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Biofuels, Rural Development, and the Changing Nature of Agricultural Demand

Rosamond Naylor

Director, Center of Food Security and the Environment,
William Wrigley Senior Fellow,
Professor, Environmental Earth System Science,
Stanford University

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Abstract

Policies promoting ethanol and biodiesel production and use in the U.S., Europe, and other parts of the world since the mid-2000s have had profound and largely unintended consequences on global food prices, agricultural land values, land acquisition, and food security in developing countries. They have also created regional opportunities in the form of agricultural investments, crop yield growth, and prosperous farm economies. This paper reviews the main policy initiatives behind the 21st century biofuels boom—with specific attention to renewable fuel mandates—and describes how these policies influence food price levels and stability in international and national markets. It also explores the implications of an expanding biofuels industry for development policy and food security in countries with persistently high rates of hunger, including virtually all sub-Saharan African countries and India. The paper ends by suggesting three themes surrounding the debate over crop-based biofuels: 1) the dominant role of uncertainty in energy and agricultural markets, especially in light of new energy investments, financial instability, and climate change; 2) the importance of government policies and well-developed supply chains as pre-requisites for profitable biofuel industries; and 3) the need to weigh opportunity costs to biofuels development in terms of fiscal expenditures, land and water resources, and political capital. These issues are particularly important for food insecure countries as they chart their development strategies for the future. Policies that appear promising for food and energy security at the macro-scale today might have major shortfalls for poor communities and households over the longer run if food availability, access, stability and nutrition are seriously compromised.

Biofuels, Rural Development, and the Changing Nature of Agricultural Demand

Many of the core lessons on food policy for low-income countries have endured since the early writings of Arthur Mosher (*Getting Agriculture Moving* 1966) and Timmer, Falcon and Pearson (*Food Policy Analysis* 1983). But two more recent trends have become defining features of the world food economy: globalization in trade and capital flows, and increased integration between the agriculture and energy sectors via the expansion of biofuels. Global and regional demands for food, animal feed, and fuel now play a dominant role in the behavior of agricultural commodity markets, contributing to rising food price levels and volatility since 2005. The burgeoning biofuel industry, in particular, is reshaping the nature of agricultural demand. What makes the 21st century biofuels boom an interesting topic for this volume is that it is propelled largely by U.S. and EU policies, which in turn stimulate new policy initiatives in developing countries. The questions for this chapter are: 1) What are the key policies behind the recent surge in biofuels production and use worldwide? 2) How does the expansion of biofuels affect agricultural markets, food prices, and food security on a global basis? And 3) What does a growing biofuels market mean specifically for development policy and food security in countries with persistently high rates of hunger, including virtually all sub-Saharan African countries and India?

The current commercial biofuels sector is comprised of ethanol and biodiesel produced from agricultural crops such as maize (corn), sugarcane, cassava, sorghum, rapeseed (canola), soybeans, and palm oil, and are commonly referred to as "first-generation" biofuels.[1] These liquid fuels are used mainly in the transportation sector. They are distinct from biomass fuels, which are comprised of renewable materials such as crop or forest residues, animal dung, and municipal solid wastes and are used widely in the developing world for regional or small-scale heating, cooking, and electricity.[2]

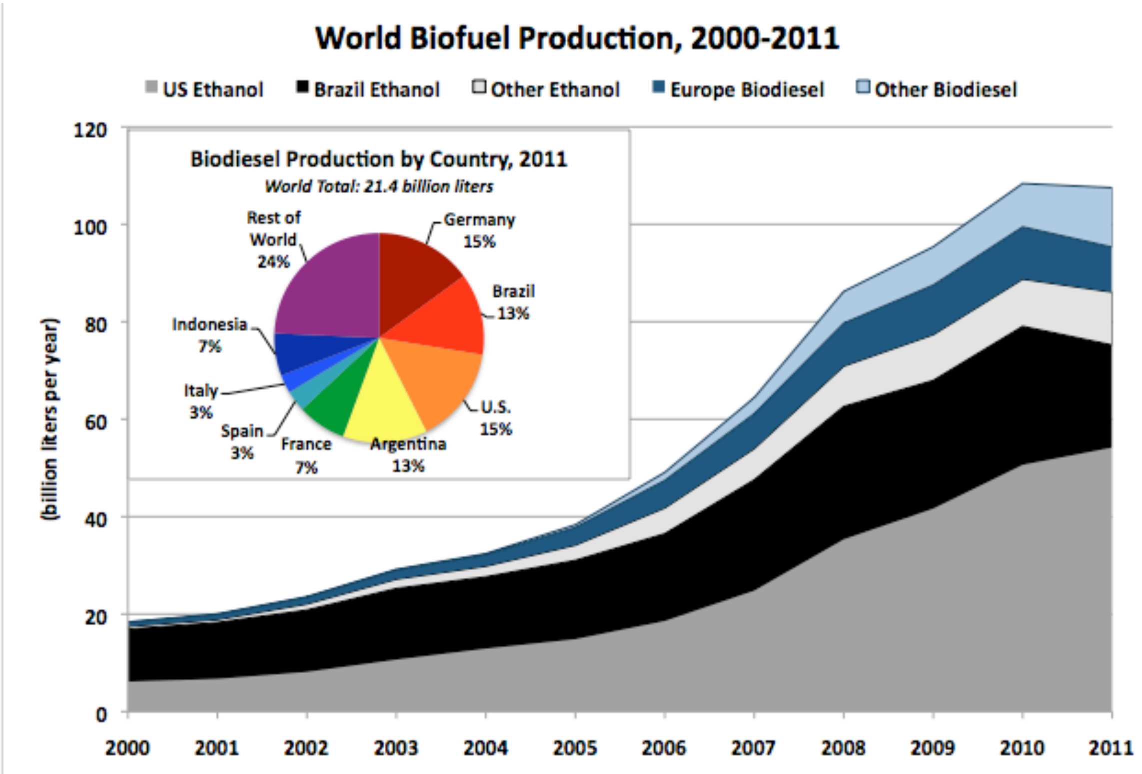
Liquid biofuel production has increased by more than five-fold since 2000 on a global scale, topping 100 billion liters (27 billion gallons) in 2010 (Figure 1). Ethanol accounts for most of the global total (86 billion liters or 22.4 billion gallons), but biodiesel production, at 19 billion liters (5 billion gallons) has also grown significantly in recent years. One of the most striking differences between the two fuels is that ethanol remains largely a story of the U.S. and Brazil—accounting for 57 percent and 33 percent of the global total, respectively, in 2010, while biodiesel is produced by numerous countries around the world. The large market shares of the U.S., Brazil, and the EU shown in

[1] Recycled cooking oils and processed animal fats are also used as biodiesels. "Second generation" biofuels are derived from cellulosic residues (e.g., maize stover), fast-growing trees (e.g., poplar), or dedicated energy plants (e.g., switchgrass, elephant grass). "Third generation" biofuels are produced mainly from algal-based materials. At present, second- and third generation biofuels are in the development stage and are not yet economically viable at a commercial scale. See IEA 2011; Gerasimchuk et al. 2012.

