol plants are also able to produce 125% of nameplate capacity (a typical industry standard) during operations, allowing plants to meet small demand increases without financing an initial expansion.

Market demand is assumed to grow for three main reasons: 1) increased adoption of flex-fuel vehicles; 2) potential export opportunities; and 3) an increase in mandated blend levels (Urbanchuk, 2006). Given these factors, demand shocks have been designed to occur at various yearly intervals and at certain percentage levels. For example, the base model imposes a demand increase of 10% over current market demand every five years, and it is assumed that these increases are absorbed by the market. As mentioned, ethanol demand in Saskatchewan is estimated at 135 Mmly (Canadian Centre of Policy Alternatives – SK., 2008) given current mandate levels and gasoline demand. This figure is the base market demand level off of which future demand increases are based. Without any specific guidance, an industry growth rate of 10% every five years is assumed, which seems reasonable given current demand and mandate levels. This means market expansion will be slow and consumable given reasons for ethanol demand increases listed above.

5.6 Ethanol Subsidies

Subsidization of the ethanol industry is currently available from both federal and provincial programs. Subsidies promote the creation and growth of the ethanol industry but shield the industry from competitive market conditions. While these subsidies have affected the organization of the current ethanol industry, their purpose is to promote rural revitalization, increase farm incomes, create new markets for agricultural producers, and reduce environmental impacts (Canadian Centre of Policy Alternatives – SK., 2008).

The base model assumes that subsidies are available for the entire 60 year plant life, as outlined in Chapter Four. However should these subsidies end, what will be the effect on the industry? Will the current industry structure be sustained or will a new structure emerge? These outcomes could have drastic effects on ethanol facilities, given potential changes to world trade agreements and pressure from low cost ethanol producers from countries such as Brazil who seek export markets. In fact, many of the policies and subsidies used in today’s biofuel industry are subject to change since they are considered actionable under Part III of the WTO’s Agreement on Subsidies and Countervailing Measures (Kerr & Loppacher, 2005). Should policies and subsidies change, the local ethanol market could be flooded with cheaper imports that could spell disaster for domestic ethanol producers.

5.7 Proposed Site and Operational Monetary Assessments

Ethanol plants are by nature idiosyncratic site specific investments where their next best use is limited and usually only within the industry. Given this, profitability is essential for guaranteed financing and operations. To ensure that ethanol agents operate according to sound business principles, a number of financial tests are administered in the model at specified intervals.

During the initialization phase, a site under consideration must meet specific returns on investment before a construction commitment can be made. By discounting future cash flows to their present value, a comparison of investment market value and cost can be made. Once present value is calculated investment capital costs can be deducted, leaving net present value. The rule used here is to accept an investment if it returns a positive NPV, whereby the latter is a widely used decision criterion in industry (Ross et al., 1996). Suggested NPV levels for the ethanol industry range from 8 to 12% (Herbst et al., 2002; Bain, 2007; Holcomb & Kenkel, 2008). Here, the base model will use an NPV of 10% (Bain, 2007).

During operations, the goal of an ethanol agent is to create an efficient and profit maximizing venture over both the short and long run. The short run is defined as the length of time during which the ethanol agent's plant and equipment are fixed, namely the scale of plant cannot be changed (Mansfield, 1997). In the short run, the ethanol agent should only produce if it is more profitable than not producing, thereby covering its variable costs. If variable costs are not being covered in the short run, then the ethanol agent should shutdown. This means the shutdown decision in the simulation occurs if the ethanol market price is less than computed average variable costs (AVC). Bain (2007) uses a construction period of three years in his analysis. In our base scenario, the shutdown decision will similarly be evaluated every three years, as this seems to be the required period of time to bring changes to plant scale in this industry.

The long run is defined as the period of time in which all inputs are variable and thus an ethanol agent can make complete adjustment to any change in its operating environment (Mansfield, 1997). As stated above, the ethanol industry requires a large capital base and is slow to respond to market changes which require plant scale to be altered. The high cost and low margins create situations where a plant may be covering its variable costs in the short run but not total average costs in the longer run. An agent's response to potential changes in demand and competition will affect fixed and total costs, especially if an expansion opportunity is presented. Therefore, reviewing average total costs at later periods in the base simulation model will allow agents an opportunity to take advantage of early expansion opportunities and create economies of scale that may be necessary to continue successful operations, thus ensuring that ethanol agents' actions do not generate total costs that affect long term financial solvency.

Lastly, a parameter has been included to test if an agent has achieved profitability during operations. At the 50 year mark, each ethanol agent sums previous profits and losses to see if their overall profitability is greater than or equal to zero. This check was added to see if a site that returned an NPV greater than zero was actually profitable over the operational life of the plant. Year 50 has been chosen for this check in the base simulation, as this will mean the plant is nearing the end of its useful life according to current estimates.

5.8 Landscape Parameters

A number of parameters pertain directly to the location of other entities on the landscape. These entities serve as reference points for ethanol agents to use when searching for stable or sustainable locations. The co-location mixture of primary highways, mainline rail, utilities, and market access points create tradeoffs for ethanol agents as they search for a viable location.

During the model initialization and operation phases, ethanol agents acquire feedstock from their initial procurement area as set by the *procurement-area* slider. Current feedstock procurement areas seem to range from 50 to 100 km (30 to 60 miles) in the literature (Eathington and Swenson, 2007; Sarmiento and Wilson, 2008), and within this buffer zone potential plants will want to avoid feedstock competition with other plants to minimize costs. Sarmiento and Wilson (2008) find that spatial competition in input procurement is essentially zero at 60+ miles (100+ km), which is an important consideration given the supply orientated nature of the ethanol industry. For the base simulation, plant procurement area has been set at 100 kilometers in the landscape. This means that during initialization only this area is available to help determine if a potential site has an $NPV \geq 0$, but during operations this procurement area is extended in the manner described in Chapter Four.

For the base simulation, feedstock production of 4 million metric tonnes (as set by slider value on the interface) is spread amongst a total of 1,369 patches distinguished by soil zone parameters. The landscape area translates approximately to the seeded acreage in Saskatchewan and the production level reflects the level of ethanol quality wheat that is likely available. This is computed by considering that ethanol producers are interested in starch and fermentable content of wheat (S&T^2 Consultants Inc., 2004). Protein and starch content typically move in opposite directions, therefore low protein wheat would generally have high starch content and be of interest to ethanol producers. In fact, this type of wheat is usually less expensive and typically would be considered a grade of Canadian Grain Commission (CGC) #3 or lower. On average this quality level accounts for 30% of the crop in the province (S&T^2 Consultants Inc., 2004). In Saskatchewan, wheat production has averaged 13,347,032 MT per year from 1976 to 2006. Therefore based on the 30% low wheat grade figure, it is calculated that approximately 4,004,110 MT of applicable wheat per year is typically available for ethanol production in the province.

The base model results will be based on the average of 1,000 runs of the simulation. These results will be used to build understanding about the relative importance of factors that affect location decisions in the foreseeable ethanol industry.

5.9 Counterfactual Simulation

In addition to the base scenario, a second set of simulations were developed to examine the effects of policy and subsidization. This counterfactual simulation retained all the base run variable settings as outlined in Tables 2 and 3, with the exception of those variables related to government subsidization of the ethanol industry. So in the counterfactual simulation, both federal and provincial subsidies were turned off and removed from initialization and operation phases. The counterfactual results give us an opportunity to examine the overall effect that government intervention through subsidization has had on the development of the ethanol industry in Saskatchewan.

5.10 Summary

A base case simulation has been programmed to represent as much as possible the current ethanol industry and its market structure as found in Saskatchewan. Parameters settings include financial, operating, demand, subsidies, fiscal monitors, and landscape location features. These are used by the ethanol agents to help identify viable plant locations. Both the base and a counterfactual simulation will be run 1,000 times with generated output collated to better understand the factors leading to stable plant location decisions over time, both with and without the presence of government intervention through subsidization.

CHAPTER 6

Simulation Results and Discussion

6.0 Introduction

The ethanol industry is heavily influenced by location, whether this means proximity to feedstock, transportation systems, or markets, since all these spatial factors must be considered in a location decision. This agent-based simulation model of ethanol plant location, as described in Chapter Four, was initially run using parameters as discussed in Chapter Five. The simulation results for both the base and counterfactual scenarios are examined and compared, allowing us a better understanding of the factors that affect both ethanol plant operation and location over time.

Each simulation was run for 60 years, where one year is equivalent to one cropping year, and the whole system was re-run for a total of 1,000 iterations. An overview of both simulated landscapes is presented below. The first or base scenario simulates the Saskatchewan ethanol market as it currently operates. The second or counterfactual scenario removes both federal and provincial subsidies. The results appraise the impact of transportation networks, market synergies, and policy on the Saskatchewan ethanol industry.

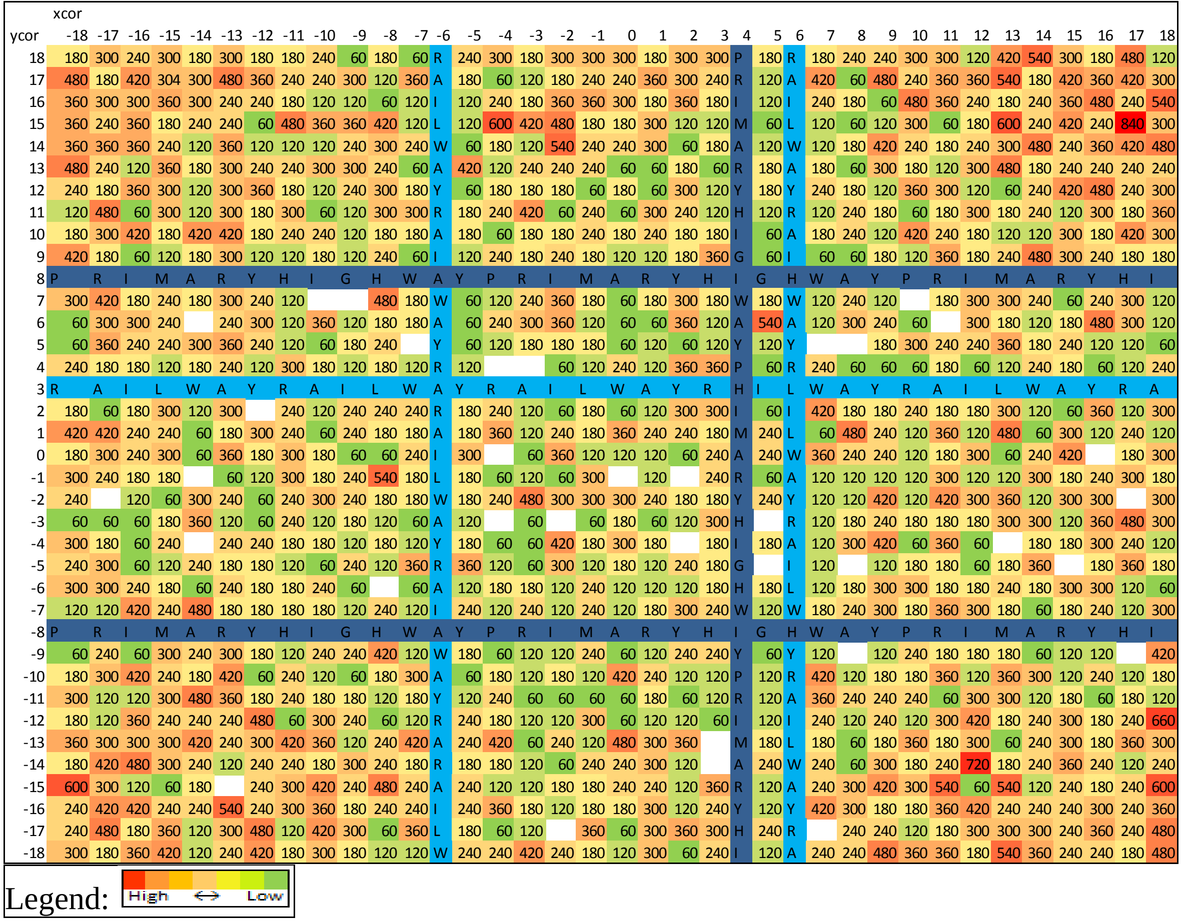
6.1 Overview of the Simulated Landscape

Both the base and counterfactual scenarios were repeated over one thousand runs of a sixty year ethanol plant lifecycle. Initially, the greatest influence appeared to be proximity to feedstock. But without further analysis on the effect of transportation networks, market synergies, or explicit subsidies on location decisions, it is not clear which of these factors might factor more heavily in the location decision.

Figures 11 and 12 display the appearance of the simulated landscape after 1,000 runs. In both instances, one notices that there are a number of visible elements on the landscapes. In both simulations the location of transportation networks, utility networks, and feedstock (wheat) production levels were kept constant. The transportation networks are identifiable by the light blue lines for main-line railways, while the dark blue lines denote primary highway routes. To prevent clutter on the visual landscape, utility networks have been layered under the transportation networks, farmland, and ethanol agents. Lastly, white spaces indicate sites where an ethanol agent did not locate during the simulation. This latter outcome results from the existence of towns and cities, or else blenders and feedlots holding these locations during the simulations.

As discussed previously, there are number of factors that can render a specific location to be lucrative. The colours in Figures 11 and 12 both show and rank desirable and undesirable locations based on the number of ethanol plant agents that were able to successfully operate. Red areas indicate an increased density of ethanol agents (plants) while lighter green areas indicate a lower density of ethanol agents. The figures provide insight into what makes for a suitable or stable location, and the factors behind these suitable or stable locations will be discussed next.

Figure 11: Ethanol Agent Density Map (Base Scenario)[27]



xcor

ycor	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18	180	300	240	300	180	300	180	180	240	60	180	60	R	240	300	180	300	300	300	180	300	300	P	180	R	180	240	240	300	300	120	420	540	300	180	480	120
17	480	180	420	304	300	480	360	240	240	300	120	360	A	180	60	120	180	240	240	360	300	240	R	120	A	420	60	480	240	360	360	540	180	420	360	420	300
16	360	300	300	360	300	240	240	180	120	120	60	120	I	120	240	180	360	360	300	180	360	180	I	120	I	240	180	60	480	360	240	180	240	360	480	240	540
15	360	240	360	180	240	240	60	480	360	360	420	120	L	120	600	420	480	180	180	300	120	120	M	60	L	120	60	120	300	60	180	600	240	420	240	840	300
14	360	360	360	240	120	360	120	120	120	240	300	240	W	60	180	120	540	240	240	300	60	180	A	120	W	120	180	420	240	180	240	300	480	240	360	420	480
13	480	240	120	360	180	300	240	240	300	300	240	60	A	420	120	240	240	240	60	60	180	60	R	180	A	180	60	300	180	120	300	480	180	240	240	240	240
12	240	180	360	300	120	300	360	180	120	240	300	180	Y	60	180	180	180	60	180	60	300	120	Y	180	Y	240	180	120	360	300	120	60	240	420	480	240	300
11	120	480	60	300	120	300	180	300	60	120	300	300	R	180	240	420	60	240	60	300	240	120	H	120	R	120	240	180	60	180	300	180	240	120	300	180	360
10	180	300	420	180	420	420	180	240	240	120	180	180	A	180	60	180	180	240	180	240	180	180	I	60	A	180	240	120	420	240	180	120	120	300	180	420	300
9	420	180	60	120	180	300	120	120	180	120	240	60	I	120	240	180	240	180	120	120	180	360	G	60	I	60	60	180	120	360	180	240	480	300	240	180	180
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6	60	300	300	240		240	300	120	360	120	180	180	A	60	240	300	360	120	60	60	360	120	A	540	A	120	300	240	60		300	180	120	180	480	300	120
5	60	360	240	240	300	360	240	120	60	180	240		Y	60	120	180	180	180	60	120	60	120	Y	120	Y			180	300	240	240	360	180	240	120	120	60
4	240	180	180	120	180	240	120	300	180	120	180	120	R	120			60	120	240	120	360	360	P	60	R	240	60	60	60	180	60	120	240	180	60	120	240
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-1	300	240	180	180		60	120	300	180	240	540	180	L	180	60	120	60	300		120		240	R	60	A	120	120	120	120	300	120	120	300	180	240	300	180
-2	240		120	60	300	240	60	240	300	240	180	180	W	180	240	480	300	300	300	240	180	180	Y	240	Y	120	120	420	120	420	300	360	120	300	300		300
-3	60	60	60	180	360	120	60	240	120	180	120	60	A	120		60		60	180	60	120	300	H		R	120	180	240	180	180	180	300	300	120	360	480	300
-4	300	180	60	240		240	240	180	180	120	180	120	Y	180	60	60	420	180	300	180		180	I	180	A	120	300	420	60	360	60		180	180	300	240	120
-5	240	300	60	120	240	180	180	120	60	240	120	360	R	360	120	60	300	120	180	120	240	180	G		I	120		120	180	180	60	180	360		180	360	180
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-9	60	240	60	300	240	300	180	120	240	240	420	120	W	180	60	120	120	240	60	120	240	240	Y	60	Y	120		120	240	180	180	180	60	120	120		420
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-11	300	120	120	300	480	360	180	240	180	180	120	180	Y	120	240	60	60	60	60	180	60	120	R	120	A	360	240	240	240	60	300	300	120	180	60	180	120
-12	180	120	360	240	240	240	480	60	300	240	60	120	R	240	180	120	120	300	60	120	120	60	I	120	I	240	120	240	120	300	420	180	240	300	180	240	660
-13	360	300	300	300	420	240	300	420	360	120	240	420	A	240	420	60	240	120	480	300	360		M	180	L	180	60	180	360	180	300	60	240	300	180	360	300
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-16	240	420	420	240	240	540	240	300	360	180	240	240	I	240	360	180	120	180	180	300	120	240	Y	120	Y	420	300	180	180	360	420	240	240	240	300	240	360
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-18	300	180	360	420	120	240	420	180	300	180	120	120	W	240	240	420	240	180	120	300	60	240	I	120	A	240	240	480	360	360	180	540	360	240	240	180	480

Legend: High ↔ Low

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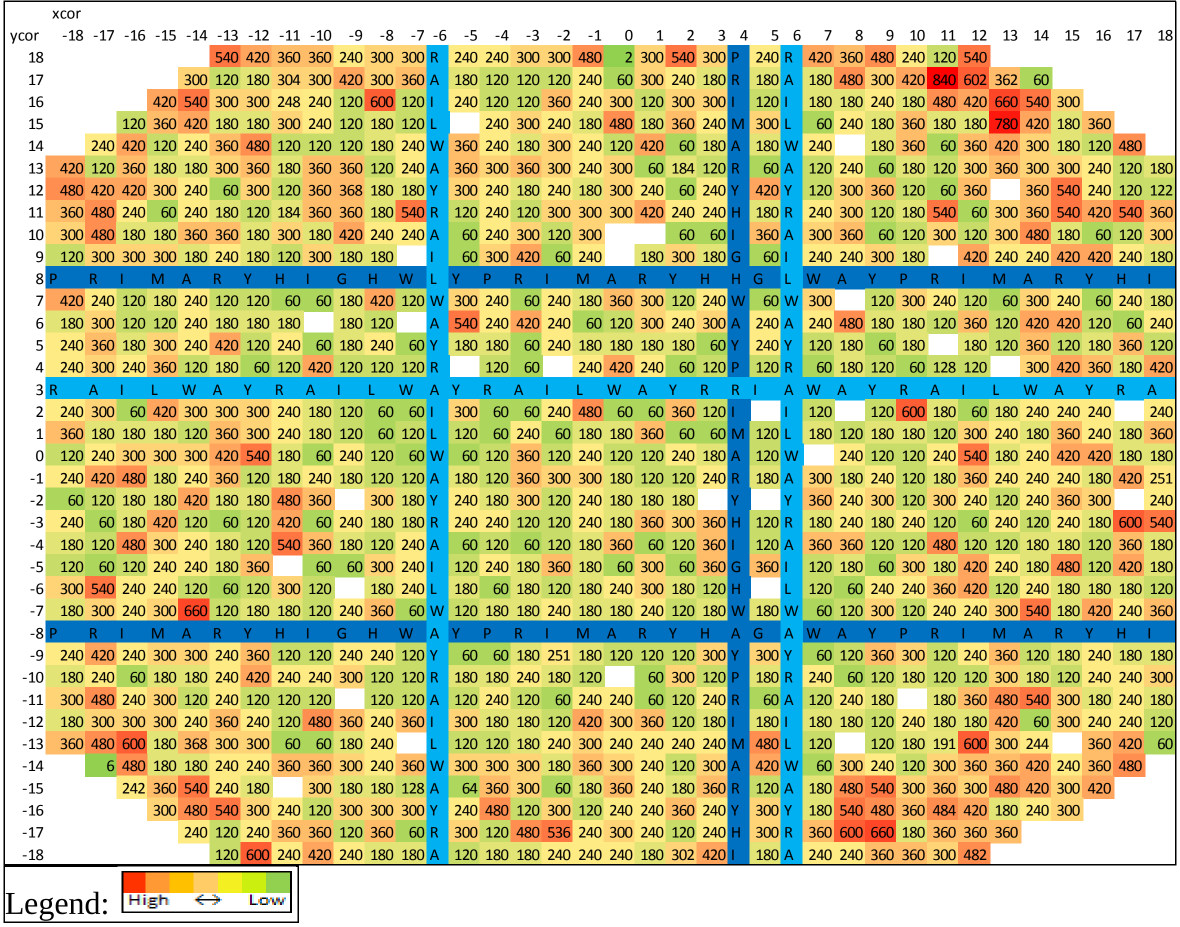
[27] Density map displays the number of times an ethanol agent successfully located on a particular site (patch).

