LONG TERM CONTRACTS AND FARM INFLEXIBILITY PREMIUM IN THE PRODUCTION OF CELLULOSIC ETHANOL

by

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Abstract

Farmers will supply the raw ingredients for the emerging cellulosic ethanol industry. The long-term relationship between a farmer and a processing firm is expected to be contractual. A processing firm has an incentive to sign long-term contracts to ensure a cost-efficient level of raw ingredient supply. However, farmers generally prefer to operate with either no contract or a short-term contract in order to maintain options for adjustments in future acreage allocations due to changes in relative prices. Of interest in this research is to understand the incentives of farmers and calculating the efficient level of the "inflexibility premium", which a processing firm must provide to a farmer when a long term contract is signed. A stochastic dynamic programming model is solved and with the help of Microsoft Excel numerically evaluated to illustrate the marginal inflexibility premium is increasing with contract length and the level of price variability, and is decreasing with the size of acreage adjustment costs.

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Chapter I - Overview and Summery

1.1. Introduction of the Subject

At the onset of the industrial age (circa 1770) natural resources were mostly plentiful and easy to exploit. It had taken humanity the whole of its existence, hundreds of thousands of years, to reach a global population of one billion inhabitants. Today, humanity will add one billion more inhabitants in just a single decade. With wide scale deforestation, desertification, species extinctions, and climate change, our natural resources are no longer plentiful and easy to retrieve. Our consumption of earthly stores is increasing exponentially. Unlike material resources used in production of marketable goods, which can eventually be partially retrieved and reused through recycling or re-fashioning into new products, energy resources are forever destroyed. The need for alternative and renewable energy resources like biofuels has high social priority for humanity to persist their lives in the continuous development of the world economy. Furthermore, in the context of climate change, the need to mitigate the emission of green-house, has contributed to the need for alternative clean sources of energy.

An overwhelming body of scientific evidence has now clearly established the urgency and importance associated with global warming. The climate of our planet is rapidly changing particularly due to the increases in green-house gasses generated by human activities since the beginning of industrialization. Carbon dioxide is the dominant contributor to current climate change and fossil fuels are the single biggest source of human-generated greenhouse-gas emissions. Reducing the sources of emissions is one way to decrease the speed of changing the climate. These facts have made the need for marketable, alternative sources of energy like biofuels quite urgent.

As an imperative energy source for the sustained development of the world economy and a viable alternative to fossil fuel, biofuels derived from plants and trees known collectively as biomass, are a means of reducing the emission of greenhouse gasses. Although the use of biomass as a source of energy goes back to the discovery of fire by humans, the modern use of it for deriving biofuels is very recent. Biofuels are currently produced and used in different parts of the world. Their reliance on biomass results in the launch and expansion of the biofuel industry to be dependent on reasonably priced and reliable sources of input. Farmers, as the primary providers of the required raw materials in biofuels production, can provide the biofuels industry with a secure input market. A secured and guaranteed farm-product market that allows for the formation of long-term relationships between biofuels producers and farmers seems to be a key parameter in providing the biofuels industry with the potential for expansion.

Biofuels can be produced either by converting sugar or starch crops such as maize corn to ethanol, or by converting soybean and other plant oils to biodiesel. Despite the popularity of biodiesel in Europe, mainly because of the advantages of biodiesel over ethanol in energy balance and post-combustion carbon dioxide emission, in North America ethanol has been taken up as the fuel of the future due to reasons out of the scope of this study. Production of corn based ethanol has attracted the attention of many investments around the world; currently, many countries including Canada, China, and the US, are investing significant amount of funds on corn ethanol development. However, direct reliance of corn ethanol on corn as a food crop and its disadvantage in energy balance provided the incentives for research and development of a new way of producing ethanol, known as cellulosic ethanol, which mainly uses corn stover, switchgrass, and woodchip in the production of ethanol.

Since cellulosic ethanol production would not compete with food supplies and due to several other unique advantages over corn ethanol such as having better energy balance and being more effective in reducing the greenhouse gasses, cellulosic ethanol has attracted the majority of attention to itself lately. However, despite all the advantages, the scale of biomass material required to generate cellulosic ethanol is huge. Consequently, firms producing cellulosic ethanol need an efficient supply chain for obtaining the required input and since this is an emerging industry, they have to follow strategies that will provide them with the long-term security required for growth and maturity. An efficient and secure supply chain that minimizes firms' administrative costs and provides them with long-term security is to sign long-term contracts with the farmers.

In the absence of contracts, the producers of cellulosic ethanol will be less likely to consistently obtain adequate inputs for production, and this lack of long-run security in the form of long-term contracts will diminish their opportunities for expansion and growth due to their vulnerability in volatile financial conditions. If farmers choose not to sell sufficient biomass supplies and use it instead to improve on-farm soil structure and fertilization, or choose to produce crops which do not yield suitable biomass, then the biofuel producers will be confronted with unplanned shortage of inputs, which makes them incapable of efficient production and meeting their financial commitments. Any new industry and technology for its expansion relies on financial resources and cellulosic ethanol industry is no exception. Insufficient assurance for investors in cellulosic ethanol industry regarding long-term guarantees for consistent supply of feed-stock will hold back the industry from access to the vital financial sources of expansion.

It is important to note that farmers typically prefer to rotate crops for agronomic and price reasons and thus tend to avoid long-term contracts. Operating without contracts or with short-term contracts, farmers can frequently respond to new information by continually adjusting their crop mix and production practices. Therefore, farmers who sign long-term contracts lose the flexibility to adjust crop mix and production practices in response to new information. This will be especially true for grain and hay farmers who are most likely to sign biomass contracts, because these farmers typically operate with highly flexible crop rotations. As a result, farmers will demand a price premium before agreeing to sign a long-term contract, which will limit their crop choice and rotation strategy. The compensation paid to farmers to give up flexible farming reduces the profits of the cellulosic ethanol firms and makes the expansion of the industry less likely. Thus, understanding farmers' incentives and minimum levels of compensation to compensate for reduced flexibility are central to understanding the reasons why the farm-based cellulosic ethanol industry may be slow to expand.

Bob Saunders of British Petroleum Future Fuels indicates that in Britain, biofuels are growing rapidly but most of the ingredients of biofuels are being traded in spot markets, an inefficient market, because farmers do not like to sign long-term contracts. He emphasizes that "Getting that contract right is very important." (Reuters-UK, 2007).

1.2. Problem statement

As early as the mid 1990s scientific research on cellulosic ethanol technologies revealed that cellulosic ethanol could technologically be as cheap to produce as corn ethanol and has several advantages over corn ethanol in energy balance and in emission of greenhouse gasses. Despite these facts, cellulosic ethanol has not since been commercialized to the level where it can compete with corn ethanol. Many researchers have studied the reasons for the slow development of cellulosic ethanol and have shown that from a production-cost perspective, cellulosic ethanol is perfectly capable of competing with corn ethanol and argue that it is the supply-chain issues that have held back the cellulosic industry [(Kulsum, 1994), (Lynd, 1996), (Lugar, 1999), (Wyman, 2001)]. One of the key components of the supply-chain is the supply of raw inputs by farmers.

As the researchers have emphasized, the most efficient strategy for obtaining the required amount of input needed by the cellulosic ethanol industry is to establish mutual long-term contracts between the firms and the farmers in order to minimize the administrative costs of the industry and to provide the producers of cellulosic ethanol with long-term input and financial security. Nevertheless, the supply-chain chosen by the cellulosic biofuel firms has been either informal exchange mechanisms or, in a few cases, short-term contracts signed with individual farmers.

The implication of the absence of long-term input contracts for the producers of cellulosic ethanol has been lack of long run security, which is needed more than anything else for this new born industry. Unreliable input market and unsteady financial situation will impede the emerging cellulosic ethanol industry from enhancing its establishments and inducing growth. So, the producers of cellulosic ethanol are eager to sign long-term contracts with farmers.

However, farmers will be reluctant to sign long-term contracts mostly because doing so will reduce the flexibility they have when optimally responding to changes in the prices of farm products. Therefore, unless they are somehow compensated for the loss of flexibility through the contracts proposed by the producers of cellulosic ethanol, they are likely to remain reluctant to lock themselves in long-term commitments.

Profit maximizing cellulosic ethanol firms, as well, do not wish to compensate farmers by anything more than the minimum required amount. Inefficient compensations, i.e. compensations that are above the minimum required amounts, reduce the turnover of investments in the cellulosic industry and will therefore generate a disincentive for further investments in and expansion of the industry.

As a result, it is important to realize that the growth and expansion of the cellulosic ethanol industry hinges on the ability of the industry to sign efficient long-term contracts with farmers that will benefit the industry as a whole and provide it with the necessary incentives for further investments and expansions. Understanding the incentives of the farmers and calculating the efficient levels of compensations, called inflexibility premium hereafter, are therefore essential to understanding the impediments that have held back farm-based cellulosic ethanol industry. Any cost-benefit analysis of cellulosic ethanol projects has to be conducted acknowledging the cost of inflexibility premium that has to be paid by the processing firm to the farmers.

Understanding the incentives of the farmers and calculating the efficient levels of compensations relies on answering the following questions: Why is an inflexibility premium required for the establishment of long-term contracts between the cellulosic ethanol firm and the farmers of cellulosic feed-stock? And, what is the relationship between the size of inflexibility premium, contract length and other technology and market parameters?

1.3. Research Objective

With focus on cellulosic ethanol, the biofuel industry will be briefly described and the literature on barriers of producing cellulosic ethanol will be reviewed. By constructing a stochastic dynamic programming model, the necessity of including inflexibility premium in contracts for inducing risk neutral farmers to commit to long-term commitments will be illustrated. Furthermore, with the help of Microsoft Excel, the stochastic dynamic programming model will be numerically solved and it will be shown that the marginal inflexibility premium is increasing with the length of contract and the level of price variability and is decreasing with the size of acreage adjustment costs.

Stochastic dynamic programming must be used to examine the issue of inflexibility premium because of adjustment costs. Since the farming environment is highly uncertain (due to changes in prices, soil moisture, disease, and new technologies), a farmer will optimally choose to frequently adjust the acreages assigned to each farm-product in response to changes in the environment. Shifting the input mix and marketing strategies, revising the machinery complement and learning new techniques associated with the change, is generally costly. Farmers can reduce adjustment costs by making small, gradual adjustments versus large, quick adjustments in farming practices. Because the optimal size of the current adjustment will depend on the level of future adjustment, which is uncertain, the problem must be solved using stochastic dynamic programming.

Naturally, the compensation that a farmer will request before agreeing to sign a long-term contract will depend on the extent that he/she is able to optimally respond to changes in the farming environment. In a largely rigid environment where there is little scope for change, the level of requested compensation will be relatively small. In a very fluid environment where there is considerable scope for change, the level of requested compensation will be relatively large. In general, the farmer's requested inflexibility premium will depend on the size and frequency of the optimal adjustments, which in turn depend on the variability of environmental elements such as prices and their relative movements. Accordingly, the inflexibility premium will depend on the variability and relative movements of prices.

Acknowledging the necessity of including the inflexibility premium in long-term contracts brings us to the matter of identifying the elements of the farming environment which affect the size of the inflexibility premium, and determining the degree of sensitivity of the inflexibility premium with respect to these elements. Identifying these elements and the sensitivity of the inflexibility premium will help us to determine situations where long-term contracts are most likely or least likely to emerge, which will help policy makers design more efficient incentive schemes.

Identifying optimal level of inflexibility premium and its sensitivity with respect to different environmental parameters, which are potentially subject to economic policies, could bring about significant positive impacts on the industry as a whole, including the farmers. An optimal inflexibility premium encompasses the joint maximization of the profits of firms and farmers together; it will resolve the incentive incompatibilities inherent in long-term contracts; it provides the firms with a more efficient and secure supply-chain; it maintains the welfare of the farmers. As well, efficient contract design provides an overall benefit to the greater society because it will enable the biofuel industry to commercially compete with highly polluting fossil fuels. In a sense, this will bring about a welfare improvement. Only the producers of the pollutant fossil fuels will lose their short-term profits if they do not become producers of biofuels!

Therefore, answering the questions addressed in this research will provide policy considerations that directly improve the benefits of the contractual parties through establishing long-term relations, and indirectly increase the welfare of the whole economy due to long-term stability of energy market based on renewable sources, lower environmental damages, and lower pollution abatement costs. In addition, the approach of this research can be used to resolve similar issues in other biofuel industries or any co-product, where the co-product may not be the major income generator. Brent Erickson, the executive vice president of the Biotechnology Industry Organization in Washington comments on the importance of cellulosic ethanol and mentions that "If you look at the amount of biodiesel you can produce, it is a drop in the bucket compared to the amount of cellulosic ethanol that could be produced one day." (The New York Times, 2006).

1.4. Thesis Outline

The thesis is organized into five chapters. In Chapter 2, the description of biofuel industry in the related literature and in the news with a focus on the cellulosic ethanol industry in Canada is overviewed. Chapter 3 presents a simple supply and demand framework to illustrate the relationship between the inflexibility premium and the length of contract, and also reviews the literature on flexibility and the theoretical basis of an appropriate model. Chapter 4 overviews the stochastic dynamic programming model suitable for the purpose of this research and its formulation. Chapter 5 provides the numerical evaluation of the model and some numerical results. Chapter 6 follows up with conclusions.