[2] Renewable energy sources supplied 16.7 percent of global energy consumption overall in 2010, and biomass energy was half of the renewable total. Biomass comprises a much larger volume of energy than liquid biofuels, which provide only 2-3 percent of global road transport fuels today (REN21 2012; IEA 2011).

Figure 1 are indicative of major biofuels policy initiatives that have encouraged domestic investments and consumption.

Figure 1: World biofuel production, 2000-2011



Sources: Ethanol Production, Europe and Other Biodiesel Production (large chart) – US Energy Information Administration International Energy Statistics (available online from www.eia.gov, accessed 04 August 2012) and REN21 Renewables 2012 Global Status Report (available online from www.ren21.net); Biodiesel Production by Country (small chart) – REN21 Renewables 2012 Global Status Report (REN21 2012).

What these policies and the resulting growth in the biofuels sector imply for global food security and food policy is the central focus of this paper. By creating a substantial new layer of demand for crops for use as a transportation fuel, the development of first generation biofuels reduces the availability of crop production for human consumption and animal feeds in the absence of significant area expansion or productivity growth. In so doing, it also bolsters crop prices, farm revenues, land values, and farm wages. How biofuels affect food security via access, stability, and nutrition thus depends on the net production versus consumption status of households, the volatility of food prices, the transmission of prices from international to national and local markets, and the extent to which crop production for biofuels displaces local food production, particularly if the latter provides important nutritional benefits to households. At a macro scale, the development of biofuels can also affect food security through domestic investments in the rural sector, trade-offs in fiscal priorities with respect to other social developments (e.g., education, health), and water and land allocations for large-scale biofuel estates versus smallholder agriculture.

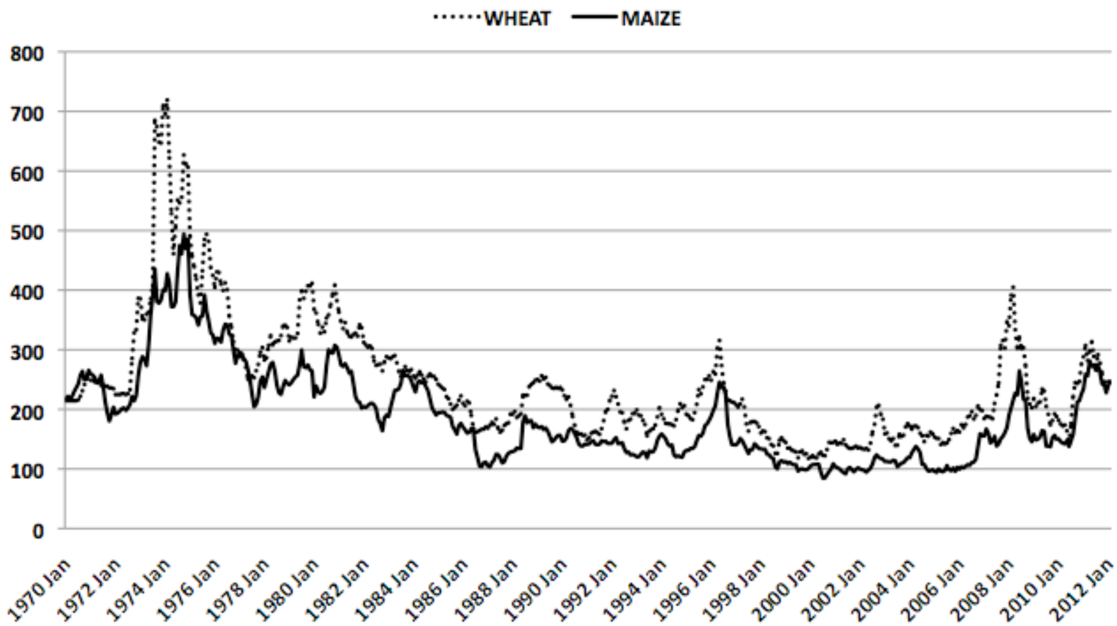
The stakes of biofuels development for low-income countries are high given the potential impacts on food security. The chapter begins by reviewing the current policy incentives underpinning 21st century growth in ethanol and biodiesel production and consumption at the global scale, and then describes how these policies influence food price levels and stability in international and national markets. The final section explores how biofuels investments in developing countries might affect food security over both the short- and long-run, and identifies some areas of future study and focus for emerging food policy leaders in sub-Saharan Africa, South Asia, and other regions with high rates of hunger. The chapter highlights, but does not exhaustively review, the vast literature that has developed on biofuels during the past decade.

The political economy of the biofuels boom

The U.S. and the EU have led the global expansion of ethanol and biodiesel production, respectively, since 2005 (Figure 1). Other large countries in the world food economy, including Brazil, Argentina, China, Indonesia, and India, have also played a significant role. What are the political and economic motivations behind this growth? The most obvious explanation is that policies promoting biofuels production, particularly in the U.S. and EU, reflect a continued response to the process of structural transformation, defined by the declining relative share of agriculture in aggregate income and employment.[3] More than a century of agricultural investments and policy incentives that opened frontiers, enhanced crop productivity, and generated growth in rural incomes and food supplies in the U.S. and Europe have resulted in surplus production and strong political constituencies formed around agricultural interests. Even with post-World War growth in agricultural trade, global grain prices trended downward (with some major spikes) over a 50-year period leading into the 21st century due to gains in crop production that exceeded increases in global demand (Figure 2). A long history of dual-purpose farm legislation has thus been established, in which production incentives and rural welfare goals go hand-in-hand (Kennedy 2007).

[3] For further discussion on structural transformation, see papers by Badiane and Timmer in this series.

Figure 2: Real wheat and maize prices, $US/MT, January 1970-February 2012



Source: International Monetary Fund. 2012. International Financial Statistics e-Library, Wheat and Maize Commodity Prices and US GDP Deflator. http://elibrary-data.imf.org/DataExplorer.aspx, accessed 11 July 2012.
Note: Annual prices for US Gulf Ports, deflated with IMF US GDP deflator.

