The Role of Cultivated Land Expansion on the Impacts to Global Agricultural Markets from Biofuels

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Abstract

The emergence of biofuels has led to an increase in crop price and subsequently global food prices but the extent of the impact is subject to debate. Fully understanding the role of biofuels on agricultural markets requires properly accounting for the response of all affected inputs and outputs. Previous studies have generally forced the amount of cultivated land, the largest input, to remain fixed regardless of price change. This study overcomes this limitation by setting alternative growth rates in farmland expansion within a general equilibrium model (GTAP-E) with a focus on agricultural and energy markets. The simulation of the model under alternative biofuel policies and market conditions reveals that a fuller utilization of available land resources significantly reduces the rise in feedstock prices brought about by biofuel policies and/or higher energy prices. Implicit land supply price elasticities calculated by the model are consistent with previous studies and lend support to the approach taken within the study.

1. Introduction

The expansion of biofuel output through either policy or energy markets has pushed up the prices for major feedstocks such as corn and soybeans (FAO, 2008; Rosegrant *et al.,* 2008; Hertel *et al*., 2010; Huang *et al.,* 2012). The ripple effect of higher crop prices for farmers on consumers has led to a re-evaluation of programs and mandates stimulating the growth in renewable fuels. For example, the US mandated requirement on the use of ethanol in gasoline was challenged in late 2012 by a variety of interest groups ranging from domestic livestock producers to international environmental coalitions. Meanwhile, a proposal released in 2012 by the European Commission aims to reduce the biofuel mandate from 10% of transportation fuel in 2020 to the current consumption level of 5%, and to eliminate public subsidies for biofuels after 2020 unless “substantial greenhouse gas savings” of biofuel are proven (EC, 2012). Although the renewable fuel mandates remain unchanged in the US, the debate surrounding the extent to which these policies have affected agricultural markets and subsequently consumers remains.

Fully understanding the role of biofuels on markets requires properly accounting for the input and output responses to price changes and policy regimes. Land is the major input into production yet the majority of previous studies assessing the global price effects of biofuels have kept total farmland constant. These studies allow for changes in the share of cultivated land allocated to alternative crops but the total amount of land is kept constant (Hertel *et al.*, 2008; Taheripour *et al.*, 2008; Fernandez-Cornej *et al.,* 2008; Huang *et al.,* 2012). An increase in the supply of farmland in response to higher crop prices, however, could dampen (and potentially eliminate) the price increase stimulated by biofuels. This study overcomes that limitation by allowing cultivated area to adjust to changing prices.

There are two approaches that can be used to estimate the impacts from allowing a growth in cultivated area to influence the output and price effects due to the emergence of biofuels. Both require assumptions and both start with a general equilibrium model of the agricultural economy (i.e., GTAP—see citations and brief explanation of this model in section 3). In the traditional GTAP model, cultivated area is more or less restricted to a minimal level of expansion. Pasture land is allowed to be switched to cultivated area, but, in most models for most countries, the effective assumption is that cultivated area is fixed.

In the first approach, Banse *et al.* (2008) and Bouet *et al.* (2010) adapt the traditional GTAP model and allow the model to add cultivated area in response to rising agricultural prices. The amount of cultivated area that enters into the model is a function of endogenous prices and outputs with higher prices attracting land to enter the model. The key assumption is how responsive is land area to changes in these agricultural commodity prices. Banse *et al.* (2008) assume the price elasticity of land ranges from 0.0 to 5.97 depending on the region while Bouet *et al.* (2010) assume a much more inelastic range from 0.05 to 0.1. It is difficult to know which value is appropriate since few studies have estimated the price elasticity of land expansion (Hertel, 2010). After a careful analysis based on the estimation by Fisher (2009), Hertel (2011) derived an implied elasticity of land supply with respect to commodity price of approximately 0.1.

An alternative approach, the one that is used in this paper, is to take a "sensitivity analysis approach" to estimating the impact of allowing additional cultivated land to enter production on the price/output effects of the emergence of biofuels. In this approach, our logic is that we do not know the price elasticity of cultivated land, particularly across regions. Without access to reliable estimates of this key parameter, we are not comfortable with allowing the model to endogenize the emergence of cultivated land in response to higher agricultural prices. Significantly more research, however, has gone into estimating the amount of cultivated area that is available to be brought into cultivation, given incentives (e.g., higher agricultural prices) to do so. We take a range of estimates on the physical potential for cultivated land to expand and see how agricultural markets might be affected if supply is allowed to increase beyond the common assumption of a fixed land base. Our derived estimate of the supply price elasticities for land using this approach is similar to the value calculated by Hertel (2011).

The purpose of this study is to assess how the impacts of biofuel production on regional agricultural markets over the next decade are affected if the area of cultivated farmland is allowed to expand. The first part of the paper describes the basis for determining low, medium and high regional growth rates in cultivated area. The range of rates assumed in this study are more conservative than studies often used to provide a baseline for potential land capability such as FAO (2000) and Campbell *et al.* (2008). The next part of the paper describes how the alternative rates of land expansion are incorporated into the Global Trade Analysis Project- Energy (GTAP-

E) model. The model is simulated under alternative scenarios regarding biofuel policies, energy prices, and elasticities of substitution between fossil and renewable fuels. The simulation reveals a fuller utilization of land resources significantly reduces the rise in feedstock prices brought about by biofuel policies and/or high energy prices.

2. Growth Rates in Cultivated Land

The first step in the analysis is to set limits on the extent to which cultivated land can expand in each of the major crop and/or biofuel producing regions globally. Six regions are considered: Brazil, China, EU, Russia, United States, and the Rest-of-the-World. Low, medium, and high expansion rates are assumed for each of the six regions based on a review of previous studies. Predictions of future growth potential are often based on the FAO (2000) projections, which are estimated using a digitalized soil map*,* a global climatic database, and soil and climatic requirements for crop growth. The FAO (2000) rates tend to be higher than the maximum of our estimates. The rates estimated by Campbell *et al.* (2008) tend to be lower than the FAO (2000) values but are also point estimates whereas a range of growth rates are examined in this study. Our assumed rates are summarized in Table 1 while the point estimates from FAO (2000) and Campbell *et al.* (2008) are listed in Appendix Table B.

