LUND UNIVERSITY
School of Economics and Management

Has Brazilian Ethanol Production Displaced Food Crops?

Anders Littorin
Master's Thesis
Department of Economics
Lund University
Supervisor: Joakim Gullstrand
October 2009

Abstract

In this thesis a first order differential supply response model, the Linear Approximate Acreage Allocation Model (Holt, 1999), is used to analyze the competition between ethanol (sugarcane) and food crops (soy, corn, cotton, rice and orange) in Brazil. In this linear multi-crop supply response model total land is assumed to exogenous, leaving the shares to be estimated along with elasticities between the crops. The empirical investigation is performed using Seemingly Unrelated Regression with panel data covering 27 regions over the years 2002 - 2007. Necessary restrictions (such as adding up, homogeneity and symmetry) imposed on the model are briefly treated. Findings indicate that soy has been displaced, i.e. it is a substitute to sugarcane, while other food crops analyzed are compliments.

Keywords: Acreage allocation, Brazil, Bioethanol, Ethanol, Proalcool, Sugar, Supply response

Table of Contents

List of Exhibits

1. Introduction

1.1 Background and purpose of the study

This thesis addresses the issue of how an increased demand for ethanol fuel from sugarcane affects the supply of food crops. Brazil, being the largest producer of ethanol in the world (Hira & de Oliveira, 2009: p 2450), is thereby arguably the most interesting case. Sugarcane is far more efficient as source of fuel than other crops such as corn or rapeseed, and has hence created an increased derived demand for sugar in ethanol production. A state funded program, Pró Alcool (National Alcohol Program), has been driving this development. Brazil has become the world leader both in terms of technology and usage of ethanol as fuel. 80 percent of Brazilian cars are *"flex-fuel"* and can run on any blend between petroleum and ethanol (ibid: p 2451). The aim of the study is to show how the demand for ethanol made of sugarcane affects the allocation of land for food crops in Brazil.

1.3 Problem definition

Brazil has the longest history of large-scale agricultural ethanol production. The impact of this ethanol cropping has been difficult to measure because its expansion has mainly been on existing land and by the fact that sugarcane can also be used for food production (Woods & Black, 2008: p 17). The problem in this thesis is to identify the interaction between Brazil's sugarcane land allocation and that of food crops. This is done under economic assumptions, i.e. those of profit maximizing. Because farmers are assumed to maximize profits over a range of crops and not just sugarcane, the issue is actually relative profits between crops. The problem is thus reduced to how the shares of different crops in Brazil can be estimated, and how their interaction in terms of competition for land can be measured.

1.5 Hypothesis and expectations

Ethanol has been an expanding substitute worldwide for petroleum. Because of the surge in demand for ethanol made from sugar in Brazil, both domestic and foreign, it is expected that it has a relatively negative effect for some crops.

1.6 Delimitations

Although the ethanol industry has been the driver in the expansion of the sugarcane output, it is never analyzed as such. All figures and concepts relate directly to production and allocation of sugarcane. Supply or prices of food on the final goods market is not analyzed. Since the model used compares the factor demand for arable land between actual crops, it is irrelevant what these crops are used for in food production. Therefore, food security (even analysed through crops and not food) relates to population-food-ratios, export rates, distribution of wealth, etc, and is hence beyond the scope of this thesis. Finally, the study encompasses Brazil only. This means that even if general conclusions can be drawn they will still have to be tested empirically outside the data used here.

1.7 Thesis disposition

In chapter 2 the origin and expansion of the ethanol industry is outlined along with the practises of agriculture in general and specifically for the crops analyzed in this study. Chapter 3 treats the previous research efforts on both the field of agricultural supply theory in general and studies on fuel (ethanol) displacing food crops. It is also a preliminary for the theory outlined in chapter 4, where the theoretical framework employed, is discussed. Chapter 4 also emphasizes the usefulness of the model chosen in terms of answering the question whether ethanol expansion in Brazil has displaced food crops. In chapter 5 the theory from the previous chapter is linked to the empiric estimation, while the data used in the study is presenting. Results are presented and analyzed in chapter 6. What conclusions may be drawn from this study, are discussed in chapter 7. This includes how the analysis fared and if the question of this thesis can be answered. Some policy implications are also proposed. Chapter 8 contains some suggestions for further studies on topics related to that of this thesis.

2. Agriculture and Ethanol Production in Brazil

This chapter provides an overview of Agriculture in Brazil. It treats both physical and economical conditions for raising crops as well as the political history of government funding of ethanol production.

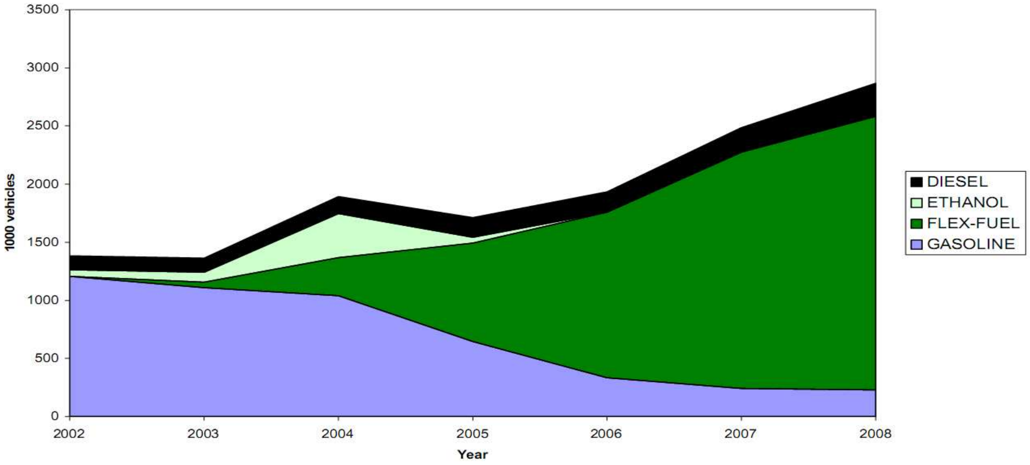
2.1 The Development of the Ethanol Industry

Ethanol as a substitute for petroleum began in 1975 with the ethanol subsidy program, Pro Álcool launched in November 1975. It was created for two reasons. Most important were the negative supply shocks on the oil market during the energy crisis of the 1970s. Brazil opted for energy independence. The other reason is that the sugar industry had recently made large modernization-investments in response to high sugar prices. These prices plummeted in the mid 1970s and the risk of incurring huge losses further induced the need for government funding (Rosillo-Calle & Cortez, 1998: p 115). Pro Álcool is largely responsible for the size of the ethanol industry in Brazil today. Its main effort was to substitute gasoline with ethanol from biomass, e.g. sugar cane, cassava and sorghum, although sugar cane became sole input (ibid). The program did have some achievements. The introduction of new varieties, better field management, improvement on fertilizers, and modernizing harvesting systems, increased productivity. Payments were changed from being based on weight to being based on sucrose concentration forcing the industry to select more efficient varieties. Ethanol production increased from 2400 litres per ha in its early years of the Pro Álcool to as high as 7900 in recent years. (Rosillo-Calle & Cortez, 1998: p 119)

Sugar cane and ethanol prices were liberalized in the 1990's and control on production and stocks were abandoned. The support for ethanol production turned legislative rather than based on direct government funds. The government dictates the particular blend of ethanol in available fuel. In 2001 a cross subsidy on ethanol, in the form of a tax on oil derivatives, was introduced. Flex-fuel vehicles offer the possibility for consumers to choose the cheapest available fuel. Also, environmental concerns have increased significantly since the 1980s and made consumers want to contribute to a reduction of greenhouse gases and pollution (Ozorio de Almeida, 2009: 12). The evolution of demand for ethanol is illustrated in figures 2.1-2

Figure 2.1

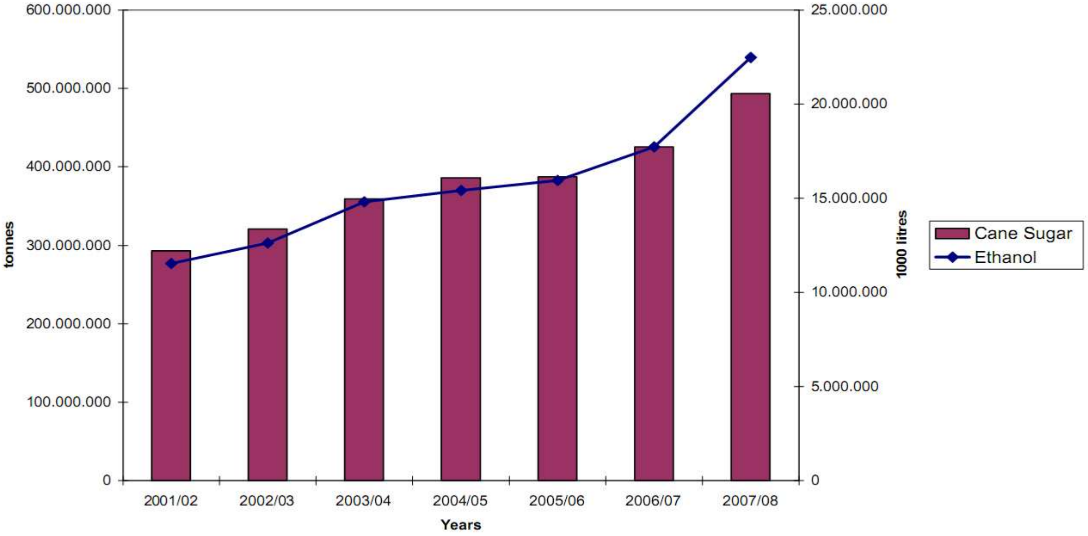
Sales of Motor Vehicles by Type of Fuel



Source: Associação Nacional dos Fabricantes de Veículos Automotores- ANFAVEA.

