BIOFUEL IMPACT ON FOOD PRICE INDEX AND LAND USE CHANGE

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AUTHORIZATION TO SUBMIT THESIS

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ABSTRACT

Some papers have questioned the benefits of biofuels, claiming that biofuels cause food prices to increase and more land to be diverted to crop production. We analyzed the consumer food price index from 1973 to 2016. It was found that US food price inflation rate was 2.6% from 1991 to 2015 with an R^2 of 1.0, fully encompassing the biofuel boom. It was concluded that biofuel had no significant impact on food price index. Agricultural Census data shows that crop land in the United States decreased by 88 million acres from 1950 to 2012. A part of our research was manual analysis of the land use classification in the US. Net 8.66% of non-agricultural lands were classified as agriculture land. Comparing 2011 and 2015 land classification, the automated classification showed 8.53% increase in agricultural land, while manual classification showed only 0.31% (±1.92%) increase.

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CHAPTER 1 INTRODUCTION

Biofuel production is a large part of the US initiative for cleaner energy. Reports have shown soybean biodiesel to produce 5.34 to 5.54 units of energy per unit of fossil fuel used in its production and reduce Green House Gas (GHG) emissions by 81.2 percent (Pradhan et al. 2011, Pradhan et al. 2012). Likewise, reports on corn ethanol found an energy ratio of 1.5 when not including byproduct credits, or 2.1 to 2.3 when including byproducts (Gallagher et al. 2016), and a 24 percent reduction in GHG emissions (Flugge et al. 2017). Despite these established life cycle analysis (LCA) results, and similar results from studies by the Environmental Protection Agency (EPA), US Department of Energy (USDOE), and the US Department of Agriculture (USDA), some researchers have reached the conclusion that biofuels are more harmful to the environment than petroleum.

A 2008 article in the journal *Science* by Searchinger et al. (Searchinger et al. 2008) was the first widely publicized report discrediting the Renewable Fuel Standard (RFS). The report claimed that past LCA studies failed to count the carbon emissions that occur when farmers respond to higher prices and convert forest and grassland to new cropland. In addition, the authors contended that higher crop prices led to higher food prices, lower food consumption, and poorer diets in developing countries. A 2015 paper by Lark et al. (Lark et al. 2015) also argued the US biofuel boom resulted in significant cropland expansion. Additionally, a 2015 research paper by DeCicco and Krishnan (DeCicco and Krishnan 2015) claimed that a flawed accounting system engrained in LCA has caused studies to underestimate the CO_2 emissions of corn ethanol (DeCicco 2015). Since these reports, the "land use change (LUC)" and "food versus fuel" debates have intensified.

It has been over ten years since the beginning of the biofuel boom. Enough data is now available to verify the predictions relating the biofuel production and LUC. Data is also available to determine if food prices rose with increased biofuel production. The purpose of this paper was to investigate the accuracy of reports using biofuel models, satellite imagery, and other non-observable methods that have shown unintended consequences of biofuel policies. Statistical analyses were used to determine if there were significant correlations between biofuel production, land use change, and food prices.

CHAPTER 2 AGRICULTURAL LAND USE IN THE UNITED STATES

The first step in looking into claims of agricultural expansion is to look into recorded data. The USDA conducts an agricultural census approximately every 5 years going back to the 1800s (USDA 2017). While this does not give year by year data, it can be useful for an overview of historic trends. Taking data from each census, we were able to build a table of values Table 2.1) for each census year. 2012 data for "Transportation, Parks and Wildlife, and Industrial" was not available in the census. Luckily, these areas were not of great concern for the purposes of this study. As well, data for "Pasture and Range land" was not specifically available for the years of 1969 and 1974. This area was instead conglomerated with "Farmsteads, Buildings, Roads, Ect." into a single "Other" category. Values for these specific categories were calculated using averages determined from previous census years. These calculated values are highlighted in (Table 2.2).

Table 2.1: Census breakdown of agricultural lands, 1950-2012

Year	Crop Land (1000 acres)	Wood Land (1000 acres)	Pasture and Range land (1000 acres)	Total Farm Land (1000 acres)	Trans-portation, Parks and Wildlife, and Industrial (1000 acres)	Harvested Cropland (1000 acres)	Other Pasture and Grazing (1000 acres)	Other cropland (1000 acres)
1950	478,315	220,561	416,802	1,161,420	87	344,564	64,263	64,263
1954	459,649	196,972	459,879	1,158,192	92	332,870	60,709	60,709
1959	448,087	164,204	466,225	1,123,508	97	311,476	71,095	71,095
1964	434,232	145,976	490,307	1,110,187	115	286,892	89,921	89,921
1969	458,990	112,013	453,722	1,062,893	112	273,016	97,753	97,753
1974	440,039	92,528	446,872	1,017,030	113	303,002	54,301	54,301
1978	461,341	94,892	436,729	1,029,695	123	320,666	64,514	64,514
1982	445,362	87,088	418,264	986,797	127	326,306	65,028	54,028
1987	443,318	79,894	410,329	964,471	135	282,224	64,980	96,114
1992	435,366	73,962	410,835	945,532	136	295,937	66,806	72,622
1997	445,325	76,855	398,232	954,753	142	318,937	66,388	59,999
2002	434,165	75,878	395,279	938,279	153	302,697	60,558	70,910
2007	406,425	75,099	408,832	922,096	169	309,608	35,711	61,046
2012	389,690	77,013	415,309	914,528	NA	314,965	12,803	61,923

Table 2.2: Calculation of 1969 and 1974 values

Year	Pasture and Range land (acres)	Farmsteads, Buildings, Roads, ect. (acres)	Sum or "Other" category (acres)	Percentage of "Other" made up of Pasture and Range
1950	416,802,416	45,741,705	462,544,121	90.11084501
1954	459,878,925	41,691,218	501,570,143	91.6878589
1959	466,224,802	44,991,142	511,215,944	91.19919038
1964	490,306,987	39,671,382	529,978,369	92.51452808
1969	453,722,045	38,167,476	491,889,521	NA
1974	446,872,367	37,591,276	484,463,643	NA
1978	436,729,233	36,733,034	473,462,267	92.24161321
1982	418,264,264	36,082,032	454,346,296	92.05847339
1987	410,329,126	30,928,768	441,257,894	92.99077287
1992	410,834,565	25,369,059	436,203,624	94.18412466
1997	398,232,125	34,340,781	432,572,906	92.06127325
2002	395,278,829	32,957,068	428,235,897	92.30399221
2007	408,832,116	31,740,212	440,572,328	92.79568643
2012	415,309,280	32,515,057	447,824,337	92.73932783
			Average of Percentages:	92.24064052

Agricultural census data from 1950 to 2012 showed that land dedicated to agriculture has declined. Total acreage decreased by approximately 246 million acres between 1950 and 2012. Some farmland was converted to residential, commercial, and industrial uses, and there was an increasing trend in land used for rural parks, wilderness areas, and wildlife refuges (Nickerson et al. 2011) Total wood land has been in steady decline, falling from about 89.3 million ha (220.5 million acres) in 1950 to 31.2 million ha (77 million acres) in 2012. Permanent Pasture and Rangeland has fluctuated greatly, beginning with 168.7 million ha (416.8 million acres) in 1950 and ending up at 168.3 million ha (415.3 million acres) in 2012. Total crop land has decreased significantly, starting at 193.5 million ha (478 million acres) in 1950 and dropping to 157.9 million ha (390 million acres) in 2012. Total cropland included cropland harvested, cropland used for pasture or grazing, failed/abandoned cropland, summer fallow, and idle cropland (USDA 2017).

Harvested Cropland started at a high point of 139.5 million ha (344.5 million acres) in 1950 and fluctuated greatly, reaching a ten year high of 127.5 million ha (314.9 million acres) in 2012. Harvested Cropland is any cropland that has been harvested for any crop, including tree crops, vineyards, berries, nurseries, and greenhouses. Other Pasture and Grazing Land experienced the most change over the study period. This category included land used only for pasture or grazing that could have been used for crops without additional improvement. Starting at 25.9 million ha (64 million acres) in 1950, other Pasture and Grazing Land had dropped to its lowest point in the study of 5.2 million ha (12.8 million acres) in 2012. However, there have been definitional changes for this land use type over the years which correlate to significant drops in acreage in this category. This methodological inconsistency doesn't always allow for direct comparisons between the years (Nickerson et al. 2011). Looking at changes in other land use categories, it is likely that land in Other Pasture and Grazing went to other purposes. Summing up increases in Other Cropland, Permanent Pasture and Rangeland, Woodland, and Harvested Cropland, only 3.0 million ha (7.4 million acres) remain that likely went to non-agricultural use.

While the overall data on the agricultural sector shows that agricultural land in the United States has been declining, we can get more precise by looking into individual crop plantings. In particular, biofuel feedstocks such as corn and soybeans can provide strong data as to the growth of the biofuel industry. The National Agricultural Statistics Service (NASS) collects data on annual crop plantings. We looked into crop plantings recorded by the NASS to get data for corn, soybeans, wheat, barley, and sorghum from 2000 to 2015. This timeframe should completely encompass the biofuel boom while also extending slightly before and after it. Compiling this data into a table (Table 2.3) allowed us to compare trends over the 15-year timeframe.

