The False Dilemma of "Food or Fuel"

The Effects of Ethanol Production on Crop Prices and Agricultural Land Use

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Abstract:

Existing studies on corn ethanol allege that US government policies encouraging its production have lead to higher food prices and an expansion of land used for corn production, raising concerns that the impoverished will lose access to food and that ethanol cannot effectively offset greenhouse gas emissions from fossil fuels. In this paper I use data from the US Department of Agriculture to attempt to determine whether any meaningful relationship can be established between historical ethanol production and crop prices or agricultural land use. I find that, while a correlation does exist between ethanol production and crop prices, this correlation is better explained by accompanying changes in oil prices. I also find that increased ethanol production has not been associated with an increase in the amount of land used for agriculture in the United States. I conclude that while no significant correlation can be established between past and present levels of ethanol production and crop prices or land use, future expansions of ethanol production may still affect these variables. Future policies should therefore be cautious about expanding ethanol production beyond what current US agricultural production capacity can support.

I. Introduction

The federal government of the United States has subsidized the production of corn ethanol for several decades. Ethanol is widely seen as environmentally friendly and as a way of reducing carbon emissions and oil imports using a resource we have in vast quantities – corn. Thus ethanol subsidies and mandates are perceived as doubly positive policies – they lessen US greenhouse gas emissions and provide support to US farmers.

However, the shock in world food prices in the middle of the 2000s exposed some possible negative effects of subsidizing ethanol. An increase in corn prices ostensibly caused by demand for ethanol made it difficult for people in developing countries to purchase basic foodstuffs, exacerbating the already severe hunger and malnutrition problems in the developing world (Runge and Senauer, 2007). As corn is an important ingredient in a huge variety of food products, the increase in food prices was not limited to products obviously linked to corn. American consumers were also faced with escalating food prices, although without the hunger problems faced in the developing world.

Such costs are supposedly justified by the beneficial environmental impacts of ethanol. That impact, however, may be nonexistent, or even negative. Environmental impact analysis of corn based ethanol production suggests that ethanol, due to the use of fossil fuels in its production and transportation and land-use changes caused by greater demand for corn, may end up providing no net reduction in fossil fuel use or carbon emissions (Searchinger, 2008). Some analysts suggest that ethanol fuel ends up causing significantly *more* greenhouse gas emissions than standard fossil fuels like gasoline; the production process for ethanol may use more fossil fuels than the ethanol can then offset (Searchinger, 2008). Other negative environmental impacts, like forest ecosystem destruction and fertilizer runoff, may result from the land-use change caused by artificial demand for corn ethanol (Fargione, 2008).

Changes in land-use and changes in food prices, using economic logic, are opposing phenomena; both result from greater demand in ethanol, but, other things being equal, the opening of land for more corn production should lower food prices by increasing supply. Thus, if ethanol subsidies' impact were primarily recognized through increased food prices, its effects on land use change would be expected to be smaller. This has implications for ethanol's environmental effectiveness – if subsidizing ethanol does not cause large changes in land use, it may be an effective means of reducing carbon emissions.

This study will analyze the relationship between the production of corn-based ethanol and both the price of staple crops and the land acreage used to produce these crops by examining the relevant data on these figures, from the time when ethanol production emerged as a viable technology (the late 1970s through the early 1980s) through the present day. While such an analysis cannot causally determine how ethanol production will affect these variables in the future, it can establish whether or not ethanol production has correlated with changes in them in the past, providing some clue as to the relationship between the variables and determining whether food prices and land use have been linked with ethanol production.

II. Review of Existing Research

Studies on ethanol tend to examine either its market or environmental effects, as one topic is in the area of economics and one in the area of the natural sciences. However, as land use affects both the supply side of ethanol's market situation and the overall carbon emissions effect of ethanol use, the two types of study should overlap on that topic, and many analyses (such as the study conducted by Leah Mazade for the Congressional Budget Office) do consider both areas of the issue. The conclusions that economic studies draw thus have an implication on ethanol's possible use as a way to reduce carbon emissions. However, experts in each issue area, with some exceptions, tend to emphasize the possible effects of expanded ethanol demand on their area, with economic studies fearing an explosion in corn prices and environmental studies fearing a vast expansion of land use for corn production. Here, the conclusions reached by studies focusing on economic effects are first reviewed, then the conclusions reached by studies focusing on carbon emissions and land use are analyzed, in order to explore how these studies differ, determine if any common conclusions are drawn, and identify where further research or analysis would be useful.

A. Economic Studies

The consensus among experts appears to be that ethanol production had a significant effect on food prices in the mid to late 2000s, although this was not solely responsible for the large increase in food prices seen in that time period. Prior to the 2000s little research appears to have been done, as neither food prices nor ethanol was an especially salient political issue at the time. Opinion is split as to whether ethanol demand will continue to cause food prices to rise, and on the magnitude of its impact during the studied periods.

Some sources, such as Donald Mitchell of the World Bank, C. Runge and Benjamin Senauer of *Foreign Affairs*, and Leah Mazade of the CBO, assert that ethanol production was the most important factor behind the high food prices of the mid-2000s, and that continued expansion of ethanol may have extreme effects on the availability of food in coming decades.

