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Biofuels and the poor: Global impact pathways of biofuels on agricultural markets

Jikun Huang[a], Jun Yang[a], Siwa Msangi[b], Scott Rozelle[c,d,*], Alfons Weersink[e]

[a] Center for Chinese Agricultural Policy, Chinese Academy of Sciences, China
[b] International Food Policy Research Institute, United States
[c] Stanford University, United States
[d] University of Waikato, New Zealand
[e] University of Guelph, Canada

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ABSTRACT

This study seeks to assess the future impacts of biofuel production on regional agricultural and related sectors over the next decade with a specific focus on the vulnerable regions of developing nations. Using a modification of the GTAP modeling platform to account for the global interactions of regional biofuel and food markets, the analysis shows that biofuel production levels depend on the assumption about the future price of energy and the nature of the substitutability between biofuels and petroleum-based transport fuels. Low energy prices reduce the demand for biofuels and thus require greater government support to meet the desired production targets. At the other extreme, when prices are high and there is scope for substituting biofuels for petroleum-based fuels, the volume of biofuels produced will exceed the mandates. Even when biofuels are being mainly produced in developed countries, our results indicate that there are impact pathways that extend far beyond the borders of the US, Brazil and the EU. Prices of feedstock and non-feedstock commodities rise in developing countries. There is also a rise in value added from the agricultural sector—a gain that is enjoyed by the owners of land and labor, including unskilled. Hence, to the extent that agriculture is a key sector in getting growth started and addressing poverty needs, the emergence of biofuels can (in this way at least) be a positive force.

Introduction

The food versus fuel debate continues to swirl due partially to the lack of understanding on the distributional consequences across sectors and regions from the expansion in biofuels. This expansion occurred rapidly in the last decade with ethanol levels increasing approximately five times over this period to 66.6 million tons and biodiesel levels growing at an even greater rate to 13.5 million tons by 2009 (see Table 1). The growth has been driven by a combination of market developments, such as high fossil fuel prices, and policy levers, such as production mandates. The motivations for policy intervention to spur biofuel production range from enhancement of domestic energy security, to reduction of CO_2 emissions, and to increasing value-added from the agricultural sector (Linden et al., 2006; Charlesa et al., 2007; FAO, 2008a; OECD, 2008; Tyner, 2008; Westhoff, 2010).

Agricultural commodity prices have risen significantly since 2006 and the increasing demand by the biofuel sector for feedstocks has contributed to that increase (Paarlberg, 2010; Westhoff, 2010). The US ethanol industry, as an example, will require almost 5 billion bushels of corn in 2011, which is approximately 40% of the previous year's crop (USDA, 2011). The reduction in supply for feedstock crops from the US and other major biofuel producers decreases the supply on world markets and pushes up global prices. These changes in agricultural commodity prices, regardless of the reason for the change, have triggered concerns from governments and development agencies about implications for food security and poverty around the world (FAO, 2008b; IFPRI, 2008; Rosegrant et al., 2008; Tangermann, 2008; Ewing and Msangi, 2009).

The effects of biofuels and the higher prices that their emergence may cause, however, may not be all bad for developing countries and the poverty that they face. In the same way that Green Revolution technology (e.g., Otsuka et al., 1994; Pingali and Traxler, 2002) and international trade agreements (e.g., Martin and Anderson, 2006) can have differential effects on the populations of developing countries, helping some, while hurting others, biofuels also may have similar impacts. In theory, consumers stand to lose the most, especially poor consumers with little ways to offset higher food prices. Many small farmers that produce some, but, buy more than they sell, would also be hurt while farmers who are net-sellers, especially if they own land, benefit from the higher crop prices. The higher prices may also lead to higher demand for labor. These hypothesized effects appear to have been validated at the aggregate level at least by the occurrence of riots spurred partially by the jump in commod-

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* Corresponding author at: Freeman Spogli Institute for International Studies, Stanford University, Encina Hall East, E407 Stanford, CA 94305-6055, United States.
E-mail address: rozelle@stanford.edu (S. Rozelle).

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Table 1
Biofuel production in major countries, 1996–2009 (million ton). *Sources*: World data are from US Renewable Fuels Association (2010), Earth Policy Institute (2010), BIODIESEL 2020 (2008), and F.O. Licht (2009); USA's data are from US Renewable Fuels Association (2010) and BIODIESEL 2020 (2008); EU's data are from European Biodiesel Board (2010); Brazil data are from Renewable Fuels Associations (2010); China's data are from Qiu and Huang (2008) and Renewable Fuels Associations (2010)

	1996	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Ethanol											
World	16.2	15	16.2	18.8	23.7	26.5	35.3	39.8	44.2	59.1	66.6
USA	3.6	5.3	5.8	7.0	9.2	11.1	12.8	15.9	21.3	29.5	34.7
EU27	n/a	0.2	0.2	0.4	0.4	0.5	0.8	1.5	1.6	2.1	2.9
Brazil	12.5	9.2	10	10.9	12.8	13.1	13.9	14.7	16.5	21.3	21.6
China	–	–	–	0	0.1	0.2	0.8	1.3	1.4	1.4	1.6
Biodiesel											
World	0.5	0.8	1	1.3	1.6	2	3.4	6.6	9	13.3	13.5
USA	n/a	n/a	n/a	n/a	n/a	0.1	0.2	0.8	2.1	2.9	1.8
EU27	n/a	n/a	0.9	1.1	1.4	1.9	3.2	4.9	5.7	7.8	9.0

n/a: data is not available. –: nearly zero.

ity prices in food importing countries with a high proportion of urban poor.

Despite these concerns and complexities, there are few systematic efforts to track the pathways of biofuel production trends from the major producing countries to the developing world through models that account for the forces of global supply, demand and trade (as well as attempt to identify what factors will amplify global price effects and what factors will attenuate them). There are a number of high quality modeling efforts that are concerned with biofuels (e.g., Banse et al., 2008; Birur et al., 2008; Hayes et al., 2009; Fonseca et al., 2010; Hertel et al., 2010; Taheripour et al., 2010; FAPRI, 2011). However, due to shortcomings such as a regional focus (i.e. US or EU) or a partial rather than general equilibrium focus, or no explicit accounting for a biofuels supply and demand sector, these models do not sufficiently capture the complexities of global biofuel and food markets.

This study seeks to assess the future impacts of biofuel production on regional agricultural and related sectors over the next decade with a specific focus on the vulnerable regions of developing nations. Using a modeling platform created to account for the global interactions of regional biofuel and food markets, the analysis aims to provide answers for the following questions. First, how will the rise in demand for biofuels affect food prices, production and trade at a global level? Second, how will the development of global biofuels affect prices, production, trade and the unskilled wage in the developing countries? Answers to the above questions will be used to discuss policy recommendations regarding the development of economically and socially sound biofuels program in the world.

Our paper, although ambitious, has several limitations. In this paper we only simulate the impact of the emergence of biofuels in the three main producing regions—the US, the EU and Brazil. Other countries have plans to develop biofuels, but, since in comparison to the major producers their volumes of production will be relatively small, we ignore the emergence of biofuels in all but the "big three." In addition, we do not allow for cellulosic or other second generation biofuels. The uncertainty of the production of biofuels from these technologies is sufficiently large that we believe it will not materially affect the world's biofuels equation in the next decade. Finally, in this paper while we allow for the expansion of biofuels feedstock crops onto cultivated land that is currently producing other crops, we do not explicitly allow for its expansion. This means, necessarily, that our price effects will be on the high side, since all of the additional pressure from the increased demand for biofuel feedstock crops will have to be met by increased yields.