Figure 2.2

Production of Sugar Cane and Ethanol in Brazil



Source: União da Indústria de Cana de Açúcar- UNICA.

2.2 The structure of Brazilian farming

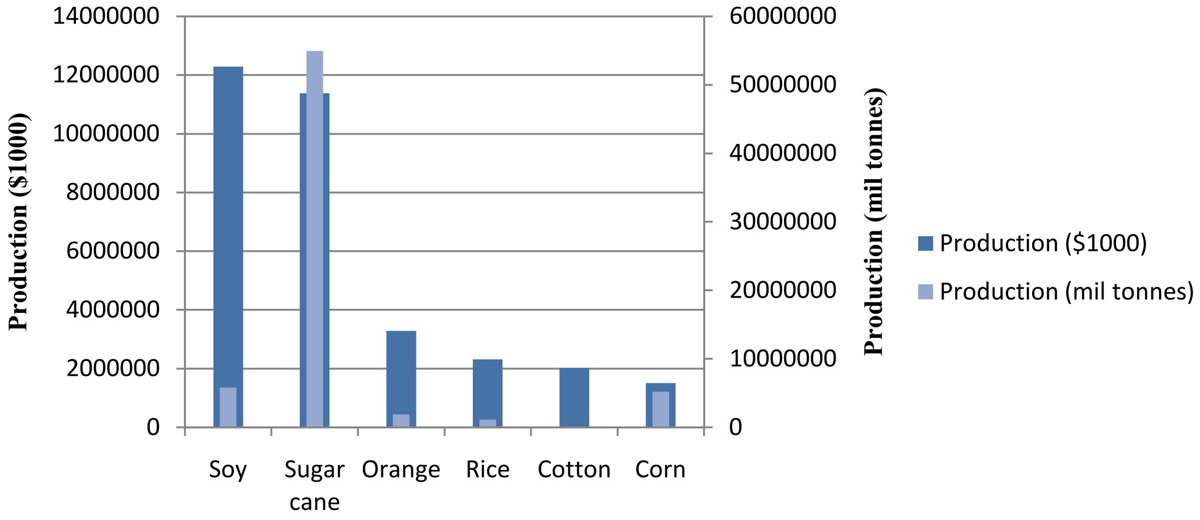
Covering nearly half of South America, Brazil is its largest country comprised by 26 states grouped into five regions, the North, Northeast, Central-west, Southeast and South region. Spanning a vast area with great variations in climate and soil, a great diversity of agricultural production take place. It is mainly divided between technically advanced harvesting of export-crops, and low-technology production of food crops mostly for domestic consumption (FAO, 2004: p 2). There are almost five million farms in Brazil, most of which are located in the Northeast, South and Southeast. Most farms are small, half of them under 10 ha and 90 percent smaller than 100 ha (FAO, 2004). Crop rotation, the sowing of crops in special rotation schemes over seasons, is an important practice in Brazil. Soybean, for instance, fixes nitrogen directly from the air. It is the most important crop in no-till areas in Brazil since it has the highest effect in soil fertilization. A common scheme of rotation is between soy and corn (Mello & van Raij, p 54), but cotton and wheat also benefit from being sowed after soy (USDA, 2008).

2.3 Major Crops and Competition for Land

The choice of what crops to include in this study is based on their market size. The two biggest crops raised in Brazil are soy and sugarcane. Orange, rice, corn and cotton follow, albeit at considerably lower production levels. (Recent production levels are shown in figure 2.3)**.** These are all market crops with large shares being exported (FAO website, 2009). They are therefore expected to react to price changes with corresponding changes in allocation.

Figure 2.3

Production levels in Brazilian Agriculture 2007

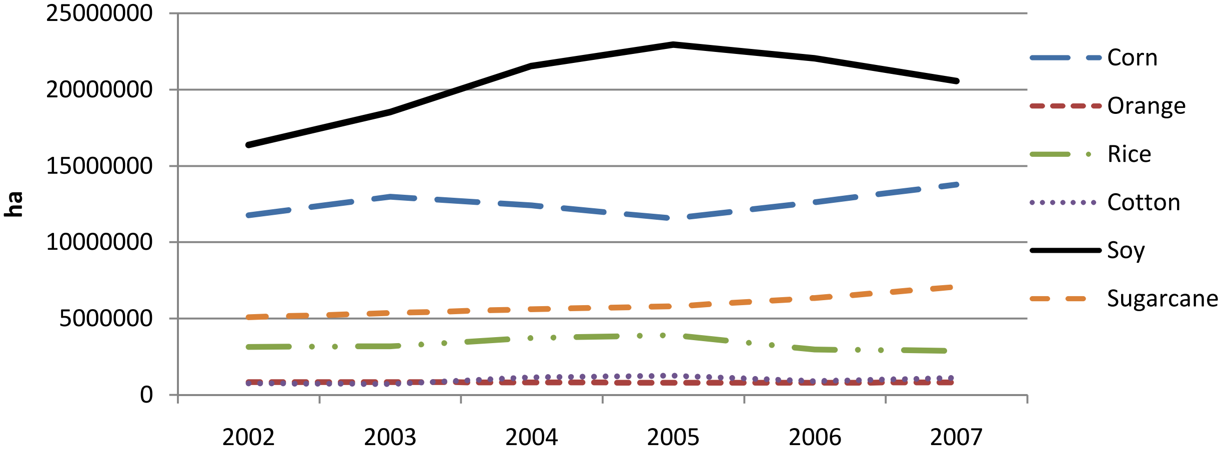


source: FAO website (2009)

Recent acreage levels are displayed in Figure 2.4. Sugarcane has continously emplyed more and more land between 2002 and 2007 while most other crops show an ambiguous development.

Figure 2.4

Acreage levels for major crops in Brazil



(Source: FAO website, 2009)

The production of sugarcane in the Center-South region is dominated by the state of Sao Paulo, which alone accounts for sixty percent of the country's sugarcane production. The harvest season is normally May through November. The North-Northeast accounts for less than 20 percent of Brazil's sugarcane production. Here harvest season is September through April. Production in this region is less mechanized than in the Center-South and production costs are generally higher. In the south east of Brazil sugar cane is planted from October to March and harvested from May to October. In the north it is planted from July to November and harvested from December to May (Bolling & Suarez, 2001: p 15). Sugarcane cropping is generally resource intensive. Only those with access to cash or credit, irrigation and good water supply, fertilizers and pesticides can raise the crop. The plant requires steady irrigation and grows for a significantly longer period of time than other crops with the first harvest usually being possible after one year to 18 months. Many subsistence or small farmers are thus unable to farm sugarcane because of insufficient tools. Also, payments for sugarcane are often delayed until the harvest has been crushed at a sugarmill. Therefore, only farmers with the means to survive with long outstanding payments can farm sugarcane (Special Unit for South-South cooperation, 2009). Sugarcane is also a perennial plant which means it lives for several, sometimes up to six years (Kutas, 2009). FAPRI (2009, p 20) suggests that sugarcane competes less, compared to corn, for land with other crops (FAPRI, 2009: p 20). The sugarcane that is expanding into the state of Sao Paulo, has also been known to displace citrus (*Bolling & Suarez1, 2001: p 14).*

Cultivation of soy in Brazil is primarily for production of feedstock as soymeal, mainly for exports. Planting season for Soy starts in October and ends in the middle of December, November usually being ideal time for planting (Mark Schultz, 2007). Crops competing for land are cotton, rice and wheat (Moraes, 2006: p 2) but also sugarcane (Gröna Bilister, 2006: p 6 and Tokgoz & Elobeid, 2006, p 42). With favourable weather, soy allows for double-cropping i.e. planting and harvesting a second time within the same year. Such double-cropping is possible in parts of the center-west and the south (Schnepf, Dolman & Bolling). Corn is also largely a feedstock product. It is planted through September to November in the north and harvesting season is February to April. In the north planting takes place between December and January and harvesting May to June (Conab 2009, p 13). Double-cropping of corn after early soybeans is fairly common in the state of Parana and is rapidly expanding into the Center-West (Schnepf & Bolling, 2001: p 8).

Cotton has traditionally mostly been produced in the South and Northeast, but in the past decade cotton production has been increasing in the Center-West. The planting season is December to February and harvest season is between May and August (Conab 2009, p 9). Cotton is known for rotating with soy, corn and wheat, but without any large increase in yield (Burmester, Reeves & Motta, 2002: p 357). It also requires specific equipment. The purchase of cotton gins[1] and special harvesters means farmers are sometimes committed to cotton even though other crops may be more profitable (USDA, 2008).

Rice production in Brazil has two types of irrigation, mechanized (upland) and irrigated by flood (lowland). The latter is more productive and hence applied more often, representing 65 percent of rice cultivated area, the rest being flood irrigated. Mechanized irrigation has lower costs however. It leads to fewer harvesters getting stuck in the mud, as the fields are kept dry and it also automatically prepares for crop rotation (Valmont Industries, 2009). Rice is planted from November to January and harvested between March and June (Conab 2009, p 10).