Declining real cereal prices helped to induce the development of the grain-fed livestock sector and the corn-fructose sweetener industry, and more recently the ethanol industry in the U.S. (Naylor and Falcon 2011). Enzyme production, distilling processes, and supply chains formed around the corn-fructose industry set the stage for corn-ethanol production, and distiller by-products from ethanol production for use in livestock feed became a key element of the sector's profitability (*ibid*). Production gains in oilseed crops (rapeseed, soybean), combined with developments in co-products (meal-oil) and supply chains, also fostered growth in the biodiesel industry. Despite these market trends, however, the ethanol and biodiesel industries would not have flourished as they did since 2005 without strong policy incentives in the U.S. and EU. The objectives for supporting biofuels have been numerous and include, at the core, the desire to support rural economies and agricultural constituents. In addition, creating incentives for biofuels development has allowed governments to reduce direct subsidies to farmers, and as a result, to come closer to meeting the targets of the Uruguay and Doha Rounds of the World Trade Organization (WTO). But there have been few savings for government budgets. Direct agricultural subsidies have been replaced by biofuel tax credits and exemptions, and high and volatile food prices related to biofuels growth have led to additional government spending on consumer subsidies (e.g., the SNAP program in the U.S.) and farm insurance safety nets.[4]

[4] Expenditures on the USDA Supplemental Nutritional Assistance Program (SNAP) benefits more than doubled between 2007 and 2011, from about $30 billion to $72 billion. Almost two-thirds of the growth in spending on SNAP benefits between 2007 and 2011 stemmed from the increasing number of participants due to the economic recession; in 2011, one in seven Americans (roughly 45 million people) received

Although rural revitalization offers one explanation for policies supporting the biofuels boom, it is certainly not the only one. Global economic growth has generated rapid increases in energy demand worldwide, particularly in emerging economies, and in turn to higher crude oil prices. The jump in crude oil prices from $60/barrel in mid-2005 to $140/barrel in mid-2008 certainly helped justify government expenditures on biofuel development at the time. In addition, dependence on foreign oil sources that are controlled by unstable governments, or on governments hostile to OECD (especially U.S.) interests, has encouraged a greater reliance on domestic sources of energy and on renewable energy. Investments in renewable energy have been supported further by commitments to curb greenhouse gas emissions (GHGs) in the face of global climate change. The extent to which biofuels policies result in GHG reductions remains hotly debated, however, particularly in light of agricultural land use change, intensive production practices on existing cropland, transportation requirements for liquid biofuels, and subsidies to energy companies that support biofuel *and* fossil fuel consumption.[5] Legislation within the U.S. and EU has been implemented to address these issues directly, although accounting accurately for GHG emissions, particularly with respect to indirect land use change, is a difficult task.[6]

U.S. biofuel policies

Policies surrounding the U.S. ethanol industry illustrate how these objectives played out between 2005 and 2012. The U.S. policy setting warrants special attention given the country's dominant contribution to global biofuels production during the past decade and its large role in international agricultural markets, particularly maize and soy.[7] Ethanol policies in the U.S. have taken three main forms: tax exemptions and credits, tariff protection, and mandates (Naylor and Falcon 2011). The first two have their origins in earlier legislation dating back to the 1970s and 1980s, but it is the third element—mandates—that are critical to the recent biofuel boom.[8] Mandates for ethanol and biodiesel fall under the Renewable Fuels Standard (RFS), first established by Congress through the Energy Policy Act of 2005, and then bolstered through the Energy

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SNAP benefits. The rising cost of the SNAP program was also due to higher food prices. For more information, see: Congressional Budget Office, "The Supplemental Nutritional Assistance Program" (April 2012), http://www.cbo.gov/publication/43173 (Accessed July 10, 2012).

[5] There is a large literature surrounding this debate. See, for example, de Gorter and Just (2007); Searchinger et al. (2008); Fargione et al. (2008); Campbell et al. (2009); Tilman et al. (2009); Loarie et al. (2011); and Gerasimchuk et al. (2012).

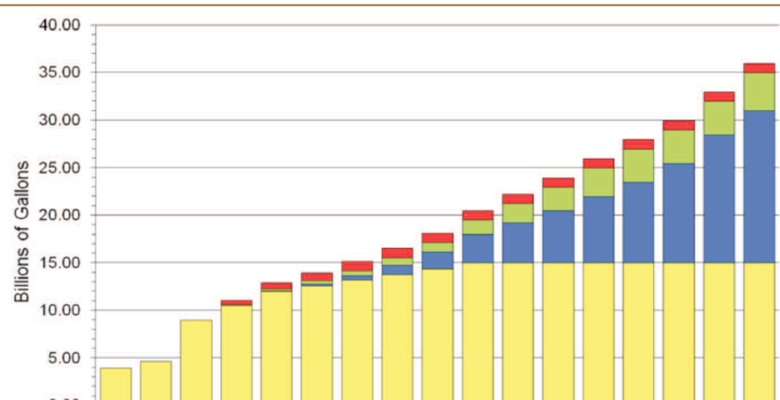
[6] Indirect land use change (ILUC) is the change in land use induced by commodity price movements related to biofuels production, within or outside of the country where the biofuels are produced. For further information on modeling efforts, see USDA (2011).

[7] In 2009-10, the U.S. accounted for over one-third of global maize and soy production, and for almost half of world exports in both commodities. See FAOSTAT: http://faostat.fao.org/.

[8] The tax and tariff policies are defined under the Renewable Fuels Reinvestment Act of 2010 and were phased out completely on December 31, 2011. They included a $0.45/gallon blender credit (volumetric excise tax credit), a $0.54/gallon tariff on imported ethanol, and a 2.5 percent ad valorem tariff (Naylor and Falcon 2011). Also included was a $1.00/gallon blending tax credit on biodiesel established initially under the American Jobs Creation Act of 2004, which provided a tax credit regardless of biodiesel source (domestic or foreign) or amount (up to 99.9 percent biodiesel blend) (de Gorter et al. 2011).

Independence and Security Act of 2007. The RFS currently requires that the amount of conventional (corn- or other first generation)[9] ethanol used in gasoline blends in the U.S. reach a minimum target of 15 billion gallons by 2015, and that advanced biofuels (made from agricultural, cellulosic, and algal materials) reach a minimum of 21 billion gallons by 2022 (Figure 3). Within the advanced biofuel mandate, at least 1 billion gallons must be comprised of biodiesel (made largely from soy oil), and a small but rising share must come from non-cellulosic fuels that include, by definition, sugar-based ethanol. The RFS mandates, which are enforced through the Environmental Protection Agency (EPA), also have a greenhouse gas stipulation: conventional biofuels satisfying the 15 billion gallon target must be 20 percent lower in GHGs than petroleum-based transportation fuels, and advanced biofuels must be up to 50 percent lower for non-cellulosic material and 60 percent lower for cellulosic material than gasoline and diesel (calculated through a life-cycle analysis).[10] Corn-based ethanol produced in modern natural gas fired plants already meets the first criterion, and sugar-based ethanol from Brazil meets the advance fuel target of 50 percent GHG reductions.