The next section of the paper provides an overview of biofuel growth in the three major production regions and future targets. The third section discusses the methodology developed for assessing the impact of biofuel development at the country-level along with defining the base reference scenario and several alternatives based on policy options, energy prices, and the ability to substitute between biofuels and fossil fuels. The following section presents the results of our modeling efforts including the impacts of alternative biofuel development scenarios on world food production and price, national production, and international trade. The last section concludes the study with a brief discussion of the policy implications of the development of biofuels on food security and poverty and discusses issues for further study.

Biofuel production; past and future developments

The biofuel sector had been in commercial existence for a generation before its rapid rise over the last decade. The United States and Brazil started their biofuel development programs in the middle of the 1970s in response to the OPEC-driven increase in fuel prices and the subsequent concern about domestic energy security. In 1975, global ethanol production was only 420 thousand tons and biodiesel was not available, as commercial manufacturing did not begin until the early 1990s. By 2000, the annual production of ethanol and biodiesel had reached a total of 15 and 0.8 million tons, respectively (Table 1). Biofuel production has increased steadily since the beginning of the decade and reached 80.1 million tons in 2009 with production concentrated in three main regions: the United States, Brazil and the European Union. The rapid growth has been spurred partially by the profitability for production, which is tied to the relative cost of oil and feedstock prices, but largely by government policies (Steenblik, 2007; FAO, 2008a; OECD, 2008).

The United States, which now produces more than half of the world's ethanol, began its promotion of ethanol production with the Energy Tax Act of 1978. Biofuel producers were granted full exemption of the federal gasoline excise tax when they produced gasoline blended with 10% ethanol resulting in an effective subsidy of US 40 cents per gallon of ethanol (UN, 2006). The subsidy was extended in 1980 to other blend levels including E85 (an ethanol–gasoline blend which is produced with 85% ethanol). In 2007, the United States provided a US 51 cent per gallon tax refund for blenders of ethanol and a tax credit to biodiesel producers (Yacobucci, 2010). In addition to subsidies, the emerging US biofuel sector was protected through an import tariff on ethanol from outside NAFTA (UN, 2006; Tyner, 2008).

The growth in US ethanol production was further spurred by the 1990 Clean Air Act that required a minimum percentage of oxygen in gasoline. Initially, this requirement was met through the addition to gasoline of methyl tertiary butyl ether (MTBE). Contamination problems with this highly toxic fuel additive arose and MTBE was gradually banned across the US and replaced by ethanol. The increase in demand for ethanol put a premium on its price. Combined with higher gasoline prices, existing subsidy levels and low feedstock prices, the profitability in ethanol production led to the rapid construction of corn-based ethanol plants in the US during the mid-2000s.

The "Energy Independence and Security Act" passed in 2007 shifted the US policy emphasis towards mandates (Tyner, 2010). The Renewable Fuel Stands (RFSs) has set ambitious targets for US's biofuel production of 15.2 billion gallons in 2012, 30 billion gallons in 2020 and 36 billion gallons in 2022. These volumetric mandates are partitioned based on source (conventional, cellulosic, and other) with the target for corn-based ethanol set at 15 billion gallons. Although subsidies and research funding exist for the development of second-generation biofuels, the RFS is not technology neutral and is biased toward corn ethanol (Tyner, 2010).

Brazil is the second largest producer of ethanol in the world with approximately one-third of global production in 2009 (Table 1). It was the largest producer until 2006 due partially to the greater energy efficiency of ethanol produced with sugar cane as opposed to corn. Its growth was stimulated largely by the government inducing consumers to choose biofuels as a fuel substitute. In the 1970s, the government of Brazil established a National Fuel Ethanol Program to increase the share of domestically produced biofuel used in the transport sector. This included promoting the availability of ethanol at most gasoline stations and mandating the manufacture of flexible fuel cars capable of using pure gasoline, E25 or pure bio-ethanol. The result is that ethanol comprised 20% of Brazil's total transport-fuel demand in 2007 (Nass et al., 2007). Although ethanol prices were liberalized in the 1990s, the government provides other measures of support for the sector including a mandatory official blending ratio of ethanol to gasoline, a lower excise tax of ethanol than gasoline, and an ad-valorem duty on imported ethanol (Pousa et al., 2007). The goal of the Brazilian government is to have ethanol production reach 9.5 billion gallons by 2012 (31 million tons) and 11.5 billion gallons by 2016 (37.7 million tons) (Timilsina and Shrestha, 2010).

The other major producing region for biofuels is Europe with the bulk of its output in the form of biodiesel produced from rapeseed. The EU accounts for three-quarters of the world's biodiesel with 5.7 million tons generated in 2007 and this level nearly doubled to 9 million tons in 2009. Within the EU, Germany is the leading producer of biodiesel with two-thirds of the world market share while France and Italy are the other major producing countries (European Biodiesel Board, 2011).

EU policy makers left the decision to support the production and use of biofuels to Member States rather than be mandated centrally but its 2003 Biofuel Directive suggested a target of 5.75% of total petrol and diesel used for transport be provided by biofuels. The share is to increase to 6.25% for 2015. In the mid-2000s, the EU began to direct its Member States to set up the necessary legislation to ensure compliance. Tax concessions for the promotion of biofuel use were also allowed and part of the reason for the significant growth in German production is the total tax exemption provided to biofuels (Steenblik, 2007). In addition, tariffs are imposed on imported biodiesel, area payments are provided for crops used in energy production, and minimum blending rates are legislated by some EU countries (Sorda et al., 2010). The latest EU directive in 2009 increased the mandatory targets for 2010 so that 20% of energy is from renewable sources with 10% of transport fuel consumption from biofuels. These mandates are based on energy units so the choice of technology and feedstock is free for the private sector to choose as opposed to the volumetric mandates in the US for first (starch-based) and second (cellulosic-based) biofuels (Tyner, 2010).

Methodology and scenarios

In this section, we present the methodology and scenarios that are used in this study to assess the implications of global and regional biofuel growth for agriculture and the rest of the economy—including impacts inside and outside countries that have major biofuel efforts.

Methodology

To assess the impacts of biofuel development on agriculture and the rest of the economy, we have built an analytical framework based on the Global Trade Analysis Project (GTAP) platform.[1] It is a general equilibrium model and as such is better suited to account for the direct and indirect feedback effects of biofuel policies in a global context (Kretschner and Peterson, 2010). The GTAP platform allows us to model the linkages among biofuel production, energy and global agricultural markets. GTAP also allows us to track the impacts from world markets to specific countries or regions, including developing countries. To carry out the impact analysis, we have made a number of key modifications and improvements to the standard GTAP model.

Introducing biofuels into the GTAP database

We use version 7 of the GTAP database in this study. 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 biofuels feedstock crops are aggregated with non-feedstock crops. For example, corn is aggregated with other coarse grains and rapeseed is part of a broader oilseeds category. The standard GTAP database also does not have an industrial sector for the production of either ethanol or biodiesel.