The cultivated land base in Brazil has expanded significantly over the last two generations and significant potential remains. The lower end estimate of 0.52% annual growth in Brazil's cultivated land is from Bruinsma (2009), who estimates current land use in 2005 and projects the amount that could be cultivated in 2050. The medium growth rate of 0.88% per year is based on Campbell *et al.* (2008), who use historical land data, satellite-derived land cover, and a global ecosystem model to estimate abandoned agriculture areas. Assuming 28.5 million ha of abandoned land, which is an average of the rates from Campbell *et al.* (2008), and the land base in Brazil of 60 million ha in 2006 (IBGE, 2006), the medium estimate is derived. The high growth rate of 1.65% annually is based on the actual increase in cultivated area by Brazilian farmers between 1995 and 2006 as calculated from historical data published by the Brazilian Statistics Bureau (IBGE).

In contrast to the situation in Brazil, increasing farming area in China is constrained due to a long history of opening up land for cultivation along with increasing demographic and economic pressures for non-agricultural uses of land. The lower bound of the growth rate is based on changes in land area over the last decade using data from China's National Statistical Bureau (NBSC). Arable land area in PRC fell from 127.6 million ha in 2001 but has been relatively stable around 121 million ha since 2004. The low rate estimate of 0% assumes cultivated land area remains constant. The high growth rate estimate of 0.13% is based on the 1.9% net increase of cultivated land between 1986 and 2000 (in total, not annually) estimated by Deng *et al.* (2005) using remote-sensing and satellite images. The same total increase is assumed between 2007 and 2020 resulting in an annual growth rate of 0.13%, which is one-third of Brazil's lower end estimate. The medium growth rate of cultivated land expansion in China of 0.06% is an average of the low and high growth rates.

The growth rates in cultivated area for the European Union are significantly higher than the rates for China but still lower than the estimates for Brazil. The low estimate of 0.26% is based on analysis by Fischer *et al.* (2010) using *AbioE* to estimate future land area requirements for Europe's food and livestock sector. Fischer *et al.* (2010) estimate there will be 124.3 million ha of cultivated land in 2030 under current policy trends in nature conservation and modest yield increases. Given the 115.1 million ha cultivated in 2000, the growth rate of 0.26% forms the lower bound estimate. The medium growth rate of 0.72% is based on the projected 64.3 million ha increase in EU farmland from the FAO (2000) as compared to the 130.1 million ha of cultivated land used in 1994. The high growth rate of 1.20% is from Banse *et al.* (2010), who use a GTAP-based model to simulate the impact of mandatory blending requirements in agricultural markets with and without biofuel byproducts. Banse *et al.* (2010) estimate a 17.9 million increase in land use between 2007 and 2020 with byproducts considered. Given the 105.9 million ha of cultivated land use in 2007 for the EU (FAOSTAT 2007), the resulting growth rate of 1.20% growth rate forms the high growth estimate for the EU.

The lower growth rate in cultivated area for Russia is assumed to be 0% given the constant level of arable land at 122 million ha for the country from 2003 to 2007. The medium growth rate of 0.38% is calculated using the estimated area of abandoned land in Russia from Campbell *et al.* (2008) and comparing it to total arable land from FAOSTAT. The same method was used to estimate the high expansion rate but with projections from the FAO (2000). Given the 87.4 million ha of potential unused, arable land in 1994 for Russia and the 132.3 million ha actually cultivated, a growth rate of 0.91% is estimated.

The low growth rate of 0.06% assumed for the United States is based on comparing the total cropland in 1992 (332 million acres) to the level in 2002 (340 million acres) using historical data from the USDA (2006). The medium estimate of 0.65% is derived from the FAO (2000) calculation of 197.8 million ha of arable land used in 1994 compared to the 81.4 million ha potentially available up to 2050. The high growth rate of 0.75% is based on comparing the average 58.9 million ha of abandoned land available for production by 2050 in 2002 from Campbell *et al.* (2008) to the estimated 137.9 million hectares cropped in 2002.

The expansion rates for the Rest-of-the-World are calculated by taking an estimate of global land expansion and subtracting the respective shares for each of the five regions discussed above multiplied by the expansion rate assumed for that region and then dividing by the Rest-of-the-World share of land area. The low growth rate of 0.1% for the Rest-of-the-World is based on a global expansion rate of 0.12% estimated by Fischer *et al.* (2001) with adjustments for the shares accounted by the five regions under minimal rates of growth in cultivated area. The same process is used to establish the medium (0.45%) and high (1.03%) rates, which respectively use global expansion rates of 0.47% from Hoogwijk *et al.* (2005) and 0.97% from CE-Delft (2007).

3. Methodology

3.1. Model

The effects of biofuel production on global agricultural markets without and with allowing for an expansion in cultivated land are based on a modification of the standard Global Trade Analysis Project (GTAP). The multi-country, multi-sector general equilibrium model is designed to account for direct and indirect effect of policies such as those related to biofuels. To carry out the impact analysis, we have made a number of key modifications and improvements to the standard GTAP model.

First, the key biofuels feedstock crops are split from the broad categories where they currently reside so that they are represented explicitly in the model database. The standard GTAP database includes 57 sectors of which 20 represent agricultural and processed food sectors. Despite the relatively high level of disaggregation, many of the biofuel feedstock crops are aggregated with non-feedstock crops. For example, corn is grouped with other coarse grains and rapeseed is part of a broader oilseeds category. The feedstock crops are disaggregated using a "splitting" program (SplitCom) developed by Horridge (2005) along with trade data from the United Nations Commodity Trade Statistics Database (UNCOMTRADE) and production/price data from the FAO.

Second, the standard GTAP database does not have a biofuel sector so we created four new industrial sectors for production activities associated with biofuels: sugar ethanol, corn ethanol, soybean biodiesel, and rapeseed biodiesel. The production of these four biofuels depends on their associated feedstock plus capital and labor, which are also inputs into the crops. Consumers in the model are allowed to substitute between biofuels and fossil fuels. Since biofuel production uses crop sector outputs for inputs, an explicit link between agriculture and energy markets is thereby created.