Table 2.3: Acres of crop planting, 2000-2015

Year	Corn planted (acres)	Soybeans Planted (acres)	Wheat planted (acres)	Barley planted (acres)	Sorghum planted (acres)
2000	79,551,000	74,266,000	62,549,000	5,801,000	9,195,000
2001	75,702,000	74,075,000	59,432,000	4,951,000	10,248,000
2002	78,894,000	73,963,000	60,318,000	5,008,000	9,589,000
2003	78,603,000	73,404,000	62,141,000	5,348,000	9,420,000
2004	80,929,000	75,208,000	59,644,000	4,527,000	7,486,000
2005	81,779,000	72,032,000	57,214,000	3,875,000	6,454,000
2006	78,327,000	75,522,000	57,334,000	3,452,000	6,522,000
2007	93,527,000	64,741,000	60,460,000	4,018,000	7,712,000
2008	85,982,000	75,718,000	63,617,000	5,239,000	8,404,000
2009	86,382,000	77,451,000	59,017,000	3,568,000	6,599,000
2010	88,192,000	77,404,000	52,620,000	2,872,000	5,369,000
2011	91,936,000	75,046,000	54,277,000	2,564,000	5,451,000
2012	97,291,000	77,198,000	55,294,000	3,660,000	6,259,000
2013	95,365,000	76,840,000	56,236,000	3,528,000	8,076,000
2014	90,597,000	83,276,000	56,841,000	3,031,000	7,138,000
2015	88,019,000	82,650,000	54,999,000	3,623,000	8,459,000

Corn acreage increased from 32.1 million ha (79.5 million acres) in 2000 to 35.6 million ha (88 million acres) in 2015, with a high of 39.4 million ha (97.3 million acres) in 2012. Soybeans rose from 30.0 million ha (74.2 million acres) in 2000 to 33.4 million ha (82.6 million acres) in 2015. Part of this increase is due to increases of exports of soybeans, vegetable oil, and protein meal as wealthier populations shift from staples to more diversified products (Lee et al. 2016). Increasing biodiesel growth also contributed to soybean oil demand, as US biodiesel production increased from 8.75 million gallons in 2001 to 1,260 million gallons in 2015 (EIA 2017-b).

While corn and soybean acreage have increased, acreage in other crops has declined. Wheat acreage declined from 25.3 million ha (62.5 million acres) in 2000 to 22.3 million ha (55 million acres) in 2015. There was a modest decrease in sorghum acreage over the study period, with average acreage falling from 3.4 million ha (8.32 million acres) over the 2000 to 2007 period to 2.8 million ha (7 million acres) from 2008 to 2015. Likewise, barley acreage averaged 1.9 million ha (4.6 million acres) from 2000 to 2007 and dropped to 1.4 million ha (3.37 million acres) from 2008 to 2015. Reductions in wheat, barley, and sorghum accounted for much of the increase in corn and soybean acreage (Riley 2015).

In addition to crop substitution, corn and soybean production benefited from higher crop yields. By analyzing census data on crop acreage and bushels cultivated we were able to calculate yield per acre. The census for corn had a few differences throughout the years of the study (Table 2.4). From 1950-1959 the census gave totals for corn planted. All years following however, gave two separate values, corn for grain and corn for silage. These values were added together to give total corn acreage. In terms of corn bushels harvested, from 1950 to 1978 only totals were included. Following years however, have corn harvested split between corn for grain in bushels and corn for silage in tons. The corn for silage was converted to bushels and added together with corn for grain to give total corn cultivated in bushels. Dividing corn harvested by corn acreage gave us yield per acre. Corn yields rose from 2.1 Mg/ha (33 bushels/acre) in 1950 to a high point of 11.2 Mg/ha (178 bushels/acre) in 2007 with a slight decrease to 9.5 Mg/ha (151.94 bushels/acre) in 2012 correlating with the drought of 2012.

Table 2.4: Corn bushels per acre calculations, 1950-2012

Year	Corn for Grain (1000 acre)	Corn for silage (1000 acre)	Corn Total (1000 acre)	Corn for grain (1000 bushels)	Corn for silage (tons)	Corn for silage (1000 bushels)	Corn Total (1000 bushels)	Corn Bushels per Acre
1950	NA	NA	83,337	NA	NA	NA	2,778,000	33.33
1954	NA	NA	78,122	NA	NA	NA	2,613,000	33.45
1959	NA	NA	79,616	NA	NA	NA	3,697,000	46.44
1964	53,751	9,764	63,515	NA	NA	NA	3,361,142	52.92
1969	52,540	7,862	60,402	NA	NA	NA	4,441,808	73.54
1974	61,654	10,677	72,330	NA	NA	NA	4,396,913	60.79
1978	70,734	8,381	79,115	NA	NA	NA	6,857,786	86.68
1982	69,858	8,019	77,877	7,508,721	110,733,566	3,954,770	11,463,492	147.20
1987	58,701	5,785	64,487	6,725,002	80,394,261	2,871,223	9,596,225	148.81
1992	69,340	6,069	75,409	8,697,363	84,905,107	3,032,325	11,729,688	155.55
1997	71,088	5,771	76,860	8,578,635	88,380,934	3,156,462	11,735,097	152.68
2002	68,231	6,684	74,914	8,613,062	97,132,738	3,469,026	12,082,088	161.28
2007	86,249	5,979	92,228	12,738,519	104,224,795	3,722,314	16,460,833	178.48
2012	87,413	7,196	94,609	10,333,410	113,153,064	4,041,181	14,374,591	151.94

Soybeans and wheat were easier to calculate (Table 2.5). The census gave acreage planted for both as well as cultivation in bushels throughout the entire study period. These values could then be respectively divided to get yield in bushels per acre. Soybeans grew from 1.1 Mg/ha (17 bushels/acre) in 1950 to a high of 2.7 Mg/ha (40.4 bushels/acre) in 2007, slightly decreasing to 2.6 Mg/ha (38.46 bushels/acre) in 2012. These increases in yield have not only been for biofuel crops, however. Wheat, for example, steadily increased from 0.9 Mg/ha (14 bushels/acre) in 1950 to 3 Mg/ha (44 bushels/acre) in 2012 (USDA 2017).

Table 2.5: Wheat and Soybean yield calculations, 1950-2012

Year	Wheat Total (1000 acre)	Wheat (1000 bushels)	Wheat Bushels per Acre	Soybean Total (1000 acre)	Soybeans (1000 bushels)	Soybean Bushels per acre
1950	71,163	1,007,000	14.15	12,265	212,000	17.28
1954	51,361	909,000	17.70	18,243	324,000	17.76
1959	49,567	1,056,000	21.30	23,070	516,000	22.37
1964	47,958	1,217,792	25.39	29,843	669,664	22.44
1969	45,373	1,328,003	29.27	38,549	1,041,489	27.02
1974	62,957	1,691,553	26.87	48,119	1,145,788	23.81
1978	54,458	1,616,060	29.68	61,833	1,734,778	28.06
1982	70,910	2,373,246	33.47	64,832	1,989,993	30.69
1987	53,224	1,887,104	35.46	55,291	1,838,054	33.24
1992	59,089	2,206,729	37.35	56,351	2,053,163	36.44
1997	62,085	2,204,026	35.50	66,148	2,504,307	37.86
2002	45,520	1,577,005	34.64	72,400	2,707,719	37.40
2007	50,933	1,993,648	39.14	63,916	2,582,424	40.40
2012	49,040	2,185,108	44.56	76,105	2,926,823	38.46

THE CONSERVATION RESERVE PROGRAM

We have seen that some farmers have been switching the types of crops they plant and the agricultural sector as a whole has been shrinking. However, the harvested cropland subsection of agricultural land has only diminished slightly. While it is likely a great deal of the decreases have come from pastures and other areas of agriculture, the consistency of harvested cropland likely would have needed additional sources. Land exiting the Conservation Reserve Program (CRP) has freed up a great deal of land for agriculture, which was the original usage of lands in the CRP.

The CRP was created by the Food Security Act of 1985, which authorized the USDA to establish contract payments to agricultural producers and landowners to remove highly erodible land from cropland and pasture production for a period of 10 to 15 years. When contracts expire, landowners have the choice of leaving the program or re-enrolling (Sullivan, Hellerstein et al. 2004). Cropland offered for the CRP must have been planted to an agricultural commodity in recent years. The maximum amount of land that can be enrolled in the program is set by Congress, typically through Farm Bill Legislation. As of September 2016, about 166,326 ha (411,000 acres) were approved for General sign up enrollment and over 0.5 million ha (1.3 million acres) in continuous enrollment. Total acreage under contract was 9.7 million ha (23.9

million acres), just slightly below the legislated maximum of 24 million acres set by the 2014 Farm Act (ERS 2017). The 2014 Farm Act reduced the CRP acreage cap by 25 percent from the previous 12.9 million ha (32 million acres) enrollment cap set by the 2008 Farm Act. The 2008 maximum of 32 million acres was also a cut in enrollment from 39.2 million acres set in 2002. However, the lower acreage limits largely reflected a declining interest in the program beginning in the late 2000s, as increasing commodity prices enticed farmers to leave the program and return acreage to crop production (Claassen 2016).