Chapter II - Background

2.1. Background on Cellulosic Ethanol

Fossil fuels are becoming less available and more difficult to obtain, resulting in a steady trend of rising oil and gasoline prices. With growing concerns over the impacts of climate change[1], most developed countries will have no choice but to reduce their dependency on fossil fuels and to expand their domestic production of renewable fuels. One of the best alternatives to fossil fuels is biofuels. According to the new legislation that has been signed by President Bush the U.S. fuel producers require to use at least 36 billion gallons of biofuel in 2022, a fivefold increase over current levels (Washington Post, 2007).

Biofuel is any fuel derived from living or recently living biological material, and unlike fossil fuels, it has renewable sources. Fuels derived from biomass can be produced either by converting sugar or starch crops to ethanol, or by converting soybean and other plant oils to biodiesel. Biodiesel accounts for approximately 40 percent of Brazil's non-diesel automotive fuel; and corn ethanol accounts for between two and three percent of America's automotive fuel. (Environment: Yale Magazine, 2007)

The history of using liquid biofuels goes back to the beginning of the automobile industry. The German inventor of the internal-combustion engine, Nikolaus August Otto, conceived his invention to run on ethanol. Rudolf Diesel, the German inventor of the Diesel engine,

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[1] A group of NASA scientists, led by James E. Hansen, argue that global warming has been more rapid over the last 30 years than anyone thought — about 0.2 degrees Celsius over each of the past three decades. He underlines that "this evidence implies that we are getting close to dangerous levels of human-made pollution." (NASA, 2006).

conceived it to run on peanut oil. Henry Ford designed the Ford Model T to run completely on ethanol (Grist magazine, 2006).

Once oil was discovered in Pennsylvania and Texas, it proved to be a much cheaper source of liquid fuel, and thus automobiles began to be designed to use fossil fuels. The oil industry had many fluctuations throughout the twentieth century. Until the end of World War II, liquid biofuels provided an alternative to imported oil in countries such as Germany and Great Britain. However, after the war, the demand for biofuel decreased with the production of cheap oil from the Middle East. Then, in 1973 and again in 1979, drops in fossil fuel supplies increased the price of oil and once again, liquid biofuels became economically viable. This was countered in 1986 and reduced oil prices sustained the world's interest in fossil fuels. Nevertheless, since 2000 the world has been confronted with persistent rising oil prices such that in the late 2007, oil price became close to $100 a barrel, while certain OPEC producers were arguing that "oil is still cheap." (The Globe and Mail, 2007).

Many governments in the developed world have stated their renewed interest in liquid biofuels. For example, the US president, George W. Bush, in his 2006 State of the Union Speech talked about plans to replace 75% of the US oil imports from the Middle East with domestically produced biofuels by 2025.

Browsing through the recent news demonstrates to what extent different countries and international organizations have become interested in biofuels again:

- “Biofuels could provide 25% of the world’s energy needs within two decades.”

The United Nations
(Globe-net, 2006)

- “America is on the verge of technological breakthroughs that will enable us to live our lives less dependent on oil.”

George W. Bush
(Globe-net, 2006)

- “Developed in a sustainable way, in the context of a wide-ranging strategy for alternative crops, biofuels offer society a win, win, win solution.”

Peter Kendall, president of the UK's National Farmers' Union (NFU)
(BBC News, 2006)

- The European Commission has recently called for increase in the use of renewable sources of energy to diminish the dependency of the 27-nation bloc on importing oil and gas.

(CBC News, 2007)

- “Bioenergy production represents one of the major mainstream opportunities for agriculture over the medium to long-term in the EU.”

The European Commission
(European Commission, 2007)

- The Chinese Ministry of Agriculture has recently announced the government’s plans to stretch out new crop bases by 2010 due to rising demand for ethanol in China.

(China Daily, 2007)

- The Indonesian local press recently announced that their government obligates the use of biofuel in the most crowded islands of Java and Sumatra that already have several biofuel projects.

(Xinhua News Agency via COMTEX, 2007)

- Up to one billion yen of the total subsidy, 1.2 billion yen ($11.2 million) which is set in the next fiscal year's budget, would be used for a project or projects using the wood for cellulosic ethanol technology.

Satoshi Ishihara
Director of the Technology Development Office
Ministry of Agriculture, Japan
(Reuters-UK, 2008)

The production of liquid biofuels from grains, especially corn, began around 1945, but it was not manufactured until 1970. There are three major problems with grain-based biofuels:

1. Grains are the main staple for most people. By allotting more food for the production of fuel, the number of chronically hungry could grow by more than 50 percent by 2020 according to the estimation of Runge et. al. (Runge, 2003). In addition, most economists predict higher demands for food and insufficient supplies leading to inflated food prices.
2. Corn ethanol achieves a negative or small positive energy balance (negative is when energy achieved by using the product is less than the energy used to produce the product). Research results have shown that the energy balance varies with the way in which the liquid biofuel is produced, and as a result some biofuels have a negative energy balance (MIT Energy and Environment, 2007).
3. The major problem with corn ethanol is that there isn't enough of it, and there will never be. If the entire U.S. corn product in 2005 allots to ethanol, it would provide less than one-sixth of the nation's gasoline consumption, which exceeds 140 billion gallons a year (The New York Times, 2006).

Although corn based ethanol has several advantages over fossil fuels, many environmentalists prefer a more eco-friendly and non-food source of ethanol known as cellulosic ethanol, which can be derived from anything rich in cellulose. Cellulosic ethanol has more advantages over fossil fuel than the corn based ethanol (Citizen's League for Environmental Action Now*,* 2006). Cellulosic ethanol technology was developed in 1993 by Dr. Nancy Ho, a scientist from Purdue University in the US, who transformed new sources of biomass into cellulosic ethanol using an advanced biotechnology (Biofuels for Sustainable Transportation, 2001). A few examples of the new biomass sources used for cellulosic biofuel are as follows:

1. Left over residues after crop harvests, such as cereal straw, corn stover, and rice hulls;
2. Fibrous and energy crops, including grasses like miscanthus and switchgrass ;
3. Fast growing trees like hybrid poplars;
4. Waste wood from trees damaged by natural disasters;
5. Left over scrap wood from paper and saw mills.

According to the US Department of Energy, Cellulosic ethanol has some unique advantages over corn ethanol (US Department of Energy, 2006):

- Cellulosic plants do not need a lot of fertilizers or pesticides;

- Cellulosic ethanol reduces greater amounts of greenhouse gases. Cellulosic ethanol produces just 20 percent of the total amount of greenhouse gases emitted from gasoline, while corn ethanol produces 70 percent of greenhouse-gas emissions emitted from gasoline;

- Crops that yield cellulosic ethanol can grow on agriculturally marginal land;

- Cellulosic plants provide more ethanol per acre. Cellulosic Plants provides 330 to 810 (US gal/acre) while corn provides 330 to 420 (US gal/acre);

- Cellulosic ethanol has 80 percent higher energy yield than grain based ethanol. According to most studies, cellulosic ethanol gives back about five times more energy than it takes to produce;

- Cellulosic plants need about one fourth of the water required for corn to produce the same quantity of ethanol;

- Cellulosic plants can be used either as forage for livestock or as a ground cover, to control erosion;

- Cellulosic ethanol is derived from plentiful renewable agriculture crops that are not used for food production, such as cereal straw, corn, and corncobs. This is while the main sources of grain-based ethanol are dietary grains, such as corn and wheat.

2.2. Canadian Biofuel Industry

Although Canada could benefit from its large agriculture industry and despite the fact that it is home to some of the world's primary biofuel firms, until 2005, Canada was behind the world in biofuel production. Total ethanol production and consumption in Canada constituted only 0.7% of the country's total gasoline consumption in 2004 (Globe-net, 2006). As well, ethanol production in Canada is almost entirely grain-based.

Both biodiesel and ethanol used in Canada are mainly in transportation and some specialized industrial applications. Industrial-scale biodiesel production takes place at Rothsay Biodiesel plant in Montreal with an estimated capacity of 30 million liters per year (Globe.net, 2006). In recent years the government of Canada has taken some measures to promote the biofuel industry. Some of these measures are:

1. Removing tax exception of 10 cents per liter of ethanol blended with gas (Globe-net, 2006);
2. Providing support to construct or expand eleven grain based ethanol plants with programs and regulations like the Ethanol Expansion Program and the Future Fuels Initiative (Globe-net, 2006);
3. Setting five percent of Renewable Fuels Standard for transportation fuels by 2010, representing 3.1 billion liters of biofuels per year, or more than twelve times what the country currently produces (Globe-net, 2006);
4. Providing $11 million to encourage farmers to participate in and benefit from increased Canadian biofuels production (Agriculture and Agri-Food Canada, 2006);

5. Delivering $345 million to help farmers acquire new market opportunities in the agricultural bio-products innovation sector and the capital formation assistance program for renewable fuels production (Agriculture and Agri-Food Canada, 2006);

6. Considering $2 billion in incentives in the 2007 budget for renewable energy fuel production over the next seven years with $1 billion of this budget for assistance to farmers (Department of Finance Canada, 2007);

7. Launching the eco Agriculture Biofuels Capital initiative (eco ABC) in April 2007 with the objective to provide an opportunity for farmer investment in biofuels plants which consists of $200 million repayable contribution based on volume and level of farmer contribution to project costs (Agriculture and Agri-Food Canada, 2007).

The Canadian government is not only interested in the environmental benefits of biofuels but is also interested in opportunities for rural areas. The Canadian government supports farmers' participation in the renewable fuels opportunities, which could be paths to higher farm income and deeper connections in value-chain. Recently, Canada's government took important steps to create new economic opportunities for farmers and the agricultural sector such as establishing "Biofuels Opportunities for Producers Initiative" and "Eco Agriculture Biofuels Capital initiative". The Biofuels Opportunities for Producers Initiative (BOPI) assists farmers with hiring technical, financial, and business planning advisors to develop feasibility and business plans for biofuels facilities. All these efforts will result in fresh energy supply, new jobs in growing Canadian renewable fuels sector including biofuels, and cleaner air. This initiative could mean new opportunities for Canadian agricultural products, and support for Canadian agriculture industry in the process. Eco Agriculture Biofuels

Capital (ecoABC) helps farmers to form the necessary capital base for new or expanding biofuels facilities that will use agricultural feed-stocks as inputs.

Resource Efficient Agricultural Production Canada (REAP-Canada) has been working with farmers, scientists, and the private sector since 1986 as an independent non-profit research, consulting and international development organization. REAP-Canada intends to develop more ecological ways of producing energy from farms both in Canada and abroad for rural development. It has been working on bio-energy systems since 1991 and it was the first agency in the world to successfully pellet and burn switchgrass as a fuel. REAP is currently working on bio-energy projects with farmers in Canada, China, Nigeria, the Gambia, and the Philippines (REAP-Canada, n.d.).

SunOpta BioProcess Inc. (SBI) is a Canadian leader in the design, construction and optimization of biomass conversion process technologies, equipment and facilities. With over 30 years of experience in delivering biomass solutions worldwide, SBI combines its application expertise with innovative, patented, and proprietary technologies to produce cellulosic ethanol, cellulosic butanol, xylitol, and dietary fiber for human consumption and is currently supplying equipment and process technology to commercially demonstrate cellulosic ethanol projects in the U.S., Spain, and China. SBI signed a letter of intent with Central Minnesota Ethanol Co-op (CMEC) of Little Falls, to construct a 10 million-gallon-per-year cellulosic ethanol plant in Minnesota on November 20th of 2007 (SunOpta Inc.,n.d.).

In April 2004, Iogen Corporation, a Canadian biotechnology firm with the world's only cellulosic ethanol demonstration scale facility, has led the world in selling cellulosic ethanol commercially, even if in small quantities (Altman, Boessen, and Sanders, 2007). Iogen is a private company with $130 million public and private investment, based in Ottawa. The Canadian government, Royal Dutch, Petro-Canada and Goldman Sachs are the key investors. Department of Energy and National Renewable Energy Laboratory of the United States are the major American investors (Iogen Corporation, n.d.).

Iogen makes its cellulosic ethanol from wheat and barley straw, and is planning a major facility in Idaho. The scale that Iogen is targeting for its first processing plant is approximately 1500 tons of biomass material per day to produce approximately 45 million gallons of ethanol per year (Fortune, 2006). This scale would require 1000 acres per day of land resources. With this amount of biomass and land resources required, an efficient supply-chain strategy is essential and is a key organizational variable to successful commercialization. The main supply-chain that Iogen has chosen to utilize is selective short-term contracts (5-year contracts) with each individual farmer because they do not accept inflexible long-term contracts (Altman et al., 2007). Although the most efficient method of exchange, being the long-term contracts, is not the one that Iogen has chosen, at least it is preferred to informal exchange mechanisms. The current study hopes to shed more light on some aspects of the farming environment that are among the likely reasons behind the lack of success in long-term contracts and provides a ground upon which policy makers can impact the relevant environmental elements and generate the incentives required for long-term relationships to take form.