---

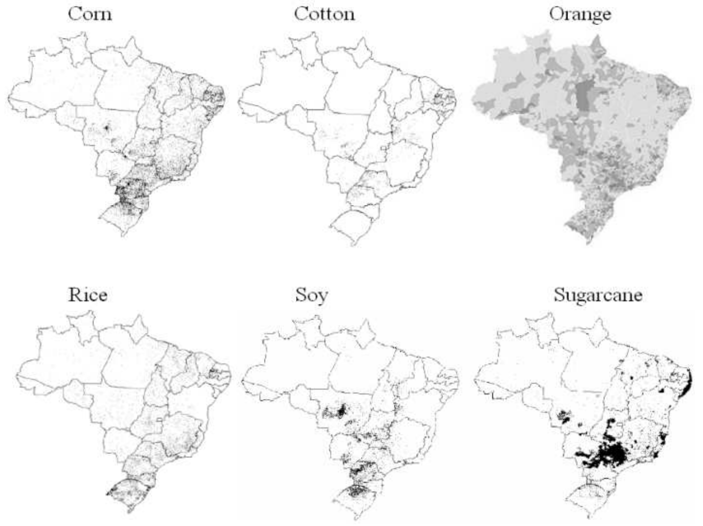
[1] A cotton gin is a machine used to separate cotton fibers from its seed

Brazil is a big producer of orange. It faces growing demand on the international market where it is the biggest exporter of orange juice in the world accounting for about 80 percent of global trade (Gonzales, 2007). Only about twenty percent is sold as oranges in natura, while the rest is crushed into orange juice (Paullilo, 2008: p 12). Farms owned by processing companies have high technological levels, as do the large independent farms. They use technology to increase the density of orchards[2] and to improve the quality of seedlings. Irrigation and fertilization is also more advanced and they hence achieve higher yields. Small and medium farms have lower technological level, usually with older orchards more susceptible to disease (Paullilo, 2008: p 15). The industry consists of vertically integrated companies where logistic bottlenecks have been eliminated by large investments in storage facilities, transport systems and own boarding terminals. Both independent orange growers as well as processing companies have the capacity to quickly expand production in case world demand for concentrated orange juice increases. (Paullilo, 2008: p 21).

The geographic distribution of the chosen crops is not entirely homogeneous. It varies across regions and is sometimes very highly concentrated within limited areas. It is summed up in figure 2.5 below, where dark shades indicate higher production.

Figure 2.5

Geographical distribution of Agricultural Production in brazil



source: Compilation from Nassar (2008) and BVS Ministério da Saúde website (2009)

---

[2] An orchard is a plantation of trees or shrubs intended for food production

The great diversity in soil, climate and land use also lead to varying rates consumptions of fertilizers in agricultural production. More importantly, they vary across crops, both in proportion and absolute volumes, which relates to cost structures of different agricultural enterprises. The consumption rates of three different fertilizers are shown in figure 2.1. It is noteworthy for instance that cotton consumes three times the total value of corn.

Table 2.1

Fertilizer consumption by crop (kg/ha)

	Nitrogen	Phosphate	Potash	Total
Cotton	83	130	122	335
	24,78%	38,81%	36,42%	100,00%
Rice	27	35	20	82
	32,93%	42,68%	24,39%	100,00%
Sugar	55	51	110	216
	25,46%	23,61%	50,93%	100,00%
Orange	55	24	45	124
	44,35%	19,35%	36,29%	100,00%
Soy	8	66	62	136
	5,88%	48,53%	45,59%	100,00%
Corn	40	35	33	108
	37,04%	32,41%	30,56%	100,00%

source: Compilation from FAO (2004, p 34-35)

As a result of agricultural expansion, reliance on fertilizers has grown recently. Brazil imports between 50 and 100 percent of important fertilizers demanded by the industry (Paullilo, 2008: p 20).

3. Previous Research

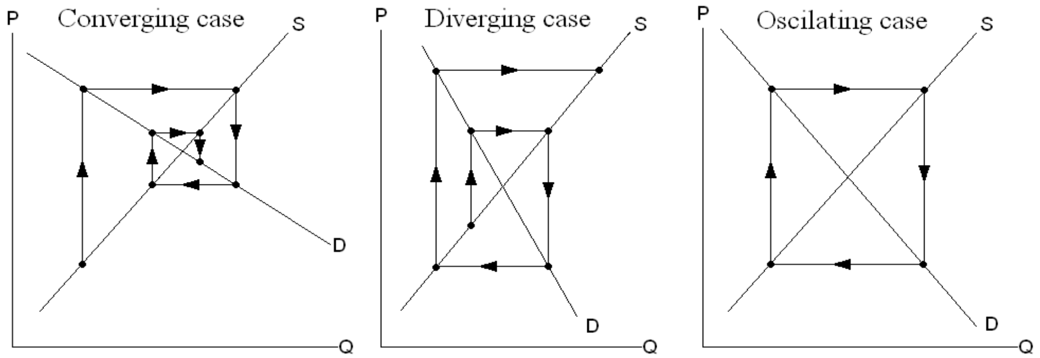
This chapter introduces some of the models from Supply Response Theory in agriculture. Some of these are preliminaries for the theoretical framework in the chapter 4. More specific studies of competition between energy crops and food crops are mentioned.

3.11 Agricultural Supply Response theory

The study of agricultural supply often involves the concept of *supply response.* This means simply, how does supply respond to price changes? Often the measure used in the end is simply a price-elasticity, relating change in production to change in price. Common to all approaches is the task of estimating how much should be planted of a crop in one specific period, when it is to be sold only after considerable time has passed. The supply (often measured in cultivated land) thus responds to prices, either only its own or that of other crops. Input prices may be involved as well. An early model approaching this problem is the Cobweb-model introduced by Hanau (1930) who modelled supply and demand on the pig market, but the model has since been applied to crops as well. It illustrates the problem in a straightforward way. Suppose a farmer has a time lag between decided acreage and the time of marketing her crops. If she does not get as high a price as expected, she may conclude that the market is over-supplied and reduce later sowings (Capstick, 1970: p 88). Hanau found that prices reflected current production, while current production was influenced by previous prices (Waugh, 1964: p 732-733), illustrated in figure 3.1 where D is present price curve (demand) and S is lagged ouput curve (supply).

Figure 3.1

The Cobweb Model of Agricultural Supply Response



Source: Waugh (1964: p 736)

If the lagged output curve is steeper than the price curve, the model will converge toward the equilibrium price and quantity. Conversely, it will diverge if the reverse is true, and move away from equilibrium in each period. If they are equally steep the pattern will simply oscillate and equilibrium production is never reached (Waugh, 1964: p 735).

This may be illustrated algebraically by using the following notation for supply and demand

price: $p_t = -aq_t$
lagged output: $q_{t+1} = bp_t = baq_t$

where a and b are coefficients and t are subscripts denoting time periods. A recursive solution to the second expression has the appearance

$$q_{t+2} = -abq_{t+1} = (ab)^2 q_t$$
$$q_{t+4} = -abq_{t+2} = (ab)^4 q_t$$

……………………………….

$$q_{t+2k} = -(ab)^{2k} q_t$$

The three cases from figure 3.1 can now be described. If $(ab)^2 > 1$ the system converges. If $(ab)^2 > 1$ it diverges. For $(ab)^2 = 1$ is oscillates. (Waugh, 1964: p 736)

The cobweb is maybe the simplest recursive model in all of economics. Often the interesting property of a variable in this model is how far away it is from its equilibrium, or its time trend (ibid), which may give useful information about a particular market. It relies on lagged values to predict production, but also assumes static supply and demand curves which may not be reasonable.

3.12 The Nerlove-model

The Nerlove model of agricultural supply response has been very popular in analyzing supply response. It relies on "distributed lags", i.e. the supply is a function of lagged variables just like in the Cobweb model. It is derived from the following set of equations, relating past prices to expectations for the future (denoted '*')

$$A_t^* = \alpha_0 + \alpha P_t^* + u_t$$
$$P_t^* = P_{t-1}^* + \beta(P_{t-1} - P_t^*)$$
$$A_t = A_{t-1}^* + \gamma(A_t^* - A_{t-1})$$

where A is acreage, P price, α ,γ β parameters to be estimated and u_t a systematic error term. In practice, the expected price for a crop may be approximated by a weighted average of past actual prices (Braulke, 1982: p 241). Unlike the Cobweb model, the Nerlove model assumes farmers adapt to past prices, each one getting gradually less significant the older it is.

While the Nerlove-model has been both successful and persistent, it is not without flaws. In its extensive use it has yielded very varying results (Diebold & Lamb, 1996: p 2). Firstly, least squares estimation may not be very useful as there appears to be risk for multicollinearity between the independent variables, namely between P_{t-1} and A_{t-1}, resulting in errors in the parameter estimation (Braulke, 1982: p 244). Secondly, expectations are assumed to be adaptive (i.e. adapting to past prices) rather than rational. Hence, a random event (hidden to the model) can distort the model. For instance, good weather at harvesting time leads to more plating of the crop. Facing resulting poor market prices, farmers may want to keep more of their output as seed stuff and thereby to expand plantation in the following season. As a result, parameters estimated will err on the low side, causing the true supply elasticity to be underestimated (Braulke, 1982: 243). Finally, like in the Cobweb model, the Nerlove-model and most of its modified versions have not been extended to a system of several crops (Coyle, 1993: p 57).

An important study applying the Nerlove framework is Askari's and Cummings' (1977) field study summing up much of the twentieth century's estimated supply elasticities for various crops.

In Diebold & Lamb (1996) the minimum-expected-loss estimator of the Nerlove-model is modified to allow for better sampling properties.