The agriculture and energy market linkages established through the biofuel sectors were accounted for by introducing energy-capital substitution relationships that are described in the GTAP-E (energy) model, which is widely used for the analysis of energy and climate change policy (Burniaux and Truong, 2002). The substitution between biofuels and fossil fuels is incorporated into the structure of GTAP-E using a nested CES function between biofuels (ethanol and biodiesel) and petroleum products in a similar way to the approaches taken by others who have added a biofuel sector to the GTAP-E model (Birur *et al.,* 2008; Hertel and Beckman, 2011). The elasticity of substitution between biofuels and fossil fuels is an important element tying energy prices and food prices.

Third, the standard GTAP model only captures multi-input and single-output production relationships; it does not account for multiple outputs. However, biofuel production generates important by-products, such as dried distillers grains and soluble (DDGS) and biodiesel by-products (BDBPs), that can serve as cost-effective ingredients in livestock rations. These additional outputs can subsequently reduce the demand for feedstock and dampen the price increase associated with a rise in biofuel levels. The production of DDGS and BDBP also generates a significant share of the total revenue stream for the biofuel industry (Taheripour *et al.,* 2010). A constant elasticity of transformation (CET) function is adopted to allow for the optimization of output between biofuels and its byproducts.

The additional extension incorporated into this analysis is to allow total cultivated farmland to change rather than remain fixed. Most computable general equilibrium (CGE) models only take economic land into account and not marginal land (Antoine *et al.*, 2010). In order to allow marginal land to be brought into the production of feedstocks, we have developed a straightforward approach as compared to the method of endogenized expansion of cultivated land adopted by Banse *et al.* (2008) and Bouet *et al.* (2010). The lands used by crops, livestock and forestry sectors in the GTAP database are separated into three types of lands: cultivated crop land, pasture, and managed forest. We allow cultivated land in different regions to expand at a given level as discussed in the previous section. The advantage of the approach is to utilize the information on agricultural land availability estimated by natural scientists and avoid potential discrepancies caused by assuming an inappropriate price elasticity of cultivated land. Significantly more research has been conducted to assess the bio-physical potential for land expansion recognizing geographical constraints, than the price elasticity of land supply. Moreover, the simulation results under this approach can be used to estimate the implied price elasticity of cultivated land.

3.2. Scenario Formulation

Major Scenarios

The model is simulated under three scenarios regarding biofuel production levels. Since the aim of this study is to assess the impacts of global biofuel development on the world food economy under different assumptions on the amount of cultivated land, the “Reference Scenario” assumes that global biofuel production does not expand beyond 2006 levels and that cropping area remains fixed. Ethanol output is set at 15.9 million tons for the US, 14.7 million tons for

Brazil, and 1.5 million tons for the EU, with biodiesel production fixed at 4.9 million tons for the EU and 0.8 million tons for the US (see Table 2).

The "Policy Scenario" assumes a low energy price (US$60 per barrel for oil) and a low elasticity of substitution between biofuels and fossil fuels (3) but forces each region to at least meet its mandated levels of biofuel production for 2020. As shown in Table 2, current government policy requires ethanol production to be 49.1 million tons in the US, 43.2 million tons in Brazil, and 21.0 million tons in the EU in 2020. Biodiesel production is targeted at 46.4 million tons for the EU and 6.9 million tons for the US.

The "Market Scenario" lets relative prices determine biofuel output and assumes a higher energy price (US$120 per barrel for oil) and a higher elasticity of substitution between the biofuels and fossil fuels (10). These conditions are conducive for the biofuel sector and represent an optimistic scenario with the greatest potential impact on crop and food prices.

Sub-Scenarios

In addition to the major scenarios as determined by the role of government mandates, energy price, and the substitution elasticity, four sub-scenario are evaluated based on the potential growth of cultivated land in different countries/regions: no land expansion, low, medium, and high rates of land expansion. No land expansion is a typical assumption in most studies and will result in the greatest price impacts for a given major scenario. In contrast, the highest rate of land expansion allows for the greatest response of feedstock output to a change in crop price and thus will represent the lower boundary on global agricultural prices from biofuels. The annual growth rates of cultivated land in different countries/regions used in the low, medium, and high scenarios were discussed in the previous section and are summarized in Table 1.

4. Results

4.1. Feedstock Markets in Biofuel Producing Countries

Without Land Expansion

Biofuel fuel production grows significantly under current government policy or favorable market conditions according to the results using a traditional GTAP modeling framework in which the potential expansion in cultivated farmland is limited (Huang *et al.,* 2012). If biofuel production is driven only by the mandate (and in the presence of low oil prices and low substitution between biofuels and traditional gasoline—henceforth, the Policy Scenario), the rise in corn ethanol output in the US (for example) is more than 209% of the 2006 level given by the Reference Scenario (see Appendix A, row 1, column 3). If biofuel production is fully market driven (in the presence of high prices and high substitution between biofuels and traditional gasoline—henceforth the Market Scenario), corn ethanol production in the US rises by 724% in 2020 compared to 2006 (see Appendix Table A, row 1, column 4). Conditions conducive for the biofuel sector result in production levels far exceeding the minimum levels required by governments but the mandates do become binding if either energy price drops or the substitutability between fuel types becomes more difficult. Increases in the levels of biodiesel in Europe and sugar ethanol in Brazil are similar under the same alternative scenarios (Appendix Table A).

The significant expansion in biofuel output translates into a large increase in the demand for the inputs used in its production and a subsequent increase in both the supply and price of those feedstocks. According to the results of Huang *et al.* (2012) using a traditional GTAP model, US corn production and price under the Policy Scenario, as an example, increase by 17% and 15% as compared to the Reference Scenario of 2006 (see Appendix Table A). When favorable market forces drive biofuel production in the US, corn production (51%) and corn prices (45%) rise even faster. Similar rises in sugar cane (rapeseed) production and prices in Brazil (Europe) are reported when using the traditional GTAP model in Huang *et al.* (2012) under the different alternative scenarios for energy price and the elasticity of substitution between biofuels and traditional gasoline.

When imposing an absolute zero change in cultivated land in our model as described previously, the rise in the production and prices of biofuel feedstocks under both the Policy and Market Scenarios are similar to those with limited land expansion from the traditional GTAP estimated by Huang *et al.* (2012) (Table 3, column 1). For example, US corn production rises by 16% (instead of 17% in Huang *et al*. (2012)) and corn prices rise by 15% (instead of 16%) when policy mandates are driving the emergence of biofuels. When markets drive biofuel production, corn production prices in the US rise by 49% and 48% respectively (instead of 51% and 45% as reported in Huang *et al.* (2012)). In fact, in our zero growth of cultivated area scenario the rise in the production and prices of all feedstock crops (corn, rapeseeds and sugarcane) in all major biofuel-producing countries/regions (the US; Brazil and Europe) are very close to those reported in Huang *et al.* (2012).