2.3. Biofuel Industry in the Literature

Roos, Graham, Hektor, and Rakos (1999) identify and analyze the barriers to bio-energy market growth, which they call “critical factors”. Critical factors in the choice of organization include the degree of integration, the scale effect on bio-energy markets, the degree of competition in bio-energy markets and with other businesses, the national and local policy, and the local opinion. They base their analysis on the application of standard economic concepts and models from transaction cost theory and industrial organization, focusing on the dynamic forces on the bio-energy market. They study five cases of existing bio-energy markets: Pellet residential heating in USA, bio-energy power in USA, pellet residential heating in Sweden, biomass district heating in Sweden, and biomass district heating in Austria. They conclude that by solving the critical factors, bio-energy industries can succeed.

Cellulosic ethanol has similar barriers as Roos and his team’s work found in their research. Cellulosic ethanol industry has to integrate with other industries by using the other industry’s production as fuel, e.g. agricultural processes. Integration can be used both as a means to get cheap input factors and to reduce transaction costs and risks. Also, the cellulosic ethanol industry can gain from scale effect as if it expands. If the industry grows, the production cost will decrease, there will be more incentives to spend on R&D, and a positive loop may be created. Therefore, the overall performance of market will improve. Another barrier to Cellulosic ethanol industry as Roos et al. identify in their research, is competition. Cellulosic ethanol industry has to compete with corn ethanol which has been in the market for a longer period than cellulosic ethanol and is supported by huge federal subsidy. So it must be difficult for cellulosic ethanol to establish its roots in the market. The last factor, the support by the local policy makers and the local population, does not seem to be a major barrier for cellulosic ethanol industry as long as it becomes technologically and economically viable. Governments and people somehow agree on the advantages of cellulosic ethanol and they have shown favorable attitudes.

Costello and Finnell (1998) analyze many organizational constraints for renewable energy technologies in four main categories: regulatory environment, financial sources, infrastructural availability, and the perceptual beliefs:

- US past policies have supported the development of commercial markets for renewable energy technologies. Now, the regulatory changes could also provide new opportunities and be favorable for biomass energy by involving utility restructuring. Some of those regulatory mechanisms are development of a renewable portfolio standard, emission caps, trading markets, and awaiting international climate change agreements.
- Financial constraints are associated with direct and indirect tax subsidies that benefit fossil fuels over biomass energy. Other financial challenges are happening because of utility restructuring. Nevertheless, they suggest that the commercial feasibility of biomass energy can be upheld by increasing consumer preference for renewables through “green pricing” and renewable energy demand.
- Exclusively, biomass energy infrastructural factors bring several fuel supply issues. The supply for biomass is a local issue and depends on a power plant’s construction and operation.

- Mostly, it is the perceptual beliefs of the public on resource availability, environmental impacts, and reliability that determine the use of biomass technologies. By educating the public about the gains of biomass energy, misconceptions will diminish.

The four organizational constraint categories that Costello and Finnell named in their paper are applying for cellulosic ethanol industry as well. The regulatory environment in different countries such as Canada, China, Indonesia, Japan, the US and etc., has changed in favor of this industry, as mentioned in the introduction section. Although cellulosic ethanol industry has to compete with both fossil fuels and corn ethanol, which is subsidized by the federal government in the US, the financial sources are becoming more available for this industry with grants that governments put aside. The infrastructures are not completely available for cellulosic ethanol industry yet, for example the industry still has problem with the development and availability of fuel-efficient cars using ethanol, and an efficient transportation system for its feed-stock and the fuel (Energy Bulletin, 2008). Although some scientists do not believe that cellulosic ethanol industry can remove the dependency on fossil fuels, the governments and farmers support the developments of cellulosic ethanol industry by their actions remarkably, as mentioned above.

Rosch and Kaltsehmitt (1999) analyze similar non-technological barriers to the use of solid biofuels and useful supply of energy in Europe. They identify two obstacles in this regard: First, the difficulties with funding, financing, and insuring and secondly, the lack of knowledge and adequate flow of information.

They look at insurance from the firms' point of view. Technologies that are in the early stages of development need funds for the risk of technical and financial failure. Usually, it is not easy to get the banks or other private financing institutions to lend credit due to the existing technical and non-technical uncertainties. In addition, insurance companies usually do not insure new processes and therefore, firms in emerging industries have difficulty with their funding. They suggest several ways to increase the chances of getting financial credits (e.g. signing contracts with well-known and reliable customers, co-operation with qualified manufactures and engineers, evaluating environmental impact by independent institutions, and providing sufficient and adequate information about their projects.).

The public and politicians who are not familiar with the benefits of biomass develop many misconceptions. To correct these fallacies, they argue, the necessary information should be provided in an adequate and fair way. The information should cover both the benefits (e.g. cutback the emission of green house gases, and creation of new jobs) and the challenges of production (e.g. difficulty of coordination between different companies and institutions, the lack of infrastructure, requiring tons of biomass material per day, and huge investments).

By the end, they also give some general recommendations to avoid delays or outright failure of biomass energy projects (e.g. improving the regulation of organization and timing of the different evolving sectors, considering transportation distances and availability of feed-stock resources within the vicinity of the biomass energy plant, and highlighting the benefits of the energy use of "clean" biowaste.).

Even though companies are getting grants to produce cellulosic ethanol[2], the industry crosses swords in finding funds and insurance to cover its costs. Since it is an emergin industry, there are many uncertainties that are left behind and insurance companies are reluctant to provide the firms in cellulosic ethanol industry with insurance under fair terms. Thus, as Rosch and Kaltsehmitt (1999) suggest, the industry is looking for other ways to increase the chances of getting financial support such as signing long-term contract with farmers. But unfortunately, farmers are also not willing to agree to signing long-term contracts.

Even though, so far, many researches and studies have been conducted on cellulosic ethanol industry, among which some are optimistic about the future of the industry and some are pessimistic, there is still lack of knowledge in this area. More research on cellulosic ethanol industry is needed in order to provide more accurate information.

Hall and House (1995) analyze empirically the constraints of bio-energy production in Western Europe and mostly focus on land availability, environmental considerations, available technology, attainable yields, energy markets, and political factors. They argue that the transfer of subsidies from conventional agriculture to energy crops would be a win-win situation. Agriculture would gain through reduced costly overproduction and export subsidies. The environment would gain through replacement of fossil fuels with more environmentally friendly renewable biomass energy.

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[2] "The Energy Department awarded $114 million in grants Tuesday to build four small-scale biorefineries in Missouri, Oregon, Colorado and Wisconsin, hoping to demonstrate production of cellulosic ethanol" (Associated Press, 2008).

Several constraints that Hall and House (1995) are pointing out in their work such as available technology are common for cellulosic ethanol as well. The technology to break down the cellulosic to sugar is not economically efficient yet. Subsidies are available for cellulosic ethanol, but governments keep their subsidy on corn ethanol as well which may cancel the effectivity of subsidy on cellulosic ethanol if the subsidy has any impact at all.

McCormick and Kaberger (2007) identify, analyze, and discuss three non-technological barriers for accelerating the accomplishment of bio-energy in European Union (EU). The key barriers for the growth of bio-energy they indentify are economic conditions, knowledge and institutional capacity, and supply chain co-ordination. Their case studies illuminate that to overcome the barriers one should change the conditions, and understand the importance and relevance of the context for bio-energy. They indicate that the non-technical barriers are dynamic, but they find consistent strategies base on their case studies to remove those barriers. The strategies are investment grants and policy measures to make bio-energy competitive with fossil fuels, leading projects to stimulate learning processes, and building networks by local champions to guide supply chain co-ordination.

Similar to McCormick and Kaberger (2007) work, cellulosic ethanol also has non-technological barriers one of which is supply chain coordination that is the focus this research. Difficulty in providing the firms with long-term commitments on the side of farmers has been an obstacle for the cellulosic ethanol industry which has resulted in rates of progress far less than those expected.

Lunnan (1997) discuses how bio-energy policy and agricultural policy can be coordinated. He argues that the notion that higher cost of biomass energy in comparison with fossil fuel energy can be canceled through transferring subsidies from traditional agriculture to energy crops, is based on a misconception. He believes that greenhouse gas emissions are a global environmental problem and it therefore needs global action rather than local subsidies to bio-energy systems.

Downing, Volk, and Schmidt (2005) describe agricultural cooperatives as examples of research, financing, and exchange mechanisms in the agro-bio-energy industry. They define the terms and conditions under which a farm-cooperative business structure is appropriate for bio-energy market development. In addition, they review and update the status of four of the new generation (NG) cooperative business structures that have been developed, or are still developing in Minnesota (Minnesota valley alfalfa producer's cooperative, Minnesota agro-forestry cooperative) , New York (Willow bioenergy producer's cooperative), and Iowa (Prairie Lands Bio-Products, Inc.).

They conclude with three realizations that are crucial for developing new generation of cooperatives. The first is the ability to secure financing. Second realization is the ability to navigate through the entire process, by which a NG Cooperative forms and does business. The third is the ability to assemble and develop a group of dedicated and committed producers with a motivated leader, who is a champion for the cause.

The first realization of Downing, Volk, and Schmidt (2005) is one of the motivations of this research; financial security. Since cellulosic ethanol industry is an emerging industry, it needs financial support. The cellulosic ethanol industry can gain the support only if it ensures the investors its performance otherwise lack of finance can hold the industry. Long-term contracts between the producers and farmers play a complementary role in providing the industry with financial security.

Gallagher and his team (2003) estimate the biomass supply of crop residues in four regions of the US. To use in their estimation, they consider both environmental and cost factors such as residue yield, geographic density of residues, and competition for livestock feed. Their study shows that maintaining soil quality and increasing the producer profits are two results of reducing tillage and partial residue harvest. They also suggest that the lowest cost of biomass supply is residues. The range of costs is more in the Great Plains than Corn Belt because of different growing conditions, protection requirements, and forage demand. They believe that by providing more development of processing technology, biomass supply from crop agriculture could account for an important share of energy consumption.

In the case of cellulosic ethanol, what Gallagher (2003) and his team suggest, development of processing technology, is also right. There is no doubt that it is necessary to invest heavily in the technology to bring cellulosic ethanol to the market. However, it is necessary to do research before investing in the cellulosic ethanol industry to figure out if it can effectively reduce the dependency on fossil fuel. Collin Peterson at the Reuters Global

Agriculture and Biofuel Summit indicated that "I'm not sure cellulosic ethanol will ever get off the ground." (Reuters-UK, 2008).

Chapter III - Literature Review

Dynamic characteristics describe many optimization problems in agricultural decision making science which has given an important role to the dynamic programming approach in this field. Using this approach, the current study tries to analyze the behaviour of a farmer facing an inter-temporal and uncertain decision making problem under which he considers the compensations required for loss of flexibility due to signing a long-term contract. In this section the literature on flexibility, dynamic programming approach, and optimal contract length is reviewed. From the last group of literature we draw a conceptual framework for thinking about the optimal length of contract.

3.1. Review of Production Flexibility Literature

One of the objectives of this research is to examine the flexibility loss of farmers as a result of signing into a long-term contract with cellulosic ethanol firms. This section looks into the work of Toni and Tonchia (1998) where the authors review the literature on flexibility.

Toni and Tonchia (1998) review the manufacturing flexibility literature. First, they look at the definitions of flexibility. Definitions can be analyzed as a:

- Characteristic of the interface between a system and its environment;
- Degree of homeostatic control and dynamic efficiency of a system; or
- Capability of adoption or change.

They find two main reasons determining the request for flexibility, which emerge from the literature:

- Environmental uncertainty (both internal and external); and
- Variability of the products and of the processes.

The authors find five different classification of flexibility in the literature:

- Horizontal classification (or by phases) aimed at limiting the analysis;
- Vertical (or hierarchical) classification concerning the degree of detail of the analyzed object, micro or macro level;
- Temporal classification;
- Classification by the objects (volume, mix etc.) of the variations, in relation to other variables; and
- Mixed logic classification considering both the object of variation and time, or both the object of the variation and level of analysis.

They propose three indicators of flexibility:

- Direct measures (objective or subjective);
- Indirect measures (relative to certain features of the manufacturing system which can determine flexibility or performances related to flexibility); and
- Synthetic measures.

They agree upon dividing the taken choices (techniques, methods, and criteria) to acquire flexibility into two categories:

- Design or technological choices
- Organizational-managerial choices.

Finally, Toni and Tonchia (1998) categorize the interpretation of flexibility according to different uses, aims, or functions in relation to which flexibility can be analyzed like competitive priority versus performance, aim versus result, potential versus effective, strategical versus operational, defensive versus offensive, and aimed at obtaining further performances.

For the case of cellulosic ethanol industry, we are using the third definition of flexibility that Toni and Tonchia (1998) has defined; the capability of adoption or change. The farmer cannot adopt and change his production according to price variability as much as he used to do as soon as he signs a contract with the cellulosic ethanol firm. This loss of flexibility implies that the farmer has to be compensated. The reasons for the request for flexibility in the case of cellulosic ethanol industry on the side of farmers is similar to what Toni and Tonchia (1998) found in manufacturing; environmental uncertainty. Each period, farmers switch between their products based on changes in prices to maximize their profit. However, by signing a contract, the farmers can no more switch as much as they want and since they do not know how the prices will change in the future, they are reluctant to sign long-term contracts.

