March 3, 2015

Maia D. Bellon
Director
Department of Ecology
300 Desmond Drive SE
Lacey, WA 98503

> **RE**: Comments of the Renewable Fuels Association (RFA) in Response to
> Washington Clean Fuel Standard Discussion Document

Dear Ms. Bellon,

The Renewable Fuels Association (RFA) appreciates the opportunity to provide comments in response to the Department of Ecology's discussion document for a Washington Clean Fuels Standard (CFS). RFA is a national trade association representing the domestic ethanol industry. Our membership includes both first- and second-generation ethanol producers, fuel marketers, vendors to the ethanol industry, agricultural organizations, and other groups dedicated to the continued expansion and promotion of fuel ethanol.

RFA has generally supported science-based policies and regulations designed to reduce the carbon intensity (CI) of our transportation fuels. In fact, ethanol producers have often cited Oregon's Clean Fuels Program and British Columbia's Low Carbon Fuel Requirement Regulation as examples of "Low Carbon Fuels Policies *Done Right*," as both programs have, to date, used a <u>consistent and level playing field</u> for CI scoring of *all fuels* (i.e., only verifiable direct emissions have been included).

Thus, the ethanol industry was disappointed to see the inclusion of highly subjective penalty factors for hypothetical indirect land use changes (ILUC) for select biofuels in Table 3 of the Washington CFS discussion document. Meanwhile, the table does not assign indirect effect penalty factors to any other fuel types. Inclusion of highly uncertain and prescriptive ILUC factors creates an asymmetrical and discriminatory carbon intensity scoring framework for the CFS.

As detailed in the attached comments, we strongly recommend that Washington exclude indirect effects from the CFS carbon intensity scoring framework until such time as there is broad scientific agreement on the best methodology for estimating the indirect effects for <u>*all fuels*</u>. Further, even if it was appropriate to include ILUC factors for biofuels in the CI scoring framework, the discussion document is proposing to use factors that have been shown to be grossly exaggerated and based on outdated information and data. In addition, a careful review of U.S. and global land use trends over the past decade provides no evidence that the types of

"biofuels-induced" land use changes predicted by economic models have in fact occurred. Thus, RFA believes Washington should conduct analysis using empirical data to ascertain whether, and to what extent, biofuels expansion has actually caused ILUC and related emissions before rushing to adopt ILUC factors.

Additionally, we are concerned by certain elements of the discussion document related to direct CI values and other issues. These matters are addressed more fully in the attached comments.

The success of the Washington CFS ultimately depends on having strong support and backing from affected stakeholder groups. The U.S. ethanol industry will continue to support performance-based low carbon fuel programs that are grounded in the principles of fairness, sound science, and consistent analytical boundaries. However, introducing concepts that lack scientific integrity and balance into the regulatory framework (i.e., ILUC for biofuels but no indirect effects for other fuels) only creates stakeholder division and controversy. Again, we urge the Department of Ecology to exclude indirect effects from CI scoring in the impending CFS regulations.

Thank you again for the opportunity to comment on the proposal.

Sincerely,

Geoff Cooper
Senior Vice President

**COMMENTS OF
THE RENEWABLE FUELS ASSOCIATION
IN RESPONSE TO WASHINGTON CLEAN FUEL STANDARD DISCUSSION DOCUMENT**

The Washington Department of Ecology released a discussion document for a Clean Fuels Standard (CFS) on February 4, 2015. The Renewable Fuels Association (RFA) offers the following comments in response to the document.

I.   **INDIRECT EFFECTS AND ILUC**

    a. *Washington should exclude indirect effects from the program's carbon intensity scoring framework until such time as there is broad scientific agreement on the best methodology for estimating the indirect effects for all fuels.*

The ethanol industry has generally supported LCFS and CFP programs that are based on fair and symmetrical carbon intensity (CI) scoring principles. In fact, ethanol producers have cited British Columbia's Low Carbon Fuel Requirement Regulation and Oregon's CFP as examples of "LCFS Policies Done Right," as both programs have, to date, based CI scoring for all fuels on verifiable <u>direct emissions only</u>.

Given the pragmatic CI scoring approach (i.e., direct emissions only) taken by the jurisdictions neighboring Washington to both the north and south, the ethanol industry was surprised and disappointed to see that the discussion document includes indirect land use change (ILUC) penalty factors for certain biofuels, but no indirect effect penalty factors for any other fuel types. Not only does inclusion of ILUC factors create an asymmetrical and discriminatory framework for the CFS, but it also potentially creates disharmony in the west coast fuel market because the proposed Washington CI scores are vastly different than the CI scores used in Oregon and British Columbia.

Six years after the concept of ILUC emissions was introduced in environmental lawyer Timothy Searchinger, there is still no scientific consensus on the best methods for estimating ILUC or other indirect effects. While published estimates of ILUC emissions have trended downward over the past six years, the latest estimates still exhibit a wide range and high level of uncertainty. Further, the use of uncertain and subjective ILUC penalty factors for regulatory purposes (e.g., CI scoring under the California LCFS) remains highly controversial and polarizing. Indeed, as a result of California Air Resources Board's (CARB) decision in 2009 to include ILUC factors, the California LCFS <u>lost the support of important industry, academic, and political stakeholders</u>. By proposing to include indirect effect penalties only for biofuels, Washington runs the risk of similarly losing the backing of key stakeholder groups at a critical juncture for the program.

    b. *As a matter of fairness and consistency, Washington should not assess penalties for indirect effects against only one class of fuels. If Washington*

***includes ILUC for biofuels, it must also include indirect emissions
associated with all other regulated fuels (including baseline petroleum).***

As stated above, Washington should exclude penalties for indirect effects until there is broad consensus on how best to estimate such effects for all fuels. The principles of lifecycle analysis require that consistent analytical boundaries are used when evaluating and comparing the attributes of various competing products. Thus, if Washington decides to penalize biofuels for predicted ILUC emissions, it must also include penalty factors for other fuels based on their potential to induce additional emissions through indirect economic effects at the resource margin. It is inarguable that all forms of energy have associated indirect economic effects, many of which have implications for the fuel's lifecycle carbon intensity. The challenge for policymakers and regulators is isolating and quantifying those effects in a manner that is scientifically defensible and driven by consensus-based methodologies.

Despite requests from leading experts that CARB and the U.S. Environmental Protection Agency undertake such analysis, there remains a substantial void of research on the potential indirect effects of transportation fuels other than crop-based biofuels. Indeed, in its January 2011 final report, the CARB-appointed Expert Work Group identified a number of potential indirect emissions sources from other fuels and recommended that CARB should, in the short-term:

> …conduct analysis, including but not limited to economic modeling, of the impact of the marginal barrel of oil[,]…the marginal supply of natural gas[,]…the potential market-mediated effect on electric power markets of using increased quantities of natural gas in the transportation sector[,]…reevaluation of marginal electricity[,]…[and] the impact of petroleum substitutes on refinery operations.[1]

To our knowledge, CARB has disregarded this recommendation to date. However, the scant body of existing research on indirect effects for other fuels does indicate the potential for significant indirect emissions that are not being captured in DEQ's proposed lookup table. For example, Liska and Perrin (2010) estimate that assigning military emissions related to protecting access to Persian Gulf oil would result in a CI value increase of 8.1 grams CO_2e/megajoule (g/MJ) (a roughly 8.5 percent increase in the overall CI value of gasoline and diesel fuel derived from Persian Gulf oil under the California LCFS).[2] Similarly, Unnasch *et al.* (2009) identified a number of direct and indirect emissions sources that are excluded from most lifecycle analyses of petroleum-based fuels. According to the study:

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[1] Heirigs et al. (2011). Air Resources Board Expert Working Group. Final Recommendations: Subgroup on Indirect Effects of Other Fuels. Available at: http://www.arb.ca.gov/fuels/lcfs/workgroups/ewg/010511-final-rpt-alternative-modeling.pdf

[2] A.J. Liska & R.K. Perrin (2010). Securing Foreign Oil: A Case for Including Military Operations in the Climate Change Impact of Fuels. *Environment* 52:4 (July/August 2010), pp. 9–22. Available at: http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1175&context=biosysengfacpub

…to the extent that economic effects are considered a part of the life cycle analysis of alternative fuels, as is the case with iLUC for biofuels, their effect vis-à-vis petroleum is also of interest. The effect of changes in petroleum supply and price will affect global goods, their movement, and the use of resources and their related GHG emissions.[3]

Similarly, the indirect effects of emerging alternative fuels/vehicles have been omitted from most lifecycle analyses because those effects are not well understood and have not been rigorously scrutinized. However, where research does exist on these effects, potentially significant indirect (and overlooked direct) effects are revealed. For example, the limited research available on the direct and consequential effects of increased reliance on electric vehicles (EVs) shows that widespread use of EVs could be worse for the climate than continued reliance on gasoline and diesel. According to Hawkins *et al.* (2012), when the impacts of EV production, battery production, battery disposal, and expansion of electricity demand are properly included in lifecycle emissions inventories, some EV pathways perform worse than gasoline and diesel. The authors concluded:

> EVs are poised to link the personal transportation sector together with the electricity, the electronic, and the metal industry sectors in an unprecedented way. Therefore the developments of these sectors must be jointly and consistently addressed in order for EVs to contribute positively to pollution mitigation efforts.[4]

Further, Tahil (2007) found that resource constraints for certain rare earth minerals used in EV battery production will present economic and environmental challenges not currently considered in lifecycle analyses of EV emissions. Tahil writes:

> Analysis of Lithium's geological resource base shows that there is insufficient economically recoverable Lithium available in the Earth's crust to sustain Electric Vehicle manufacture in the volumes required…Depletion rates would exceed current oil depletion rates and switch dependency from one diminishing resource to another. Concentration of supply would create new geopolitical tensions, not reduce them.[5]

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[3] Unnasch. S., et al. (2009). Assessment of Life Cycle GHG Emissions Associated with Petroleum Fuels; Life Cycle Associates Report LCA-6004-3P. 2009. Prepared for New Fuels Alliance. Available at: http://www.newfuelsalliance.org/NFA_PImpacts_v35.pdf

[4] Hawkins, T. R., et al. (2013). Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. *Journal of Industrial Ecology*, 17: 53–64. doi: 10.1111/j.1530-9290.2012.00532.x. http://onlinelibrary.wiley.com/doi/10.1111/j.1530-9290.2012.00532.x/full

[5] Tahil, W. (2007) Meridian International Research. The Trouble with Lithium: Implications of Future PHEV Production for Lithium Demand. Available at: http://www.meridian-int-res.com/Projects/Lithium_Problem_2.pdf

Clearly, all fuels have associated indirect effects. If Washington opts to include ILUC penalties for biofuels, it must also analyze and include economically-derived indirect effects penalties for all other fuels as well.

      c. Even if it was appropriate to include ILUC factors for biofuels in the CI scoring framework, Washington is proposing to use factors that have been shown to be grossly exaggerated and based on outdated information and data.

Table 3 ("Carbon Intensity Lookup Table for Gasoline and Gasoline Substitutes") of the proposal assigns an ILUC penalty of 30 g/MJ to all corn ethanol pathways. It appears Washington has simply "copied and pasted" the lookup table from CARB's LCFS regulation without performing any due diligence or modeling to determine whether the CARB factors are accurate or appropriate. Because CI values are the engine that drives the CFS program, and because ILUC factors have been the subject of intense scientific debate and scrutiny, it is critical that Washington conduct its own evaluation of indirect effects before rashly inserting CARB's values into the regulation.

In any event, CARB is in the midst of revising both its direct emissions factors and its ILUC factors for the California LCFS. While there are still many significant problems with CARB's draft revisions to its ILUC penalties, it should be noted that CARB is reducing the ILUC penalty for corn ethanol from 30 g/MJ to 19.8 g/MJ.[6] However, CARB's preliminary revised ILUC values for corn ethanol still remain well outside the range of recent estimates from Argonne National Laboratory (developer of the GREET model), Purdue University, the European Commission, Michigan State University, Oak Ridge National Laboratory and others. In a March 2014 letter to CARB Chair Mary Nichols (Attachment A), 14 leading bioenergy researchers (*including five members of CARB's Expert Work Group on ILUC*) wrote:

> Many of us continue to believe the use of point-estimate ILUC factors is inappropriate for the purposes of regulation. However, to the extent that CARB continues to rely upon the use of ILUC factors in calculating CI scores for the LCFS, we believe the Board should be familiar with the most recent independent modeling results. In general, our recent work—and analyses conducted by other experts in the field—indicates that CARB's existing CI factors significantly overestimate the GHG emissions associated with potential ILUCs resulting from corn ethanol expansion. Analyses conducted

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[6] Comments submitted by RFA outline a number of technical concerns with CARB's newest ILUC analysis. RFA comments are available at: http://www.arb.ca.gov/fuels/lcfs/regamend14/rfa_04092014.pdf; http://www.arb.ca.gov/fuels/lcfs/regamend14/rfage_10142014.pdf (with Growth Energy); http://www.arb.ca.gov/fuels/lcfs/regamend14/rfa_10152014.pdf; and http://www.arb.ca.gov/lists/com-attach/9-lcfs2015-WigAYAZmV1sLbgdo.pdf.

since CARB adopted the LCFS in 2009 show that potential ILUC emissions associated with corn ethanol are **more likely in the range of 6-15 grams per megajoule of CO2 equivalent (g/MJ), compared to CARB's estimate of 30 g/MJ** (emphasis added).