Allowing the Expansion of Cultivated Area

Allowing the amount of cultivated land to expand at the three alternative rates in our model reduces the effect of biofuel production on crop production and prices relative to the zero expansion scenario (Table 3). For example, when policy drives the emergence of biofuels (and we assume a low energy price and a low substitutability), allowing cultivated land to expand from the low to medium to high rates of growth steadily increases the production of corn in the US from 16.6% above the Reference Scenario with no growth to 16.9% (low), 21.7% (medium) and 20.8% (high) percent (Table 3, row 1). Corn prices, in contrast, fall as the amount of cultivated land is allowed to expand. In fact, with a high growth rate in cultivated land and under the Policy Scenario, corn price is 1% lower than the original Reference scenario, which itself was projected to be 14% lower in 2020 as compared to 2006. The nonlinearity in corn output can be explained from the cap on biofuel production under the Policy Scenario; as cultivated land expands, the increase in corn production is initially taken up by biofuel use but it ultimately falls as demand for biofuels is limited by policy and the incentive to produce more falls with the falling prices.

A similar pattern exists in the US for soybeans, which while not a feedstock crop for ethanol, is a close substitute in production for corn (Table 3, rows 3 to 4). Under the Policy Scenario, soybean output rises as cultivated area is allowed to expand though in a nonlinear pattern. As biofuel production emerges, prices, as in the case of corn, fall from the zero growth scenario (13.3% above the no biofuels expansion scenario) to a price rise of 9.8% in the low cultivated area expansion scenario to a 5.6% price fall in the high growth rate in cultivated area scenario. In other words, even when biofuels production is forced to hit the policy-mandated quantity, if cultivated land can expand, the higher corn and soybean price effects in the US shown in the GTAP models (e.g., Huang *et al.,* 2012) are mitigated and reversed for the biofuel feedstock crops and close substitutes.

Similar production and price patterns are evident for rapeseed in Europe and sugarcane in Brazil under the policy mandated-driven biofuels production scenario as cultivated area is allowed to increase from a fixed amount (Table 3, rows 5 to 8). In the case of both rapeseed and sugarcane, crop production rises modestly then falls as cultivated land area expands. Output under the highest growth rate in farmland area is still higher than at the fixed land base scenario. Prices, in contrast, fall monotonically as cultivated area is allowed to expand. Unlike the case of corn in the US, the prices for EU rapeseed and Brazilian sugarcane under the maximum assumed growth rate in land are higher than prices in the Reference Scenario. For example, sugarcane prices rise by 12.8% in Brazil by allowing cultivated land area to expand but this is still significantly less than the projected 52.4% increase if land remained fixed. Since biofuel production levels are restricted from falling below the mandated levels in the Policy Scenario under each of the alternative land growth rates, the impacts of the land expansion are felt primarily through a reduction in feedstock prices.

When market prices drive biofuel production (Market Scenario), feedstock output rises continuously as cultivated area is allowed to expand and not in the non-linear fashion as estimated under the Policy Scenario (Table 3). In the case of corn in the US, output increases from 49.6% above the Reference Scenario with a fixed land base to 65.6% above the Reference Scenario when a high rate of expansion in cultivated area is assumed (row 9). Corn prices fall steadily as cultivated land is allowed to expand (row 10). When there is no growth in cultivated area and when prices drive biofuel production under favorable market conditions, prices expand by 48.4% but the rise in prices is attenuated to only 33.5% from the base with the maximum increase in farmland. This price increase is still double the 15.7% rise if biofuel volumes are at the mandated levels and there is no change in land area. Hence, although the price effects fall when cultivated land is allowed to expand at high growth rates versus when it is assumed that there is no expansion in cultivated area, prices are still above the Reference Scenario when markets are driving biofuels production (unlike the case of when policy mandates are driving biofuel production). The reason, of course, is clear. Under the Market Scenario, more of the feedstock is consumed by the rise in the production in biofuels; enough to keep prices higher despite the expansion in cultivated area.

Similar patterns are found in the cases of rapeseed in Europe and sugarcane in Brazil. Under the Market Scenario, the production of the biofuel feedstock rises as cultivated area is allowed to expand (Table 3, rows 13 and 16). In contrast, prices fall. For example, EU rapeseed prices fall from 35% above the Reference Scenario under no cultivated area expansion to 27.4% above in the case of high rates of cultivated area expansion. Similarly, the 88% increase in Brazilian sugarcane prices with a fixed land base falls to a 62.3% increase over the Reference Scenario in the case of a high rate of growth in cultivated area (row 16). This is still larger than the 52.4% increase projected when biofuel production is set at the mandates and land is fixed. Allowing cultivated area to expand dampens but does not reverse the price effects of the emergence of biofuels if biofuel production is market driven.

In summary, then, while production rises and prices fall when policy mandates drive the emergence of biofuels, the Market Scenario allows energy and crop sectors to adjust to price changes resulting in higher feedstock prices from biofuels even with land expansion. Increasing the amount of cultivated land dampens the price increase for feedstocks, which subsequently increases the profitability of biofuel production. The larger volume spurs more demand for feedstocks and increases output. The equilibrium point (when the expansion of cultivated land is high) results in somewhat lower prices and much higher output levels for the feedstocks than if land area had remained fixed.

4.2. Global Crop Markets

The effects on global output and prices for four crops under the two biofuel scenarios (policy-driven/low-low and market-driven/high-high) and alternative land expansion assumptions are listed in Table 4. The results are consistent with the impacts noted for individual crops for individual biofuel producing regions discussed in the previous section and given in Table 3.

Global prices for the four crops increase by approximately 10% on average if biofuel production is restricted to the mandated levels and cultivated land area remains fixed (Table 4, column 1, rows 1 to 4). This result is similar to that reported in Huang *et al.* (2012). Such predictions have caused concern among some in the international community that the emergence of biofuels in the US, Europe and Brazil would have large price effects on the world food economy (FAO, 2008; Rosegrant *et al.*, 2008).