The flexibility of farmers that is of concern along this research can be put in the fifth class of flexibility that Toni and Tonchi (1998) talk about; mixed logic classification considering both the object of variation and time. The object of variation for farmers is price variability over time. As a result, farmers ask for higher flexibility premium when the length of contract increases because their uncertainty increases over the time. According to Toni and Tonchi (1998), categories of indicators of flexibility, we use direct indicators for the farmers' flexibility, change in the farmer's welfare before and after signing the long-term contract. In general, although Toni & Tonchi's work (1998) is related to flexibility in manufacturing, many common concepts could be found between flexibility in manufacturing and farming.

3.2. Review of Dynamic Programming and Uncertainty Literature

A dynamic framework is required to model the behavior of a system over a finite, but very long, horizon. Using a dynamic stochastic model, the current study examines the inflexibility premium offered by the cellulosic ethanol firm to the farmer in order to induce him to sign into long-term contracts in the presence of adjustment costs. This section briefly reviews some of the literature on dynamic programming and uncertainty.

In a standard dynamic programming model, a decision maker has to choose his schedule for time horizon of planning at the beginning of the initial period in which only the state variables for the first period are revealed. The state variables are those that define the state of the system at each period of decision making upon which a decision maker bases his choices in each period. The control variables – the decision variables of the decision maker – are the variables that must be chosen for every period by the decision maker at the beginning of the first period.

The control variables in each period are contingent on the realization of the state variables up to that period and optimal forecasts of their future values in addition to the chosen values for the control variables for the previous periods. The state variables are realized at the beginning of each period, but their values are not available to the decision maker at the beginning of the initial period when the decision maker has to optimally make his decisions for the first period and all the future periods. A solution to such a stochastic dynamic programming problem is a rule that shows how the control variables are determined as a function of the realized state variables at each period.

The solution to the model starts by pretending that the decision maker has made the decision about all the previous periods but the last period. Therefore only the optimization of the last period considered under the assumption that the state variables up to, and including, that period are known to the decision maker. The solution to the optimization of the last period determines the value of the control variables for the last period as functions of all the known sate variables and the value of the previous period's control variable. Then, working[3] backwards, the decision maker is moved to the period before the last period pretending that he knows the value of the state variables up to and including that period, while he already knows the solution to the next period. In this period he has to forecast the value of the solution in the final period and optimally choose the value of the control variable for that period. After finding the solution for the control variable of the period before the last period, the decision maker is moved to the period before that and the whole process will be repeated until all the value of all the control variables are optimally derived as functions of the revealed values of the state variables in the first period and the optimally forecasted values of all the future state variables. At that point, given the values of the state variables for the initial period and the optimal forecasting rule for predicting the values of the future state

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[3] This process is referred to as backward induction.

variables, the optimal values of the control variables can be calculated. Inserting these values into the objective function will generate the maximized value of the objective function.

The stochastic dynamic programming optimization model used in this research is solved by the use of the certainty equivalence principle, a principle under which the case of uncertainty can be reduced to the case of certainty by replacing the certain future values of variables with their unconditional expectations in the first order optimization conditions. This principle in general does not apply to all stochastic dynamic programming models. The conditions under which this principle can be applied to a dynamic programming problem is developed over time by Simon (1956), Theil (1957), Malinvaud (1969), and Laffont (1975), the formers respectively generalizing the conditions derived in the previous ones or relaxing some of the redundant assumptions that were assumed in previous works (for more details see appendix I). Briefly, the certainty equivalence principle is "… a special property of the optimal linear regulator problem and is due to the quadratic nature of the objective function and the linear nature of the transition equation[s]." (Sargent, 1987).

Zacharias, Liebman, and Noel (1986) use a dynamic programming structure to determine optimal management decision rules for the control of a soil-born pest. Their state variables are pest infestation level, previous land use decisions, and product price expectations. They find that the optimal management rule is sensitive to the state variables.

In the current research, a dynamic optimization model under uncertainty is used to determine the optimal inflexibility premium requested by farmers. The state variables are the prices of different farm products in every period and the control variables are the quantities of each product in every period. It is found that the inflexibility premium is sensitive to the state variables and length of contract.

Strotz (1955) considers a consumer who makes a future consumption plan via maximizing the utility of the plan evaluated at the present time subject to his budget constraint. Strotz (1955) claims that there can be two situations. The optimally chosen future consumption plan could be consistent or inconsistent with the optimized plan of the individual at the present time. Strotz (1955) argues that generally the individual's future behaviour would be inconsistent with his optimal plan because of continual updating of the discount function. Strotz (1955) suggests using a discount rate by which an individual can solve his problem. In addition, Strotz (1955) addresses pre-commitment of future behavior. The individual will commit to the desired future consumption plan of the present by precluding future options.

In the model used in this thesis, instead of a consumer as in Strotz (1955), there is a farmer making decisions about future production plans by maximizing his expected discounted present value of profits over time subject to land constraints. Similar to Strotz (1955), a discount factor is used for discounting the future values in order to calculate the present values. The difference between the model used here and his is that the farmer cannot change his production plan as he desires after signing into a long-term contract while before signing the contract, as in Strotz (1955), the farmer can update his production decision with changes in prices or expectations of the prices.

3.3. Review of Optimal Contract Length Literature

One of the objectives of this research is to find the optimal length of a contract that farmers willingly sign with cellulosic ethanol firms. In this section we review some of the related literature and will ultimately try to present an appropriate framework to think about the optimal length of contract. For the formal analysis, the optimal contract length is left exogenous. However, it is useful to consider the factors which determine contract length.

Antle et al. (2003) develop methods to evaluate the efficiency of different types of contract for carbon sequestration in cropland soils, taking into account the spatial heterogeneity of agricultural production systems and the costs of implementing more efficient contracts. They apply the methods in a case study of the dry land grain production system of the Northern Plains region of the United States that would pay farmers for adoption of alternative per-hectare or per-tonne contracts. Based on site-specific biophysical simulation models and data that can be used to simulate farmers' decisions to participate in both per hectare and per-tonne contracts they derive increasing marginal cost for per-hectare and per-tonne contracts for carbon sequestration and decreasing marginal benefit of contract efficiency. The case study results confirm that the relative inefficiency of per-hectare contracts varies spatially and increases with the degree of spatial heterogeneity. They show that economic incentives for a landowner to enter a carbon offset contract depends on the opportunity cost of changing production practices relative to the rate of soil carbon sequestration. However, as Gulati and Vercammen (2005) argue, the fact that marginal costs and benefits of sequestration are changing over time and will thus give rise to an optimal contract length has apparently not been discussed.

Gulati and Vercammen (2005) consider economic determinants of optimal length of a one-time fixed-term carbon offset contract. They use a dynamic model to evaluate the economic determinants underlying a farmer's choice of contract length, and the associated benefits to society from a temporary carbon contract. In their model, the optimal length of contract is determined by declining marginal benefit and increasing marginal cost schedules. They find that although the net present market value of the sequestered carbon rises with the length of contract, farm profits reach a maximum at some unique value of length of contract at which the marginal benefit of extending the contract by one more year is equal to the marginal profits forgone by not operating under no-contract land use. They numerically simulate the model and analyze the sensitivity of the optimal length of contract with respect to the key parameters of the model. For instance, they find that if the contract requires the farmer to use greater carbon conserving technology, the farmer chooses the contract for a shorter period of time. Or, if society places a higher value on carbon accumulation, meaning that the farmer receives a higher payment, the contract is chosen for a longer length of time.

Similar to Gulati and Vercammen (2005), to find the optimal length of contract between a farmer and a cellulosic ethanol firm, the logic of marginal benefit and marginal cost schedules of singing a contract is used here where the intersection of these schedules gives the optimal contract length. As Gulati and Vercammen (2005) argue, we also argue that if signing a contract is more costly for the farmer then a shorter length of contract will maximize the profits of the farmer and on the other hand if having a long-term contract is very beneficial for the cellulosic ethanol firm, that is the firms pays higher compensations to the farmer, then a longer length of contract is expected to be chosen by the farmer. The case of optimal contract length of cellulosic industry has been described in more details in follow.

Consider the process through which a cellulosic ethanol firm signs a long-term contract with a farmer. The cellulosic ethanol firm needs to sign a long-term contract with the farmer to obtain the required feed-stock to produce ethanol. Since the farmer is not willing to accept the long-term contract unless it includes compensations for the loss of flexibility, the firm tries to optimally design a contract that includes satisfying levels of compensation for the farmer. A supply and demand framework can be used here to understand the relationship between the size of the inflexibility premium and the length of contract.

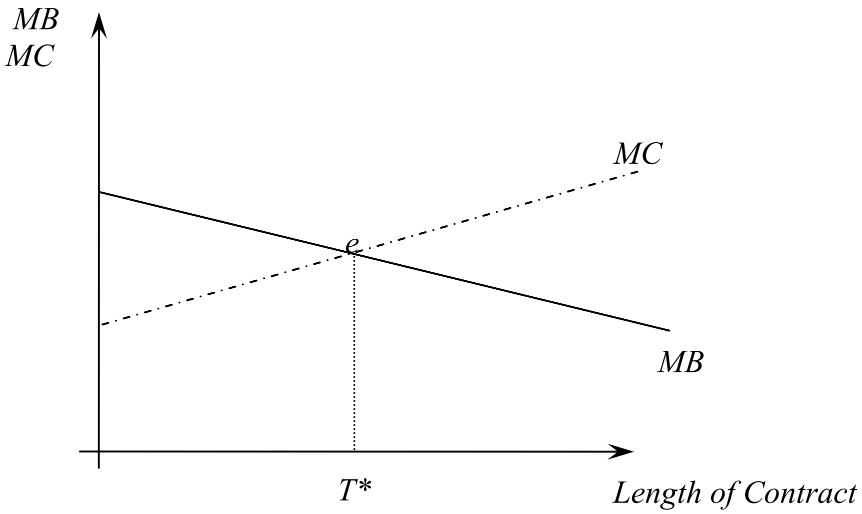
The benefits of the cellulosic ethanol firm increases with the length of contract at a diminishing pace since security of supply remains positive and important, but is less and less relevant as the time horizon becomes longer. Therefore, the firm's marginal benefit from an additional year of contract decreases as the length of contract is extended. It should be noted that the height of each point on the marginal benefit schedule is a measure of the gain in profit for the firm from extending the length of the contract by one year. The area under the marginal benefit schedule is therefore a measure of the gain in profits for the cellulosic ethanol firm from operating with a multiple year contract versus a year by year contract.

On the other hand, a longer length of contract generates higher cost (or lower profits) for the farmer since as the length of contract increases the farmer can respond less to price variability, changes in soil moisture, etc. We assume that marginal cost is increasing as the length of contract increases. Therefore the farmer operates with an upward sloping marginal cost schedule as a function of the length of contract. The height of each point on the marginal cost schedule is a measure of the increase in farm cost (i.e., loss in profits due to lost flexibility) from an extension of the length of contract for an additional year. The area below the marginal cost schedule is a measure of the total farm cost of operating with a multiyear contract rather than with a year by year contract.

We assume the cellulosic ethanol firm and farmer will negotiate a longer contract as long as the firm's marginal benefit for an additional year of contract is larger than the farmer's marginal cost for that additional year. Indeed, as long as there is a positive net joint benefit, the firm can provide to the farmer an amount which at least covers his marginal cost if he signs the contract. The two firms will bargain over the length of contract to a point at which their joint surplus is maximized, which occurs where marginal benefit for the ethanol firm is equal to marginal cost for the farmer. Thus, the intersection of marginal benefit and marginal cost schedules determines the optimal length of the contract, T*, (see figure I).

Given the relative location and slope of these two curves with respect to each other, the outcome (T*) can be a long-term or a short-term contract. If having a long-term contract is very beneficial for the cellulosic ethanol firm and is not too costly for the farmer, then a longer equilibrium length of contract is expected. In the opposite case, a shorter equilibrium length of contract is expected if a long-term contract costs much more for the farmer than benefits the cellulosic ethanol firm.

Figure I - Relationship between the Size of the Inflexibility Premium and the Length of Contract



Chapter IV - The Model

4.1. Overview of the Model

A risk neutral farmer chooses acreages of two crops, y_t and x_t on the farm's aggregate land base, A, in each period t with prices p_t and b_t respectively. Each period, depending on the prices at the time, the farmer adjusts the acreage of each crop such that the expected discounted value of his profit stream is maximized. A steady state is defined as a situation where the two prices have been equal for a large number of periods and the farmer no longer makes adjustments to crop acreage. Later in the analysis the farm cost function is specified such that the steady state is characterized by equal division of the land.

While the farmer is in steady-state, a biofuel firm proposes a 'T' year contract to the farmer. The terms of the contract are such that the firm guarantees to buy all the production of cellulosic plants produced by the farmer at a fixed price over the horizon of the contract. In exchange, the farmer is required to devote a pre-specified number of acres to the production of cellulosic plants (e.g., switch grass), which is denoted by s. Aggregate steady state farm production costs are minimized when the farm equally allocates the land base to the three crops (i.e., $y_t = x_t = s$). Thus, the firm and the farmer will negotiate and eventually agree that one third of the farmer's land base will be devoted to the production of cellulosic plants for the length of the contract (i.e., $s = A/3$ for $t \in \{1, 2, ..., T\}$.