Donald Mitchell of the World Bank, in his "A Note on Rising Food Prices" analyzes the effects of various phenomena, such as the weakened dollar, rising energy prices, and, notably for this project, rising demand for biofuel products like ethanol, on world food prices. He finds that biofuel demand has accounted for over 50% of the increase in food prices seen since 2002 – he isolates it as having this large effect by comparing the relative price increases between ethanol crops, like corn, and non-ethanol crops, like wheat (Mitchell, 2008). This study does not reflect the effect of individual ethanol policies, merely overall increased demand, but does demonstrate the important effect corn ethanol can have on food markets. Mitchell himself notes that his methodology was ad hoc – he does not use a mathematical model for comparison of variables, but instead compares the relative amount of change in each of the variables considered. His analysis is also limited to the 2002-2008 period, which prevents it from being able to establish real correlations between variables (Mitchell, 2008).

C. Ford Runge and Benjamin Senauer, writing for *Foreign Affairs*, generally echo Mitchell's findings, and explore the effects increased corn prices are having on seemingly disconnected food markets, like those for beef and chicken (Runge and Senauer, 2007). They also describe some specific examples of ethanol-based corn price increases causing crises, such as the 2006 surge in corn prices in Mexico, which caused many impoverished Mexican citizens to lose access to a major component of their food supply. Runge and Senauer note that ethanol production is using up a larger and larger portion of the US corn supply each year (Runge and

Senauer, 2007), but they do not specify whether or not this is causing an overall decline in the amount of corn available for food (given that corn production has also been increasing, it is not necessarily true that rising ethanol production would cut down on the absolute amount of corn available).

Leah Mazade's study for the CBO goes into the specific effect of ethanol policies on corn prices and government expenditures, but covers only between April 2007 and April 2008 (Mazade, 2009). Mazade attributes a large percentage of the increase in food prices in that period to the effects of corn ethanol subsidies, but is unable to predict whether these effects will continue in the future as market are forces pulling in different directions (Mazade, 2009). Mazade also implies that ethanol subsidies end up costing the US government more than the value of the subsidy, as the resulting higher corn prices increase expenditure on the food stamps program (Mazade, 2009).

Others question the assertion that ethanol production has, will, or can have large effects on food prices and availability, and speculate that other trends in agriculture and the economy in general may either cancel out ethanol's effect on the food supply or turn out to be responsible for the effects commonly attributed to ethanol production.

Ronald Trostle's study for the USDA, for instance, conflicts with Mitchell and Mazade's indications that ethanol demand has been primarily responsible for the increased prices of food in the last decade (Trostle, 2008). Trostle takes a longer-term approach than those mentioned above, and attributes most of the increase in food prices to larger trends like a slowing rate of agricultural production growth, growing economies in the developing world, and increased consumption of meat worldwide (Trostle, 2008). He also alleges that weather phenomena in the mid-2000s were partially responsible for the spike in food prices in that time period (Trostle, 2008). He says that ethanol demand has had a notable but not a major effect on food prices, and views the other trends as more significant (Trostle, 2008).

Taking a somewhat different approach, Josef Schmidhuber of the UN's Food and Agriculture Organization argues that even though ethanol production may have serious effects on food prices, it is unlikely that it will be expanded enough to realize these effects. Biofuels like ethanol are only profitable now because of high fossil fuel prices, and that a return to normal fossil fuel prices would end the growth in biofuel production (Schmidhuber, 2006). If fossil fuel prices decrease, corn producers will stop making ethanol, as even with subsidies, ethanol would not be economically competitive. Energy (fossil fuel) prices effectively create a "ceiling" on biofuel production, as biofuels will only ever be produced up to the point that their price is equivalent to the price of fossil fuels (this argument is internally coherent, but it depends on fossil fuel prices stabilizing rather than increasing, which seems unlikely given the world's limited stock of fossil fuels and the ever-increasing demand for those same resources). Schmidhuber also notes that agricultural prices have generally been decreasing over the last four decades, due to technological advancements in agriculture and the slowing of world population growth; if these trends continue, ethanol production could be expanded without an overall increase in food prices (Schmidhuber, 2006). It should be noted, though, that agricultural production growth is slowing (Trostle, 2008), so again, the trends Schmidhuber's arguments rely on appear to be contrary to his position. Additionally, Schmidhuber published his study in 2006, before the highest point in the food price spike.

All of these writers use some statistics and quantitative analysis in making their arguments, but the models they use in making these analyses are assumption-based; Mitchell, for example, assumes that the differences between corn and wheat price changes are entirely due to ethanol production (Mitchell, 2008), not taking into account the possibility that other market factors could account for corn's greater price increases. They also are predictive models; they attempt to generalize a trend from existing data and project it into the future. The fact that these studies use a very compressed period of data to find their trends (as in Mitchell, Runge and Senauer, and Mazade), use abstract, difficult-to-measure variables (weather in Trostle, agricultural production growth in Trostle and Schmidhuber), and predict continuations of trends that do not seem likely (Schmidhuber), makes it hard to piece out the actual (past, present, or future) relationship of ethanol production with food prices.

B. Environmental Studies

Opinion on ethanol's effects on land use and role as a reducer of carbon emissions is quite divergent– the experts are divided on whether ethanol can have a positive impact on carbon emissions, and those who say it cannot due to its effects on land use give very different numbers on how much land use will change due to ethanol demand. Despite differences in the magnitude of the impact they predict, all of the studies that incorporate land use as a major factor in the emissions impact of ethanol contend that land use change significantly reduces corn ethanol's effectiveness as a way to reduce carbon emissions, probably making it impossible for it to have a positive impact on greenhouse gas reduction.