If DEQ remains committed to including ILUC factors in the CFS lookup table (which we strongly oppose for the reasons stated in previous sections), the penalty factors should at least be based on the best available science and data from the leading experts and institutions in the field. We do not believe DEQ should rely entirely on CARB for estimating potential ILUC emissions.

d. *Before deciding whether to include ILUC penalties for biofuels, Washington should conduct analysis using empirical data to determine whether, and to what extent, biofuels expansion caused ILUC and related emissions.*

CARB's ILUC analysis, upon which Washington's proposed ILUC penalty factor is based, is meant to simulate the land use effects of biofuels growth from 2001 to 2015. Obviously, the time period in question is drawing to a close. Thus, empirical land use data is available for most of the simulation period. Any objective scientist would find it prudent to examine the real-world data to determine whether predictive model results agreed with actual observed outcomes.

Certainly, it is difficult to disentangle the real-world impact of biofuels expansion from the effects of other factors on actual global land use—but that does not mean regulatory agencies considering ILUC factors shouldn't at least attempt to ground-truth predictive results against real-world data. For example, CARB's ILUC analysis predicts that biofuels growth from 2001 to 2015 would cause roughly 100,000 hectares of forest to be converted to cropland in the U.S. However, empirical data from the U.S. Department of Agriculture and U.N. Food & Agriculture Organization show no loss of forestland in the U.S. during that period; instead, U.S. forestland has grown by approximately 7 million hectares.

Further, a November publication by the Center for Agricultural and Rural Development (CARD) at Iowa State University makes a remarkably important contribution to the debate over ILUC modeling. The report (Attachment A) marks the first time that actual land use changes over the past decade (i.e., the period in which commodity crop prices rose to record levels) have been quantified and discussed in the context of CARB's ILUC modeling results. The CARD/ISU paper, which is discussed in detail in the attached comments, found that "[t]he pattern of recent land use changes suggests that **existing estimates of greenhouse gas emissions caused by land conversions due to biofuel production are too high** because they are based on models that do not allow for increases in non-yield intensification of land use." In essence, the authors found that the primary response of the world's farmers to higher crop prices "…**has been to use available land resources more efficiently rather than to expand the amount of land brought into production**."

The principles of good policymaking and sound scientific analysis require that model predictions be validated when possible. Indeed, other predictive models utilized by CARB and other agencies for other regulatory purposes have been validated and results have been verified. One potential means of validating CARB's analysis would be to "back-cast" the new dynamic version of the GTAP model. We encourage Washington to conduct such an exercise.

II. DIRECT EMISSIONS

a. *The California LCFS direct CI values, which serve as the basis for Washington's proposed values, are currently in the process of being revised by CARB based on updated versions of the GREET model. Final revised values for the California LCFS have not yet been proposed for adoption. Thus, DEQ is proposing direct CI scores based on CARB values that may change substantially in the near term.*

As noted above, CARB is in the process of revising both direct and indirect CI values for corn ethanol and other fuels. The revisions are the result of CARB's migration to the latest version of the GREET model maintained by Argonne National Laboratory. The newest Argonne version of GREET contains important updates and corrects several flawed assumptions from previous versions of the model. Yet, the Washington discussion document look-up table uses direct CI values based on the 2008 version of CA-GREET1.8b and CARB's original lookup table, which is soon to be outdated and irrelevant.

We understand the Department of Ecology has developed a Washington-specific version of GREET (called "WA-GREET"). The discussion document says WA-GREET is based on the 2013 version of Argonne's GREET model, but the CI values in Table 3 are clearly based on the outdated 2008 CA-GREET1.8b. If the WA-GREET model is truly based on the 2013 Argonne GREET model, then the corn ethanol CI values in Table 3 should not be *identical* to CARB's soon-to-be revised CI values based on the 2008 GREET model.

Nonetheless, if Washington remains committed to using CARB values for direct CI scores (which we would discourage), we believe it should at least use values from the CA-GREET2.0 model under development. Preferably, however, Washington would not simply rely on CARB's direct CI analysis for regulated fuel pathways and would conduct its own lifecycle modeling using Argonne's GREET1_2014 or a new version of WA-GREET based on Argonne's GREET1_2014.

III. APPROVAL OF INDIVIDUAL CARBON INTENSITY VALUES PATHWAY PETITIONS

We are encouraged by the fact that Washington plans to allow individual biofuel producers to secure approval of unique carbon intensity values. This process will be particularly important if Washington finalizes the outdated lookup table in the discussion document, as it overstates the direct CI of the most common corn ethanol pathways. However, the experience of the Method

2A/2B process in California has demonstrated that reviewing and approving petitions for individual CI scores can be a resource-intensive process. In order to ensure the efficient and timely approval of petitions for individual CI values, we strongly recommend that Washington prioritize this review process when allocating staff resources for management of the CFS program.

APPENDIX A:

Babcock, B.A. and Z. Iqbal (2014), Using Recent Land Use Changes to Validate Land Use Change Models. Center for Agricultural and Rural Development Iowa State University Staff Report 14-SR 109.

Using Recent Land Use Changes to Validate
Land Use Change Models

Bruce A. Babcock and Zabid Iqbal

Staff Report 14-SR 109

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For questions or comments about the contents of this paper, please contact Bruce A. Babcock, *babcock@iastate.edu.*

Executive Summary

Economics models used by California, the Environmental Protection Agency, and the EU Commission all predict significant emissions from conversion of land from forest and pasture to cropland in response to increased biofuel production. The models attribute all supply response not captured by increased crop yields to land use conversion on the extensive margin. The dramatic increase in agricultural commodity prices since the mid-2000s seems ideally suited to test the reliability of these models by comparing actual land use changes that have occurred since the price increase to model predictions. Country-level data from FAOSTAT were used to measure land use changes. To smooth annual variations, changes in land use were measured as the change in average use across 2004 to 2006 compared to average use across 2010 to 2012. Separate measurements were made of changes in land use at the extensive margin, which involves bringing new land into agriculture, and changes in land use at the intensive margin, which includes increased double cropping, a reduction in unharvested land, a reduction in fallow land, and a reduction in temporary or mowed pasture. Changes in yield per harvested hectare were not considered in this study. Significant findings include:

- In most countries harvested area is a poor indicator of extensive land use.
- Most of the change in extensive land use change occurred in African countries. Most of the extensive land use change in African countries cannot be attributed to higher world prices because transmission of world price changes to most rural African markets is quite low.
- Outside of African countries, 15 times more land use change occurred at the intensive margin than at the extensive margin. Economic models used to measure land use change do not capture intensive margin land use changes so they will tend to overstate land use change at the extensive margin and resulting emissions.
- Non-African countries with significant extensive land use changes include Argentina, Indonesia, Brazil, and other Southeast Asian countries.
- Given the lack of a definitive counterfactual, it is not possible to judge the consistency of model predictions of land use to what actually happened in each country. Some indirect findings are that model predictions of land use change in Brazil are too high relative to other South American countries; and model predictions of increasing extensive land use that are larger than what actually occurred are consistent with actual land use changes only if cropland was kept from going out of production rather than being converted from forest or pasture.

The contribution of this study is to confirm that the primary land use change response of the world's farmers from 2004 to 2012 has been to use available land resources more efficiently rather than to expand the amount of land brought into production. This finding is not necessarily new and it is consistent with the literature that shows the value of waiting before investing in land conversion projects; however, this finding has not been recognized by regulators who calculate indirect land use. Our conclusion that intensification of agricultural production has dominated supply response in most of the world does not rely on higher yields in terms of production per hectare harvested. Any increase in yields in response to higher prices would be an additional intensive response.

Using Recent Land Use Changes to Validate
Land Use Change Models

In the mid-2000s prices for major agricultural commodities began a long, sustained increase. Prices increased dramatically due to growth in demand for food and biofuel producers, underinvestment in agricultural infrastructure and technology, and poor growing conditions in major producing regions. Figure 1 shows the percent change in inflation-adjusted prices received by US producers for corn, soybeans, wheat, and rice relative to the previous five-year average.[1] The predominance of negative changes shows that since 1960 average real prices for these commodities have dropped. These figures show that the commodity price boom in the early 1970s resulted in the largest increase in real prices, but the recent increase in prices since 2006 resulted in the longest sustained increase, especially for corn and soybeans. For wheat and rice, real prices increased sharply in the mid-2000s and have stayed high even though the year-over-year increases were not as long lasting as for corn and soybeans. The magnitude of these real price increases after such a prolonged and sustained period of flat or falling prices presents a unique opportunity to quantify how world agriculture responds to incentives to produce more.

The United States, California, and the EU have enacted regulations based in part on model predictions of agricultural supply response to price increases induced by increased biofuel production. The model predictions of land use changes are called indirect land use changes because the predicted changes are due to a modeled response to higher market prices rather than a direct response to the need to grow more feedstock for biofuel production. Thus, for example, the corn used to produce corn ethanol in the United States was met by US corn production; however, the diversion of corn from other uses increased corn prices and crop prices of other commodities that compete with corn for market share and land. Because corn and other commodities are traded on world markets, prices in other countries also increase. The response in the US and in other countries to these higher prices is what the models measure.

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[1] Prices are average annual prices received by US farmers adjusted by the US CPI.
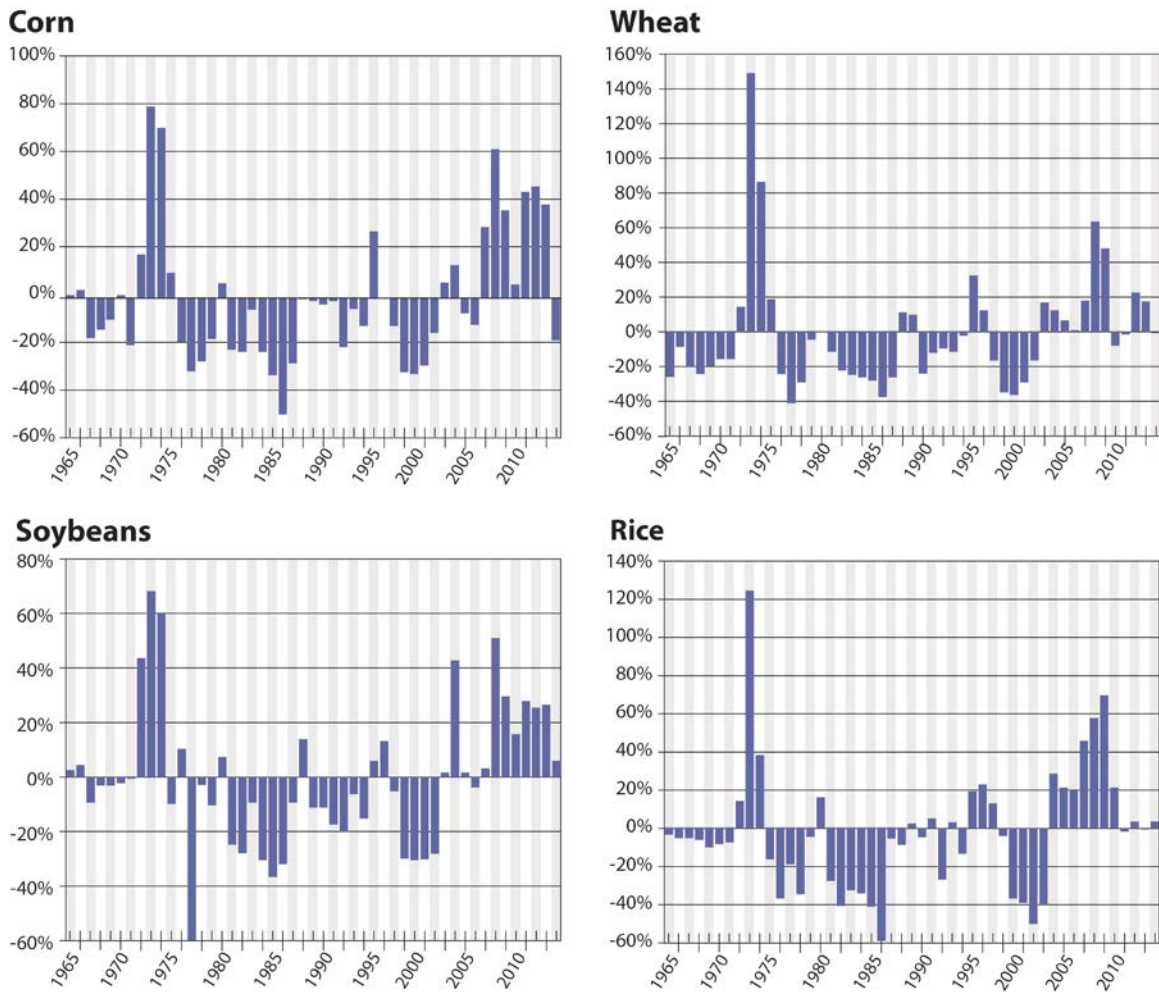
Figure 1. Deviations in Real US Commodity Price Levels from Lagged Five-Year Average Measuring World Land Use Changes

Some portion of the higher prices since the mid-2000s was caused by increased bio-fuel production. For example, Fabiosa and Babcock (2011) estimate that 36% of the corn price increase from 2006 to 2009 was due to expanded ethanol production. Carter, Rausser, and Smith (2010) estimate that 34% of the corn price increase between 2006 and 2012 was due to the US corn ethanol mandate. This implies that a portion of the actual response of land use since this price increase is due to US ethanol production. Other factors such as crop shortfalls and other sources of increased demand account for the rest of the price increase.