Initially in Figure 11 the increased tendency for ethanol agents to locate in the hinterland[28] is evident, indicative of a possible tradeoff between feedstock access and transportation proximity. However, as it is argued later, when the influence of subsidies are considered as part of the location analysis, the efficiency and long-term profitability of hinterland locations may not yield the most stable locations.

Note that in the counterfactual scenario without subsidies (Figure 12), we see an immediate drop in the number of distant hinterland plants that were generated using the base scenario. In the latter case, the removal of subsidy revenue seems to have caused plants to locate even closer to transportation corridors, indicative of the importance of transportation costs to locational success, all else equal.

Figure 12: Ethanol Agent Density Map (Counterfactual Scenario, without Subsidies)[29]



	xcor																																				
ycor	-18	-17	-16	-15	-14	-13	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
18						540	420	360	360	240	300	300	R	240	240	300	300	480	2	300	540	300	P	240	R	420	360	480	240	120	540						
17					300	120	180	304	300	420	300	360	A	180	120	120	120	240	60	300	240	180	R	180	A	180	480	300	420	840	602	362	60				
16				420	540	300	300	248	240	120	600	120	I	240	120	120	360	240	300	120	300	300	I	120	I	180	180	240	180	480	420	660	540	300			
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14		240	420	120	240	360	480	120	120	120	180	240	W	360	240	180	300	240	120	420	60	180	A	180	W	240		180	360	60	360	420	300	180	120	480	
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12	480	420	420	300	240	60	300	120	360	368	180	180	Y	300	240	180	240	180	300	240	60	240	Y	420	Y	120	300	360	120	60	360		360	540	240	120	122
11	360	480	240	60	240	180	120	184	360	360	180	540	R	120	240	120	300	300	300	420	240	240	H	180	R	240	300	120	180	540	60	300	360	540	420	540	360
10	300	480	180	180	360	360	180	300	180	420	240	240	A	60	240	300	120	300			60	60	I	360	A	300	360	60	120	300	120	300	480	180	60	120	300
9	120	300	300	300	180	240	180	120	300	180	180		I	60	300	420	60	240		180	300	180	G	60	I	240	240	300	180		420	240	240	420	420	240	180
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6	180	300	120	120	240	180	180	180		180	120		A	540	240	420	240	60	120	300	240	300	A	240	A	240	480	180	180	120	360	120	420	420	120	60	240
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-7	180	300	240	300	660	120	180	180	120	240	360	60	W	120	180	180	240	180	180	240	120	180	W	180	W	60	120	300	120	240	240	300	540	180	420	240	360
-8	P	R	I	M	A	R	Y	H	I	G	H	W	A	Y	P	R	I	M	A	R	Y	H	A	G	A	W	A	Y	P	R	I	M	A	R	Y	H	I
-9	240	420	240	300	300	240	360	120	120	240	240	120	Y	60	60	180	251	180	120	120	120	300	Y	300	Y	60	120	360	300	120	240	360	120	180	240	180	180
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-12	180	300	300	300	240	360	240	120	480	360	240	360	I	300	180	180	120	420	300	360	120	180	I	180	I	180	180	120	240	180	180	420	60	300	240	240	120
-13	360	480	600	180	368	300	300	60	60	180	240		L	120	120	180	240	300	240	240	240	240	M	480	L	120		120	180	191	600	300	244		360	420	60
-14		6	480	180	180	240	240	360	360	300	240	360	W	300	300	300	180	360	300	240	120	300	A	420	W	60	300	240	120	300	360	360	420	240	360	480	
-15			242	360	540	240	180		300	180	180	128	A	64	360	300	60	180	360	240	180	360	R	120	A	180	480	540	300	360	300	480	420	300	420		
-16				300	480	540	300	240	120	300	300	300	Y	240	480	120	300	120	240	240	360	240	Y	300	Y	180	540	480	360	484	420	180	240	300			
-17					240	120	240	360	360	120	360	60	R	300	120	480	536	240	300	240	120	240	H	300	R	360	600	660	180	360	360	360					
-18						120	600	240	420	240	180	180	A	120	180	180	240	240	240	180	302	420	I	180	A	240	240	360	360	300	482						

Legend: High ↔ Low

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[28] These are typically remote or rural areas that are on the fringe or detached from major urban locations.

[29] Density map displays the number of times an ethanol agent successfully located on a particular site (patch).

Table 4 contains the descriptive statistics for average plant size of ethanol agents when subsidies are present, and then removed during the simulations. The statistics are based on the 1,000 runs generated for each simulation. In sum, the average ethanol plant size with subsidies was 249.5 Mmly, compared to 257 Mmly without subsidies. To test that these differences in means are statistically significant a two-sample t-test[30] assuming unequal variances was performed. The results in Table 5 show that the means are statistically different from one another at 5%, as are the variances in Table 6. In addition, a fully non-parametric Wilcoxon/Mann Whitney U Test was also conducted, showing that the data are normal from non-identical populations, further supporting the t and F-test results.

Furthermore, the results in Table 4 on plant size distribution show a positive kurtosis, implying a higher peak with fatter tails, an outcome that occurs with frequent extremes. While both simulations are similar in many respects, the inclusion of subsidies leads to slightly fatter tails than when subsidies are not present. Both simulations are also positively skewed, suggesting a greater concentration to the left of the distribution, the lower end of the ethanol plant size distribution. One can see that the removal of subsidies increases average plant size and moves the distribution further to the right, possibly indicating greater operational efficiencies, economies of scale, and competitiveness.

Table 4: Descriptive Statistics: Average Ethanol Plant Size (Litres) with/without Subsidies[31]

Statistical Parameters	Subsidy On	Subsidy Off
Mean	249517545.5	257039996.3
Median	247258542	256199004
Mode	266601240	#N/A
Standard Deviation	28203029.06	25214812.04
Kurtosis*	0.32	0.29
Skewness*	0.44	0.36
Range	173261380.8	164985162
Minimum	175996771.2	187350360
Maximum	349258152	352335522
Observations*	1000	1000

*Not shown in litres

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[30] See: Schedecor, George W. and Cochran, William G. (1989). *Statistical Methods, Eighth Edition.* Iowa State University Press.

[31] Base simulation incorporates federal and provincial subsides (Subsidy On) while counterfactual simulation excludes federal and provincial subsidies (Subsidy Off).

Table 5: Two Sample T-Test of Simulation Means with/without Subsidies

t-Test: Two-Sample Assuming Unequal Variances	
df	1973
t Stat	6.29
P(T<=t) two-tail	0
t Critical two-tail	1.96

Table 6: Two Sample F-Test for Variance of Simulations with/without Subsidies

F-Test Two-Sample for Variances	Subsidy On	Subsidy Off
df	999	999
F	1.25	
P(F<=f) one-tail	0	
F Critical one-tail	1.11	

The influence on location stability of transportation networks, market synergies, and policy through subsidization will be examined in detail in the next three sections.

6.2 Transportation Network Proximity

As identified in the relevant literature about ethanol markets, proximity to primary highway and/or mainline rail service seems to be essential to ensure market access and plant survival within the industry. Primary highway and mainline rail are located on the simulated landscape and ethanol agents do incur additional transportation related costs as plant distance increases from this infrastructure. In fact, the simulations show some tradeoff is made between the distance of a plant to a primary highway and mainline rail by the ethanol agents. Here, Tables 7 and 8 display descriptive statistics for plant access distances to the two modes within the transportation network.

Table 7: Descriptive Statistics: Primary Highway Access[32]

Statistical Parameters	Subsidy On	Subsidy Off
Mean	4.52	4.20
Median	4.60	4.20
Mode	5.00	4.00
Standard Deviation	1.33	1.21
Kurtosis	-0.46	-0.12
Skewness	-0.12	0.07
Range	7.00	7.50
Minimum	1.00	1.00
Maximum	8.00	8.50
Observations	1000	1000

Table 8: Descriptive Statistics: Mainline Rail Access[32]

Statistical Parameters	Subsidy On	Subsidy Off
Mean	4.95	4.48
Median	5.00	4.50
Mode	5.00	4.00
Standard Deviation	1.40	1.29
Kurtosis	-0.17	0.08
Skewness	0.10	0.14
Range	8.67	8.41
Minimum	1.00	1.00
Maximum	9.67	9.41
Observations	1000	1000

Access to primary highway dominates rail access in both simulations, as indicated by the comparatively lower mean and median values of highway access. It is concluded from this that primary highway access plays a more important role in determining a stable plant location than access to mainline rail. When subsidies are removed in the counterfactual simulation, a dramatic decrease in plant distance from transportation infrastructure occurs with little variation. The impact of subsidies on location relative to transportation network access is apparent, with distributional mode decreasing by twenty percent and standard deviation falling by nine percent for both highway and rail access. With the majority of ethanol agents locating 20% closer to primary transportation networks in this scenario, subsidization of the ethanol industry has allowed these plants to locate farther from transportation corridors. Thus in the current ethanol

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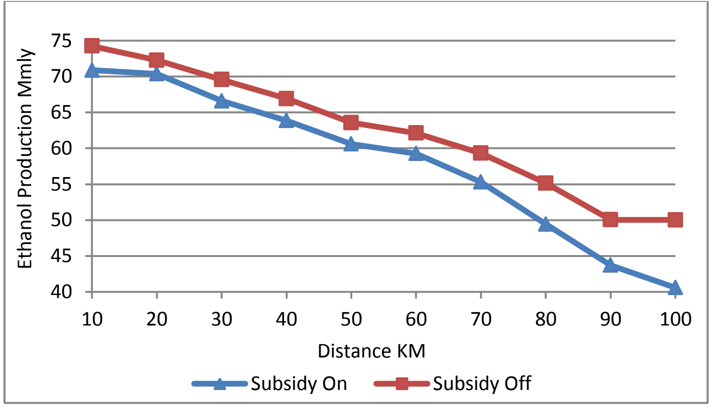
[32] Figures list the average number of patches between the ethanol agent and the transportation mode. As previously discussed each patch is 9.6 KM^2, therefore multiplying the listed numbers by 9.6 will yield the kilometer distance.

industry, the sudden removal of these subsidies may leave many hinterland plants unprofitable due to high transportation costs.

The results also show that proximity to a reliable transportation network affects an ethanol agent's production and average variable cost structure. As plant locations grow increasingly distant from primary highway and mainline railway, a significant decline in ethanol production is observed[33] (Figure 13). However, one interesting finding is the consistently higher ethanol production volumes when subsidies are removed, a fact also evident in Figure 13.

In sum, subsidization of the ethanol industry has downgraded the importance that access to reliable transportation networks has on ethanol production (Figure 13), a point that is supported by increasing average variable costs (see Figure 14). Average variable costs of ethanol agents not receiving subsidies are marginally lower, which would be indicative of better economies of scale, especially for smaller plants located away from primary transportation networks in hinterland regions.

Figure 13: Ethanol Agent Production Contingent on Transportation Network Access[34]



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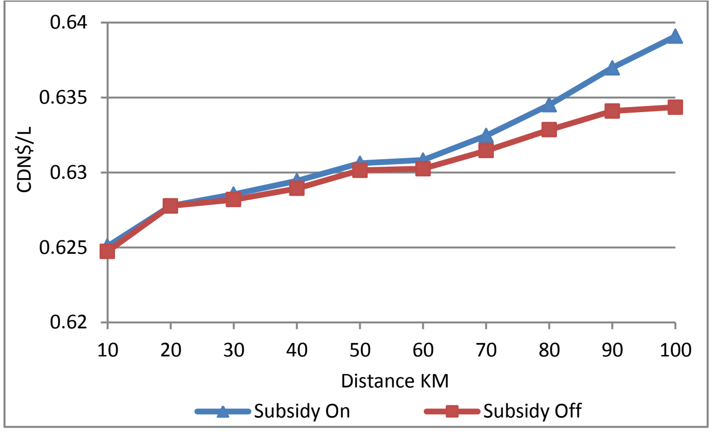
[33] As ethanol production volume declines so does DDGS production (given its by-product nature) and plant nameplate capacity of the ethanol agents.

[34] Average ethanol production given ethanol agent's distance to primary highway and mainline railway access.

Figure 14: Ethanol Agent Average Variable Cost Contingent on Transportation Network Access



6.3 Market Synergies and Plant Location

In the simulation, ethanol agent proximity to market varies based on transportation mode. An interesting finding from the simulation is that DDGS market access dominates ethanol market access in both scenarios. DDGS is characteristically a lower value, bulky product with inherent transportation difficulties such as bridging[35]. Thus closer DDGS markets are preferred to efficiently market and transport at least cost, thereby reducing potential shipment difficulties. Comparatively, the ease of transporting ethanol in liquid form using designated truck and railcar containers appears to reduce location constraints related to ethanol market proximity. But given that ethanol contracts can account for up to 80% of a plant's revenue (Coltrain, 2004), spatial market proximity must be duly considered, especially if contractual shipping terms favour the ethanol buyer.

Typically ethanol markets are not located in proximity to plants. Shipping ethanol by tanker truck is usually cost effective at distances less than 300 kilometers, whereas beyond this distance rail becomes more cost effective (OECD, 2004). The simulation results are consistent with these observations, showing that ethanol agents stabilize on locations that average about 175 KM shipment distance when subsidies are in place, and approximately 169 KM as subsidies are removed for highway shipments to ethanol markets. Shipping ethanol short distances by rail in the simulation is not advantageous to stable plant locations. Rather in the simulation, it appears

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[35] Bridging takes place during shipment of DDGS. Bridging means the product binds and compacts during shipment reducing flowability and leading to potential unloading problems (see Section 4.9.4).

that rail shipments begin to support an ethanol agent's location at distances greater than approximately 700 KM[36].

The comparison of ethanol shipment by road and rail clearly displays the cost efficiency of short distance shipments by tanker truck compared to longer distance rail shipment. The mix of local shipments by tanker truck and more distant shipments by rail create greater savings for stable locations and optimize transportation cost efficiency. However, one caveat to this discussion relates to smaller ethanol plants. Without the model assumption that all plants can access storage and transloading terminals, smaller plants may find rail shipment especially ineffective given they will usually be unable to produce the typically required unit train volumes. Without this assumption, smaller plants may be additionally disadvantaged if they rely on rail shipments.

Proximity to DDGS markets generates similar findings. However, ethanol agents tend to favour local DDGS markets even more so than ethanol markets. This was an interesting outcome from the model considering that DDGS contracts typically only account for up to 20% of an ethanol plants revenue stream (Coltrain, 2004). Feedlots are the traditional buyers of DDGS and are usually concentrated in select areas. Concentration of feedlots can create a locational constraint that when combined with the high production of DDGS from the ethanol industry can lead to a highly competitive feed market and a likely reduction in DDGS revenue. Therefore, the agents seem to discover that minimizing transportation costs and concentrating on local markets is extremely important.

Access and proximity by primary highway to DDGS markets is helpful in generating stable ethanol plant locations. Simulation findings show that ethanol agents stabilize on locations that average 146 KM (with subsidies) and 140 KM (when subsidies are removed) for DDGS market access via primary highway. Shipping DDGS via rail may be cost effective at very long distances but it is not favoured by the ethanol agents in this model. This supports the previous finding that the ability to use local bulk truck shipments via primary highway seems to be more conducive to identifying a stable location. The benefit of shipping DDGS long distances via rail was

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[36] At this point the MT cost per KM to move ethanol via rail falls below the MT cost per KM to ship ethanol via highway. This observation is supported by highway and rail rates obtained for use in the model, as the small number of observations generated in the simulation could not be used alone to draw a firm conclusion.

inconclusive in the simulation, specifically at distances greater than 300 KM where the number of observations was insufficient to confidently draw conclusions. It must also be noted that in the simulation model, ethanol agents not located on mainline rail must also pay a transloading fee to ship by rail, so it is possible this may be generating these inconclusive results. Based on highway and rail rates obtained for use in the model it appears that DDGS shipment via rail is cost effective at distances greater than approximately 300 KM[37]. Given these considerations, this is an area worthy of future research.

In this light, the descriptive statistics displayed in Tables 9 and 10 indicate that proximity to DDGS markets by both primary highway and mainline rail are sought by ethanol agents over those locations closer to ethanol markets. In fact, these findings show that ethanol agents located twenty percent closer to DDGS markets, a result that was not affected by industry subsidization.

Table 9: Descriptive Statistics: Average Market Distance via Primary Highway Network

Statistical Parameters	Blender		Feedlot	
	Subsidy On	Subsidy Off	Subsidy On	Subsidy Off
Mean	18.27	17.63	14.61	14.00
Median	18.00	17.40	14.50	14.00
Mode	19.00	16.00	15.00	15.00
Standard Deviation	3.82	3.75	3.09	2.84
Kurtosis	1.05	1.00	0.50	0.32
Skewness	0.44	0.52	0.09	0.02
Range	32.75	26.67	22.00	20.17
Minimum	5.50	6.33	2.00	3.50
Maximum	38.25	33.00	24.00	23.67
Observations	1000	1000	1000	1000

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[37] At this point the MT cost per KM to move DDGS via rail falls below the MT cost per KM to ship DDGS via highway.

Table 10: Descriptive Statistics: Average Market Distance via Mainline Rail Network

Statistical Parameters	Blender		Feedlot	
	Subsidy On	Subsidy Off	Subsidy On	Subsidy Off
Mean	15.65	15.68	11.98	11.96
Median	15.25	15.50	11.75	11.80
Mode	14.00	15.00	11.00	12.00
Standard Deviation	3.75	3.89	2.95	3.12
Kurtosis	0.86	0.91	0.29	0.71
Skewness	0.44	0.52	0.31	0.29
Range	30.00	28.83	21.83	24.67
Minimum	2.50	6.67	1.50	2.00
Maximum	32.50	35.50	23.33	26.67
Observations	1000	1000	1000	1000

All considered, proximity to DDGS markets in the simulation appears to help generate stable ethanol plant locations. Reasons for this location preference could include higher relative per unit transport costs, transportation difficulties, and the fact that DDGS buyers (i.e. feedlots) considered in the simulation typically locate in rural areas since feed supply and cost is one major economic factor considered in the feedlot location decision (Carter and Schmitz, 1986). So while these findings indicate agent preferences for DDGS market access, the underlying cause may be that both ethanol plants and feedlots share similar locational traits, striking a balance between feedstock access and final market proximity.