Ethanol's use as a fuel, even disregarding any effects of land use, is not firmly established as an efficient means for reducing carbon emissions. Hosein Shapouri, in a 2002 study for the USDA, suggests that corn ethanol will have a positive impact on emissions reductions. This assertion is based on an analysis showing that the energy that can be yielded from ethanol is greater than the fossil fuel energy necessary to produce it (used for factors such as fertilizer and transportation of the corn) by a factor of 1.34, meaning ethanol produces less emissions than an equivalent amount of fossil fuel (Shapouri, 2002). This figure, while demonstrating that ethanol may at least be able to offset some carbon emissions, is not an especially impressive one, especially when it is considered that ethanol is rarely used as a pure fuel source; it is instead mixed with gasoline at varying ratios, the most common being 10% ethanol, 90% gasoline (Wallace, 2006). Shapouri's study also neglects the effects of land use change on ethanol's emissions profile, focusing solely on per-unit comparisons of ethanol and fossil fuels (Shapouri, 2002).

Timothy Searchinger and Joseph Fargione, both writing for *Science*, take notice of the problem of land use change, and come to alarming conclusions on its effects on ethanol's emissions. Searchinger states that ethanol demand's effects on land use effectively increase the carbon emissions from ethanol by 50%, making it so that, per unit, burning corn ethanol for fuel ends up releasing more carbon than just burning fossil fuels (Searchinger, 2008). Fargione has a different way of presenting the same conclusion – according to him, any positive effect on emissions from using corn ethanol in the United States will be pushed back 48 years due to the impacts of changes in land use (that is, it would take 48 years for the carbon emissions avoided by using ethanol rather than fossil fuels to equal the loss in carbon absorption capacity lost by clearing the land needed to produce the ethanol) (Fargione, 2008). Leah Mazade of the CBO also addresses the land-use concern, and states that land use change will force corn ethanol's positive impact on emissions back 170 years (Mazade, 2009).

Again, these studies rely on certain assumptions to make their points. Shapouri (for the purposes of his study, at least), assumes that ethanol production will not require any changes in land use. Searchinger, Fargione, and Mazade, contrarily, assume that any new corn ethanol production will require the use of currently conserved land. No study addressed here actually considers past experience; has ethanol production in the United States actually required the use of previously unused land? Ethanol production has expanded to the point that it now uses 20% of the US's corn supply – are we then using more land for corn than before? Ethanol production could come at the expense of the use of previously conserved lands, and the effects of this shift could be dire, but it is not established that this has happened or will happen.

C. Analysis and Areas for Further Investigation

It is unclear why these experts come to such divergent estimates on the impacts of land use change on ethanol's emissions profile, but it may be due to the fact that the data they use largely comes from only a small time period, the mid-2000s. It is also interesting that the experts who fear further increases in food prices due to ethanol demand downplay land use change, and vice versa. As noted earlier, most of these studies used predictive models, approximating the expected impacts of ethanol production using mathematical projections. While such models can be useful, they can also give flawed and unreliable predictions if the modeler fails to incorporate all variables and inputs into them.

An analysis of the actual, observed historical relationship between ethanol production and both corn prices and agricultural land use, while on its own unable to provide predictions for the future effects of ethanol production, could prove useful by providing a basis on which to devise better predictive models. This study will attempt to carry out such an analysis. Specifically, it will ask this question: since 1982, what has been the relationship between corn ethanol production in the United States and:

- The price for corn received by US farmers?

- Average crop price (of corn, wheat, and soybeans) received by US farmers?

- Total agricultural land in the United States?

- Acres of corn planted in the United States?

III. Methodology

The central element of this study will be regression analyses examining the relationship of corn ethanol production with corn prices and land use. These regressions will have to incorporate broader economic variables, like GDP, inflation (CPI), and oil prices, in order to establish that any changes in the dependent variables are specifically linked to changes in ethanol production, rather than general changes in the economy. The regression models will also incorporate changes in the federal subsidy for ethanol as a general indicator for federal support for ethanol production, to see if government policy has any impact on the dependent variables distinct from the total changes in ethanol production.

A. Time Scale for Measurement

It is necessary to conduct this study over a wide timeframe (1982-2010 or last year data is available) for several reasons. First, the US has maintained a relatively constant level of subsidies for corn ethanol since 1978 (between $.40 and $.60 per gallon produced) and there have been no drastic shifts in this level (Duffield, 2008). Given the small variation in subsidies, an analysis dealing with any one policy change (the Energy Act of 2005, for instance) would likely see the effects of the policy shift being overshadowed by other economic factors present at that time. Taking data over a wide time period allows the economic climates present at each individual change in the subsidy level to be factored out, letting a relationship between production and food prices/land use change be discerned.

It is also unreasonable to assume that changes in ethanol production have effects immediately after their introduction. Measuring over a wider period allows for the possibility that market or policy changes may only begin affecting the relevant variables several years after their introduction, as is quite likely the case in the market for a product reliant on emerging technology. In this case, by measuring data over a large time frame, it will hopefully be possible to find out how long this time lag between the implementation of new policies and the effect on the market lasts, if indeed there is a lag. A study using a shorter time frame might miss the presence of such a lag and attribute market changes to more immediate circumstances. It might also miss the effects of independent variables that do not vary within the small timeframe but do have a significant relationship with the dependent variables when a larger timeframe is used.

Using a wide time frame also makes the statistical model more robust – regression models require around 30 data points for their results to be considered valid. As only yearly data is available for some of the variables, it is necessary to go back around 30 years to get the requisite number of data points. Ethanol has only been produced in significant quantities since 1982, so it is impossible to extend the model any further back, even though doing so would add more data points (for the variables other than ethanol production) and improve the robustness of the model.