THE EPA'S AGGREGATE COMPLIANCE APPROACH

The data shows that, while overall agricultural land is on the decline, biofuel feedstock crops have been gaining ground. However, further research has shown that there are measures in place to limit the growth in the biofuel sector to try and prevent rampant agricultural land growth. The Energy Independence and Security Act of 2007 (EISA) limits the types of feedstocks that can be used to make renewable fuel, as well as the land used to produce them. Renewable biomass that qualifies for the program includes planted crops and crop residues harvested from "existing agricultural land" cleared or cultivated and actively managed fallow and nonforested land as of December 19, 2007 (Schnepf and Yacobucci 2013). The EPA developed an aggregate land use approach to verify the eligibility of renewable biomass. Using the USDA's Farm Service Agency (FSA) crop acreage data, the EPA assesses land use change annually. The first step of this approach involved determining the total amount of "existing agricultural land" in the United States at the enactment date of the EISA, which was 162.7 million ha (402 million acres). Secondly, at the end of each calendar year the EPA conducts a posterior assessment of total agricultural land to determine if the national agricultural land acreage increased above the 2007 baseline. If the EPA finds that the total amount of qualified land used for feedstock production is equal to or greater than 160.7 million ha (397 million acres) – i.e. within 5 million acres of the EPA's established 402 million acre baseline – an investigation is triggered. Using this approach, the EPA has determined that the national aggregate baseline of 402 million acres has not been exceeded since the RFS2 was first implemented in 2010 (Federal Register 2010).

CHAPTER 3 BIOFUEL COPRODUCTS AS ANIMAL FEED

When analyzing the economic impact of biofuels, it is important to note coproducts of biofuel production. In the production of biofuels, only a portion of the plants are used. The remainder can be used to produce other products. These coproducts can offset perceived economic losses in using crops to produce fuel. The primary coproduct of US ethanol production is distillers' dried grains (DDG). About a third of every bushel used to make ethanol ends up as DDG, or about 17.5 pounds per bushel (Riley 2015). The USDA Economic Research Service records data on DDG production and demand in the United States. This data was available from 1993 to 2015 measured in million metric tons (Table 3.1).

Table 3.1: DDG Production vs Demand

Year	Production from Ethanol (million metric tons)	Demand as feed and residual (million metric tons)
1993	0.8	1.6
1994	1.1	1.6
1995	1.3	1.2
1996	1.1	1.4
1997	1.3	1.5
1998	1.6	1.9
1999	1.7	1.9
2000	2.1	2.3
2001	2.3	2.4
2002	2.7	2.8
2003	4.4	4.6
2004	5.7	6.0
2005	7.0	7.0
2006	9.2	9.0
2007	12.4	11.7
2008	19.8	16.9
2009	26.0	22.2
2010	32.4	25.4
2011	35.6	28.6
2012	35.3	29.1
2013	32.5	25.7
2014	35.5	25.0

DDG output began to increase significantly along with increased ethanol production. By 2005, DDG production had met US feed demands at 7 million metric tons. This continued to increase until seeming to level off at around 35 million metric tons of DDG produced and 25 million metric tons of DDG in demand. This excess can then be exported for profit.

In recent years, mills started to produce another coproduct by extracting corn oil before the DDG is processed. This oil is not food grade, but it can be used to create other products such as biodiesel. Data for US biodiesel production showed the use of corn oil increasing from 29.04 Gg (64 million pounds) in 2009 to 484.57 Gg (1,068 million pounds) in 2013 (EIA 2017-b). In 2015, 479.58 Gg (1,057 million pounds) of corn oil were used to make an estimated 498.96 ML (132 million gallons) of biodiesel. Adding these coproducts to the ethanol production process has increased the supply of biodiesel and animal feed without adding more resources, including land, to corn production.

Like the relationship of DDG to ethanol, the production of soybean meal increases as more soybean oil is used to make biodiesel. For every bushel of soybeans crushed, about 11 pounds of oil are produced, along with 44 pounds of the meal which supplies about 19 pounds of protein animal feed (Pradhan et al. 2009). Processed soybeans are the world's largest source of animal protein feed and the United States is the world's leading soybean producer (Ash 2017). The amount of soybean oil used to produce biodiesel increased from 762.25 Gg (1,680 million pounds) in 2009/10 to 2285.39 Gg (5,037 million pounds) in 2014/15 to help meet the RFS2. The soybeans crushed to produce the soybean oil for biodiesel also resulted in the production of soybean meal, ranging from 3.31 Tg (7.3 billion pounds) in 2009/10 to almost 9.98 Tg (22 billion pounds) in 2014/15 (USDOC 2012, EIA 2017-a). This increased amount of soybean meal allows for more animal feed as well as more export potential of animal feed.

CHAPTER 4 FOOD PRICE INFLATION RATE

Several opponents of biofuel production have argued that biofuel production has increased the prices of biofuel crops and, in turn, the prices of food. The USDA Economic Resource Service provides information on food prices and food price inflation going back to 1973 (Appendix A: US Food Price Index). This data is given in percent increase or decrease from the previous year. Using 1973 as a baseline, we could add each respective year to the cumulative total to give the cumulative inflation each year. These points were then graphed (Figure 4.1) and separated into distinct regions based on determining the highest possible R^2 value in each. This resulted in three regression areas with high coefficients of determination (R^2) and low standards of error.

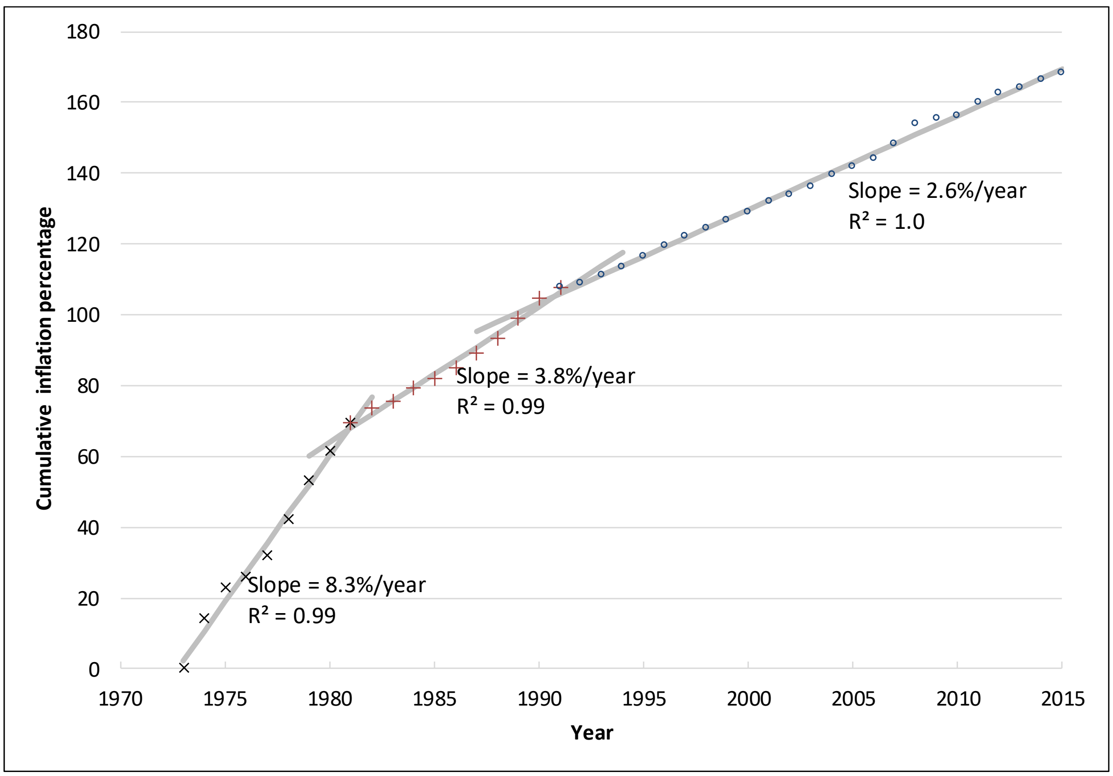

Figure 4.1: The United States food price index inflation from 1973 baseline.

The resulting data shows that US food price inflation remained stable through the biofuel boom. Using trend lines, we find that from the period of 1973 to 1981, food prices were increasing at a steady rate of 8.3 percent per year with a coefficient of determination (R^2) of 0.99, and standard error of 2.7%. From 1981 to 1991 this had dropped to a rate of 3.8 percent increase per year with an R^2 of 0.99 and standard error of 1.7%. Finally, trend lines show that from the period of 1991 to 2015 there was a rate of 2.6 percent increase per year with an R^2 of 1.00 and standard error of 1.1%. This period encompasses the biofuel boom yet does not demonstrate an associated increase in food price inflation during that period.