As mentioned above, under the contract there is no price variability for cellulosic plants, because the farmer is assured that his entire cellulosic plants yield will be bought at a fixed contract price, k, by the cellulosic ethanol firm. Although the total acreage left for y and x is fixed after signing the contract, the farmer still can respond to the price variability of y and x and therefore he will continue to rotate crops y and x but on two thirds of the land base compared to the whole land base which was devoted to the two crops before signing the contract. Therefore, the price variability of y and x remains important for the farmer, but it is less important than in the no-contract case because of the shrunken land base upon which these two crops are produced.

For simplicity and without loss of generality, it is assumed that the crop price state variables, p_t and b_t, follow a random walk process. The reason for focusing on a random walk process is that in an efficient market, all the information that would allow the farmer to predict the future price movements is already reflected in the current prices. As a result, assuming the shocks are independently and identically distributed according to a known distribution function with mean zero, the farmer cannot do any better than to expect the same prices to prevail over the whole period:

$$p_{t+1} = p_t + \varepsilon_{t+1}\,,\ \text{where } E_t(\varepsilon_{t+1}) = 0 \Rightarrow E_t(p_{t+1}) = p_t$$

$$b_{t+1} = b_t + \upsilon_{t+1},\ \text{where } E_t(\upsilon_{t+1}) = 0 \Rightarrow E_t(b_{t+1}) = b_t$$

Solving the model requires solving for the optimal values of x_t and y_t as a function of current prices and the values of x_{t-1} and y_{t-1}. These acreage rule equations are used to calculate the expected discounted value of the stream of farm profits from the date the contract is signed to the date the contract expires. The greater the variability in price, the greater the variability in the farmer's optimally chosen values of x_t and y_t and thus the greater the expected value of the stream of farmer profits. The expected discounted value of farm profits can be calculated with and without the contract in place. The price premium which must be paid to the farmer is such that the expected discounted value of the stream of farm profits is equal with and without the contract.

4.2. Formulation of the Dynamic Programming Model

4.2.1. Before Signing the Contract

It was assumed above that in steady-state, aggregate farm costs are minimized when the land base is equally divided between crops x and y in the absence of a contract and is equally divided between crops x, y and s with a contract. The equal allocation assumption was made primarily to simplify the analysis, but it can be rationalized as follows. Equal acreages will tend to minimize natural disease costs because the crops can be evenly rotated. If the farmer moves away from an equal acreage allocation, the cost of dealing with disease rises. Similarly, equal acreages might minimize capital and labor costs. Moving away from an equal allocation will raise the cost of capital and labor.

To achieve the equal acreage steady-state outcome for the no-contracting case, assume that the total cost function of the farmer in any period t is as follows:

$$C_t\left(y_t, x_t; y_{t-1}, x_{t-1}\right) = \frac{\gamma}{2}\left[\left(y_t - y_{t-1}\right)^2 + \left(x_t - x_{t-1}\right)^2\right] + \frac{\beta}{2}\left[y_t^2 + x_t^2\right] \qquad (1)$$

The cost function satisfies the required regularity condition of convexity. The first bracket on the right hand side captures the adjustment costs of a change in production from one period to another, where γ is the adjustment-cost coefficient. The adjustments are costly. For instance, a farmer is constrained to rotate crops, to minimize the chance of disease outbreak, or to shift acreages. These imply shifting the input mix and marketing strategy, which are likely to be costly. The second pair of brackets is the production cost, where β is the production-cost coefficient. Production cost is designed so that it is minimized with equal acreages.

As indicated above, the farmer understands that prices follow a correlated random walk when forming expectations because there is no way of exactly predicting their future values. Since our objective function is a linear sum of quadratic terms, we can use the certainty equivalence principle to solve our dynamic programming problem. Therefore, we replace the uncertain future values of the price variables with their unconditional expectations. We also assume that the farmer discounts unconditional expected profits at a fixed discounted rate, δ.

At the beginning of period *1*, taking the current set of steady-state prices, p_1 and b_1, as given and the steady-state acreage allocations, x_0 and y_0, as given, the farmer chooses the rule that connects current and future choices of x_t and y_t with current and future prices in order to maximize the following discounted expected profit function[4]:

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[4] FC: Fixed Cost

$$\left\{ \max_{y_t, x_t} \; E_1 \sum_{t=1}^{T} \delta^{t-1} \pi_t \left(y_t, x_t, p_t, b_t\right) \right\} = V_1\left(y_0, x_0, p_1, b_1\right)$$

$$s.t. \;\; \pi_t(y_t, x_t, p_t, b_t) = p_t y_t + b_t x_t - \left[\frac{\gamma}{2}\left(y_t - y_{t-1}\right)^2 + \frac{\gamma}{2}\left(x_t - x_{t-1}\right)^2 + \frac{\beta}{2}\left(y_t^{\,2} + x_t^{\,2}\right) \right] - FC$$

$$x_t = A - y_t \tag{2}$$

It can be shown that in general the solution to the discounted expected profit maximization is the same as when the inter-temporal problem is solved backwards (Sargent, 1987), as if in each period the farmer makes the decision for all the future periods, starting from the last period to the first, while in every preceding period the subsequent optimizations are reconsidered again. Thus, the optimization strategy proceeds by first looking at the last period(T):

$$\left\{ \max_{y_T, x_T} \; \pi_T(y_T, x_T, p_T, b_T) \right\} = V_T\left(y_{T-1}, x_{T-1}, p_T, b_T\right)$$

$$\text{s.t.} \;\; \pi_T(y_T, x_T, p_T, b_T) = p_T y_T + b_T x_T - \left[\frac{\gamma}{2}\left(y_T - y_{T-1}\right)^2 + \frac{\gamma}{2}\left(x_T - x_{T-1}\right)^2 + \frac{\beta}{2}\left(y_T^{\,2} + x_T^{\,2}\right) \right] - FC$$

$$x_T = A - y_T$$

Replacing for x_T according to $x_T = A - y_T$, the optimum solutions for the period (T) will be derived as follows:

$$\max_{y_T} \left\{ \pi_T(y_T, x_T, p_T, b_T) = p_T y_T + b_T\left(A - y_T\right) - \frac{\beta}{2}\left(y_T^{\,2} + \left(A - y_T\right)^2\right) - \frac{\gamma}{2}\left(\left(y_T - y_{T-1}\right)^2 + \left(y_{T-1} - y_T\right)^2\right) \right\} - FC$$

Taking the derivative of π_T with respect to y_T is equal to:

$$\frac{d\pi_T}{dy_T} = p_T - b_{T-1} - 2\beta y_T + \beta A - 2\gamma y_T + 2\gamma y_{T-1} = 0$$

Therefore the optimal value of y_T is equal to:

$$y_T^* = \frac{p_T - b_T + \beta A + 2\gamma\, y_{T-1}}{2(\gamma + \beta)} \tag{3}$$

Using $x_T = A - y_T$, the optimal value of x_T is:

$$x_T^* = \frac{\beta A + 2\gamma A - p_T + b_T - 2A\gamma\, x_{T-1}}{2(\beta + \gamma)} \tag{4}$$

Therefore, considering the replacement for x_T according to $x_T = A - y_T$, the optimal value of profit for the last period of contract would be:

$$V_T\left(y_{T-1}, x_{T-1}, p_T, b_T\right) \equiv$$

$$V_T\left(y_{T-1}, p_T, b_T\right) = k_1 + k_2 p_T^{\,2} + k_3 p_T + k_4 b_T^{\,2} + k_5 b_T + k_6 y_{T-1}^2 + k_7 y_{T-1} + k_8 b_T y_{T-1} + k_9 p_T y_{T-1} + k_{10} b_T p_T \tag{5}$$

where

$k_1 = \frac{-\beta A\left(\beta^2 A + 2\gamma^2\right)}{4(\beta+\gamma)^2} - \frac{3\beta^2 A^2 \gamma}{4(\beta+\gamma)^2}$, $\quad k_2 = \frac{1}{2(\beta+\gamma)} - \frac{(\beta+\gamma)}{4(\beta+\gamma)^2}$, $\quad k_3 = \frac{\beta A}{2(\beta+\gamma)}$,

$k_4 = \frac{1}{2(\beta+\gamma)} - \frac{(\beta+\gamma)}{4(\beta+\gamma)^2}$, $\quad k_5 = \frac{A(\beta+\gamma)}{2(\beta+\gamma)}$, $\quad k_6 = \frac{-\gamma\,\beta(\beta+\gamma)}{(\beta+\gamma)^2}$,

$k_7 = \frac{\gamma\,\beta\,A(\beta+\gamma)}{(\beta+\gamma)^2}$, $\quad k_8 = \frac{-\gamma}{(\beta+\gamma)}$, $\quad k_9 = \frac{\gamma}{(\beta+\gamma)}$,

$k_{10} = \frac{-1}{(\beta+\gamma)} + \frac{(\beta+\gamma)}{2(\beta+\gamma)^2}$.

As it is shown $y_T^*(y_{T-1}, p_T, b_T)$ and $x_T^*(x_{T-1}, p_T, b_T)$ are linear functions of p_T, b_T, and y_{T-1}, and V_T is a quadratic function in p_T, b_T, and y_{T-1}. Therefore, since all the conditions for using the certainty equivalent principle are satisfied, we can use it for solutions to the problem in periods before the final period.

Going one period back, to '*T-1*', the farmer now optimizes the profits in period *'T-1'* plus the expected discounted profit in period '*T*', knowing $y_T^*(y_{T-1}, p_T, b_T)$ and $x_T^*(x_{T-1}, p_T, b_T)$, to find $y_{T-1}^*(y_{T-2}, p_{T-1}, b_{T-1})$ and $x_{T-1}^*(x_{T-2}, p_{T-1}, b_{T-1})$, where $E_{T-1}(p_T) = p_{T-1}$ and $E_{T-1}(b_T) = b_{T-1}$, and the optimized values of period '*T*' are considered for re-optimization.

The optimization strategy for period '*T-1*' is:

$$\left\{ \max_{y_{T-1}, x_{T-1}} \pi_{T-1}(y_{T-1}, x_{T-1}, p_{T-1}, b_{T-1}) + \delta E_{T-1}[V_T\left(y_{T-1}, x_{T-1}, p_T, b_T\right)] \right\} = V_{T-1}\left(y_{T-2}, x_{T-2}, p_{T-1}, b_{T-1}\right)$$

$$s.t.\ \pi_{T-1}(y_{T-1}, x_{T-1}, p_{T-1}, b_{T-1}) = p_{T-1}y_{T-1} + b_{T-1}x_{T-1} - [\frac{\gamma}{2}\left(y_{T-1} - y_{T-2}\right)^2 + \frac{\gamma}{2}\left(x_{T-1} - x_{T-2}\right)^2 + \frac{\beta}{2}y_{T-1}{}^2 + \frac{\beta}{2}x_{T-1}{}^2] - FC$$

$$x_{T-1} = A - y_{T-1} \qquad (6)$$

where $V_T\left(y_{T-1}, p_T, b_T\right)$ is defined in (5). Using $x_{T-1} = A - y_{T-1}$ to replace for x_{T-1}, and using (5) and applying the expectation operator to it, the optimal value y_{T-1}^* will be the solution to the following problem:

$$\max_{y_{T-1}} \Big\{ \pi_{T-1}(y_{T-1}, x_{T-1}, p_{T-1}, b_{T-1}) = p_{T\text{-}1}y_{T\text{-}1} + b_{T\text{-}1}(A - y_{T\text{-}1}) - \frac{\beta}{2}\left(y_{T\text{-}1}{}^{2} + (A - y_{T\text{-}1})^{2}\right) - \gamma(y_{T\text{-}1} - y_{T-2})^{2} + G_{T-1} + F_{T-1}y_{T-1} - C_{T-1}y_{T-1}^{2} \Big\} \tag{7}$$

where $G_{T-1} + F_{T-1}y_{T-1} - C_{T-1}y_{T-1}^{2} = \delta E_{T\text{-}1}[V_T\,(y_{T\text{-}1}, x_{T\text{-}1}, p_T, b_T)]$ and in applying the expectation operator the following rules based on the definitions for variance and covariance have been used to replace for $E\left(p_T^2\right)$, $E\left(b_T^2\right)$, and $E(p_T b_T)$ to derive $y_{T-1}^{*}(y_{T-2}, p_{T-1}, b_{T-1})$ and $x_{T-1}^{*}(x_{T-2}, p_{T-1}, b_{T-1})$:

$$\sigma_{P_T}^{2} = E(p_T - E(p_T))^2 = E\left(p_T^2\right) - E(p_T)^2 \quad \Rightarrow \quad E\left(p_T^2\right) = \sigma_{P_T}^{2} + E(p_T)^2$$

$$\sigma_{b_T}^{2} = E(b_T - E(b_T))^2 = E\left(b_T^2\right) - E(b_T)^2 \quad \Rightarrow \quad E\left(b_T^2\right) = \sigma_{b_T}^{2} + E(b_T)^2$$

$$\rho_{p_T b_T} = E[(p_T - E(p_T))(b_T - E(b_T))] = E(p_T)E(b_T) - E(p_T b_T) \quad \Rightarrow$$

$$E(p_T b_T) = \rho + E(p_T)E(b_T) \tag{8}$$

From (7), the first order condition implies that:

$$p_{T-1} - b_{T-1} - 2\beta y_{T-1} + \beta A - 2\gamma y_{T-1} + 2\gamma y_{T-2} + F_{T-1} - 2C_{T-1}y_{T-1} = 0$$