Figure 3: U.S. renewable fuels mandates



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass-based Diesel				0.50	0.65	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Non-celulosic Advanced				0.10	0.20	0.30	0.50	0.75	1.00	1.50	2.00	2.50	3.00	3.50	3.50	3.50	4.00
Celulosic Advanced					0.10	0.25	0.50	1.00	1.75	3.00	4.25	5.50	7.00	8.50	10.5	13.5	16.0
Conventional Biofuels	4.00	4.70	9.00	10.5	12.0	12.6	13.2	13.8	14.4	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

Source: Energy Independence and Security Act of 2007, U.S. Congress.

Source: Energy Independence and Security Act of 2007. U.S. Congress.

On the consumption side, a key policy measure encouraging the use of ethanol in the U.S. was the phase-out of MTBE (methyl tertiary butyl ether) as a gasoline additive in 2005 due to environmental and health risks. Ethanol quickly emerged as the preferred MTBE substitute as part of a 90%/10% (E10) gasoline blend, and as a result, the demand for

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[9] Maize and corn are used interchangeably throughout this paper; because "corn" is a word widely used in the U.S., it is used predominantly when discussing the U.S. ethanol sector.

[10] For further information on the RFS see: http://www.epa.gov/otaq/fuels/renewablefuels/index.htm (accessed June 21, 2012).

ethanol became tightly linked to growth in transportation fuel demand overall.[11] Herein lies the opportunity for, but also the constraint on, future expansion of corn-based ethanol. Presently, Americans consume about 135 billion gallons of gasoline per year (IEA 2012), and thus the amount of ethanol consumed in E10 blends is 13.5 billion gallons—close to the conventional fuel mandate (Figure 3). Without setting a blending mandate above E10 (e.g., at E15 or higher) the U.S. ethanol industry faces a ceiling on demand, commonly known as the "blending wall".[12] In 2011, the U.S. exported over 1 billion gallons of ethanol, over one-third of which went to Brazil—historically the world's leading ethanol producer and exporter.[13] Ironically, because there are limited domestic supplies of advanced biofuels to meet the current RFS mandate, the U.S. also imported ethanol from Brazil!

In order to circumvent these types of inefficiencies, the EPA has three options. First, the agency has the authority to waive one or more sub-mandates depending on potentially harmful economic or environmental outcomes.[14] Waivers are possible, for example, if the projected volume of cellulosic biofuel production is inadequate to meet the mandate or if a major disruption in biodiesel feedstock production is likely to cause fuel prices to rise above acceptable levels. According to current legislation, corn-based ethanol cannot fill the gap for advanced biofuels, although this regulation could change in the future if advanced biofuels remain commercially unviable. The second option is that the EPA can expand its system of mandate compliance certificates (referred to as Renewable Identification Numbers, or RINs), which allows for the banking and trading of renewable fuels compliance among energy refiners over space and time.[15] Finally, in June 2012 the EPA provided final approval for the use of E15 blends in gasoline for all cars and light trucks manufactured since 2001.[16] Although E15 is not yet generally available at pumping stations, this policy measure will likely expand the demand for corn-based

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[11] The blending arrangement has been particularly important for the pricing and profitability of ethanol. Ethanol contains only about two-thirds the energy (BTUs) of gasoline. To be competitive as a direct energy source, its per gallon price must therefore be two-thirds the cost of gasoline.

[12] In practice, the current blending wall in the U.S. is below 13 billion gallons, because infrastructure and other constraints prevent 10 percent blending in all gasoline. Although some E85 pumps exist, the volume of use is small. Most of the residual ethanol production in the U.S. is exported. For further details, see Abbott et al. (2011).

[13] See http://ethanolproducer.com/articles/8563/billion-gallons-u-s-ethanol-exported-brazil-top-destination (accessed June 22, 2012).

[14] Under the Energy Independence and Security Act of 2007 (EISA) and the preceding Energy Policy Act of 2005, the EPA Administrator, in consultation with the U.S. Secretary of Agriculture, may waive individual biofuels mandates if "the implication of the requirement would severely harm the economy or environment" (http://www.farmdocdaily.illinois.edu/2011/09/epa_mandate_waivers_create_new_1.html (accessed June 22, 2012).

[15] For further information on RINs see McPhail et al. (2011) and Farmdoc Daily: http://www.farmdocdaily.illinois.edu/2012/03/is_the_ethanol_mandate_truly_a.html (accessed June 22, 2012).

[16] Ethanol blends above E10 can erode catalytic converters, especially in older car models, because ethanol burns hotter than gasoline. To avoid this barrier on ethanol demand, the EPA approved in October 2010 the use of E15 for cars and light trucks manufactured after 2007, and in January 2011 approved an extension for vehicles made since 2001. The latest approval ensures that E15 will not be mislabeled and will thus comply with the Clean Air Act (see http://www.epa.gov/otaq/regs/fuels/additive/e15/, accessed June 22, 2012).

ethanol in the U.S. beyond the current 15 billion gallon target. Whether or not EPA waivers will allow conventional ethanol to meet a larger share the total RFS mandate in the future is a key question for the industry's growth, and in turn for agricultural commodity markets.

International policy initiatives: the rising role of mandates

Like the U.S., Brazil and the EU also adhere to mandates as a guiding policy tool. Brazil developed its sugar-ethanol sector early on with public support through direct budgetary spending, subsidized credit, tax relief, and provision of government-owned assets (especially land and water) at below-market value. With these early investments and abundant land resources, Brazil has been able to attract foreign investment for its biofuels industry, and to establish a well-integrated sector with flex fuel cars since 2003 (Schmidhuber 2007; Valdez 2011a,b; Rabobank 2012). Brazil eliminated its import tariffs in 2007 and has reduced its use of tax exemptions for ethanol blending and exports; however, it still relies on subsidized credit for sugar planting and for ethanol refining and storage (Gerasimchuk et al. 2012). More importantly, it uses an aggressive set of mandates, set at E20-25 and B5,[17] to ensure a market for its expanding sugar and ethanol output. It has been difficult for Brazil to meet its ethanol mandates with domestic supplies in recent years, however, because international sugar prices have escalated and spiked several times since 2009, creating incentives to shift the use of sugar from fuel to food production and exports (Barros 2011). In addition, domestic sugar yields have been afflicted by adverse climate. In 2010-11, Brazil imported almost 400 million gallons of ethanol from the U.S. and cut its exports. To meet mandates in the future, Brazil is expanding its sugarcane production into the *cerrado* (grassland) region—a move that is effectively pushing soybean production up into the Amazon and creating tradeoffs with environmental objectives related to biodiversity protection and GHG emissions (Loarie et al. 2011). By expanding its sugar and ethanol production targets, Brazil is also positioning itself to capture a greater share of the U.S. market given the composition of RFS mandates and the elimination of ethanol import tariffs in the U.S. in December 2011.[18]