The other factor to note in assessing the effect of the emergence of biofuels on global production and prices is that global crop prices do not increase as much as prices do in the countries that are the biofuels-producing regions (even under a fixed land scenario). The differential response is due to concentration of biofuel production within the three regions assessed in Table 2 (Brazil, EU and US) that make up approximately one-fifth of global harvested land. The increase in demand due to higher biofuel volumes is concentrated where production occurs. Feedstock prices in the non-biofuel producing regions will be lowered by the transportation costs if those regions wish to export their output. Additional factors, such as tariffs, product heterogeneity, market power, regulations and other transaction costs, will also reduce the price transmission effects so that an increase in prices in the biofuel producing regions does not translate into a similar effect on global prices (Barrett and Li 2002; Keats *et al.* 2010).

The concerns about the high impact of the emergence of biofuels when driven by policy mandates on global price levels might be able to be reconsidered if cultivated area expanded in response to the higher prices. Allowing cultivated area to increase at the high rate of expansion results in average prices falling below the Reference Scenario by approximately the same percentage (Table 4, column 4, rows 1 to 4). It should be remembered that in the Reference Scenario where biofuel production remains at the 2006 level, feedstock prices in 2020 were predicted to fall in real terms; about 8% lower than actual feedstock price levels in 2006. Consequently, when land is allowed to expand, the expansion results in those crop prices falling below long-term averages. In other words, globally, crop prices under the high expansion rate, even with the emergence of biofuel production at the mandated levels, would be lower than in the

Reference Scenario (which essentially reflected the pre-biofuels agricultural economy that was characterized by decades of falling real crop prices).

In fact, our results suggest that even the medium growth rate of cultivated land is sufficient to mitigate the global price increases caused by the growth in biofuel volumes to meet the mandates (Table 4, column 3, rows 1 to 4). If the emergence of biofuels is driven by government requirements and cultivated land expands by the medium growth rates in all countries, world prices of corn are almost the same as the Reference Scenario (-0.42%). Global soybean (-2.9%), rapeseed (-2.4%) and sugar (-7.2%) prices continue to fall slightly compared to the Reference Scenario.

The sharpness of the fall in global prices under the Policy Scenario (Table 4, rows 1 to 4) is in part due to the relatively moderate production effects. According to our results (rows 5 to 8), the output of biofuels feedstock crops increases only marginally as feedstocks are still necessary to meet the mandated growth in biofuel production. The relatively moderate rise in production occurs since global production for biofuels is located in only a handful of countries and their emergence (by assumption) is limited to the mandated levels. Hence, the consequences of allowing cultivated land area to grow in response to mandated biofuel production is felt largely through crop prices, rather than output. As a result of this, medium projected rates of growth in cultivated area are sufficient to eliminate the increases in crop prices spurred by biofuel producing regions meeting their domestic requirements.

The relationship between global prices/production and the emergence of biofuel production changes when biofuel production is driven by the market (Table 4, rows 9 to 16) rather than policy mandates (rows 1 to 8—as discussed above). According to our analysis, the level of biofuel production exceeds the mandated levels if energy prices are high and it is easy to substitute between fossil and renewable fuels (i.e., the assumptions of the Market Scenario).

When cultivated area cannot expand, the market driven levels of biofuel feedstock crops rise from 18.9% for sugarcane to 34.8% for corn in comparison to the Reference Scenario. The increase in crop output from the increase in biofuel production spurred by favorable market conditions increases further if cultivated land is allowed to expand. With the high growth rate in land expansion under the Market Scenario, the global supply of corn increases by 47.3%, rapeseed by 39.1%, and sugarcane by 33.7%.

Because of the increased demand by biofuel producers for feedstocks, global crop prices under the Market Scenario dampen as cultivated land is allowed to increase but it does not fall below the Reference Scenario price level as it did under the Policy Scenario. Our study's model predicts that if land is not allowed to expand, the rise the demand for biofuel feedstock crops increases global corn prices by 36.2%, soybeans by 19.2%, rapeseed by 17.9%, and sugarcane by 32%.

When cultivated area is allowed to expand, our model shows that even in the market-driven scenario of the emergence of biofuels, global prices for these crops still increase but the price increase is mitigated (Table 4, rows 9 to 12, columns 2 to 4). For example, in the case of global corn prices, the rise in price from market-driven biofuels falls by 15 percentage points from 36.2% when cultivated land cannot expand to 21.1% when cultivated land is allowed to expand at the high rate. Similarly, the expansion of cultivated area from zero to a high growth rate under the Market Scenario leads to a drop in the increase in global crop prices; soybeans increase at 6% as opposed to 19.2%, rapeseed price increases at 1.9% rather than 17.9%, and sugarcane price grows at 15% instead of 32%. In other words, there is an increase in production that is spurred by favorable market conditions for the production of biofuel feedstock crops, which leads to an increase in output that increases with more farmland. Biofuel production grows further with the increase in profitability, and the enhanced demand for global feedstocks results in more supply of those crops. The net effect is an increase in prices, albeit the price rise is much lower than without land expansion, and higher production levels.

4.3. Robustness Checks

One concern about our approach of setting fixed growth rates for the expansion in cultivated land on the basis of a literature review is that there is not a single study that contains a consistent set of individual, country-specific land expansion assumptions. Unfortunately, to our knowledge, there are only two research teams/organizations, FAO (2000) and Campbell *et al.* (2008) that have produced assumptions for all major countries as well as the world. In this section, we adopt their assumptions and create two new alterative scenarios. We examine the price/production predictions from the effect of the emergence of biofuels with land expansion using the country-specific land assumptions from the FAO and Campbell teams. The growth rates in cultivated land from these two studies are summarized in Appendix Table B alongside the assumptions that we presented in Table 1 (and discussed above). For brevity, we use these alternative scenarios in conjunction with the Market Scenario.