B. Regression Model and Variables

The most important source of data for this thesis will be the United States Department of Agriculture's Economic Research Service, which has time-tracked data for many of the relevant variables, like individual and bundled agricultural commodity prices, agricultural output, and land-use acreage.

Data for the main independent variable, ethanol production, can be obtained from the USDA ERS, and will be represented as a continuous variable measured by million gallons of ethanol. To avoid reverse causality issues with corn prices (corn price is an input variable for ethanol production), ethanol production will be time-lagged one year; the ethanol production level for 1989 will be matched with the corn price from 1990. Ethanol production has increased steadily during the time period being studied, so the overall relationship will still be captured despite the incongruity in the dates (if ethanol production oscillated wildly from year-to-year, the real relationship between corn prices and ethanol production could not be identified using time-lagged data). Since ethanol production increases steadily, corn producers can devise relatively accurate expectations for the demand for corn for ethanol production using the previous year's ethanol production, and adjust their price accordingly, allowing the previous year's ethanol production to be a factor in the current year's price for corn.

Variables like market demand and general commodity prices can be represented by market indicators like GDP and commodity price indexes (such as the CPI), which are readily available from public databases. In any regression models, it will be important to pick only the most relevant and distinct of these overarching economic indicators, as they are likely dependent on each other, and including all of them in a model will cause multicollinearity problems and reduce the explanatory power of the model. It may be wise to create many different regression models, some of them using the most general market indicators (like GDP and CPI), and others examining more narrow market areas (like agricultural commodity prices and energy/fossil fuel prices). This will allow the most significant variables affecting land-use change and corn prices to be determined. Some of these variables may be discovered to work more effectively as interactor variables (modifiers on other variables).

It should be noted that the CPI data used here does not take into account food prices. As such, corn prices do not have an impact on the CPI variable, avoiding the issue of reflexivity.

The CPI, however, does include the price of various goods throughout the economy that could have an impact on corn prices, and so may correlate with that variable.

The variable representing ethanol policy will be a categorical representation of the federal subsidy available for ethanol production (supplied to ethanol producers, who are corn buyers, rather than to corn producers). This variable will need to be represented as an indicator variable rather than a continuous variable, as the level of subsidy has not varied enough to get the wide range necessary to justify use of a continuous variable. The subsidy to ethanol is periodically changed through separate policy actions – it is set at a certain monetary value per gallon produced and does not vary with inflation or market changes. Ethanol policy, as it influences economic expectations, could have effects that are not captured by its relation with present ethanol production, so additional data could be obtained by including both policy and production in the model.

The actual market price of ethanol would almost certainly be a significant factor, but it would also almost certainly co-vary with ethanol policies, oil prices (obtainable from the Energy Information Administration website), and food prices, so its inclusion in the model would be redundant.

The dependent variables (corn prices, average crop prices, total agricultural land and land planted with corn), will be represented as continuous variables, using dollars per unit (bushel in all cases here) as the unit for corn prices and acres of land as the unit for land-use.

Any and all continuous variables may need modification once initial models have been created, to attempt to make more powerful models. This may involve taking different powers or transformations of the variables, or examining non-linear relationships. A final model can be arrived at by using analysis of variance to sort through the various possible models and select the one involving the least error and least likelihood of the patterns observed resulting from chance alone.

C. Variables to be Included

Dependent: Land acreage used for corn in the US, total agricultural land acreage in the US, price of corn received by farmers, average price of corn, wheat, and soybeans received by farmers (all data obtained from the US Department of Agriculture's Economic Research Service)

Independent/Explanatory: Federal subsidy level for corn ethanol(placed at a certain monetary credit per gallon produced, does not vary with market changes or inflation)(Wallace, 2006), agricultural commodity prices (USDA ERS), CPI (from US Bureau of Labor Statistics), US real GDP (US BLS), price of oil (from Energy information Administration), production of ethanol in millions of gallons (from EIA).

IV. Results

A. Data Compilation

The results are presented in three tables; one detailing the relationships of each independent variable with each dependent variable in a series of simple, single-variable regression models, one describing the results of full multiple regression models where all five independent variables are applied to each dependent variable, and one showing the results of reduced multiple regression models selected for each dependent variable on the basis of maximum statistical robustness, as measured by the F-statistic and R-squared values.

Single-Variable Model Data

Independent Variables (columns) Dependent Variables (rows)	Ethanol Production (previous year, millions of gallons)	Oil Price (dollars per barrel)	Subsidy Available for Ethanol (indicator)	CPI (percent of 1982 prices, base 100)	US Real GDP (billions of dollars)
Corn Price ($ per bushel) Coefficient	1.990e-04	0.025228	NA	0.006818	8.974e-05
R-squared	0.3929	0.5023	0.3975	0.1442	0.1057
F-statistic p-value	0.0003581	2.436e-05	0.003075	0.04622	0.09146
Average Crop Price ($ per bushel) Coefficient	3.530e-04	0.042259	NA	0.013023	1.782e-04
R-squared	0.4838	0.5518	0.3988	0.2061	0.1631
F-statistic p-value	3.976e-05	5.975e-06	0.003008	0.01525	0.03308
Total Agricultural Land Use (millions of acres) Coefficient	-0.006413	0.01951	NA	-0.19764	-0.002729
R-squared	0.1795	0.0002307	0.3371	0.2013	0.1724

F-statistic p-value	0.03481	0.9426	0.01449	0.02447	0.03902
Land Used for Corn (millions of acres) Coefficient	1.590e-03	0.18581	NA	0.07761	0.001144
R-squared	0.2618	0.2845	0.2487	0.1951	0.1793
F-statistic p-value	0.005389	0.003468	0.03036	0.01860	0.02475

The three statistics given for each model above are the coefficient of the independent variable with the dependent variable, the R-squared variable, and the P-value associated with the F-statistic. The coefficient is a numerical association of the independent variable with the dependent variable. It indicates the value by which the independent variable is multiplied to calculate its input in the equation that determines the dependent variable. It is not a measure of the robustness of the model – the GDP and ethanol production coefficients are very small because the data points for those variables are very large.