While food price inflation rates in the United States have been decreasing, the US has been ramping up biofuel production. Data for US ethanol production is available going back to 1980. Biodiesel is a newer product in the US, with production data only available going back to 2000 (Appendix B: Biofuel Production). Using trend lines, we find that ethanol production from 1980 to 2000 grew at a rate of 256.7 ML (67.9 million gallons) per year. From 2000 to 2010, the height of the biofuel boom, ethanol production grew exponentially, increasing from 6.0 GL (1.6 billion gallons) produced in 2000 to 50.3 GL (13.3 billion gallons) produced in 2010. Growth slowed down from there, with production increasing to 55.9 GL (14.8 billion gallons) in 2015 (FRA 2016). The US Energy Independent and Security Act of 2017 caps corn based ethanol to 15 billion gallons per year (EISA 2007). Similarly, biodiesel production from 2001 through 2008 also followed an exponential growth trend. This embodied the growth from the production of 34 ML (9 million gallons) of biodiesel in 2001 to 2.56 GL (678 million gallons) in 2008. From here production fluctuated, reaching 4.77 GL (1,263 million gallons) in 2015 (EIA 2017-b).

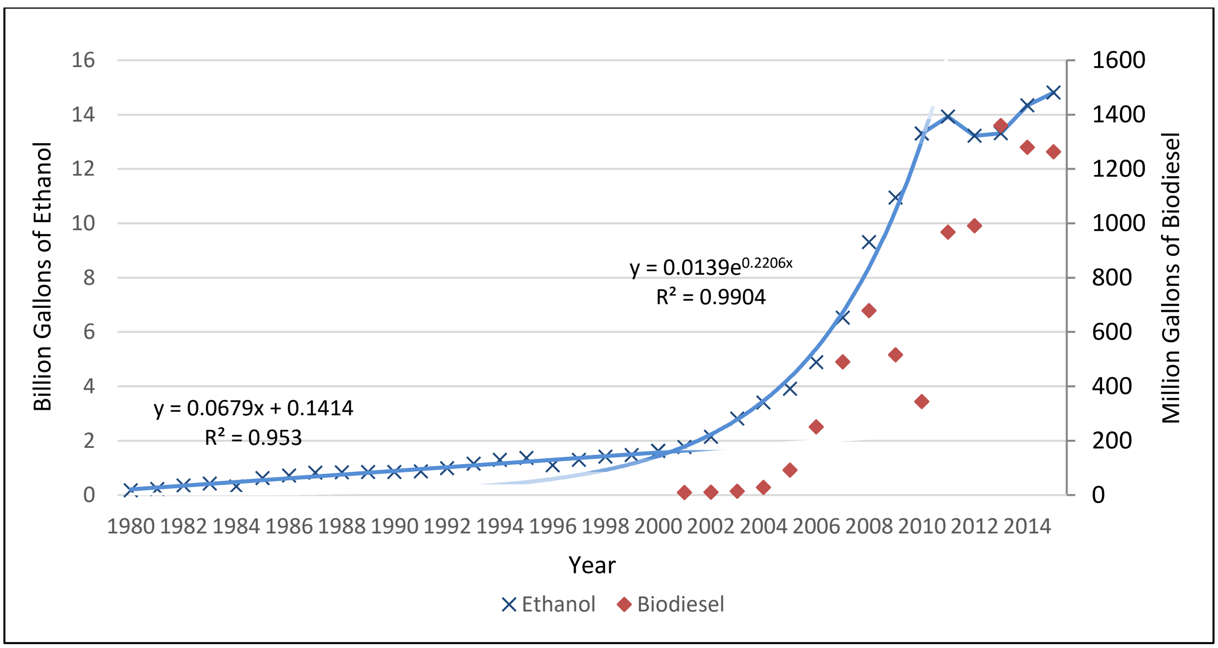

Figure 4.2: US Ethanol and Biodeisel production, 1980 to 2015

The lower inflation rate in recent years may partially be due to higher per capita food production. Using USDA data for crop production (USDA 2018) and population (World Bank 2018), the per capita corn and soybean production in the US was calculated. Per capita corn production grew from 750 kg (29.5 bushels) in 1991 to 1,192 kg (46.9 bushels) in 2016. Similarly, soybean production grew from 215 to 362 kg (7.9 to 13.3 bushels) per capita, an annual 2.3% and 2.8% increase for corn and soybean respectively. In contrast, the per capita production of corn and soybean from 1973 to 1991 grew by only 0.6% and 0.4% respectively.

The biofuel provided the market for excess grain and oil crop production. The US export data (USDA 2018) for total grain from 1991 to 2016 showed no significant change over time ($R^2 = 0.05$, with $p>F = 0.25$) (Figure 4.3). The total grain consists mainly of corn along with wheat, milled rice, sorghum, barley and other mixed grains. For the same period, the oilseed export grew at the rate of 1.2 ±0.2 Million MT/year ($R^2 = 0.87$, with $p>F = 0.00$). The results indicate that there may be an anomalous year like 2013, stemming from 2012 drought year, where grain and oil crop export were low, in general, there was no change in grain export during biofuel era, and there is a steady increase in oil crop export before and after biofuel boom.

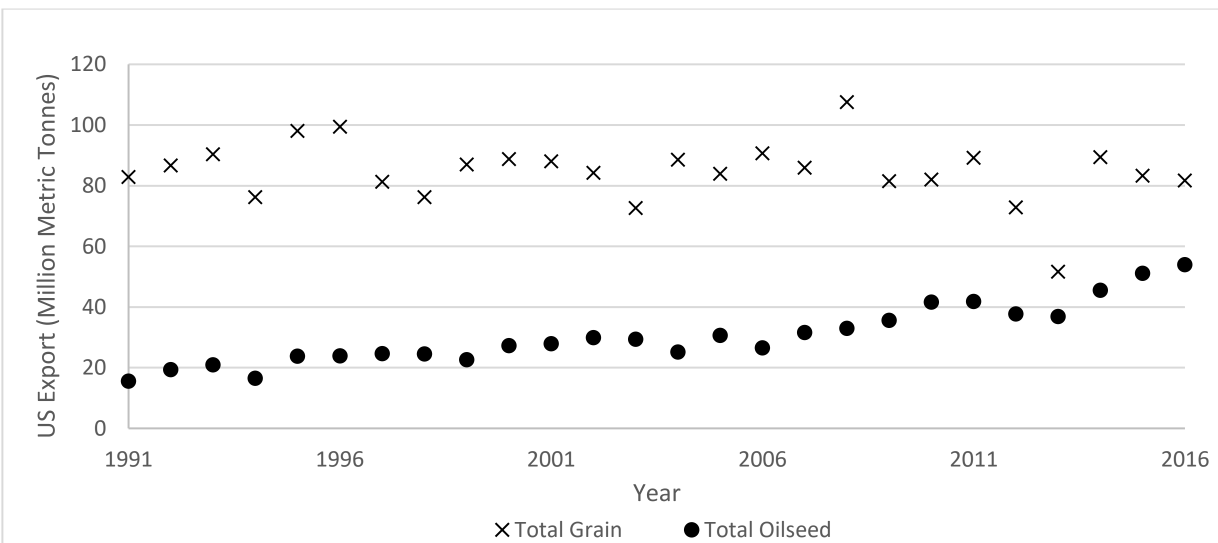

Figure 4.3: The United States export of total grain and oilseed.

While biofuel demand likely had some part in increasing crop prices, there are many other contributing factors, including market speculation, stockpiling policies, trade restrictions, macroeconomic shocks to money supplies, exchange rate, and economic growth. Climate change and spikes in oil and energy prices have also had a large impact on crop production and prices. Time series annual average price of corn and soybean prices (Good and Li 2017) were correlated with potential variables that could impact their prices. The variables considered were US population (World Bank 2018), total corn production (USDA 2018), total soybean production

(USDA 2018), West Texas Intermediate crude oil price (EIA 2018-d), urban CPI for other than food and energy (BLS 2018), ethanol production (EIA 2018-b), and biodiesel production (EIA 2018-a). Among the selected variables, both corn and soybean price had the strongest correlation with crude oil price. Corn price had weaker correlation with CPI for other than food and energy (r = 0.66), population (r = 0.65) and corn production (r = 0.55), and stronger correlation with crude price (r = 0.82) and with ethanol production (r = 0.79). Similarly, Soybean price had weaker correlation with CPI for other than food and energy (r = 0.75), population (r = 0.74) and soybean production (r = 0.68), and stronger correlation with crude price (r = 0.86) and with biodiesel production (r = 0.83). For a visual representation, the variables values from 1991 to 2016 were transformed to a unitless number between 0 and 1 using the following equation:

$$Relative\ value = \frac{Actual\ value - Minimum\ value}{Maximum\ value - Minimum\ value}$$

The plot of relative corn and soybean price with strongly correlated variables showed that crude oil price has a significant impact on crop price (Figure 4.4). The plot also shows the relative growth of ethanol as linear until about 2000 and then exponential growth until 2010. Our results agree with observations made by Tadesse et al. (2014) that crude oil prices, in particular, can have dramatic effects on food price volatility, with a 1% increase in oil price volatility correlating to a 0.42-0.45% in food price volatility. Economic factors can have a severe effect as well; for example, the export boom of the 1970s caused food prices to skyrocket, with corn prices almost tripling (Ray 2015). Since population, prices, production, and inflation rates were correlated, it was not possible to estimate the absolute effect of biofuel on corn and soybean price.

