SATELITE PRODUCTION FORECASTS:
VAULED WITH SIMULATED FUTURES AND OPTIONS TRADING

by

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ABSTRACT

Both the USDA and private firms are allocating substantial capital towards providing accurate and timely crop production forecasts. Production forecasts based on satellite imagery have been suggested as a means of making forecasts earlier, more frequent, and cheaper. This thesis attempts to determine if satellite data increases information with respect to crop condition and final production. If so, does the additional information have value and can it be used to make profitable trades in the futures market?

These questions are answered using NDVI data for Iowa and Illinois. Jackknifed out-of-sample crop production estimates are calculated for both corn and soybeans for the individual states. A variety of models were used, each including different bi-weekly periods. USDA crop condition scores are also tested in some of the models. A model based on the current stocks-to-use ratio for each commodity is used to predict the market’s expected production level. When the satellite forecast differed from the market’s expectation a trade was made in the futures markets. Both futures and option strategies were tested.

Results suggest that satellite based production forecasts may result in profitable soybean trades, particularly when downside risk can be reduced by trading options. Further work should focus on refining the satellite images used in the model and exploring more complex option trading strategies.
CHAPTER 1

INTRODUCTION

Accurate production predictions are essential for agricultural markets. To that effect, the USDA was allotted $128 million to fund the National Agricultural Statistics Service (NASS) in 2005, with an expected $16.7 million increase planned for 2006 (USDA 2005). Furthermore, there are now numerous private firms that produce production forecasts that are available to subscribers prior to USDA report release dates. The forecast errors from these reports tend to be unbiased and highly correlated with USDA forecast errors (Egelkraut et al. 2003).

One of the newer forecasting methods involves the use of satellite imagery. If satellite imagery has information value then yield forecasts could be made earlier, cheaper and more frequently than with existing methods.

This thesis explores the value of production predictions derived from satellite image based yield forecasts. Two primary questions are examined:

1. Can satellite data increase information with respect to crop condition and final production?
2. Does the additional information from satellite data have value? Can it be used to make profitable futures trades?

The thesis is organized as follows. Chapter 2 reviews the existing work from the value of information field. It highlights how and why the satellite yield predictions can be valued using a willingness-to-pay test. Chapter 3 explains the technical side of remote sensing
and highlights the work that has previously been done in this field. In Chapter 4, the data and the model used for developing out-of-sample crop reporting district (CRD) yield forecasts for corn and soybeans is explained. A model is developed in Chapter 5 that converts the CRD level yield forecasts for Iowa and Illinois into a national production estimate. This production estimate is then compared to an estimate of the market’s production expectation and an appropriate futures or options trade is made. Profit and losses from these trades are evaluated to determine the value of the satellite based yield forecasts. Conclusions and qualifications follow in Chapter 6.
CHAPTER 2

VALUE OF INFORMATION

It has been shown that the greatest social welfare occurs when price information is accurate and known well in advance. When price information is known in advance producers can adjust their output to the optimal market clearing level, and total surplus is higher as a result. Hayami and Peterson (1972) use a two period inventory adjustment model to illustrate that better yield and production predictions result in larger surplus. Furthermore, a clear vision of future production helps to drive storage decisions, resulting in more stable levels of consumption and price (Wright and Williams 1982).

For many producers futures markets are their primary source for price discovery. There has been considerable work on the efficiency of futures markets. Fama (1965) defines an efficient market as:

"...a market where there are large numbers of rational, profit-maximizers actively competing, with each trying to predict future market values of individual securities, and where important current information is almost freely available to all participants. In an efficient market, competition among the many intelligent participants leads to a situation where, at any point in time, actual prices of individual securities already reflect the effects of information based both on events that have already occurred and on events which, as of now, the market expects to take place in the future. In other words, in an efficient market at any point in time the actual price of a security will be a good estimate of its intrinsic value."

Futures markets require accurate timely information in order to be efficient and hence useful as a price discovery tool. Any information that guides the futures market to the equilibrium price level will increase total surplus.

There is a wide array of both public and private agricultural production information available in the market. There is considerable work that examines the value of this information. Much of the focus has been on testing whether USDA production
forecasts have value. Sumner and Mueller (1989) examined the informational content of USDA corn and soybean domestic supply reports for 1961-1982 by measuring the absolute change in futures prices around the release date, and comparing it to absolute price changes on non-release days. They found that there were significant price change differences between release and non-release days and concluded that the USDA reports provided value to the market. However, Fortenbery and Summner, (1993) using a similar methodology, found that the USDA forecasts did not contain value from 1985-1989. As technology advances it becomes relatively cheaper and easier for private companies to make accurate production forecasts. Private companies typically sell their forecasts to subscribers, releasing their reports prior to the respective USDA report. The increase in private predictions, made in advance of USDA reports, is one reason why USDA reports may have a decreasing effect on markets over time.

If futures markets are efficient they should contain all available information (Fama 1965). Therefore private production forecasts which are released prior to USDA forecasts tend to be priced into the market (Collings and Irwing 1990). The market will only react to the unexpected information contained in the USDA report. Past research has used the residual between a public forecast and the private forecast as a measure of unanticipated information (Collings and Irwin 1990; Egelkraut et al. 2003). Live hog futures do not react to anticipated information, but prices do adjust significantly when there is unanticipated information in Hogs and Pigs Report (Collings and Irwin 1990).

A variety of work has addressed the issue of whether USDA or private forecast reports have informational value. Garcia et al. (1997) identified three alternative tests of
information. The first test is based on Baur and Orazem (1994) finding that greater value comes from government supply forecasts when the market’s supply forecast variance decreases as a result of the government forecast. When this happens the market price moves closer to the equilibrium price that would exist if all traders possessed perfect information. As such Garcia et al. compared the market’s supply forecast variance before the release of the USDA report to the variance of the market’s supply forecast after the USDA report. They found that the USDA report lowered the variance of the market’s supply forecast of corn early in the season, and was therefore valuable. Later in the corn season, and throughout the soybean season Garcia et al. found that the USDA report did not significantly lower the market’s supply forecast variance.

The second test comes from Fama’s Efficient Market Hypothesis (1970). In an efficient market all new information that enters the market should quickly be factored into the prevailing price. The market will only react to unanticipated information. Garcia et al., following the work of Collings and Irwin (1990), use the difference between USDA forecast and private forecasts to define unanticipated information. They regress the unanticipated information on the change in futures price from the closing price on the day of the USDA announcement to the first non-limit opening or closing price following the announcement. They find that the USDA report explains approximately a third to a half of the variance of the futures price immediately following the release of the report.

The final test by Garcia et al. is a willingness-to-pay test inspired by Carter and Galopin’s (1993) test of the value of the quarterly hog and pig report. Carter and Galopin found that although there is a significant movement in price following the release of these
reports, a trader would not be able to earn a risk-adjusted profit, after transaction costs, by having these reports in advance. If a trader could not earn a profit, his willingness to pay would be zero, and therefore the value of the quarterly hogs and pigs report would also be zero.

Garcia et al. constructed a willingness-to-pay test, modeling it after a market timing test developed by Henriksson and Merton (1981). This test calculates the probability of successful market timing. A trading rule that sells (buys) corn or soybeans if the USDA production forecast is higher (lower) than the market forecast was developed, and the probability of a profitable trade was analyzed. They were able to strongly reject the null hypothesis of no market timing for both corn and soybean USDA production reports from 1971-1992. While this test does not indicate what a trader would pay to obtain the information it does suggest that a trader would have a positive willingness-to-pay.

Other work by McNew and Espinoza (1994) has pointed out that evaluating the information value of the USDA production report should not be based solely on changes in the futures market price. It is possible that the mean price level of the futures market does not change following a report, as Sumner found occurred for the USDA crop reports after 1985. If this was the case the traditional willingness-to-pay type tests would also indicate that the report contained no value, as a trader would be unable to trade futures profitably by obtaining the report in advance. However, as McNew and Espinoza argue, a trader’s total return is a function of both changes in price, and changes in risk. If a report narrows the distribution of the futures market, decreasing risk, then the report is valuable.
By examining option prices McNew and Espinoza was able to conclude that USDA crop reports reduced uncertainty in the markets, and therefore contained value. In such cases it may be more appropriate to use options when doing a willingness-to-pay test.

Many of the previous attempts at valuing information have been event studies whereby the authors evaluate the effects of information –usually a USDA report- as it hits the market. An event study such as these, however, is not a feasible method of evaluating the effects of a satellite based yield model. It is likely that there are traders using satellite imagery to guide their decisions, however it is not possible to decipher when they are using the imagers or how. Until satellite imagery is more prevalent, and its effects on the market are measurable, an event study is not possible. A willingness to pay test then becomes the next best alternative. A trading strategy based upon the satellite imagery yield predictions must be determined and tested. In order to do this there are two primary issues that must be examined: When would a trade be initiated, and how long would that trade be held?