Because indirect land use is a response to higher market prices, model predictions of land use change should be similar whether the higher prices came from increased biofuel

production, increased world demand for beef, or from a drought that decreased supply in one or more major producing areas. This implies that the pattern of actual land use changes that we have seen since the mid-2000s should be useful to determine the reliability and accuracy of the models that have been used to measure indirect land use. The purpose of this paper is to look at what has happened over approximately the last 10 years in terms of land use changes and to determine whether and how these historical changes can provide insight into the reliability of model-predicted changes in land use. We address the following questions in this paper:

- How has cropland changed around the world in approximately the last 10 years?
- What were the major drivers of observed land use changes?
- When can actual land use changes be compared with model predictions?
- What can be said about the types of land that were actually converted?

How Has Harvested Area Changed Since 2004?

The most complete source of data on annual cropland is from the Statistics Division of FAO (FAOSTAT), which measures annual harvested area by crop and country. These data have been widely used to measure the impact of biofuel production on expansion of land used in agriculture (Roberts and Schlenker 2013) and to calibrate the land cover change parameter in the GTAP model (Taheripour and Tyner 2013). Figure 2 shows the change in harvested land according to FAO. The data are smoothed by calculating the change in harvested area as the average in 2010, 2011, and 2012 minus the average in 2004, 2005, and 2006. The earlier period measures harvested area before the large increase in price. The later period represents harvested area after prices had increased substantially. India, China, Africa, Indonesia and Brazil had the largest increase in harvested land. These data seem to suggest that these countries had the largest increase in land conversion; however, harvested land is not equal to planted land. Harvested land will deviate from planted land when a portion of planted land is not harvested and when a portion of land is double or triple cropped.
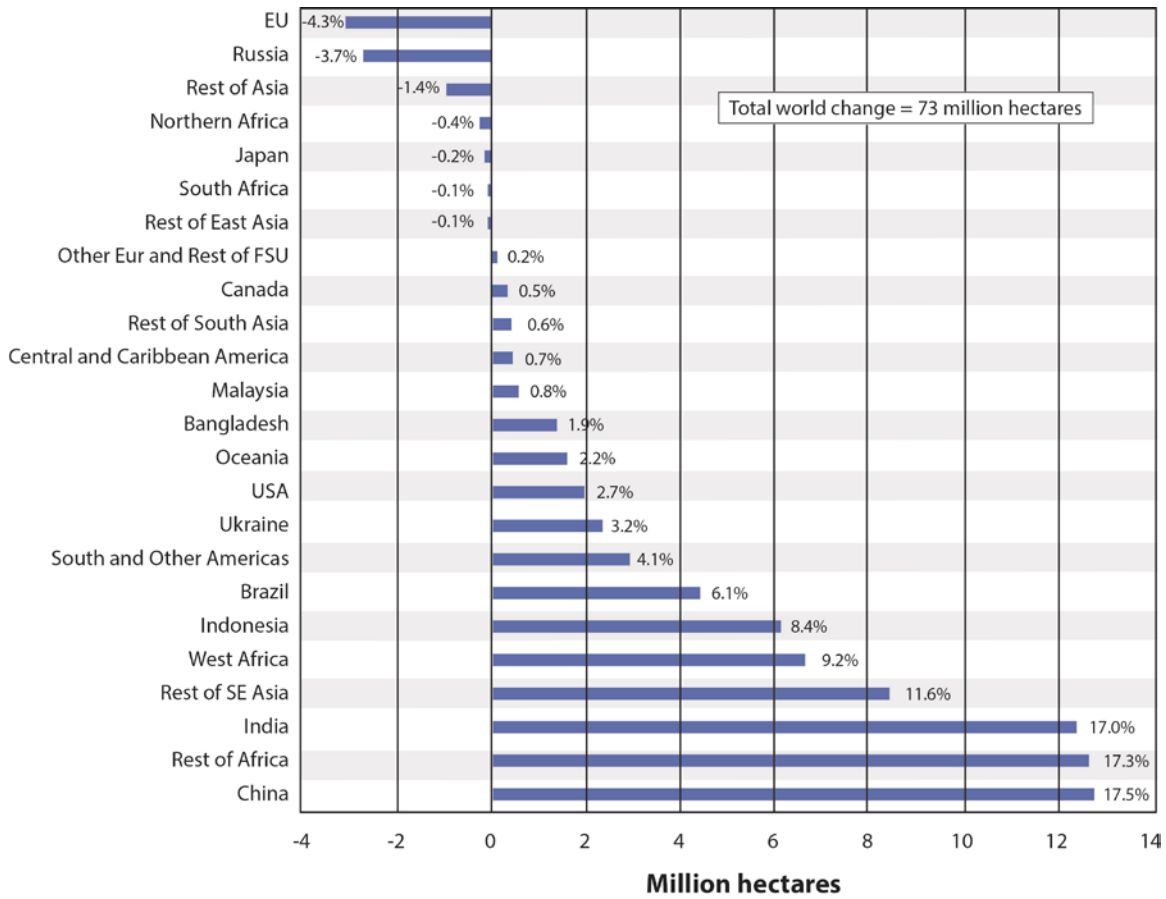
Figure 2. Change in Harvested Land 2010–2012 Average Minus 2004–2006 Average and Country's Share of Total World Change
Source: FAOSTAT

Suppose that a portion of land that is planted to a first crop is not harvested and that a portion of first crop land that is harvested in a country is double-cropped, which simply means that a second crop is planted on land that was already planted to a crop in the same year.[2] By definition, total harvested land, H, equals total harvested land from the first crop, H_1, plus total harvested land from the second crop, H_2. Total harvested land from the first crop equals total land planted to the first crop, P_1 minus land that was planted but not harvested, a_1. Thus we have in any year t

$$P_{1,t} = H_t - H_{2,t} + a_{1,t}$$

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[2] Throughout this article land the phrase double crop should be interpreted as two or more crops being grown on a single parcel of land.

For the purpose of greenhouse gas emissions from land use changes, it is most relevant to calculate the change in planted area between two time periods $t = T$ and $t = 0$. Thus, we have

$$P_{1,T} - P_{1,0} = (H_T - H_0) - (H_{2,T} - H_{2,0}) + (a_{1,T} - a_{1,0})$$

If second crop acreage has increased over time, then use of FAO data on total harvested land overstates land use change by this amount. If the change in first crop land that is not harvested also increases over time, then at least some portion of this upward bias in measuring land use change is overcome. If, instead, the amount of unharvested land has decreased over time then the upward bias is increased. A more in-depth examination of data available for a few countries gives insight into the extent to which use of FAO harvested area data provides a good indication of land use changes.

United States

Figure 3 illustrates that reliance on harvested area as an indicator of land use change can lead to a large bias, and shows annual changes in harvested and planted land to corn in
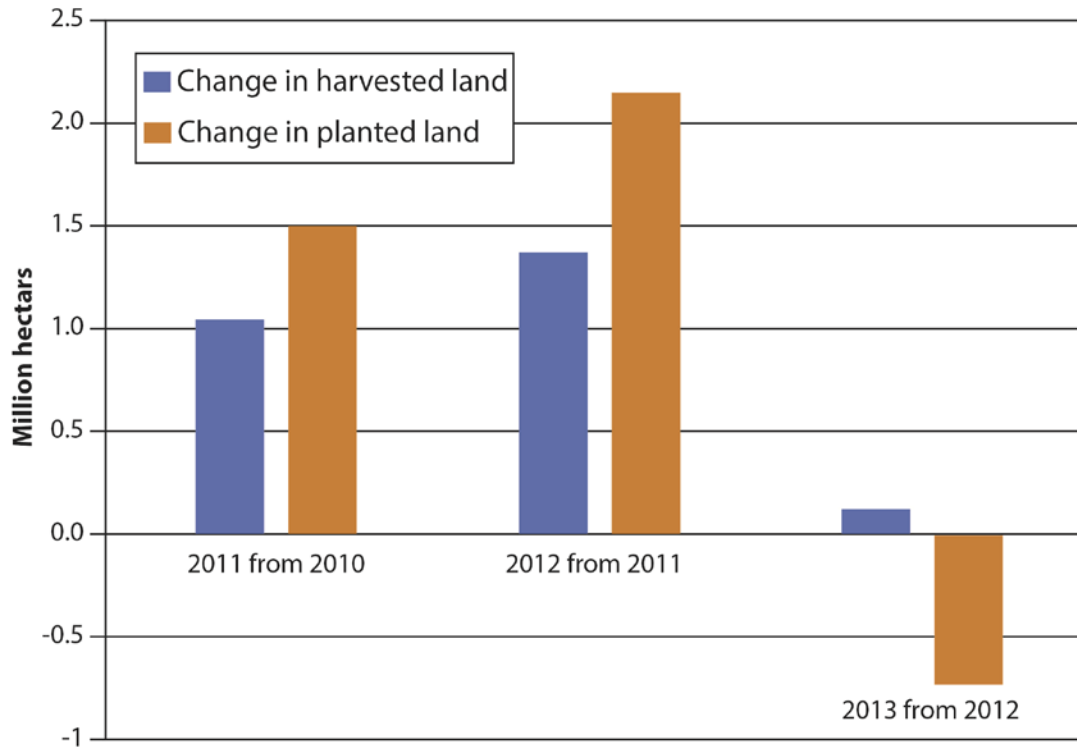

Figure 3. Annual Change in Harvested and Planted Corn Land in the United States

the United States from 2011 to 2013. A widespread drought in the United States resulted in an increase in the amount of planted land that was not harvested. Thus in 2012, use of harvested land to measure land use change understates land use change, whereas in 2013, it overstates land use change. Taking average changes over some time period will reduce the impact of an outlier like 2012, but it will not eliminate it. Thus, use of 2012 harvested data in the United States will tend to understate land use change relative to an earlier period and overstate it relative to a later period. Because data on US planted land is available from USDA's National Agricultural Statistics Service, it makes much more sense to use these data rather than FAO harvested land data.

Brazil

Brazil is another country that collects data on both harvested and planted land.[3] In addition, Brazil collects data on land that is double cropped. Figure 4 shows total harvested land and total harvested land from double cropped land. The axes have been set to the same scale to show that a large proportion of the increase in Brazilian harvested land is a result of increased double cropping. The change in total harvested land from 2004–2012 is 5.4
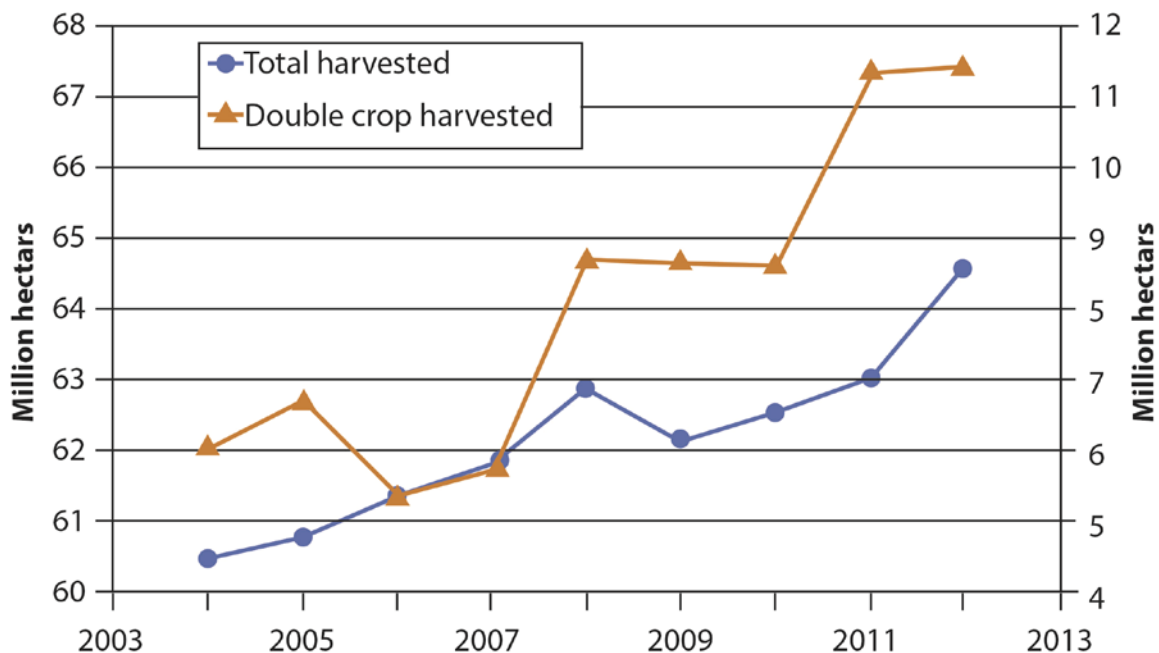

Figure 4. Brazil Harvested Land Data

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[3]Brazilian IBGE data is available at http://www.sidra.ibge.gov.br/bda/pesquisas/pam/default.asp?o=27&i=P

million hectares. The change in double cropped land is 4.1 million hectares. Thus, more efficient use of land accounts for 76% of the change in harvested land in Figure 4.