Our model modifies the standard database in three ways. First, we spilt the key biofuels feedstock crops from the broad categories where they currently reside so that they are represented explicitly in the model database. For example, we disaggregate corn from coarse grains along with soybeans and rapeseed from oilseeds using a "splitting" program (SplitCom) developed by Horridge (2005). In making the split, we used trade data from the United Nations Commodity Trade Statistics Database (UNCOMTRADE) and production and price data from the FAO. Second, we created four new industrial sectors for production activities associated with biofuels: sugar ethanol, corn ethanol, soybean biodiesel and rapeseed biodiesel. Third, our model was adjusted to consider the effects of the by-products from biofuel production. The price impacts on feedstocks from ethanol can be reduced since livestock producers can substitute by-products for feed inputs, such as grains and oilseed meals (Taheripour et al., 2010).

Linkage between agriculture and energy markets through biofuel sectors

One of the key parts of the modification to the basic GTAP framework is the comprehensive representation of biofuel production. The manufacturing of the four biofuels depends on the main feedstocks plus capital and labor, which are inputs also used in crop production. Consumers in the model are allowed to substitute between biofuels and fossil fuels, and since biofuel production uses

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[1] GTAP is a well-known, multi-country, multi-sector computable general equilibrium model (Hertel, 1997). The model is based on the neo-classical assumptions that producers minimize their production costs and consumers maximize their utilities subject to a set of certain common constraints. Supplies and demands of all commodities clear by adjusting prices in perfectly competitive markets. On the production side, firms combine intermediate inputs and primary factors (e.g., land, labor, and capital) to produce commodities with constant-return-to-scale technology. Intermediate inputs are composites of domestic and foreign components with the foreign component differentiated by region of origin (the Armington assumption).

crop sector outputs for inputs, an explicit link between agricultural and energy markets is thereby created.

The linkages were made as realistic as possible with several modifications to the original GTAP framework. For example, we extended the standard GTAP model by introducing the 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 fuel 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 (e.g., Birur et al., 2008; Hertel et al., 2010). The elasticity of substitution between fossil fuel and biofuels is crucial in our research since it will be an important element that ties the price of energy to the price of food. Interestingly, in past research on biofuels in the US, EU and Brazil, the values of the elasticity of substitution are almost all identical to those used by Hertel et al. (2010), who set their substitution parameters for the US, EU and Brazil equal to 3.0, 2.75 and 1.0 respectively. Our assumptions (and the impact of using different substitution parameters on the predictions of future outcomes) are discussed below.

Allocation of agricultural land

An increase in biofuel production will increase the demand for feedstock crops but the feasibility of changing land use from one crop to another may differ significantly by type of land. The standard version of GTAP allocates land using a constant elasticity of transformation (CET) structure. While this assumption means that different types of land use are imperfect substitutes for each other (a plausible assumption), all uses have the same degree of substitutability. This land-use structure makes it difficult to capture differences in substitutability that will likely emerge when we see a rapid expansion of feedstock crops.

To account for the substitutability problem of crops across land types, different land-use modules are incorporated into the standard GTAP model. Birur et al. (2008) use different agro-ecological zones (AEZs) to distinguish productive activities within the agricultural sector following the methodology outlined in Lee et al. (2005). We do not follow this approach because of the lack of information on the nature of the substitution parameters between land currently under cultivation and land not being cultivated with different AEZ scores.

An alternative way to address the issue is to follow the land-usage structure of the OECD PEM model (OECD, 2003). Using this structure, Banse et al. (2008) developed a stylized demand structure for land by producers of different crops that allows for different degrees of substitutability among cultivated land for different crops. We use an approach similar to that used in Banse et al. (2008) to capture the different degrees of substitutability between agricultural land uses. Unlike the Banse et al. (2008) study, however, we do not allow for an endogenous adjustment of total land supply as we do not have either necessary information on availability of new land for agricultural production or the nature of the response of land supply to shifts in land and agricultural prices.

Multi-output production relationship in biofuel industries

The standard GTAP model only captures multi-input and single-output production relationships and does not account for by-products of the single output. However, biofuel production generates a large amount of 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 (Skinner et al., 2012). DDGS and BDBP generate a nontrivial share of the total revenue stream of the biofuel industry. About 15% of a corn-based dry milling ethanol plant's revenues are derived from DDGS sales while the share for a typical rapeseed-based (soybean-based) biodiesel producer is about 23% (53%) (Taheripour et al., 2010).

Because of the importance of byproducts, it is essential to introduce a multi-output structure in the analysis on the impacts of biofuels to account for the full value of production. A constant elasticity of transform (CET) function is adopted to allow for the optimization of output between biofuel and its byproducts. Because the byproducts are produced at an almost fixed share of their corresponding biofuel products, the elasticities embedded in the CET function are given small values. Similar to Taheripour et al. (2010), we use -0.005 in both the bio-ethanol and biodiesel industrial sectors. If the value were assumed zero, ethanol and its byproduct (DDG) would be produced in fixed proportions regardless of their relative prices.

Substitution between biofuel byproducts and feed inputs in livestock industries

As discussed above, as biofuel production increases, the supply of byproducts also increases. For example, the DDGs produced in the US have grown from 2.7 million tons in 2000 to 23 million tons in 2008 and the use of DDGs as a protein source has grown correspondingly. The substitution between the biofuel by-products and other feed is carefully considered in our model. In contrast to the standard GTAP model, two-levels of CES functions are used to reflect such substitution effects in the demand for feed by livestock sectors. In the first level, substitution among various feedstuffs in livestock production is allowed with an elasticity value set at by 0.9, based on the research of Keeney and Hertel (2005). In the standard GTAP model, a Leontief production function is assumed and there is no substitution among intermediate inputs such as feed inputs. In the second level, the substitution among DDGs and corn and between BDBP and processed feed are incorporated into our model.[2] Although the high correlations among prices provide evidence that biofuel by-products and feedstuff are highly substitutable, there are no direct empirical estimations of these elasticities. In this research, we adopt the same values as used by Taheripour et al. (2010) of 30 for the elasticity of substitution between maize and DDGS, and 125 for the elasticity of substitution between BDBP and processed feed.

Formulation of scenarios

Major scenarios

We develop three scenarios over the period of 2006–2020 in this study in order to highlight the way in which the emergence of biofuels will affect agricultural producers and consumers: one reference and two alternatives. Since the main aim of this study is to assess the impacts of global biofuel development on the world food economy, we assume for the "reference scenario" that global biofuels production does not expand beyond the production levels of 2006; it still exists but it is not allowed to grow.

The projections for the "reference scenario", along with the other two scenarios described below, are solved using a recursive dynamic method. Since the benchmark of GTAP database (version 7) is 2004, four periods (2004–2006, 2006–2010, 2011–2015 and 2016–2020) were considered and the model solved for each period. During each step, exogenous shocks from macroeconomic parameters and technological improvements in crop productivity are introduced. The annual growth rates assumed in the simulations for these exogenous parameters are listed by region in Appendix A. The regional growth rates for the macroeconomic variables (GDP, population, labor supply, and capital) for 2004–2010 were

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[2] Since processed feed is included in the processed food sector in GTAP, the substitutability between BDBP and processed feed is captured by the substitution between BDBP and processed food.

based on historical records obtained mainly from the World Development Index (WDI) and the World Labor Organization (WLO) while future projections for 2011–2020 were based on other forecasts (Tongerne and Huang, 2004; Walmsley, 2006; Yang et al., 2011). Annual increases in the yield of the major crops used as feedstocks for biofuels are based on the International Food Policy Research Institute's (IFPRIs) IMPACT model.