The satellite yield predictions will only have value if they contain unanticipated information. Therefore it is necessary to determine the market’s yield expectation. Previous willingness to pay tests on USDA reports used an average of the private market forecasts as a proxy for market expectation. Profitable trading strategies from using satellite yield predictions are more likely if one can trade prior to the release of the private yield forecasts. This is because more of the information contained in the satellite images is expected to be priced into the market after the release of the private reports.
With no readily available proxy for market expectation it becomes necessary to determine a relationship between the stocks to use ratio of a given commodity and the price of that commodity. The stocks-to-use ratio, which is total ending stocks divided by total ending supply, both of which are quoted monthly in the World Agricultural Supply and Demand Expectation (WASDE) report, is a commonly examined ratio that depicts supply levels. It is the most important statistic in developing a price forecast because it measures the surplus that will be carried forward to the next crop year (Purcell and Koontz, 1999). McNew and Musser (2002) used this ratio to develop price forecasts for corn. They found that the model fit relatively well with $R^2$ ranging from .74 to .98.

This paper uses the stocks-to-use ratio model in reverse. From the current futures price, an expected stocks-to-use ratio is calculated. With an expected stocks-to-use ratio, the market’s expectation of US production can be determined by comparing the expected stocks-to-use ratio to the most recent production numbers in the World Agricultural Supply and Demand Estimate (WASDE) report.

The market’s current expectation of production can be compared to the satellite forecast of production. If the market expects lower production than the satellite forecast, a short futures position would be entered into by a trader having the satellite forecast. The futures price should fall as the market becomes aware of the higher production levels forecasted by the satellite imagery, and the futures position would generate profit. If consistent, risk-adjusted opportunities are possible by having access to the satellite
imagery, then a trader would have a positive willingness-to-pay and it can be concluded that the satellite images have value.

The focus of this paper is on empirically measuring the value of satellite information by assessing a trader’s ability to generate profitable trades by using satellite based production forecasts. It is useful however, to examine the value of information question from a wider perspective. Specifically, what would a producer be willing to pay for a satellite based production forecast? McNew (1997) found that based on the coefficient of variation, corn yield variability had increased from 8% to 11% from the year 1920 to 1990. Crop yields are primarily impacted by weather events, and so this variability in yields, and the consequent agricultural losses, might be diminished by a more accurate satellite based yield forecast.

A model where producers make production decisions based upon price levels is provided to illustrate willingness to pay. In this model prices levels are a function of total aggregate output $Q$, with:

$$Q = f(z, \varepsilon_1) \text{ and } \varepsilon_1 \sim h(\mu_1, \delta \sigma_1)$$

where $z$ is a vector of variables affecting output, $Q$. The error term $\varepsilon_1$ is defined by a function $h$ and is distributed with a mean of $\mu_1$ and a standard deviation of $\delta \sigma_1$. Assuming the producer has imperfect information $\delta = 1$ and $\delta \sigma_1$ is positive. A producer’s profit function under uncertainty can be then be defined as:

$$E[\pi(Y(x, \varepsilon_2), P(Q)), w] \text{ and } \varepsilon_2 \sim k(\mu_2, \sigma_2)$$

Where $E$ is the expectation operator, $\pi$ is the profit which the producer would want to maximize by choosing the input level $x$, and producing output of $Y$ with an error of $\varepsilon_2$. 
caused by fluctuations in weather, rainfall, etc. The error, $\varepsilon_2$ is defined by a function $k$ and is distributed with a mean of $\mu_2$ and a variance of $\sigma_2$. The producer chooses the optimal $x$ based on the given price level, $P$ and a vector of input prices is represented by $w$. The key to this decision is the function $h$ which will effect how dispersed the producer’s aggregate price forecast will be.

The optimal level of $x$, assuming the implicit function theorem holds is:

\begin{equation}
    x^*(h(\cdot, \cdot), k(\cdot, \cdot), z, w)
\end{equation}

Where $h$ and $k$ are defined above as $\varepsilon_1$ and $\varepsilon_2$ respectively. This decision to use inputs of $x^*$ results in $E[\pi(Y(x^*), P, h, k)]$, or the highest expected profit for the current level of information on price forecasts, weather, drought conditions, rainfall etc. If a producer were able to obtain a perfect forecast of these conditions then all uncertainty as to aggregate quantity and price levels would disappear. In this perfect information scenario $\delta=0$ and the optimal level of $x$ is:

\begin{equation}
    x^{**}(k(\cdot, \cdot), z, w).
\end{equation}

A producer’s willingness-to-pay (WTP) for this perfect forecast would be the difference between the two maximized profit scenarios:

\begin{equation}
    \text{WTP} = \pi(Y(x^{**}), P, k) - E[\pi(Y(x^*), P, h, k)]
\end{equation}

While satellite images may be able to provide producers with better production forecasts they will not eliminate uncertainty. Therefore a theoretical model that allows for uncertainty is more accurate.
With the addition of satellite imagery an improved forecast is possible and the variance of the error term will decrease. To model this decrease, $\delta = .5$. The producer’s profit is:

\[(2.6) \ E[\pi (P(Q), Y(x, \varepsilon_2), w)]\]

The first order conditions are:

\[(2.7) \ x^{**}(h(\cdot, \cdot), k(\cdot, \cdot), z, w)\]

Where $x^{**}$ is the optimal level of inputs if one has access to satellite imagery. In this scenario of less than perfect information a producer would have the following willingness-to-pay:

\[(2.8) \ WTP= E[\pi(Y(x^{**}),P, h, k) - E[\pi(Y(x^{*}),P, h, k)]\]

The willingness to pay will be positive if the expected profits are greater as a result of having the increased level of information provided by the satellite images. While expected profits from having satellite imagery may be positive on average it is not possible to conclude that in every state of nature a producer would be better off with this information. There would certainly be occasions where a satellite image based forecast may encourage a producer to undertake an action that he would not have done if he had only the first information set. The results of these actions could cause a substantial loss at any one point in time. On average, however, if the willingness to pay is positive then the satellite imagery has some predictive power, and the producer would be better off as result of having it.
USE OF SATELLITE IMAGERY IN YIELD PREDICTIONS

A basic understanding of the process used to generate the vegetative index scores, which are the primary explanatory variables in the economic model, is provided below. Chlorophylls within plant vegetation absorb light from the visible red spectrum (0.9-0.7um). Mesophylls in plants will reflect 40%-60% of the near infrared (0.7-1.3) (Lillesand and Kiefer 1994). Changes in the levels of absorption and reflection of the visible red spectrum and the near infrared can be used as indicators of the photosynthetic capacity and efficiency of the observed plant canopy (Lillesand and Kiefer 1994).

If a plant is experiencing stress from disease, insects, or nutritional deficiencies, the plant will lose vegetative mass. Bare ground or non-vegetative matter will be visible in the plant canopy under such stress. Bare ground and non-vegetative matter reflect similar amounts of light from the visible red and near infrared (Lillesand and Kiefer 1994). This reflectance is distinct, and therefore a stressed plant canopy can be distinguished from a healthy plant canopy. Even mild plant stress that does not result in defoliation is observable because the level of chlorophylls in the plant will drop and less visible red light will be absorbed as the photosynthetic capabilities of the plant decrease.

There are a variety of vegetative indices (VI) that convert the multi-band observations of visible red and near infrared into a single numerical index. Indices can be sums, differences, ratios or another linear combination of the two wavelengths (Wiegand et al. 1991). An extensive body of literature illustrates that VI correlate highly with the
photosynthetic process of non-wilted plants. They have been found to be good predictors of plant biomass, vigor, and stress. (Tucker, 1979) Hatfield (1983) correlated VI to canopy development and was able to quantify canopy responses and measure the amount of photosynthetically active plant tissue. The VI is also highly correlated with the plant stand parameters green leaf area index (L) (Wiegand et al. 1991). Tucker et al. (1981) used a hand held radiometer to measure red and infrared spectral data. They found these measures to be highly related ($R^2=.86$) to the dry matter accumulation of winter wheat, and suggested that satellite measures of this spatial data could be used to monitor plant growth.

Due to the nature of the VI, yield predictions are most accurate if the crop’s yield comes entirely from above ground production, mainly leaves. Alfalfa and other fodder crop yields are directly linked with the VI score. However, for grain crops whose yield is determined solely by the storage organs, the photosynthetic ability of the plant’s leaves to assimilate CO$_2$ is key to the filling rate of the storage organs. Yield on these crops is only indirectly related to the VI score, and it is therefore essential that any model that predicts grain yields must recognize this constraint (Benedetti and Rossini, 1993). Zhen (2001) highlighted this fact by showing that early green up in wheat, prior to filling, can lead to erroneously high yield predictions if precipitation is not adequate during the filling stage.