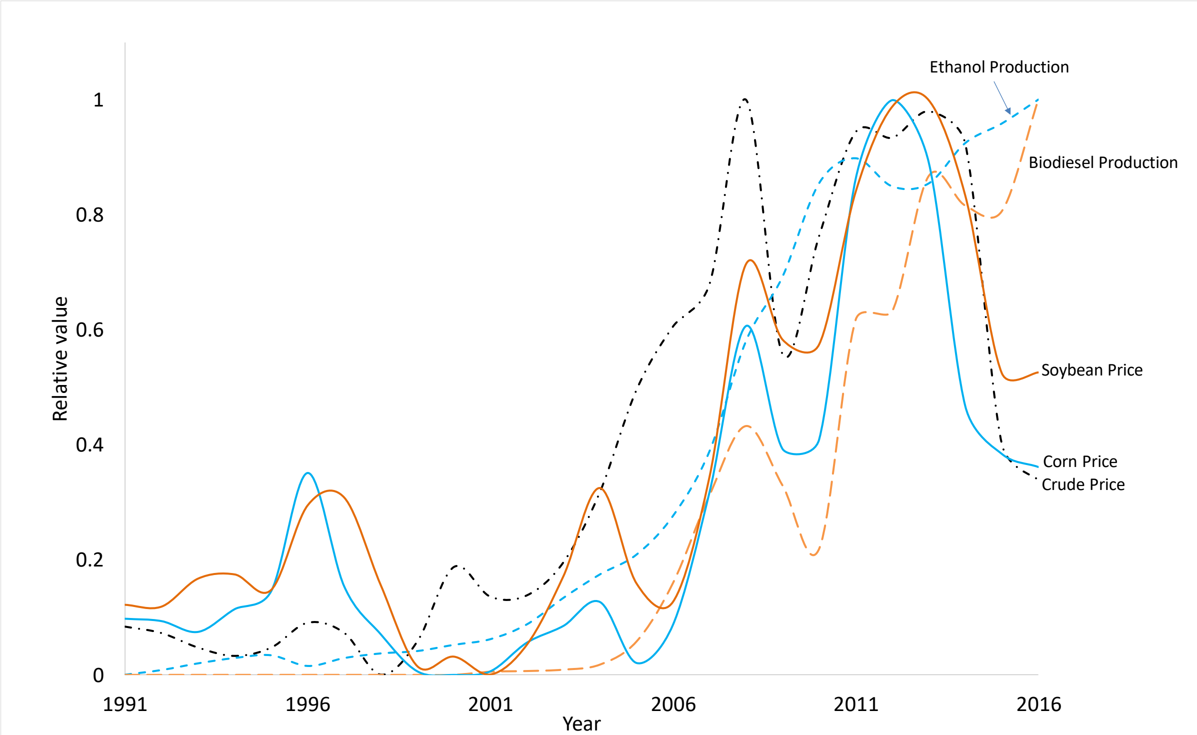

Figure 4.4: US corn and soybean prices compared to normalized crude oil price, and normalized ethanol and biodiesel production.

On the global scale as well, along with population, per capita food production is increasing. Using FAO data (FAO 2018), we found that per capita cereal production has increased from 352 kg in 1991 to 383 kg in 2016; per capita oil crop has increased from 14.5 kg of oil to 28.4 kg of oil equivalent. The Global Food Price Index (FPI) (FAO 2017) was correlated with population (World Bank 2018), per capita production of cereal and oil crops (FAO 2018), ethanol and biodiesel production (EIA 2018-c), inflation rate (World Bank 2018), and Brent Crude oil price (EIA 2018-d). FPI and CPI for food as discussed earlier are similar concepts, but the list of food included in FPI and CPI for food may not be the same. FPI had the highest correlation (r = 0.92) with the crude oil price. The relation was even stronger in biofuel era (since the year 2000) with a correlation of 0.94. Compared to this, FPI had a correlation of 0.87 and 0.77 with world ethanol and biodiesel production respectively. A linear model predicting FPI using crude oil price and the population was found to be:

$$FPI = 39.5 * N + 1.1 * COP - 184.3$$

Where COP is the crude oil price (Brent Crude Oil Price, $/barrel) and N is the global population in billions.

The linear model had R^2 value of 0.96. The predicted FPI with this regression model and actual FPI is shown in Figure 4.5. It worth noting that even though FPI correlates with oil price and population well, it was not possible to single out these two variables as the cause of increasing FPI because of a significant positive correlation between population, food production, ethanol production, crude price, inflation rate, and other economic factors. We chose oil price for its highest correlation with FPI and population was another logical choice that explained the increase in FPI. From this analysis, we concluded that the per capita food production is increasing over time and biofuel provided a market for excess grain and oil production. The price of food most strongly correlated with crude oil price and because of correlated data, it was not possible to point out a single factor causing food price increase.

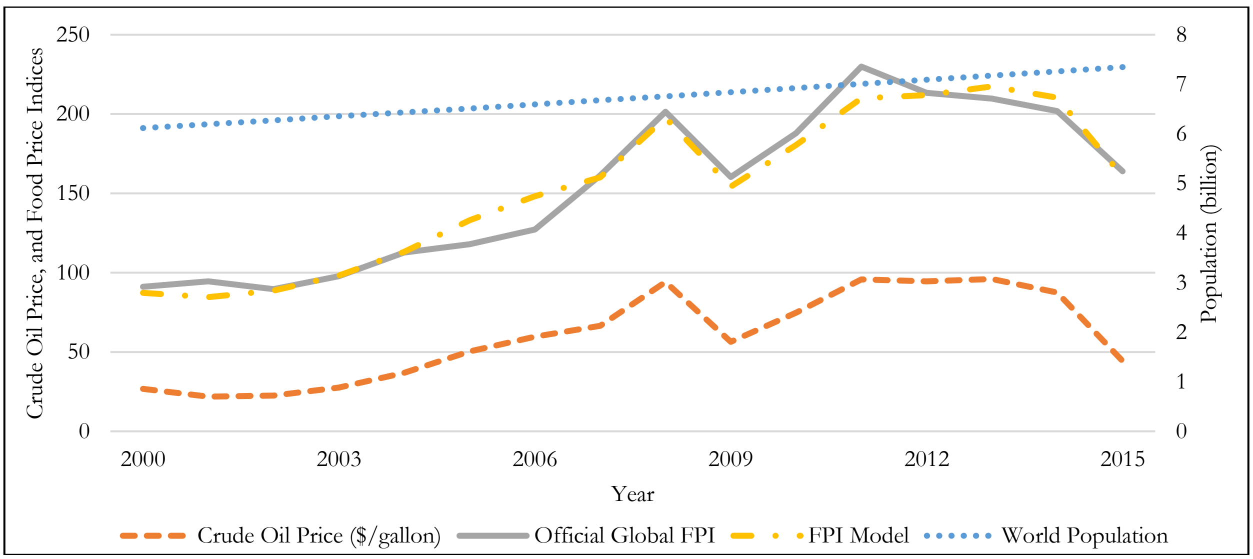

Figure 4.5: Crude oil price vs the International Food Price Index, 2000 to 2015.

CHAPTER 5 SATELLITE ANALYSIS

Land use data derived from machine-classified satellite imagery has been used in studies such as Lark et al. (2015) to estimate the amount of agricultural land use change. These studies commonly utilize the NASS CropScape Cropland Data Layer (CDL) (NASS 2016) and Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Database (NLCD) data (Homer et al. 2018). However, neither the NLCD or the CDL are designed for land use change analysis. The MRLC website (EROS 2018) states that the NLCD is designed for "assessing ecosystem status and health, modeling nutrient and pesticide runoff, understanding spatial patterns of biodiversity, land use planning, deriving landscape pattern metrics, and developing land management policies." The NASS states (NASS 2018) that the CDL is designed to provide crop specific, georeferenced estimates. It also fully acknowledges that the spatially-distributed CDL is not official data; official data is available from the yearly NASS reports and is aggregated to the county level. The acreage data in the CDL is pixel based and highly in need of bias correction. As the NLCD and CDL have become more widely used in land use policy decisions, the respective agencies in charge of these datasets have been performing accuracy assessments of the datasets.

Wickham et al. have been performing accuracy assessments of the NLCD for each release as they come out. They have performed assessments of the 2001 and 2006 NLCD layers and in 2017 published an accuracy review of NLCD 2011. They also analyzed accuracy in comparing the three different years of publication for change analysis (Wickham et al. 2017). The accuracies were separated into Level I and Level II classification hierarchies. Level I hierarchies pertained to classifications of perennial snow/ice and for open water. Level II hierarchies pertained to all other land classification categories. Level I classes had relatively high overall accuracy at 88%, 89%, and 89% for 2001, 2006, and 2011 respectively. Level II classes had slightly lower overall accuracies at 82%, 83%, and 83% for 2001, 2006, and 2011 respectively. When looking into change analysis, the accuracy decreased. Non-change categories commonly exceeded 85%, but categories that exhibited change tended to have lower accuracy. Of all the change categories, only forest loss, forest gain, and urban gain had accuracy that exceeded 70%. Agricultural loss and gain analysis over the same time period showed accuracies of only 48% and 40% respectively. It was concluded that some of the lower accuracy in other change areas may be due to the difficulty in determining open urban, grassland, and agriculture from one other on a spectral scale.