India

Figure 2 shows that India increased harvested area by 6.8% from 2004–2006 to 2010–2012 which is 12.4 million hectares. Given India's long agricultural history it seems unlikely that so much land would be suitable for conversion to crops in such a relatively short time. India collects data on both planted and harvested land as well as double cropped land (India Ministry of Agriculture). Figure 5 shows that the variation in multiple crop area explains most of the variation in total planted area, which includes double cropped area. Subtracting double cropped area from total planted area shows that net planted area decreased by 147,000 hectares between 2004–2006 and 2010–2012. What then accounts for the increase in harvested area? Figure 6 shows that the proportion of planted area that is harvested has increased dramatically over this time period. An examination of previous years' data shows that the wide gap between planted and harvested
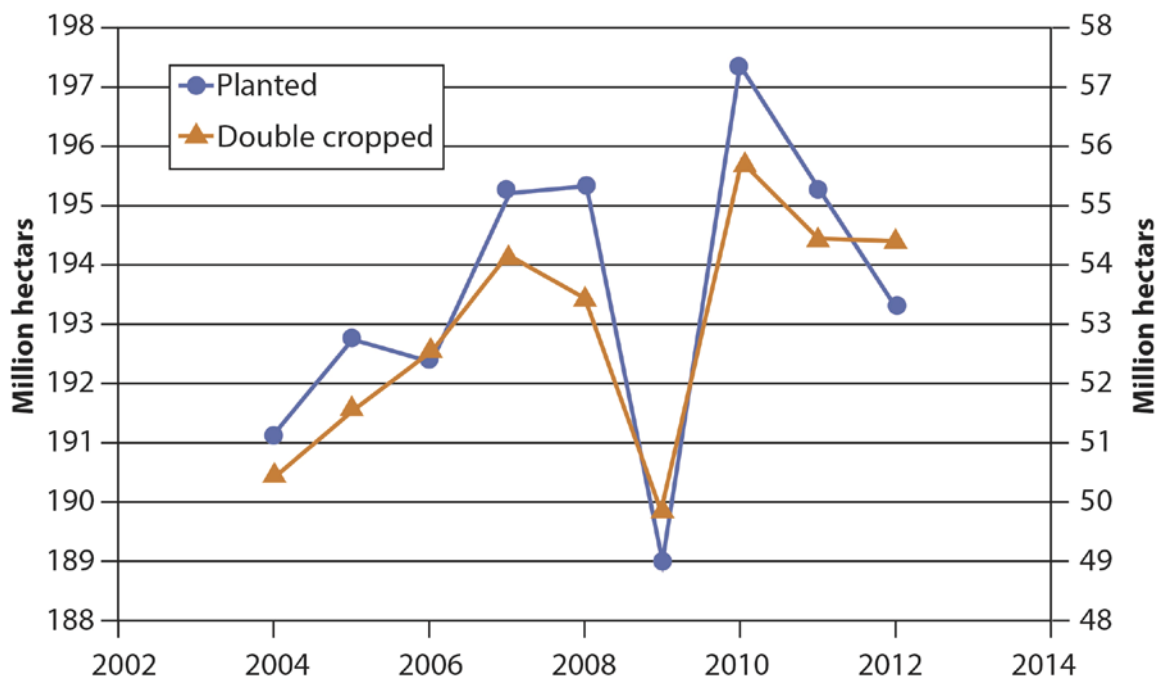
Figure 5. Total Planted and Multiple Crop Area in India
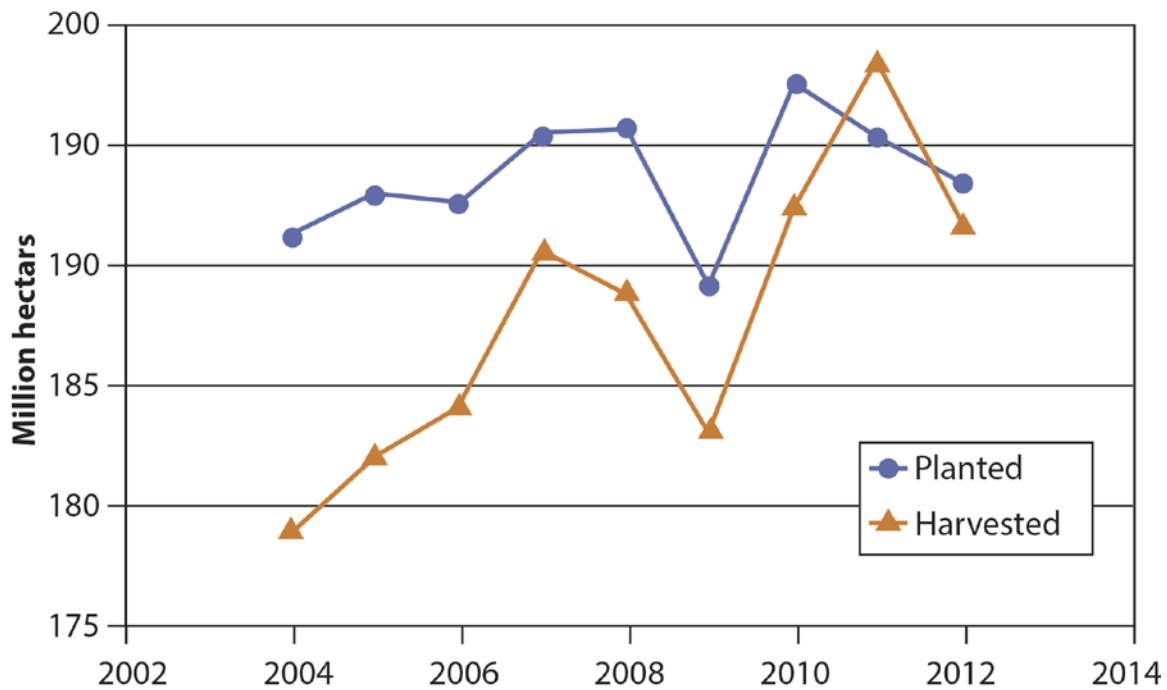
Figure 6. Total Planted and Harvested Area in India

area shown in Figure 6 from 2004 to 2006 was typical. For example, the 2004–2006 gap averages 10.6 million hectares, and the gap from 1992 to 2000 averages 10.4 million hectares. The average gap in 2010 and 2012 is 3.4 million hectares. Thus, an increase in double cropped area accounts for about 3.5 million hectares of the increase in harvested area, and a decrease in non-harvested area accounts for another 7 million hectares. Thus, all of the increase is harvested area is accounted for by intensification of land use. One reason why non-harvested area has increased so much is the 6 million hectare increase in irrigated area from 2004 to 2011. More irrigation allows a greater proportion of planted area to grow to maturity, thereby making it worth harvesting. In addition, India increased support prices and input subsidies in the mid-2000s to combat stagnant growth in the agricultural sector. These actions, combined with the expansion of irrigation, increased the opportunity cost of not harvesting land.

China

FAO harvested area data shows an increase of 8% from 160 million hectares to 173 million hectares from 2004–2006 to 2010–2012. Figure 2 in Cui and Kattumuri (2012) shows that

total cultivated land in China dropped from about 130 to about 122 million hectares from 1996 to 2008. The four reasons cited for the loss of agricultural land are urbanization, natural disasters, ecological restoration, and agricultural structural adjustment, with restoration and urbanization accounting for about 80% of losses. Cui and Kattumuri (2012) claim that the loss of agricultural land slowed down in 2004 and 2005 only because of "…stringent land protection policies" (p. 14). Based on this conclusion, it seems that economic forces in China were trying to reduce cultivated land, not increase it, in the mid-2000s. If correct, then it seems highly unlikely that a significant portion of the increase in harvested area was caused by an increase in the amount of land cultivated. If both FAO harvested area data and data used by Cui and Kattumuri (2012) are correct, then at least 38 million hectares of harvested area came from double cropped land in 2004–2006 and 51 million hectares of harvested area came from double cropped areas in 2010–2012.

Sub-Saharan African Countries

Figure 2 shows that sub-Saharan African countries have been large contributors to increases in harvested land. With some exceptions, much of African crop production is carried out by small-scale producers without use of modern technologies. While differences exist between countries, typically most production is consumed domestically and most commercial trade occurs between adjoining African countries (Minot 2010). Sub-Saharan African countries account for 34 of the top 50 countries in the UN data base in terms of population growth rates in 2010.[4] The average population growth rates for these 34 countries in 2010 was 2.93%. Leliveld et al. (2013) show that food production in Tanzania has just about matched population growth and that almost all of the food production increase has been due to an increase in the amount of land planted. Although it is possible to plant more than one crop in many African countries by developing shorter-season varieties and better management (Ajeigle et al. 2010), a lack of access to technology and capital is one defining characteristic of traditional agriculture in sub-Saharan Africa, so there is no evidence that double cropping is widely adopted. Thus, the change in harvested land shown in Figure 2 for African countries is likely a better measure of the change in planted land than in other countries.

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[4] Population growth rates are available at
http://data.worldbank.org/indicator/SP.POP.GROW/countries?display=default

Indonesia

Figure 7 shows the change in area harvested from 2004–2006 to 2010–2012 for the top eight crops and for all other crops in Indonesia according to FAOSTAT. As shown most of the expansion has occurred in rice and palm oil fruit. Because perennial crops do not generally produce more than one crop per year, the extent to which FAO harvested land data overstates the change in planted land is limited. Adding the change in harvested land of palm, rubber, coffee, coconuts, and cocoa together accounts for 54% of the change in harvested area. According to USDA-FAS (2012) the availability of suitable rice-growing land is severely restricted in Indonesia. Most of the increase in harvested rice area that has been achieved has come about from investment in irrigation facilities that allow two or three crops of rice to be planted on the same land rather than a single crop. The extent to which intensification explains the 1.4 million hectare increase in rice harvested area shown in Indonesia cannot be determined by harvested area data alone. However, given that Indonesia is one of the world's most densely populated countries, and 1.4 million hectares represents a 12% increase in harvested production, it is unlikely that a significant portion of this 1.4 million hectares is new land. According to USDA-FAS (2012) about
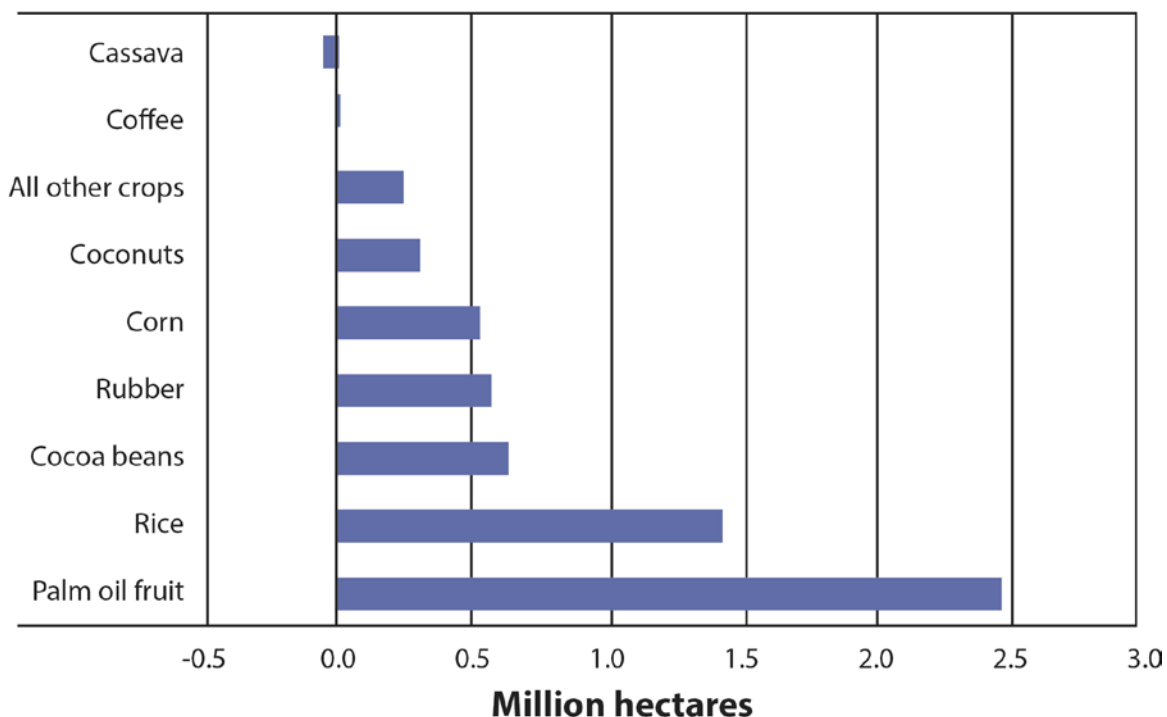
Figure 7. Change in Harvested Area by Crop for Indonesia as Reported by FAO

50% of Indonesian rice area grew rice in both the rainy and dry seasons in 2011, which implies that there is significant room for harvested area growth with greater irrigation. Thus it is likely that most of the increased rice area in Indonesia is accounted for by increased double and triple cropping.