The most common VI used for yield predictions is the normalized difference vegetation index (NDVI). NDVI is defined as the difference between near infrared and visible red divided by their sum or:

$$\text{NDVI} = \frac{(\text{NIR} - \text{R})}{(\text{NIR} + \text{R})}$$
where NIR and R represent near infrared and visible red respectively. This is a unitless measure that usually ranges from -1 to 1. Water, snow, clouds or any other non-vegetated scene is represented by a negative number. Low positive numbers near zero indicate rock and bare soil, which reflect near infrared and red at the same level. Increasingly positive numbers indicate greener vegetation (Lillesand and Keifer 1994).

NDVI is a product of the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR). The output form NOAA satellites have been used frequently in scientific studies because it provides low cost twice daily global coverage. The primary drawback to this data is that NDVI has a low spatial resolution of 1km. Agricultural fields are of a much smaller size, and therefore it can be difficult to determine how much of a 1 km NDVI score is the result of agricultural practices and not something else such as a lake, or timber. To use the NDVI scores this drawback must be overcome by selecting only those 1 km pixels that are predominately agricultural land. In this paper, only those pixels that are considered at least 80% cropland are included.

Noting the high correlation between plant biomass and NDVI scores, many researchers have attempted to predict crop yields using NDVI over both large and small areas. Most of this work has involved integrated or summed NDVI scores across the growing period. One approach is to keep a running sum of NDVI scores as the season progresses (Tucker et al. 1981; Benedetti and Rossini 1993; Quarmby et al. 1993). while another is break the growing season into distinct periods and sum the NDVI score across that period (Sellers 1986).
These integration methods have seen considerable use because a large sample of NDVI scores is difficult to come by. With a small sample size the focus has been on preserving degrees of freedom. The drawback, however, is that summed or integrated models force the weight of the NDVI score in each period to be the same. Although the two weeks of filling may be the most crucial time for determining corn yields, these models allow no distinction between time periods.

Regardless of the problems, these integration models have been shown to produce exceptionally large adjusted R²s. Zhen (2001) however made a strong case for reassessing these models. Prior to Zhen’s work on Montana wheat yields most of the studies were in sample, and the results appear misleading. Despite a high in-sample adjusted R² of .747 for his July wheat forecast, Zhen found that the July out-of-sample forecasts appeared to have limited predictive power.

This paper will expand on Zhen’s findings using a large pooled sample of NDVI scores to evaluate an out-of-sample model of sequential NDVI scores.
The National Center for Earth Resources Observation and Science (EROS) collects NOAA NDVI scores on a daily basis. Cloud cover can distort the NDVI score and in order to limit the effects of cloud cover EROS uses an algorithm to select the highest NDVI score from a two week period. This data is then changed from a -1 to 1 scale to a 0 to 200 scale. Scores that were -1, become 0, the original score of zero becomes 100, and 1 becomes 200.

The Kansas Applied Remote Sensing Program (KARS) at the University of Kansas obtained biweekly AVHRR NDVI from EROS. KARS processed the images using three GIS software packages, IMAGINE, ArcMap, and MatLab. The result of their work was a dataset that contained bi-weekly NDVI scores for each square kilometer (km) pixel of Iowa and Illinois. For each km, or pixel, the county was listed, and the percent of crop land in that km was listed. The percent of crop land is calculated by overlaying a land use footprint over each square km pixel. For each km pixel there are 10,000 land-use pixels. Only those km square pixels where at least 80% of the land-use pixels were cropland, were included in future calculations. Figure 1 visually depicts this process. The large squares each represent a one km NDVI pixel; while the smaller squares represent land-use pixels. Cropland pixels are shaded in gray. Only two of the six NDVI pixels are
used (they are highlighted with a darker border), because 80% of the land-use pixels within their boundaries are cropland.

From this dataset it was possible to compile average bi-weekly NDVI scores for each of the nine crop reporting districts (CRD) in Iowa and Illinois. The bi-weekly periods begin on January 1st. For the final data each year of NDVI data for each CRD is stacked on top of each other. This results 135 data points for each state (15 years of data multiplied by 9 CRDs). Various models are evaluated, and unlike similar work by Zhen...
the bi-weekly periods are not limited to those that are perceived as being within the growing period. Table 1 lists the last date of each two week satellite period.

Table 1. Satellite Periods and Corresponding Dates

<table>
<thead>
<tr>
<th>Satellite Period</th>
<th>Ending Date of Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>14-Jan</td>
</tr>
<tr>
<td>S2</td>
<td>28-Jan</td>
</tr>
<tr>
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<tr>
<td>S4</td>
<td>25-Feb</td>
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<td>11-Mar</td>
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<td>S6</td>
<td>25-Mar</td>
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<tr>
<td>S7</td>
<td>8-Apr</td>
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<td>S8</td>
<td>22-Apr</td>
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<td>S25</td>
<td>16-Dec</td>
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<td>S26</td>
<td>30-Dec</td>
</tr>
</tbody>
</table>

Final harvested yields\(^1\) for each CRD in Iowa and Illinois were obtained from NASS’s online database of state and county level field crops. An estimate of the yield

---

\(^1\) Harvested yields are used because the WASDE reports, which are later used to derive the market’s expectation of production, use harvested yields. It is possible that this could be problematic. If a portion of the crop is very poor in a given region those acres may be abandoned and thus not counted in the final harvested yield. This could cause yields to actually increase as crop conditions get worse. (Fackler and Norwood, 2000)
trend line from 1950 to 1988 was calculated. A strong trend in corn and soybeans was apparent. For corn, trend ranged from 1.58 to 2.14 bushels per year across the CRD’s. Soybean trend ranged from .33 to .55 bushels per year for the various CRDs. Using the trend model, deviations from trend were calculated for the years 1989 to 2003. The deviations from trend are used as the dependent variable in the model, rather than the actual yields. The model forecasts deviations from trend, and the previously mentioned trend model is then used to convert the deviation forecasts into actual yield predictions.

In addition to NDVI, USDA crop conditions scores were used in the model. During the growing season, on a weekly basis, NASS produces state level crop progress reports based upon subjective surveys. One component of these reports is condition scores for the various crops. The condition scores list the percentage of the crop that falls into one of five categories: very poor, poor, fair, good and excellent. Analysts that frequently use these reports tend to summarize the five conditions into one variable in one of two ways. One method is to weight the percentages in some fashion and sum them together. Another common method is to simply add the percentage of good crop and excellent crop together. This second method is employed here.

The Model

Prior to Zhen (2001) the remote sensing literature focused on models using summed or integrated NDVI scores. This approach forces the effect of each two week period to be the same. Realistically the marginal importance of each bi-weekly NDVI
score should be allowed to differ. As mentioned before, the filling stage may be more crucial to the final yield than the first two weeks of the growing season.

This model uses sequential NDVI scores to forecast deviations from trend for each CRD. Forecasts are made for Iowa and Illinois separately. For each state there are nine CRD’s and there is data for a total of fifteen years, (1989-2003) resulting in 135 data points for each state model. Predictions are made for both corn and soybeans using the following basic model:

\[
(4.1) \quad \text{DEV}_{i,t} = \alpha + \sum \beta_k S_{i,t,k} + \epsilon_{i,t}
\]

for \(i = 1 \ldots 12\)

for \(t = 1 \ldots 15\)

for \(k = 1 \ldots 19\)

where \(\text{DEV}_{i,t}\) is the deviation from trend for harvested acres for region \(i\) in year \(t\). The period \(S_{i,t,k}\) is the NDVI value for region \(i\) in year \(t\), during the bi-weekly period \(k\). As there are only 15 years of data these data were pooled. This pooling allows \(\beta\) to change for each bi-weekly period \(k\), but forces \(\beta_k\) to be the same across all of the regions \(i\). For corn, forecasts are made beginning in period 13 while forecasts are made beginning in period 14 for soybeans.\(^2\) The forecasts are made every two weeks as an additional NDVI score becomes available. For each forecast period each of the possible beginning dates were tested. For example, when producing a forecast for period 15, it is possible to use all of the satellite periods after period 1 (January 1\(^{st}\)) or it is possible to only include those images after period 2 (January 15\(^{th}\)) or period 3, up to period 15. For the July 1\(^{st}\) or the 13\(^{th}\) period forecast, models were run beginning with all of the satellite scores, S1-S13.

\(^2\) Crop condition scores were not available for soybeans for all years prior to period 14. (July 15\(^{th}\)).
Next the first period was dropped and the model was run with only S2-S13. This continued until the model was run with only the final 13th period, S13. In the following discussion, S refers to a satellite period. However, where a period is mention without the S, it is assumed that it is in reference to one of the bi-weekly satellite periods. All of these models were evaluated in an out of sample process.