The R-squared value, also called the coefficient of determination, measures how much of the variation in the data can be explained by the model. Higher R-squared values indicate a more powerful model – the maximum value is 1.

The F-statistic's p-value is a measure of how likely it is that the results explained by the model were actually pure chance, and that no association exists between the variables. A lower p-value indicates that this is less likely and therefore that the model's relationships are significant. Establishing significance customarily requires a p-value of less than 0.05.

The Ethanol Subsidy Level variable is an indicator variable rather than a continuous variable. It has four different coefficients, each indicating an addition to or subtraction from the mean line rather than a multiplier applied to a specific x-value. All other variables are continuous, and are not transformations – the simple data in all cases proved to provide better correlations than any transformations like exponents or logarithms.

Full Multivariate Model Data

Independent Variables (columns) Dependent Variables (rows)	Ethanol Production (previous year, millions of gallons))	Oil Price (dollars per barrel)	Subsidy Available for Ethanol	CPI (percentage of 1982 prices, base 100)	US Real GDP (billions of dollars)	Model Statistics
Corn Price ($ per bushel) Coefficient:	-7.548e-05	1.545e-02	NA	9.723e-02	-1.256e-03	R-squared: 0.6168
P-value:	0.57045	0.18670	0.24477	0.02281	0.00969	F-statistic p-value: 0.000427
Average Crop Price ($ per bushel) Coefficient:	-3.327e-05	2.853e-02	NA	1.329e-01	-1.731e-03	R-squared: 0.6115
P-value:	0.8760	0.1323	0.3948	0.0488	0.0235	F-statistic p-value: 0.0004797
Total Agricultural Land Use (millions of acres) Coefficient:	0.01719	0.81992	NA	-1.20239	0.01838	R-squared: 0.3383
P-value:	0.2219	0.2013	0.0895	0.2987	0.1763	F-statistic p-value: 0.05403
Land Used for Corn (millions of acres) Coefficient:	0.002374	0.252956	NA	-0.579034	0.005539	R-squared: 0.2541
P-value:	0.1993	0.1168	0.0828	0.2934	0.3646	F-statistic p-value: 0.08168

The full models suffer from multi-correlation, resulting in p-values for the individual variables that indicate they are not significant when they actually may be. Oil prices and ethanol production, for example, correlate with each other with an R-squared value of 0.6343. Both appear to be insignificant within the full corn prices model (as highlighted above), but the model itself is highly significant, more so than would be expected if there were really only one significant variable. The variables that are affected by multi-correlation can be determined by comparing the full model table above to the reduced model table below; variables with large p-values above but low p-values below are distorted by multi-correlation effects.

All R-squared values in the multivariate models (both full and reduced) are actually R-squared adjusted values. R-squared adjusted is a statistic that modifies the R-squared value based on the number of independent variables included, reducing it with each additional variable. This corrects the R-squared value's tendency to increase when more variables are used, regardless of the significance of the variables.

<u>Reduced Multivariate Model Data</u>

Independent Variables (columns) Dependent Variables (rows)	Ethanol Production (millions of gallons, previous year)	Oil Price (dollars per barrel)	Subsidy Available for Ethanol	CPI (percentage of 1982 prices, base 100)	US Real GDP (billions of dollars)	Model Statistics
Corn Price ($ per bushel) Coefficient:	-	0.0281389	-	0.0488791	-0.0007921	R-squared: 0.6194
P-value:	-	2.78e-05	-	0.00487	0.00316	F-statistic p-value: 7.51e-06
Average Crop Price ($ per bushel) Coefficient:	-	0.0437049	-	0.0724242	-0.0011383	R-squared: 0.6343

P-value:	-	3.11e-05	-	0.00726	0.00607	F-statistic p-value: 4.696e-06
Total Agricultural Land Use (millions of acres) Coefficient:	-0.013028	0.797516	-	-	-	R-squared: 0.3172
P-value:	0.00150	0.01579	-	-	-	F-statistic p-value: 0.005771
Land Used for Corn (millions of acres) Coefficient:	-	0.18581	-	-	-	R-squared: 0.2845
P-value:	-	0.00347	-	-	-	F-statistic p-value: 0.003468

Reduced models are an attempt to more accurately represent the relationships between variables by removing variables that do not add significant information to the model. This cuts the multi-correlation problems and improves the overall F-statistic p-values.

The reduced models were selected on the basis of ANOVA comparisons with the full model. This method generates an F-statistic that indicates how likely it is that the full model's results could be generated by the reduced model. A p-value for this F-statistic of less than 0.05 indicates that the full model adds significant power to the model. Variables were eliminated from the models on the basis of their coefficients' p-values until the ANOVA comparison showed a loss of power, then the last model that did not show a loss of power was selected.