The first of the alternative scenarios is called the "Market Scenario." This scenario is intended to simulate the nature of the emergence of the biofuel sector driven by market forces only. We do not include the effect of any of the policy interventions beyond those in effect prior to 2006. The outcomes from the Market Scenario differ from the reference scenario only if biofuel producers decide to expand biofuel production beyond the 2006 level of production based solely on relative prices; the expansion occurs because biofuels can compete with fossil fuels without subsidies or mandated targets.

The other alternative scenario is called the "Policy Intervention Scenario" and is intended to illustrate the effect of the increasing level of government support expected to affect biofuel production in the coming decade. To implement this scenario, we force the model to produce at least enough biofuels to meet the country-specific targets for biofuel production discussed in the previous section. The actual target levels used in the modeling effort for the Policy Scenario by the different countries are shown in Table 2 and the other policy instruments given in Appendix B. It is important to note that in the Policy Scenario, the target levels in Table 2 are the minimum level of production. The biofuel sector may produce a higher level of output depending on the profitability of production as determined by relative output and input prices.

To meet the minimum target levels under the Policy Intervention Scenario, the price subsidy to the biofuel industry is endogenously determined. When the market solution for biofuels production is less than the volume of biofuels production mandated by policy, the model provides a subsidy to the producer. This price subsidy is raised increasingly higher until the targeted volume of the production of biofuels is exactly fulfilled. By construction, if the market-guided solution is greater than the policy solution, the price subsidy is zero as it is not necessary to meet target level of production.

Sub-scenarios

In addition to these two major scenarios (the Market Scenario and the Policy Scenario), we have four sub-scenarios that are built around what we believe are two key assumptions: energy price and the elasticity of substitution between fossil fuels and biofuels.

Energy price directly affects the profitability of biofuel production and consequently its potential growth and the level of government support. Two energy price levels are modeled within the Reference, Market and Policy Scenarios over the study's forecast period, 2006–2020.[3] The Low Energy Price sub-scenario assumes the price of oil remains at the 2006 level of $60 per barrel, which is slightly higher than the predicted petroleum price in 2020 from the International Energy Agency (IEA) (IEA, 2008). The High Energy Price sub-scenario assumes that the price of oil is $120 per barrel, a level that has been reached and exceeded during several periods within the last 3 years. Similar values have been projected by other studies. For example, forecasts by the USDA, the Energy Information Administration (EIA) and the IEA in their most recent outlook assumed a crude oil price of approximately $110 per barrel in 2020 for their base projections (EIA, 2010; IEA, 2010; USDA, 2011). Much higher prices have also been forecast for 2020 including a projection of $169 per barrel by EIA under high global economic growth (EIA, 2010) and $185 per barrel by Barclays Capital (Smith, 2011).

Table 2
Biofuel production in the base year (2006) and targeted production in 2020 in major countries/regions in reference and policy intervention scenarios.

	2006 (million tons)	2020		
		reference scenario (million tons)	Policy Intervention Scenario (million tons)	Growth Rate (%)
Ethanol				
USA	15.9	15.9	49.1	209
EU	1.5	1.5	21.0	1300
Brazil	14.7	14.7	43.2	194
Biodiesel				
USA	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 data in 2020 in the last column are the governments' targeted levels based on the discussions in 'Biofuel production; past and future developments' of this paper.

The elasticity of substitution between biofuel and petroleum products determines the ease at which one fuel can be substituted for another and thus the influence of energy prices on the profitability of biofuel production. As with the energy price sub-scenario, two values are assumed: a low value of 3 and a high value of 10. As the elasticity of substitution rises, we are assuming that there is increasing substitutability between gasoline and biofuel.

The Low Substitution sub-scenario estimate is based on a historical simulation of ethanol and gasoline consumption in the US, EU and Brazil between 2001 and 2006 by Birur et al. (2008). In their analysis, the elasticities of substitution were estimated to be between 1.0 and 3.0. The High Substitution sub-scenario estimate of 10 assumes that the substitutability between biofuel-based fuels and conventional petroleum-based fuels will increase over time. When biofuels are in their infancy and when the infrastructure to allow cars to use either type of fuels is underdeveloped, the elasticity of substitution may indeed be low. However, we do not believe that the nature of the substitution possibilities of biofuels and gasoline in 2020 will necessarily be the same as 2000. In Brazil today, for example, drivers act in a way in which the substitutability of biofuels and gasoline is very high. When drivers pull into a gas station to add fuel to their vehicle, they often will stop to calculate the price of gasoline relative to ethanol. If the price of ethanol is less (greater) than 0.7 that of gasoline, many drivers fill up with ethanol (gasoline). Such behavior is consistent with a high degree of substitutability.

It is not a trivial process, however, that enables an economy to be transformed into one in which there is greater substitutability between biofuel-based and petroleum-based transport fuels. In fact, there are at least two (or more) different types of investments/technological changes that are needed. First, there needs to be facilities available at the refueling stations that can provide both biofuel-based and petroleum-based fuels. Second, drivers need to have vehicles that are able to use either type of fuel (that is, flex-fuel vehicles). Assuming that the distribution infrastructure also can provide fuel to the stations in a timely and reliable way, there is no reason to think that the elasticity of substitution would not be substantially above the level that it was at in the 1990s in the US. Of course, there is no guarantee, because of the potentially high coordination costs that an economy would shift from a petroleum fuel-only economy to one offering drivers both fuels, that the transformation could occur without the intervention of government policy. However, we believe that if the US government took similar actions as those executed in Brazil (require filling stations

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[3] Similar to Birur et al. (2008), we swap the endogenous variable of the price index for global crude oil (pxwcom) with the exogenous variable of technology change of oil sector (aosec) in GTAP. The technology adjusts endogenously through the given fuel price under such a closure.

to add ethanol pumps; encourage flex fuel vehicle production and sales; support or encourage investment in the ethanol distribution system) that the level of substitutability between biofuel-based fuels and petroleum-based fuels would rise.

Other assumptions

There are a number of other assumptions in our study. For example, we assume that only first-generation biofuel production technology is adopted during the study period, 2006–2020. Although the second-generation is being invested in, there are no commercially viable technologies now and we do not want to make an assumption on when they will be adopted. In addition, we do not model certain first generation technologies due to the lack of data and difficulty in modeling in our framework (that optimizes on an annual basis). For example, we do not include jatropha or oil palm, which are perennial crops.