Additional variables were added to the basic model and a prediction was made for each of the forecast periods S13-S19 for corn and S14-S19 for soybeans. The same pattern of including all of the satellite periods and then decreasing by one until only the last available NDVI score was used in the model was employed. The additions resulted in three variations of the basic model.

First dummy variables for each region were tested, using the model:

\[
(4.2) \quad \text{DEV}_{i,t} = \alpha + \sum \omega_i D_i + \sum \beta_k S_{i,t,k} + \varepsilon_{i,t}
\]

where D represents dummy variables for region 2-9. Next a model that contained the crop condition score variable was tested:

\[
(4.3) \quad \text{DEV}_{i,t} = \alpha + \sum \beta_t C_t + \sum \beta_k S_{i,t,k} + \varepsilon_{i,t}
\]

where C is the USDA crop condition score for year t at the time of the forecast. Condition scores are only available at a state level, and only the most recent crop condition score was used. The models 4.2 and 4.3 were combined to test the effects of dummy variables and the crop condition score.

\[
(4.4) \quad \text{DEV}_{i,t} = \alpha + \sum \omega_i D_i + \sum \beta_t C_t + \sum \beta_k S_{i,t,k} + \varepsilon_{i,t}
\]

Finally a model using only condition scores was run.
As the focus of this work is on testing the value of these models for futures traders, all of the above models were run out-of-sample. While in-sample forecasts may yield seemingly positive results, the value of any in-sample prediction will be suspect. Are the results the effect of data mining, or is the forecast error small because a large number of explanatory variables have been added? As all of the degrees of freedom are exhausted due to a large quantity of right-hand side regressors, a spurious perfect model fit will occur. (Fair and Shiller 1989) To avoid these problems the model must be tested out-of-sample.

Due to the limited years of data the standard method of time series out-of-sample estimation is not possible. Instead a jackknife procedure is used. A given year is left out of the model. The model parameters are then estimated using data from the remaining years. The parameters are applied to the data from the skipped year to create an out of sample prediction. This process of skipping a year and then using the year’s data to generate a forecast was done for each of the years, 1989-2003, and for each of the models described above.

Tables 2-5 display the root mean squared forecast error (RMSFE) percents for each of the models. The prediction period is listed at the top of the sheet, and the first satellite image included in the model is listed on the left hand side.
### Table 2. Percent RMSFE for Iowa Corn Yield Prediction

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<tr>
<th>Models</th>
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<td>16.26</td>
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<td>15.52</td>
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<td>20.82</td>
<td>16.30</td>
<td>15.71</td>
<td>15.99</td>
<td>16.20</td>
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<td>16.31</td>
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<td>15.96</td>
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<td>NDVI and crop conditions scores</td>
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<td>16.03</td>
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<td>20.14</td>
<td>21.00</td>
<td>16.03</td>
<td>16.52</td>
<td>16.71</td>
<td>17.02</td>
</tr>
</tbody>
</table>

| Conditional Score Only | 15.24  | 14.75  | 13.27  | 11.99  | 9.48   | 12.69  | 11.28  |
| Conditional Score Only | 14.71  | 14.58  | 14.18  | 12.38  | 9.70   | 12.60  | 10.58  |
| Conditional Score Only | 13.89  | 15.71  | 13.23  | 11.52  | 10.67  | 12.68  | 10.53  |
| Conditional Score Only | 14.27  | 15.97  | 13.26  | 11.34  | 10.14  | 12.12  | 10.49  |
| Conditional Score Only | 14.07  | 15.80  | 13.16  | 11.08  | 10.31  | 11.97  | 10.42  |
| Conditional Score Only | 13.89  | 15.95  | 13.49  | 11.90  | 10.46  | 14.86  | 12.69  |
| Conditional Score Only | 12.34  | 16.80  | 13.08  | 11.41  | 13.40  | 14.43  | 12.54  |
| Conditional Score Only | 17.30  | 21.00  | 14.67  | 12.72  | 15.52  | 16.43  | 14.15  |
| Conditional Score Only | 16.84  | 20.31  | 14.44  | 13.41  | 15.63  | 16.29  | 13.72  |
| Conditional Score Only | 16.94  | 20.08  | 14.72  | 13.82  | 15.55  | 16.12  | 13.54  |
| Conditional Score Only | 16.80  | 19.84  | 14.52  | 13.99  | 15.40  | 15.94  | 13.34  |
| Conditional Score Only | 19.40  | 14.06  | 13.90  | 14.66  | 14.70  | 12.77  |  |
| Conditional Score Only | 13.93  | 13.71  | 13.16  | 16.05  | 14.01  |  |
| Conditional Score Only | 13.53  | 13.15  | 16.07  | 14.27  |  |
| Conditional Score Only | 16.15  | 17.13  | 16.58  |  |
| Conditional Score Only | 16.83  | 16.57  |  |
| Conditional Score Only | 14.48  |  |

| First Satellite Period Used in The Forecast Model | 15.60  | 15.42  | 14.98  | 12.59  | 10.13  | 12.94  | 10.37  |
| First Satellite Period Used in The Forecast Model | 14.88  | 15.10  | 14.04  | 11.80  | 10.93  | 12.95  | 10.01  |
| First Satellite Period Used in The Forecast Model | 17.24  | 20.99  | 14.92  | 12.49  | 15.08  | 15.76  | 12.95  |
| First Satellite Period Used in The Forecast Model | 17.13  | 20.25  | 14.82  | 13.99  | 15.41  | 15.67  | 12.78  |

| Condition Score Only | 16.55  | 19.61  | 13.78  | 14.74  | 15.89  | 16.88  | 16.03  |

*Periods in this table represent bi-weekly satellite periods beginning January 1st.
Period 13=1-Jul, 14=15-Jul, 16=12-Aug, 17=26-Aug, 18=9-Sept, 19=23-Sept*
## Table 3. Percent RMSFE for Illinois Corn Yield Prediction

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<th>Models</th>
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<td>11.28</td>
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<tr>
<td>18</td>
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<td>10.90</td>
<td></td>
<td></td>
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<tr>
<td>19</td>
<td>10.55</td>
<td></td>
<td></td>
<td></td>
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<td>Condition Score Only</td>
<td>12.55</td>
<td>11.85</td>
<td>11.67</td>
<td>11.85</td>
<td>11.30</td>
<td>10.89</td>
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</tbody>
</table>

Periods in this table represent bi-weekly satellite periods beginning January 1st.
Examining the RMSFE percent of each of the models it becomes apparent that the yield predictions generally tend to improve towards the end of the season, and that the scores improve when ground level information, in the form of crop condition scores, is added. It does not appear that adding regional dummy variables improves the predictions. For corn, the lowest RMSFE percent occurs during the 16th period (August 12th) in Iowa and the 17th period (August 26th) in Illinois. The lowest RMSFE result from Model 4.3 which contains crop conditions scores and NDVI scores. This model appears to be the most useful. Running a simple F-test on an in-sample version of this model indicates that the crop condition score and NDVI variables are jointly significant at the 99% level, with F statistics of approximately 30 across the different states and commodities.

There is an interesting difference between the Iowa and Illinois crop condition scores. It appears as though the Illinois crop condition scores contain more information than the Iowa scores. The RMSFE from model 4.5, which contains only the condition scores is much lower in Illinois than in Iowa. Furthermore the difference between the RMSFE in Models 4.1 and Models 4.3 is much larger for Illinois than Iowa. One of the goals of running multiple models was to determine if the need for the inclusion of early vs. late season satellite images varied based upon when the prediction is made. For corn in Iowa, it appears as though the later the prediction the earlier the satellite periods that should be included in the model. For Illinois, prior to the August 26th prediction, the lowest RMSFE occurs when only the last satellite image and the crop condition score is used in the model. The three predictions after August 26th have the lowest RMSFE when
they contain the satellite scores from period 16 (August 26th) and up, and the most recent
crop condition scores. For corn it appears that the satellite imagery scores from Iowa
contain more information than those from Illinois, as the NDVI only model (4.1) for Iowa
results in considerably lower RMSFE that Illinois.

In the case of soybeans the opposite is true. For Illinois, the NDVI only model
(4.1) results in considerably lower forecast errors than the Iowa, NDVI only model.
Illinois condition scores, for all but the final two periods contain more information than
the Iowa condition scores as the RMSFEs for model 4.5 (condition scores only) are much
lower. The forecast errors for both corn and soybeans are similar, however due to their
later growing season soybeans have very high RMSFEs for the early season predictions
compared to corn. Furthermore for soybeans in both Iowa and Illinois the forecast errors
are lowest when only the most recent satellite images are included. Based upon the
RMSFE the optimal model for predicting soybean yields would involve the use of the
most recent crop condition scores and the very last satellite image.