The EU has similarly transformed its policy approach, from an earlier emphasis on tax and trade incentives and indicative consumption targets to a more recent focus on blending mandates (Kutas et al. 2007; Swinbank 2009; Blandford et al. 2011). In 2009, the EU passed legislation through its Renewable Energy Directive (RED) that required 10 percent of all transportation fuel to come from renewable resources by 2020 (EU 2009; Flach et al. 2011). Implementation of the EU mandate is in the hands of individual member states, most of which now have legislation in place to meet the targets. A key issue related to the EU directive is the sourcing of feedstocks to meet its mandate via biofuels according to its sustainability criteria. These criteria require that biofuels use under the mandate lead to a 35 percent reduction in GHG emissions relative to fossil fuel

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[17] A blending mandate of E20 implies 20 percent ethanol and 80 percent gasoline. For B5, the target is 5 percent biodiesel blended with 95 percent fossil fuel diesel.
[18] Sugar ethanol qualifies as an advanced non-cellulosic fuel in the RFS (Figure 3).

sources (gasoline and diesel) upon implementation, and that the reduction in GHGs be scaled to 50 percent for existing plants by 2017 and 60 percent for new installations. The directive also provides a double mandate credit for the use of second-generation biofuels, and restricts the use of palm and soy oils due to their direct and indirect impacts on tropical deforestation. The use of biodiesel from rapeseed is expected to account for most of the RED mandate in the near term, and electric cars are anticipated to play an increasing role over time.[19]

Beyond these core production regions, over 50 other countries also support biofuels currently through some combination of tax incentives, trade protection, and blending mandates (IEA 2011). The global cost these biofuels subsidies, calculated on the basis of direct budgetary spending, tax relief, and import duties, and indirect market price transfer was estimated at $22 billion in 2010 (IEA 2011; Gerasimchuk et al. 2012). Mandates, in particular, have become the preferred instrument of support as a result of worsening public sector deficits worldwide.[20] The rising use of mandates worldwide has transferred the burden of costs from governments to consumers through fuel and food markets. But mandates still come at a high cost to many governments, especially in countries where public investments are required to develop agricultural supply chains or refining and transportation infrastructure in order to meet the targets. Moreover, if mandates are set sufficiently high (e.g., at blending rates of 10 percent or more), they have the potential to distort prices more than conventional subsidies or tariffs and can thus have a significant impact on food security.

Agriculture-energy linkages

Biofuel subsidies and blending mandates have created a tighter connection between energy and agricultural markets, with major implications for global food prices. Energy has always been an important input into agricultural production, particularly in more advanced systems where nitrogen fertilizers and machinery are widely used and where transportation plays a major role in tradable inputs and outputs in the farm sector (as reviewed in Naylor 1996). However, agriculture-energy market linkages have become stronger in recent years as evidenced by high correlations for monthly prices of crude oil and key biofuel feedstocks (Abbott et al. 2008, 2009, 2011).[21] What do these connections imply for both the level and stability of food prices as the demand for transportation fuel continues to grow, especially in emerging economies?

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[19] In 2010, the EU biofuels sector was comprised of 80 percent biodiesel and 20 percent ethanol (Flach et al. 2011).

[20] For more information on specific mandates and targets throughout the world, see IEA 2011.

[21] For example, the correlation between maize and crude oil prices was insignificant (r=0.12) between 1980-2005 and rose to 0.77 between 2006-2011 when the U.S. introduced its renewable fuels standard (author's calculations based on crude oil prices from the U.S. Energy Information Administration, see http://www.eia.gov/dnav/pet/pet_pri_rac2_dcu_nus_m.htm, accessed January 2012. Calculations for corn prices were from the USDA National Agricultural Statistics QuickStats online database: http://www.nass.usda.gov/Quick_Stats/, accessed January 2012.

To answer this question, there are three key points to keep in mind. First, the size of the energy sector is vastly greater than the size of the biofuels sector, and as a result, energy prices have a direct affect on biofuel production but not vice versa. Second, the profitability of ethanol and biodiesel production is a function of crude oil and diesel prices (which determine the amount and type of fuel demanded), the price of natural gas (for refining ethanol and as a competitive fossil fuel in energy use), and the price of biofuel feedstocks (Cassman et al. 2006; Schmidhuber 2007). With mandates for biofuel consumption, agricultural commodities used as feedstocks tend to fluctuate between a floor price determined by the mandated demand, and a ceiling price above which biofuel refining is no longer profitable (also known as the "parity price" or the breakeven price for biofuel producers). Feedstocks typically account for 50-80 percent of variable costs in biofuels production, and therefore an endogenous cap on crop prices is set by the profitability criteria of the biofuels sector (Schmidhuber 2007; Mitchell 2010). Finally, alternations in the price of agricultural commodities used as feedstocks, such as maize and rapeseed, influence prices of other crops that are used as substitution in production and consumption at local to global scales. Given these relationships, it is not surprising that agriculture and energy prices have moved together, as have major agricultural commodity prices since 2006.[22]

The tight linkage between agriculture and energy prices introduces substantial uncertainty into the biofuels market, and into agricultural markets on which biofuels depend. Petroleum prices have historically been more volatile than the prices of agricultural commodities used as feedstocks (Naylor and Falcon 2010); large swings in energy prices can thus lead to major fluctuations in biofuel demand when the mandate is not binding. Recent experience in the U.S. raises additional questions about energy price volatility. Natural gas prices in the U.S. have plummeted since 2008 with rapid development and deployment of horizontal drilling and fracking technologies for shale gas (Greenstone et al. 2012). The gap between crude oil and natural gas prices has been increasing since the beginning of 2009, but this trend is unstable. During the 12-month period from the beginning of July 2011-2012, the price of light crude oil fluctuated from under \$80/barrel and to over \$110/barrel.[23] Declining natural gas prices have helped to lower costs of ethanol refining, but ethanol's competitive edge as a transportation fuel will be diminished if crude oil prices, which are strongly correlated with gasoline prices, were to remain under \$80/barrel. Moreover, if natural gas-based transportation infrastructure is widely developed in the U.S. in response to rising natural gas supplies and declining prices, investments in new ethanol-based technologies such as flex-fuel cars or E85 fleets could be crowded out.[24]

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[22] The correlation between crude oil prices and selected agricultural prices (maize, wheat, and soy) for the period 2006-2011 was above 0.7 for all three commodities. The correlations between commodities over the time period were 0.87 for maize-soy, 0.77 for wheat-soy, and 0.73 for maize-wheat (author's calculations based on IMF financial statistics deflated by IMF U.S. GDP deflator, 2005=100).