The removal of subsidies in the counterfactual simulation did not produce a large effect on mean distance to markets via highway or rail. This could be due to the scale of the simulation or the cost effective nature of rail transport, where movement by highway means considerably higher costs compared to rail. Market distance via highways showed a 4 – 5% decrease when federal and provincial subsidies were removed. This supports the supposition that subsidies may in fact be affecting the location decision of ethanol plants, and the potential removal of subsidies could alter the industry through the removal of plants operating at or near the shutdown point.

Plant production levels are affected by geographical distance to markets. Simulation results were consistent at generating an inverse relationship between distance to market and production levels. As shown in Figures 15 and 16, ethanol and DDGS[38] production as a function of market distance declines. This declining relationship was consistent for both simulations.

Figure 15: Average Distance to Ethanol Markets as a Function of Ethanol Production

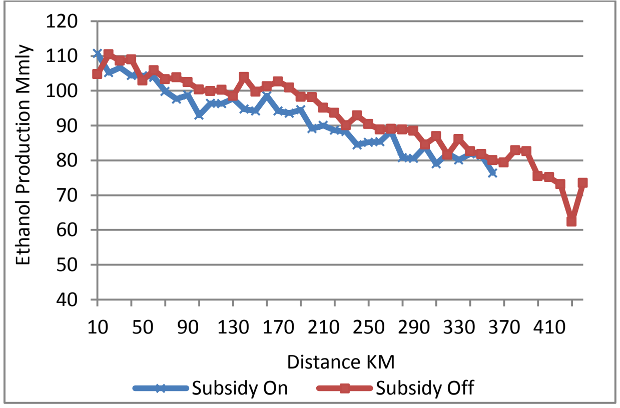
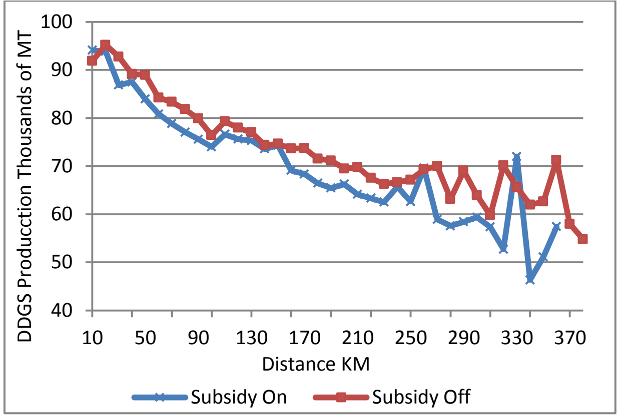


Figure 16: Average Distance to DDGS Markets as a Function of DDGS Production



The removal of subsidies resulted in a slight increase in production and the ability for some ethanol agents to successfully operate at greater distances to both ethanol and DDGS markets. These findings are consistent with simulated results regarding transportation network access. It is concluded that these increases in production and market distances can be attributed to ethanol agents getting more rigorous in their location decisions as the simulation progresses. This typically leads to lower cost structures through the achievement of economies of scale, thus increasing their marketplace competitiveness.

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[38] Given DDGS is a by-product of ethanol production this finding would be consistent with ethanol demand.

6.4 Policy, Prices, and Plant Operations

The role policy has played through subsidies of fostering rapid growth of the ethanol industry in the last five to ten years is clear. However, what is also clear is that desired social or political impact of such subsidies may not have been achieved. Subsidies benefit both small and large ethanol producers, but it seems the small producers have the most to lose should subsidies end. Specific to Saskatchewan, provincial subsidy targets rural revitalization by ensuring small ethanol producers are guaranteed thirty percent of provincial market share. Small producers receive a higher subsidization level, but when compared to most simulation runs where no small producers[39] survive, it seems the intended outcome of rural revitalization policy will ultimately fall short. The variability in subsidy payments is further compounded by industry competition, as strategically located firms expand, with ethanol imports from highly efficient firms reaching the local market. These factors indicate that subsidy dependent plants will find it difficult to compete and remain financially viable should subsidies be reduced or removed from the current marketplace.

The costs associated with ethanol plant operation in the simulation seem to vary mostly based on economies of scale, location, and market access. The following section gives a brief overview of costs in the model – including average variable costs, average costs, revenue/income, breakeven ethanol price, along with the distribution of both small and large ethanol plants within the simulations.

Locational effects on operating costs can be significant, and can lead to plant closures when not carefully considered by the agents. During startup, high fixed costs raise average costs above average revenues, leading to short run deficits. When combined with procurement area competition, this situation leads to a number of plant closures. As financial responsibilities associated with capital building costs are overcome over time average costs decrease, leading to profits (that are taxed). The effects of demand increases are indicated by higher revenue, and when combined with small decreases in average costs, creates situations where economies of scale can be realized by a plant. The outcome of this process will ultimately reduce average operational costs.

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[39] Small ethanol producers are classified as having a plant nameplate capacity of 25 Mmly or less.

With respect to the magnitude of production costs, the generated average variable costs are CDN$0.64/ L in the baseline simulation and CDN$0.635/L when subsides are removed (Table 11). These are close to the cost levels listed in a recent study by Perrin et al. (2009). But interestingly, in a number of other studies, net operating costs are usually presented in a manner where DDGS sales, carbon dioxide sales, and subsidy revenue have been deducted. The latter combined effects mean that the average cost results of this study appear to be elevated by comparison. However, when deduction information is taken into consideration along with higher production costs for wheat ethanol than corn ethanol (Outlook Market Research and Consulting Ltd., 2008), it turns out that the base simulation average variable costs are very much in line with the Perrin et al. (2009) results.

Table 11: Descriptive Statistics: Ethanol Agent Average Variable Cost per Litre Produced

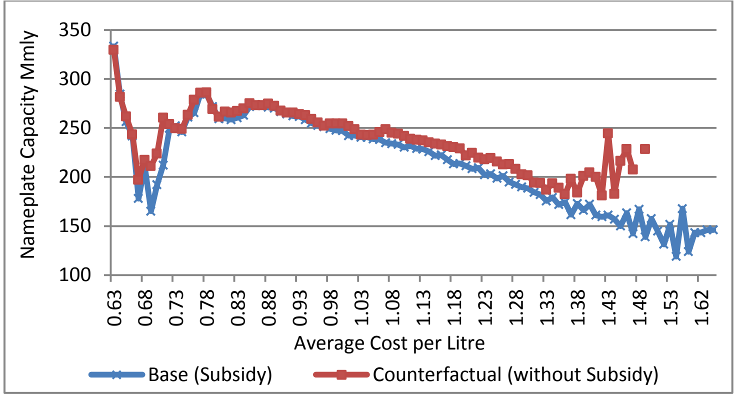
Statistical Parameter	Subsidy On	Subsidy Off
Mean	0.64	0.635
Median	0.64	0.635
Mode	#N/A	#N/A
Standard Deviation	0.027386128	0.024494897
Kurtosis	-1.2	-1.2
Skewness	0	0
Range	0.08	0.07
Minimum	0.6	0.6
Maximum	0.68	0.67
Observations	9	8

Average costs by plant size vary greatly, as shown by the descriptive statistics (see Table 12). The removal of subsidies reduces average costs by $0.06 per litre and narrows the range of plant cost variability. In the simulation, as plants take advantage of the effects of economies of scale we see plant size increase as average cost per unit declines (see Figure 17).

Table 12: Descriptive Statistics: Ethanol Agent Average Cost per Litre Produced

Average Cost	Subsidy On	Subsidy Off
Mean	1.116836735	1.055116279
Median	1.115	1.055
Mode	#N/A	#N/A
Standard Deviation	0.287583594	0.249902306
Kurtosis	-1.139546941	-1.195889797
Skewness	0.040448723	0.002852086
Range	1.04	0.86
Minimum	0.63	0.63
Maximum	1.67	1.49
Observations	98	86

Figure 17: Average Cost per Litre of Ethanol Produced



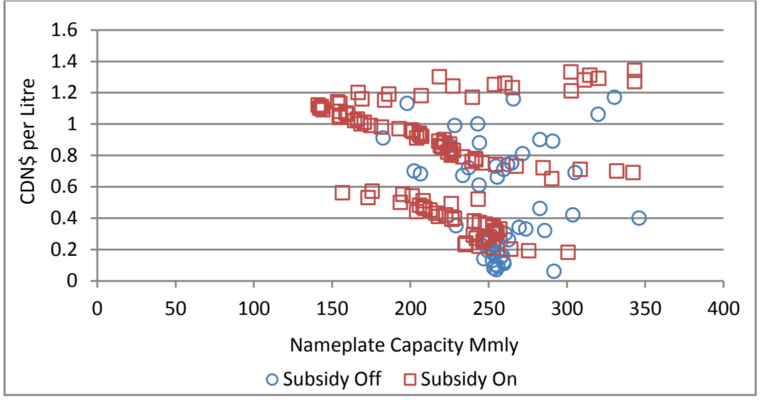
Also of interest is the dramatic reduction in the maximum average cost (Table 12). The removal of subsidies reduces average cost to $1.49 per litre from $1.67 per litre. Thus, the removal of subsidies dramatically reduces the number of high cost inefficient ethanol plants, effectively driving them out of the industry. One consistency is that subsidization of the industry often keeps inefficient ethanol plants operational. This knowledge can be used to infer that high subsidy rates, which are currently at about $0.25 per litre in Saskatchewan, are leading the market away from competition and cost efficiency, and instead are creating widespread inefficiencies in ethanol production.

Income or revenue per litre of ethanol output is the final indicator of industry status examined here. As costs increase and subsidies are removed, an immediate decrease in average income is observed among the plants. Average income drops across scenarios by approximately $0.28 per litre (Table 13). But within the average income variable, we find a wide range even after the removal of subsidies, again indicating the importance of economies of scale in maintaining stable plant locations. In Figure 18 there is a distinct group of high and low income plants, but once subsidies are removed, these widespread groupings begin to cluster. The end result is a high concentration of ethanol agents with an approximate nameplate capacity of 260 Mmly earning an average net income of approximately $0.33 per litre without the aid of subsidies.

Table 13: Descriptive Statistics: Ethanol Agent Average Income per Litre Produced

Average Income	Subsidy On	Subsidy Off
Mean	0.762857143	0.479464286
Median	0.8	0.335
Mode	#N/A	#N/A
Standard Deviation	0.34855392	0.335908102
Kurtosis	-1.296837934	-1.049026561
Skewness	-0.081972662	0.539682744
Range	1.16	1.11
Minimum	0.18	0.06
Maximum	1.34	1.17
Observations	105	56

Figure 18: Average Income by Nameplate Capacity



When subsidies are not present, the range between average income and average costs narrows dramatically. This implies that only those plants that ultimately realize substantial economies of scale remain viable.

The removal of subsidies has a similar effect on breakeven ethanol price. This price[40] is the ethanol market price required for the firm to cover its variable costs in the short run. The removal of subsidies leads to a smaller variation in plant size, with inefficient plants closing down. As seen in Table 14, the removal of subsidies leads to an average increase in the ethanol breakeven price of $0.12 per litre. Note that without subsidy the industry does not collapse, but rather the efficient plants continue to operate and exploit their economies of scale to dominate the market.

Table 14: Descriptive Statistics for Ethanol Breakeven Price Comparison

Ethanol BE Price	Subsidy On	Subsidy Off
Mean	1.2366	1.355357143
Median	1.235	1.355
Mode	#N/A	#N/A
Standard Deviation	0.292910232	0.244547511
Kurtosis	-1.151124542	-1.187183708
Skewness	0.03360921	0.008915524
Range	1.05	0.85
Minimum	0.74	0.94
Maximum	1.79	1.79
Observations	100	84

Figure 19 shows the effect of subsidization on the ethanol industry. As subsidies are removed, high cost plants exit the industry resulting in an evident inverse relationship between ethanol breakeven price and name plate capacity. Clearly, efficiencies realized through economics of scale are important in the ethanol industry, meaning that overall, the simulated counterfactual outcome generates a more economically efficient marketplace due to the removal of subsidies.

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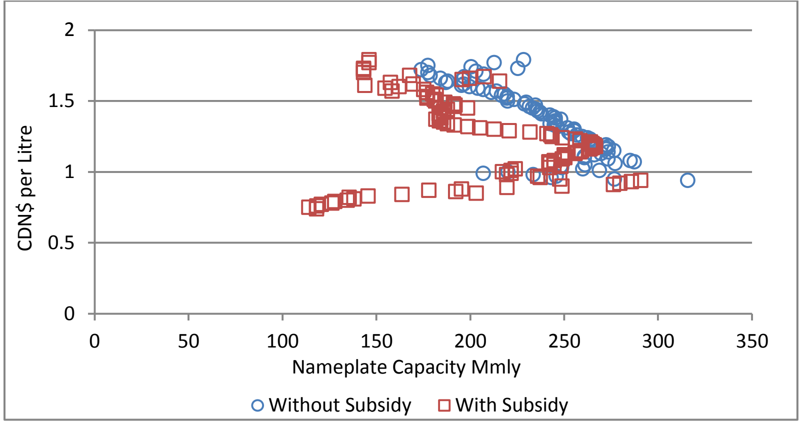
[40] The ethanol breakeven price only includes the sale of ethanol, whereas sales of DDGS and subsidy income are not included since these are not guaranteed given the high level of competition in the feed market and that government policy can change without notice. See Section 4.8.4 for further discussion.

Figure 19: Ethanol Breakeven Price by Nameplate Capacity



In the simulations a wide range exists between the minimum and maximum ethanol breakeven prices. These are $1.05 per litre when subsidies are available, and $0.85 per litre when removed (Table 14). As the ethanol agents meet simulated operational challenges and adjust to market forces, they strive for operational efficiency to avoid premature industry exit. The effect of these adaptations results in a narrowing of ethanol breakeven price spreads. To illustrate this point, Figures 20 and 21 show average ethanol breakeven price at simulated years ten and sixty. Efficient ethanol agents (those with lower breakeven prices) show very little variation in efficiency, whereas the ethanol breakeven price for inefficient ethanol agents varies dramatically, which may be an indicator of either poor location choices or unrealized economies of scale. Note also that the ethanol breakeven price decreases over time as agents become more competitive, operate at or near nameplate capacity, and reduce fixed costs related to capital building expenses.

Figure 20: Ethanol Breakeven Price at Year 10

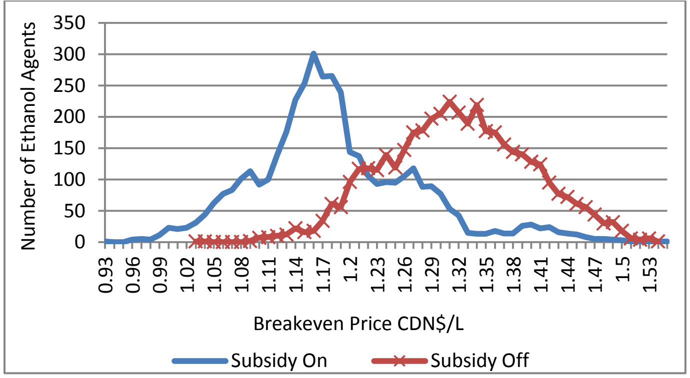
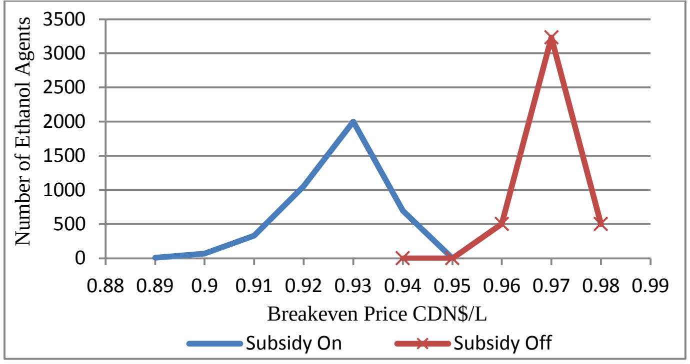


Figure 21: Ethanol Breakeven Price at Year 60



Ultimately, even though DDGS and subsidy income are not part of the data used to generate Figures 20 and 21, the effects of subsidies on average ethanol price are apparent. The breakeven price spread is greater when subsidies are present, indicating their strong influence on daily operational costs. And as seen in Figure 21, the breakeven price spread is narrows significantly after the removal of subsidies. This produces a concentration of firms around an ethanol breakeven price of approximately $0.97/L, as compared to approximately $0.93/L when subsidies are included.

6.4.1 Plant Scale and Profitability

As might be expected, ethanol plant size plays an important role in attaining profitability and economies of scale. During the simulations, a number of plant sizes where generated based on the location attributes of the individual ethanol agent. Figures 22, 23, 24, and 25 display the frequency and production levels for which small and large ethanol agents successfully located at stable locations during each scenario. The production of ethanol at a specified level is identified by the vertical axis, with the horizontal axis indicating specific operational years. Within Figures 22, 23, 24, and 25, each bar identifies the total number of ethanol agents that were operating in a particular year and their average ethanol production level. For example, from Figure 22 we observe that over time the number of small ethanol plant agents decline, while their production levels modestly grow. However, there were no small ethanol agents who survived the entire 60 year time frame of a simulation run.

Figure 22: Ethanol Production Growth by Count of Small Plants[41] (Subsidy On)

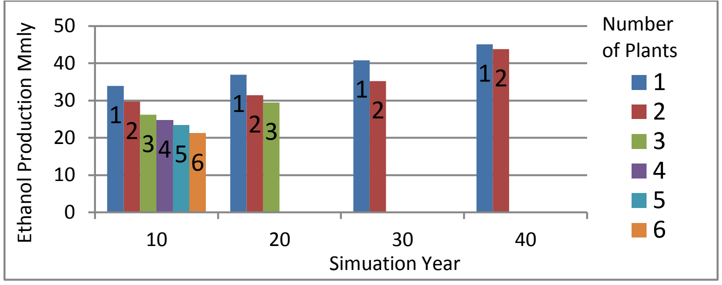
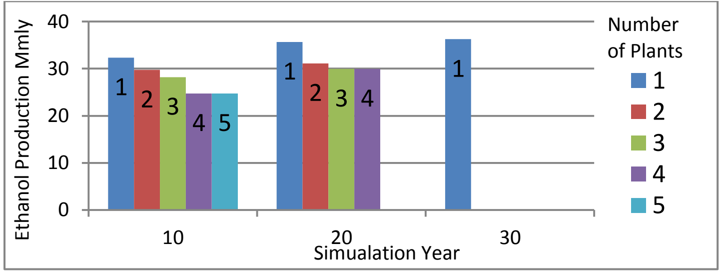


Figure 23: Ethanol Production Growth by Count of Small Plants[41] (Subsidy Off)



Once again, we see that the removal of subsidies significantly affected small ethanol agents. Comparing Figures 22 and 23, without subsidization small plants exit the industry an average of 10 years sooner as well as generating reduced ethanol production levels. While subsidization in the simulation allows small ethanol plants to flourish initially, the effects are not long lasting. In most cases, the failure of small plants to gain economies of scale is the most likely cause of their decline.

The simulation results also show that although small production plants are not successful in the simulations, larger production plants are very successful. Large plants dominate in the majority of the runs, with small plants initially making up what appears to be a competitive fringe. Figures 24 and 25 present production levels for large plants at specified time periods. In both base and counterfactual simulations, large ethanol agents increase their production levels over time taking advantage of economies of scale, and this situation is even more pronounced when subsidies are removed (Figure 25). While the distribution of ethanol agents occupying the simulated landscape between the two simulations shows similarities, one interesting result is apparent. That is, when subsidies are available, we obtain two ethanol agents with dominant levels of production (Figure

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[41] Classified nameplate capacity at t = 1 of less than or equal to 25 Mmly

24), while with the removal of subsidies we obtain only one ethanol plant/agent with a dominant level of production (Figure 25).