In all but the late season forecasts the condition scores alone are the best yield
predictors. It is apparent that the inclusion of such ground information dramatically
increases the predictive power of the forecast model. Figures 2-8 provide a graphical
representation of the importance of ground information. These charts examine Iowa corn
yield predictions for each of the predictive periods. USDA yields are compared to three
distinct forecast models: NDVI scores alone, NDVI scores with crop condition scores,
and crop condition scores alone (models 4.1, 4.3, 4.5). The NDVI scores on their own
can vary dramatically from the USDA yields, but with the addition of the crop condition
scores the forecast errors decrease significantly. By the end of the season the NDVI scores with the crop condition scores forecast better than the other two models. The findings are similar for Illinois corn, and Iowa and Illinois soybeans.

The value of satellite imagery for trading purposes appears questionable, given that the publicly available crop conditions scores have a lower RMSFE than the satellite imagery models. However, a final conclusion regarding the optimal model can not be determined by RMSFE alone as it is an averaging process. Large profits or losses will result from the tail events. The true value of the different models can only be determined by evaluating the final profit or loss from trading on them.

Figure 2. Iowa Corn – Prediction for Period 13 (1-Jul)
Figure 3. Iowa Corn – Prediction for Period 14 (15-July)

Figure 4. Iowa Corn – Prediction for Period 15 (29-July)
Figure 5. Iowa Corn – Prediction for Period 16 (12-August)

Figure 6. Iowa Corn – Prediction for Period 17 (26-August)
Figure 7. Iowa Corn – Prediction for Period 18 (9-September)

Figure 8. Iowa Corn – Prediction for Period 19 (23-September)
CHAPTER 5

TESTING THE VALUE OF YIELD PREDICTIONS

The Data

The state level yield predictions must be converted into a national production estimate so that a comparison can be made between the market’s expected production and the satellite imagery driven production forecasts. A number of different data sources were used in this process.

To calculate a production estimate some measure of harvested acres must be used. To make the production forecasts out-of-sample the measure of harvested acres must be available prior to the actual forecast. NASS produces a supplemental acreage report on or around June 30th of each year. This report contains estimates of planted and harvested acres. The estimates are based on farmer surveys from the first two weeks of June, trend predictions, and changing weather factors. There is a .8 and 1.4 percent root mean square error for corn and soybeans respectively and the 90% confidence intervals are plus or minus 1.4 and 2.4 percent. (NASS Crop Production – Acreage – Supplement) This report is the earliest subjective estimate of harvested acreage from USDA. Prior WASDE reports contain acreage estimates but they are based only on trend models.

The final state level production estimates must be turned into a national estimate. A relationship between the sum of Iowa and Illinois production was calculated using the historical production numbers of Iowa, Illinois and the US from the NASS website. (USDA)
The market’s expectation of production is derived by finding a relationship between stocks to use and the current futures price. The World Agricultural Supply and Demand Expectations (WASDE) report is the main component of this model. The USDA produces WASDE reports every month in the growing season on or near the 11th of the month. These reports contain information on USDA’s expectation of supply (beginning stocks, production, and imports) and demand (domestic use and exports). For each report a stock to use ratio can be calculated as:

\[
SU = \frac{\text{total supply} - \text{total demand}}{\text{total demand}}
\]

Futures prices are used in both the calculation of the market’s production expectation and in the final evaluation of profit or loss. The December Chicago Board of Trade contract is used for corn and the November contract is used for soybeans.

The Model

Efficient markets should only react to unexpected information. The first step in valuing a production estimate based upon satellite imagery, therefore, is to determine what the market expects. Should the satellite imagery prediction suggest that the market expectation is not in line with reality, then an opportunity for a profitable trade becomes likely. If a trader can consistently profit by having access to satellite imagery yield predictions then the information has value.
To decipher the market’s expectation of production for a given year the relationship between price and stocks to use is determined. The following model is used to arrive at this relationship:

\[(5.2) \quad \text{LnP} = \alpha + \beta \text{LnS}\]

where LnP is the log of the average November futures price for the December contract from the 13\textsuperscript{th} to the 17\textsuperscript{th}. This time period was selected because reports are usually released on the 10\textsuperscript{th}-12\textsuperscript{th} of the month. LnS is the log of the stocks to use ratio from the November WASDE report. Figure 9 and 10 provide a graphical display of the relationship between the log of November stocks-to-use and the futures price.

Figure 9. Relationship Between Corn Stocks-To-Use Ratio and Futures Price (1989-2003)
The stocks to use ratio is calculated as:

\[
SU = \frac{\text{Total Supply} - \text{Total Use}}{\text{Total Use}}
\]

Total supply is the sum of beginning stocks, production, and imports. Total use is the sum of exports and domestic use. By November the market has a good understanding of the final condition of that year’s crop. Traders are buying and selling based on a wider set of information, and therefore the relationship between stocks to use and price should contain less noise and be more reliable than at points earlier in the year. \( \beta \) is calculated for each year, using the previous ten years of data. The intercept term tends to vary over time as market conditions such as exchange rates shift. Rather than attempting to model all of these potential shifters it is preferable to discard the intercept term that is calculated above, and instead calibrate the intercept each year by using the stocks to use ratio and the futures
price from the previous month. For example, in order to predict the stocks to use ratio for corn in July of 2000, data from November of 1990 to 1999 is used to determine β from equation 5.2. In this example α was 6.503 and β equaled -.366. The intercept term from equation 5.2 is ignored and a new intercept is calculated by using the stocks to use ratio and futures price from the June WASDE report. For 2000 the recalibrated intercept was 6.505. Using equation 5.2 with the adjusted α it is possible to calculate the markets expected stocks to use ratio by inserting the future price on July 1 of the December contract into the formula. In 2000 the futures price was 191.25 which results in a stocks to use ratio of 30.43%.

With an expected stocks to use ratio in hand it is possible to return to the most recent WASDE report, June 10th of 2000 in this example, and calculate expected production. The expected stocks-to-use ratio of .3043 is multiplied by reported total use, 9.985 billion bushels to arrive at estimated ending stocks of 3,038 billion bushels. Ending stocks are then added to total use in order to calculate total supply, 13.023 billion bushels. Total supply is the sum of beginning stocks, 1.621 billion bushels and imports, 15 million bushels and production. Subtracting beginning stocks and imports from total supply we are left with the markets estimate of production, 9,360 billion bushels.

After securing the market’s production expectation it is necessary to derive a national forecast from the state level satellite imagery forecasts. Using simple OLS the relationship between National production and the sum of Iowa and Illinois production is established.

\[
USprod_t = \alpha + \beta (IAprod_t + ILprod_t) + \epsilon_t
\]
In order to simulate the most realistic scenario, and to avoid in-sample errors, the alpha and beta coefficients for time \( t \) were estimated using production data from the previous 19 years. For example, the relationship in 1989 was calculated using production data from 1970-1988. For each additional year the 19 years of data rolled forward by one year. The sum of Iowa and Illinois production explains a great deal of the variation in US production. Table 6 displays the results of equation 5.4.

Table 6. Results of Regressing IA and IL Production on U.S. Production

<table>
<thead>
<tr>
<th>Year</th>
<th>Corn Coefficient</th>
<th>Adj R²</th>
<th>Soybeans Coefficient</th>
<th>Adj R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td>2.5316</td>
<td>0.9446</td>
<td>3.2005</td>
<td>0.8834</td>
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<td>1990</td>
<td>2.4945</td>
<td>0.9379</td>
<td>3.1049</td>
<td>0.8586</td>
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<td>1991</td>
<td>2.4903</td>
<td>0.9426</td>
<td>2.9780</td>
<td>0.8257</td>
</tr>
<tr>
<td>1992</td>
<td>2.4646</td>
<td>0.9442</td>
<td>2.8043</td>
<td>0.8139</td>
</tr>
<tr>
<td>1993</td>
<td>2.4526</td>
<td>0.9548</td>
<td>2.7027</td>
<td>0.8265</td>
</tr>
<tr>
<td>1994</td>
<td>2.3689</td>
<td>0.9504</td>
<td>2.5901</td>
<td>0.7622</td>
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<tr>
<td>1995</td>
<td>2.3837</td>
<td>0.9716</td>
<td>2.5410</td>
<td>0.8150</td>
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<tr>
<td>1996</td>
<td>2.3544</td>
<td>0.9736</td>
<td>2.2419</td>
<td>0.7619</td>
</tr>
<tr>
<td>1997</td>
<td>2.4045</td>
<td>0.9634</td>
<td>2.2812</td>
<td>0.7833</td>
</tr>
<tr>
<td>1998</td>
<td>2.5283</td>
<td>0.9432</td>
<td>2.4741</td>
<td>0.8350</td>
</tr>
<tr>
<td>1999</td>
<td>2.5342</td>
<td>0.9469</td>
<td>2.5207</td>
<td>0.9052</td>
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<tr>
<td>2000</td>
<td>2.6091</td>
<td>0.9580</td>
<td>2.5195</td>
<td>0.9188</td>
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<tr>
<td>2001</td>
<td>2.6377</td>
<td>0.9634</td>
<td>2.5911</td>
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<tr>
<td>2002</td>
<td>2.5693</td>
<td>0.9354</td>
<td>2.7273</td>
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<tr>
<td>2003</td>
<td>2.5502</td>
<td>0.9388</td>
<td>2.7309</td>
<td>0.9486</td>
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All of the coefficients were significant at the 99% level, and the adjusted \( R^2 \) from the corn model ranged from .9379 to a high of .9736. The relationship is weaker for
Soybeans with adjusted R² ranging from .7619 to .9498. It appears that the relationship has strengthened over the past five years.