3.13 Multiple Crops and Risk Aversion

More recently, research has focused on supply response where agriculture is viewed as a multi-input, multi-product industry. Observing risks across crops has improved accuracy in measuring supply response.

Bettendorf & Blomme (1993) incorporates these features in their model. They assume that acreage allocation in Agriculture is decided the same way an investor composes a portfolio of different assets given fixed interests. Covariance between yields and prices is included in their profit maximization function. They apply a first-order differential acreage allocation model, which means it is linear and a first order conditions (FOC) yields the optimal solution. Estimates of price and scale elasticities are shown to be attainable from their model. They study acreage allocation of eight crops in Belgium over two time periods, 1900-1913 and 1919-1939. No R^2 values are given but 25 out of 64 elasticities were highly significant.

Another approach is Coyle (1993) who emphasizes and explores the concept *weak separability*, which in this case means that crops over time are not bound to specific strips of land but rather shares a total acreage (ibid: p 59). This is a central issue in profit maximization between different technologies (crops). To illustrate its meaning the opposite, strong separability, is first defined. Profit maximizing in two separate industries A and B may described by the expression

$$\pi(p,w,z)=\pi_A(p_A,w_A,z_A)+\pi_B(p_B,w_B,z_B)\,.$$

where (subscripts denoting total values or for industry A or B alone) π is profit maximum of a linear homogeneous function, p output price, w is input price, and z total available land.
total profit, that of industry A and that of industry B, respectively. Two separate maximization problems are thus posed. The sum of these yields total profit. In hope of improving on efficiency, weak separability is less restrictive in terms of resource (land) usage (allocation). It is defined as

$$\pi(p,w,z)=\pi(\pi_A(p_A,w_A,z_A),\pi_B(p_B,w_B,z_B))$$

which means that profit is maximized jointly between sectors, specifically regarding total available land $\bar{z}=\bar{z}_A+\bar{z}_B$. This allows for a larger profit assuming risk aversion. It is also a necessary restriction in a model where total acreage is budgeted between enterprise groups A and B (Coyle, 1993: p 59).

Coyle (1993) also uses the concept of duality. It may be explained as follows. Any concept defined in terms of a production function has a dual defined in terms of a cost function, and vice versa. More precisely this means that given any technology, the cost function is found by simply solving the cost minimization problem. By applying duality, this process can be reversed. Thus, given any cost function, the technology that could have generated it (as a minimum cost) can be solved for (Varian, 1995: p 81). Using Coyle's notation (1993, p 58) a farmer faces the maximization problem

$$\begin{aligned}&\max_{(y,x,z)\in T(K)}\sum_{j=1}^{m}p^j y^j-\sum_{i=1}^{n}w^i x^i=\pi(p,w,K,\bar{z})\\&s.t.\sum_{j=1}^{m}z^j\le\bar{z}\end{aligned}\qquad\text{(equation 3.1)}$$

where the new variables K and y are quasi fixed capital and yield respectively. The dual profit function to this problem is defined as

$$\max_{(y,x)\in T(K,z)}\sum_{j=1}^{m}p^j y^j-\sum_{i=1}^{n}w^i x^i=\pi(p,w,K,\bar{z})\qquad\text{(equation 3.2)}$$

Interpreting (3.1) in terms of (3.2) yields the profit function

$$\begin{aligned}&\max_{\bar{z}\ge0}\pi(p,w,K,z)=\pi(p,w,K,\bar{z})\\&s.t.\sum_{j=1}^{m}z^j\le\bar{z}\end{aligned}\qquad\text{(equation 3.3)}$$

where profit is decided through acreage allocation and with first order conditions for an interior solution: $\partial\pi(p,w,K,z^*)/\partial z^j = \partial\pi(p,w,K,z^*)/\partial z^i$

The profit maximization problem is used as assumed microeonomic behaviour to solve for the acreage allocations. Specifically, Coyle (1993) applies the model to acreage allocation for three crops, wheat, barley and rapeseed, in Western Canada during the period 1961-84. R^2 for the equations describing the crop acreage allocations were (in the same order) 0.966, 0.899 and 0.825.

In Holt (1999) the process of reversing the optimization problem by finding its dual, is approached using linear algebra. Reallocating a matrix representing cost restraints from the left hand side to the right hand side of the system of equations, yields a vector representing acreage allocation under assumptions similar to those given in equations 3.1-3, namely the assumption of profit maximization. Also, both Coyle (1993) and Bettendorf & Blomme (1994) use rather long time-series in their estimations. Holt (1999) allows for cross regional panel-data to be used in a first-order differential acreage allocation system, without violating any necessary restrictions posed on the model. This means that shorter time series or cross regional panel-regressions can be used in estimation. The model is applied to state-level panel data for the U.S. Corn Belt region during 1991-95. R^2 for the equations modelling corn, soy and 'other' were 0.810, 0.854 and 0.920 respectively.

3.2 Competition between energy crops and food crops

Rathmann, Szklo & Schaeffer (2009) analyzed how biofuel (from sugar and soy) in both the United States and Brazil competed for land against other crops. In Brazil, they suggest Sugar Cane has in some areas systematically replaced soy having the second order of increasing its price (ibid, p 15). More directly, they suggest that the increase in ethanol fuel demand in the state of Paraná has pushed up prices so for sugar cane that areas used for less profitable products have been displaced (ibid, p 16).

Perrin (2008) studied the effect of ethanol production on food prices through three different economic simulations. His conclusion is that Ethanol production from corn in the United States has contributed to 30-40 percent of the increase of grain prices over a two year period. He further extends his analysis beyond the market of food crops and into the actual food market (which is not the intention of this thesis). In that respect, the figure is closer to one percent in the United States, but in food insecure areas of the world as high as 15 percent (related only to Production in the United States).

Collins (2008) performed a survey study on how demand for bio-fuels affects food crops, focusing on corn. He suggests that quantifying price changes of corn in terms of ethanol demand is difficult, which has led to varying results in previous studies (ibid, p 12). He further argues that results vary not only with the different methods used to measure these impacts, but with time periods investigated as well (ibid: p 13). One method employed was studying price effects (on corn and ethanol) based on other fields of economic study, e.g. how tax reductions will affect production of the two commodities. A number of retrieved values allowed for the construction of multipliers describing the effect of corn use in ethanol production. The results showed that price of corn due to the increase in corn use in ethanol would vary between 25 to 50 percent, over the period 2006/07 - 2008/07 (ibid, p 13).

A field study on Brazil's food shortage was undertaken by Rosillo-Calle & Hall (1987). They conclude that there is no evidence to support the view that ethanol production from sugar has affected food production, but that the problem lies in a failure of economic policies in general and agricultural policies in particular. They claim Brazilian food shortage has had many factors, such as food exports out of proportion, high inflation, currency devaluations, price control of foodstuffs and adverse weather condition (Rosillo-Calle & Hall, 1987: p 123). They also noted that Pró Alcool has inadvertently helped expand production of (land) competing crops. Machinery and equipment used for growing sugarcane have also been used for food crops in the same areas and in rotational practice, benefiting the raising of alternative crops.

4. Agricultural Supply Response Theory

In this chapter, the theory behind supply response in a systems approach, is outlined. It expands on the supply response theory from the previous chapter. First the mathematical foundation of the model is outlined. Following this, interpretations of the results are applied to the dynamics of ethanol versus food specifically.

4.1 The Linear Acreage Allocation Model

The acreage response model used in this thesis is an application of Holt's (1999) Linear Approximate Acreage Allocation Model (LAAAM). The model assumes that farmers maximize their certainty equivalent profit, π, according to

$$\max CE(\pi) = \{a^T r^e - \frac{1}{2}\lambda a^T \sum a \mid a_{tot} - i^T a\} \qquad \text{(equation 4.1)} \qquad \text{(Holt, 1999: p 384)}$$

where a is an $n \times 1$-vector denoting the acreage allocation among n crops.

Σ is a positive definite second moment matrix of expected returns per acre (Holt, 1999: p 385):

$$\Sigma = \begin{bmatrix} \mathrm{var}(r_1) & \mathrm{cov}(r_1, r_2) & \dots & \mathrm{cov}(r_1, r_n) \\ \mathrm{cov}(r_1, r_2) & \mathrm{var}(r_2) & \cdots & \mathrm{cov}(r_2, r_n) \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{cov}(r_1, r_n) & \mathrm{cov}(r_2, r_1) & \dots & \mathrm{var}(r_n) \end{bmatrix}$$

where $\mathrm{var}(r_i, r_j) = E[r_i, r_i^e]$ is the variance of returns for r_i and $\mathrm{cov}(r_i, r_j) = E[r_i - r_i^e][r_j - r_j^e]$ is the covariance of returns between r_i and r_j. A positive (negative) covariance means that the returns move in the same (opposite) direction on the average (Bettendorf & Blomme, 1994: p 54).

r^e is an $n \times 1$ vector with elements

$r_i^e = E(p_i, y_i) = p_i^e y_i^e + \mathrm{cov}(p_i, y_i) - c_i$ (equation 4.2).

p_i^e and y_i^e are expected price and yield per ha, respectively, of crop i. $\text{cov}(p_i, y_i)$ is the covariance between the two and c_i is the cost of production per ha for crop i. Finally, a_{tot} is total available land, so that $a_{tot} = \sum_{i=1}^{n} a_n = i^T a$ where i is a unit vector of size n.

In Holt (1999, p 385) total acreage is viewed exogenous. Therefore, the change of the acreage allocations (for instance through increased yield of some crop) must always equal the sum of the total area. This means that $\sum_{i=1} b_i = 1$ and $\sum_{i=1} s_{ij} = 0$ (ibid, 392).