While somewhat unexpected, this finding is not surprising when previous research has shown that subsidization of the industry allows firms to operate below their efficient output level. The removal of subsidies allows a dominant firm to continue operating in a significant number of the simulation runs (Figure 25). Over the long run, this emergent oligopolistic industrial organization is representative of industries that produce homogeneous goods, and where the dominant firm finds it more profitable to keep price above the shutdown price and not drive fringe firms out of the industry (Cherry, 2000). In the simulation model, each firm is aware of the production of others in the market but all are competing for more market share. Moreover, efficient firms are able to increase their market share and produce more ethanol at the expense of their competitors. As such, relatively few small ethanol plants survive in the model, as their high cost structure limits their ability to produce ethanol at a competitive price and compete with those firms that have managed to achieve economies of scale.

Figure 24: Ethanol Production Growth by Count of Large Plants[42] (Subsidy On)

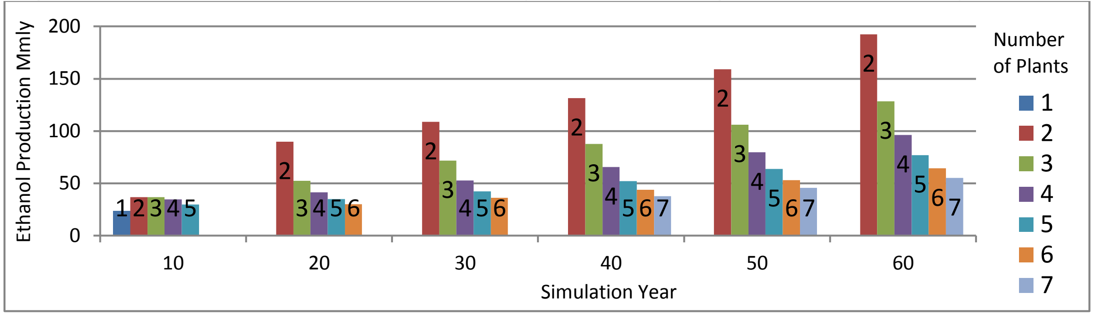
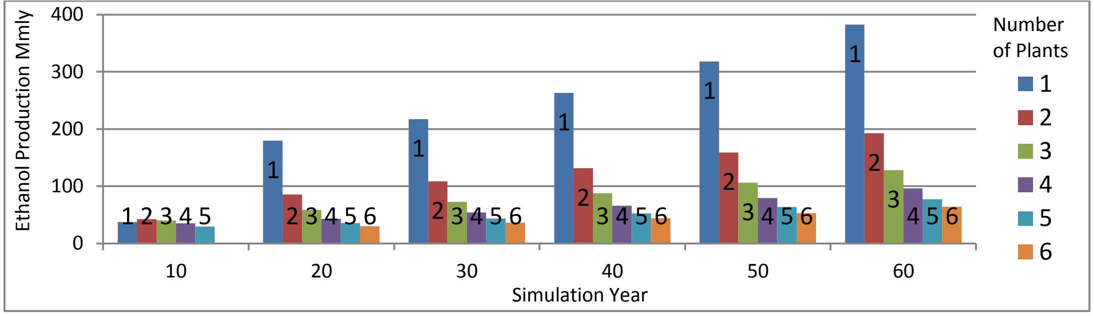


Figure 25: Ethanol Production Growth by Count of Large Plants[42] (Subsidy Off)



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[42] Classified nameplate capacity at t = 1 of greater than 25 Mmly

Both simulations produced a wide variety of plant sizes over all runs. Descriptive statistics displayed in Table 15 present average ethanol plant sizes across both simulations. The negative kurtosis across both simulations implies flatter peaks and shorter tails suggesting relatively infrequent size extremes. But variation in nameplate capacity is evident given the substantial range between minimum and maximum plant capacities, while subsidization further amplifies this variation.

Table 15: Descriptive Statistics: Average Nameplate Capacity[43] (Litres)

Statistical Parameter	Subsidy On	Subsidy Off
Mean	208924164.2	231991965.1
Median	209763960.9	235776239.4
Mode	#N/A	#N/A
Standard Deviation	69741197.52	53220747.46
Kurtosis*	-1.94723775	-2.013948019
Skewness*	-0.06673191	-0.105133142
Range	173274102	129029085.1
Minimum	119055996	165628164
Maximum	292330098	294657249.1
Observations*	9	8

*Not shown in litres

Interestingly, the simulation produces an average minimum plant size of 119 Mmly (Table 15) with subsidy, a level larger than the current average plant size of about 70 Mmly in Saskatchewan (Canadian Renewable Fuels Association, August 17, 2009). With the removal of subsidies, average plant size increases approximately eleven percent, but the most notable change is a twenty-eight percent increase in minimum plant size. The substantial minimum plant size yielded by the simulation would also seem to indicate that economies of scale are not being fully realized within the current subsidized Saskatchewan ethanol industry.

Figures 26 and 27 complement the preceding nameplate capacity discussion and display the frequency at which small and large ethanol agents appear on the simulated landscape over the 1,000 runs of each simulation. Small production plants (Figure 26 – those with a nameplate capacity less than or equal to 25 Mmly at t = 1), decline rapidly without the aid of subsidies. As

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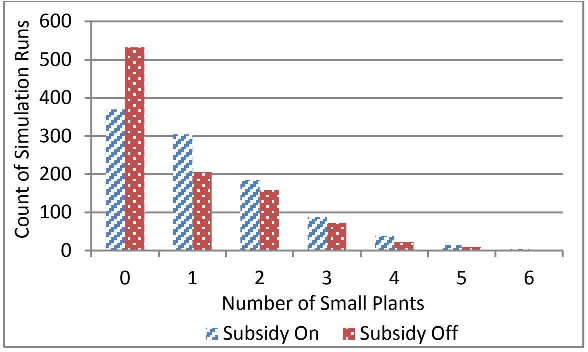
[43] Table 15 uses average cost per litre as the base to retrieve average nameplate capacity.

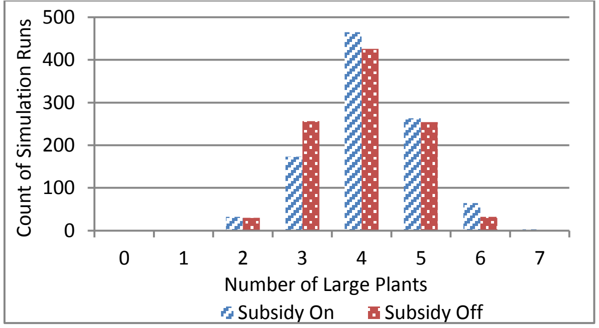
discussed previously (see Figures 22 and 23), these small plants exited the industry by year 40 with subsidization, while industry exit decreased to year 30 when subsidies were removed. In fact, small ethanol plants did not emerge in over a third of the base simulation runs even when subsidies were present, while this amount grew to over half of the simulation runs when subsidies were removed (Figure 26).

Figure 26: Emergence of Small Ethanol Agent Plants (≤ 25 Mmly at t=1)



Large ethanol agents (Figure 27) dominate both scenarios in the simulations. While fewer plants emerge with the elimination of subsidies, these large plants were significantly larger in size, as shown in Figure 25. These findings also further reinforce the heavily concentrated nature (by number of firms) of the industry that emerges when subsidies were removed. This suggests economies of scale are crucial to the industry, a situation favoring the survival of larger ethanol plants, even though subsidization policies specific to small plants geared to rural revitalization were present in the base simulation.

Figure 27: Emergence of Large Ethanol Agent Plants (> 25 Mmly at t=1)



In Figures 28 and 29, capital costs are illustrated as a function of output. This data again confirms the presence of significant economies of scale in the simulation model. Initially it appears that gains in economies of scale are significant, but this effect appears to become less important as plant size approaches 300 Mmly. These findings again support the supposition that specific subsidization policy currently in-place may not in fact be realizing the desired effects on this industry.

Figure 28: Ethanol Agent Capital Building Costs (Subsidy On)

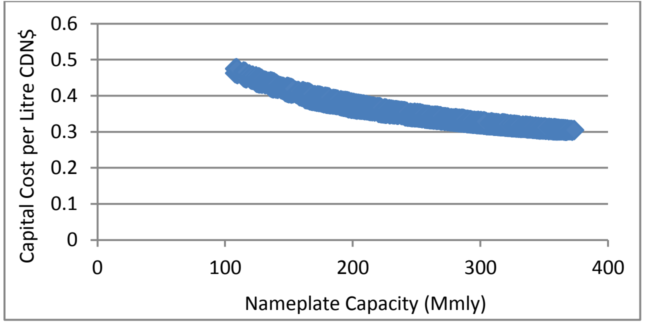
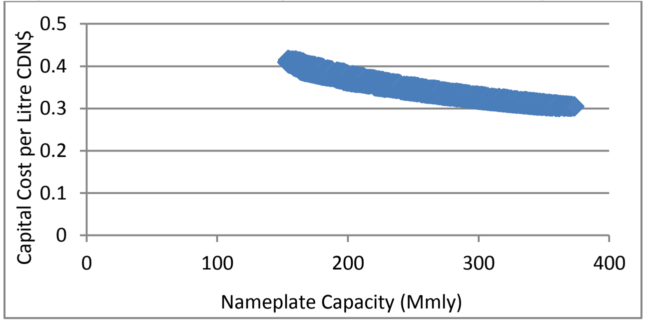


Figure 29: Ethanol Agent Capital Building Costs (Subsidy Off)



An optimal nameplate capacity of 240 – 275 Mmly was suggested in Section 4.8, but the model expanded optimal nameplate capacity to over 350 Mmly. While capital costs begin to flatten at this point, there is no indication of increasing costs beyond that point, implying that true minimum efficient scale may still not have been attained during the simulations. In fact, minimum efficient scale may not have been identified due to the rather limited ethanol market in Saskatchewan. For instance, the inclusion of export markets may allow minimum efficient scale to be identified in the model, a point that should be a consideration for future research.

Profitability of the ethanol agent ultimately decides their success or failure in the industry. Table 16 displays the average net income after taxes (NIAT) for each litre of ethanol produced. The effects of industry subsidization are readily apparent, with subsidized NIAT seventy percent higher than non-subsidy results. Even though profits are lower without subsidies, as previously shown, cost efficiency levels are higher through attainment of both economies of scale and stable location attributes.

Table 16: Descriptive Statistics: Average per Litre Net Income After Tax

Statistical Parameters	Subsidy On	Subsidy Off
Mean	0.066	0.020
Median	0.064	0.02
Mode	0.06	0.01
Standard Deviation	0.022	0.0115
Kurtosis	4.71	2.53
Skewness	0.79	1.45
Range	0.24	0.08
Minimum	0	0
Maximum	0.24	0.08
Observations	43057	34660

The mean generated NIAT findings in Table 16 are comparable to industry results listed in a report by Outlook Market Research and Consulting Ltd. (2008). In this study, the average NIAT[44] was CDN$0.051 per litre for a proposed ethanol plant in Alberta, again supporting the overall simulation model results. The lower mean NIAT generated when subsidies are removed (CDN$0.020/L) is probably quite reliable, given that the Outlook Market Research and Consulting Ltd. (2008) findings include access to federal and provincial subsidies. While subsides in this industry are targeted to support the development of rural locations, these locations typically support smaller plants that typically cannot achieve economies of scale and thus suffer from marginal profitability. The simulation results indicate that subsidies do increase the likelihood that an ethanol plant can survive in rural areas, but the potential termination of such a policy will also almost surely signal the end of smaller ethanol plants that are unable to

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[44] The results presented in Outlook Market Research and Consulting Ltd. (2008) were for an estimated net income before taxes. From their findings a 30% corporate tax rate was applied (as used in the simulations) to acquire an average net income after tax of $0.051/L (based on the five scenarios presented in their analysis).

take advantage of economies of scale or locate in superior places close to transportation and market access.

6.5 Summary

The set of base and counterfactual simulation results presented in this chapter illustrate the characteristics of stable, cost effective, and efficient ethanol plant operations as generated by the model. Locational access to transportation and markets was found to lead to plant stability, with (cost) economies of scale growing as distance to road and rail decreases. DDGS market access was also found to be preferential as ethanol agents selected locations that were on average twenty percent closer to DDGS than ethanol markets.

Simulated and sustainable ethanol plant size was found to be larger than found in the current Saskatchewan market. The average simulated plant size of 208 Mmly (subsidy on) and 231 Mmly (subsidy off) is much larger than the current market average of 70 Mmly in the province. These results seem to indicate that economies of scale are not being realized within the extant Saskatchewan ethanol industry. This finding also brings into question whether the current or future market can appropriately deal with policy shocks such as altered or zero ethanol subsidy levels or less expensive ethanol imports. While this work did not examine the latter, the research found that the former has the potential to drastically change the composition of this industry.

Finally, the results strongly indicate that the intended social goal of ethanol subsidies is not being met. The majority of successful ethanol operations in both base and counterfactual simulations were large plants, suggesting that current attempts at rural revitalization through subsidization of the ethanol industry is not likely to be successful over the long run. Overall, the simulation results also show that identified stable plant locations will need to be located close to transportation networks and output markets, while simultaneously avoiding procurement area competition for wheat inputs. Interestingly, DDGS markets were found to influence location choice more so than ethanol. Ultimately, the latter may be the result of higher DDGS freight costs per unit, or alternatively that both ethanol plants and feedlots share similar location traits.

CHAPTER 7

Summary and Conclusions

7.0 Summary

The ethanol industry is currently in a period of rapid growth fueled by methyl tertiary butyl ether restrictions, high energy prices, gasoline alternatives, recognition of environmental consequences of fossil fuels, concerns about gasoline supplies, and governmental policy and subsidies. These factors have pushed ethanol production in Canada from approximately 300 Mmly per year in 2005 to over 1.8 billion litres in 2011. This dramatic increase has brought hope of wide-spread rural revitalization and new markets for farm production, but to date has also required large subsidies and has also placed additional strain on aging transportation infrastructure. The direction of specific policy has supported the entrance of many ethanol plants without much regard for choosing sustainable or stable locations that properly support ethanol production. The effects of such actions on the future state of industry could be very dramatic, and given the current political and economic environment, understanding these potential outcomes has never been more important.

Due to the complexity and dynamic nature of this problem, in this research an agent-based simulation model was developed to uncover better understanding of those factors influencing ethanol plant location decisions over time. The model effectively merges an industry level cost optimization problem with a simulation of interacting plant agents competing for scarce resources. In addition, previous optimization work in this area has centered on the use of linear programming models, geographical information system applications, and traditional econometric top down methods. However, these methods cannot readily incorporate explicit spatial factors at the individual decision-making level. Finally, the simulated landscape was intended to be representative of the province of Saskatchewan, but it could be readily modified for other regions and ethanol location scenarios.

The inclusion of spatial factors in the simulation allows location to be studied in relation to certain geographical characteristics that may affect the market. In this case, spatial access to feedstock, transportation networks, infrastructure, and final markets is of primary concern to plant location (Huang et al., 2010). Capturing these spatial effects along with the inherent heterogeneity of the plant agents modeled within this framework allows near equilibrium stable states to emerge and be identified. The desire to model this complex problem in this manner was one of the key motivations for performing this analysis. The approach has provided an opportunity to better understand how site location decisions within the ethanol industry evolve through individual interactions while moving towards a number of stable locational states.

7.1 Conclusions

The main components of sustainable or stable ethanol plant locations are access to dependable transportation networks, proximity to final markets, adequate feedstock access, and aversion to procurement competition. The research found that the importance of proximal access to transportation networks is essential with primary highway access exceeding the need to secure mainline rail access. Changing policy through the removal of subsidies dramatically decreases transportation network distances but preference for primary highway access is maintained. The research also found that as distance between plant location and transportation networks increased there was a significant decrease in ethanol production. While these impacts were pronounced, the removal of subsidies heightened this inverse relationship.

As distance to markets increases, so do operating costs with a noticeable decrease in profitability and nameplate capacity. Stable locations were supported by better access to markets, specifically DDGS markets. The latter was a somewhat surprising result. It was anticipated that ethanol market placement should dominate the location decision given that it accounts for approximately eighty percent of typical plants revenue stream. However, the simulations confirmed that stable plant locations were on average twenty percent closer to DDGS markets, a finding that was consistent with and without subsidization of the industry.

A generated average ethanol market distance of 175 KM with industry subsidization, and 169 KM without subsidies supported locational stability. In addition, DDGS market proximity averaged 146 KM with and 140 KM without subsidies respectively. The locational stability that DDGS market proximity appears to add is that it reduces costs and issues associated with transport. However another underlying cause may be that ethanol plants and feedlots share similar locational traits related to balancing feedstock access and final market proximity. Lastly, ethanol plant rail usage was not favoured for DDGS movement, but was beneficial for accessing distant ethanol markets.

Ethanol production costs are significantly affected by economies of scale, location, and market access. The research generated average variable costs of CDN $0.64/L when subsidies are available to ethanol agents, a result similar to that of Perrin et al (2009). The removal of subsidies reduces average variable costs to CDN $0.635/L, indicating increased operating efficiencies within a highly competitive industry. Further, it was shown that subsidies have a dramatic effect on average costs in the simulation. Removal of industry subsidization reduces average cost by CDN $0.06/L as ethanol agents respond to economies of scale through increased nameplate capacity and ethanol production levels, forcing high cost inefficient plants to exit the industry. These findings suggest that subsidies are preventing the industry from operating at an efficient level.

The variance in average nameplate capacity of ethanol plants was significant, with larger plants dominating in both scenarios. Subsidization of small plants, those designated as 25 Mmly or less production at t=1 in the simulations, repeatedly exited the industry before year 50, and the severity of industry exit increased to below year 40 after the removal of subsidies.

While large ethanol agents, those designated as 25 Mmly or larger production at t=1 in the simulations, dominated the landscape there was a significant difference in industry organization. Subsidization not only lowered nameplate capacities, it also increased the number of large ethanol agents operating during simulations. The base findings point to a minimum of two large ethanol agents, but with the removal of subsidies this number drops to one in a significant number of counterfactual runs. While the concentrated market structure generated by the simulations is representative of industries that produce homogeneous goods, it was still a surprising result and one that could signal major changes in a post subsidized ethanol industry in Saskatchewan.

The removal of subsidies increased mean nameplate capacity by 23 Mmly, indicating that economies of scale play an important role in this industry. Gaining economies of scale had a dramatic effect on capital cost per litre, with this value ranging from approximately $0.49/ L down to $0.29/ L. This is an important finding because it signifies that the current Saskatchewan ethanol industry is not exploiting potential economies of scale and therefore operates with excessive operating costs. The potential effects of a changing marketplace could radically alter the ethanol industry in Saskatchewan, given the low margins of smaller plants with a high level of competition.

Saskatchewan has a unique subsidy program where small ethanol producers (25 Mmly and less) receive 30% of the provincial ethanol market, thereby guaranteeing market access. The goal of this subsidy is to promote rural revitalization, but the desired effect may not be realized over the long run. Potentially this creates subsidy dependent firms that may be unable to compete should the subsidy be withdrawn. If provincial subsidies were removed from the marketplace, it is concluded that this would lead to closure of small ethanol producers as their production levels would easily be picked up by the larger and more efficient ethanol plants.

At this time, subsidies and policy decisions have set the ethanol industry to its current development path. But as changes in policy come forward this path may change. Current weather related events in the US and other high volume exporting countries are affecting corn and wheat production estimates for the 2012/13 crop year. These events are creating potential demand rationing scenarios for feed corn as the major input in US ethanol production and livestock feed industry. In the US, the ethanol industry is now estimated to use 40% of the dwindling US corn crop (McMillan, July 19, 2012) which will put additional pressure on increasing the use of wheat in feed rations leading to increased wheat prices. The potential fallout from this scenario is that livestock feeders may start to lobby for a reduction in the ethanol mandate to free up additional corn for feed (McMillan, July 19, 2012).