It is not surprising that the total corn production in Iowa and Illinois explains so much of US corn production. Figures 11 and 12 illustrate where corn and soybeans are produced. Iowa and Illinois combined produce 32% of US corn, and no other state produces as much corn as Iowa or Illinois. Furthermore, the remainder of the corn production is in nearby states with similar climates and growing conditions. The adjusted R² for soybeans is noticeably lower, despite that fact that on average 35% of soybean production is in Iowa and Illinois. This is likely due to the fact that soybeans are grown in more geographically diverse regions of the United States.

Figure 11. Percent of Total Corn Production by State
Arkansas, for instance accounts for 5% of production and because of differences in climate Iowa and Illinois production is not likely to be a good predictor of production in Arkansas.

**Futures Trading Strategy**

The market’s production expectation can be compared with satellite based production expectations. If these two predictions differ sufficiently a trade could be initiated. If the satellite imagery production prediction is higher than the market’s expectation and if it is correct then there will be a larger supply and price will fall. A short position in futures would be taken in order to profit from the satellite imagery
model. Conversely, if the satellite production predictions indicate that production will be lower than the market expects a long position in futures would be taken.

The simplest type of trade is to sell when it appears that supply will be higher than expectation and buy when supply appears lower than expectation. For each of the models the profit or loss from such a trade was calculated. The trades were entered into the day after the last day of each two week satellite imagery period, beginning July 1st for corn and July 15th for Soybeans. If there was no trading on that day the price from the next available trading day was used. Short term and long term trading scenarios were examined. For the short term, the positions were closed after two weeks, and in the long term scenario the positions were closed on November 15th.

An alternative, more selective, trading strategy was also tested. If the difference between the satellite imagery production estimate and the market’s production estimate was greater than 5% of the market’s production estimate then a trade was made. If the difference was not greater than 5% then no trade was made for that year. This method should have decreased the number of losing trades, because a trade would only be entered into if there was a very strong signal that the market was out of line.

Tables 18-30 in the appendix display detailed profit and loss information from the various trading strategies. As there are multiple strategies and multiple models, an examination of this data is worthwhile. Table 7 and 8 shows the profit and loss from trading the non-selective strategy, using the model containing NDVI scores and crop condition scores. The use of period 13 as the beginning period in these tables is somewhat arbitrary, but it allows for a comparison between corn and soybeans. At
different points in time models with a later or earlier beginning period were more profitable. It is also important to note that the model that contained the lowest RMSFE was very rarely the model that resulted in the largest profits. Due to the convex relationship between stocks to use and price it is possible that if a yield model is primarily wrong when the stocks to use ratio is high, then the price impact of this error may be small. However, even small errors, when supply is tight may result in large price impacts.

Table 7. Corn Profit/Loss and Standard Deviation Summary

<table>
<thead>
<tr>
<th>Prediction Time</th>
<th>Model-w/crop cond. scores - held 2 weeks</th>
<th>Average Profit</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Jul</td>
<td>Period 13:13</td>
<td>-192</td>
<td>831</td>
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<tr>
<td>15-Jul</td>
<td>Period 13:14</td>
<td>19</td>
<td>867</td>
</tr>
<tr>
<td>29-Jul</td>
<td>Period 13:15</td>
<td>56</td>
<td>537</td>
</tr>
<tr>
<td>12-Aug</td>
<td>Period 13:16</td>
<td>-90</td>
<td>277</td>
</tr>
<tr>
<td>26-Aug</td>
<td>Period 13:17</td>
<td>103</td>
<td>364</td>
</tr>
<tr>
<td>9-Sep</td>
<td>Period 13:18</td>
<td>-378</td>
<td>545</td>
</tr>
<tr>
<td>23-Sep</td>
<td>Period 13:19</td>
<td>188</td>
<td>400</td>
</tr>
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</table>

Table 8. Soybean Profit/Loss and Standard Deviation Summary

<table>
<thead>
<tr>
<th>Prediction Time</th>
<th>Model-w/crop cond. scores – held 2 weeks</th>
<th>Average Profit</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-Jul</td>
<td>Period 13:14</td>
<td>417</td>
<td>1736</td>
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<tr>
<td>29-Jul</td>
<td>Period 13:15</td>
<td>258</td>
<td>1397</td>
</tr>
<tr>
<td>12-Aug</td>
<td>Period 13:16</td>
<td>-343</td>
<td>759</td>
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<tr>
<td>26-Aug</td>
<td>Period 13:17</td>
<td>255</td>
<td>990</td>
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<tr>
<td>9-Sep</td>
<td>Period 13:18</td>
<td>278</td>
<td>1007</td>
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<tr>
<td>23-Sep</td>
<td>Period 13:19</td>
<td>395</td>
<td>1304</td>
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</table>

For corn, when the beginning satellite period used is the 13th, the results are mixed. Larger profits and losses occur at the end of the year. When examining all
possible starting periods (see appendix ) profit levels tend to be higher later in the year, but as in the case of the September 9\textsuperscript{th} forecast period, in table 5.2 above, some periods still had negative profits. The standard deviation of the profit is so large that the trader would have to risk significant losses if he were to make trades at this time. Soybeans also display positive profits. Surprisingly, some of the largest profits appear early in the season with trades made on July 15\textsuperscript{th}. Profit vacillates during the season, and is again high at the end of the season. On average, if there is a possibility to make profitable trades in both corn and soybeans using satellite imagery it would likely be at the end of the growing season. Average profit from September 23\textsuperscript{rd} corn predictions from all of the different possible models and beginning time periods ranges from approximately $200-$800. For soybeans profits, examining all of the possible models and beginning time periods, are as high as $1100 during the same time period. While the standard deviation of profit is still high the risk-return tradeoff might be bearable if risk was managed using options.

The results indicate that there is a higher possibility of profit from trading soybeans than corn. This is unexpected, because U.S. soybean production is a smaller percent of the world production than is corn.

One hypothesis was that the short term trading strategy would be more profitable than the long term strategy. If the satellite imagery predictions are close to the USDA’s forecasts, then a trade that is entered near the first of the month, before the WASDE report becomes available, would see some positive price movement when similar production numbers are released two weeks later. Late season droughts, disease, or even
shifts in demand could not be forecasted with the early satellite prediction. Therefore, holding a position through November would increase the probability of losing money on the trade. For corn, this proves true for all but the last two prediction period of September 9th and September 23rd. For soybeans the opposite appears true. For most periods there is more profit if positions are held until November.

Examining the average profit and loss and the standard deviation of corn and soybeans does not provide a complete picture of the possible risk and returns from such an investment. A look at the distribution of the profit and loss is useful. F display histograms of profit from trading futures in corn and soybeans for the last two trading periods. (September, 9 and September, 23)

The distribution of trading profit for corn and soybeans illustrates that trading soybeans could be more profitable, but also with higher risks. It is interesting that the selective strategy appears to under perform the simple strategy. Using the selective strategy decreases the number of profitable trades without significantly reducing the number of large losses.

It is possible that if there was plentiful rain early in the season, and a late drought after the NDVI images are examined, the GIS forecast could be off considerably, causing large losses. By using the selective strategy this could exacerbate the problem because there would be greater reliance on these losing trades.
Figure 13. Dollars of Corn Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) December Contract Held to Nov 15 - Simple Scenario

Figure 14. Dollars of Corn Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) December Contract Held to Nov 15 - Simple Scenario
Figure 15. Dollars of Corn Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) December Contract Held to Nov 15- Selective Scenario

Figure 16. Dollars of Corn Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) December Contract Held to Nov 15- Selective Scenario
Figure 17. Dollars of Soybean Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) November Contract Held to Nov 1- Simple Scenario

Figure 18. Dollars of Soybean Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) November Contract Held to Nov 1- Simple Scenario
Figure 19. Dollars of Soybean Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) November Contract Held to Nov 1- Selective Scenario

Figure 20. Dollars of Soybean Futures Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) November Contract Held to Nov 1- Selective Scenario
Option Trading Strategy

For both corn and soybeans much of the average profit is made up of tail events in the distribution, large profits or large losses. A trading strategy that involves buying a put or call option would eliminate a large portion of the downside risk, as the maximum loss would be limited to the price of the call or put option. To that effect a simple option trading strategy was also tested. The summary of profits and losses as well as the histograms indicate that the only likely time that options would be profitable would be late in the season. Therefore the strategy was tested on the last three periods, August 26th, September 9th and September 24th for both corn and soybeans. Using the same information as the futures scenario, where previously a futures contract was shorted, a put option was purchased. Conversely, if the data suggested purchasing a futures contract, a call option was purchased instead. For both calls and puts the nearest out-of-the-money option was purchased. The profit from selling the options in either two weeks or on October 15th was calculated. Tables 9-14 list the profits from the option trades.