According to our model, if favorable market conditions increased the production of biofuels and subsequently induced the expansion of cultivated land at the levels assumed in FAO, the output of biofuel feedstock crops would increase beyond the levels predicted in our high land expansion scenario (Appendix Table C, rows 5 to 8). For example, the global output of corn rises 55.3% above the Reference Scenario using FAO land expansion rates, which is 8 percentage points (or more than 15%) higher than our high land expansion result. Under the FAO assumptions, the predicted growth of the output in rapeseed (+10 percentage points) and sugarcane (+20 percentage points) are even higher. As crop output expands under the FAO assumptions regarding cultivated area, the price impacts from the emergence of biofuels on corn falls to a level only 11.7% above the Reference Scenario, which is about half the estimated impacted of our high land expansion scenario (21.1% versus 11.7%). Global prices actually fall below the Reference Scenario for the other crops (rows 2 to 4, columns 4 and 5). In summary, it is clear that even compared to our high cultivated area expansion scenario, the higher rates estimated by the FAO result in offsetting the crop price impacts of biofuel growth.

The global crop price and output predictions under the Market Scenario using Campbell *et al.*'s estimates on growth in land area fall between our medium and high cultivated area expansion results. According to our model, the Campbell scenario produces predictions of the output of corn, soybeans, rapeseed and sugarcane (Appendix Table C, rows 5 to 8, column 6) that are almost exactly in the middle of the output predictions of our medium and high growth rate scenarios (rows 5 to 8, columns 3 and 4). Predicted prices from the Campbell scenario likewise fall between the predicted prices from the medium and high cultivated area expansion scenarios of our model.

Finally, we examine the effect of altering our assumption on the potential growth rate in farmland area outside the major agricultural producing regions for which we obtained specific growth rate estimates. The growth rate of 1.03 used for the Rest-of-the-World (see Table 1) may be too generous as barriers may keep this land from being shifted into cultivation. In order to assess the effect of an alternative, more conservative estimate, the growth rate in cultivated land area was cut in half to 0.51. The results on global agricultural markets are given in Appendix Table D. While production falls and prices rise relative to the results given in Table 4 (and discussed above), the results on the price mitigating effects of land expansion do not fundamentally change.

4.4. Land Supply Elasticities

Another check of the validity of the land expansion rates listed in Table 1 and an assessment of our approach to setting these rates as fixed is to derive implicit price elasticities of cultivated land and compare to those previously estimated. The comparison will allow us to assess the nature of the findings in Banse *et al.* (2008) and Bouet *et al.* (2010), since the value they set on the price elasticities of cultivated land is a key assumption that results in the ability of their GTAP models to predict how biofuels production will lead to expanded cultivated area.

The implicit price elasticities of cultivated land are calculated here as the percentage change in cultivated land area divided by the percentage change in crop price. The change in cultivated area is fixed in our approach. Since there are three rates assumed for each of the major producing regions, there are three price elasticities of cultivated land for each of those regions. The percentage change in crop price is endogenous to the model. Individual crop price impacts from the emergence of biofuels by region under the two major scenarios were discussed above and presented in Tables 3 and 4. A single crop price for a region was calculated as a weighted average of crops in the region with weights determined by the share of a crop in overall crop production. The ratio of the percentage change in cultivated area to percentage change in crop price is an implicit elasticity since it is not ceteris paribus; the emergence of biofuels is causing adjustments in many markets. The implicit elasticities estimated using the approach are listed in Table 5 for the various land expansion rates assumed.

According to our results, there is a range of estimated price elasticities of cultivated land. For example, a percentage increase in crop price is calculated to increase cultivated land in the US by 0.03 percent under the low growth scenario; 0.48 percent in the medium growth rate scenario and 0.69 in the high growth rate scenario.[1] The lower elasticity values are similar to

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[1] To show how the implicit elasticitities are calculated and help the reader with interpreting the results, we use the case of corn for the US under the low land expansion scenario. The land supply price elasticity is the percent change

those estimated by Barr *et al.* (2011) and the most responsive rate similar to the elasticity calibrated from Campbell *et al.* (2008). These higher elasticities are within the range of 0.38 to 0.90 estimated by Barr *et al.* (2011), but, significantly lower than the 15.66 using the FAO (2000) values. Brazil's price elasticities of cultivated land are higher. Brazil land supply rises by 0.27% if land area is allowed to grow by 0.52%, and by 1.62% if land area grows at the high rate of 1.65%. Using land rental rates rather than crop price, Ahmed *et al.* (2008) estimated a short run land supply elasticity of 0.05 and a long run elasticity of 0.28, while Choi (2004) obtained an elasticity of 0.52. Our range of elasticity estimates of 0.01 to 0.41 using land rent as the driver of land supply is similar to those values.

The global land supply elasticities in response to a change in global agriculture price (weighted average of prices of all agricultural commodities across all countries) are more elastic than those for the individual biofuel producing regions and range from a low of 0.12 to a high of 2.92. Hertel (2011) calculated a global supply elasticity of approximately 0.1 on the basis of results from Fisher (2009) but the 3.30 estimate from Campbell *et al.* (2008) is higher than our maximum. Given the potential for land expansion in the non-biofuel producing regions of the world, the global land supply elasticity estimates seem reasonable.

In summary, the domestic and global land supply elasticities calculated using the results of the model are in line with the ranges of previous studies. The consequence is that the assumed

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in cultivated area divided by the percentage change in price, given the emergence of biofuels. The conservative estimate of the annual change in US farmland 0.06% so that the percentage change for the years 2006 to 2020 is 0.84%. The change in price due to the emergence of biofuels can be read in part from Table 3. It is only in part because the price in the elasticity calculation is the change in all agricultural prices while Table 3 only gives price changes for corn and soybeans. The percentage price change due to the emergence of biofuels under the low land expansion scenario is 27.10% (calculated from the model). This price change is the weighted average of price changes for all agricultural commodities in the US. However, this is reasonable since it is between the predicted change in the price of corn (46.6% from Table 3, column 2, row 10, row due to the low expansion of cultivate land) and the predicted change in the price of soybeans (21.6% from Table 3, column 2, row 12). Dividing 0.84 by 27.10 results in 0.03, the implicit price elasticity of cultivated land listed in Table 5 (column 1, row 3).

rates of land expansion based on bio-physical projections from previous studies are also reasonable, which in turn provides confidence in the main outcome of our analysis- allowing cultivated land to expand mitigates significantly (and in some cases completely offsets) the price increases for feedstocks resulting from higher biofuel production due to mandates or favorable market conditions.