What does a reduced corn crop in the US mean for the Canadian ethanol industry? The potential for increased use of wheat in feed rations along with an increased price may push both small and inefficient plants to shut down, especially if current demand for gasoline decreases, thereby reducing demand for additives such as ethanol. Should policy decisions reduce ethanol subsidies, the outcome would drastically change the industry. In this authors’ opinion, such a scenario would again lead to closures of small rural plants that are unable to take advantage of economies of scale while reducing margins for large efficient plants. In that situation, the industry would be mainly composed of large ethanol plants competing on an output basis.

In Saskatchewan, the combination of tightening margins due to increased feed wheat price and decreased demand may significantly strain the industry. If the US acted on the potential call for mandate reductions, the outcome could seriously harm the current Saskatchewan ethanol industry. A mandate reduction in the US would potentially lead to increased exports that may find their way into the Canadian market, thereby reducing demand for wheat based ethanol. A more serious threat though would be a change in Canadian ethanol policy to match that of the US. If mandates or subsidies were reduced in Canada and Saskatchewan, the impact would dramatically change the wheat based ethanol industry. Closure of small and inefficient plants would affect rural areas where the majority of small plants are located, but this would also create growth opportunities for efficient plants. Either way, a change in policy will affect the wheat based ethanol industry, potentially upsetting the current policy goal of rural revitalization.

7.2 Limitations

The continued development and application of agent-based models in applied agricultural economic research faces a number of hurdles. This highly flexible and adaptable computational toolkit has led to advances in the study of complex agricultural systems, but issues regarding model communication, data needs, calibration, verification, and validation provide unique limitations. While the model in this thesis is built upon specific financial and behavioural equations, striking a balance between model realism and tractability proved challenging. Lastly, the limited, dispersed, and isolated nature of ethanol industry data provided additional challenges when creating a model designed to reflect as much as possible Saskatchewan’s current industry environment.

While the model does reflect reality, certain assumptions made may have played a major part in generating these results. For example, the use of large land plots may have limited the number of ethanol plants operating on the landscape, which in turn may have had some effect on the number of potential stable locations. While the landscape does represent soil and growing conditions in Saskatchewan, specific areas within the assumed soil zones do have actual higher wheat production levels but were not individually identified within the broad soil zones. And while the transportation network mapped within the simulation approximately represents major road and rail passages within the province, limitations prevented all useable routes form being included, and this likely affected the identification of stable ethanol plant locations within the simulation.

The combination of an optimization problem within the agent-based simulation framework offers many benefits but may also have limited the results. The model starts with ethanol agents populated on the landscape, and through predetermined constraints these agents gradually identify stable plant locations over time. However, this algorithmic assumption may have prevented other suitable locations from emerging, since ethanol agents were not given the option to regenerate or emerge at favourable situations after the simulation began.

Agent-based modeling was an appropriate modeling tool within the context of this research, but it is acknowledged that it was not exploited to its full potential given the steep learning curve associated with learning efficient language programming skills. While the NetLogo© language is relatively uncomplicated to learn, it still benefits from knowledge of efficient and effective programming methods. Future work with agent-based simulation would benefit greatly from prior programming knowledge and additional programming resources. This will help ensure this style of modeling is completed in a more timely and efficient manner.

7.3 Suggestions for Future Study

The research conducted within this thesis focused on the location of individual ethanol plants and the factors that promote stable locations over time. Within the current industry, a number of new developments are centered on co-location relationships, with either high-throughput elevators or feedlots. Including location options for co-location with high-throughput elevators may change the location equation. High-throughput elevators share similar procurement area features and co-location may reduce feedstock competition, while easing producer deliveries by offering a central delivery location for the majority of local grain producers. Inclusion of co-located feedlots offers a direct market for DDGS output while reducing natural gas costs. The close proximity of a feedlot would allow transport of wet distillers grains (WDG) which can reduce natural gas usage by approximately 35%, providing a substantial costs savings (Perrin et al., 2009b) along with reduced transportation costs for distillers grains.

Nevertheless, the transportation of WDG over short distances may be viable. Bonnardeaux (2007) found that in Australia the transportation of WDG was usually viable up to 200 km from the ethanol plant. This finding offers alternative location choice to ethanol plants that are unable to locate adjacent to a feedlot but may benefit from the costs savings associated with WDG. Simulating potential effects on location due to the shipment of WDG within close proximal distance of an ethanol plant may increase sustainability and competiveness within the industry.

The exchange rate effect between Canada and US is a potential area of concern regarding the viability of wheat DDGS in the Canadian market. Boaitey (2010) found that as the Canadian dollar appreciates wheat DDGS is displaced by lower cost imported corn DDGS for use in feed rations. Increased DDGS imports from the US may affect wheat ethanol plant locations in Saskatchewan since the Southern Alberta feedlot area was assumed to be a major DDGS market in this simulation model. Therefore, the exchange rate effect on sustainability and competiveness within the industry should be considered in future simulations given that the Canadian dollar is currently near par with the US dollar.

Understanding the effects of reduced trade barriers and the potential entry of lower cost ethanol imports would allow formation of improved ethanol policy as well as better understanding of industry competitiveness. Future changes to national and international policy may dramatically alter the current industry structure. The inclusion of import and exports of ethanol may lead to changes in capital cost structure beyond what was done in this research. Simulating how these effects could alter the industry would likely increase ethanol plant survivability while improving overall competitiveness. Understanding how ethanol plants ultimately respond to policy and competition changes will surely improve the future of this relatively new industry.

REFERENCES

Abengoa Bioenergy. Abengoa Bioenergy Corporation Portales Ethanol Facility Rail Siding Project. September 1, 2003 News Release. Accessed September 13, 2011. www.abengoabioenergy.com/corp/web/en/acerca_de/sala_de_prensa/historico/2003/200309_noticias.html

Aguilar, Francisco X. 2009. Spatial Econometric Analysis of Location Drivers in a Renewable Resource-Based Industry: The U.S. South Lumber Industry. *Forest Policy and Economics* 11 pp 184-193

Akanle, O.M. and Zhang, D.Z. 2008. Agent-based Model for Optimizing Supply-chain Configurations. *International Journal of Production Economics* 115 pp 444-460

Alliant Energy. Electric and Gas Loads for Ethanol Plants – Midwest Rural Energy Council. February 23, 2007

Arsenault, Adam M. 2007. A Multi-Agent Simulation Approach to Farmland Auction Markets: Repeated Games with Agents that Learn. Masters of Science Thesis. Department of Agricultural Economics, University of Saskatchewan

Asami, Yasushi and Isard, Walter. 1989. Imperfect Information, Uncertainty and Optimal Sampling in Location Theory: An Initial Reexamination of Hotelling, Weber, and Von Thünen. *Journal of Regional Science* 29 (4) pp 507-521

Associated Engineering. Final Report for Rural Municipality of Blucher #343; Industry Servicing Study. Appendix H – Raw Water Pipeline Cost Estimates. June 2010

Associated Engineering. Saskatchewan Watershed Authority Surface Water Approval Fact Sheet. January 28, 2008

Axelrod, Robert. The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration. Princeton University Press. 1997

Bain, R.L. December 2007. World Biofuels Assessment. Worldwide Biomass Potential: Technology Characterizations. National Renewable Energy Laboratory

Bank of Canada. Consumer Price Index (CPI), 2000 to Present. Accessed September 12, 2011. www.bankofcanada.ca/rates/price-indexes/cpi/

Bank of Canada. Daily Noon Rates. Date Range: 2007-03-09 to 2011-07-29. Accessed August 30, 2011. www.bankofcanada.ca/rates/exchange/10-year-lookup/

Berger, Thomas. 2001. Agent-based Spatial Models Applied to Agriculture: A Simulation Tool for Technology Diffusion, Resource Use Changes and Policy Analysis. *Agricultural Economics* 25 pp 245-260

Binger, Brian R. and Hoffman, Elizabeth. Microeconomics with Calculus. Second Edition. Addison-Wesley Educational Publishers Inc. 1998

Boaitey, Albert. 2010. Distillers Grains and the Livestock Industry in Western Canada. Masters of Science Thesis. Department of Agricultural Economics, University of Saskatchewan

Bonabeau, Eric. 2002. Agent-based Modeling: Methods and Techniques for Simulating Human Systems. *PNAS (Proceedings of the National Academy of Sciences)* 99 (3) pp 7280-7287

Bonnardeaux, John. Potential Uses for Distillers Grains. Department of Agriculture and Food, Government of Western Australia, South Perth, Western Australia. March 2007

Bresnahan, David M. October 2, 2006. Ethanol Plants, Construction Companies Need Protection from Unique Risks. Ethanol Producer Magazine. http://www.ethanolproducer.com/articles/2380/ethanol-plants-construction-companies-need-protection-from-unique-risks

Canadian Centre of Policy Alternatives – SK. Saskatchewan Notes. Biofuels: Bonanza or Boondoggle for Saskatchewan? Volume 7. Issue 2. April 2008.

Canadian National Railway. CN Rail website Carload Tool, fuel surcharge rate. Accessed September 2011. www.cn.ca/en/shipping-prices-tariffs-transit-time.htm

Canadian National Railway. CN Rail website Carload Tool. Accessed September 2011. www.cn.ca/en/shipping-prices-tariffs-transit-time.htm

Canadian Renewable Fuels Association (CRFA). August 17, 2009. Plant Locations. http://greenfuels.org/index.php

Canadian Renewable Fuels Association. November 2010. Growing Beyond Oil Delivering Our Energy Future. A Report Card on the Canadian Renewable Fuels Industry. www.greenfuels.org

Carlton, Dennis W. and Perloff, Jeffery M. *Modern Industrial Organization, Fourth Edition*. Addison Wesley, 2005

Carter, Colin A. and Schmitz, Andrew. 1986. Cattle Feeding in Western Canada: The Economics of Its Location. *Agribusiness* 2 (1) pp 119-135

Chan, Jin Hooi and Reiner, David. 2011. Dynamics of Evolution in the Global Fuel-Ethanol Industry. Electricity Policy Research Group Working Paper 1111/ Cambridge Working Paper in Economics 1129. University of Cambridge. March 2011

Chen, Shu-Hang. 2012. Varieties of Agents in Agent-Based Computational Economics: A Historical and an Interdisciplinary Perspective. *Journal of Economic Dynamics & Control* 36 pp 1-25

Cherry, Robert. 2000. The Dominant Firm Model Revisited. *Review of Industrial Organization.* 16 pp 89-95

Coltrain, David. 2004. Economic Issues with Ethanol, Revisited. Department of Agricultural Economics, Kansas Cooperative Development Centre, Kansas State University, Manhattan, KS

Dunn, John R., Caswell, Peggy., Crooks, Tony., Eidman, Vernon., Hrubovcak, Hosein., Richman, Scott., and Scott, Tom. 2005. The Role of Information Technology in the Fuel Ethanol Industry. *Paper presentation at the NCERA-194 2005 Annual Meeting.* Minneapolis, Minnesota. November 8-9, 2005

Durlauf, Steven N. 1998. What Should Policymakers Know about Economic Complexity?. *The Washington Quarterly* 21 (1) pp 157-165

Eathington, Liesl and Swenson, Dave. 2007. Dude, Where's My Corn? Constraints on the Location of Ethanol Production in the Corn Belt. Paper prepared for the 46th Annual Meeting of the Southern Regional Science Association. Charleston, SC. March 29-31, 2007

Emerson, David. 1973. Optimum Firm Location and the Theory of Production. *Journal of Regional Science* 13 (3) pp 335-347

Freeman, Tyler R. 2005. From the Ground Up: An Agent-Based Model of Regional Structural Change. Master of Science Thesis. Department of Agricultural Economics, University of Saskatchewan

Freeze, Brian S. and Peters, T. 1999. A Note on the Profitability of Wheat-ethanol-feedlot Production in Alberta. *Canadian Journal of Agricultural Economics* 47 pp 67-78

Fuller, Stephen and Shanmugham, Chiyyarath. 1978. Network Flow Models: Use in Rural Freight Transportation Analysis and a Comparison with Linear Programming. *Southern Journal of Agricultural Economics* 10 (2) pp 183-188

Funk, Samuel M., Zook, James E., and Featherstone, Allen M. 2008. Chicago Board of Trade Ethanol Contract Efficiency. Prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Dallas, TX, February 2 – 6, 2008.

Gallagher, Paul W., Brubaker, Heather, and Shapouri, Hosein. 2005. Plant Size: Capital Cost Relationships in the Dry Mill Ethanol Industry. *Biomass & Bioenergy* 28 pp 565-571

Gilbert, Nigel and Troitzsch, Klaus G. Simulation for the Social Scientist: Second Edition. Open University Press. 2005

Gilbert, Nigel. Agent-Based Models. Sage Publications, Inc. 2008

Gjerdrum, Jonatan., Shah, Nilay., and Papageorgiou, Lazaros G. 2001. A Combined Optimization and Agent-based Approach to Supply Chain Modelling and Performance Assessment. *Production Planning & Control* 12 (1) pp 81-88

Government of Saskatchewan, News Release July 25, 2002. Government Enhances Road Weight System. Accessed October 6, 2011. http://www.gov.sk.ca/news?newsId=f448a0b5-401f-4db7-b2f6-567c152c8983

Government of Saskatchewan. May 16, 2011. Ministry of Highways and Infrastructure. Accessed February 22, 2012. News release. http://www.highways.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=730,149,1,Documents&MediaID=5128&Filename=newspringorder.pdf

Graubner, Marten., Balmann, Alfons., and Sexton, Richard J. 2011 (b). Spatial Price Discrimination in Agricultural Product Procurement Markets: A Computational Economics Approach. *American Journal of Agricultural Economics* 93 (4) pp 949-967

Graubner, Marten., Balmann, Alfons., and Sexton, Richard J. 2011. Spatial Pricing and the Location of Processors in Agricultural Markets. *Paper prepared for presentation at the EAAE 2011 Congress Change and Uncertainty, Challenges in Agriculture, Food and Natural Resources*. Zurich, Switzerland. August 30 – September 2, 2011

Hailu, Atakelty and Thoyer, Sophie. 2007. Designing Multi-unit Multiple Bid Auctions: An Agent-based Computational Model of Uniform, Discriminatory and Generalized Vickrey Auctions. *The Economic Record* 83 (Special Issue, September) pp S57-S72

Happe, Kathrin. 2004. Agricultural Policies and Farm Structures: Agent-based Modelling and Application to EU-policy Reform. Institute of Agricultural Development in Central and Eastern Europe (IAMO)

Happe, Kathrin., Kellermann, Konrad., and Balmann, Alfons. 2006. Agent-based Analysis of Agricultural Policies: An Illustration of the Agricultural Policy Simulator AgriPoliS, its Adaptation and Behavior. Ecology and Society 11 (1): 49

Heckbert, S. Experimental Economics and Agent-Based Models. 2009. *18th World IMACS / MODSIM Congress*. Cairns, Australia. July 13 – 17, 2009

Herbst, Brian K., Outlaw, Joe L., Anderson, David P., Klose, Steven L., and Richardson, James W. 2002. The Feasibility of Ethanol Production in Texas. Selected Paper for presentation at the Southern Agricultural Economics Association 35th Annual Meeting. Mobile, Alabama. February 1-5, 2003.

Hill, Jason., Nelson, Erik., Tilman, David., Polasky, Stephen., and Tiffany, Douglas. 2006. Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels. *Proceedings of the National Academy of Sciences of the United States of America* 103 (30) pp 11206-11210

Hilletofth, Per., Lättilä, Lauri., and Hilmola, Olli-Pekka. 2009. Agent Based Decision Support in Manufacturing Supply Chain. *Proceedings of the Third KES International Symposium on Agent and Multi-Agent Systems: Technologies and Applications (KES-AMSTA '09).* Springer-Verlag, Berlin, Heidelberg. pp 677-686

Hirankitti, Visit and Krohkaew, Jaturapith. March 2007. An Agent Approach for Intelligent Traffic-Light Control. *First Asia International Conference on Modelling and Simulation, 2007. (AMS'07).* pp 496-501

Hofstrand, Don and Johanns, Ann. Agricultural Marketing Resource Center. Weekly Ethanol, Distillers Grain, & Corn Prices; Excel Sheet. Last accessed on August 30, 2011. www.agmrc.org/renewable_energy/ethanol/ethanol__prices_trends_and_markets.cfm

Hofstrand, Don. 2011. Ag Decision Maker, D1-10 Ethanol Profitability. Iowa State University, University Extension (in cooperation with the USDA). File updated: August 2, 2011.

Holcomb, Rodney and Kenkel, Phil. Enzymatic Hydrolysis Ethanol Plant Feasibility Assessment Template. Oklahoma State University. September 30, 2008.

Huang, Arthur and Levinson, David. 2009. Retail Location Choice with Complementary Goods: An Agent-Based Model. Complex Sciences: Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. Part 1 Volume 4 pp 175-187. Springer Berlin Heidelberg.

Huang, Arthur. and Levinson, David. 2008. An Agent-Based Retail Location Model on a Supply Chain Network. University of Minnesota. Working Paper

Huang, Yongxi., Chen, Chein-Wei., and Fan, Yueyue. 2010. Multistage Optimization of the Supply Chains of Biofuels. *Transportation Research* Part E 46 pp 820-830

Husky Energy Inc. Ethanol Fact Sheet. Accessed August 28, 2011. http://www.huskyenergy.com/downloads/abouthusky/publications/factsheets/FS_2009_Ethanol.pdf

Ileleji, Klein. May 2011. Granulation: A Novel Method to Improve the Bulk Density and Flowability of Distillers Grains with Solubles (DDGS). Accessed on September 21, 2011. www.feedandgrain.com/article/10111614/granulation-a-novel-method-to-improve-the-bulk-density-and-flowability-of-distillers-grains-with-solubles-ddgs

Informa Economics. DDGS Transportation Study. November 2007.

Katchova, Ani L. 2009. The Spatial Effect of Ethanol Biorefinery Locations on Local Corn Prices. *Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2009 AAEC & ACCI Joint Annual Meeting*. Milwaukee, WI. July 26-28, 2009

Kawa, Arkadiusz and Golinska, Paulina. 2010. Supply Chain Arrangements in Recovery Network. Agent and Multi-Agent Systems: Technologies and Applications. Springer Berlin/ Heidelberg. pp 292-301

Keeney, Dennis (senior fellow). Ethanol Production: Environmental Effects. Institute for Agricultural and Trade Policy. Minneapolis. January 25, 2007.

Kenkel, Phil and Holcomb, Rodney B. 2006. Challenges to Producer Ownership of Ethanol and Biodiesel Production Facilities. *Journal of Agricultural and Applied Economics* 38 (2) pp 369-375

Kerr, William A. and Loppacher, Laura J. 2005. Trading Biofuels – Will International Trade Law Be a Constraint? *Current Agriculture, Food & Resource Issues, A Journal of the Canadian Agricultural Economics Society* Number 6 pp 50-62

Kilkenny, Maureen. 1998. Transport Costs and Rural Development. *Journal of Regional Science* 38 (3) pp 293-312

Kilkenny, Maureen and Thisse, Jacques-François. 1999. Economics of Location: A Selective Survey. *Computers & Operations Research* 26 pp 1369-1394

Kotrba, Ron. February 5, 2008. Denaturant Pricing Movement Affects Blend Volume. Ethanol Producer Magazine. http://www.ethanolproducer.com/articles/3708/denaturant-pricing-movement-affects-blend-volume

Krugman, P. 1996. Urban Concentration: The Role of Increasing Returns and Transport Costs. *International Regional Science Review* 19 pp 5-30

Kuznets, Simon. 1930. Static and Dynamic Economics. *The American Economic Review* 20 (3) pp 426-441

Lambert, D.M., Wilcox, M., English, A., and Stewart, L. April 2008. Ethanol Plant Location Determinants and County Comparative Advantage. *Journal of Agricultural and Applied Economics* 40 (1) pp 117–135

Le Roy, Danny G. and K.K. Klein. 2007. The Development and Sustainability of the Biofuel Industry in Canada. *National Agricultural Biotechnology Council Report #19 - Agricultural Biofuels: Technology, Sustainability and Profitability. Proceedings from the 19th Annual National Agricultural Biotechnology Council Conference.* December 2007. pp 177-186

Lechner, Thomas., Watson, Ben., Ren, Pin., Wilensky, Uri., Tisue, Seth., and Felsen, Martin. 2004. Procedural Modeling of Land Use in Cities. Technical Report (NWU-CS-04-38), Computer Science Department, Northwestern Univeristy. August 20, 2004

Low, Sarah A. and Isserman, Andrew M. 2008. Ethanol: Implications for Rural Communities. *Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meetings*. Orlando, Florida, July 27-29 2008

Low, Sarah A. and Isserman, Andrew M. 2009. Ethanol and the Local Economy: Industry Trends, Location Factors, Economic Impacts, and Risks. *Economic Development Quarterly* 23 (1) pp 71-88

Macal, CM and North, MJ. 2010. Tutorial on Agent-based Modelling and Simulation. *Journal of Simulation* 4 pp 151-162

Mansfield, Edwin. Microeconomics Theory / Applications, Ninth Edition. W.W. Norton & Company, Inc. 1997.