The optimal value of y_{T-1} becomes:

$$y_{T-1}^{*} = \frac{p_{T-1} - b_{T-1} + \beta A + 2\gamma\, y_{T-2} + F_{T-1}}{2(\gamma + \beta + C_{T-1})} \tag{9}$$

Using $x_{T-1} = A - y_{T-1}$, the optimal value of x_{T-1} is:

$$x_{T-1}^{*} = \frac{\beta A + 2\gamma A + 2C_{T} A - p_{T-1} + b_{T-1} - 2A\gamma\, x_{T-2} - F_{T-1}}{2\left(\beta + \gamma + C_{T-1}\right)} \tag{10}$$

Where F_{T-1} and C_{T-1} are equal to:

$$F_{T-1} = \delta\left[\frac{\gamma}{(\beta+\gamma)}\left(p_{T-1} - b_{T-1}\right) - \frac{\beta}{(\beta+\gamma)^{2}}\left(\gamma\, p_{T-1} - \gamma\, b_{T-1} - \gamma^{2} A\right) - \frac{\gamma}{(\beta+\gamma)^{2}}\left(\beta\, b_{T-1} - \beta\, p_{T-1} - \beta^{2} A\right)\right] \tag{11}$$

$$C_{T-1} = \delta\left[\frac{\beta\gamma}{(\beta+\gamma)^{2}}\left(\beta + \gamma\right)\right] \tag{12}$$

If we go one period back, to '*T-2*', the farmer optimizes the profit in period '*T*-2' plus the expected discounted profits over periods '*T*' and '*T-1*' to find $y_{T-2}^{*}(y_{T-3}, p_{T-2}, b_{T-2})$ and $x_{T-2}^{*}(x_{T-3}, p_{T-2}, b_{T-2})$, where again $E_{T-2}(p_{T-1}) = p_{T-2}$ and $E_{T-2}(b_{T-1}) = b_{T-2}$, and the optimized values of periods '*T*' and '*T-1*' are considered for re-optimization.

$$\left\{\max_{y_{T-2},x_{T-2}} \pi_{T\text{-}2}(y_{T-2}, x_{T-2}, p_{T\text{-}2}, b_{T\text{-}2}) + \delta E_{T-2}[V_{T-1}\left(y_{T\text{-}2}, x_{T\text{-}2}, p_{T-1}, b_{T-1}\right)]\right\} = V_{T\text{-}2}\left(y_{T-3}, x_{T-3}, p_{T\text{-}2}, b_{T\text{-}2}\right)$$

$$s.t.\ \pi_{T-2}(y_{t-2}, x_{t-2}, p_{T-2}, b_{T-2}) = p_{T-2}y_{T-2} + b_{T-2}x_{T-2} - [\ \frac{\gamma}{2}\left(y_{T-2} - y_{T-3}\right)^{2} + \frac{\gamma}{2}\left(x_{T-2} - x_{T-3}\right)^{2} + \frac{\beta}{2}{y_{T-2}}^{2} + \frac{\beta}{2}{x_{T-2}}^{2}] - FC$$

$$x_{T-2} = A - y_{T-2}$$

$$\tag{13}$$

Calculating $\delta E_{T-2}[V_{T-1}(y_{T\text{-}2}, x_{T\text{-}2}, p_{T-1}, b_{T-1})]$ using similar rules to (7) and replacing for x_{T-2} by $x_{T-2} = A - y_{T-2}$, from (13) the optimal value y^{*}_{T-2} will be the solution to the following problem:

$$\max_{y_{T-2}} \left\{ \pi_{T-2}(y_{T-2}, p_{T-2}, b_{T-2}) = \mathrm{p}_{\mathrm{T\text{-}2}} y_{\mathrm{T\text{-}2}} + \mathrm{b}_{\mathrm{T\text{-}2}}(A - y_{\mathrm{T\text{-}2}}) - \frac{\beta}{2}\left(y_{\mathrm{T\text{-}2}}{}^{2} + (A - y_{\mathrm{T\text{-}2}})^{2}\right) - \gamma(y_{\mathrm{T\text{-}2}} - y_{\mathrm{T-3}})^{2} \right\}$$

$$+ G_{T-2} + F_{T-2} y_{T-2} - C_{T-2} y_{T-2}^{2} \tag{14}$$

The first order condition for (14) becomes:

$$p_{T-2} - b_{T-2} - 2\beta y_{T-2} + \beta A - 2\gamma y_{T-2} + 2\gamma y_{T-3} + F_{T-2} - 2C_{T-2} y_{T-2} = 0$$

The optimal value of y_{T-2} equals to:

$$y^{*}_{T-2} = \frac{p_{T-2} - b_{T-2} + \beta A + 2\gamma\, y_{T-3} + F_{T-2}}{2(\gamma + \beta + C_{T-2})} \tag{15}$$

Using $x_{T-2} = A - y_{T-2}$, the optimal value of x_{T-2} is:

$$x^{*}_{T-2} = \frac{\beta A + 2\gamma A + 2C_{T-1}A - p_{T-2} + b_{T-2} - 2A\gamma\, x_{T-3} - F_{T-2}}{2(\beta + \gamma + C_{T-2})} \tag{16}$$

Where F_{T-2} equals to:

$$F_{T-2} = \delta \cdot [\frac{\gamma}{(\beta + \gamma + C_{T-1})}(p_{T-2} - b_{T-2}) - \frac{\beta}{(\beta + \gamma + C_{T-1})^2}(\gamma\, p_{T-2} - \gamma\, b_{T-2} - \gamma^2\, A + \gamma F_{T-1} - A\gamma C_{T-1})$$

$$- \frac{\gamma}{(\beta + \gamma + C_{T-1})^2}(\beta\, b_{T-2} - \beta\, p_{T-2} - \beta^2\, A - p_{T-2}C_{T-1} + b_{T-2}C_{T-1} - \beta A C_{T-1} - \beta F_{T-1} - C_{T-1}F_{T-1})$$

$$+ \frac{F_{T-1}\gamma}{(\beta + \gamma + C_{T-1})} - \frac{C_{T-1}}{(\beta + \gamma + C_{T-1})^2}(\gamma p_{T-2} - \gamma b_{T-2} + \gamma\beta A + \gamma F_{T-1})]$$

(17)

As it is clear from equation (17), F_{T-2} is a function of F_{T-1}, and in the same way F_t in each period *t* becomes a function of the next periods' value, F_{t+1}.

C_{T-2} equals to:

$$C_{T-2} = \delta\left[\frac{\beta\gamma}{(\beta + \gamma + C_{T-1})^2}(\beta + \gamma) + \frac{\gamma\, C_{T-1}}{(\beta + \gamma + C_{T-1})^2}(C_{T-1} + 2\beta + \gamma)\right] \tag{18}$$

The same thing as in for F_{T-2} is happening for C_{T-2} as equation (18) indicates. C_{T-2} depends on C_{T-1}, and in the same way C_t in each period *t* will depend on its next periods' value, C_{t+1}.

Proceeding with the backward induction for a few more periods and solving for optimal values y_t^* and x_t^* reveals a general form for the solutions to the problem. Comparing the three equations (3), (9), and (15) for *y* and (4), (10), and (16) for *x* shows the general form. Equations (3) and (4) are slightly different from the rest because these are the solutions for the last period and there is no next period to them. Therefore, there is no F_T and C_T terms in those equations. But the rest are similar and the general form can be derived by modifying the time subscript appropriately for each period.

The process continues until we reach period one, where we find the optimal values for the first period variables $y_1^*(y_0, p_1, b_1)$ and $x_1^*(x_0, p_1, b_1)$, where $E_1(p_2) = p_1$ and $E_1(b_2) = b_1$ have been used. Now, we have the optimal discounted expected profit for the whole T periods from (2), $V_1(y_0, x_0, p_1, b_1)$, before signing the contract.

4.2.2. After Signing the Contract

Now, consider the problem when the farmer has signed onto the long-term contract with the cellulosic ethanol firm. We assume the farmer does not produce the crop required by the firm if he does not sign a contract with the firm. Therefore, the firm can acquire the input only by offering a contract to the farmer that will be accepted by the farmer. Under the contract, the farmer will devote one third of his land to the production of the cellulosic plants during the years of contract and will sell this commodity to the biofuel firm at a fixed contract price, 'k'.

If the farmer signs the long-term contract, he locks himself in a situation that partially takes his flexibility away for 'T' periods of contract. This is because assigning a third of his acreage of land to the cellulosic plants for 'T' periods under the contract, will actually determine the fixed total acreage available for the other two crops, 'y_t' and 'x_t', simply because the total acreage of land that the farmer owns is fixed. Therefore, due to the loss of flexibility, he will be reluctant to sign the contract unless he is compensated for the loss. As a result, the contract price must be such that at least makes the farmer indifferent between signing and not signing the contract.

The units of the contracted crop and the cost function are assumed to be such that in steady state the total farm operating cost of allocating half of the land to x and half of the land to y in the no-contract situation is the same as the total farm operating cost of allocating one third of the land to each of x, y and s in the contract situation. Therefore, in the absence of price uncertainty, the farmer would earn equal profits with and without the contract if the contract price is equal to the steady price of x and y. With price uncertainty, the contract price must be raised above the steady state price of x and y to ensure the farmer remains indifferent between signing and not signing the contract.

'Inflexibility premium' is the smallest necessary increase in the contract price of the cellulosic plants over the steady state price of x and y that makes the farmer indifferent between signing and not signing the contract. Therefore, the firm has to figure out the minimum 'inflexibility premium', which should be included in the contract so that the farmer is willing to ratify it.

After signing a long-term contract, the farmer has to carry out an optimization problem similar to (2) except now the land base is two thirds the size of the no-contract case. There is no price uncertainty and no acreage adjustment costs for producing the cellulosic plants so the discounted value of the contract can be calculated separately and added to the solution to

(2) with two thirds of the land base in order to calculate the total value of the farm under contract.

The next step is to ensure that the parameters of the cost function are such the aggregate steady-state farm operating cost is the same with and without the contract. This restriction is imposed to ensure that a difference in the expected level of profits with and without the contract is due entirely to inflexibility rather than production costs. Without a contract, the steady-state values of y and x, will be equal at $y^{SS} = x^{SS} = 0.5A$[5]. His aggregate production cost before signing the contract at the equal-price steady-state is therefore:

$$\text{Production Cost Function at Steady State}=\frac{\beta}{2}\left(\frac{A}{2}\right)^2+\frac{\beta}{2}\left(\frac{A}{2}\right)^2=\frac{\beta}{4}(A)^2 \qquad (19)$$

After signing the long-term contract, the farmer will produce three crops; 'y_t', 'x_t', and 's_t'. Assume that the aggregate production cost function after signing the contract becomes:

$$\text{Aggregate Production Cost Function after Signing the Contract}=\frac{3}{2}\left(\frac{\beta}{2}y_t^2+\frac{\beta}{2}x_t^2+\frac{\beta}{2}s_t^2\right) \qquad (20)$$

This function ensures that in the contracting steady-state where, $y^{SS} = x^{SS} = s^{SS} = 0.33A$, aggregate production cost is equal to:

$$\text{Aggregate Production Cost}=\frac{3}{2}\left(\frac{\beta}{2}\left(\frac{A}{3}\right)^2+\frac{\beta}{2}\left(\frac{A}{3}\right)^2+\frac{\beta}{2}\left(\frac{A}{3}\right)^2\right)=\frac{\beta}{4}(A)^2 \qquad (21)$$

which is the same as the no-contract case.

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[5] See appendix II.

After signing a long-term contract, the farmer has to carry out an optimization problem similar to (2), where now the cost function is updated according to (20):

$$\{ \max_{s,y_t,x_t} E_1 \sum_{t=1}^{T} \delta^{t-1} \pi_t \left(y_t, x_t, s, p_t, b_t, k\right) \} = V_1\left(y_0, x_0, s, p_1, b_1, k\right)$$

$$s.t\ \ \pi_t(y_t, x_t, s, p_t, b_t, k) = p_t y_t + b_t x_t + k\, s - [\, \frac{\gamma}{2}\left(\left(y_t - y_{t-1}\right)^2 + \left(x_t - x_{t-1}\right)^2\right) + \frac{3\beta}{4}(y_t^{\ 2} + x_t^{\ 2} + s^2)] - FC$$

$$x_t = A - y_t - s \tag{22}$$

The solution strategy is exactly similar to the case without contract, with only difference that there is no uncertainty in price of the cellulosic plants due to the contract.