Results

Biofuel sector

While the world with no biofuels expansion experiences no rise in production under all sub-scenarios (by definition of the reference scenario—Table 3, column 2), when it is left to the market to determine the level of biofuels production (the Market Scenario), the results of our model demonstrate that the magnitude of the rise in biofuel production depends on the assumption about the future price of energy and the nature of the substitutability between biofuels and petroleum-based transport fuels (Table 3, columns 3 and 4). If energy prices in the future are low, the growth of biofuel production in Brazil, USA and EU is modest (Table 3 column 3, rows 1–8). From 2006 to 2020, ethanol production rises by less than 50% in Brazil and less than 25% in the US. The production of biodiesel in the US and EU increases by less than 40% over the same period under the Low Energy Price sub-scenario. The small increase in biofuel production relative to the reference scenario is due to the falling prices for agricultural commodities (see next section) that increases the profitability of ethanol production even though energy prices are low.

Biofuel production levels rise significantly with the High Energy Price assumption under the Market Scenario (Table 3, column 4). Instead of rising less than 50% with low energy prices, Brazil's ethanol production increases by up to 290%. Similarly, US ethanol production would be approximately 10 times greater under higher energy prices and increase by up to 724% over the forecast period. Biodiesel in the US and the EU would rise even more in percentage terms.

The importance of the elasticity of substitution assumption can be seen by comparing the difference in the predicted levels of biofuels production under the High and Low Substitution Elasticity assumptions in the High Energy Price version of the Market Scenario (Table 3, column 4). Brazilian ethanol production rises by 290% when the elasticity of substitution between ethanol and gasoline is high compared to 193% when it is low. The difference is even greater in the case of US ethanol production, which increases by over three times the level when the elasticity of substitution between ethanol and gasoline is high as compared to when it is low (724% versus 225%). Biodiesel production levels in the US and EU are also significantly larger under the assumption of a high elasticity of substitution. Clearly, the easier it is to substitute between biofuel transport fuel and petroleum-based transport fuel, the greater the profitability of the biofuel sector and the higher the output levels. Note that with a low energy price future under the Market Scenario (Table 3, column 3), that the production under the High Substitution sub-scenario is lower than when we assume limited substitution. The reason for this is that the real price of energy in 2020 is actually lower than the price during the 2006 baseline with the Low Energy Price scenario and producers are better able to move away from biofuels and substitute back into cheaper petroleum-based transport fuels with the higher elasticity of substitution.

The importance of the role of policy mandates in the future of biofuels production is highlighted by comparing the results of the Policy Scenario with the results from the reference scenario (and the Market Scenario). One of the most important results is that future production predictions of ethanol for all major producers are the same under the assumption of Low Energy Price regardless of the substitutability sub-scenario or under the assumption of High Energy Price with the Low Substitution Elasticity sub-scenario. For example, Brazilian ethanol production in 2020 is predicted to be 194% higher than 2006 levels with low energy prices regardless of the substitutability of ethanol for gasoline (Table 3, column 5, rows 1 and 2) or if energy price is high and low substitutability (Table 3, column 6, rows 2). Similarly, the predicted level of US ethanol production rises by 209% under the Policy Scenario when the energy price is assumed to be low or if the substitutability between ethanol and gasoline is assumed to stay low.

Comparing the results of Policy Intervention Scenario with those of the Market Scenario shows that policy matters except in a world characterized by high energy price and high substitutability

Table 3
Ethanol and biodiesel production in US, Brazil, and EU under various oil price scenarios and assumptions on elasticities of substitution between fossil fuels and biofuels.

	2006–2020 (% Change) reference scenario	2020 (% Change from reference)			
		Market Scenario		Policy intervention scenario	
		Low energy price	High energy price	Low energy price	High energy price
Ethanol production					
USA	0				
High subst. elasticity		5	724	209	724
Low subst. elasticity		22	225	209	209
Brazil	0				
High subst. elasticity		34	290	194	290
Low subst. elasticity		46	193	194	194
Biodiesel production					
USA	0				
High subst. elasticity		−20	814	763	814
Low subst. elasticity		12	237	763	763
EU	0				
High subst. elasticity		35	978	847	978
Low subst. elasticity		39	313	847	847

between biofuels and gasoline. Especially under low energy prices, the production of biofuels in the Policy Intervention Scenario in all countries for both ethanol and biodiesel (Table 3, column 5) is significantly higher than the production of biofuels under the Market Scenario (Table 3, column 2). This is also true under high energy prices but with low substitutability. The effect of policy on production levels is particularly evident for biodiesel. Under low energy prices and low substitutability, US (EU) ethanol production increases by 763% (847%) over the time period with policy mandates versus 12% (39%) under a Market Scenario.

While policy mandates have a significant impact on biofuel production levels under low prices, they have no effect if future energy prices are high and consumers are able to substitute relatively easily between ethanol and gasoline. For example, the policy mandates require US ethanol production to increase 209% by 2020 from the 2006 level. This increase is just obtained under the Market Scenario with the High Energy Price and Low Substitution Elasticity sub-scenarios (225%) whereas it is far exceeded if the elasticity of substitution is assumed high (724%). The changes in biodiesel production are similar to that for ethanol. Biodiesel production under the high price and easy substitution Market Scenario will increase slightly more than the level of mandate (814% versus 763%). The relatively low rising extent of biodiesel production is due to the competition between biodiesel and ethanol production for feedstocks (discussed further in the next sub-section) and the effect of relative output prices. Overall, the results from our analysis demonstrate that the policy targets are not binding under a high–high scenario with production decisions driven by the market. A similar result was reported for US biofuels by Hertel and Beckman (2011).

Because of the way the policy mandates are imposed in the model (the price of biofuels is increased above the market clearing rate until the point that biofuels production exactly meets the target), we can examine the level of the subsidies that will be required for each country to meet their biofuels targets. The greatest levels of subsidies are needed if future energy prices are low and there is little substitutability between ethanol (biodiesel) and gasoline (diesel). The required payments are $12.5 billion for the US, $24.8 billion for the EU, and $4.8 billion for Brazil (Table 4, column 2). Low energy prices reduce the demand for biofuels and thus require greater government support to meet the desired production targets. At the other extreme, when prices are high and there is scope for substituting biofuels for petroleum-based fuels, no subsidy is needed for any of the countries, for as noted in the previous paragraph, the policies are not binding. Under the assumptions of high–high, even in the Policy Intervention Scenario, the market solution dominates and producers produce volumes of biofuels that exceed the mandates when they are facing market prices. Hence, subsidies are not needed. The other sets of assumptions (low–high and high–low) require government aid but the subsidies are much lower than with low energy prices and low substitutability between fuels. As a result, there are considerable differences in the subsidy rates that must be paid depending on the energy price and substitutability levels.

Table 4
Government subsidies required for US, Brazil and EU to meet biofuel mandates under various oil price scenarios and assumptions on elasticities of substitution between fossil fuels and biofuels policy.

	2020			
	Low energy price		High energy price	
	Low subst. elasticity	High subst. elasticity	Low subst. elasticity	High subst. elasticity
Total subsidy (billion US$)				
USA	12.5	6.0	5.1	0
EU	24.8	16.5	17.0	0
Brazil	4.8	2.3	1.6	0
Subsidy rate (US$ /gallon)				
USA	0.8	0.3	0.3	0
EU	1.2	0.8	0.8	0
Brazil	0.3	0.2	0.1	0

Feedstock sector

Biofuel impacts on production, prices and international trade of agricultural commodities are closely related to the growth rate of biofuel production (Table 5). No growth results in a return to declining real prices for feedstocks while biofuel growth supports the recent upward trend in prices. Specifically, if biofuel production was kept as its 2006 level, US corn price in 2020 is projected to fall by 14.6% compared to its 2006 level. Over the same period, US corn production rises by 32.8% and exports increase by 88.1%. Stalling biofuel production levels results in a continuation of a century old trend of supply outpacing demand with the effect being falling prices and rising exports (Johnson, 1998).