As expected, simulation option trades rather than futures trades significantly reduced the negative tail events. However, in the case of corn, it still does not appear that it would be profitable to trade based on the information. Profits were mostly negative, and when profits were positive, their magnitudes were not sufficient to offset transaction costs. Soybeans appear more promising. Profits were almost always positive, even as early as Aug 26th. The occurrence of profits increased on September 9th and Sept 24th but the magnitudes declined. This is primarily a function of the declining cost of the options as they move closer to expiration.
Table 9. Average Corn Option Trading Profit - Forecast on Aug 26

<table>
<thead>
<tr>
<th>Holding Period</th>
<th>Simple Scenario</th>
<th>Selective Trades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>-83</td>
<td>176</td>
</tr>
<tr>
<td>Week 2</td>
<td>-83</td>
<td>176</td>
</tr>
<tr>
<td>Week 3</td>
<td>-83</td>
<td>176</td>
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<td>Week 4</td>
<td>-83</td>
<td>176</td>
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<td>Week 5</td>
<td>-83</td>
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<td>Week 6</td>
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<td>Week 7</td>
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<td>Week 9</td>
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<td>-83</td>
<td>176</td>
</tr>
<tr>
<td>Week 12</td>
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*Beginning Period of The Forecast Model*
Table 10. Average Corn Option Trading Profit - Forecast on Sept 9

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<td>405 -150 232 -111</td>
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|                     | 2 Weeks Profit  | Nov-15th Profit  | Nov-15th Profit |
|                     | 1 -75 328 -194  | 253 -188 202 -209| 250             |
|                     | 2 -75 328 -194  | 253 -150 232 -111| 407             |
|                     | 3 -75 328 -194  | 253 -150 232 -111| 407             |
|                     | 4 -75 328 -194  | 253 -150 232 -111| 407             |
|                     | 5 -37 334 -95   | 405 -188 202 -209| 250             |
|                     | 6 -37 334 -95   | 405 -150 232 -111| 407             |
|                     | 7 -37 334 -95   | 405 -150 232 -111| 407             |

|                     | 2 Weeks Profit  | Nov-15th Profit  | Nov-15th Profit |
|                     | 1 -74 322 -110  | 393 -136 219 -98| 392             |
|                     | 2 -74 322 -110  | 393 -150 232 -111| 407             |
|                     | 3 -62 323 -149  | 383 -138 237 -149| 398             |
|                     | 4 -74 322 -110  | 393 -138 237 -149| 398             |
|                     | 5 -74 322 -110  | 393 -150 232 -111| 407             |
|                     | 6 -161 208 -112 | 394 -62 335 -109| 407             |
|                     | 7 -141 217 -105 | 393 -130 239 -104| 407             |
|                     | 8 -161 208 -112 | 394 -130 239 -104| 407             |
|                     | 9 -161 208 -112 | 394 -150 232 -111| 407             |
|                     | 10 -161 208 -112| 394 -150 232 -111| 407             |
|                     | 11 -161 208 -112| 394 -150 232 -111| 407             |
|                     | 12 -161 208 -112| 394 -150 232 -111| 407             |
|                     | 13 -161 208 -112| 394 -150 232 -111| 407             |
|                     | 14 -127 243 -80 | 405 -184 190 -143| 394             |
|                     | 15 -74 322 -110 | 405 -96 318 -141| 393             |
|                     | 16 -40 337 -79  | 404 -184 190 -143| 394             |
|                     | 17 -127 243 -80 | 405 -62 335 -109| 407             |
|                     | 18 -161 208 -112| 394 -184 190 -143| 394             |

|                     | 2 Weeks Profit  | Nov-15th Profit  | Nov-15th Profit |
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|                     | 2 -161 208 -112 | 394 -150 232 -111| 407             |
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|                     | 9 -170 203 -128 | 395 -140 235 -95| 406             |
|                     | 10 -100 241 -18 | 553 -113 205 -66| 378             |
|                     | 11 -208 163 -226| 220 -117 245 -63| 488             |

Condition Score -161 208 -112 394 -178 207 -193 254

*Beginning Period of The Forecast Model*
Table 11. Average Corn Option Trading Profit - Forecast on Sept 23

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| Condition Score | -55 | 130 | -64 | 239 | -13 | 128 | -10 | 270 |

*Beginning Period of The Forecast Model*
Table 12. Average Soybean Option Trading Profit - Forecast on Aug 26

<table>
<thead>
<tr>
<th>Holding Period Week</th>
<th>Simple Scenario</th>
<th>Selective Trades</th>
<th>Nov-15th</th>
<th>No-15th</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 Weeks Profit Std. Dev. 2 Weeks Profit Std. Dev. 2 Weeks Profit Std. Dev. 2 Weeks Profit Std. Dev.</td>
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<td>92 626 -86 1077</td>
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Condition Score 258 630 845 1947 316 677 506 1119

1Beginning Period of The Forecast Model
Table 13. Average Soybean Option Trading Profit - Forecast on Sept 9

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<td>2 Weeks</td>
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<td>150</td>
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<td>1876</td>
<td>-27</td>
<td>556</td>
<td>548</td>
<td>1832</td>
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<td>Condition Score</td>
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<td>150</td>
<td>-25</td>
<td>630</td>
<td>150</td>
<td>1684</td>
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1Beginning Period of The Forecast Model
Table 14. Average Soybean Option Trading Profit - Forecast on Sept 23.

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<th>NDVI and crop conditions scores</th>
<th>NDVI scores, Conditions scores, and regional dummy variables</th>
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1 Beginning Period of The Forecast Model
Table 15. Returns From Trading November Soybean Options

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<th>Aug. 26</th>
<th>Sept. 9</th>
<th>Sept. 26</th>
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<tbody>
<tr>
<td>Average Option Cost</td>
<td>700</td>
<td>650</td>
<td>465</td>
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<tr>
<td>Average Profit - Held to Oct. 15</td>
<td>845</td>
<td>863</td>
<td>499</td>
</tr>
<tr>
<td>Less Assumed Trading Costs</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Average Return</td>
<td>114%</td>
<td>125%</td>
<td>97%</td>
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</table>

Modeled using NDVI scores starting in period 15 and current crop condition scores

Looking at the histograms of profit and loss it would appear that more complex option trading strategies may even result in larger profits, or lower risk. Figures 21-28 display profit histograms from trading options. The dispersion of profits would indicate that a bear or bull spread trading strategy might be useful.

If the satellite images indicated that the option price would increase then, a call option at a high strike price would be sold, and a call option at a lower strike price would be purchased. Selling the call would cap profits, but the proceeds from the sale would finance the purchase of the other option, limiting the potential loss. A similar strategy could be used if it appeared that the market price would fall. A put option could be sold with a low strike price and a put option with a slightly higher strike price would be purchased.

A trader’s willingness to pay is based on the additional profits that he would hope to earn by obtaining the satellite information. The trader makes his trading decisions in a world of uncertainty, and while the satellite information can potentially decrease this uncertainty, it can by no means eliminate it.
Figure 21. Dollars of Corn Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) December Contract Held to Oct 15- Simple Scenario

Figure 22. Dollars of Corn Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) December Contract Held to Oct 15- Simple Scenario
Figure 23. Dollars of Corn Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) December Contract Held to Oct 15- Selective Scenario

Figure 24. Dollars of Corn Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) December Contract Held to Oct 15- Selective Scenario
Figure 25. Dollars of Soybean Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) November Contract Held to Oct 15- Simple Scenario

Figure 26. Dollars of Soybean Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) November Contract Held to Oct 15- Simple Scenario
Figure 27. Dollars of Soybean Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-18) November Contract Held to Oct 15- Selective Scenario

Figure 28. Dollars of Soybean Option Trading Profit (modeled using NDVI and crop cond. scores, periods 15-19) November Contract Held to Oct 15- Selective Scenario
The profit the trader derives in the initial state of uncertainty can be empirically estimated by calculating the profits from trading options, based upon model 3.5, which only contains the most current crop condition scores released by the USDA. This information is widely available and can be obtained at little or no cost to the trader. The average profit a trader could earn, per option, using this model, is displayed in table 16.