The reduced models were not selected solely on the basis of R-squared (adjusted) values. However, all of the selected models except the model for total agricultural land use generated the highest R-squared value of available models for their particular dependent variable. The total agricultural land use model that incorporated GDP in addition to ethanol production and oil prices had a higher R-squared value than the selected model, but ANOVA comparison showed that the inclusion of GDP did not significantly add to the model's power.

B. Data Analysis

Corn Prices:

Neither ethanol production nor the federal subsidies available to ethanol producers appear to be significant variables in predicting corn prices. While ethanol production appears to be significant when used alone as a predictor of corn prices, using it alongside the other variables shows that much of the variation it appears to explain is instead tied to these other variables, which with ethanol production correlates. The correlation with oil prices is puzzling in that the ethanol production data used for each data point is from the previous year, indicating that ethanol production is significantly tied to the oil prices in the next year – this could be explained, however, by ethanol producers' future expectations, as they would produce more ethanol if they expected oil prices to rise, since high oil prices lead to a higher demand, and price, for ethanol.

GDP appears to have a significant but very small negative correlation with corn prices. The CPI has a positive relationship with corn prices, which is expected, as CPI indicates the general price level. A general increase in prices would logically entail higher corn prices, due to the effect on the prices of inputs in corn production. Oil prices also have a positive correlation with corn prices, which makes sense due to the importance of oil in the production process of corn.

A possible alternative explanation for the lack of a significant correlation between ethanol production and corn prices is the expansion of corn production over this time period.

Corn production has increased by almost sixty percent since 1982, allowing corn to be used for ethanol without reducing the amount available for conventional uses. This increase in production can be attributed to improvements in technology, such as better fertilizers, machinery, and selective breeding techniques (Schmidhuber, 2006).

Average Crop Prices:

The relationships between average crop prices (mean price of corn, soybeans, and wheat) and the independent variables are similar to those between corn prices and the independent variables – ethanol production and subsidies are insignificant, while oil prices and CPI have a positive correlation, and GDP a negative correlation, with crop prices.

Oil prices, CPI, and GDP have a slightly stronger correlation with average crop prices than they do with corn prices. This may be explained by crop producers shifting their production in favor of more corn when crop input prices increase. Such a practice would lessen the impact of economic shifts on corn prices but would not mask changes in average crop prices.

Total Agricultural Land Use:

Ethanol production in the previous year appears to have a slightly negative correlation with total agricultural land use. This may be a spurious connection, though, as ethanol production has increased and total agricultural land has generally decreased over the measured time period, leading to a correlation when no real connection exists. In any event, the coefficient for this correlation is very small, indicating a minimal impact.

Oil prices have a positive correlation with total agricultural land use. The coefficient for this relationship is small but not negligible – it indicates that if oil prices rise by a dollar, land use will increase by around 800,000 acres. This connection is puzzling, especially given that when oil prices are used in a single-variable model as a predictor for land use, the correlation is insignificant. One possible explanation is that when oil prices are high, farmers have higher input costs, and thus a lower profit margin. If they are seeking a certain level of income, they would need to increase production, and thus open up more land to cultivation. Although typical economic models do not assume this type of behavior (higher input costs typically necessitate lower production), it might be a rational strategy for farmers who must make certain fixed payments (like the payment for a mortgage) and need a certain amount of revenue regardless of profitability. Adding ethanol production provides a variable to correlate with the generally decreasing trend for total agricultural land use, and allows the slight positive correlation with oil prices to register as significant.

It should be noted that agricultural land in the United States has actually decreased by 53 million acres, from 383 million to 330 million acres, since 1982. The percentage of agricultural land used for corn has grown significantly over this time period, from 22.0% to 26.2%, but this is reflective of the loss of total agricultural land, not an increase in the amount of land being used for corn.

Land Used for Corn:

Oil prices are the only significant independent variable with regard to corn acres planted, and even the coefficient for oil prices is small to the point of practical insignificance. Corn acres planted also shows no clear pattern over time.

The amount of land used both for corn and for total agriculture may not correlate with the quantity of corn and crops produced. Agricultural production is subject to variability due to weather conditions, leading to differences in harvest size over time even when similar amounts of land are in use. Additionally, technological progress has led to more efficient production processes over time, allowing, all other things being equal, for more crops to be produced on the same amount of land; since 1982, the amount of land used for corn production has increased by only 2.8%, but total corn production has increased by 59.4%. This increase in corn production capacity has made it possible to supply sufficient corn for ethanol production without significantly expanding the amount of land under cultivation.

V. Conclusion

This study finds that, at least up until now, ethanol production in the United States has not had a meaningful relationship with either food prices or land use. However, it cannot prove that increasing ethanol production in the future will not affect either of those variables.

The correlation indicated by rising ethanol production and rising food prices in the mid-2000s appears to primarily be a result of the correlation of both factors with oil prices. As oil is a key factor of production in agriculture, a dramatic increase in the price of oil, like the one that occurred from 2006 through 2008, would be expected to drive up the price of crops. The price of oil also plays a large role in determining the production of ethanol, as higher oil prices make ethanol a more cost-effective source of energy. The production of ethanol would intuitively be expected to drive up the price of corn through the logic of supply and demand; in this case, however, ethanol production itself does not appear to have had that effect on the corn market.