McMillan, D'Arce. July 19, 2012. Shrinking Corn Crop Presents Growing Problem for Ethanol Industry. The Western Producer 90 (3). pp 9

Michaels, Gregory H., Levins, Richard A., and Fruin, Jerry E. 1982. Rail/Truck Competition for Grain Traffic in Minnesota: Implications for Rate Making. *American Journal of Agricultural Economics* 62 (2) pp 276-279

Miller, John H. and Page, Scott E. Complex Adaptive Systems – An Introduction to Computational Models of Social Life. Princeton University Press. 2007

Mills, Geofrey T. The Impact of Inflation on Capital Budgeting and Working Capital. *Journal of Financial And Strategic Decisions*, Spring 1996, 9 (1) pp 79-87

National Academy of Sciences. 2009. Liquid Transportation Fuels from Coal and Biomass: Technological Status, Costs, and Environmental Impacts.

National Renewable Energy Laboratory. May 2011. Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol. Technical Report NREL/TP-5100-47764

Natural Resources Canada. Office of Energy and Efficiency (OEE). February 12, 2011. Alternative Fuel Facts: Ethanol. http://oee.nrcan.gc.ca/transportation/alternative-fuels/fuel-facts/ethanol/benefits.cfm?attr=8

Natural Resources Canada. Office of Energy Efficiency (OEE). EcoEnergy Program for Biofuels. Accessed November 4, 2011. http://oee.nrcan.gc.ca/transportation/alternative-fuels/programs/ecoenergy-biofuels/biofuels-incentive.cfm?attr=16

NGV Global. Natural Gas. Accessed November 8, 2011. http://www.iangv.org/natural-gas-vehicles/natural-gas.html

Nilles, Dave. May 1, 2006. Time Testing. Ethanol Producer Magazine. http://www.ethanolproducer.com/articles/2005/time-testing

Nolan, James., Parker, Dawn., van Kooten, Cornelis G., and Berger, Thomas. 2009. An Overview of Computational Modeling in Agricultural and Resource Economics. *Canadian Journal of Agricultural Economics* 57 pp 417-429

Noon, Charles E., Zha, Benjamin F., and Graham, Robin L. 2002. GIS-Based Analysis of Marginal Price Variation with an Application in the Identification of Candidate Ethanol Conversion Plant Locations. *Networks and Spatial Economics* 2 pp 79-93

Noramera Bioenergy Corporation. Accessed August 28, 2011. http://www.noramerabioenergy.com/

North, Michael J. and Macal, Charles M. 2007. Managing Business Complexity: Discovering Strategic Solutions with Agent-Based Modeling and Simulation. Oxford University Press, Inc.

Oak Ridge National Laboratory. Conversion Factors for Bioenergy. Published by North Carolina Cooperative Extension. 2008.

OECD. International Energy Agency. Biofuels For Transport, An International Perspective. 2004.

Olar, M., Romain, R., Bergeron, N., and Klein, K. 2004. Ethanol Industry in Canada. Research Series. Centre for Research in the Economics of Agrifood. Laval University. August 2004.

Outlook Market Research and Consulting Ltd. June 5, 2008. Business Case: Ethanol Business for: The County of Newell #4.

Parker, Dawn C., Manson, Steven M., Janssen, Marco A., Hoffmann, Matthew J., and Deadman, Peter. 2003. Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers* 93 (2) pp 314-337

Patel, Amit. 2012. Amit's Game Programming Site. Heuristics, Amit's Thoughts on Pathfinding. Accessed June 11, 2012. http://theory.stanford.edu/~amitp/GameProgramming/Heuristics.html

Perrin, Richard K., Fretes, Nickolas P., and Sesmero, Juan P. 2009. Efficiency in Midwest US Corn Ethanol Plants: A Plant Survey. Faculty Publications: Agricultural Economics. University of Nebraska – Lincoln

Perrin, Richard K., Fretes, Nickolas P., and Sesmero, Juan P. 2009 b. Efficiency in Midwest US Corn Ethanol Plants: A Plant Survey. *Energy Policy* 37 pp 1309-1316

Partridge, Mark., Olfert, Rose M., and Alasia, Alessandro. 2007. Canadian Cities as Regional Engines of Growth: Agglomeration and Amenities. *Canadian Journal of Economics* 40 (1) pp 39-68

Ross, Brent R. and Westgren, Randall E. 2009. An Agent-Based Model of Entrepreneurial Behavior in Agri-Food Markets. *Canadian Journal of Agricultural Economics* 57 pp 459-480

Ross, Stephen A., Westerfield, Randolph W., Jordan, Bradford D., and Roberts, Gordon S. Fundamentals of Corporate Finance, Second Canadian Edition. The McGraw-Hill Companies Inc. 1996

Runge, C. Ford. 2006. Agricultural Economics: A Brief Intellectual History. Center for International Food and Agriculture Policy. University of Minnesota. Working Paper WP06-1

Russell, Dawn M., Ruamsook, Kusumal., and Thomchick, Evelyn A. 2009. Ethanol and the Petroleum Supply Chain of the Future: Five Strategic Priorities of Integration. *Transportation Journal* 48 (1) pp 5-22

S&T^2 Consultants Inc. The Addition of Ethanol from Wheat to GHGenius. Prepared for Natural Resources Canada, Office of Energy Efficiency. January 31, 2003

S&T^2 Consultants Inc. and Meyers Norris Penny LLP. Economic, Financial, Social Analysis and Public Policies for Fuel Ethanol Phase 1. Prepared for Natural Resources Canada. November 22, 2004

Sakellariou, Ilias., Kefalas, Pertos., and Stamatopoulou, Ioanna. 2008. Enhancing NetLogo to Simulate BDI Communicating Agents. Artificial Intelligence: Theories, Models and Applications. Springer Berlin/ Heidelberg. pp 263-275

Sarmiento, Camilo and Wilson, William W. 2007. Spatial Competition and Ethanol Plant Location Decisions. Agribusiness and Applied Economics Report No. 604. Department of Agribusiness and Applied Economics, Agricultural Experiment Station, North Dakota State University

Sarmiento, Camilo and Wilson, William W. 2008. Spatial Competition and Ethanol Plant Location Decisions. *Presented at the American Agricultural Economics Association, Annual Meeting*. Orlando, FL. May 2008

Saskatchewan Ministry of Agriculture. Average Wheat Prices 1968 – 2008

Saskatchewan Ministry of Agriculture. Soil Zones in Southern Saskatchewan. 2009. Accessed March 17, 2011. http://www.agriculture.gov.sk.ca/soil_zones_map

SaskEnergy Communication. D.J. (Dale) Farthing, Business Supervisor. October 14, 2011

SaskEnergy. Business Rates – Commercial, Effective November 1, 2010. Accessed November 8, 2011. http://www.saskenergy.com/business/comrates_curr.asp

SaskPower Communication. Murray Black, Manager, Customer Development and Support. October 19, 2011

SaskPower. SaskPower Supplied Transformation – Standard metered non-residential and non-farm load rates. Accessed November 8, 2011. http://www.saskpower.com/customer_service/rates/supplied_transformation/

Scheffran, Jürgen., BenDor, Todd., Wang, Yun., and Hannon, Bruce. 2007. A Spatial-Dynamic Model of Bioenergy Crop Introduction in Illinois. *The 25th International Conference on the System Dynamics Society.* Boston, MA. July 29 – August 2, 2007

Schenk, Timlan A., Löffler, Günter., and Rauh, Jürgen. 2007. Agent-based Simulation of Consumer Behavior in Grocery Shopping on a Regional Level. *Journal of Business Research* 60 pp 894-903

Shapouri, Hosein and Gallagher, Paul. USDA's 2002 Ethanol Cost-of-Production Survey. United States Department of Agriculture, Office of Energy Policy and New Uses. Agricultural Economic Report Number 841. July 2005

Solomon, Barry D., Barnes, Justin R., and Halvorsen, Kathleen E. 2007. Grain and Cellulosic Ethanol: History, Economics, and Energy Policy. *Biomass and Bioenergy* 31 pp 416–425

Statistics Canada. 2000. Vista on the Agri-Food industry and the Farm Community. Catalogue No. 21-004-XIE. March 2000

Statistics Canada. 2006. Agricultural Division, Crops Section. Historical Data, 1976 – 2006, November 2006 Crop Survey. Accessed April 15, 2011. http://library2.usask.ca/data/files/file.html/451,1

Statistics Canada. 2012. Latest Release from the Consumer Price Index. Accessed March 29, 2012. http://www.statcan.gc.ca/subjects-sujets/cpi-ipc/cpi-ipc-eng.htm

Stolniuk, Peter C. 2008. An Agent-Based Simulation Model of Structural Change in Agriculture. Master of Science Thesis. Department of Agricultural Economics, University of Saskatchewan

Swain, Bibb. October 26, 2006. Designed to Go Above Nameplate Capacity. Ethanol Producer Magazine. http://ethanolproducer.com/articles/2463/designed-to-go-above-nameplate-capacity

Taylor, Richard D. and Koo, Won W. February 2010. Optimizing Ethanol Production in North Dakota. Center for Agricultural Policy and Trade Studies, Department of Agribusiness and Applied Economics, North Dakota State University

TDI Projects Inc. 2004. Saskatchewan Feasibility Report Ethanol-Feedlot Facilities. Primary Producer-Owned Multiple Saskatchewan Locations. September 2004

Teahan, W. J. (2010). Manhattan Distance NetLogo model. Artificial Intelligence. Ventus Publishing Aps.

Tesfatsion, Leigh. 2000. Agent-Based Computational Economics: A Brief Guide to the Literature. Iowa State University. Working Paper

Tesfatsion, Leigh. 2002. Agent-Based Computational Economics: Growing Economies From the Bottom Up. *Artificial Life* 8 pp 55-85

Tiffany, Douglas G. Economic Comparison of Ethanol Production from Corn Stover and Grain. Applied Economics, University of Minnesota. AURI Energy Users Conference, Redwood Falls, MN, March 13, 2007

Tisue, Seth and Wilensky, Uri. 2004. NetLogo: Design and Implementation of a Multi-Agent Modeling Environment. *Presented at SwarmFest.* Ann Arbor, Michigan. May 9-11, 2004

Transport Canada, Bulletin. Ethanol and gasoline mixture - classification and emergency response. Accessed September 21, 2011. www.tc.gc.ca/eng/tdg/publications-bulletins-ethanolgasoline-1105.htm

Tyner, Wallace E. and Taheripour, Farzad. 2008. Policy Options for Integrated Energy and Agricultural Markets. *Presented at the Transition to a Bio-Economy: Integration of Agricultural and Energy Systems Conference.* Westin Atlanta Airport. February 12-13, 2008

Ullman, Edward. 1941. A Theory of Location for Cities. *American Journal of Sociology* 46 (6) pp 853-864

University of Illinois. November 2007. Corn-Based Ethanol in Illinois and the U.S.: A Report from the Department of Agriculture and Consumer Economics, University of Illinois. http://www.farmdoc.illinois.edu/policy/research_reports/ethanol_report/index.html

Urbanchuk, John M. 2006. Contribution of the Ethanol Industry to the Economy of the United States. Prepared for the Renewable Fuels Association. LECG LLC. February 21, 2006

USDA Agricultural Marketing Service, Agricultural Transportation, Biofuel Database. Accessed on August 30, 2011. www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?startIndex=1&template=TemplateV&page=BiofuelTransportationDatabase

Van Wart, Justin and Perrin, Richard K. 2009. Understanding Spatial Welfare Impacts of a Grain Ethanol Plant. *Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference*. Beijing, China. August 16-22, 2009

Vidal, José and Huyuh, Nathan. 2010. Building Agent-Based Models of Seaport Container Terminals. *Proceedings of 6th Workshop on Agents in Traffic and Transportation*. Toronto, Canada. May 11, 2010

Viju, Crina. 2008. Subsidization of the Biofuel Industry. Three Essays in International Trade: Market Integration, Subsidization, and Antidumping. PhD Thesis University of Saskatchewan

Weyburn Inland Terminal. August 1, 2011. *Dial-a-Truck Rates*. Accessed August 16, 2011. http://www.wit.ca/index.php/Rates.html

Kansas State University. 2002. Corn Based Ethanol Costs and Margins Attachment 1. Agricultural Marketing Resource Center, Department of Agricultural Economics. May 2002

Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

APPENDIX A
The Simulation: Variables and Equations

A.0 Introduction

A number of key variables are assumed to affect ethanol plant location and form part of the simulated locational analysis during both initialization and operations. These variables are detailed with reference to the discussions in Chapter Four. The following Appendix provides a more complete description of the simulation environment, including assumptions and specific relationships utilized.

A.1 Feedstock Movement

The cost of transporting feedstock by truck from the farmer to the ethanol plant is based on a per (metric) tonne rate. These costs are recorded but are assumed to be the responsibility of the farm agent. In turn, feedstock trucking rates are separated into primary and secondary weight costs based on the distance to the nearest primary highway. It is assumed that if the patch in question is located less than or equal to 1.5625 patches from a primary highway, then the primary weight applies, but a distance greater than 1.5625 patches implies secondary weight restrictions. This is done in the simulation because of what is known as the 15 km rule used in the province. This rule, allows primary weights to be moved without penalty on secondary roads up to a distance of no more than 15 km from initial primary/secondary intersection (Government of Saskatchewan, May 16, 2011). So within the simulated landscape, each patch is 9.6 km^2 in area (one township), and this fact combined with the distance factor of 1.5625 emulates the 15 km rule. The applicable truck transport rate, if needed, can be accessed by all agents that locate on a particular patch. Primary and secondary truck transportation rates are shown below. Michaels et al. (1982) provide evidence that bulk trucking rates increase with distance, but at a decreasing rate. This quadratic relationship was estimated for primary and secondary rates using data obtained from Weyburn Inland Terminal (August, 2011), and these results are shown in Figures 30 and 31.

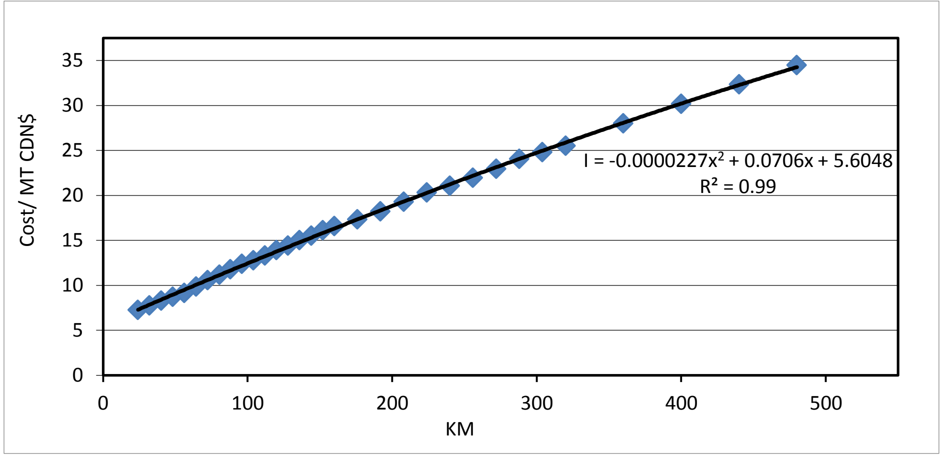
Feedstock primary truck rate per MT:

$I = -0.0000227x^2 + 0.0706x + 5.6048$
$R^2 = 0.99$

Where: I is rate per MT; CDN$

x is distance in kilometers

Figure 30: Primary Highway Cost per MT for Bulk Feedstock Shipment



Feedstock secondary truck rate per MT:

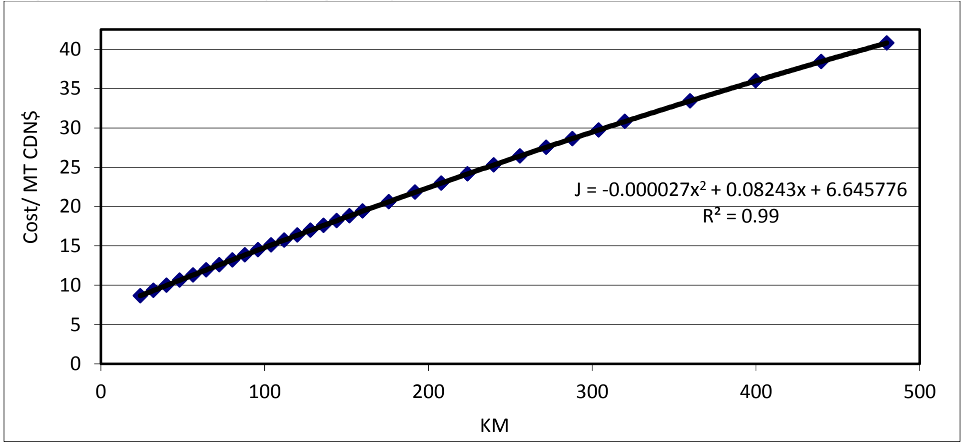
$$J = -0.000027x^2 + 0.08243x + 6.645776$$
$$R^2 = 0.99$$

Where: J is rate per MT; CDN$

x is distance in kilometers

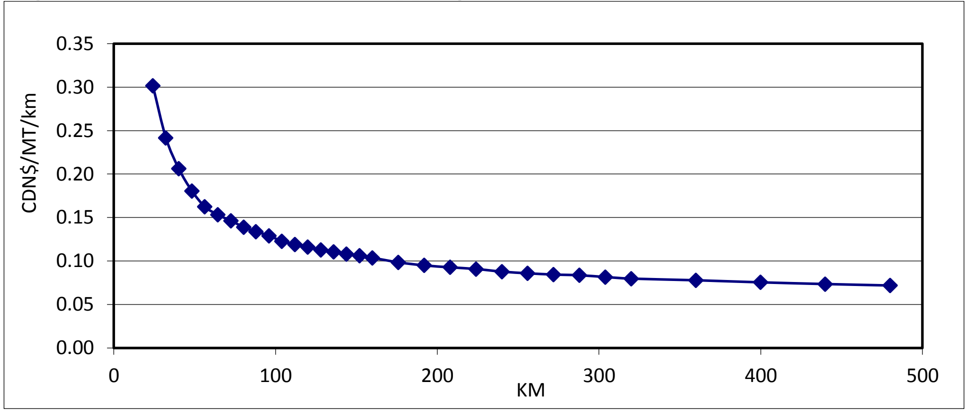
This secondary rate was altered to reflect that on average, non-primary shipment weight is 16% lower than primary shipment weight (Government of Saskatchewan, July 25, 2002).

Figure 31: Secondary Highway Cost per MT for Bulk Feedstock Shipment



The shipment cost for a single primary weight load of bulk feedstock over increasing distances results in significant costs savings as shown in Figure 32[45]. Initial shipment cost is high when the truck is loaded, but dramatically decreases until approximately 200 km when these cost decreases begin to level off.