5. Conclusions

The impact of biofuels on agricultural markets depends on factors, such as government mandates on renewable energy and relative prices. While the effect of these variables has been examined previously, this study highlights the importance of an additional variable; the ability for the output of feedstocks to increase through an expansion in cultivated area in response to higher demand from biofuel producers. Rather than keep total land area fixed with adjustments in the share of this total allocated to individual crops, we have allowed cultivated land area to expand at several potential growth rates. These rates were based on a review of studies assessing the bio-physical potential for land expansion.

If biofuel production is forced to hit the policy-mandated quantity, the subsequent increased demand for the associated feedstock crops pushes up both the supply and price of those crops. For example, US corn prices rise by approximately 16% and Brazilian sugar prices go up by 50% if ethanol production increases by the nearly 200% required in each country. However, if total farmland is allowed to grow in response to the higher crop prices, the resulting increase in supply pushes the crop prices back down. For example, US corn prices remain essentially unchanged compared to the levels in 2006 while Brazilian sugar prices increase by only 20%. The consequences of allowing cultivated land area to grow in response to mandated biofuel production is felt largely through crop prices, since a given amount of feedstock is necessary to produce the biofuel requirements. As a result, medium projected rates of growth in cultivated area are sufficient to eliminate the price increases for most feedstocks that were spurred by biofuel producing regions meeting their domestic requirements.

Favorable market conditions for biofuel production as characterized by a high energy price and a high degree of substitutability between fossil fuels and biofuels results in biofuel production levels higher than those required by government mandates. The result is significantly higher feedstock supply and prices. For example, US corn price increases by around 50% (as opposed to 16% with mandates) and Brazilian sugar price nearly doubles. Allowing cultivated land area to expand and prices/production to respond dampens the price increase for feedstocks, which subsequently increases the profitability of biofuel production. The larger volume spurs more demand for feedstocks and increases crop output. The net effect is an increase in prices, albeit the price rise is much lower than without land expansion, and higher production levels.

Comparing the percentage changes in crop prices to the assumed changes in cultivated land area allows us to calculate regional land supply elasticities. These implicit land supply elasticities, such as 0.1 globally under low potential for expansion, are similar to those for the few studies that have estimated such elasticities. The implication is that our approach of using fixed rates of land expansion based on bio-physical projections from previous studies is reasonable. This in turn provides confidence with regard to our main result; the price increases for feedstocks resulting from higher biofuel production due to mandates or favorable market conditions are reduced significantly or even offset completely if cultivated land area is allowed to expand within reasonable rates.

If just from the point view of agricultural development and energy supply, our results indicate that biofuel development provides great opportunity across the world to exploit the potential land resources. Meanwhile, the full utilization of land resources will not only lower the pain of high agricultural price brought by biofuel development, but also loosen the constraints of fossil fuel confronted by global economic development.

6. References

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Table 1. Assumed low, medium, and high regional growth rates in cultivated land

Region	Share of Global Harvested Area (%)	Annual Growth Rate in Cultivated Land		
		Low	Medium	High
Brazil	4	0.52	0.88	1.65
China	9	0.00	0.06	0.13
EU	13	0.26	0.72	1.20
Russia	8	0.00	0.38	0.91
United States	5	0.06	0.65	0.75
Rest-of-the-World	61	0.10	0.45	1.03

Source: Rates are based on a review of previous studies discussed in text.

Point estimates from the FAO (2000) (Campbell *et al.* (2008)) are 3.78 (0.89) for Brazil, 0.65 (0.35) for China, 0.72 (0.99) for the EU, 0.91 (0.38) for Russia, 0.65 (0.75) for the US, and 2.66 (0.78) for the Rest-of-the-World.

Table 2: Biofuel production in the base year (2006) and targeted production in 2020 in major countries/regions under Policy Scenario.

	2006 (million tons)	**2020**		
		Reference Scenario (million tons)	**Policy Scenario** (million tons)	**Growth Rate (%)**
Ethanol				
US	15.9	15.9	49.1	209
EU	1.5	1.5	21.0	1300
Brazil	14.7	14.7	43.2	194
Biodiesel				
US	0.8	0.8	6.9	763
EU	4.9	4.9	46.4	847

Note: Data for production in 2006 are actual numbers and serve as the Reference Scenario for 2020. Biofuel output in 2020 under the Policy Scenario representes the mandated levels for the associated country/region.

Table 3. Percentage change in feedstock output and price for major biofuel producing regions under policy scenario with different growth rates of cultivated land[a]

				Growth Rate in Cultivated Land			
Scenario	**Country**	**Feedstock**	**Variable**	**Zero**	**Low**	**Medium**	**High**
Policy[b]	US	Corn	Output	16.6	16.9	21.7	20.8
			Price	15.7	13.3	4.0	-1.0
	US	Soybeans	Output	8.2	6.9	11.1	9.2
			Price	13.3	9.8	0.1	-5.6
	EU	Rapeseed	Output	80.8	83.4	84.8	83.9
			Price	34.0	29.3	19.8	12.0
	Brazil	Sugarcane	Output	94.3	95.3	95.4	95.3
			Price	52.4	38.8	26.5	12.8
Market[c]	US	Corn	Output	49.6	51.0	63.3	65.6
			Price	48.4	46.6	38.1	33.5
	US	Soybeans	Output	3.5	3.6	11.4	12.8
			Price	23.6	21.6	15.5	12.1
	EU	Rapeseed	Output	79.6	88	104.6	122.3
			Price	35	33.5	30.4	27.4
	Brazil	Sugarcane	Output	137.5	155.7	173.7	205.2
			Price	88.0	80.5	73.5	62.3

[a] – Percentage change from 2006 to 2020 compared to fixed 2006 biofuel production levels

[b] – Assume a low energy price and a low elasticity of substitution between fuels but forces each region to at least meet its mandated levels of biofuel production for 2020

[c] – Assume a high energy price and a high elasticity of substitution between biofuels and fossil fuels

Table 4. Percentage change in price and output of major biofuel feedstock crops with policy and market scenarios under alternative growth rates in cultivated land[a]