The possible reasons for this are many and complex, but can be represented in a fairly accurate manner through the observation that the market for corn in the United States does not adhere to the typical economic model of perfect competition and production on the margin. The U.S. government has involved itself heavily in the agricultural sector for decades, going back to the New Deal's Agricultural Adjustment Act of 1933 (Alston, 2006). One primary effect of this involvement has been an underuse of production capacity by farmers – in any given year, much of the U.S.'s agricultural land lies fallow. This does not necessarily mean the market is suboptimal, as leaving some land fallow allows the long-run productivity of that land to be maintained, preventing Dust Bowl scenarios. However, the underuse of agricultural land is partially intended to keep crop prices at an artificially high level (Alston, 2006), so there is some degree of “slack” in the market, where additional crops could be produced without clearing new land or overusing existing land. Agricultural production, as a result, does not significantly co-vary with the total amount of land available for agricultural use.

Additionally, technological improvements in the corn production process have made it possible to produce more corn without using significantly more land (Trostle, 2008). Corn production has expanded by 59% since 1982, while the amount of land used for corn production (land actually planted with corn each year) has remained virtually the same. This has allowed ethanol to be produced in large quantities without altering the amount of corn available for conventional uses; indeed, the expansion in corn production more than covers the corn necessary for the current level of ethanol production.

A. Policy Implications

While this study cannot prove that a future expansion of ethanol production will not increase corn prices or require more land use for agriculture, it can at least establish that ethanol production has not as of yet led to these effects. The analyses claiming that increased ethanol production caused the surge in food prices during the mid-2000s appear to be wrong, or at least misleading; food prices did rise during this period, but more in line with rising oil prices than with increased ethanol production. Mitchell, Runge and Senauer, and Mazade’s assertions on this topic rely on the existence of a large, significant correlation of ethanol production with higher corn prices, which is simply not present.

Similarly, the arguments advanced by Searchinger and Fargione, that ethanol production will increase greenhouse gas emissions due to the use of new land for agriculture, appear to be as of yet unfounded. Greater ethanol production has not coincided with an expansion of agricultural land, but rather a significant decrease in agricultural land, so any prospects of incurring carbon debts by cultivating previously untouched grassland (Fargione, 2008) appear to be unrealistic.

However, this relationship may not repeat itself in the future. Continued expansion of the production of ethanol will require continuing advances in corn production technology if corn prices and land use are to remain steady with regard to ethanol production. It is conceivable that corn production will not be able to keep pace with demand for ethanol, especially if rising oil prices make ethanol more economically competitive. In this situation, either corn prices would have to rise (even more than they would normally due to rising oil prices) or land use for corn would have to be expanded, or both. Completely replacing oil use with ethanol would almost certainly entail radical changes in both of these variables. In this respect, the arguments of the previously cited authors are important; even though they do not describe any past or current pattern in the corn market, they do provide poignant warnings against taking the paths they describe.

Similarly, speculations on past possibilities cannot be proven or disproven here. As corn production has expanded by such a great amount over the last 30 years, it could be imagined that corn prices, in the absence of demand for ethanol, would have radically decreased. As such, ethanol production, although it shows no significant correlation with corn prices, might in reality be driving up corn prices from a possible lower level. However, it is not at all clear that this additional corn would have been produced without the demand for ethanol. US agricultural policy gives farmers an incentive to not use all of their production capacity unless they can achieve a certain price for excess production (Alston, 2006); if the farmers had expanded their production, they would have forced down the price of corn, and their profits would not have exceeded the subsidies they eschewed by expanding production. Only the prospect of earnings greater than those which the farm subsidies provided could entice farmers to expand their corn production, and ethanol demand provided the possibility of such earnings. Ostensibly, an enlightened US government could have devised some other policy to persuade farmers to expand production even without ethanol demand, but this reaches far into the realm of speculation – it simply cannot be established what would have happened in the US corn market had ethanol not emerged as a major corn product.

The wisdom of US agricultural policy is called into question by the above speculation; if farm subsidies are artificially keeping crop prices high, and people in developing countries are therefore unable to buy as much food from the US as they would like, why should these subsidies be continued? This appears to be an example of special interests (in this case, big agricultural companies and the farm lobby), exerting undue influence on the political process (possibly due in part to the very early position of Iowa, a very agriculturally oriented state, in the presidential primaries) and creating an economically suboptimal situation. However, it may be that the real situation is not nearly so easy to characterize. Overproduction by farmers lead to disastrous situations in the 1920s and 1930s and was a major factor behind the Great Depression (Alston, 2006); there was, and possibly still is, a very good reason for the adoption of policies to limit farm production, and any movement to stop these policies should be carefully evaluated.

This analysis also has implications for wider energy policy; namely, it shows just how dependent our agricultural markets are on the price (and thus the availability) of oil. Those who assert that there is a choice of "food or fuel" are mischaracterizing the situation – without fuel, there is no food, or at least not very much of it. Any change in oil prices, whether motivated by a natural decline in the oil supply, an artificial restriction on the oil supply (as in the OPEC oil embargo during the 1970s), or a domestic policy affecting the use of oil, could have an ensuing effect on food prices and availability. A carbon cap-and-trade system or tax, if it targeted emissions resulting from the processes involved in crop production, could increase food prices, and any such policies should therefore be crafted to take into account such effects and address them accordingly.

B. Limitations

Despite the acknowledgement that many of the problems associated with rising food prices occurred in the developing world, this analysis only considered variables associated with the US; the inclusion of international markets into the models used here would have introduced too many variables for the models to remain useful, given the low number of available data points for the key variables. As a result, any changes in non-American markets were not measured or incorporated into the regression models. It is possible that the relative stability in US markets was not in line with world patterns, or even that the stability in the US was achieved through changes in other countries; the US may have reduced corn exports or increased corn imports to accommodate its use of corn for ethanol, reducing the amount of corn available in other countries. However, the price data considered here should at least partially reflect trends in world markets, as both oil and crops are commodity goods that are traded internationally in large quantities.