Swastika et al. (2004) explain that most corn production in Indonesia is grown on land that produces two crops. Corn is typically grown with tobacco, cassava, another corn crop, or sometimes with rice. Given land constraints in Indonesia and the significant expansion of palm oil production, which has been accomplished by converting forestland and cropland (Susanti and Burgers 2013; Koh and Wilcove 2008), it is likely that a significant portion of the corn production increase came about by increasing double cropped area.

## An Alternative Measure of Land Use Change

Use of harvested area to measure land use change can lead to a large bias in estimates of how much land has been converted to crops from other uses. While this may be an obvious point, it is too often missed in analysis of land use changes. Reliable country-specific data, such as in the United States, that can measure the change in net planted area should be used when available. Where it is not available, land cover data can be used. For global coverage FAOSTAT data on arable land and land planted to permanent crops are available. The FAO definition of arable land is "the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category."[5] This definition is different than the common meaning of arable land—land that is capable of producing a crop rather than land that is actually in crop production. Adding FAO's measure of arable land to land that is in permanent crop provides a measure of land use that is appropriate to use in determining the amount of new land that has been brought into production. Figure 8 reproduces Figure 2 using this measure with the exception of the United States, for which USDA's NASS planted area data is used. For the United States, total planted area of principal field crops minus double crop area is

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[5] http://faostat.fao.org/site/375/default.aspx

used instead of FAOSTAT data because FAOSTAT reports a 9 million hectare loss in total cropland because of a sharp reduction in temporary pasture.

The implications of Figure 8 are strikingly different than Figure 2. Furthermore the Figure 8 data is much more consistent with the country-specific data in China, India, Brazil, Indonesia, and Africa. Figure 8 data suggest that the net change in global cropland over this period is 24 million hectares. African countries increased cropland by 20 million hectares. Other countries with more than a million-hectare increase include Argentina, Indonesia, Brazil, Rest of Southeast Asia, Rest of South Asia, and South and Other Americas. Countries with significant reductions in cropland include the EU, Canada, China, Russia, and South Africa.
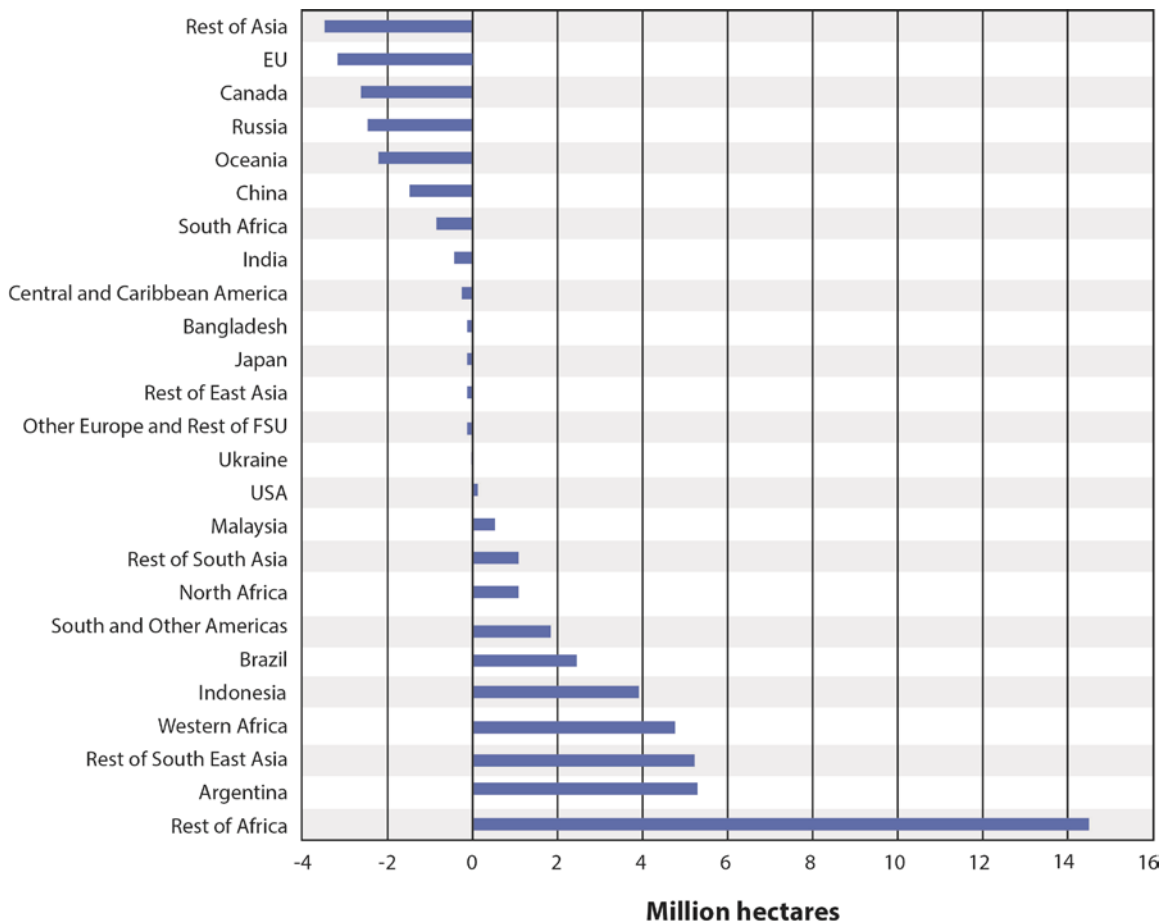
Figure 8. Change in Arable Land Plus Permanent Crops: 2004–2006 to 2010–2012

The data in Figures 2 and 8 can be used to determine the relative importance of land use changes at the intensive and extensive margin. Intensive margin changes are changes in double cropped area and a reduction in land that is available to plant but that is not harvested. The total change in harvested area in Figure 2 is the sum of extensive changes and intensive changes to land use. Thus, intensive changes equal the total change in harvested area from Figure 2 minus the changes in cropland given in Figure 8.[6] Both intensive and extensive changes are shown in Figure 9. Countries are sorted from the left according to their level of extensive acreage changes.

Most of the change in land use in African countries and Argentina is at the extensive margin. Most or all of the response in the developed world, India, China, South Africa, and the rest of Asia is at the intensive margin. The response in Indonesia and Brazil is mixed.

Major Drivers of Recent Land Use Changes

Broadly speaking, the land use changes shown in Figure 9 are consistent with a model of the world in which countries that have available land to convert to agriculture will have relatively more extensive land use change than countries that have long histories of agricultural development and limitations on available land. Thus, one major driver of recent land use changes is the availability of land to convert to agriculture. Most developed countries, along with China and India, have little land available, however, countries in Africa and South America have abundant land resources. There are striking differences, however, in land use indicated by Figure 9 that must be due to other drivers.

Growing demand for soybean imports was a major driver of land use decisions in Argentina, Brazil and the United States. The increased demand for soybeans resulted mainly from China's decision to meet its domestic needs for soybeans through imports rather than domestic production. This decision freed up resources in China to devote to production of other commodities and led to much higher soybean area in Argentina, Brazil, and the United States. Higher demand for high-protein foods in China and other developing countries increased the demand for soybean meal.

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[6]One other use of this measure as an indicator of the amount of land that is used in agriculture is OECD-FAO (2014) when total agricultural land is discussed.
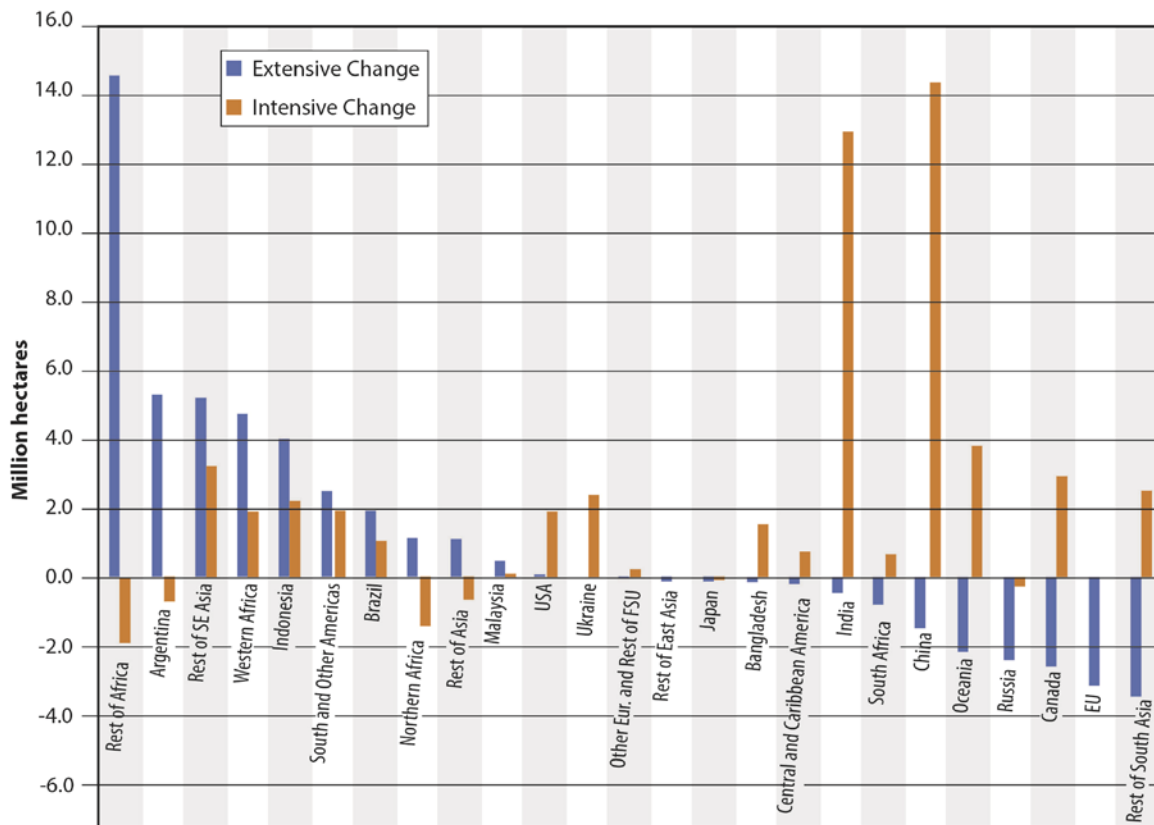
Figure 9. Extensive and Intensive Land Use Changes: 2004–2006 to 2010–2012

Increased demand for vegetable oils for food production, cooking, and biodiesel increased the demand for soybean oil.

Brazil responded to this increased soybean demand by expanding soybean area, however, a second crop of corn was planted on a good portion of expanded soybean acreage. This expansion in double cropping reduced the amount of corn area planted to the first crop of corn. Thus, Brazil expanded at both the extensive and intensive land use margins.

Argentina also expanded soybean area, but it did so at the extensive margin rather than by intensifying land use. The prime soybean production areas in Argentina are farther south than in Brazil, which shortens the time period available for double cropping. However, a second crop of soybeans can be planted in Argentina after winter wheat is harvested in December. One explanation for a lack of intensification is that Argentine area planted to wheat has declined from about 6 million hectares in 2005 to 3.6 million hectares in 2012. This decline simply means that there is less land available for double cropping soybeans after wheat. Therefore, if soybean area needs to increase, less wheat

land means less land available for double cropping, thus, soybean first crop area by definition must increase. The decline in wheat area has been mainly driven by government policy interventions in the form of export taxes and export subsidies that were implemented in a way that favored soybeans over corn and wheat (Nogues 2011). This suggests that government policy is what caused a lack of an intensive land use response in Argentina, in contrast to the significant intensive response shown in Figure 9 in Brazil and other South American countries.

As discussed, Indonesian expansion of palm production was accomplished at least in part at the extensive margin. This expansion resulted from increased investment drawn to the industry due to higher profit margins caused by higher prices and higher yields. The higher prices resulted from an overall increase in demand for vegetable oil, driven by increased demand for food production, cooking oil, biodiesel, and other uses. The data show that Indonesian expansion of rice and corn harvested area was done at the intensive margin because the area devoted to perennial crops in Figure 7 is greater than the total extensive expansion shown in Figure 9.