			Growth Rate in Cultivated Land			
Scenario	**Variable**	**Crop**	**Zero**	**Low**	**Medium**	**High**
Policy[b]	Price	Corn	9.7	7.3	-0.4	-6.5
		Soybeans	9.7	5.8	-2.9	-9.7
		Rapeseed	11.7	7.8	-2.4	-13.1
		Sugar	5.8	2.0	-7.2	-17.6
	Output	Corn	9.3	9.9	11.7	13.5
		Soybeans	5.1	5.5	6.5	7.5
		Rapeseed	21.6	22.2	24.3	27.0
		Sugar	6.9	7.2	8.4	9.9
Market[c]	Price	Corn	36.2	34.2	27.1	21.1
		Soybeans	19.2	16.7	10.9	6.0
		Rapeseed	17.9	15.7	9.3	1.9
		Sugar	32.0	29.6	23.0	15.0
	Output	Corn	34.8	36.3	42.4	47.3
		Soybeans	6.1	7.4	11.5	15.3
		Rapeseed	21.3	23.8	30.5	39.1
		Sugar	18.9	21.1	25.9	33.7

[a] – Percentage change from 2006 to 2020 compared to fixed 2006 biofuel production levels

[b] – Assume a low energy price and a low elasticity of substitution between fuels but forces each region to at least meet its mandated levels of biofuel production for 2020

[c] – Assume a high energy price and a high elasticity of substitution between biofuels and fossil fuels

Table 5. Land elasticity with respect to crop price under assumed low, medium, and high regional growth rates in cultivated land

	Annual Growth Rate in Cultivated Land		
Region	**Low**	**Medium**	**High**
Brazil	0.27	0.59	1.62
EU	0.25	0.87	1.87
United States	0.03	0.48	0.69
United States (rent)	0.01	0.23	0.41
World	0.12	0.93	2.92

Appendix A: Percentage change in biofuel production and associated feedstock markets from 2006 to 2020 under Policy Scenario and Market Scenario relative to Reference Scenario.

Region	**Variable**	**Policy Scenario** [a]	**Market Scenario** [b]
US	Ethanol	209	724
	Biodiesel	768	814
	Corn		
	Output	17	51.2
	Price	15	45.2
EU	Biodiesel	847	978
	Rapeseed		
	Output	33	38
	Price	82	95
Brazil	Ethanol	194	290
	Sugar		
	Output	51	84
	Price	94	147

Source: Huang et al. (2012)

[a] – Assumes a low energy price and a low elasticity of substitution between fuels but forces each region to at least meet its mandated levels of biofuel production for 2020 (see Table1)

[b] – Assumes a high energy price and a high elasticity of substitution between biofuels and fossil fuels with no restriction on biofuel output

Appendix Table B: Cultivated land expansion per year by different regions (%)

	Share of global harvested land (%)	**Lower**	**Medium**	**Higher**	**FAO (2000)**	**Campbell (2008)**
Brazil	4	0.52	0.88	1.65	3.78	0.89
China	9	0.00	0.06	0.13	0.65	0.35
EU	13	0.26	0.72	1.20	0.72	0.99
Russia	8	0.00	0.38	0.91	0.91	0.38
United States	5	0.06	0.65	0.75	0.65	0.75
World in average		0.12	0.47	0.97	2.03	0.74
Rest of World[a]	61	0.10	0.45	1.03	2.66	0.78
Rest of World[b]	61	0.05	0.23	0.51		

[a] the annual growth of cultivated land on Rest of World is induced based on the estimated growth of Brazil, China, EU, Russia, United states and world in average.

[b] It takes the half value of growth rate to carried out the sensitive analysis and the corresponding results are put in appendix table 2a and 2b.

Appendix Table C. Percentage Change in Price and Output of Major Biofuel Feedstock Crops with Market Scenario [a] under Alternative Growth Rates in Cultivated Land [b]

Variable	**Crop**	**Growth Rate in Cultivated Land**					
		Zero	**Low**	**Medium**	**High**	**FAO (2000)**	**Campbell *et al.* (2008)**
Price	Corn	36.2	34.2	27.1	21.1	**11.7**	**23.6**
	Soybeans	19.2	16.7	10.9	6.0	**-2.0**	**8.6**
	Rapeseed	17.9	15.7	9.3	1.9	**-9.4**	**4.9**
	Sugar	32.0	29.6	23.0	15.0	**-0.6**	**18.5**
Output	Corn	34.8	36.3	42.4	47.3	**55.3**	**45.5**
	Soybeans	6.1	7.4	11.5	15.3	**22.3**	**13.4**
	Rapeseed	21.3	23.8	30.5	39.1	**49.7**	**35.2**
	Sugar	18.9	21.1	25.9	33.7	**53.8**	**29.4**

[a] – Assumes a high energy price and a high elasticity of substitution between biofuels and fossil fuels but no mandates

[b] – Percentage change from 2006 to 2020 compared to fixed 2006 biofuel production levels

Appendix Table D. Effect of lower land expansion rates in rest of the world on percentage change in price and output of major biofuel feedstock crops with policy and market scenarios under alternative growth rates in cultivated land[a]

			Growth Rate in Cultivated Land			
Scenario	**Variable**	**Crop**	**Zero**	**Low**	**Medium**	**High**
Policy[b]	Price	Corn	9.7	7.8	1.4	-3.1
		Soybeans	9.7	6.3	-1.0	-6.3
		Rapeseed	11.7	8.8	1.6	-5.7
		Sugar	5.8	3.1	-3.2	-10.2
	Output	Corn	9.3	9.7	11.2	12.4
		Soybeans	5.1	5.5	6.2	6.9
		Rapeseed	21.6	21.9	23.2	24.8
		Sugar	6.9	7.0	7.7	8.5
Market[c]	Price	Corn	36.2	34.6	28.7	24.4
		Soybeans	19.2	17.0	12.1	8.4
		Rapeseed	17.9	16.5	12.1	7.3
		Sugar	32.0	30.3	25.7	20.4
	Output	Corn	34.8	36.0	41.2	44.8
		Soybeans	6.1	7.2	11.7	13.4
		Rapeseed	21.3	23.4	28.5	34.6
		Sugar	18.9	20.6	23.7	28.5

[a] –Percentage change from 2006 to 2020 compared to fixed 2006 biofuel production levels

[b] – Assume a low energy price and a low elasticity of substitution between fuels but forces each region to at least meet its mandated levels of biofuel production for 2020

[c] – Assume a high energy price and a high elasticity of substitution between biofuels and fossil fuels