Under either the Market Scenario or the Policy Intervention Scenario, however, corn prices in the US fall less, corn production is higher and exports almost always rise less in comparison to the reference scenario. The price and production of US corn increases (and the dampening of exports) are generally greater when policy mandates are in place than either the reference scenario or the Market Scenario. The largest corn price and production (and export) effects in the US, however, are found when we assume a high energy price and high fuel substitutability. Under this scenario, US corn prices rise by 45.2% by 2020 compared to the 14.6% decline if biofuel production remained at 2006 levels. These projected price and production increases for US corn are slightly higher than other GE models (i.e. Banse et al., 2008; Hertel et al., 2010; Taheripour et al., 2010) but the scenarios and time horizon differ.

The predicted patterns of prices, production and exports for US soybeans by 2020 demonstrate strong spillovers to related feedstock sectors from biofuel production with the impacts largely associated with ethanol (Table 5, rows 7–12). No change in biofuel production results in a decline in prices and an increase in output at rates similar to those predicted for the corn sector. Allowing market prices to determine biofuel output increases US soybean prices and production with the effects increasing with the ease of substitutability between fuels and, particularly, with energy prices. Policy mandates have a much larger impact since the targeted increase in biofuels is greater than with only market forces (except in the high–high sub-scenarios). The market responses of biofuel producers (assuming high–high) are mainly created because corn begins to compete with soybeans for resources as farmers seek to meet the demand for corn by US ethanol plants. The result is that soybean prices rise by approximately half the rate of corn prices in the US with favorable conditions for biofuel expansion.

Changes in the expected prices, production and exports of sugar in Brazil (Table 6, rows 1–6) and rapeseed in the EU (rows 7–12) follow almost identical paths as corn in the US. With no change in biofuel output from 2006 levels, the 2020 prices for Brazilian sugar cane and EU rapeseed fall by approximately 20%. These prices and output increase with domestic biofuel production and rise if market forces determine output but particularly with policy mandates. Even with low energy prices and low substitutability, sugar cane prices (output) in Brazil rise by 50% (94%) and rapeseed prices (output) in the EU rise by 33% (82%) with biofuel production targets in place. In the high–high sub-scenario, biofuel output is greater than the policy mandates so the price and output impacts are even greater, particularly for Brazilian sugar cane for which the price increases by 83.7% and output by 147%. Since domestic demand rose relatively more than production, exports of sugar

Table 5
Maize and soybean prices, production and exports in US under various oil price scenarios and assumptions on elasticities of substitution between fossil fuels and biofuels.

	2006–2020 (% Change) reference scenario	2020 (% Change from reference scenario)			
		Market Scenario		Policy intervention scenario	
		Low energy price	High energy price	Low energy price	High energy price
USA maize					
Price	−14.6				
High subst. elasticity		0.7	45.2	15.0	45.2
Low subst. elasticity		1.4	12.8	15.0	13.9
Production	32.8				
High subst. elasticity		1.0	51.3	17.0	51.3
Low subst. elasticity		2.1	19.8	17.0	18.6
Exports	88.1				
High subst. elasticity		1.2	−57.4	−16.6	−57.4
Low subst. elasticity		−0.3	−8.0	−16.6	−16.4
USA soybean					
Price	−11.6				
High subst. elasticity		0.4	21.5	12.5	21.5
Low subst. elasticity		0.7	6.7	12.5	11.7
Production	31.7				
High subst. elasticity		0.0	4.7	8.5	4.7
Low subst. elasticity		0.3	2.8	8.5	8.7
Exports	48.3				
High subst. elasticity		0.7	−21.9	−13.3	−21.9
Low subst. elasticity		0.1	−3.9	−13.3	−13.3

Table 6
Sugarcane and rapeseed prices, production and exports in Brazil and EU under various oil price scenarios and assumptions on elasticities of substitution between fossil fuels and biofuels.

	2006–2020 (% Change) reference scenario	2020 (% Change from reference scenario)			
		Market Scenario		Policy intervention scenario	
		Low energy price	High energy price	Low energy price	High energy price
Brazil sugar					
Price	−20.0				
High subst. elasticity		6.5	83.7	50.6	83.7
Low subst. elasticity		9.1	43.6	50.6	45.7
Production	17.5				
High subst. elasticity		16.3	147.1	94.1	147.1
Low subst. elasticity		22.6	100.1	94.3	99.1
Export	269.0				
High subst. elasticity		−28.7	−95.5	−87.5	−95.5
Low subst. elasticity		−36.4	−82.4	−87.5	−85.3
EU rapeseed					
Price	−17.3				
High subst. elasticity		1.2	38.0	33.0	38.0
Low subst. elasticity		1.4	10.9	33.0	30.5
Production	28.9				
High subst. elasticity		3.9	95.0	81.6	95.0
Low subst. elasticity		4.5	35.7	81.6	84.6
Export[a]	294.5				
High subst. elasticity		−4.9	−65.2	−62.8	−65.2
Low subst. elasticity		−5.3	−32.1	−62.9	−62.3

[a] The trade of rapeseed inside EU member countries is not included.

cane (rapeseed) in Brazil (the EU) fell relative to the reference scenario.

In summary, then, the emergence of biofuels from either policy mandates requiring minimum levels or due to market-based decisions of biofuel refiners are predicted to have profound impacts on the agricultural economies of the major producing countries. Unlike the past in which prices fell over time, higher biofuel production from either policy intervention or the market will lead to higher prices in 2020 than if biofuel output was fixed at the reference level of 2006. However, this rise in prices is not coming from lower production since output rises sharply. Demand from the biofuel plants, in fact, is strong enough that domestic users procure enough of output that exports fall in both the Market Scenario and the Policy Scenario relative to the base case. In other words, after the emergence of biofuels there is relatively more corn, sugar and rapeseed being produced, but less of it is going onto world markets.

Developing countries

Agricultural production in developing countries will also be significantly affected by the emergence of biofuels in the US, Brazil and the EU. Because of the price changes (and reduction of exports) due to global biofuel development, world agricultural production and trade will change remarkably. To show this relatively succinctly, we examine the impact of the emergence of biofuels on developing countries under the assumption of high future energy prices and high substitutability of biofuels and petroleum-based

Table 7
The impacts on the price, production, export and self-sufficiency level of selected developing countries in high–high scenario (expressed in% change relative to reference scenario, 2020).