Beginning in 2016 the NASS began also creating accuracy assessments for each of their published Cropland Data Layers (CDL). The most recently published is the 2017 CDL with its associated accuracy assessment (NASS 2018). As the CDL focusses on crop-specific land covers, the accuracy of non-agricultural land classes are dictated entirely from the NLCD. The CDL uses a third-party software called See5 (NASS 2018) which uses a decision tree learning algorithm coupled with a Bayesian type probabilistic model for pixel classification. Training and validation of data used to create the CDL has been based on ground truth data buffered inward by 30 meters. This was done to try and correct for satellite inaccuracies and for the coarseness of the 56-meter AWiFS sensor imagery that was utilized for several years. The accuracy assessments were created using unbuffered validation data. The 2016 assessment also provides an accuracy assessment for buffered validation data. This allowed for the determining of bias due to buffering. Looking into the CDL 2017 accuracy assessment we find that the agricultural sector has an overall accuracy of 82.9%. As mentioned before, the accuracy assessment only covers agricultural classifications. Principal crops, tilled crops, and orchards had relatively high accuracy with 82.7%, 82.4%, and 93.6% accuracy respectively. However, forage, vegetables, and berries had low accuracies of 62.3%, 58.2%, and 62.3% respectively. In terms of biofuel production, corn and soybeans have fairly high accuracy at 88.5% and 88.2% respectively.

With these accuracy assessments in mind, we decided to test the accuracy of the NLCD and CDL ourselves in ArcMap. To evaluate the accuracy of the land cover classifications used in these datasets we performed raster analyses on three selected areas in the US for the years 2011 and 2015. Those years were the most current for which land classification data was available at the time of this analysis. In this research we chose three areas centered around Moscow, ID (Latitude and longitude of NW corner 46.769, -117.04 to SE corner 46.696, -116.872), Lemoore, CA (NW corner 36.331, -119.881 to SE corner 36.245, -119.713), and Le Roy, NY (NW corner 43.024, -78.08 to SE corner 42.946, -77.912). These locations were chosen for their differing climates and proportion of land types. Each area was measured to be 221,324 km^2. A total of seven classified images were downloaded for the above locations, CDL data layers from 2015 for all three areas, CDL data layers from 2011 for ID and NY and NLCD data layers from 2011 for ID and NY. Only two points in the NLCD were chosen as they were demonstrating comparable results to the CDL data points. The raster maps were imported and further analyzed using ArcMap V10.4.

Preliminary work in ArcMap with the CropScape data between 2008 and 2016 showed non-agricultural lands being swallowed up by developed lands (urban sprawl) and agriculture. However, when this was adjusted to isolate the vaguely defined "grass/pasture" classification, the majority of the non-agricultural lands being converted fell into the "grass/pasture" category. Grass pasture is defined by the system as lands used for either undisturbed grass lands or for grazing of animals. In other words, it could count towards either agricultural lands that would be considered eligible under the Renewable Fuel Standard for biofuel feedstock growth, or as natural grasslands that should not be encroached upon. This land also seemed to be largely interspersed within farmland. Further inspection also found a large amount of local soccer fields and larger lawns inside of urban areas were being defined as grass/pasture. Preliminary examinations using the NLCD data showed only urban expansion with little change in other categories. Both the NLCD and CropScape data showed error with misclassifying land as wetlands or open water. Actual open water areas, particularly rivers, were often misclassified as wetlands or agriculture.

In order to verify land classifications, we overlaid the classified data onto non-classified satellite imagery. This imagery was available for both 2011 and 2015 as "base maps" directly through ArcMap. These base maps were built using multiple sources of differing resolutions depending on how zoomed out you were in ArcMap; however, for our purposes we were making use of the highly zoomed in, 0.5-meter spatial resolution Digital Globe satellite imagery built in to the base maps. The base maps have global coverage, and the same spatial resolution for the entirety of the conterminous United States for the scale we were zoomed in at for our analysis. Therefore, we only had to make sure to use a 2011 base map for the 2011 data and a 2015 base map for the 2015 data. The classification value for each pixel was manually edited to match the land cover type in the satellite imagery and the edited file was compared back to the original files using the Raster Calculator tool with the formula: "original file" x 10 + "edited file".

This then gave an "error raster" that could tell the accuracy of the data point. The first digit of the classification values would show what the pixel was originally classified as, and the second digit would show what the pixel was now classified as. Ergo, any repeating numbers (11, 22, 33, etc.) would demonstrate no change, meaning that the original file was correct. Anything else, however, demonstrated an error. The downloaded map had categories for each crop grown in that area (NASS 2015) which we consolidated as agricultural land (AG) except for grassland/pasture (GLP) category. Although original raster legend classified GLP as part of agriculture (NASS 2015), after further analysis we found that only a small fraction of land classified as GLP was agricultural. For instance, in Idaho we found only 10.57% of GLP belonged to AG. The rest belonged to other categories, mostly virgin grassland, wild meadows, shrubland, and some developed land. To account for GLP error, and to make CDL data layer users aware of these discrepancies, we included two separate analyses: 1) with GLP as separate category, and 2) reclassifying GLP as manually verified land use categories. GLP areas that were virgin grassland, wild meadows and shrubland were included with Shrubland and this category was relabeled as Grass/Shrubland (GLS). Non-agriculture land categories included Developed, Grass/Shrubland, Wetland, Forest, Barren, Open Water (Water), and Perennial Ice/Snow. There was no perennial ice/snow in the areas considered in this study.

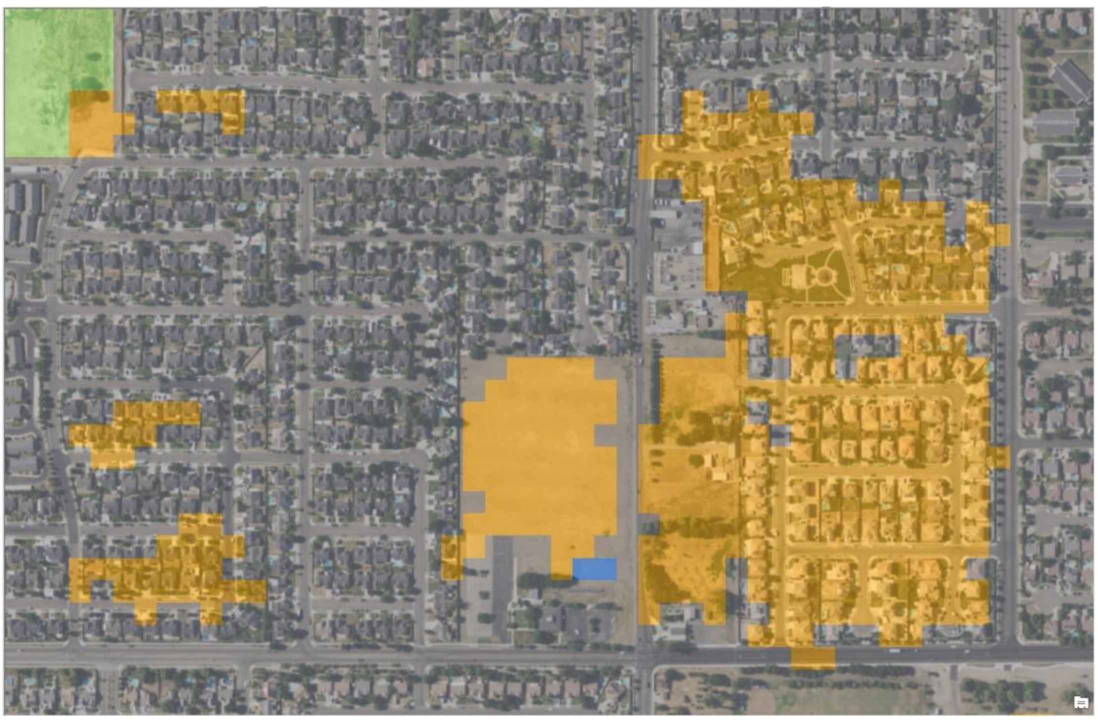

Figure 5.1: Screenshot of satellite classifications in the California 2015 CDL data.

The screenshot in Figure 5.1 shows an example of errors found during this analysis. In this image we see large swaths of residential and open developed land (color coded as grey) being identified as cropland (color coded as yellow). Overall findings from this analysis are summarized in Table 5.1 and amount to an average total error of 27.86% (±2.52%) of land incorrectly classified. Most of this error was from misclassification of other lands as agriculture. 10.90% of all land in the study was incorrectly identified as AG. If all GLP land were considered as AG land according to CDL legend (NASS 2015), the total incorrectly classified land as AG would have been 18.77% (sum of AG and GLP).

Table 5.1: Percentage of total land incorrectly classified in CDL and NLCD data for selected region in year 2011 and 2015.