Figure 32: Bulk Feedstock Shipping Cost as a Function of Distance



A.2 Utilities: Access and Rates

Location factors related to utility services include the cost of acquiring water, electrical, and natural gas service to a potential plant site. Water access cost is based on laying an industrial water pipeline to the potential site[46] and includes trench excavation and backfill, pressure pipe, and pressure pipe fittings. Based on recent engineering estimates for industrial contracts in the province of Saskatchewan, this cost is assumed to be $151,145.00 per km and does not include water usage costs (Associated Engineering, 2010). Thus the water access formula[47] used in the simulation is:

$$K = 151145x$$

Where: K is total water access infrastructure cost; CDN$
x is distance in kilometers

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[45] Data used in this analysis was obtained from Weyburn Inland Terminal (August, 2011) and is based on a primary weight bulk shipment of feedstock (grain).

[46] Pumping costs were not included in this calculation as it is assumed that water could be allocated from an urban site or an established pumping station.

[47] Linearity has been assumed for tractability.

Water use for the plants in this simulation is based on corn ethanol production data. Given similarities between wheat and corn ethanol production, it is assumed here that wheat ethanol production operates on the same 4:1 ratio, meaning four litres of water is required to produce one litre of ethanol (Kenney, 2007). Industrial water use cost data for applications in the province of Saskatchewan was obtained from Associated Engineering (2008), with an estimated cost per cubic meter of $0.0462[48]. This implies water cost associated with one litre of ethanol production is $0.0001848, therefore access to water is more important than actual water cost.

Ethanol production requires 0.004 m^3 of water to produce one litre of ethanol, thus the following water cost formula was used in the simulation:

$$L = (x * 0.004) * 0.0462$$

Where: L is water cost/expense; CDN$ per year
x is ethanol production (litres)

For a point of reference based on these assumed cost figures, a 130 Mmly ethanol plant would use approximately 520,000 m^3 of water at an approximate cost of $24,000 per year[49].

Electrical access cost includes building infrastructure to the potential site and varies based on the MVA (Megavolt-Ampere) service required. Most ethanol plants up to 100 MGY (378 Mmly) can be serviced by the nearest 138 kV interconnection (Alliant Energy, February 23, 2007). This model assumes that ethanol agents will not become larger than 378 Mmly, therefore access cost is limited to the commonly found 138 kV interconnections. Should agents become larger than 378 Mmly, the additional cost to access the larger 230 kV interconnection would add minimal fixed costs to an operation of that scale (SaskPower, October 14, 2011; Alliant Energy, February 23, 2007). This level of service can be obtained from most urban centres, but rural locations may in fact require installation of a substation to serve the increased load. If this is the case, then additional costs beyond those assumed here would be required and this could be done on a case

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[48] Cost applies to untreated water.

[49] Water use calculated as follows: [(130,000,000 * 0.004m^3) * 0.0462].

by case basis. Estimated construction and metering costs[50] for service from the 138 kV interconnections are \$289,000 per KM (SaskPower, October 19, 2011). Thus the electrical access cost formula[51] used in the simulation is:

$M = 289000x$

Where: M is total electrical infrastructure access cost; CDN\$
x is distance in kilometers

Based on industry references, electrical use is assumed to be 0.3 kWh (kilo-watt hour) per litre (S&T^2 Consultants Inc., 2003). SaskPower rates for non-residential and non-farm use are levied on a tiered system, meaning that as demand increases, the average rate declines per kWh. For instance, use up to 15,500 kWh costs \$0.09185/ kWh and over 15,500 kWh the charge is \$0.05602/ kWh, plus a basic monthly metering charge of \$55.00 (SaskPower, Supplied Transformation). For a 130 Mmly ethanol plant, approximately 39,000,000 kWh (130,000,000 times 0.3 kWh) would be required at an estimated cost of \$2,192,104 (including basic monthly metering charges).

Natural gas access infrastructure costs are significantly less than electrical. Estimated construction cost[52] for an ethanol plant to access natural gas is \$10,000 per KM (SaskEnergy, October 14, 2011). The natural gas access cost formula[53] is then:

$N = 10000x$

Where: N is total natural gas infrastructure access cost; CDN\$
x is distance in kilometers

Natural gas use is estimated at 11.98 MJ (mega joules) per litre (S&T^2 Consultants Inc., January 2003). Natural gas sales are done in cubic meters, and one cubic meter produces 3.2 litres[54] of

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[50] Winter construction costs, environmental reviews, road crossings, and type of terrain can impact and can lead to increased costs.

[51] Linearity has been assumed for tractability.

[52] Winter constructions costs can be double or triple the estimated shown, also environmental reviews, road crossings, and type of terrain also impact and can lead to increased costs.

[53] Linearity has been assumed for tractability.

[54] There are 38.3MJ/ m^3 (NVG Global); therefore it follows that 38.3 ÷ 11.98 = 3.2.

ethanol. SaskEnergy rates for commercial customers are levied on a tiered system and as demand increases the average rate decreases per cubic meter. Natural gas use up to 40,000 m^3 is \$0.039/ m^3 and for use over 40,000 m^3, the rate is \$0.0333/ m^3, plus a delivery charge of \$0.1725/ m^3 and a basic monthly metering charge of \$216.00 (SaskEnergy Business Rates, 2010). For a 130 Mmly ethanol plant, approximately 40,663,000 m^3 of natural gas[55] is required at an estimated cost of \$8,373,812 (including basic monthly delivery and metering charges). As is evident, the use and cost of electricity and natural gas has a significant effect on an ethanol plant's variable costs[56].

A.3 Farm Agents

Farm agents locate on patches that do not contain other items like primary highways, rail lines, cities, towns, blenders, or feedlots. They are endowed with feedstock production based on specific criteria that will be discussed below. Farm agents produce feedstock, store it in farm inventory, and then ship it to ethanol plants when called by the plant to deliver. Since farmer agents are considered to be price takers in this market, no other actions by these agents are considered in the simulation[57].

Feedstock production is set based on patch location within the landscape. As mentioned, slight differences have been coded into the model to mimic the effects of various growing regions. Soil types are first classified (black, dark brown, and brown) and then the total production slider on the software interface sets wheat feedstock production. This is then split based on the average percent figures for each soil zone (black 33%; dark brown 34%; brown 33%). Furthermore, production levels for each soil zone are split equally among the patches located within.

Average production by census agricultural regions is shown in Figure 33 and as can be seen, specific CARs do have higher production levels. The latter run mostly through the centre of the crop production region of the province. These particular CARs may have a somewhat higher possibility of gaining and keeping an ethanol plant, but each of them possess the ability to

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[55] Natural gas required: 130,000,000 divided by 3.2 litres of produced ethanol per cubic meter.

[56] It should be noted that sales of wet distillers grain were not considered in this thesis. Wet distillers grain may reduce variable costs associated with electricity and natural gas as they do not require the high volumes of energy needed to reduce moisture content to 10% associated with dried distillers grains with solubles (Perrin et al., 2009).

[57] During the simulation farm agents do not increase their land size or change their feedstock production quantities.

support at least one ethanol plant under the assumptions made in this model. Table 17 lists CARs by soil zone as used in the simulation. For illustrative purposes, Figure 34 is an overview of Saskatchewan's soil zones and CAR locations.

Figure 33: Average Wheat Production for 30 Years by CAR[58]

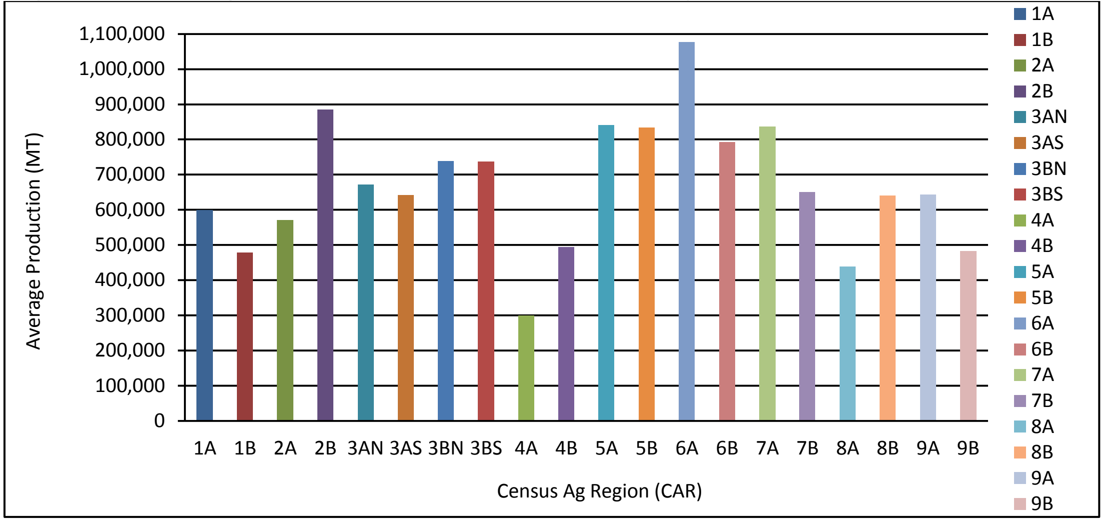

Table 17: CAR Location by Soil Zone[59]

	Black Soil Zone	Dark Brown Soil Zone	Brown Soil Zone
CAR	1B; 5A; 5B; 8A; 8B; 9A; 9B	1A; 2A; 2B; 6A; 6B; 7B	3AN; 3AS; 3BN; 3BS; 4A; 4B; 7A

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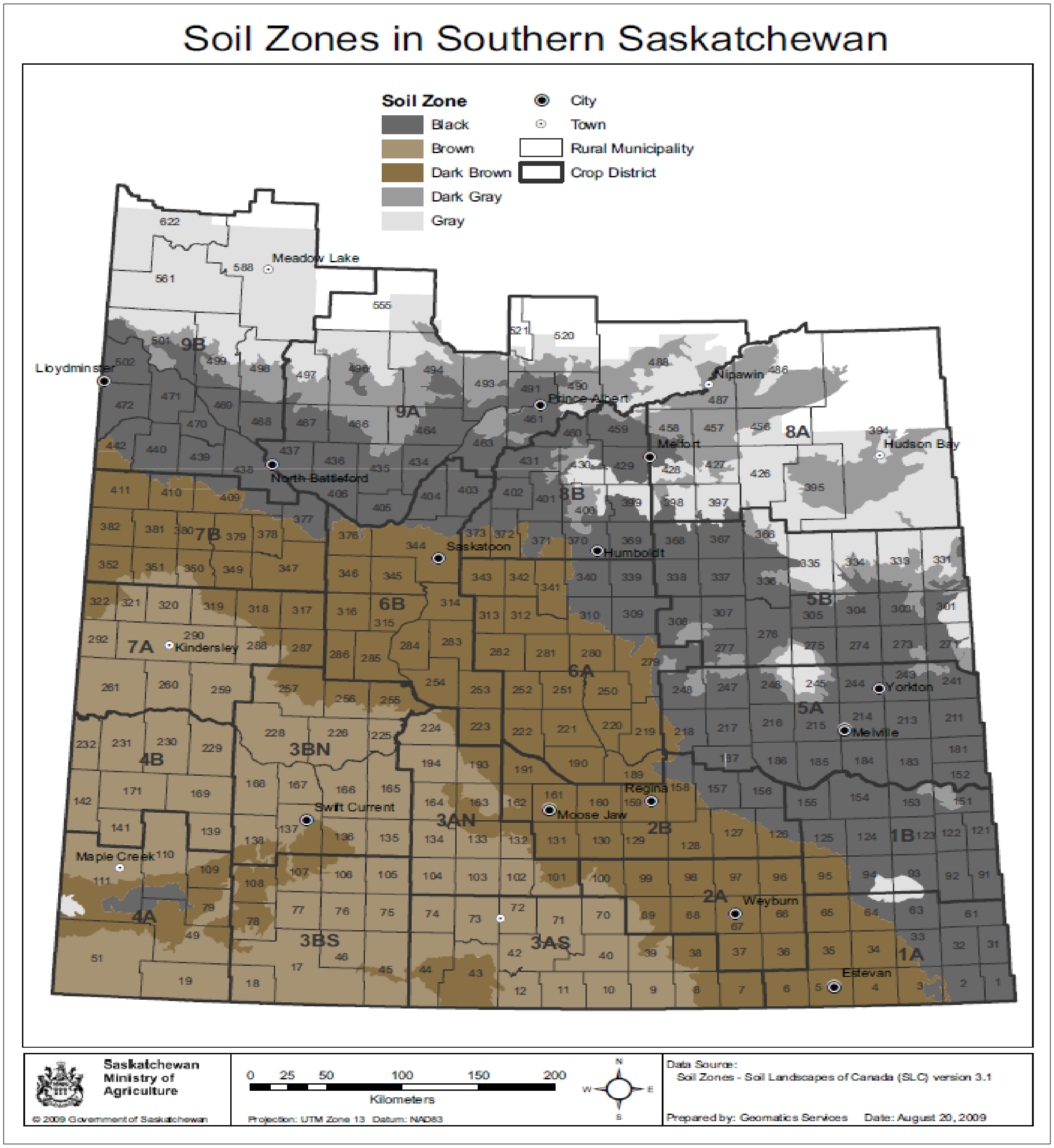
[58] Statistics Canada, November 2006 Crop Survey.
[59] Saskatchewan Ministry of Agriculture, 2009.

Figure 34: Saskatchewan Soil Zones and Census Agricultural Regions[60]



A.4 Inflation

All production costs in the simulation are assumed to be subject to inflation. This can be set by the user via the *inflation-on-expenses* slider programmed into the NetLogo© interface. Inflation is applied during both the NPV initialization and operation phases. Given the long lifespan of a typical ethanol project, ignoring inflation could lead to a bias against accepting these projects.

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[60] Saskatchewan Ministry of Agriculture, 2009.

Inflation reduces buying power and therefore the return on investment from a proposed plant (Mills, 1996; Ross et al., 1996). Therefore, inflation must be considered during the NPV analysis conducted in the simulation given that it is multiplicative and not additive (Mills, 1996). The general inflation equation (Mills, 1996) for both revenue and expenses used here is:

$$C^{*} = Q(1+p)^{t}$$

Where: C^* is nominal or inflated cash or expense flow
Q is actual average price at t – 1
p is inflation rate for expenses or revenue
t is time period (relative to base year or t = 0)

A.5 Feedstock Cost

One of the main costs to operate an ethanol plant is feedstock. Average feedstock price was calculated from 30 years of Saskatchewan wheat price data. An average price[61] of $4.21/ bushel or $154.69/ MT was found (Saskatchewan Ministry of Agriculture, 2008) and this value is used in the model. Note again that using an average price/cost also helps to maintain stability within the model. During the NPV initialization phase, the total feedstock use is derived from the available feedstock in the procurement area, while issues concerning competition for feedstock are not considered until the operation stage.

A.6 Freight

Freight cost for the ethanol agents include delivery of supplies required during plant operations. This includes items such as chemicals, denaturant, and other inputs. Hofstand (2011) estimates this cost at USD $825,000/ year for a 100 MGY corn ethanol plant. Based on this work, the converted freight cost used in the simulation is CDN $0.0021/ L of produced ethanol.

A.7 Marketing of Ethanol and DDGS

Tiffany (2007) estimated marketing cost for corn based ethanol plants at US$0.20/ gallon. When converted to CDN$/ L, the estimated marketing cost is $0.056/ L of ethanol produced. This cost covers marketing of both ethanol and DDGS products.

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[61] Saskatchewan average wheat prices, detrended, 2008 dollar equivalent, 1968 – 2008.

A.8 Chemical Inputs

The production of ethanol requires specific chemicals, enzymes, and yeast. It is likely there are purchasing economies present due to plant size, but for reasons of tractability, that possibility has not been incorporated into the simulation. Alternatively, a simple cost per litre of ethanol produced has been used for individual plant decision making. On aggregate, these inputs cost CDN $0.0196/ L of ethanol produced and are converted from equivalent corn ethanol requirements (Bain, 2007; Hofstrand, 2011).

Denaturant is natural gasoline and is blended with ethanol to render it undrinkable (Kotrba, 2008). Natural gasoline is a byproduct of natural gas production and usually follows the liquefied petroleum gas price (Kotrba, 2008). The quantity needed is a function of ethanol production and costs CDN$0.01/ L, as converted from equivalent corn ethanol requirements (Herbst et al. 2002; Hofstrand, 2011).

A.9 Maintenance, Insurance, and Property Taxes

Maintenance, repairs, and other direct costs associated with keeping the plant operational are critical to ensuring costly down time is avoided. Bain (2007) and Hofstrand (2011) estimated these costs are approximately CDN $0.0126/ L, derived from corn ethanol data.

While improving, insurance companies typically lack experience regarding the special needs and liability issues found in the ethanol industry, therefore given this risk, insurance premiums can be costly for ethanol plants (Bresnahan, 2006). Bain (2007), Outlook Market Research and Consulting (2008), and Hofstand (2011) all derived approximate insurance rates of 0.5% in their various economic cost analyses. Therefore, a basic insurance rate of 0.5% of capital cost seems to be consistent and well documented, and is employed in this simulation model.

The use of local tax breaks to entice an ethanol plant to build can be represented in the simulations in a number of ways. In reality, property tax abatements are usually offered, which creates difficulty in establishing an industry average for property taxes. Previous related studies have represented property taxes as a percentage of capital cost, ranging from 0.1% to 0.5% (Holcomb and Kenkel, 2008; Outlook Market Research and Consulting, 2008; Hofstand, 2011).

Based on this research, a property tax rate equivalent to 0.5% of capital cost (Holcomb and Kenkel, 2008) is used in the simulation model. This level seems to capture the average locational variability of this expense.

A.10 Labour

Economies of scale have some effect on labour costs for ethanol plants, but in fact labour use is also related to the age of the plant. Data indicates that doubling ethanol plant size from 50 MGY to 100 MGY requires only 14% more labour - with 40 employees needed compared to 35 employees for the smaller plant (University of Illinois, 2007). Shapouri and Gallagher (2005) assert that new ethanol plants use labour more efficiently with increased use of automated technology. Labour and management costs used in the simulation have been estimated from Bain (2007)[62] and Holcomb and Kenkel (2008). Employee benefits are an important consideration for both employers and employees that create additional operational costs, and Holcomb and Kenkel (2008) state that labour benefit costs are 40% of wages. The cost of employee benefits has been included in the calculation of wages to form the following labour cost relationship (Bain, 2007; Holcomb and Kenkel, 2008):

$$P = 13216x^{0.2523}$$

$R^2 = 0.99$

Where: P is total labour cost; CDN$ per year
x is plant size (Mmly)

Figure 35 displays the inverse relationship of labour cost to plant size and illustrates the effect that economies of scale have on this variable.

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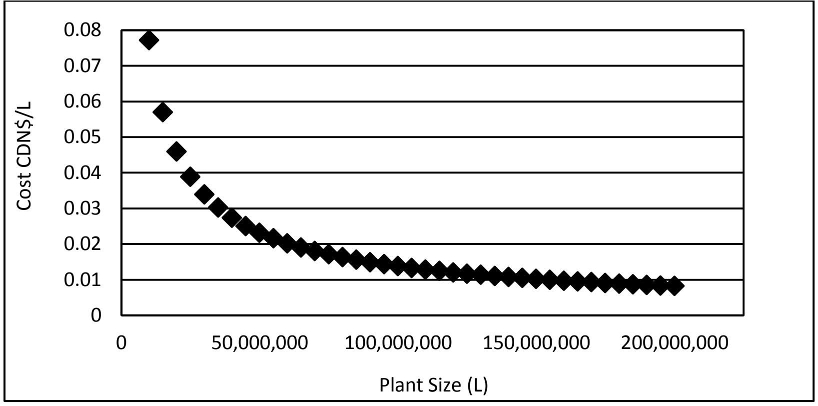
[62] Review of figures from Shapouri and Gallagher (2005), Noramera Bioenergy, and Husky Energy are very similar to labour costs presented by Bain (2007).