<table>
<thead>
<tr>
<th>Forecast Period 17</th>
<th>Average Profit</th>
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<tbody>
<tr>
<td>- Satellite Based</td>
<td>Corn</td>
<td>-95</td>
<td>845</td>
</tr>
<tr>
<td>- Crop Condition Scores</td>
<td>Soybeans</td>
<td>-141</td>
<td>845</td>
</tr>
<tr>
<td>Willingness to Pay</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forecast Period 18</td>
<td>- Satellite Based</td>
<td>-79</td>
<td>863</td>
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<tr>
<td>- Crop Condition Scores</td>
<td>Soybeans</td>
<td>-112</td>
<td>863</td>
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<tr>
<td>Willingness to Pay</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forecast Period 19</td>
<td>- Satellite Based</td>
<td>28</td>
<td>499</td>
</tr>
<tr>
<td>- Crop Condition Scores</td>
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<tr>
<td>Willingness to Pay</td>
<td>92</td>
<td>303</td>
<td>0</td>
</tr>
</tbody>
</table>

The crop cond. score plus NDVI model, held to Oct 15th, simple trading scenario was used. For the satellite based profit figure, the optimal time frame model was used.

The trader can improve his production forecast by including NDVI scores in his production forecasting model. The inclusion of satellite information is costly and the trader would only be willing to incur this cost if the information results in a profitable trade that at least offsets these costs. Table 16 lists the optimal level of profit that could be obtained by buying puts or calls and holding them until October 15th. It is apparent that under these circumstances a trader would only be willing to pay for satellite imagery...
that allows him to forecast production in period 19. For corn the estimated willingness to pay is $92. However, this figure is questionable. While the satellite imagery results in a more profitable trade, the profit of $28 would likely be consumed by trading costs ranging from $15 to $50. Trading costs would make the trade unprofitable and so despite the fact that the model results in less of a loss, a trader would not be willing to pay for the information. In the case of soybeans the willingness to pay for a risk neutral trader would be positive even after paying transaction costs.

The willingness to pay is calculated in per option terms. Obviously a trader that could risk more capital and trade in higher volumes would be willing to pay more for the data as their profit potential will increase linearly with the number of options they trade.

Table 17 illustrates what a trader would be willing to pay to move between states of imperfect information. Perfect information is not a possibility, but it is useful to model the trading results of having perfect production information. USDA final production estimates can be used as a proxy for perfect production information. Assuming a trader knew final Iowa and Illinois production numbers at time periods 17-19, the trader would be able to calculate final U.S. production numbers using model 5.4. The U.S. production estimate could be compared to the market’s expectation derived from the stocks-to-use ratio.

This perfect production information scenario was tested. It appears that having perfect information does not result in exceptionally larger average trading profit. Table 5.33 compares option trading profits under the three different levels of information.
Profit, while still negative, is slightly higher for corn trades in period 17 and 18. In period 19 trading profit is actually highest from using satellite imagery based forecasts. For soybeans, using USDA final production numbers results in an additional $62 of profit. In periods 18 and 19 average trading profit is the same using satellite imagery or USDA production numbers.

<table>
<thead>
<tr>
<th>Table 17. Option Trading Profit With Different Levels of Information</th>
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<tbody>
<tr>
<td>Average Profit</td>
</tr>
<tr>
<td>Forecast Period 17</td>
</tr>
<tr>
<td>Imperfect Information - Crop Condition Scores</td>
</tr>
<tr>
<td>Improved Imperfect Information - Satellite Based</td>
</tr>
<tr>
<td>Perfect Information - Final USDA Production</td>
</tr>
<tr>
<td>Forecast Period 18</td>
</tr>
<tr>
<td>Imperfect Information - Crop Condition Scores</td>
</tr>
<tr>
<td>Improved Imperfect Information - Satellite Based</td>
</tr>
<tr>
<td>Perfect Information - Final USDA Production</td>
</tr>
<tr>
<td>Forecast Period 19</td>
</tr>
<tr>
<td>Imperfect Information - Crop Condition Scores</td>
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<tr>
<td>Improved Imperfect Information - Satellite Based</td>
</tr>
<tr>
<td>Perfect Information - Final USDA Production</td>
</tr>
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</table>

The crop cond. score plus NDVI model, held to Oct 15th, simple trading scenario was used. For the satellite based profit figure, the optimal time frame model was used.
CHAPTER 6

CONCLUSIONS AND QUALIFICATIONS

Considerable resources are being spent on crop production forecasts. Many of the forecasts rely on subjective surveys or expensive ground research. A systematic and unbiased forecast that can be produced earlier and cheaper than other forecasting methods would be valuable. Remote sensing is one such forecast, and there have been a variety of studies that have indicated that satellite base forecasts contain valuable information.

Natural resource scientists have been making yield forecasts based on satellite images for some time. While they strive to improve the scientific accuracy of their forecasts by testing different vegetative indexes and cloud filters, there may be some statistical improvements that could result in an improved forecast.

This thesis used the established technology to generate out of sample predictions based upon non-cumulative, bi-weekly NDVI scores. In order to assess the value of the satellite information, the production predictions were used to implement a trading strategy. If trades based on satellite information were profitable then a trader would have a positive willingness to pay for the information. Assuming that corn and soybean futures and options markets are efficient then only unexpected information will influence the market. To determine the market’s current production expectation a simple model establishing the relationship between futures price and the stocks-to-use ratio was used. This model resulted in the market’s expectation of production. If satellite based forecasts
indicated that the markets expectations were out of line then an appropriate futures position was entered into.

The results of this trading strategy indicate that trading futures in both corn and soybeans based on this information would be extremely risky. While mean profit levels are positive late in the season the standard deviation is very large. It is important to note that this risk becomes apparent when analyzing the production forecasts in an out of sample forecast. Previous in sample work may have made diminished the possibility for large losses, making a trading strategy appear more profitable than it really was.

In order to eliminate some of the downside risk a simple option trading strategy was tested. With options the losses are mitigated and the possibility for a profitable trade increases. It is not surprising, considering the efficiency of the corn market, that even with options there was very little chance for profit in corn. While there was profit late in the season it would have been eroded by transaction costs, making the value of satellite information to a trader low. Profits did appear feasible in soybeans late in the season. These profits were on the same level as those that could be had by making trades based on final state level production numbers, or in other words near perfect information.

One qualification to this work is the fact that while soybeans appear to be the more profitable commodity to trade in, the recent relationship between the futures price and the stocks to use ratio is much weaker than that of corn. The breakdown of this relationship is likely due to South American soybean production becoming a much larger
share of world production in the past several years.\textsuperscript{3} However when a South American stocks to use variable was added to the regression the coefficient was insignificant and $R^2$ decreased. Assuming that the relationship between soybean futures prices and the U.S. stocks to use ratio will only get weaker, the model will have to be modified in order to accurately estimate the futures market’s production expectation.

Another qualification and avenue for additional research is the option trading strategy used. The option trading strategy was very simple. It involved buying a call or put based on the production forecast being higher or lower than market expectation. A more complex options strategy involving spreads may have made the trades even more profitable, and more research on different option strategies is warranted.

These findings indicate that the satellite images contain valuable information and they will be useful to traders, assuming appropriate risk controls are in place. While satellite image based forecasts can not replace USDA forecasts; they deserve more attention and research. Their main value may be found in developing nations where an accurate USDA type forecast is unavailable. Considering that the images contain information, it is now a question of how to best harness and use this information productively.

\textsuperscript{3} $R^2$ dropped from .74 in 1999 to .16 in 2003. Removing trading profit and loss from 2000 to 2003 still resulted in profitable trades for soybeans.
REFERENCES


Hayami, Y., Peterson, W. (1972): “Social Returns to Public Information Services:


APPENDIX A:

FUTURES TRADING PROFIT
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1Beginning Period of The Forecast Model
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1Beginning Period of The Forecast Model
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1Beginning Period of The Forecast Model
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¹Beginning Period of The Forecast Model
Table 24. Average Corn Futures Profit - Sept 23

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NDVI and crop conditions scores with Regional Dummy Variables

| NDVI scores, Conditions scores, and regional dummy variables | 1              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 2              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 3              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 4              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 5              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 6              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 7              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 8              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 9              | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 10             | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 11             | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |
|                                                            | 12             | 158     | 414      | 346     | 863      | 115     | 444      | 408     | 705      |

Condition Score

| Condition Score | 40     | 443    | 44     | 933    | 218    | 382    | 278    | 627    |

1Beginning Period of The Forecast Model
Table 25. Average Soybean Futures Trading Profit - July 15

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1Beginning Period of The Forecast Model
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¹Beginning Period of The Forecast Model
### Table 30. Average Soybean Futures Trading Profit - Sept 23

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1Beginning Period of The Forecast Model