[23] These prices are for light crude WTI (West Texas Intermediate). Brent crude has similarly fluctuated within a higher range, peaking at almost \$130/barrel in March 2012 and then falling by more than 30 percent to \$88/barrel in June 2012. See www.oil-price.net (accessed July 10, 2012).

[24] The replacement of oil for natural gas in transportation fleets can occur with: 1) the conversion of natural gas to methanol, an alcohol with similar properties to ethanol; 2) the use of compressed natural gas (CNG)

The major state of flux in energy and agricultural commodity prices in the first half of 2012 is indicative of the type of market uncertainty that is likely to prevail in the years ahead. One could easily imagine a different scenario, in which crude oil prices were to soar due to political disruptions in the Middle East (e.g., the blockage of the Strait of Hormuz). In the absence of widespread natural gas technology or other transportation fuel alternatives, such an event would cause the demand for biofuels to shoot up and stay on a perfectly elastic course; that is, at a constant (high) price despite continued growth in supply. This sort of reliance on biofuels—particularly first generation biofuels—would have serious implications for agricultural demand and food prices. How large the shock would be, and how long it would last, are highly uncertain.

Biofuel mandates and crop prices

A more predictable scenario is that the implementation of mandates for first generation biofuels will lead to high and volatile prices for key feedstock commodities irrespective of political disruptions. Rapid growth in the biofuels sector since the turn of the century has broken the long-term downward trend in real agricultural prices that was caused mainly by surplus production in advanced economies. Much of this surplus is now being taken up directly or indirectly through the mandated use of biofuels. Enforced mandates essentially create an additional and inelastic level of demand for crops used as feedstocks, up to the point where the mandate is binding (Figure 4). With this new demand, any supply shock (e.g., drought) will be amplified in the market, causing a larger price hike than would be the case without the mandate. Moreover, if agricultural stocks decline as a result of the expansion in biofuel mandates, price spikes will be even higher.

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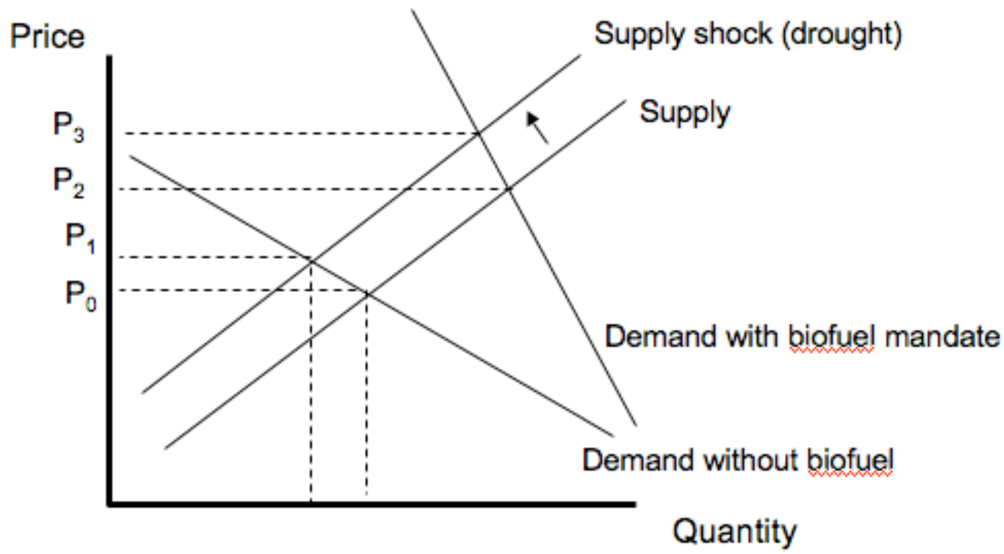
in light- to medium-duty vehicles using existing engine technologies; and 3) the use of CNG or liquefied natural gas (LNG) in medium- to heavy duty vehicles. For more information, see Knittel (2012).

Figure 4: Biofuels mandates create an added and inelastic level of demand for agricultural commodities used as feedstocks*



* Adapted from Abbott et al. (2009)

Growth in the U.S. corn ethanol market, spurred largely by mandates, illustrates this point (Naylor and Falcon 2011; Hertel and Beckman 2012). Between 2000 and 2010, U.S. corn ethanol production grew by a factor of eight, and by the end of this period, 40 percent of domestic corn consumption went to the ethanol industry—surpassing use in animal feeds for the first time on record. Domestic stocks-to-use for corn fell to 14 percent in the beginning of 2012, far below the levels for soy (22 percent) and wheat (31 percent).[25] Low stock levels have fueled expectations in commodity markets associated with speculative and, more important, non-speculative activity (Wright 2011). As a result, corn prices have been highly volatile since 2006 and rising in real terms despite continued growth in corn production. Allocating a greater share of corn to ethanol has played a key role in international price movements, amplifying shocks caused by climate and China's recent entry into global corn market.[26] Extreme heat and drought throughout the U.S. in 2012, coupled with low stock levels and ethanol mandates, has driven corn prices to an unprecedented peak, highlighting once again this pattern of volatility (Babcock 2012).

[25] USDA Production, Supply, and Distribution database http://www.fas.usda.gov/psdonline/ (accessed on March 13, 2012).
[26] Given the short time series by which to test the interaction between energy and agricultural price volatility in the recent biofuels era, Hertel and Beckman (2012) apply stochastic simulation techniques and use a general equilibrium model, GTAP (Global Trade Analysis Project), to assess the global economic impacts of the U.S. renewable fuels mandate and blending wall.

Price transmission and price-income effects

Understanding the food security implications of a global agricultural system linked to energy markets requires both macro- and micro- analyses. At the macro level, fluctuations in international agricultural prices affect food producers and consumers within any country only to the extent that prices are transmitted from global to domestic and local scales. Price transmission depends on a country's exchange rate (which in turn is a function of its macro-economic policy and financial capital flows), its trade policy, and transportation costs (Naylor and Falcon 2010). Relative to three decades ago when *Food Policy Analysis* was first published (Timmer, Falcon, and Pearson 1983), the magnitude and rate of global capital flows have exploded, and the majority of countries have transitioned from fixed exchange rates to some sort of flexible exchange rate regime. Trade policies have also changed course. Progress on opening agricultural trade through the WTO has proceeded slowly, and during the past decade, many developing countries have sought to insulate their domestic economies from global food price volatility. Several African nations have resorted once again to government-run marketing boards (Jayne et al. 2010a), and other countries throughout the world have implemented a variety of tariffs and quantitative controls in an attempt to protect domestic agricultural producers or consumers (Naylor and Falcon 2008; Martin and Anderson 2012).[27] Unfortunately, policies aimed at stabilizing domestic markets typically result in greater instability in international markets, particularly when such policies are implemented by countries that account for a large share of global trade (Timmer 2009; Timmer 2010; Naylor and Falcon 2010; Martin and Anderson 2012).