	East Africa	West Africa	South Africa	India	Rest of South Asia
Maize					
Price	6.2	4.6	5.4	8.1	8.7
Production	4.2	2.0	4.5	2.2	4.3
Export	178.8	183.6	44.9	96.5	262.5
Self-sufficiency ratio	4.0	1.7	4.6	2.6	4.7
Wheat					
Price	4.0	4.8	3.3	3.2	3.1
Production	1.8	3.5	3.9	0.4	1.4
Export	14.1	10.0	12.9	19.1	16.1
Self-sufficiency ratio	0.6	0.8	1.4	0.3	1.1
Rice					
Price	2.4	2.5	4.0	4.9	1.4
Production	−0.2	0.0	−0.3	0.2	0.1
Export	12.9	11.7	4.1	−5.5	30.3
Self-sufficiency ratio	0.0	0.7	0.0	0.0	0.2
Beef and Mutton					
Price	0.7	0.5	0.5	3.0	1.2
Production	−0.1	−1.3	2.1	0.3	0.1
Export	13.4	9.5	16.0	−0.8	6.0
Self-sufficiency ratio	0.4	0.4	1.8	−0.3	0.0

Notes: In the definition of self-sufficiency, the value of 100 indicates that the net export is zero, and the domestic consumption equal to the domestic production. The numbers of self-sufficiency in above table is the difference between the high–high scenario and reference scenario (i.e., the value of self-sufficiency in H–H minus that of the corresponding reference scenario).
High–high refers to high energy price and high elasticity of substitution between biofuels and fossil fuels.

fuels. This sub-scenario results in biofuel production levels greater than the policy targets. We aggregate the effects in developing countries into region-wide effects, including Eastern Africa, Western Africa, Southern Africa, India and Rest of South Asia (see Appendix C for regional aggregation).

The increases in feedstock prices predicted for the major biofuel producing countries are transmitted by global markets to developing countries (Table 7). In the case of corn, the range of the price increases from the emergence of biofuels is between 4.6% in West Africa to 8.1% in India. These price increases are much less than the approximate 45% rise predicted for US corn price because of imperfect price transmission across the boundaries of nations.[4] The predicted effects of biofuels would be magnified if the commodity price changes more closely matched the price increases previously discussed for developed countries. The higher corn prices in developing countries causes production to increase by 2% (West Africa) to 4.5% (South Africa). Because of the higher levels of production, exports rise (or at the very least imports fall) and the net result is an increase in the self-sufficiency ratio of developing countries for corn.

Food consumption is projected to decline under the scenarios of global biofuel development, especially for crops used as biofuel feedstock. Unfortunately, the impacts on the poor could not be derived directly because consumers in the model are not differentiated by income. However, many studies have suggested that rising food prices threaten the caloric consumption and nutritional intake of the poor (World Bank, 2008; FAO, 2009). Therefore, increases in biofuel production globally will likely reduce per capita consumption for the poor who are net food purchasers.

As in the case of biofuel producing nations, rising prices for corn (and sugar and rapeseed) in developing countries have spillover effects on prices of commodities that are not feedstocks. The rise in wheat prices in developing countries (relative to the reference scenario) ranges from 3.1% in South Asia (not counting India) to 4.8% in West Africa. Rice and meat prices also rise in all regions.

While non-feedstock commodities prices in developing nations all rise in the high–high scenario relative to the reference scenario, the impact on production, exports and self-sufficiency is mixed. The pattern of wheat mirrors that of corn. However, the production of rice and meat fall in most developing countries despite the higher prices. The reason for the output decline is that the price rises for rice and meat are less than that for maize and wheat; resources are shifted to the crops with higher relative prices. Exports and self-sufficiency ratios are mostly determined by production patterns.

The rise in biofuel production under the assumption of high energy prices and high substitutability has a positive effect on value added in the agricultural sectors across all regions (Table 8, Panel A). Agricultural value-added grows most in the major biofuel producing regions with it rising by 12.5% in the US, 10.2% in the EU, and 15.4% in Brazil relative to the no biofuel production growth scenario. The greatest returns, percentage wise, are enjoyed by those in the unskilled labor sector and those that own (or get the returns to) land. Laborers and landowners in developing countries also enjoy rising returns due to the higher biofuel production levels (Table 8, Panel B). The overall increase in agricultural value-added in the developing regions included in our study ranges from 3.2% in South Asia (not counting India) to 5.6% in South Africa. The owners of land resources receive the greatest benefits of the higher value added, but both unskilled and skilled laborers also benefit.

In summary, even when biofuels are being mainly produced in developed countries, our results indicate that there are impact pathways that extend far beyond the borders of the US, Brazil and the EU. Prices of feedstock and non-feedstock commodities rise in the developing countries. In the case of maize and wheat, the price rise increases production, increases exports (or reduces imports) and improves self-sufficiency. There is also a rise in value added from the agricultural sector—a gain that is enjoyed by the

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[4] The pass-through of rising global prices does not translate into a proportionate rise in domestic price levels due to a variety of factors including transaction costs, existence of market power, existence of non-constant returns to scale, degree of product homogeneity, changes of the exchange rates, and effects of border and domestic policies (Barrett and Li, 2002; Conforti, 2004). Although the domestic agricultural price in developing countries is correlated with movements in the global price, actual price transmission is muted in most cases (Keats et al., 2010). Such an incomplete price transmission among countries is mainly reflected in the GTAP model through the price margin between FOB and CIF, and the elasticities of substitution between imported and domestic products (the Armington assumption).

Table 8
Impacts on value-added and the return to labor, capital and land in agricultural sectors in selected countries in high–high scenario in 2020 (comparison to reference scenario, %).

	USA	EU27	Brazil
Panel A			
Value-added	12.5	10.2	15.4
Unskilled labor	6.0	8.7	10.8
Skilled labor	4.2	5.3	3.6
Capital	6.0	4.1	9.3
Land	57.7	57.9	59.1

	East Africa	West Africa	South Africa	India	Rest of South Asia
Panel B					
Value-added	3.7	3.8	5.6	4.9	3.2
Unskilled labor	2.4	3.0	4.0	2.2	1.7
Skilled labor	1.1	2.1	2.8	0.9	1.6
Capital	1.5	2.7	2.8	2.0	1.6
Land	4.3	5.0	9.8	6.9	4.5

Notes: the real change of value-add and return to labor, capital and land are calculated by the nominal change minus the change of private consumption price.
High–high refers to high energy price and high elasticity of substitution between biofuels and fossil fuels.

owners of land and labor, including unskilled. Hence, to the extent that agriculture is a key sector in getting growth started and addressing poverty needs, the emergence of biofuels can (in this way at least) be a positive force. In fact, all major development agencies (e.g., the World Bank; FAO; IFPRI) are proponents of policies that promote the agricultural sector (Swinnen and Sqicciarini, 2012).

Of course, it also needs to be noted that as the price levels of agricultural commodities become higher, the cost of living will increase. If the cost of the food basket rises high enough, it could have a negative impact on the standards of living (and level of poverty) of those that live in cities and do not farm as well as those who live in rural areas and are not net sellers of food (or their labor). In this way, the higher prices initiated by biofuels can have negative impacts. The nature of the GTAP modeling framework, however, does not allow us to address this issue in any depth. In order to fully understand the distributional implications of biofuel production growth within less developed countries, we would need to simulate the household level response to higher wages, prices and land rental rates with detailed micro-level that is disaggregated by income class and urban–rural status. This level of analysis is beyond the scope of this paper, but has been done by others in the literature (Agoramoorthy et al., 2009; Arndt et al., 2010, 2011; Schut et al., 2010).