Data Source*	Percent of total land incorrectly classified as								
	Developed	GLS	AG	GLP	Wetland	Forest	Barren	Water	Total
CDL ID 2015	2.13	5.38	7.45	2.79	0.00	0.07	0.00	1.38	19.19
CDL CA 2015	2.49	0.01	19.19	0.16	0.65	0.08	0.12	0.00	22.71
CDL NY 2015	2.43	1.39	6.15	9.87	0.08	7.98	0.43	3.15	31.48
CDL ID 2011	2.45	3.36	3.08	21.75	0.00	0.02	0.00	1.83	32.50
CDL NY 2011	2.32	2.98	8.81	4.80	0.07	3.93	0.50	14.02	37.41
NLCD ID 2011	1.85	2.05	15.94	N/A+	0.00	0.11	0.00	1.91	21.87
NLCD NY 2011	2.48	1.67	15.66	N/A+	0.03	8.37	0.00	1.68	29.90
Average Error	2.31	2.41	10.90	7.87	0.12	2.94	0.15	3.43	27.86
Standard Error	0.09	0.65	2.27	3.23	0.09	1.45	0.08	1.80	2.52

* ID, CA, and NY represent 221, 324 km^2 areas of Idaho, California, and New York states. CDL uses NLCD data for all non-agriculture category classification.

+ NLCD data does not have GLP category.

There were also AG lands that were incorrectly classified as other categories. Figure 5.2 shows the breakdown of the specific errors in the agriculture misclassifications. Arrows point to the direction of the error. For instance, 4.23% of the land that should have been classified as developed was incorrectly classified as agriculture. Meanwhile, only 1.18% of land that should have been classified as agriculture was classified as developed. The number in parenthesis shows the standard errors. GLP is not included in this analysis. The classification error was divided into two categories, the agricultural land classified as something else (omission error) and some other land classified as agriculture (commission error). It was observed that, compared to 10.90% of land incorrectly classified as agriculture, only 2.23% of agricultural land was incorrectly classified as different category. This corresponds to 8.66% of net land incorrectly classified as agriculture.

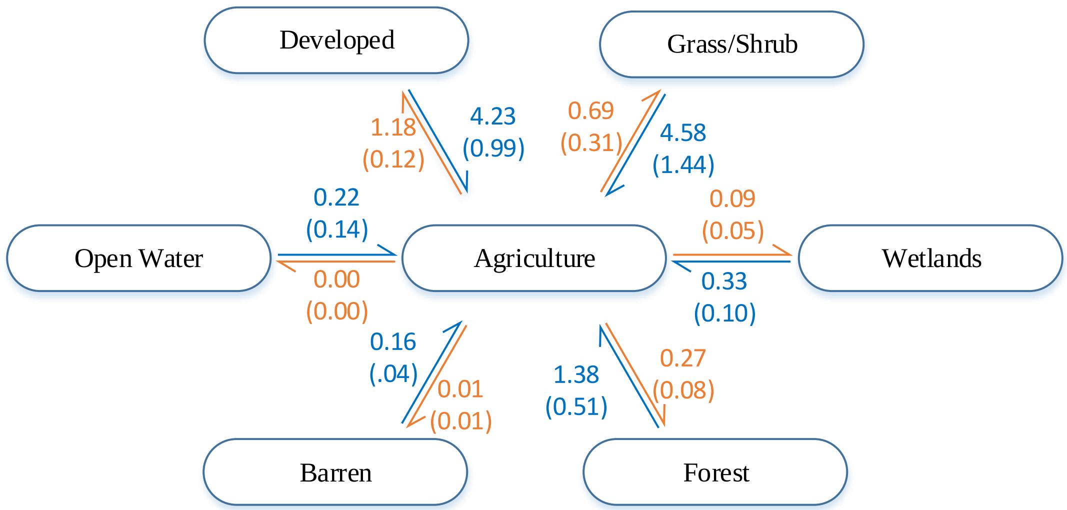

Figure 5.2: Breakdown of agricultural land classification errors in percent of total land.

The highest misclassification as agriculture came from grass/shrub land (4.58%). Classifying grassland as crop land is one of the weaknesses of remote sensing analysis. Lark et al. 2017 identified the grassland to cropland misclassification error as one of the weaknesses of utilizing the CDL and cautions that, due to the spectral similarity of grassland and cropland during remote sensing classification, it is difficult to accurately discern among various grassland vegetation types and uses (Lark et al. 2017). However, it was surprising to see the second-highest classification error (4.23%) from the developed category to agriculture. Further analysis showed that California and New York had particularly high rate of misclassification of developed land as agriculture land. We suspect that this high rate of classification error is stemming from unrepresentative a-priori probability assigned to land categories. The training dataset is obtained from the USDA Farm Service Agency's Common Land Unit (CLU) program. The CLU is not in public domain and therefore could not be verified for its a-priori probability of agriculture to non-agriculture fraction. If the training dataset has more agricultural pixels, say 90%, then a boundary pixel will be classified as agriculture 90% of the time. If the training rules are applied to an area that has only 80% agriculture, 10% more boundary pixels will be classified as agriculture.

We also analyzed the effects of these errors on land use change calculation. This was estimated by performing error analyses of CDL data between 2011 and 2015 to determine land use change in ID and NY. Two change analysis raster layers were created, one for original data from the satellite and one for our manually edited data (Table 5.2). The average of NY and ID in original data shows that the GLP has decreased by 15.82 km^2, wetland by 0.45 km^2 and barren land by 0.15 km^2, of which 8.53 km^2 was converted into AG and 5.50 km^2 was converted to GLS. The corrected image analysis shows that AG land has increased by only 0.31 km^2 with 95% confidence interval of ±2.7 km^2. This corresponds to 0.05±0.41% of the land area change to agriculture. As the change in the 95% confidence interval includes 0, and the standard deviation is greater than the amount of change, the null hypothesis "there is no significant land use change" could not be rejected and the analysis concluded that the land use change is not statistically significant.

Table 5.2: Land Use Change Analysis between 2011 and 2015. Negative numbers represent decreases in land area, and positive numbers are increases in land area.

Data source	Land Use Change from 2011 to 2015 in km^2							
	Developed	GLS	AG	GLP	Wetland	Forest	Barren	Water
ID Original	1.03	16.26	24.77	-41.98	0.13	-0.19	-0.01	0.00
ID Corrected	-0.28	-0.77	0.61	0.00	-0.04	0.40	0.01	0.07
NY Original	-0.02	-5.27	-7.71	10.35	-1.02	4.01	-0.28	-0.05
NY Corrected	0.01	-0.16	0.00	0.00	-0.01	0.15	0.00	0.00
Average Original	0.51	5.50	8.53	-15.82	-0.45	1.91	-0.15	-0.03
Average Corrected	-0.14	-0.47	0.31	0.00	-0.03	0.28	0.01	0.04

CHAPTER 6 ADDRESSING CONTRADICTORY FINDINGS

Contrary to model predictions, the data does not support claims that increases in biofuel production caused US cropland expansion. For example, the results of Searchinger et al. (2008) are based on an economic scenario that resulted in annual US corn ethanol production increasing to upwards of 30 billion gallons in 2016. This result is unrealistic as the EISA limits the annual corn ethanol requirement to 15 billion gallons starting in 2015. In order to satisfy the large quantity of corn needed for ethanol use, the model reduces US corn exports by over 62 percent from the 2008 level. With the exception of the 2012 drought year, the largest reduction in corn exports occurred in 2009, when exports fell from the 2008 record high of 2,437 million bushels to 1,849 million bushels. Over the last three crop years, exports have been relatively steady, averaging about 1,895 million bushels or about a 22 percent reduction compared to 2008, in contrary to predicted 62 percent. Also adding to the authors' inflated global acreage requirements were model predictions of sharply declining soybean and wheat exports. However, soybean exports have been increasing since the early 1990s, reaching a peak of 1,843 million bushels in 2014 (Ash 2017). Wheat exports have fluctuated sharply over time with no apparent trend since 2000 (Bond 2017, FAS 2017). However, assuming that increases in biofuel production are solely responsible for higher commodity prices is shortsighted. Other factors have played a major role, including increasing world per capita consumption of animal products, rising energy prices, depreciation of the US dollar, slower growth in agricultural productivity, and changes in trade practices in some countries (Trostle et al. 2011).

Another major weakness in the Searchinger et al. paper is assumptions about land conversion. They assume that increases in global corn acreage could not come from existing cropland and would have to come exclusively from deforestation and cultivating grasslands for crop production. However, according to the data found in this report, agricultural land has been decreasing despite increased biofuel production. Searchinger et al. assumed that China would convert about 5.7 million acres of grassland into cropland, but China adopted policies in the late 1990s to do just the opposite, i.e., convert marginal cropland into grassland and forest land (Wang and Haq 2008, Bennett et al. 2014).