Due to the yearly measurement pattern for many of the data categories used and the relatively short time that ethanol has been in production, the number of data points used here was quite low – varying between 28 and 29 points depending on the variable. This is on the very low end of acceptability for statistical models; the typical minimum number of data points is 30. The models established here are therefore quite imprecise, and may not fully capture the correlations between the variables. However, this limitation is partially offset by the reliability and aggregate nature of the data used; since many of these data points (such as corn prices, oil prices, and CPI) are actually yearly averages of larger data sets, and all of the data are gathered by reliable, official sources, the low number of data points is not as large of an obstacle as it would have been had the data consisted of singular primary observations of specific cases.

Many of the US's states have independent ethanol policies (Duffield, 2008), which this study did not address. Although their effects were likely captured through the use of ethanol production as an independent variable, additional information could probably have been gleaned by finding a means to include state ethanol policies in the models; as the original aim was to analyze the impact of policies, not production, state policies could have added much to the picture. The difficulty of obtaining and quantifying data on each state's subsidy programs precluded their inclusion here; however, as stated above, their overall effects were likely captured by the ethanol production variable.

C. Areas for Further Research

An obvious extension of this study would be to apply the framework described here to international markets. This would allow the effects of corn ethanol production in the US to be more fully understood, as any costs or effects that are being externalized by the US would then be recognized.

Additionally, the effects of ethanol production in other countries could be studied. Many developing countries, most notably Brazil, have extensive ethanol markets, and use different crops to produce ethanol, predominantly sugarcane (Fargione, 2008). While land use changes may not have occurred as a result of US ethanol production, they could be occurring in these other countries. The effects of land use change in Brazil on greenhouse gas concentrations would likely be far larger than those of land use change in the US, as in Brazil, new agricultural land comes at the expense of carbon-intensive rainforest, not relatively barren grassland. An analysis of the effects of sugarcane ethanol production in Brazil and its effects on sugar prices and land use, similar to the one conducted here on corn ethanol's effects, could yield very different results, and could potentially reveal extremely important information.

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VII. Appendix I - Data

Year	Corn Prices	Oil Prices(non-inflation adjusted)	CPI(1982 base 100)
1982	2.55	31.83	96.5
1983	3.21	29.08	99.6
1984	2.63	28.75	103.9
1985	2.23	26.92	107.6
1986	1.5	14.44	109.6
1987	1.94	17.75	113.6
1988	2.54	14.87	118.3
1989	2.36	18.33	124
1990	2.28	23.19	130.7
1991	2.37	20.2	136.2
1992	2.07	19.25	140.3
1993	2.5	16.75	144.5
1994	2.26	15.66	148.2
1995	3.24	16.75	152.4
1996	2.71	20.46	156.9
1997	2.43	18.64	160.5
1998	1.94	11.91	163
1999	1.82	16.56	166.6
2000	1.85	27.39	172.2
2001	1.97	23	177.1
2002	2.32	22.81	179.9
2003	2.42	27.69	184
2004	2.06	37.66	188.9

2005	2	50.04	195.3
2006	3.04	58.3	201.6
2007	4.2	64.2	207.342
2008	4.06	91.48	215.303
2009	3.6	53.48	214.537
2010			

Ethanol Subsidy Level	Corn Production (millions of bushels)	US Real GDP (billions of dollars)
1	8235.101	5870.9
2	4174.251	6136.2
2	7672.13	6577.1
3	8875.453	6849.3
3	8225.764	7086.5
3	7131.3	7313.3
3	4928.681	7613.9
3	7531.953	7885.9
3	7934.028	8033.9
4	7474.765	8015.1
4	9476.698	8287.1
4	6337.73	8523.4
4	10050.52	8870.7
4	7400.051	9093.7
4	9232.557	9433.9
4	9206.832	9854.3
4	9758.685	10283.5
4	9430.612	10779.8
4	9915.051	11226
4	9502.58	11347.2
4	8966.787	11553
4	10087.292	11840.7
4	11805.581	12263.8
5	11112.187	12638.4
5	10531.123	12976.2
5	13037.875	13254.1
5	12091.648	13312.2
5	13130.632	12990.3
Ethanol Production (million gallons)	Agricultural Land Use (million acres)	Corn Acres Planted

		(million acres)
83	383	84.1
225	333	81.86
415	373	60.21
510	372	80.52
617	357	83.4
712	331	76.58
819	327	66.2
831	341	67.72
843	341	72.32
748	337	74.17
866	337	75.96
985	330	79.31
1154	339	73.24
1289	332	78.92
1358	346	71.48
973	349	79.23
1288	345	79.54
1405	344	80.17
1465	345	77.39
1622	340	79.55
1765	340	75.7
2140	342	78.89
2804	336	78.6
3404	336	80.93
3904	330	81.78
4884		78.33
6521		93.53
9309		85.98
		86.48

Average Crop Price ($/bushel)
3.93666667
4.85666667
3.95333333
3.45333333
2.9
3.46333333
4.56

3.92333333
3.54333333
3.65
3.62333333
4.05333333
3.73
4.83666667
4.78666667
4.09333333
3.17333333
2.97666667
3.00333333
3.04333333
3.80333333
4.38666667
3.73333333
3.69333333
4.57666667
6.92666667
6.93666667
5.97333333

Data obtained from the US Department of Agriculture's Economic Research Service, the US Bureau of Labor Statistics, and the US Energy Information Administration.