Summary and conclusions

In this paper, we assess the future impacts of biofuel production on the agricultural sectors of developed and developing nations with and without policy mandates and under a number of alternative assumptions on future energy prices and the elasticity of substitution between fossil fuels and biofuels. According to our analysis, biofuels production is driven to expand aggressively by policy mandates even when future energy prices are expected to be low and when there is little scope for substituting biofuels for petroleum-based transport fuels. If future energy prices are high and if biofuels can be substituted easily with petroleum-based transport fuels, the development of biofuels will not be driven by government policy. Rather, producers responding to market signals will be the driving force and production will exceed the mandated levels in all major biofuel producing countries. Hence, if a government wants to stop the expansion of biofuels in a high–high world, the only way to do so would be to ban production by regulation.

The analysis demonstrates, that whatever the reason for the expansion of biofuels (either from policy mandates or market-based decisions of producers), there are likely to be important effects on the agricultural economies of the major producing countries. Unlike the past in which prices fell over time, biofuel production will lead to higher feedstock prices in 2020 compared to the base case in 2006. However, this rise in prices is not coming from lower production since crop output rises sharply. Demand from biofuel plants, in fact, is strong enough that domestic users procure enough of the feedstock that exports rise. In other words, after the emergence of biofuels there is relatively more corn, sugar and rapeseed being produced, but, less of it is going onto world markets.

Greater biofuel production from the US, Brazil and the EU leads to price rises in the developing countries in Africa and South Asia. The prices of all crops rise, including the prices of corn, sugar and rapeseed as well as non-feedstock crops, such as wheat and rice. In the case of feedstock crops, such as corn (and non-feed stock crops, such as wheat), developing countries also experience increases in production, exports and self-sufficiency. There is also a rise in value added in the agricultural sector—a gain that is enjoyed by the owners of land and labor, including unskilled.

One of the most important findings in our study may be the finding that the exact magnitude and source of the impact of biofuels on the developing world depends on two important factors. One is the international oil price. The other is the degree of possible substitution between biofuels and gasoline. If energy prices rise to a certain level (e.g., $120/barrel in our study) in 2020, and assuming ethanol and gasoline become increasingly substitutable, then biofuel production will occur on the basis of market forces. This means that like it or not, developing countries will have to live with the higher prices and relatively less availability of commodities in world markets.

So is biofuels good for poverty reduction? We cannot answer this question definitively in this study. We do show that the growth of biofuels is good news for agricultural producers who own their land and are net-sellers of their crops on the market. With rising agricultural prices and the corresponding rise in land rents and agricultural wages, the income of these farmers (and wages of farm workers), they will have some increases in income and greater ability to increase expenditures. Of course, prices will also be higher. But, in general, the expansion of biofuels is good news for those in agriculture that are net-producers.

The emergence of biofuels is bad news for consumers, including those that produce food, but, who are still net purchasers. From the perspective of aid agencies and governments in developing countries, the safest policy stance might be to assume that it is inevitable that biofuels will be here for the foreseeable future and that there will be consumers that get hurt. Hence, it is essential to construct a social security system to provide the necessary support for vulnerable citizens (or enhance it where it already exists). To offset the negative effects, safety nets need to be installed and maintained. The need for safety nets is especially pronounced if the volatility of prices increases along with the increase in its average.

On the other hand, there are more intangible, longer-term dynamic effects that might come with biofuels. With higher prices, as in any industry, there will almost certainly be more opportunities for agricultural investment from both governments and the private sector. If increasing investments in agriculture that are induced by higher food prices end up raising agricultural productivity, this may be a source of additional output (and income) that can at least in part off-set the rise in agricultural prices from the expansion of the biofuel industry.

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Appendix A

Main biofuel support policies by countries considered explicitly in model.

Country	Support policies	Implemented in model
USA	Blender Tax Credit	Yes
	Secondary ethanol tariff	Yes
	Mandate targets	Yes (in policy scenario)
Brazil	Blending ratios	Yes
	Tax credit	Yes
	Strategic purchase	No
	Ad valorum duty	Yes
	Targets	Yes (in policy scenario)
EU	Tariffs	Yes
	Area payments	No
	Targets	Yes (in policy scenario)
China	Tariffs	Yes
	Tax credit	Yes
Canada	Tariffs	Yes
India	Tariffs	Yes
Argentina	Tariffs	Yes
Rest of world	Tariffs	Yes

Appendix B

Region and their member countries in GTAP.

Region	Corresponding countries in GTAP
Australia and New Zealand	Australia, New Zealand
Brazil	Brazil
China	China
USA	United States of America
European Union	Austria, Belgium, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom
India	India
Rest of South Asia	Bangladesh, Pakistan, Sri Lanka, Rest of South Asia
Southeast Asia	Cambodia, Indonesia, Lao People's Democratic Republic, Myanmar, Malaysia, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia
West African countries	Nigeria, Senegal, Rest of Western Africa, Central Africa, Ethiopia, Rest of Eastern Africa
East African countries	Madagascar, Tanzania, Uganda
North African countries	Egypt, Morocco, Tunisia, Rest of North Africa
South African countries	South Central Africa, Malawi, Mauritius, Mozambique, Zambia, Zimbabwe, Botswana, South Africa, Rest of South African Customs Union
South America	Bolivia, Chile, Ecuador, Paraguay, Peru, Uruguay, Venezuela, Rest of South America, Costa Rica, Guatemala, Nicaragua, Panama, Rest of Central America, Caribbean
Rest of World	Remaining countries not listed above

Appendix C

Annual growth rates of macroeconomic variables and crop yield by region under reference scenario, 2006–2020 (%).

	Macroeconomic variables					Crop yield			
	GDP	Population	Skilled labor	Unskilled labor	Capital	Maize	Sugar	Soybean	Other oilseeds
Australia and New Zealand	3.4	0.9	0.8	−0.2	3.9	0.5	0.4	0.7	0.6
Brazil	4.3	1.2	0.8	3.0	3.5	2.0	1.4	2.0	2.0
China	8.0	0.5	0.4	3.0	8.5	1.7	1.1	0.8	1.1
USA	2.5	0.8	0.6	−0.1	2.4	0.8	0.6	1.6	1.8
European Union	2.0	0.0	−0.1	−0.8	3.0	0.4	0.8	1.3	1.2
India	7.0	1.5	1.5	3.9	7.8	2.6	1.3	1.0	1.0
Rest of South Asia	5.4	2.0	2.2	3.7	5.4	1.7	1.1	0.8	1.4
Southeast Asia	5.4	1.4	1.3	3.8	5.0	1.7	0.9	0.8	0.4
West African countries	4.3	2.8	3.1	3.2	4.2	1.9	0.9	1.6	1.2
East African countries	5.2	2.7	3.2	3.2	5.3	2.4	2.0	1.8	0.6
North African countries	4.4	1.8	1.8	2.4	5.2	1.2	0.9	1.5	1.6
South African countries	3.9	2.1	2.5	2.5	4.0	2.4	0.9	1.1	0.6
South America	4.3	1.8	1.4	3.5	4.0	1.9	1.6	0.7	0.6
Rest of World	3.4	1.5	1.3	1.5	2.9	1.1	1.1	0.8	1.2

Source: Assumptions on growth rates for macroeconomic parameters estimated by authors mainly based on research by Tongeren and Huang (2004), Walmsley (2006) and Yang et al. (2011). Annual crop yield values by region are from IFPRI's IMPACT model.

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