Transportation costs have also factored into trade strategies. Global freight costs have been relatively high and volatile since the mid-2000s due to fluctuations in crude oil markets. In addition, poor infrastructure and high fuel costs in many developing countries have resulted in wide CIF (import) and FOB (export) price bands that effectively insulate domestic markets and stifle governments' ability to drive food policy off of their trade policy (Timmer, Falcon and Pearson 1983; Naylor and Falcon 2010). Generalizations about price transmission across countries do not come easy. But understanding domestic price dynamics is key for assessing economic behavior at the household and firm levels in response to the expansion in global biofuels.

At the micro level, a set of own-price, cross-price, and income effects characterize the nature of food security outcomes with respect to changes in agricultural commodity prices. In addition, growth in the biofuels sector affects factor markets, as evidenced most clearly through changes in land values. Following from the U.S. ethanol discussion above, these price and income effects can be traced through an analysis of the corn market. Corn is often considered to be a lynchpin commodity in the world food system because of its multiple end uses in food, feed, fructose, and fuel, and because of its substitutability with other commodities in these end uses (Naylor and Falcon 2011). In an era of high prices, low-income households that are dependent on corn as a primary staple food either eat less or allocate more of their incomes to food and away from other

[27] Government attempts to stabilize domestic prices for key staple crops in sub-Saharan Africa have not succeeded, particularly when the role of the private sector has been subordinated (Jayne et al. 2010a, b).

expenditures.[28] Since food comprises up to 80 percent (and sometimes more) of household expenditures for the world's poorest households, a jump in staple food prices can have a devastating effect on nutrition, especially for girls and women who are fed last in many cultures when food supplies are short. Corn is a primary staple in eastern and southern Africa and in Central America, and most of the poorest households are net consumers (Jayne et al. 2010b; Naylor and Falcon 2010). Their ability to substitute into other low valued food commodities is limited, and thus price hikes for corn often translate directly into increased hunger.

Because corn is used as feed, fructose, and fuel in the global economy, a variety of cross-price responses also occur when corn prices rise. On the demand side, livestock producers and feed companies substitute away from corn and into wheat and other substitute ingredients. Ethanol blenders and food processors dependent on fructose (e.g., the soft drink industry) similarly adjust their inputs to use sugar over corn at certain price ratios. On the supply side, higher expected prices for corn linked to RFS mandates induce area expansion and investments in technology, inputs, and capital that are reflected in yield gains over time (Box 1). These partial-equilibrium dynamics become much more complicated in the real world when supply chains, macro prices (exchange rates and interest rates), trade policies, biophysical and nutrient constraints, factor markets, and financial markets come into play. As a result, computable general equilibrium (CGE) models have been developed to assess the economy-wide impacts of biofuels.[29] The bottom line with both approaches is that rising prices for corn due to the expansion of the ethanol industry have far-reaching effects on other agricultural commodity markets through substitutions in production and consumption, and on rural incomes and assets. Similar analyses could be done for other first generation biofuel systems, such as rapeseed-based biodiesel in the EU and its affects on the global vegetable oils market, or sugar-based ethanol in Brazil and its effects on land and labor markets.

Box 1: Direct and indirect effects of biofuels growth - the U.S. corn-ethanol case[30]

Growth in first generation biofuels alters prices of staple food crops through direct and indirect channels, as illustrated by the hypothetical example of U.S. corn-ethanol (Figure B-1). Creating a new level of demand for corn as an energy crop leads to price increases for corn, wheat, and soy in the short run in the absence of significant yield growth or crop area expansion. The ripple effects are seen in pristine land areas cleared for agriculture (e.g., conservation land in the U.S. or rainforests in Brazil), on the livestock sector, and on consumers of these staple food commodities—and they depend importantly on yield

[28] The theoretical foundation of this behavior is based on the Slutsky equation (which shows that the own-price response is a function of a pure substitution and an income response), and Timmer's Law (which shows that poor households are affected more than wealthier households by staple price increases because their budget shares for food are higher). See Timmer, Falcon, and Pearson (1983).

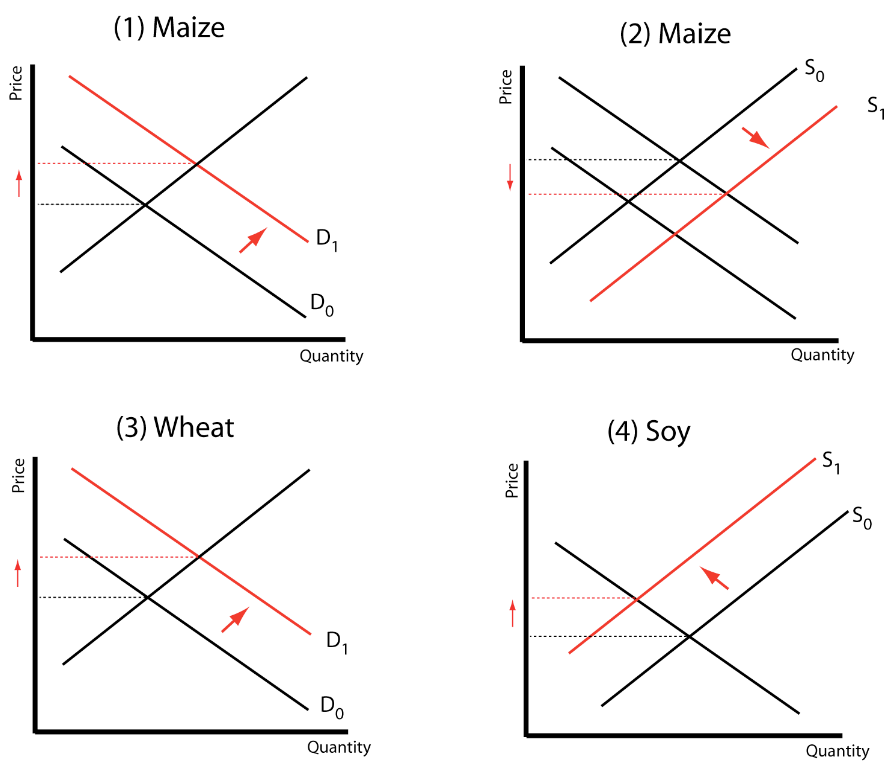
[29] There is a wide body of literature focused on economic assessments of biofuels using computable general equilibrium models, which is reviewed only partially in this chapter. For a broader review of the CGE studies, see Timilsina et al. (2012) and Zivin and Perloff (2012).

[30] Adapted from Naylor et al. (2007).

responses to rising prices over time. The magnitude of impact depends on adjustments in grain, oilseed, and livestock markets, and on price transmission domestically and internationally.