For a profit maximizing producer, the factor demand function must be homogeneous of degree zero, i.e. the shares of factor inputs do not change if prices are multiplied by some number t (Varian, 1995: p 31). The same must thus be true for the dual, namely that a proportional increase of all allocations will not change their proportions, or formally $\sum_j s_{ij} = 0$. This is known as the homogeneity restriction (Bettendorf & Blomme, 1994: p 55).

Another restriction is that of symmetry, $s_{ij} = s_{ji}$. This means that the effect of the change in the yield of crop j on the area of i is equal to the change in the yield of crop i on the area of crop j (Bettendorf & Blomme, 1994: p 55). Finally, the monotonicity restriction means that all estimated crop shares b must be positive (Holt, 1999: p 394).

It is possible to interpret equation 4.1 in the following way: if the farmer does not pay attention to risks (reflected in the second part of 4.1) then the maximization of her returns would be given by cultivating only one crop, namely the one which has the highest expected yield. But a risk aware (averse) farmer will accordingly seek to diversify the crops in her business (Blomme & Bettendorf, 1994: p 55). The scalar parameter $\lambda \geq 0$ can thus be interpreted as a measure of risk aversion (Holt, 1999: p 385). It will not be estimated however.

Simplifying equation 4.1 with Lagrange notation, the problem for a farmer may be stated as

$$\max\ L(a,\mu) = a^T r^e - \frac{1}{2}\lambda a^T \sum a - \mu[a_{tot} - i^T a] \quad \text{(equation 4.3)}$$

where μ is a positive Lagrange multiplier associated with the constraint of total available land.

For n crops, the n+1 FOC-equations are

$$\frac{\partial L}{\partial a_1} = r_1 - \lambda\big(a_1 \operatorname{var}(r_1) + a_2 \operatorname{cov}(r_1, r_2) + \ldots + a_n \operatorname{cov}(r_1, r_n)\big) + \mu = 0$$

$$\frac{\partial L}{\partial a_2} = r_2 - \lambda\big(a_1 \operatorname{cov}(r_1, r_2) + a_2 \operatorname{var}(r_2) + \ldots + a_n \operatorname{cov}(r_2, r_n)\big) + \mu = 0$$

…

$$\frac{\partial L}{\partial a_n} = r_n - \lambda\big(a_1 \operatorname{cov}(r_1, r_n) + a_2 \operatorname{var}(r_2) + \ldots + a_n \operatorname{var}(r_n)\big) + \mu = 0$$

$$\frac{\partial L}{\partial \mu} = a_{tot} - \big(a_1 + a_2 + \ldots + a_n\big) = 0$$

This FOC-equation system is expressed in matrix notation as

$$\begin{bmatrix} \lambda \Sigma & i \\ i^T & 0 \end{bmatrix} \begin{bmatrix} a \\ \mu \end{bmatrix} = \begin{bmatrix} r^e \\ a_{tot} \end{bmatrix} \qquad \text{(equation 4.4)} \qquad \text{(Holt, 1999: p 387)}$$

Calling this system A*b=c, it is possible to solve for the vector b, by multiplying both sides of the equation by A's inverse, A^{-1}. Because A is only a 2x2 matrix visually, and contains more elements when Σ is given explicitly, its inverse is found by applying matrix-partitioning (Sydsaeter et al, 2005: p 9). Multiplying A^{-1} into both the left and right hand side of equation 4.4 yields the solution

$$\begin{bmatrix} a \\ \mu \end{bmatrix} = \begin{bmatrix} \lambda \Sigma & i \\ i^T & 0 \end{bmatrix}^{-1} \begin{bmatrix} r^e \\ a_{tot} \end{bmatrix} = \begin{bmatrix} \big(\lambda \Sigma^{-1} - \lambda \Sigma^{-1} i (i^T \lambda \Sigma^{-1} i)^{-1} i^T \lambda \Sigma^{-1}\big) r^e + \big(\lambda \Sigma^{-1} i (i^T \lambda \Sigma^{-1} i)^{-1}\big) a_{tot} \\ \big((i^T \lambda \Sigma^{-1} i)^{-1} i^T \lambda \Sigma^{-1}\big) r^e - (i^T \lambda \Sigma^{-1} i)^{-1} a_{tot} \end{bmatrix}$$

Since total land is exogenous in this model, the estimation is made of shares of crops. a is hence divided by a_{tot} to form a new vector v with elements summing up one, given by

$$v = \left((\lambda \Sigma)^{-1} - (\lambda \Sigma)^{-1} i (i^T (\lambda \Sigma)^{-1} i)^{-1} i^T (\lambda \Sigma)^{-1}\right) \frac{r^e}{a_{tot}} + \left((\lambda \Sigma)^{-1} i (i^T (\lambda \Sigma)^{-1} i)^{-1}\right) \quad \text{(equation 4.5)}$$

(Holt, 1999: p 389)

From the estimated parameters, elasticities can be calculated

$$\varepsilon_{ij} = \frac{\partial a_i}{\partial p_j^e e} \frac{p_j^e}{a_i} = \frac{s_{ij}}{v_i} p_j^e y_j^e \quad \text{(equation 4.6)}$$

$$\eta_i = \frac{\partial a_i}{\partial a_{tot}} \frac{a_{tot}}{a_i} = \frac{b_i}{v_i} \quad \text{(equation 4.7)}$$

where p_j^e is expected price for the other crop and y_j^e its expected yield. ε_{ij} is a price elasticity measure that has its regular own price meaning for i = j but measures the cross price elasticity for $i \neq j$, i.e. how acreage changes with a one percent change in price. Similarly, η_{ij} is a scale elasticity that measures the increase in acreage of crop i as total available land increases (Holt, 1999: p 390).

4.2 Ethanol Production and Competition for Land

Elasticities similar to equation 4.6-7, are explained by Bettendorf & Blomme (1994, p 61) as indicating that two crops are substitutes if cross price elasticity is negative. Conversely, if the cross price elasticity is positive they are compliments. This interpretation becomes very useful in answering the question whether ethanol production has displaced food crops. This is natural since production of a substitute for sugar will suffer if sugar production rises. Furthermore, since total area is considered exogenous and the estimated parameters make up only shares of that area, this model should be especially suitable for identifying competition between crops. This means that the model will ignore that total area has expanded during the sample period. Furthermore, since both ethanol and sugarcane were also shown to have increased, any negative cross price elasticity will indicate a relative displacing of a food crop. Comparisons of scale elasticity can also be of use. If total area is increased (decreased), it is interesting to see how acreages of the different crops respond to this, and to compare these responses.

5. Empirical specification

This chapter describes the link between the theory outlined in the previous chapter and the empiric estimation. Data format is also treated. It deals also with the problems and disturbances the model may encounter in implementation.

5.1 Data

The data available covers all 26 states (plus the so called federal region) which amounts to 27 regions over the years 2002 - 2007. The variables used are: yearly production, planted acreage, harvested acreage, average yield and income. Thus, in all 162 observations are used for each crop and variable. These data were obtained from the Agricultural Cencus in Brazil (IBGE). In order to limit the size of the equation system, four outputs are used in estimation. This is accomplished by treating cotton, rice and corn as a single crop. For this figure, acreages are simply added and revenues are added appropriately weighted with regard to acreage.

Detailed producer prices are available for crops, states and year separately. Ratios between future contracts with maturity at harvest time and spot prices at the time of sowing are used to calculate expected producer price p^e, given by $p^e = p^{future} / p^{spot} \cdot p$, where p^{future} is the expected price at time of harvest and p_t^{spot} is price at the time of sowing and p is the local producer price. Expected prices from local commodity markets in Brazil were unattainable. These data are gathered from American sources. Prices of futures contracts from Chicago Board of Trade (CBOT) are used for orange and Internatcontinental Exchange (ICE) for sugarcane. The price for Frozen Concentrated Orange Juice is used instead of the price for orange as they are very well correlated (Market Technologies website, 2009). White sugar (contract no. 11) is used for sugarcane. The contract closest to the forthcoming harvest season is used. Price conjectures for remaining crops were gathered from the Food and Agricultural Research Institute (FAPRI). Since both these sources are American, they rely on price signals and the law of one price. Margarido, Turolla & Bueno (2007, p 16) showed that in the Soybean market the law of one price holds in the long run. Under normal conditions the United States is a price maker and Brazil a price taker. Brazil converges towards a new price after a change in the United States in five to six months. Similar price signalling is assumed to hold for the other crops as well. For the sake of precision the planting and harvesting periods treated in chapter 2 are used as often as possible to identify expected prices.

Calculating expected yield has been done with weights 1/6, 1/3, 1/2 over the last three years. Holt (1999, p 392) assumes farmers ignore historically very high (low) harvests as they are deemed unreasonable in forming expectations, but this feature is absent here. The covariance between price and yield is calculated in the same fashion, with these same weights over three years.

A complete set of production costs for all crops has not been attained. To compensate, a national production cost index is used in the same capacity as a time trend. It is obtained from the Gertuilo Vargas Foundation's (FGVDADOS) public statistics archive. Annual averages are created with monthly time series. This index is expected to capture operating costs like wages and fertilizers as well as costs for quasi-fixed capital such as harvesters. Unfortunately it does so only with regard to time; it will not specialize regionally or for individual crops.