Sugarcane and soybeans account for nearly all of the land expansion in Brazil. Increased sugarcane production was used to meet growing demand for sugar and to meet growing domestic demand for ethanol. The number of flex vehicles in Brazil grew by 20 million from 2005 to 2012. If all of these vehicles used ethanol, Brazilian consumption of ethanol in 2012 would have exceeded 24 billion liters just from these vehicles, and additional consumption would have come from the 15 million gasoline vehicles in Brazil. Actual consumption in Brazil was about 18 billion liters.[7] These figures demonstrate that the growth in sugarcane area was primarily driven by the Brazilian government policy that increased the sales of flex vehicles in Brazil. The expansion in Brazilian soybean area was driven by increased world demand for soybean imports, which was mainly driven by China, as previously discussed. The ability to plant a second crop of corn after soybean due to adoption of shorter-season soybeans and agronomic advances reduced the amount of new land that was needed to accommodate this expansion.

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[7] All figures on Brazilian vehicle numbers and ethanol consumption were obtained from UNICA: http://www.unicadata.com.br/?idioma=2

In China, India, and most of the developed world, agricultural land resources are limited. Limited land resources means that expansion at the extensive margin is costly relative to expansion at the intensive margin. Thus, we see a large response in both China and India at the intensive margin rather than the extensive margin. Cui and Kattumuri (2012) argue that Chinese intensification would have been even greater but for the government policy objective of maintaining a minimum of 120 million hectares of land in agriculture. India's intensification was facilitated by government investment in irrigation facilities and price subsidies that increased agricultural profitability (OECO-FAO 2014).

The lack of a large extensive response in Ukraine, Russia, and other FSU countries is somewhat surprising given the availability of land. The lack of response at the extensive margin could be due to a lack of investment in the agricultural sectors of these countries.

How much of the changes in land use shown in Figure 9 can be attributed to high commodity prices cannot be known precisely without observing an alternative history in which the run-up in commodity prices did not occur. Economic theory suggests that some portion of the changes in Figure 9 came about because of high prices in those countries where high world prices were transmitted to farmers. However, some of the changes in land use would have occurred even if prices had remained constant at their 2004–2006 levels.

The extent to which extensive expansion in African countries was caused by high world prices is likely small for the simple reason that higher world prices were not transmitted to growers in many African countries. Minot (2010) concludes that domestic grain prices in Tanzania bear little relationship to world prices. In a more complete study, Minot (2011) studies price transmission in multiple markets in Ethiopia, Ghana, Uganda, Zambia, Mozambique, Tanzania, Kenya, South Africa, and Malawi. Of the 62 markets studied, he found that only 13 showed a statistically significant long-run relationship with world prices. He found some evidence of a linkage in large urban centers and in coastal markets, which is consistent with markets in cities and in coastal ports being more integrated with world markets. However, given his overall findings, these limited linkages to world prices did not find their way through to rural areas where most crops are grown. With such weak evidence supporting price transmission to rural areas one can conclude that the main driver of land expansion in many African countries was not higher world prices.

Empirical Measures of Land Use Changes

Aggregating land use changes across all countries, the aggregate world extensive change was a net increase of 24 million hectares from 2004–2006 to 2010–2012. The aggregate world intensive land use change was 49.1 million hectares. Thus, across all countries, more intensive use of existing land was double the change from more extensive use of land. Outside of African countries, the aggregate intensive change in land use was almost 15 times as large as extensive changes. This wide disparity between more intensive use of land and more extensive use means that the reliability of current models used to estimate indirect would be dramatically increased if they were modified to account for non-yield intensification of land use.

The recent historical changes in land use can provide some guidance about the effect of dramatically higher prices on land use change over an eight-year period. An estimate of the amount of extensive land use change that can be attributed to higher commodity prices can be made under fairly restrictive assumptions.

First is assuming that land use change at the extensive margin due to high prices is zero in those countries or regions in Figure 9 that had negative extensive changes. This assumption implies that the forces that caused countries to lose agricultural land during this time would have caused the same amount of loss even without the high prices. Clearly, it would seem that at least some land in these countries was kept in production from the high prices, so this assumption understates land use change at the extensive margin. From a greenhouse gas perspective, this assumption is equivalent to saying that the net amount of carbon sequestration that would have occurred on land that was kept in production by high prices in these countries is negligible.

Second is assuming that all the extensive margin changes in Figure 9 in countries and regions that have positive changes are due to high world prices. This too is an extreme assumption because some land would have been brought into production even if commodity prices had not increased. Thus this assumption overstates the response of land use at the extensive margin.

If we include extensive changes in Africa, then world extensive land use changes equals 41.2 million hectares, which represents a 2.68% increase over the average level of land in production in 2004–2006. If we assume that the extensive land use changes in

Africa were primarily caused by internal domestic food demand from growing popula-tions and income, and they would have occurred even without high world commodity prices, then the extensive land use increase equals 20.7 million hectares or 1.35%.

It is instructive here to make a rough estimate of the response of the world exten-sive margin to aggregate higher commodity prices. The average real prices of corn, soybeans, wheat, and rice received by US farmers increased by 123%, 85%, 59%, and 47% respectively in 2010–2012 relative to 2004–2006. A simple average of these price increases is 78%. With this real price increase, the elasticity of the world extensive margin is 0.034 if African extensive response is included, and 0.017 if the African extensive response is not included.

Similarly, if the intensive response in countries and regions where the response is negative is set to zero, then the aggregate intensive response to high prices is 49.1 million hectares if we attribute all the intensive response to higher prices. Without the African country response, the aggregate response is 47.2 million hectares. The result-ing elasticities of intensive response are 0.041 and 0.039. Thus, if we attribute all the African extensive land use changes to high prices, then the world intensive elasticity is 19% higher than the extensive elasticity. If none of the African response is attribut-ed to higher prices than the non-African intensive elasticity is almost three times as great as the extensive response.

These rough estimates demonstrate that the primary land use change response of the world's farmers in the last 10 years has been to use available land resources more effi-ciently rather than to expand the amount of land brought into production. This finding is not new and is consistent with the literature that finds significant option value in waiting to convert land (Song et al. 2011). OECD-FAO (2009) recognized that intensive land use change has been the driving force behind higher production levels, however, this finding has not been recognized by regulators who calculate indirect land use. Note that our measure of more efficient land use does not include higher yields in terms of production per hectare harvested. Any increase in yields would be an additional intensive response. Rather the intensive response measured here is due to increased multiple cropped area, a reduction in unharvested planted area, a reduction in fallow land, and a reduction in temporary pasture. Because greenhouse gas emissions associated with an intensive

response are much lower than emissions caused by land conversions (Burney, Davis, and Lobell 2010), ignoring this intensive response overstates estimates of emissions associated with land use change because most of the land use change that has occurred is at the intensive rather than extensive margin.

## Comparison of Actual Land Use Changes with Model Predictions

Model predictions of land use change from increased biofuel production are conceptually appealing. This is because the effects of higher biofuel production on land use are measured in isolation—the effects of everything else that influences agriculture are held constant. Thus, the effects of biofuel production alone can, at least conceptually, be measured. The way that the models assume increased production impacts land use is through higher prices. Thus, if the actual changes in land use in Figure 9 were the result of a response to the large increase in commodity prices that actually occurred, then it seems reasonable to compare model predictions to the actual changes that occurred. However reasonable this seems, we simply do not know with certainty what land use changes would have occurred without the increase in commodity prices. What needs to be compared to model predictions is the difference in land use with the commodity price increase relative to what it would have been without the commodity price increase.

What information then can be gleaned from a comparison of model predictions with actual changes? At one extreme, if none of the observed changes in extensive land use were the result of high prices, then we know that indirect land use is not empirically important because land use changes are caused by other forces. At the other extreme, if extensive land use would have stayed constant at base period levels if prices had not increased then all of the observed changes resulted from high prices. In this case it would be valid to judge the accuracy of model predictions with observed changes, because both would be caused by price responses. Reality likely falls somewhere in between these two extremes in that land use in 2012 would have been different than in 2004 even without the price increase, and that at least some portion of the observed changes we see can be attributed to higher prices. Taheripour and Tyner (2013) use observed land use changes as a guide to selection of a key model parameter in GTAP in an attempt to reconcile model predictions with observed changes. Hence, they assume that observed changes in

land use are a useful guide to determine how the GTAP model should predict how land use changes in response to a change in commodity prices.

The two most widely used international models used in the United States to predict land use changes associated with increased biofuel production are GTAP and FAPRI (Gohin 2014). Both models allowed crop yields to respond to higher prices, and neither model allowed land use intensity, as measured here, to increase. Given that the primary way that non-African countries have increased effective agricultural land was through intensification, both models have an upward bias in their predictions of land use change at the extensive margin in non-African countries.[8]

Figure 10 shows the predicted increases in cropland from the FAPRI model that was used by the Environmental Protection Agency to determine greenhouse gas emissions
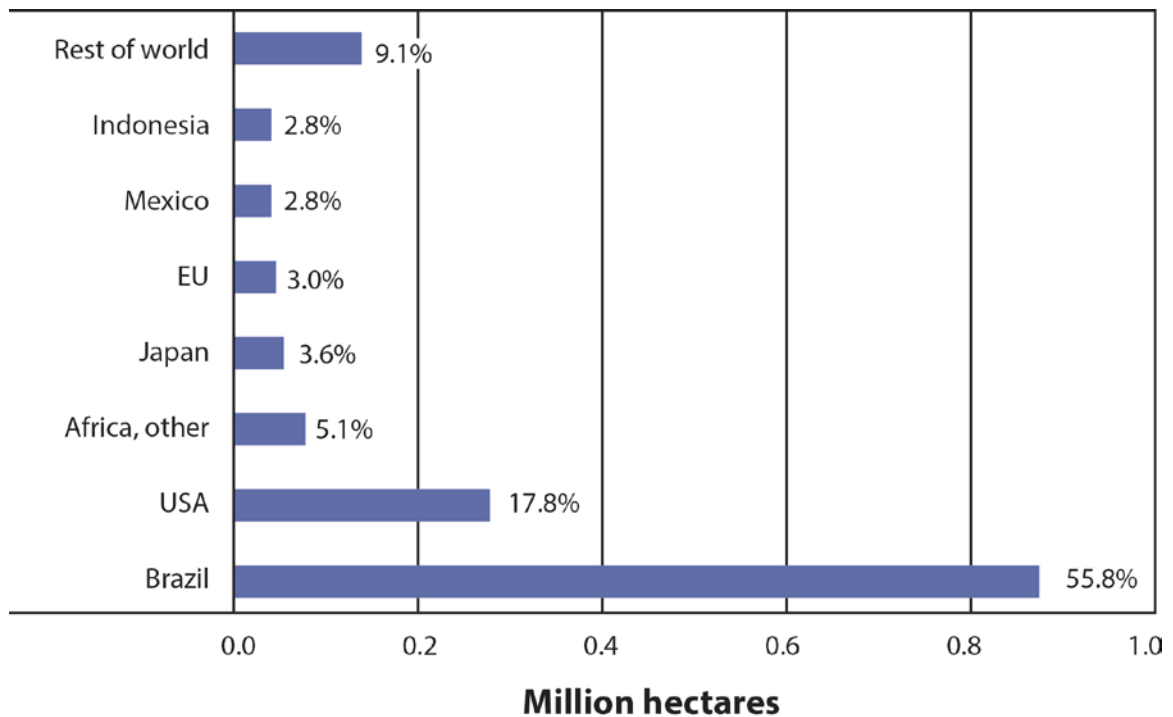
Figure 10. Predicted Land Use Change in EPA "All Biofuel" Scenario: Hectares and Share of World Total

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[8] One way that production per unit of agricultural land can increase in the GTAP model is through its yield elasticity, therefore at least some of the upward bias in GTAP's prediction of extensive land use changes is offset by using a yield elasticity value that is higher than can be supported empirically.

associated with land use changes from increased biofuels. What is illustrated is the difference between EPA's "Control Case" that includes levels of biofuels in the RFS and EPA's "AEO Reference Case," which contains lower levels of biofuels (EPA 2010). This scenario simulated increases in many different biofuels including biodiesel made from vegetable oil and waste greases, corn ethanol, sugarcane ethanol, and cellulosic ethanol. How these land use changes were calculated is that the FAPRI predictions of land use in the AEO Reference Case were subtracted from the predictions in the Control Case. The total predicted world change in land use is 1.45 million hectares.

What is striking about Figure 10 is the concentration of predicted land use change in Brazil and the United States. These two countries account for almost 75% of the total predicted change in land use, with Brazil alone accounting for more than half of all change in the world at the extensive margin. In the AEO Reference Case total cropland in Brazil is increasing, thus the predicted increase in area must come from conversion of land that would have been devoted to other uses.

The first valid comparison that can be made between the CARD-FAPRI model prediction and what actually occurred is that the predicted land use change in Brazil due to higher prices is far too high relative to land use changes that actually occurred at the extensive margin in Argentina and other South American countries. As shown in Figure 9 Argentina and other South American countries together increased land use at the extensive margin by almost four times as much as did Brazil. The CARD-FAPRI model results used by EPA predicted almost no land use change in Argentina and other South American countries due to higher prices. It is notable that the CARD-FAPRI model predicted that growth in Brazil cropland from 2002 to 2009 would be about 9.1 million hectares, whereas Argentina's growth would be 3.7 million hectares in the Reference Case. Thus, the larger increase in agricultural area in Argentina that actually occurred cannot be attributed to the model being right about predicting a larger baseline increase in Argentina than in Brazil. The first conclusion one can draw from this comparison is that the CARD-FAPRI model dramatically over-predicted land use change in Brazil relative to Argentina and other South American countries.