Using satellite-based data to measure annual US agricultural land use change, Lark et al. concluded that there was a significant amount of previously untouched grassland converted to cropland from 2008 to 2012. As reported above, the Census of Agriculture did show an increase in harvested cropland and a marked decline in cropland used for pasture or grazing. Cropland used for pasture and grazing, and CRP cropland are included in the total cropland acreage reported by the Census and qualify for feedstock production under the Renewable Fuel Standard. The use of satellite data cannot provide information on certain land uses as opposed to land covers and land misclassification. This is a common problem with satellite imaging (Mueller and Copenhaver 2009). For example, satellite imaging can't distinguish between cropland used to grow hay, and pasture land used for grazing (Nickerson et al. 2011). Therefore, much of the converted grassland identified by Lark et al. is likely cropland as defined by the Census. Another indication that they likely overestimated the amount of grassland converted to cropland in some states comes from data reported in NASS's Crop Production Annual Summary (NASS 2017). Looking at estimates of area planted of principal crops in North Dakota, the survey reported about 23.7 million planted acres in 2008 compared to about 23 million acres in 2012, or about 735,000 acres decline. In contrast, using satellite imaging data, Lark et al. concluded that cropland acreage expanded by 206,418 acres from 2008 to 2012 in North Dakota.

The papers by DeCicco and coauthors have also made claims that ethanol and policies encouraging biofuel production are likely increasing greenhouse gas emissions and causing cropland expansion worldwide (DeCicco and Krishnan 2015, DeCicco 2016). The authors assert that biofuel production has been causing LUC that, in turn, increases GHG emissions (DeCicco 2015). However, none of the research papers by DeCicco and coauthors provide any data or other evidence that biofuel production has caused GHG emissions to rise due to LUC. They simply cite other research, namely the papers by Searchinger et al. and Lark et al.

The three papers reviewed above assume that the RFS biofuel mandates could only be satisfied with global cropland expansion. In addition, it is assumed that new cropland would be needed to satisfy the RFS and this could only come from deforestation and converting grasslands. DeCicco et al. and Lark et al. started their analysis with the premise that any LUC occurring since the implementation of the RFS had to be entirely related to biofuel mandates. However, these papers lacked the methodology to measure the correlation between biofuels and commodity prices, feedstock production and LUC, and the effect of commodity prices on food prices.

CHAPTER 7 CONCLUSION

Biofuels are a cleaner alternative to offset petroleum fuel usage. Studies have shown that as biofuel production becomes more efficient, ethanol and biodiesel have increasingly higher GHG reductions and energy content per unit of petroleum fuel used in production. However, economic models used in some studies indicated a negative overall impact of biofuel. These impacts included crop land expansion and increased food price. This paper focused on the "Food Vs. Fuel" issue and "Land Use Change" issues associated with biofuels.

An analysis of FPI from 1973 to 2016 showed three distinct periods of inflation. The linear regression showed that the inflation was the lowest since 1991 which included the era of biofuel boom. From 1991 to 2015, linear inflation at 2.6% per year with $R^2 = 1.0$ and standard error of 1.7% was observed. Compared to this, the period from 1973 to 1981 had linear inflation of 8.3%, and from 1981 to 1991 had a 3.8% annual inflation rate. Further analysis of inflation rate found that per capita corn production grew from 29.5 bushels in 1991 to 46.9 bushels in 2016. Similarly, soybean production grew from 7.9 to 13.3 bushels per capita, an annual 2.3% and 2.8% increase for corn and soybean respectively. In contrast, the production per capita for corn was 26.8 bushels and for soybean was 7.3 bushels in 1973, an annual increase of 0.6% for corm and 0.4% for soybean from 1973 to 1991. There was also no shift in the pattern of grain or oil seed export before and after the biofuel era. While grain export has not changed significantly since 1991, oil seed export has been increasing at an average rate of 1.2 Million MT/year.

Potential variables causing an increase in the US and global FPI were correlated with soybean price, corn price and FPI in general for global analysis. It was found that the commodity prices had the highest correlation with crude oil price and 96% of the variability could be explained form crude oil price and global population. Because of the high correlation between predictor variables, it was not possible to single out one variable that was responsible for the increase in FPI.

The USDA Census data shows total agricultural land has been declining since the 1950s. Over the years, farmland shifted to urban uses and there is more land dedicated to rural parks, wilderness areas, and wildlife refuges. Focusing on cropland, the Census data recorded about 88.6 million acres less in 2012 compared to 1950, but it has fluctuated over the study period. Annual decisions to use cropland for crop production are generally based on commodity prices, changes in government programs, and expectations of net returns. More evidence that cropland has not been increasing are results from the EPA's Aggregate Compliance Approach, which uses various sources of annual data to track changes in the agricultural land base. Using this method, the EPA determined that total existing cropland, as measured in 2007, has not increased since the RFS2 was first implemented in 2010.

A great deal of land use change research is being performed using satellite analysis. However, these the CDL and NLCD were not built for agricultural land use change analysis and accuracy assessments of them do not demonstrate a high enough accuracy to support using them for these purposes. We analyzed three selected areas in the US with total of 664 km^2 from a diverse geographic location to manually verify the CropScape CDL automated satellite image land use classification and NLCD image data. We found an average of 27.86% total land cover classification error. While satellite analysis can be a useful tool in determining land use data, it is very important to look at the accuracy assessments of any satellite data utilized.

Although CDL has included grassland/pasture (GLP) into agriculture, only 10.57% land under this category was manually verified as agriculture land, the rest belonged to something else, mostly developed land, shrubs, virgin grasslands, and wild meadows. Therefore, we analyzed AG land separately from GLP. We found 10.9% of non-agriculture land was classified as agriculture and 7.87% other lands as GLP. If we combine grassland/pasture into agriculture as in the original classification, there would be 18.77% non-agriculture land classified as agriculture land. There was also 2.23% of agricultural land classified as something else, so the net 8.66% of non-agriculture land was classified as agriculture land.

Machine-based CDL image classification from 2011 to 2015 shows average increase in agriculture land of 8.53 km^2, which is 1.28% of the land area considered. When the manually verified land classifications were compared, the agricultural increase was only 0.31 km^2 with 95% confidence interval of $\pm$2.7 km^2. This corresponds to 0.05$\pm$0.41% of the land area. Since 95% confidence interval of the change in agricultural area included zero, it was concluded that land area change to agriculture was not statistically significant. Based on our findings, it was concluded that satellite analysis is not an accurate method of determining land use change. In summation, our findings indicate that there has been no significant change in US food prices due to biofuels, and biofuels have not caused any significant land use change.

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APPENDICES

APPENDIX A: US FOOD PRICE INDEX

Year	US FPI (% change from previous year)	US FPI cumulative inflation from 1973	US Food Price Index region 1	US Food Price Index region 2	US Food Price Index region 3
1973	Baseline	0.0	0.0		
1974	14.3	14.3	14.3		
1975	8.5	22.8	22.8		
1976	3.0	25.8	25.8		
1977	6.3	32.1	32.1		
1978	9.9	42.0	42.0		
1979	11.0	53.0	53.0		
1980	8.6	61.6	61.6		
1981	7.8	69.4	69.4	69.4	
1982	4.1	73.5		73.5	
1983	2.1	75.6		75.6	
1984	3.8	79.4		79.4	
1985	2.3	81.7		81.7	
1986	3.2	84.9		84.9	
1987	4.1	89.0		89.0	
1988	4.1	93.1		93.1	
1989	5.8	98.9		98.9	
1990	5.8	104.7		104.7	
1991	2.9	107.6		107.6	107.6
1992	1.2	108.8			108.8
1993	2.2	111.0			111.0
1994	2.4	113.4			113.4
1995	2.8	116.2			116.2
1996	3.3	119.5			119.5
1997	2.6	122.1			122.1
1998	2.2	124.3			124.3
1999	2.1	126.4			126.4
2000	2.3	128.7			128.7
2001	3.2	131.9			131.9
2002	1.8	133.7			133.7
2003	2.2	135.9			135.9
2004	3.4	139.3			139.3
2005	2.4	141.7			141.7
2006	2.4	144.1			144.1
2007	4.0	148.1			148.1
2008	5.5	153.6			153.6
2009	1.8	155.4			155.4
2010	0.8	156.2			156.2

2011	3.7	159.9			159.9
2012	2.6	162.5			162.5
2013	1.4	163.9			163.9
2014	2.4	166.3			166.3
2015	1.9	168.2			168.2

APPENDIX B: BIOFUEL PRODUCTION

Year	Ethanol Production (Billion gallons)	Ethanol Production (Billion gallons)	Ethanol Production (Billion gallons)	Biodiesel Production (Million gallons)
1980	0.175			
1981	0.215			
1982	0.35			
1983	0.415			
1984	0.31			
1985	0.617			
1986	0.712			
1987	0.819			
1988	0.831			
1989	0.843			
1990	0.848			
1991	0.866			
1992	0.985			
1993	1.154			
1994	1.289			
1995	1.358			
1996	1.088			
1997	1.288			
1998	1.405			
1999	1.465			
2000	1.622	1.622		0
2001		1.765		9
2002		2.14		10
2003		2.81		14
2004		3.404		28
2005		3.904		91
2006		4.884		250
2007		6.521		490
2008		9.309		678
2009		10.938		516
2010		13.298	13.298	343
2011			13.929	967
2012			13.218	991
2013			13.312	1359
2014			14.34	1279
2015			14.81	1263