5.2 Econometric Method

The system for empiric estimation of the Linear Approximate Acreage Allocation Model (Holt, 1999: p 392) is specified as

$$v_{ijt} = b_i + \sum_{k=1}^{n} s_{ij} r_j^e + \sum_{l=1}^{27} c_{il} D_l + k_{ijt} C_t + e_{ijt} \quad \text{where i = 1, ..., n}$$

where the parameters to be estimated are b, s and c. v_{ijt} are shares of total land and r_j^e is expected revenue for each crop, as defined in equation (4.2). D is a state-level dummy variable compensating for regional scale effect differences in production. This term must be included in the restrictions in order not to disrupt them. It assumes the value one if the state is represented in the equation and zero otherwise. This will allow for panel data with variations in profit across regions and hence also a shorter time series. C_t is the yearly production cost index and k its corresponding parameter which is of no interest to the study. It does not vary between regions or crops and hence is not subject to any restrictions, not even homogeneity between crops as these may react differently to cost changes. e_{ijt} is a mean zero random error term.

The corresponding restrictions for this equation are:

$$\sum_i b_i = 1, \sum_i s_{il} = 0, \sum_i c_{il} = 0 \qquad \text{(adding-up)},$$

$$\sum_k s_{ik} = 0 \qquad \text{(homogeneity)}$$

$$\sum_i s_{ik} = s_{ki} \qquad \text{(symmetry)}$$

In order to justify the theoretically attractive properties of the LAAAM, these restrictions must of course be realized in its empiric estimation. The issue of imposing (or rather attaining) symmetry is resolved by dropping each parameter s_{ji} from estimation in equation n, if its value s_{ij} (by virtue of symmetry) is already computed in any of the (n-1) previous equations. (When later calculating the elasticities from equations 4.6-7 the values are simply substituted). This handily implies that homogeneity is guaranteed by the adding-up restriction. This is true since the restriction $s_{ij} + s_{ij+1} + .. + s_{ij+n}$ is now equal to $s_{ji} + s_{ji+1} + .. + s_{ji+n}$. Monotonicity is not imposed; it is simply expected. (Some combinations of crops were tried with this restriction ending up violated).

Because the matrix used for final estimation which is associated with the error terms, is singular, one equation is often deleted in estimation and the parameters for this equation can later be retrieved. It is however possible to estimate the system in its complete formulation (Barten, 1969: p 16) which is attempted here. To estimate the parameters of the LAAAM supply response, a standard least squares normal will not be sufficient. The seemingly unrelated variables in the vector a (or v) are not independent of each other. They are connected by the adding up restriction (Haupt & Oberhofer: p 7). Therefore a Seemingly Unrelated Regression (SUR) is applied, which means all equations share a common error term. This SUR-analysis with aforementioned restrictions imposed, was performed using Stata ® 10.0.

Elasticities are estimated using equations 4.6-7 are used. v's are given directly beforehand and the parameters are given in estimation. For the p's and y's their means are used.

5.3 Empirical problems with the LAAAM

In assessing the validity of this study one needs to look at the choice of supply response model and how it is applied. Since it deals with measuring the dynamics between crops with partly common factors (soil and quasi fixed-capital) and with land assumed exogenous it should be good at capturing competition for land. However, weak separability also imples the unrealistic assumption that allocations of a group of crops can be modelled independently of variable and fixed input (Coyle, 1993: p 368) which may violate validity. These inputs are in this case fertilizers and equipment. Fertilizers are perhaps the most harmless of these problems. In chapter 2 usage of fertilizers were shown to vary between crops. It is of course much likelier that these are purchased in accordance with the composition of crops for the season, than the other way around. Nevertheless, they could influence decisions on what crops to raise through price fluctuations or large remaining stocks. More importantly, chapter 2 showed that equipment vary between crops. Sugarcane, cotton and orange all require investment in specific equipment, irrigation and logistics which will tend to make quick changes to capture profits from price changes difficult.

Since all the crops analyzed are market crops, even in a small time frame rational producers will change crops according to demand shifts. All crops except orange and sugarcane have an annual production cycles. This turns attention to the concept of crop rotation, which appears to obstruct the rational profit maximizing behaviour of farmers. In Bettendorf & Blomme (1994: p 60) it is described as an ancient rotation scheme passed on from generation to generation and partly from tradition but also from fear of dislocating the ecosystem. Hence, farmers will only deviate from it slightly. As this study limits itself to six years it may therefore be disturbed by this phenomenon. Also, for sugarcane harvest is delayed at least one year in comparison to the food crops. It is also a perennial plant. While this does not affect decisions on plantation of sugar cane in addition to the present allocation, it does mean that the economic behaviour of farmers is not as dynamic in the short run as with other crops. This will have a negative bearing on reliability as the time frame of the study is rather small.

The distribution of the crops across the country is also relevant. Cross regional panel-data is used, while more than half of all the sugarcane is produced in the state of Sao Paolo alone. This also questions the validity of the model. But a lot of the production is also spread out over small farms and across Brazil, where farmers are assumed to be risk averse and raise several crops on their land.

The fact that revenue is used as a proxy for profit is also a matter of some concern in empiric estimation. It completely neglects the cost structures both between regions and between crops. This is expected to cause some multicollinearity and hence yield less reliable parameters in estimation. Burt and Worthington (1988) for example, in their estimation of acreage response for wheat, omit all prices of all alternative crops due to multicollinearity between prices. However this effect may be partially offset by the production cost index and regionally by the dummy-variables c which capture varying costs.

6. Results and analysis

This chapter contains the results from the regression analysis. Their usefulness and limitations are also analyzed.

Table 6.1 shows the estimates of the SUR-analysis. It contains estimates for all variables in the four equations explaining acreage allocation shares for sugarcane, soy, corn, rice and cotton and orange. Table 6.2 contains cross price elasticities and table 6.3 scale elasticities.

Table 6.1 - Estimated Acreage Allocation Model Parameters[3]

Equation	**Observations**	**Paramters**	**RMSE**	**R-square**	**P-value**
(1) Sugarcane	162	30	0,0330673	0,9839	0.0000
(2) Soy	162	30	0,0514955	0,9582	0.0000
(3) Corn, Rice & Cotton	162	29	0,0657987	0,9297	0.0000
(4) Orange	162	28	0,0255588	0,7947	0.0000
Variable		**Estimate**	**Std. Error**	**t-Ratio**	**P-value**
b_1		.1465888	.0202523	7.24	0.000
b_2		.0696951	.0277793	2.51	0.012
b_3		.7014022	.028991	24.19	0.000
b_4		.0823139	.0179882	4.58	0.000
s_{11}		-6.51e-06	1.93e-06	-3.38	0.001
s_{12}		-.0000257	5.35e-06	-4.80	0.000
s_{13}		.0000284	5.78e-06	4.91	0.000
s_{14}		3.81e-06	1.88e-06	2.02	0.043
s_{22}		-.0000371	5.59e-06	-6.64	0.000
s_{23}		.0000608	6.70e-06	9.08	0.000
s_{24}		2.06e-06	2.99e-06	0.69	0.492
s_{33}		-.0000772	.0000115	-6.70	0.000
s_{34}		-.000012	3.20e-06	-3.76	0.000
s_{44}		6.15e-06	1.88e-06	3.27	0.001

---

[3] The remaining set of parameters are found in the appendix.

Table 6. 2 Cross-price Elasticities

	with respect to			
with respect of	Sugarcane	Soy	Cotton, Rice & Corn	Orange
Sugarcane	-0,101	-0,165	0,144	0,017
Soy	-0,304	-0,182	0,235	0,033*
Cotton, Rice & Corn	0,144	0,128	-0,128	-0,084
Orange	0,081	0,085*	-0,392	0,847

* values are not significant

Table 6.3 Scale Elasticities

Sugarcane	0,811
Soy	0,293
Cotton, Rice & Corn	1,267
Orange	2,931

First notice in table 6.1 that the four equations for each of the crops are all significant in total and fit the data quite agreeably, all yielding high correlation coefficients with orange slightly behind the rest. These results are similar to Holt (1999) and Coyle (1993). Further, the b:s are all positive, sum up to one and are highly significant. Sums of s's show small numbers, close to zero as imposed by the restrictions. In total 111 of the 117 parameters were (often highly) significant.

But some of the results are disappointing. Most worrying is that three out of four s_{ii} are negative. This would mean that an increase in expected revenue acts as a disincentive for production, an obvious impossibility assuming rational producers. This may be explained by the fact that many of the conjectures used, missed the future prices by quite a lot and sometimes in the wrong direction. It can also be explained by the fact that price signalling from foreign commodity stock markets is used and not local expectations. The so called positivity condition (Holt, 1999: p 390), i.e. that $x^T Sx > 0$ for all x's not proportional to i, has not been used because it involves the use of Cholesky factorization. This means that the latter part of equation 4.5 is factorized as $S = C^T C$ upon which it is possible to force coefficients to be positive (negative). The method could have been improved by imposing positive own cross-price elasticities of supply by using this method, but it was omitted due to difficulties in implementation. Another reason is that since the signs of the coefficients, rather their sizes, were sought in this study, it would not be a good idea to tamper with them.

The non-significant parameter s_{24} is probably the result of multicollinearity, and not unreasonable economic assumptions, given the high R^2 values. Multicollinearity has been detected through variations in estimated coefficients when adding or deleting a variable. Further evidence of this is are the mean random square errors which are sometimes quite large and some of the the t-ratios are quite small (Körner & Wahlgren, 2000: p 361).