Finding the solution to (22) enables us to compare the expected discounted profits before and after signing into the contract without considering any inflexibility premium, $V_1(y_0, x_0, p_1, b_1)$ and $V_1(y_0, x_0, s, p_1, b_1, k)$, respectively. The difference between $V_1(y_0, x_0, p_1, b_1)$ and $V_1(y_0, x_0, s, p_1, b_1, k)$ will determine the optimal inflexibility premium required to make the farmer indifferent between the two cases and make the long-term relationship work.

Since under the contract, '*s*' has to be a fixed amount over the horizon of the contract, the solution to (22) can be derived according to the general form solutions to (2) with only noting the difference in the production costs, equation (20), and including the profits from the production of cellulosic plants in each period.

Therefore, $V_1(y_0, x_0, s, p_1, b_1, k)$ can be derived using the modified general form solutions to (2) for the new cost function:

$$\{\max_{y_t, x_t} E_1 \sum_{t=1}^{T} \delta^{t\text{-}1} \pi_t \left(y_t, x_t, p_t, b_t\right)\} = V_1\left(y_0, x_0, p_1, b_1\right)$$

$$s.t\ \pi_t(y_t, x_t, p_t, b_t) = p_t y_t + b_t x_t - [\frac{\gamma}{2}\left(\left(y_t - y_{t-1}\right)^2 + \left(x_t - x_{t-1}\right)^2\right) + \frac{3\beta}{4}(y_t{}^2 + x_t{}^2)] - FC$$

$$x_t = A - y_t \tag{23}$$

and adding the present value of the profits from production of cellulosic plants in the initial period:

$$\text{Present Value of Cellulosic Plant Profits} = \left(1 + \frac{1}{\delta}\right)\left[ks - \frac{3\beta}{4}\left(s^2\right)\right] - FC \tag{24}$$

Now comparing the two discounted expected profits determines the optimal inflexibility premium and will enable us to analyze its sensitivity with respect to different parameters of the model such as the length of contract and the variances and covariance of the prices.

Chapter V - Numerical Evaluation and Sensitivity Analysis

5.1. Approach

Comparing the numerically evaluated value function before and after signing the contract with no inflexibility premium at steady-state prices and finding the amount of inflexibility premium by changing the periods of contract supports the main idea of this research, which is the necessity of inflexibility premium and higher premium demand with longer contract. The maximized expected discounted profits after signing the contract with no inflexibility premium at the steady-state prices is less than before signing it. In addition, the required inflexibility premium increases with the length of contract. The reason is that by signing the long-term contract the farmer extracts part of his land on which he does not have any flexibility. The remaining land on which he can respond to price variability of 'y_t' and 'x_t' is smaller than before, so that he is losing part of his flexibility. Therefore the farmer asks for inflexibility premium to compensate this loss of flexibility. As the length of contract becomes longer he demands higher inflexibility premium because of losing more flexibility. Thus, the biofuel firm has to at least offer a contract price, 'k', above the steady-state price of 'y_t' and 'x_t' by exactly the 'inflexibility premium,' such that the farmer is compensated for the loss of flexibility and becomes indifferent between operating with or without a contract.

5.2. Base-Case Numerically Evaluated Results

In the base case with no contract, some numerical values for the parameters of the model are chosen to allow for the model to be numerically evaluated. The numerical values are chosen such that the resulting ratios take on realistic values; variable farm costs equals 63% of revenue, the ratio of fixed costs to revenue is 38%, the discount factor is 0.95 (discount rate of 0.05), and the prices are changing independently with the standard deviation of price divided by mean prices equal to 2.

Parameters	Values
A	20
p_t	2
b_t	2
β	0.25
γ	1
δ	0.05
σ_p^2	16
σ_b^2	16
ρ	0
Y_0	10
Fixed Cost	15

A : Total Acreage

p_t Price of y_t at period t

b_t : Price of x_t at period t

β : Coefficient of Production Cost

γ : Coefficient of Adustment Cost

δ : Discounted Rate

σ_p^2 : Price Variability of 'y_t'

σ_b^2 : Price Variability of 'x_t'

ρ : Covariance between the Prices of 'x_t' and 'y_t'

Y_0 : Starting the Production of Y at Period 0

y_t : First Category of Crops that Change under the contract

x_t : Second Category of Crops

Y_0 : Starting the Production of Y at Period 0

After evaluation of the model with these base-case values, the sensitivity of the model with respect to the choice of different values for these parameters is analyzed.

- *Before Signing The Long-Term Contract*

The farmer by construction is in the steady-state, where $y_0 = y^{ss} = x^{ss} = 10$. Since the model remains at the steady-state, there will be no need for the farmer to adjust his productions. The sell prices for both categories of crops y_t and x_t are assumed to be equal, $p_t = b_t = 2$. Also, the per unit cost of production is chosen such that it is reasonable to have a steady half of each category of crops in the long-run.[6] The farmer's present value function before the contract is equal to 99.297 units.

- *After Signing The Long-term Contract*

After signing the long-term contract with no compensation, the maximized expected discounted profits of the farmer will decrease to 89.062 units, so that the farmer is not willing to sign the long-term contract with the firm. Therefore, the cellulosic ethanol firm has to propose a higher contract price for the cellulosic plants to compensate the farmer. The least contract price that makes the farmer indifferent between signing and not signing the contract is 2.07, which essentially makes the maximized expected discounted profits of the farmer after signing the contract equal to the one before signing the long-term contract, 99.297 units. Therefore, the inflexibility premium in this case becomes equal to 3.67% of the steady-state prices of the crops. The inflexibility premium is calculated by subtracting the sell price of

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[6] See Appendix III.

crops before signing the contract from the contract price of cellulosic plants and dividing it by the sell price of crops before signing the contract, (2.07-2)/2.

The economic reason for asking a higher contract price for cellulosic plants, k, by the farmer is that by signing the long-term contract, the farmer locks himself in a situation where he has less flexibility compared to his situation without signing the contract. Before signing the long-term contract he could adjust his productions as the relative prices would change. However, after signing the contract he is no more able to adjust the production of 'y_t' and 'x_t' to benefit from their price changes as much as he could before signing the contract. Since after signing the long-term contract allocated land to 'y_t' and 'x_t' becomes smaller. Therefore, due to loss of flexibility, a higher contract price should be asked by the farmer to compensate his flexibility loss such that at least he becomes indifferent between signing and not signing the long-term contract. In the case above, the inflexibility premium becomes equal to 3.67% of the steady-state price to make the farmer indifferent.

5.3. Sensitivity of Variables Analysis

In this section sensitivity of the results with respect to different choices for the values of the parameters of the model are considered. [7]

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[7] See appendix III.

5.3.1. Price Variability Analysis

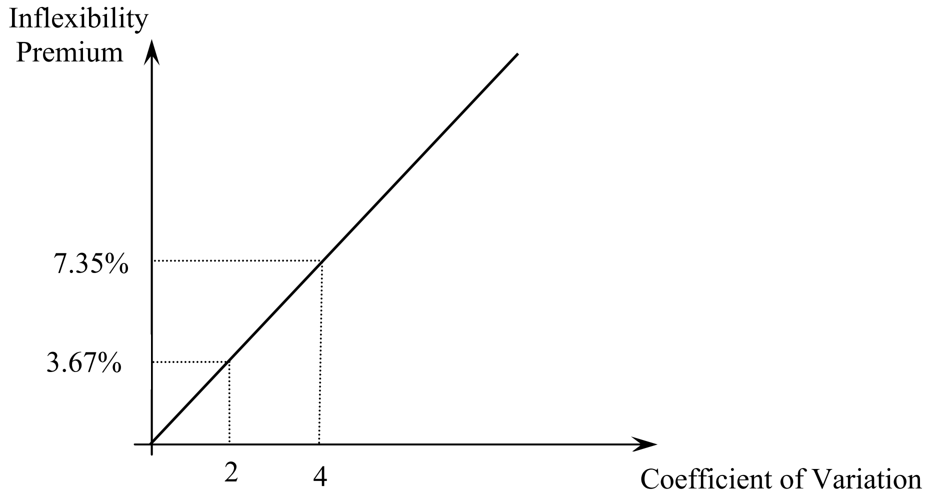
- Greater Price Variability for 'y_t' and 'x_t' Crops

If we set a greater value for the price variability of 'y_t' and 'x_t' – the crops that the farmer used to produce before signing the contract and under the contract he continues to produce but on the smaller acreage of land – and keep the other parameters of the model the same as the base case, the inflexibility premium will increase compared to the base case, and the optimal contract price should be equal to 2.15 for a doubling of the price variability of both crops. This means the cellulosic ethanol firm must include an inflexibility premium equal to 7.35% (compared to the base case evaluation of 3.67%) of the steady-state price of cellulosic plants to induce the farmer to sign into the contract. Therefore, higher price variability of 'y_t' and 'x_t' crops results in higher inflexibility premium.

The economic intuition for this result is that the farmer adjusts his production more frequently when the price variability of the crops is higher since he wants to gain from the price differences. Under this scenario, if 'y_t' and 'x_t' crops have higher price variability before signing the contract, the farmer will lose more opportunities of adjusting his production with respect to the changes in prices and therefore asks for a higher inflexibility premium in order to sign the contract.

To graph the comparison between the base case and the case after increasing the price variability of both 'y_t' and 'x_t', we use the concept of the coefficient of variation. The coefficient of variation is useful because it represents the standard deviation of prices in the context of their mean. It can be calculated by dividing the standard deviation by the mean.

Figure II - Relationship between the Size of Inflexibility Premium and the Coefficient of Variation



- Greater Positive Correlation Coefficient between the Prices of 'y_t' and 'x_t'

If we set the value of correlation coefficient between the prices of 'y_t' and 'x_t' to its highest value, plus one, such that the prices of both crops have a perfect positive linear correlation, and keep the other parameters of the model the same as the base case, the inflexibility premium will be equal to zero and the optimal contract price becomes equal to 2 for a change from independent price changes to the perfect positive linear correlation of the prices. This means the cellulosic ethanol firm does not have to add to the steady-state price to induce the farmer to sign the contract. Therefore, there is no need for compensation when there is a perfect price correlation.

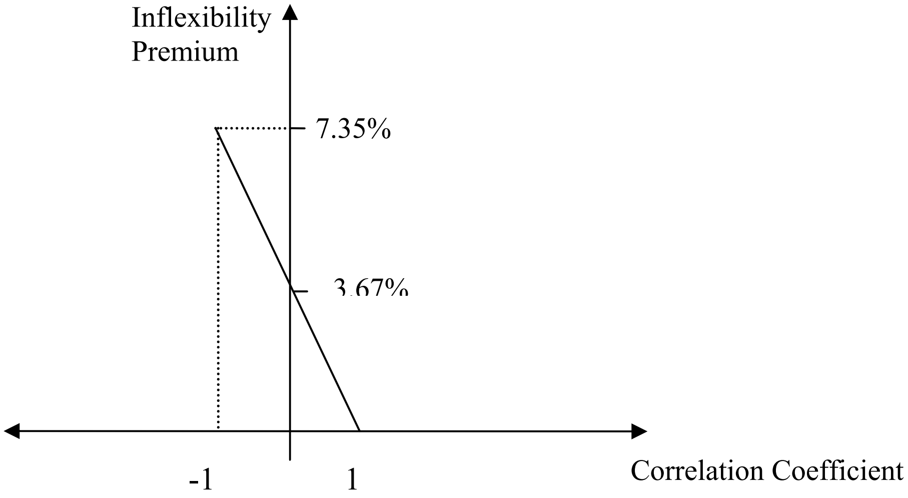
The economic explanation for this result is that when there is a perfect positive linear correlation between the prices of 'y_t' and 'x_t', the farmer does not have any incentive to adjust his production to gain more. This is because if the price of one crop goes up/down, the price of the other crop also moves in the same direction and therefore the relative prices does not change. When the correlation between prices is equal to its maximum of one, it is equivalent to farming with just one crop. Therefore, the relative prices will not change at all and the farmer requires no adjustments to the relative productions. As a result, when he signs into the long-term contract, when the correlation between the prices of the crops is large enough, loss of flexibility is not a major issue for the farmer since there is no substitution between crops and therefore, he asks for no inflexibility premium.

- Greater Negative Correlation Coefficient between the Prices of 'y_t' and 'x_t'

If we set the value of the correlation coefficient between the prices of 'y_t' and 'x_t' equal to minus one, which means there is a perfect negative linear correlation between prices of 'y_t' and 'x_t' and they do not vary in the same direction, and keep the other parameters of the model the same as the base case, the inflexibility premium will be at its highest level, and therefore higher than the base case. The optimal contract price becomes equal to 2.15 for a change from independency to a strong negative linear correlation of the prices. This means the cellulosic ethanol firm must add 7.35% to the steady-state price (compared to 3.67% in the base evaluation) to induce the farmer to sign the contract. Therefore, the compensation required is much higher when there is a strong negative linear correlation between the prices of crops, 'y_t' and 'x_t'.