The CARD-FAPRI prediction that the United States would account for about 18% of the world's increase in extensive land use seems inconsistent with the large changes that

occurred in African countries and Argentina. The only way that the US land use prediction is consistent with the historical record is if cropland in the United States would have dropped by a large amount in the absence of the large price increase. The CARD-FAPRI model predicted that US crop area would decline in both the Reference and Control Cases.

The CARD-FAPRI model includes some South African production and a limited number of other crops in a limited number of African countries. The CARD-FAPRI model implicitly assumes that most of African agricultural production of major crops is isolated from world markets. As discussed above if this isolation is in fact a correct characterization of African agriculture, then the large land use changes in African countries shown in Figure 9 would have occurred even without the high commodity prices. The only other conclusion that can be drawn regarding African countries is that the CARD-FAPRI model underpredicts land use changes there to the extent that land use in African countries responded to world prices.

The commodity price increases that led to the Figure 10 predicted changes in land use were a 3.1% increase in corn prices and a 0.8% increase in soybean prices. These simulated price changes are dwarfed by the actual price changes that have occurred as shown in Figure 1. The FAPRI model prediction of a small increase in extensive land use in Japan and the EU due to small changes in price seems inconsistent with the fact that land use in Japan has been largely unchanged over the last 10 years and the EU has experienced a decline in land use. Again, it is not possible to know the extent to which a small increase in world commodity prices would have kept a small amount of land in production in the EU.

The small model-predicted change in Indonesia in extensive land use is generally consistent with observed changes if we assume that no changes would have occurred except for the higher market prices that actually occurred and not from government development priorities.

Figure 11 shows predicted land use changes by the GTAP model. [9] GTAP predicts that 38% of land use changes occur in the United States. As discussed, although

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[9] GTAP model predictions of land use changes associated with biofuels vary across publications. Figure 11 land use change predictions were taken from Hertel et al. (2009) which were published about the same time that California's Air Resources Board was making their determination of greenhouse gas emissions from land use change that relied on GTAP model predictions. For the purposes of this paper, we assume that the
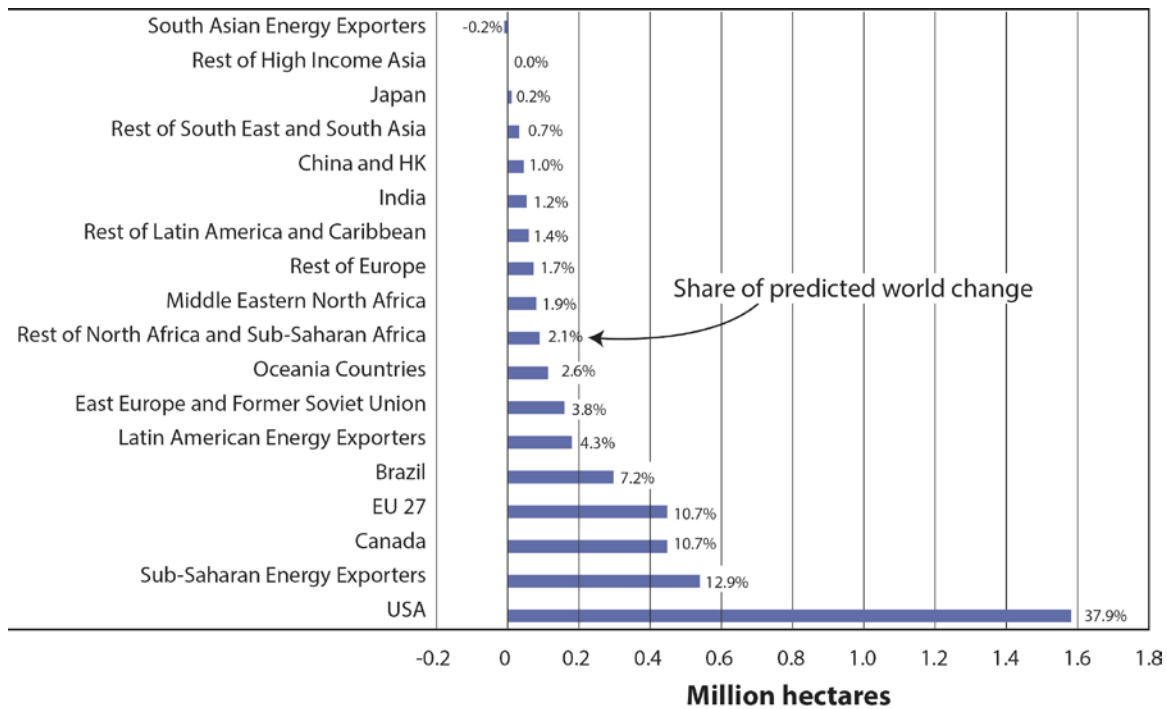
Figure 11. GTAP Predictions of Indirect Land Use Change from Corn Ethanol
Source: Hertel et al. (2009)

this seems like a large over-prediction of the US contribution, it is not possible to say this prediction is inconsistent with the recent historical data given that we cannot observe what land use would have been without the price increase. However, for this prediction to be true, the fairly small price increase simulated by GTAP would have kept a sizeable amount of land in production in the United States.

As with the CARD-FAPRI model, GTAP over-predicts the land use change for Brazil relative to other Latin American countries assuming that the baseline in Hertel et al. (2009) shows Brazil's area increasing more than agricultural area in the rest of Latin America. This baseline level of data was not available for inspection but GTAP's baseline was developed using 2001 data that incorporates land use changes that occurred in previous years. Brazil's agricultural land was expanding in this prior period, so it is reasonable to assume that Brazil's land use in the baseline was increasing more than in

Figure 11 land use changes are consistent with those used by California. There exist many GTAP-based estimates of land use change due to biofuels. An alternative estimate was provided by Tyner (2010). First and Second Generation Biofuels: Economic and Policy Issues, Presented at the Third Berkeley Bioeconomy Conference, June 24, 2010, http://www.berkeleybioeconomy.com/ wpcontent/uploads//2010/07/TYner%20Berkeley%20June%202010.pdf.

other South American countries. This would imply that the predicted change in Brazil relative to the rest of Latin America is too large.

Despite the large discrepancies between model predictions and the actual land use changes that have occurred since 2004 it simply is not possible to conclude with certainty that the model predictions have been proven wrong and should be disregarded. For example, the Hertel et al. (2009) prediction that large land use changes from output price increases resulting from US corn ethanol production would occur in the United States, Europe, and Canada seems inconsistent with the fact that cultivated land decreased in the EU and Canada and stayed constant in the United States despite price changes that were many times larger than those predicted by the model. However, it could be that the amount of actual land reduction that would have occurred in the EU and Canada would have been much larger without the commodity price boom and that if actual land use changes were calculated relative to what would have happened without the price impact then the GTAP model predictions would be consistent with what we observe. Thus, without being able to observe the alternative history that did not contain the commodity price boom, it is not possible to conclude with certainty that the model predictions are wrong. As Babcock (2009) pointed out, economists who run models to predict future land use changes are in the enviable position that skeptics of the predictions will find it difficult to use the actual land use change data to prove that the model predictions were wrong. However the historical record of land use changes can be used to provide insight into the types of land that were converted assuming that the model predictions are correct.

Using the Historical Record to Guide Estimates of Land Conversion

Table 1 below presents some GTAP results that were used by California's Air Resources Board to calculate CO_2 emissions associated with land conversion due to corn ethanol production. By regressing emissions on the amount of land converted, it is possible to obtain a rough estimate of how each of the four land conversions affect estimated emissions separately. Table 2 provides the regression results.

An increase in land conversion increases GTAP's estimates of emissions. Conversion of a million hectares of forest increases emissions much more than conversion of pasture. How to interpret these coefficients is that a one million hectare increase in, for

Table 1. GTAP Model Predictions of Land Conversion and Associated GHG Emissions

| Scenario | Forest Converted | | Pasture Converted | | LUC Emissions |
	U.S.	ROW[a]	U.S.	ROW	
	million hectares				*gCO₂e/MJ*
A	0.70	0.34	1.04	1.96	33.6
B	0.36	0.01	0.79	1.53	18.3
C	0.82	0.64	1.19	2.83	44.3
D	0.81	0.08	1.31	2.34	35.3
E	0.48	0.52	0.66	1.35	27.1
F	0.46	0.27	1.00	2.10	27.4
G	0.40	0.15	0.92	2.18	24.1

Source: Provided by staff at the Renewable Fuels Association
[a]ROW means Rest of World

Table 2. Impact on CO₂ Emissions of a Million Hectare Increase in Land Conversion

Land Type Converted	Impact on Emissions
	gCO₂e/MJ
US Pasture	6.17
ROW Pasture	3.08
US Forest	22.69
ROW Forest	14.41

Source: Estimated from Table 1.

example, US pasture to crops, leads to a 6.17 increase in emissions measured by grams CO_2 per MJ of gasoline energy replaced by corn ethanol. Across all seven scenarios the average prediction of forest conversion in the United States is 0.58 million hectares.

Multiplying 0.58 by 22.69, which is the coefficient relating conversion of forest to emissions, results in an estimate of the average contribution of US forest conversion to the final CO_2 emission number. The result is that GTAP estimates that conversion of US forests contributes 13.06 gCO₂/MJ or 43% of total estimated emissions.

As shown in Figure 8, US cropland did not appreciably increase at the extensive margin in response to higher prices on average in 2010–2012 relative to 2004–2006.[10] As

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[10] A more detailed examination of US data is provided in the next section, which shows there is some evidence of an increase in planned area to be planted from 2007 to 2013. The 2004–2006 and 2010–2012 time periods were used to make US data consistent with available data for other countries.

discussed in the previous section, it is not possible to conclude whether the GTAP model prediction that US cropland would be 1.6 million hectares higher due to higher prices is inconsistent with what actually happened, because it could be that US cropland would have declined from 2004 to 2012 if the higher prices had not occurred. For example, if US cropland would have declined by 5 million hectares if the high prices had not occurred, then the GTAP prediction that 1.6 million of these hectares would have been kept in production is consistent with the historical record. More formally, a necessary condition for consistency of the model prediction of an increase in US cropland due to higher prices is that US cropland would have declined by at least the amount of the model prediction were it not for the higher prices that actually occurred.

So suppose that there would have been a 5 million hectare decline in US cropland were it not for the higher prices and the GTAP prediction is correct that 1.6 million hectares of this land would have been kept in production because of higher prices caused by corn ethanol production. This means that the type of land converted to accommodate biofuels was not forest or pastureland but rather cropland that did not go out of production. Calculation of foregone carbon sequestration depends on what would have happened to the cropland if it did not remain in crops which, in turn, depends on where the cropland is located and the potential alternative uses. The magnitude of the change in estimated CO_2 emissions from cropland that is prevented from going out of production relative to forest that is converted to cropland is potentially large. For example, from Table 2, converting one million hectares of grassland instead of forest would reduce land-based CO_2 emissions by 11.3 gCO_2e/MJ in the rest of the world and by 16.5 gCO_2e/MJ in the United States. If foregone carbon sequestration is less than the amount of carbon lost from converting pasture to crops then the magnitude of the emission reduction would be larger.

The countries in Figure 8 that either had negligible or negative extensive land use changes should be presumed to not have converted pasture or forest to crops in response to biofuel-induced higher prices. Rather, the presumption should be that any predicted change in land used in agriculture came from cropland that did not go out of production. From Figure 11 this would include Canada, the EU, Russia, the Ukraine, and India.

The countries in Figure 8 that had significant extensive land increases cannot be presumed to have only kept cropland in production because of biofuels. Whether the

expanded cropland due to the portion of the actual price increase attributable to biofuels expansion came from cropland that would have gone out of production or from pasture is an accounting decision. For these countries that expanded extensive land use, the historical pattern of where in the country the land use expansion occurred provides insight into the type of land that was converted to crops.