Figure 35: Labour Cost per Production Litre



A.11 Corporate Taxes

Corporate taxes are only calculated during years when the ethanol agent has positive net income. The level of taxation is set on the simulation interface using the *corporate-tax-rate* slider, and a range of applicable rates between 27% to 38% based on various regions have been identified (S&T^2 Consultants et al. 2004; Holcomb and Kenkel, 2008). S&T^2 Consultants et al. (2004) list a manufacturing and processing income tax rate of 32.12% for Saskatchewan, but state that federal and provincial governments generally enact a lower rate to stimulate manufacturing and processing activities. Given this, an initial corporate tax rate of 30% has been used in the simulation, as this rate is most commonly mentioned in the literature.

A.12 Marketplace Shocks

Demand shocks for energy are common and from a good business practice perspective it is imperative that associated industries can respond proactively rather than reactively. To emulate a proactive response system in the simulation, demand shocks are averaged over the operating ethanol agents and the simulation targets those agents with a stronger financial position for future expansion. Interval and intensity of demand shocks can be set via two inputs on the model interface. *Timed-demand-shock* sets the yearly interval and *percent-increase-in-demand* sets the level of the demand shock. The level of these settings can have a profound impact on the market and ethanol agent operation, with very “intense” settings often leading to model instability.

If an increase in demand is detected, the model calculates the percentage market share of the ethanol agents based on their production compared to total industry production. From an evolutionary perspective, in this model the ethanol agent on the landscape with the highest average cost and breakeven price is allotted a zero percent market share of the given demand increase. The basic premise here is that it is unlikely that an organization with higher than average industry costs would be able to successfully implement a timely or viable expansion strategy.

Next, a check is done regarding the allocated size of the market increase to ensure that expansions do not continually occur. If expansions continually occur in the simulation then this can lead to model instability, where the ethanol agents expand at every opportunity thereby risking financial solvency. During model testing this outcome led to a high failure rate among the ethanol agents. Therefore, in the simulation each ethanol agent ensures that a potential expansion is larger than 10% of their current production capacity. If the allocated output expansion is less than 10% of current capacity then the expansion does not occur for that plant. However, if the expansion is greater than 10% of current production, then the ethanol agent is permitted to increase the potential expansion size by an additional 25% of the awarded amount. Heuristically, the additional capacity allows ethanol agents to handle any small future demand increases and creates some excess industrial capacity.

Financially, potential plant expansion plans can only be finalized if the agent does not currently hold more than two capital expansion loans. Two options are assumed to exist for capital expansion loans during model operation. Expansion loans are financed over a period of up to 10 years and are set by an *expansion-finance-plant-life* slider on the interface. The method for calculating expansion capital costs is the same as when an ethanol agent first built the plant, but it is assumed that the final cost is approximately one third of new building costs. Shapouri and Gallagher (2005) state that average capital cost for ethanol plants in the US at startup was USD $1.57 per gallon and that expansion costs averaged USD $0.50 per gallon. Based on Shapouri and Gallagher (2005), it was computed that the average cost of expansion used in the model is equivalent to about 32%[63] of capital cost to build an ethanol plant[64]. Acquiring technology,

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[63] Expansion cost percentage found by comparing Shapouri and Gallagher (2005) startup and expansion costs (USD 0.50/USD 1.57 = 0.32). This percentage is then applied to capital cost figures previously identified in the thesis to acquire expansion costs.

[64] As discussed in section 4.8.

finding greater efficiencies, and generating lower costs seems to be the business rationale behind plant expansion in this industry versus purchasing an existing (but out of commission) plant. Expansion capital building costs are calculated as follows (Shapouri and Gallagher, 2005; Outlook Market Research and Consulting, 2008):

$$Y = (262.87x^{0.6917}) * 0.32$$

Where: Y is total expansion capital building costs; CDN\$
x is proposed plant expansion size in millions of litres per year

Salvage value, interest, and principal repayment calculations are completed using the same methods described during plant startup. To maintain a set of heuristics that remain responsive to demand shifts and allows all ethanol agents equal opportunity to expand, a second expansion option is available and operates in an identical manner. Thus, an ethanol agent can expand a second time, but may only hold two expansion loans at one time. Expansion costs become part of fixed costs, therefore regulating expansion is necessary to ensure ethanol agents are able to remain financially solvent in the long term.

If a given demand shock results in decreased market demand, then the current plants will hold excess production in inventory. The simulation is designed to stabilize to the lower demand level as ethanol agents only seek feedstock that sets their production equal to the difference between nameplate capacity and inventory. However, this will increase operating costs for ethanol agents and may result in some agents exiting the industry. It is at that point where the remaining agents will obtain increased market share and possibly a return to their respective full production levels, until the next shock sets the process in motion all over again.

A.13 Summary

Appendix A provides more detailed information on the construction of this agent-based simulation of ethanol plant location and duration, including highlighting the various assumptions and statistical relationships. The Appendix is a supplement to the information found in Chapter Four. The description of additional factors specific to the simulated ethanol plants during both initialization and operational stages completes the agent-based model description.

APPENDIX B
NetLogo© Agent-based Model Variables and Descriptions

Global Variables:

Variable	**Description**
run-number	Number of simulation runs completed
year	Simulation year
procurement-area-2	Second procurement area for ethanol agents to call farm agents, multiple of procurement-area slider on interface
procurement-area-3	Third procurement area for ethanol agents to call farm agents, multiple of procurement-area slider on interface
procurement-area-4	Fourth procurement area for ethanol agents to call farm agents, multiple of procurement-area slider on interface
timed-year-demand-increase	Variable that captures the years that a demand increase will happen as set by the chooser timed-demand-shock; the corresponding demand increase is shown by the chooser percent-increase-in-demand on the interface

Patch Variables:

Variable	**Description**
prod-volume	Total production as set by production slider on the interface
prod-volume-black	Production volume of the black soil zone on landscape
prod-volume-dark-brown	Production volume of the dark brown soil zone on landscape
prod-volume-brown	Production volume of the brown soil zone on landscape
prim-hwy-access	Variable showing if patch is located within 1 patch distance of primary highway
nearest-ethanol	Nearest ethanol to the patch, used by the farmer to calculate distance
nearest-main-rail	Nearest mail rail to patch, used by ethanols when reviewing a potential site
nearest-prim-hwy	Nearest primary highway to patch, used by ethanols when reviewing a potential site
nearest-feedlot	Nearest feedlot to patch, used by ethanols when reviewing a potential site
nearest-blender	Nearest blender to patch, used by ethanols when reviewing a potential site
main-rail-distance	Distance from patch to nearest mail rail, used for site review
feedlot-distance-rail	Distance from patch to nearest feedlot by mail rail, used for site review
blender-distance-rail	Distance from patch to nearest blender by mail rail, used for site review
prim-hwy-distance	Distance from patch to nearest primary highway, used for site review
feedlot-distance	Distance from patch to nearest feedlot, used for site review
blender-distance	Distance from patch to nearest blender, used for site review

nearest-water-access	Nearest water access to patch, used by ethanols when reviewing a potential site
nearest-electrical-grid	Nearest electrical access to patch, used by ethanols when reviewing a potential site
nearest-natural-gas-grid	Nearest natural gas access to patch, used by ethanols when reviewing a potential site
water-access-cost	Cost to access water to potential site
electrical-access-cost	Cost to access electrical to potential site
natural-gas-access-cost	Cost to access natural gas to potential site
feedstock-truck-dist	distance for farmers to ship feedstock from patch to ethanol plant
feedstock-truck-prim-rate-MT	Cost for farmers to ship feedstock from patch to ethanol plant, based on patch located on primary highway
feedstock-truck-sec-rate-MT	Cost for farmers to ship feedstock from patch to ethanol plant, based on patch located on secondary highway
patch-truck-trans-rate	Rate for farmers to ship feedstock from patch to ethanol plant, based on whether patch is on primary or secondary highway
ddgs-truck-rate-MT	Cost to ship one MT of ddgs by truck
ethanol-truck-rate-MT	Cost to ship on MT of ethanol by truck
ddgs-transloading-cost-MT	Cost to transload one MT of ddgs from truck to rail if not located on mail rail line
ddgs-rail-rate-MT	Rail rate per MT for ddgs
ethanol-rail-rate-MT	Rail rate for one MT of ethanol
ethanol-transloading-cost-MT	Cost per MT to transload ethanol from a truck to rail if not located on a main rail line

Farm Agent Variables:

Variable	**Description**
farm-inventory	Inventory on farm that has not been shipped
farmer-can-deliver-inventory	Amount that farmer can deliver, balance of inventory not accepted by another ethanol agent
farmer-delivery-cost	Cost for farmer to deliver to plant, it is assumed farmers cover the cost of delivery to the plant
ethanol-delivered-too	The ethanol plant that the farmer delivered to
farmer-delivery-rate	Rate per MT for feedstock to deliver to the ethanol plant

Ethanol Agent Variables:

Variable	**Description**
payment-period-interest	Interest ethanols pay on yearly capital loan payments
capital-loan-principal	Principal capital loan cost for ethanol plant
salvage-value	Salvage value of the plant, 10% of capital cost
rate	Depreciation rate
depreciation	Deprecation figure, based on calculated rate over 20 years
accumulated-depreciation	Deprecation accumulated over the life of the plant

ethanol-price	Ethanol price, set at average price 0.53 cents per L
ethanol-indexed-revenue	Price for ethanol including inflation
ddgs-price	Average ddgs price as calculated from price data
ddgs-indexed-price	Average ddgs price - set at $151.86/ MT
npv-prov-subsidy	Amount of provincial subsidy per litre
npv-fed-subsidy	Amount of federal subsidy per litre
feedstock-price	Feedstock price, average Saskatchewan wheat price over 30 years
feedstock-avail-for-npv	Available feedstock for npv analysis during initialization, based on procurement-area slider
feedstock-indexed-price	Indexed feedstock price over npv life of plant
freight-cost	Freight cost for moving items needed to the plant like chemicals, does not include any transport costs for feedstock, ethanol or ddgs
freight-indexed-cost	Indexed freight cost over npv plant life
mktg-cost	Marketing cost for to sell ethanol and ddgs
mktg-indexed-cost	Indexed marketing cost over npv plant life
chemical-costs	Chemical cost used in ethanol production
chemical-indexed-cost	Indexed chemical cost over npv plant life
denaturant-costs	Denaturant cost used in ethanol production
denaturant-indexed-cost	Indexed denaturant cost over npv plant life
maintenance-costs	Maintenance cost of keeping plant operational
maintenance-indexed-cost	Indexed maintenance cost over npv plant life
insurance-costs	Insurance costs as required for operations
insurance-indexed-cost	Indexed insurance costs over npv plant life
property-tax-cost	Property taxes as levied
property-taxes-indexed-cost	Indexed property taxes over npv plant life
labour-cost	Labour cost to operate plant
labour-cost-indexed-cost	Indexed labour costs over npv plant life
water-use-cost	Water cost for production of ethanol
water-cost-indexed-cost	Indexed water cost over npv plant life
electric-use-cost	Electric cost for production of ethanol
electric-cost-indexed-cost	Indexed electrical cost over npv plant life
natural-gas-use-cost	Natural gas cost for production of ethanol
natural-gas-cost-indexed-cost	Indexed natural gas cost over npv plant life
net-income	Net income from operations
net-expenses	Net expenses of operations
corp-tax-list	Corporate taxes, rate based off slider on interface
net-income-before-tax-list	Net income before tax rate applied
net-income-after-taxes-list	Net income after tax rate applied
Ro	Capital cost and utility access costs to proposed site, listed as a negative number in net present value calculation of project, based on total available feedstock in procurement area
S	Salvage value of ethanol plant, coded at 10%

NIBT	Net income before tax variable used in npv analysis
corp-tax	Corporate tax rate, set at 30%
NRt	Net income after tax, used in Present value and net present value calculations
Df	Discount factor used in present value calculations
total-operational-fs-availble	Feedstock available in initial procurement area as specified by the interface slider, used for initial plant setup during operations
in-radius-farmers	First group of farmers called, contained in the original procurement area
out-radius-farmers	Second group of farmers for potential delivery
expansion-radius-farmers	Third group of farmers for potential delivery
farmers-outside-largest-radius	Fourth group of farmers for potential delivery
in-radius-farmers-with-inventory	An agent set from the first group of farmers with deliverable inventory
out-radius-farmers-with-inventory	An agent set from the second group of farmers with deliverable inventory
expansion-radius-farmers-with-inventory	An agent set from the third group of farmers with deliverable inventory
farmers-outside-largest-radius-with-inventory	An agent set from the fourth group of farmers with deliverable inventory
ethanol-feedstock-capacity	Plant feedstock capacity required to meet nameplate capacity
plant-size-operations	Plant size determined in year 1 of operations, based on feedstock capacity multiplied by 372 litres (amount of ethanol produced per MT of feedstock received)
ethanol-feedstock-space	Feedstock required to meet nameplate capacity
ethanol-feedstock-inventory	Feedstock currently in inventory
remaining-feedstock-space	Additional feedstock required that must be obtained outside of current procurement area
capital-cost-operations	Operational capital cost of ethanol plant based on initial procurement area available feedstock
salvage-value-operations	Salvage value of plant at end of operational life, 10% of capital value
capital-loan-payment-operations	Operational payments made to capital loan
payment-period-interest-operations	Interest paid each year, based on remaining balance, payment increases as interest decreases
rate-operations	Depreciation rate during operations
depreciation-operations	Amount of depreciation expense each year, fluctuates depending on accumulated depreciation as it compares to salvage value, loan amount and payments
accumulated-depreciation-operations	Total accumulated depreciation
feedstock-price-operations	Price of feedstock for operations, based on average wheat price over 30 years in Saskatchewan
feedstock-cost-operations	Cost of feedstock, based on feedstock delivery

	numbers
freight-cost-operations	Cost of freight for chemical and other inputs needed in the production of ethanol, does not include feedstock
mktg-cost-operations	Cost of marketing ethanol and ddgs
chemical-costs-operations	Chemical cost per litre of ethanol produced
denaturant-costs-operations	Denaturant cost per litre of ethanol produced
maintenance-costs-operations	Cost of maintenance, repairs, and other direct costs associated with keeping the plant operational and avoiding costly down time
insurance-costs-operations	Insurance costs, charged as a percentage of capital cost
property-tax-cost-operations	Property taxes, charged as a percentage of capital cost
labour-cost-operations	Labour cost, based on litres of ethanol produced
water-use-cost-operations	Water cost, based on litres of ethanol produced
electric-use-cost-operations	Electric cost, based on litres of ethanol produced
natural-gas-use-cost-operations	Natural gas cost, based on litres of ethanol produced
ethanol-price-operations	Price of ethanol, average price based off of USDA data out of South Dakota
ddgs-price-operations	Price of ddgs, average price based off of USDA data out of South Dakota
income-operations	Income for the plant from ethanol sales, ddgs sales and subsidies
expense-list-combined-operations	Both expense lists combined for use in calculated net income. Combines average and fixed expenses
corp-tax-list-operations	Corporate taxes as per rate set by slider
total-net-income-after-taxes-operations	Total net income after corporate taxes of plant during operations
operation-cost-per-litre-no-tax	Cost per litre to produce ethanol before deducting corporate taxes, used for checking if plant is exceeding average variable costs, fixed costs, or average costs
average-variable-cost-with-transportation	Average variable cost per litre for the ethanol agent
average-cost-with-transport	Average cost per litre for the ethanol agent
average-fixed-costs	Average fixed costs per litre of ethanol produced. This includes maintenance, property taxes, insurance, etc. Costs that would happen even if the plant shut down in the short run
my-percent-share-of-sales	Gives each plant a percentage of market demand (sales) based on their production capacity
my-share-of-ethanol-demand	The litres of ethanols the plant can sell based on the calculated percentage market share figure
my-ethanol-sale	Ethanol sale made by the agent
ethanol-inventory	Ethanol inventory that the plant was unable to sell when supply exceeds demand
ethanol-inventory-demand	When production does not meet market demand, as calculated based on market share and if ethanol

	inventory > 0 then inventory will be accessed for sales
average-income-per-litre	Average income based on ethanol, ddgs, and subsidies
remaining-market-demand	Amount of demand left unfulfilled by plants, may be a result of demand shocks from increased demand and/ or plant closures
my-ddgs-sale	ddgs sale for the plant, based off of market percentage share calculated for the ethanol market, ddgs market is assumed to follow the ethanol market given the number of competing options in the feed market
my-share-ddgs-market-demand	Share of ddgs that can be sold by the plant into the market place, found using my-percent-share-of-sales variable used for ethanol market share
ddgs-inventory	ddgs inventory that is unable to be sold is held in inventory for futre sales
ddgs-inventory-demand	If ddgs demand exceeds ddgs production then this is the demand required from inventory to meet sales
ddgs-b/e-price	Breakeven price for ddgs, required for calculation of ethanol breakeven price
ethanol-b/e-price	Breakeven price for ethanol after corporate taxes, ethanol market price required continued operations
ethanol-truck-rate-MT-operations	Rate to ship a MT of ethanol by truck in the operations portion of the model
ethanol-rail-rate-MT-operations	Rate to ship a MT of ethanol by rail in the operations portion of the model
ddgs-truck-rate-MT-operations	Rate to ship a MT of ddgs by truck in the operations portion of the model
ddgs-rail-rate-MT-operations	Rate to ship a MT of ddgs by rail in the operations portion of the model
ethanol-market-output-increase	Increased market demand due a demand shock
increased-ethanol-demand	Variable that is set via a slider on the interface, if ethanol-market-demand-increase slider is increased this is the additional amount of demand over and above current market demand required
ethanol-with-highest-cost	Selects plants with highest average cost, these plants are shown as a cirlce on the interface, low cost plant are a displayed as a star (visual only)
low-cost-my-percent-share-of-increased-demand	When there is demand shock the plant with the highest average cost does not receive a demand increase as it is assumed that it will not be able to finance an expansion, therefore the additional demand it would receive is split between the remaining plants with lower average cost figures
my-percent-share-of-increased-demand	Share of excess demand when the supply drops due to plant closures or demand increases
plant-expansion-size	Size of plant expansion based on market share to meet excess demand in the market place, listed in litres

additional-fs-needed	Additional feedstock needed to meet planned plant expansion
expansion-capital-cost	Capital cost of first expansion option
expansion-salvage-value	Salvage value of first expansion option
expansion-capital-loan-payment	Capital loan payment for first expansion option
expansion-payment-period-interest	Interest on first capital expansion loan option
expansion-rate	Depreciation rate for first expansion option
expansion-depreciation	Depreciation expense on first expansion option
expansion-accumulated-depreciation-list	Accumulated depreciation on first expansion option
average-fixed-expansion-costs	Average fixed cost per litre of ethanol produced based on total production, after first expansion option
second-plant-expansion-size	Size of second expansion option
second-additional-fs-needed	Additional feedstock needed to satisfy second expansion option
second-expansion-capital-cost	Capital cost of second expansion option
second-expansion-salvage-value	Salvage value of second expansion option
second-expansion-capital-loan-payment	Capital loan payment on second expansion option
second-expansion-payment-period-interest	Interest on second expansion capital loan option
second-expansion-rate	Depreciation rate on second expansion option
second-expansion-depreciation	Depreciation expense for second expansion option
second-expansion-accumulated-depreciation-list	Accumulated depreciation for second expansion option
average-fixed-second-expansion-costs	Average fixed cost per litre of ethanol produced, based on total production, after second expansion option
ethanol-converted-fs	Ethanol production as converted from feedstock deliveries
ddgs-converted-fs	ddgs production as converted from feedstock deliveries

APPENDIX C
NetLogo© Simulation Code

The SKETHANOL-ABM NetLogo© simulation source code and documentation is available via open source at www.openabm.org or by contacting the author of this thesis.