Revenues being used as a proxy for profits probably caused some of these problems. The covariances were often very small in comparison to the revenues. This could mean that the risk-effect was not allowed to fully enter the system. Also, dummies may not have kept scale differences in complete check since profits are bound to be more varied across regions than are revenues (prices). The coefficient for the dummy would specialize and exploit returns to scale differences, whereas with revenues it will have to compensate for states having high or low costs which are already known in the former case.

But whatever failures the model faced, it still managed to yield significant variables for cross price elasticity of sugarcane with respect to the other crops, displayed in table 6.2. The elasticities in general exhibit a credible range of values. Sugarcane with respect to soy has a cross price elasticity of -0.165, meaning that an increase of 10 percent in the expected price of sugarcane results in a decrease of acreage for soy by 1.65 percent, which makes sugarcane and soy substitutes. As for the other crops, they are compliments, with corresponding values 1.44 percent for cotton, corn and rice and 0.17 percent for orange.

The scale elasticities in table 6.3 are all calculated from significant coefficients, which accordingly only yield positive values. It seems a 10 percent increase in total land results in an acreage increase of 8.3 percent for sugarcane. Corresponding values for soy, cotton, corn and rice and orange are 2.93, 12.67 and 29.31 percent. Sugarcane thus uses up roughly three times the same land given the possibility for expansion, but values for the remaining crops are higher, orange especially.

7. Conclusion

This thesis has attempted to model the competition for land between four crops in order to find out how the expansion of sugar has affected acreage levels for food crops. The LAAAM showed some signs of coping with the task of analyzing the interaction between the chosen crops, given the limited data. With a more substantial data set including production costs for each crop, state and year, it might have performed very well.

The interaction between sugarcane and food crops in Brazil has been modelled with some success. Since the production of ethanol made from sugarcane has steadily increased over the sample period, it is evident that soy has been partially displaced by sugarcane. It is a substitute to sugarcane while orange along with the bundled crops corn, cotton, and rice are compliments. But the unreliable results of the LAAAM estimation in general means this conclusion is not completely trustworthy. It is probably best to limit the answer in this thesis to a qualitative analysis and not put too much faith in the sizes of the calculated elasticities. But doing so, results show that an increase of 10 percent in expected sugar price will decrease soy production by 1.65 percent. As an example, using price projections from FAPRI (2009), this means that soy production decreased two percent in 2007 due to expected higher sugar prices.

The policy implications of the results attained would be that soy and the reliance on soy in terms of export and income for its farmers (or states with especially large production volumes) need to be paid extra attention to when forming policies on ethanol consumption, as its production is bound to suffer. Ethanol production is currently not dictated by the government in terms of production, but in terms of consumption through the minimum ethanol percentage in fuel. Should this be altered, soy production will be affected accordingly. The Brazilian government has in the past made deals with car manufacturers, deciding on mass production of ethanol based vehicles (Journal of Energy Security Website, 2009). Should a policy in this field be altered, it would also affect soy production. Policies outside Brazil, relating to its exports, may affect domestic agricultural production as well. The United States applies a restrictive tariff on ethanol imports from Brazil (The Bio Website, 2009). Should this be removed, the ethanol industry in Brazil is dynamic enough to respond with a significantly increase in production. This means soy would experience increased competition for land.

Regarding land related policies, expansion (contraction) of the chosen crops will not be proportional, as sugar was shown to use up three times as much land as soy when increasing total acreage, albeit less than orange and cotton, corn and rice. This is especially interesting in the case of Brazil as only around 20 percent of its arable land is used (Zuurbier & van de Vooren, 2008: p 108).

8. Further studies

Expansion of sugarcane production due to increased demand for ethanol has been criticized for implicitly causing environmental devastation in the form of deforestation (e.g. Fearnside, 2006 or Klink & Machado, 2005). Food crops have returns to compete with sugarcane for land and are also grown on somewhat similar conditions regarding budgeting. Forest areas will be more difficult to include in a model such as the LAAAM. It would therefore be an interesting challenge to model economic incentives behind deforestation through expansion of sugarcane production in a similar way.

Covariances in the profit function of Bettendorf & Blomme (1994) and Holt (1999) only refer to those between prices of different crops and between prices and yields. It is of course equally conceivable that costs also vary, for instance caused by overseas purchasing of fertilizers through a fluctuating dollar. The value of such a risk term (for instance covariance between cost and yield) could be included in the profit function of a first order differential acreage allocation model such as the one used here. This might be useful in determining acreage allocation with increased accuracy, or when fluctuations in costs are greater than those in commodity prices.

Oil and sugar prices have been shown to be very well correlated. In fact the long term sugar price is actually determined by oil rather than ethanol prices (Rapsomanikis & Hallam, 2006). Considering also that the oil market is much bigger and that projections of oil prices are founded on different (often political) grounds, it might be interesting to see how oil prices themselves affect food supply and the allocation of food crops.

References

Barten, A. P. *"Maximum Likelihood Estimation of a Complete System of Demand Equations."* Eur.Econ. Rev. 1(Fall 1969):7-73.

Bettendorf, L., and J. Blomme. *"An Empirical Study of the Distribution of Crops in Agricultural Land in Belgium: 1900-1939."* Historical Social Res. 19,2(1994):53-63.

Bolling, Christine & Suarez, Nydia R. *"The Brazilian Sugar Industry: Recent Developments",* Sugar and Sweetener Situation & Outlook *(2001)*

Braulke, Michael (1982): *"A Note on the Nerlove Model"*, International Economic Review, vol 23, University of Konstanz, Konstanz Germany

Burt, R & Worthington, V. E. *"Wheat Acreage Supply Response in the United States"* West. J. Agr. Econ. (1988):13:100-11.

Burmester, C. H., Reeves, D. W., Motta, A. C. V (2002): "*Effect of crop rotation/tillage systems on cotton yield in the Tennessee Valley area of Alabama, 1980-2001"*

Capstick, Margaret. *"The economics of Agriculture"*, George Allen & Unwin, London (1970)

Calle-Rosillo.F & Hall, D.O. *"Brazilian Alcohol: Food versus Fuel"*, Biomass, (1987) p 97-128

Coyle, Barry T: *"On modeling Systems of Crop Acreage Demands"*, Journal of Agricultural and Resource Economics 18 (July 1993): p 57-69

Food and Agriculture Organization of the United Nations (FAO): *"Fertilizer use by crop in Brazil"*, Land and Plant Nutrition Management Service & Land and Water Development Division, Rome (2004)

Hanau, Arthur. *"Die Prognose der Schweine Preise", Berlin (1930)*

Haupt, Harry & Obenhofer, Walter *"Estimation of Constrained Singular Seemingly Unrelated Regression Models"* University of Regensburg (2000)

Holt, Mathew T. *"A Linear Approximate Acreage Allocation Model"*, Journal of Agricultural and Resource Economics 24(2) (1999): p 383-397

Fearnside, Philip M. *"Containing destruction from Brazil's Amazon highways: Now is the time to give weight to the environment in decision-making"* Environmental Conservation. 28, 23 (2006)

Gonzales, Mariana. *"Brazilian Orange Juice – Opportunities and Challanges in the Global Market"*, Rabobank International (2007)

Kutas, Géraldine. *"Biocombustíveis e desafios climáticos: A contribuição do setor sucreenergetico"*, Unica (2009)

Margarido, Mario A., Turolla, Frederico A. & Bueno, Carlos R. F. *"The world market for soybeans: price transmission into Brazil and effects from the timing of crop and trade", Nova Economia*, , vol. 17, issue 2 (2007): p 241-270

Mello, I. and Van Raij, B. *"No-till for sustainable agriculture in Brazil" Proc. World Assoc. Soil and Water Conserv*, (2006): p 49-57.

Nassar, Andre M. *"Sugarcane Ethanol and Land Use in Brazil"* Woodrow Wilson International Center for Scholars Brazil Institute, Washington (April 2008)

Klink, CA & Machado, RB. "Conservation of the Brazilian Cerrado" Conservation Biology 19, (2005): p 707 - 713

Körner, Svante & Wahlgren, Lars. *"Statistisk Data-Analys"* Studentlitteratur, Lund (2000)

Lagercrantz, Jacob: "*Ethanol production from Sugar Cane in Brazil - Review of potential for social- and environmental labelling of ethanol production from sugar cane"*, Swedish Association of Green Motorists (2006)

de Almeida, Anna Ozorio. *"Exports, Energy, Food: The Multiple Functions of Brazilian Agriculture"* Centro Studio di Politica Internazionale, Working Papers 69 (july 2009)

Paullilo, Luiz Fernando. *"Competitiveness of Orange Agri-System*", EUMercoPol Project, São Carlos (2008)

Rapsomanikis, George & Hallam, David: *"Threshold cointegration in the sugarethanol-oil price system in Brazil: evidence from nonlinear vector error correction models"*, FAO Commodity and Trade Policy Research working paper No.22 (2006)

Schnepf, Randal D., Dolman, Erik & Bolling, Christine. *"Agriculture in Brazil and Argentina: Developments and Prospects for Major Field Crops"*, Agriculture and Trade Report No. (WRS013) (2001): 85 pp

Sydsaeter, K., Hammond, P., Seierstad, A. & Strøm, A. "*Further Mathematics for Economic Analysis"*, Pearson Education Limited, Harlow (2005)

Tokgoz, Sima & Elobeid, Amani: *"An Analysis of the Link between Ethanol, Energy and Crop Markets"*, Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa (2005)

United States Department of Agriculture (USDA), Foreign Agricultural Service: *"Commodity Intelligence Report"* (April 14, 2008)