Brazil is one country that expanded extensive land use and has data on where this expansion occurred. Figure 12 shows each state's share of extensive land use change in Brazil measured by the change in the 2010–2012 average from the 2010–2012 average.[11] Not surprisingly extensive land use increased the most in Mato Grosso. Expansion of sugarcane area in Sao Paulo explains its increase. The states of Goias, Maranhao,
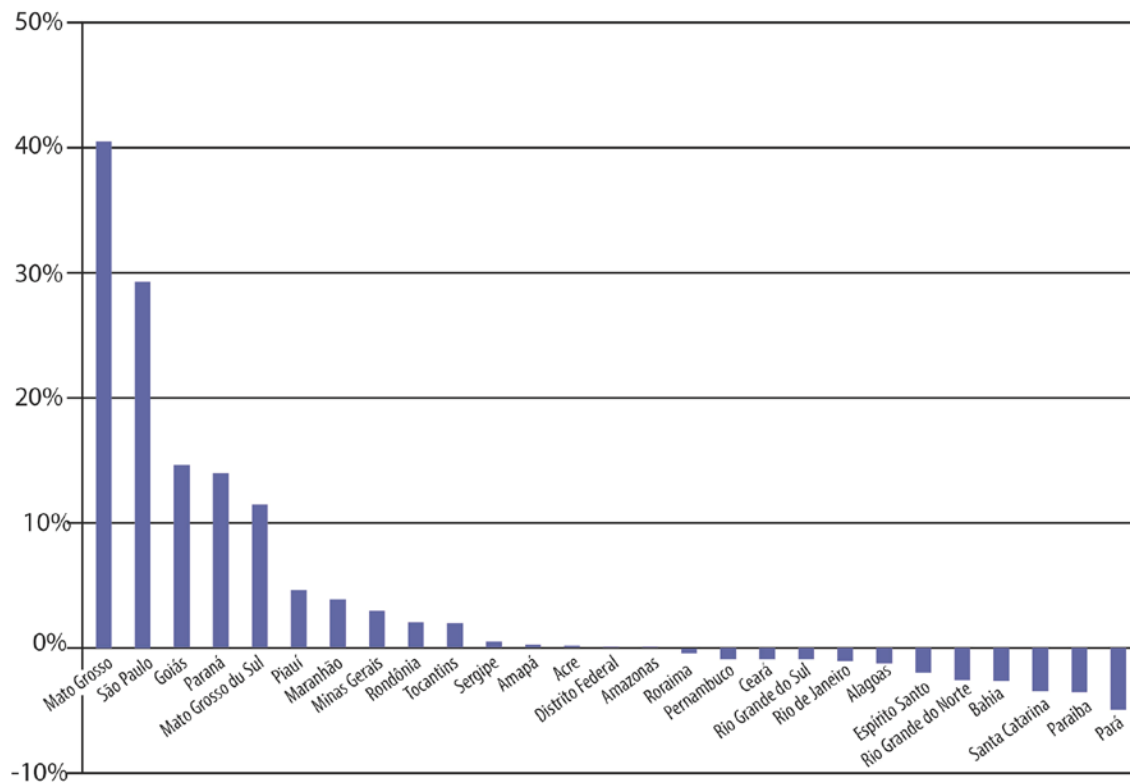

Figure 12. State Share of Brazil's Change in Extensive Land Use from 2004–2006 to 2010-2012.

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[11]Only land that was planted to crop was considered in calculating each state's share of extensive land use change. The cropland planted data comes from the IBGE website: http://www.sidra.ibge.gov.br/bda/acervo/acervo9.asp?e=c&p=PA&z=t&o=11. Total planted cropland in Brazil is less than FAOSTAT data on arable land plus permanent crops that was used to determine extensive and internsive land use changes in Figure 10 and 11.

Tocantins, and Piaui all have large land areas in the vast Brazilian Cerrado biome which has also seen large-scale development (The Economist). Rondonia is the only state in the Amazon biome that shows an increase in cropland. Where cropland has expanded in Brazil (and in other countries where data allows) can be used as a guide to determine if model predictions of the type land converted are accurate.

A More Detailed Look at US Extensive Area Data

Figure 13 shows what has happened to one measure of US cropland from 1993 to 2013. This measure is area planted to US principle crops as measured by USDA-NASS, less double cropped harvested area, plus fallow cropland. This measure reached its peak in 1996. In 2007, this measure increased after a long downturn, suggesting some impact of higher prices. However, in 2010 it fell below 130 million hectares before increasing in 2011 and 2012. It is somewhat surprising that total land in agriculture has not increased more than indicated since 2006 because land enrolled in the Conservation Reserve
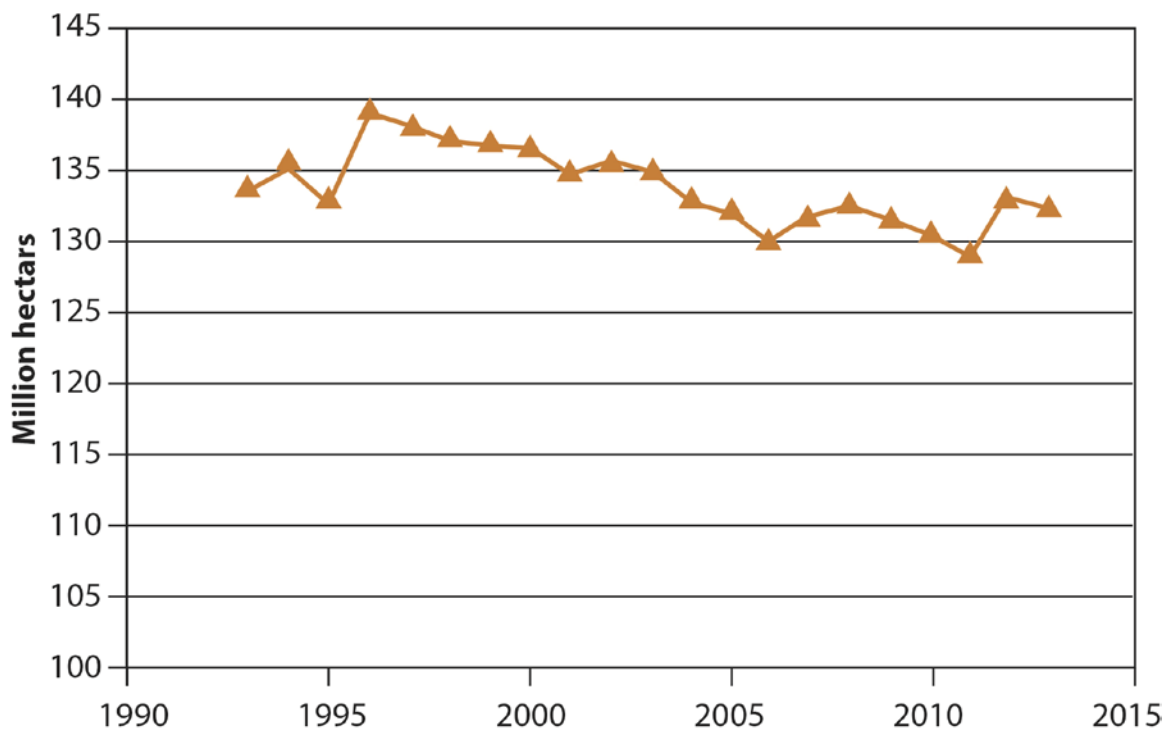

Figure 13. US Cropland Since 1993

Program (CRP) declined by 4 million hectares from 2007 to 2013. One explanation for a lack of response in this measure of land use could be an increase in area that is reported as prevented planting area.

The US crop insurance program creates an incentive for farmers to report area that they had planned to plant but were not able to due to adverse weather. This land is called prevented planted acres. Farmers who buy crop insurance receive a crop insurance payment on these acres. Aggregate data on the amount of prevented planted acres can be added to the Figure 13 data to measure how much land US farmers intend to plant each year. Data on the area designated as prevented planting area are available since 2007.[12] Figure 14 shows the change in CRP land since 2007 (grey line), the change in US cropland since 2007 (blue line calculated from Figure 13), and the change in intended planted land since 2007 (orange line). It is striking how close the change in intended
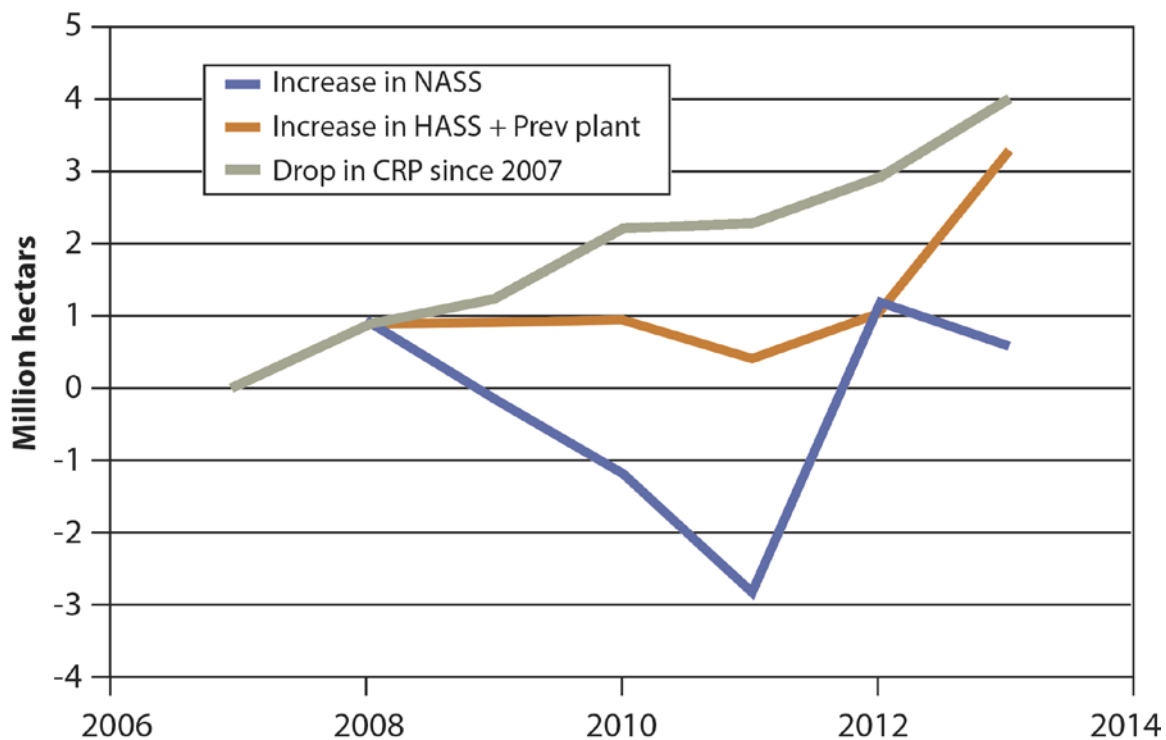
Figure 14. CRP Land Showing up as Increased Prevented Planting Acres

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[12] Prevented planting has been part of the US crop insurance program before 2007 but data on total area designated as prevented planting are not readily available.

planted land is to the reduction in CRP, and it is also striking how little of the land that is no longer enrolled in CRP shows up as land in production.

What can be concluded from this more detailed examination of extensive land use in the United States is that the data seem to indicate a reversal of a long-term trend of declining total US cropland since 1996 beginning in 2007—the first crop planted in response to significantly higher prices for US corn and soybeans. The large reduction in land enrolled in CRP is much greater than the amount of land that is reported as being in productive use in crop production. This suggests that there is an abundance of ex-CRP land that is available for planting or that a large proportion of ex-CRP land has not yet been available for crop production and is being reported as having been prevented from being planted. The data are consistent with any increase in extensive land use since prices increased in 2006 as coming from a stock of available land that had been planted to crops previously or from land that was enrolled in CRP. This finding is consistent with USDA (2013), which found that the only net contributor to US cropland from 2007 to 2010 was a reduction in CRP land. There was no net increase in cropland from conversion of forests, from conversion of urban land, or from conversion of pasture.

Conclusions

That countries primarily responded to higher world prices by intensifying land use rather than by converting land from forests and pastures should not be surprising. Many countries, such as China and India, simply do not have available land to bring into agriculture. In countries with land suitable for crops, the investment and other transaction costs of developing new land make the process quite costly relative to the cost of increasing the intensity of land use. In addition, the value of waiting to invest in land conversion projects is large, which leads to a significant delay in land conversions.

The pattern of recent land use changes suggests that existing estimates of greenhouse gas emissions caused by land conversions due to biofuel production are too high because they are based on models that do not allow for increases in non-yield intensification of land use. Intensification of land use does not involve clearing forests or plowing up native grasslands that lead to large losses of carbon stocks.

The recent data on land use changes reveals the importance of policy in determining land use decisions. In Argentina, higher export taxes and quotas on corn and wheat relative to soybeans caused soybean area to increase and wheat area to decrease. The drop in wheat area limits the availability of land on which soybeans can be double cropped which means that expansion of soybeans can only take place by replacing existing crops or by expanding onto new lands. In Brazil, increased enforcement of laws restricting clearing of forests and the resulting drop in the rate of deforestation is consistent with Brazil expanding land use at both the intensive and extensive margin.

It might be argued that recent data are a poor indicator of what we should expect to happen if more time passes because supply response is always larger in the long-run than in the short-run. Land conversion takes time but the time gap used here to measure land use change is long enough to allow a significant amount of change to happen. In addition, the incentive to expand agricultural supply between 2006 and 2012 was as strong as any period since at least 1960. Furthermore, if the recent sharp declines in commodity prices continue then the incentive to expand supplies in the future will be muted.

We plan on extending our analysis of land use changes by attempting to develop a statistical model to explain more systematically why some countries expanded land use more at the extensive margin and others expanded more at the intensive margin. Such a model could provide better insights into the role that policy, price transmission, and resource availability plan in determining agricultural supply response. Improved understanding could be useful to future attempts at estimating greenhouse gas emissions caused by extensification of agricultural production.

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Data Sources

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India: http://eands.dacnet.nic.in/
FAO: Area harvested: http://faostat3.fao.org/download/Q/QC/E
FAO: Land Cover: http://faostat3.fao.org/download/R/RL/E
USA: USDA-NASS: http://quickstats.nass.usda.gov