The economic explanation for this result is that when there is a stronger negative linear correlation between the prices of 'y_t' and 'x_t', the farmer has strong incentive to adjust his production to gain more from price variability of crops. Because if the price of one crop goes up/down, the price of the other crop moves in the different direction, down/up. Therefore, when the correlation between prices is at its minimum, the relative prices change significantly and the farmer requires more adjustments to his relative productions. As a result, by signing into the long-term contract when the correlation between the prices is small enough, loss of flexibility is a major issue for the farmer and therefore, he asks for much higher inflexibility premium compared to the base case.

Figure III - Relationship between the Size of Inflexibility Premium and the Correlation Coefficient



5.3.2. Discount Rate Variability Analysis

If we set the discount rate to a very high number and keep the other parameters of the model the same as the base case, the compensation required will be less than the base case and the optimal contract price becomes equal to 2.05 for a 0.9 unit increase in the discount rate from 0.05 to 0.95. This means that the cellulosic ethanol firm must add 2.31% to the steady-state price (compared to 3.67% in the base evaluation) to induce the farmer to sign the contract. As a result, a greater discount rate substantially reduces the amount of the compensation required.

The reason behind this result is that under a very high discount rate the farmer heavily discounts the future profits, and accordingly future adjustments in relative productions, are of substantially less importance in terms of the present value of the profits.

5.3.3. Adjustment Cost Variability Analysis

If we set the coefficient for the adjustment cost, γ, to a higher number and keep the other parameters of the model the same as the base case, the compensation will be less than the base case and optimal contract price becomes equal to 2.03 for a doubling of the coefficient of the adjustment cost. This means that the firm must add only 1.55% to the steady-state price (compared to 3.67% in the base evaluation) to induce the farmer to sign onto the contract. Therefore, greater adjustment cost results in lower compensations requested for the loss of flexibility.

Economic intuition behind this result is that when it is highly costly for the farmer to adjust his production due to changes on relative price, loss of this flexibility is not worth much to the farmer since naturally the farmer is not enjoying the adjustments at a high cost. As a result, he requires less inflexibility premium compared to the base case. It can be the case that if the coefficient for the adjustment cost is set high enough then the farmer does not ask for inflexibility premium at all.

5.3.4. Production Cost Variability Analysis

When we set a high value for the production cost coefficient, β, meaning that production is more costly than the base case, and keep the other parameters of the model the same as the base case, the inflexibility premium required becomes higher than the base case and the optimal contract price becomes equal to 2.08 for a doubling of the coefficient of production cost from 0.25 to 0.5. This means that the firm must add 4.02% to the steady-state price (compared to 3.67% in the base evaluation) to induce the farmer to sign onto the contract. Therefore, higher production cost increases the requested inflexibility premium.

The economic intuition behind this result is that at the presence of the same adjustment costs, a higher production cost coefficient means more curvature in the static marginal production cost resulting in higher gains in profit from changes in relative production of crops in response to changes in their relative prices. Therefore, for any given price change, the farmer is able to gain more from changing the relative production of the crops in response the relative price change as he could with lower production cost coefficient. As a result, a greater production cost function coefficient (more curvature in or steeper marginal cost) is associated with higher inflexibility premium demanded by the farmer.

5.3.5. Changing the Length of Contract

If we stepwise decrease the duration of contract to twenty, ten, and five years, while keeping the other parameters of the model similar to the base case, the value of maximized expected discounted profits (the value function) under contract increases by the decrease in the length of contract until it equals the value of the maximized expected discounted profits without a contract at five years length of contract.

Thus, the optimal contract price decreases as the length of contract decreases. Or the other way around, as the length of contract increases the optimal contract price increases smoothly, which means that the cellulosic ethanol firm must increase the inflexibility premium in order to induce the farmer signs into the contract if it is looking for a longer contract. Therefore, longer contract is associated with higher inflexibility premium.

The economic intuition for this result is that the farmer looses more flexibility when the length of contract is extended. Because as the length of contract increases the farmer has to respond to the price variability of ‘ y_t ’ and ‘ x_t ’ on a smaller land for a longer time, so that he is losing part of his flexibility for a longer time. Therefore, as the length of contract become longer, the farmer will ask for a higher inflexibility premium in order to sign the contract due.

Chapter VI - Conclusion

6. Conclusion

The issue of energy is front-page news these days as a result of two challenges: oil dependency and global warming. Oil dependency, although an old issue, has become more of an issue due to lower proven levels of oil reserves around the world and higher oil prices. Global warming, however, is a much more urgent matter compared to the issue of oil prices and is subject to more serious challenges that we are facing today.[8] These challenges have made the alternative renewable fuels highly appealing to governments, environmentalists, and foreign policy activists in the hope of reducing the consumption of fossil fuels and reducing greenhouse gas emissions.

During the recent few decades, corn ethanol has been at the heart of farmers', governments', and scientists' attentions. But its image has been fainted with the technological and economical disadvantages associated with it and its place is taken by another kind of ethanol, cellulosic ethanol, which is relatively cleaner and is not based on a food source. However, in spite of the advantages of cellulosic ethanol over corn ethanol, it has not yet been as commercialized as corn ethanol. During this research, we focused at one of the likely issues in the supply-chain of the cellulosic ethanol that seems to have played an important role in the inability of the cellulosic ethanol industry to enhance its establishments and expand its market.

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[8] Scientists have found out if the trend of warming the earth continues at the same rate as today 60 percent of species around the world could die by the end of the 21st century (Stern, 2006**)**.

Commercial production of cellulosic ethanol requires huge amount of cellulosic feed-stock, like switchgrass, that is supposed to be produced and supplied by farmers. Due to being an emerging industry in need of financial stability and input security for growth and maturity, cellulosic ethanol industry is highly reliant on being able to attain the stability and security through long-term contracts with farmers. Signing long-term contracts with farmers will ensure the supply of the required cellulosic feed-stock in a cost-efficient way that guarantees the financial stability at the same time.

On the other hand, however, risk neutral farmers generally prefer to perform with either no contract or short-term contracts in order to preserve their flexibility to response to future price changes by changing their relative productions in order to make a better use of their opportunities. As a result, the farmers are reluctant to lock themselves in long-term contracts and lose their flexibility unless they are compensated for the loss in expected profits due to the loss in their flexibility.

Along this research, the necessity of the "inflexibility premium" that is essential for establishing long-term relationships between the cellulosic ethanol firms and the farmers of cellulosic feed-stock, was illustrated through solving and numerically evaluated a stochastic dynamic programming model of farmer behaviour under a contract. The inflexibility premium is essentially defined as the percentage increase over the steady state price of a substitute farm product that has to be added to the contract price of the cellulosic feed-stock in order to induce a risk neutral farmer to sign a long-term contract with the cellulosic ethanol firm.

The solution to the inter-temporal model of farmer's decision behaviour and numerical evaluation of the model implies that the inflexibility premium has to be considered in the contracts in order to establish long-term relationships between farmers and cellulosic ethanol firms. Furthermore, it has been shown that the size of inflexibility premium is increasing with the length of contract and is quite sensitive to the parameters defining price uncertainty and the elasticities of crops substitution.

Understanding the sensitivity of the inflexibility premium with respect to parameters that are subject to economic policy, which has been the core objective of this research, could have a crucial impact on providing policy considerations that directly improve the benefit of the contractual parties through generating incentives for establishing a more stable and secure supply-chain, providing the incentives for further investments in the industry, and essentially maintaining or improving the welfare of the farmers. In addition, by improving long-term stability of energy market based on renewable sources and reductions in greenhouse gas emissions, it is capable of having a strong and positive impact on the well being of humanity and the planet. Furthermore, the same approach can be applied around the globe to other biofuel industries and other co-products and have a multiplying positive effect on the ability to tackle with serious environmental challenges ahead.

This research can be extended in two ways. Evaluation of the model can be accompanied by estimation or calibration of the parameters of the model, which will enhance the empirical implications of the research. At the same time, further research to identify other likely barriers to the expansion of cellulosic ethanol industry and similar industries is essential in facing the challenges of the 21 century.

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Appendix I

Explanation on Simon (1956)

Simon (1956) determines the optimal course of actions in dynamic programming under uncertainty. If the payoff function depends both on the strategy selected and on the joint probability distribution of environmental variables with a quadratic criteria function that is negative semi-definite, then the relation between instruments and results are linear and stochastic only by additive random disturbances, and these disturbances have zero expectations. He shows that the case of uncertainty with a quadratic function can be reduced to the case of certainty by replacing the certain future values of variables with their unconditional expectations in the calculation of first period action as if there were no uncertainty.

Simon assumes that the decision maker may have one of the three kinds of information about the future values of certain variables:

1. Might know these future values with certainty,
2. Might know their unconditional expected values,
3. Might know the joint probability distribution of the variables over the whole sequence of future.

The decision maker determines the first period action and then base on the new information chooses the second period action and so on.

In General Programming Method the decision maker knows (3), the joint probability distribution of the variables, but not (1), the certain values in future. The decision maker can determine the optimal action for the first period by using his complete knowledge of the joint probability distribution, and then carry out this action for the next period base on new information and so on periods. With this method the decision maker needs to know (3).

Alternatively, If the decision maker knows (3), the joint probability distribution of the variables, by the law of Iterated Expectation can compute (2), the unconditional expected values, and can behave as if these expected values were (1), certain values. Solving for the latter problem, the decision maker can take the optimal action for the first period and base on that can compute for the second periods and so on. Therefore, the decision maker reduces the uncertainty problem to one of certainty. This method is called Certainty-equivalent Method. In the certainty equivalent method decision the maker does not need to know (3), but only (2).

By definition, no planning procedure can yield a higher expected value of the criterion function than general programming method. Simon shows that the certainty equivalent method gives the same optimal solution to the problem of dynamic programming under uncertainty with a quadratic criterion function as the general programming method.

Theil (1957) generalizes Simon's result for using certainty equivalent to choose the optimal course of actions in dynamic programming under uncertainty with a quadratic criteria function. Simon's analysis is a special case of Theil's model for an inventory problem.

Theil (1957) considers a decision maker having certain variables, to be called instruments, whose values in period t are denoted by $x_1(t), x_2(t), \ldots, x_m(t)$. Also, he is interested in non-controlled variables denoted by $y_1(t), y_2(t), \ldots, y_n(t)$ in period t. The non-controlled variables are subject to simultaneous probability distribution in which the x's enter parametrically. y's are distributed according to $y = Rx + s$ where R is a $T \times T$ lower triangular matrix of fixed coefficients and s is a column vector of $n \times T$ elements whose joint distribution is independent of x.

In addition to the assumptions of the Simon's result, Theil's model requires one more assumption that the variances and covariances of the elements of random elements, s, are independent of instruments, x.

Malinvaud (1969) extends the classical certainty equivalence theorem for a dynamic programming introduced by Theil to very general models and payoff functions. Malinvaud (1969) proves that even if the conditions such as quadratic payoff do not hold but "if the payoff function is twice differentiable and concave in the controlled and uncontrolled variables, increasing in the uncontrolled variables, if the functions defining the model are twice differentiable and strictly concave in the controlled variables, if the random variables are independent of instruments, if a solution exists in the certainty case, then the first-order certainty equivalence holds in its neighborhood if the Hessian matrix of the payoff function is non singular in the certainty case." (Laffont, 1980)

Laffont (1975) relaxes one of the assumptions that was common between Theil, and Malinvaud which was distribution of random elements to be independent of the instruments. Laffont (1975) focuses on the first-order certainty equivalence property for models with random variables dependent on the instruments by using static model.

Laffont (1975) proves that "if the payoff function $U(x, y, e)$ and the functions $g(x, e)$ defining the model are twice differentiable in all their variables, and also the probability density of the random vector, e, is twice differentiable in the instruments, then, when a unique optimal solution exists for the certainty case, first-order certainty equivalence holds if the Hessian matrix of the function $U[x, g(x, e),e]$ is non-singular in the certainty case." (Laffont, 1975)

Appendix II

Proof of Steady State

The steady-state equilibrium of y^{SS} and x^{SS} before signing the contract are going to be:

$$y^{SS} = \frac{p_T - b_T + \beta A + 2\gamma\, y^{SS}}{2(\gamma + \beta)} = \frac{p_T - b_T + \beta A}{2\beta}$$

$$x^{SS} = \frac{\beta A - p_T + b_T + 2A\gamma\, x^{SS}}{2(\beta + \gamma)} = \frac{\beta A - p_T + b_T}{2\beta}$$

Because at the equilibrium the prices are equal we will have $y^{SS} = x^{SS} = 0.5A$

Appendix III

Base Case Parameter Values

Parameters	Values
A	20
p_t	2
b_t	2
β	0.25
γ	1
δ	0.05
σ_p^2	16
σ_b^2	16
ρ	0
Y_0	10
Fixed Cost	15

A : Total Acreage
p_t : Price of y_t at period t
b_t : Price of x_t at period t
β : Coefficient of Production Cost
γ : Coefficient of Adustment Cost
δ : Discounted Rate
σ_p^2 : Price Variability of 'y_t'
σ_b^2 : Price Variability of 'x_t'
ρ : Covariance between the Prices of 'x_t' and 'y_t'
Y_0 : Starting the Production of Y at Period 0
y_t : First Category of Crops that Change under the contract
x_t : Second Category of Crops
Y_0 : Starting the Production of Y at Period 0