Valmont Irrigation *"Rice Production and the Endeavor to Conserve Water"*, Inc Valley (2009)

Zuurbier, Peter & van de Vooren, Jos *”Sugarcane Ethanol – Contributions to climate change mitigation and the environment”,* Wageningen Academic Papers, 2008

Waugh, Frederick V. *“Journal of Farm Economics”*, vol. 46, no. 4 (1964) pp. 732–750

Woods, Jeremy & Black, Mairi. *“Local land use change impacts and opportunities”* Gallagher Report (May 2008)

Internet resources

ANFAVEA, National Association of Automobile manufacturers

Main website: http://www.anfavea.com

http://www.anfavea.com.br/tabelas.html (oct 2009)

Gertuilo Vargas Foundation's (FGVDADOS)

Main website: http://www.fgvdados.com.br (oct 2009)

BVS Ministério da Saúde

Main website: http://bvsms.saude.gov.br

Used web page: http://bvsms.saude.gov.br/bvs/publicacoes/ans/atlas/jpg/mapas/ (oct 2009)

FGVADOS

Main website: http://www.fgvdados.fgv.br/ (oct 2009)

Food and Agriculture Organization of the United Nations (FAO)

Main website: http://www.fao.org

Used web page: http://faostat.fao.org/site/339/default.aspx (oct 2009)

Food and Agricultural Program Research Institue (FAPRI)

Main website: http://www.fapri.org

Used web page: http://www.fapri.iastate.edu/outlook/archive.aspx (july 2009)

Intercontinental Exchange

Main website: http://www.theice.com

Used web pages:

https://www.theice.com/publicdocs/futures_us_reports/sugar/Sugar11Hist_Prices.xls

(march, 2009)

Journal of Energy Security

Main website: http://www.ensec.org/

Used web page: http://www.ensec.org/index.php?option=com_content&view=article&id=179:brazilian-ethanol- policy-lessons-for-the-united-states&catid=92:issuecontent&Itemid=341

Market Technologies

Main website: http://www.tradertech.com/

Used web page: http://www.tradertech.com/information/orangejuicetrading.asp (oct 2009)

Sugarcane Industry Association (UNICA)

Main website: http://www.unica.com.br

Used webpages:

http://www.unica.com.br/downloads/estatisticas/eng/BRAZILIAN%20ETHANOL%20PRODUCTION.xls (oct 2009)

http://www.unica.com.br/downloads/estatisticas/eng/BRAZILIAN%20SUGARCANE%20PRODUCTION.xls (oct 2009)

The Bio Energy Site

Main website: http://www.thebioenergysite.com

Used web page: http://www.thebioenergysite.com/articles/74/shortrun-price-and-welfare-impacts-of-federal-ethanol-policies

APPENDIX

Table 6.1 Continued

c_{11}	-.1995266	.0186704	-10.69	0.000
c_{12}	-.1972674	.0190007	-10.38	0.000
c_{13}	(dropped)			
c_{14}	-.2345281	.0223122	-10.51	0.000
c_{15}	-.1933138	.0189777	-10.19	0.000
c_{16}	-.1744523	.0164091	-10.63	0.000
c_{17}	-.2057529	.0185172	-11.11	0.000
c_{18}	-.1714387	.0178727	-9.59	0.000
c_{19}	-.1860187	.0192987	-9.64	0.000
c_{110}	-.1559992	.0217958	-7.16	0.000
c_{111}	.1256236	.0188408	6.67	0.000
c_{112}	.1645476	.0187212	8.79	0.000
c_{113}	.3618917	.018473	19.59	0.000
c_{114}	.6290234	.019109	32.92	0.000
c_{115}	-.1115381	.0195248	-5.71	0.000
c_{116}	-.070501	.0182004	-3.87	0.000
c_{117}	-.0462312	.0226305	-2.04	0.041
c_{118}	.2675937	.0212053	12.62	0.000
c_{119}	.6090141	.0236315	25.77	0.000
c_{120}	.331148	.0208334	15.90	0.000
c_{121}	-.1687234	.0205954	-8.19	0.000
c_{122}	-.207211	.0186528	-11.11	0.000
c_{123}	-.235287	.0209788	-11.22	0.000
c_{124}	-.1698339	.0203365	-8.35	0.000
c_{125}	-.2429126	.0208927	-11.63	0.000
c_{126}	-.1804972	.0213253	-8.46	0.000
c_{127}	-.248121	.0226423	-10.96	0.000
c_{21}	.087049	.0232142	3.75	0.000
c_{22}	-.1882919	.0232536	-8.10	0.000
c_{23}	-.1351187	.0243872	-5.54	0.000
c_{24}	-.1055922	.0266296	-3.97	0.000
c_{25}	-.1022243	.0226044	-4.52	0.000
c_{26}	-.2023329	.0242213	-8.35	0.000
c_{27}	.3095282	.0229203	13.50	0.000
c_{28}	.1018069	.023407	4.35	0.000
c_{29}	.1023107	.0225573	4.54	0.000
c_{210}	(dropped)			
c_{211}	-.1885134	.0245016	-7.69	0.000
c_{212}	-.18479	.0250313	-7.38	0.000
c_{213}	-.1793752	.0256421	-7.00	0.000
c_{214}	-.0959686	.019989	-4.80	0.000
c_{215}	-.1867897	.023677	-7.89	0.000
c_{216}	.1698269	.0223049	7.61	0.000
c_{217}	.0831425	.0219268	3.79	0.000
c_{218}	-.2194094	.0236325	-9.28	0.000
c_{219}	-.2216942	.0237495	-9.33	0.000
c_{220}	-.09307	.0229207	-4.06	0.000
c_{221}	.3560522	.0225369	15.80	0.000
c_{222}	.0277045	.0246143	1.13	0.260
c_{223}	.3686304	.0238386	15.46	0.000
c_{224}	.4517918	.0227087	19.90	0.000

c_{225}	.3668579	.0175404	20.92	0.000
c_{226}	.4351525	.0233812	18.61	0.000
c_{227}	.3145738	.0245671	12.80	0.000
c_{31}	.205879	.0247344	8.32	0.000
c_{32}	.4662786	.0237561	19.63	0.000
c_{33}	.1351187	.0243872	5.54	0.000
c_{34}	.4091123	.027762	14.74	0.000
c_{35}	.3743196	.0239296	15.64	0.000
c_{36}	.3021544	.023721	12.74	0.000
c_{37}	-.0068043	.0236172	-0.29	0.773
c_{38}	.1587354	.0247267	6.42	0.000
c_{39}	.1794206	.0245308	7.31	0.000
c_{310}	.2963405	.0185353	15.99	0.000
c_{311}	.1310743	.0245122	5.35	0.000
c_{312}	.0830256	.0250715	3.31	0.001
c_{313}	-.1224247	.0257924	-4.75	0.000
c_{314}	-.4420509	.0228029	-19.39	0.000
c_{315}	.0612247	.0214121	2.86	0.004
c_{316}	.1438334	.0212008	6.78	0.000
c_{317}	.1809838	.0211818	8.54	0.000
c_{318}	-.0716115	.0206211	-3.47	0.001
c_{319}	-.4113664	.0212806	-19.33	0.000
c_{320}	-.2299852	.023374	-9.84	0.000
c_{321}	-.0772012	.0232333	-3.32	0.001
c_{322}	.2622604	.0254827	10.29	0.000
c_{323}	-.0348359	.023686	-1.47	0.141
c_{324}	-.1750708	.0232928	-7.52	0.000
c_{325}	(dropped)			
c_{326}	-.1424279	.0236217	-6.03	0.000
c_{327}	.0542986	.0247945	2.19	0.029
c_{41}	-.0934014	.0158271	-5.90	0.000
c_{42}	-.0807193	.0167248	-4.83	0.000
c_{43}	(dropped)			
c_{44}	-.068992	.0166603	-4.14	0.000
c_{45}	-.0787815	.0162497	-4.85	0.000
c_{46}	.0746307	.0158167	4.72	0.000
c_{47}	-.0969711	.0162731	-5.96	0.000
c_{48}	-.0891036	.0156223	-5.70	0.000
c_{49}	-.0957126	.016447	-5.82	0.000
c_{410}	-.1403413	.0170106	-8.25	0.000
c_{411}	-.0681845	.0162502	-4.20	0.000
c_{412}	-.0627832	.0160268	-3.92	0.000
c_{413}	-.0600918	.015864	-3.79	0.000
c_{414}	-.0910039	.0160406	-5.67	0.000
c_{415}	.146282	.0164369	8.90	0.000
c_{416}	.0226362	.0162133	1.40	0.163
c_{417}	-.0387841	.0195453	-1.98	0.047
c_{418}	-.1000136	.0174746	-5.72	0.000
c_{419}	-.101679	.01965	-5.17	0.000
c_{420}	-.0080927	.0186569	-0.43	0.664
c_{421}	-.1101276	.0181357	-6.07	0.000
c_{422}	-.0827538	.0157636	-5.25	0.000
c_{423}	-.0985075	.0183414	-5.37	0.000
c_{424}	-.1068871	.0179652	-5.95	0.000
c_{425}	-.1239453	.0190233	-6.52	0.000
c_{426}	-.1122275	.0190533	-5.89	0.000
c_{427}	-.1207514	.0207985	-5.81	0.000

$cost_1$	.0002265	.0000478	4.74	0.000
$cost_2$	.0003219	.0000763	4.22	0.000
$cost_3$	-.0003116	.0000822	-3.79	0.000
$cost_4$	-.0000442	.0000474	-0.93	0.352