The food security implications of biofuels expansion must be considered in the context of food-feed-fuel linkages. Corn designated for ethanol in the U.S. returns roughly 30 percent of its volume to the livestock (mainly cattle and dairy) sector. Distiller grains are thus important by-products of the ethanol industry, contributing 15-20 percent of total revenue from ethanol processing.[31] Similar livestock feed by-products are produced from other forms of ethanol and biodiesel production worldwide. If these by-products are ignored in the analysis of biofuels, the implications for price consequences will be overstated, and the profitability of the biofuel sector will be understated (Taheripour et al. 2010).

Figure B-1. Dynamics of a biofuels-induced increase in demand for corn in the US



Notes: Y-axis = price; x-axis = quantity. D = demand curve; S = supply curve. Panel (1) – rising demand for corn leads to growth in supply along the curve that includes production at higher marginal costs. Panel (2) – longer run shift in supply due to technical change induced by higher prices. Panel (3) – higher corn prices increase demand for wheat in livestock markets, causing wheat prices to rise. Panel (4) – greater area sown to maize reduces area planted to soy, causing soy prices to rise.

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[31] Approximately 40 percent of ethanol plants in the U.S. produce wet distiller grains and 60 percent produce dry distiller grains. For more information on the role of by-products for livestock feeds, see Taheripour et al. (2010), Mitchell (2010), and Naylor and Falcon (2011).

Factor market effects

The rising demand for agricultural crops for food, feed and fuel has caused land to become an increasingly scarce factor of production at national and global scales. Over the short term, rising land scarcity and limited supply chains servicing land that is available suggests more inelastic agricultural supply (Abbott et al. 2011). The agricultural sector is unique relative to other sectors of the economy (with the exception of forestry) in its fundamental dependence on land. Creating additional value from agriculture through its use as fuel is thus reflected in greater marginal returns to land and higher land values, both for land dedicated to feedstock crops and for land planted with substitute crops. With well-functioning land markets, marginal returns to land are equated across crops, raising land values across the board (*ibid.*). In the U.S., for example, higher corn prices have been capitalized into high farmland values that mirror the record-breaking farm real estate spike of the early 1980s (Duffy 2011).[32]

Several CGE models have been developed to capture the effects of biofuels growth on land markets (as reviewed in Timilsina et al. 2012). These models differ in their treatment of crop yields, biofuels feedstocks and policies, land use, and trade, but generally show increased land values over the longer run. Yield growth in response to higher commodity prices and land values is critical to keeping land use change in check over the longer run (*ibid*.).[33] However, as Lobell points out in his paper for this series, ensuring future growth in crop yields will become increasingly challenging in the face of global climate change.

Using recent history as a gauge, biofuels are likely to have a major impact on global land use. Abbott et al. (2011) show that farmers have responded to the new agricultural demand since 2005/2006 by bringing new land into production, and by shifting away from crops that are not directly or indirectly related to the biofuels sector and into high-demand crops (Figure 5). For 13 of the world's major food crops, harvested area increased by 38 million hectares (three percent of current global agricultural land use) between 2005/6 and 2010/11. Only 30 percent of this land came from crop substitution, and 70 percent resulted from new area expansion. The major first-generation biofuels crops and their substitutes in staple food production and consumption accounted for most of the growth (sugar was not included as a staple food). In the U.S., land area for major food crops has remained fairly constant since 2005; most of the growth in corn area has come from substituting out of other crops and out of land dedicated to conservation. By

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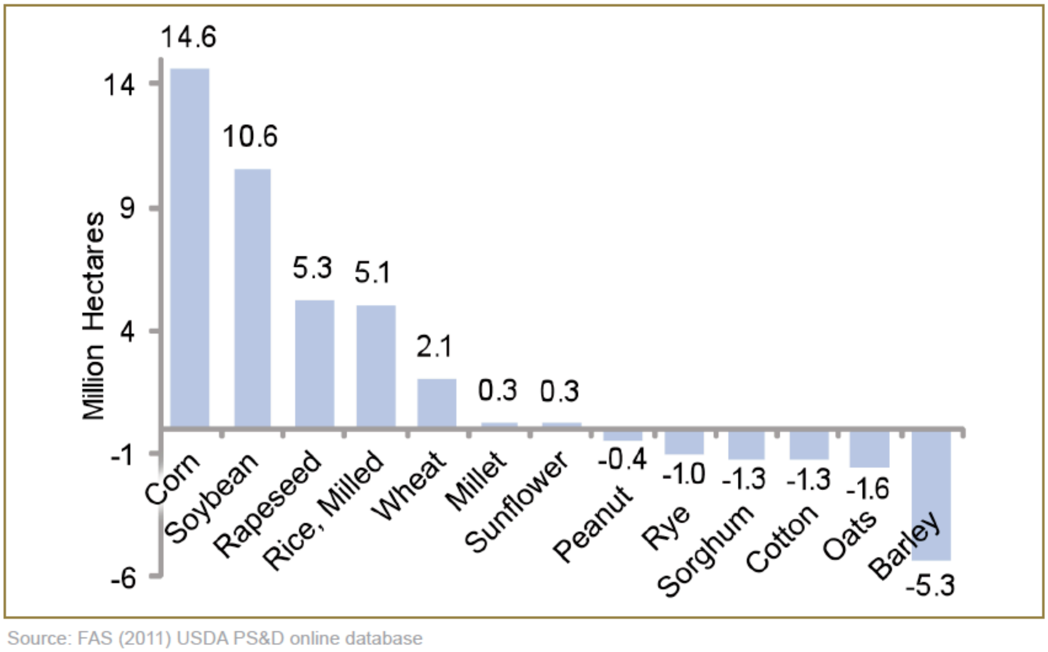
[32] Farm real estate values in the U.S. corn-belt rose from an average of $2500/acre in 2005 to $3500/acre in 2010 (with the top state, Illinois, surpassing $4000/acre). These values are almost identical to the highest values recorded during the 1980 land value spike in the U.S. (Farmdoc.com). The difference between the two periods is that interest rates in the current period have been hovering close to zero, reinforcing the fact that land is an excellent investment in the U.S., especially with expected high returns stemming from the RFS mandates.

[33] The CGE model developed by Timilsina et al. (2012) uses an explicit land use module and detailed biofuel sectors and targets for countries throughout the world; it suggests significant reductions in pasture and forest land by 2020 in some key countries, but only moderate price increases for food commodities (with the exception of sugar) due to yield responses over time.

contrast, sub-Saharan Africa has experienced widespread acquisitions of undeveloped land during the past decade, a topic that is discussed further in the following section.

Figure 5: Change in global harvested area for 13 major food crops (2005/6 to 2010/11)



Source: Abbott et al. (2011)

The increased value of agricultural production related to biofuels also feeds back to higher wage rates in agricultural production and processing, with potential spillovers to other sectors of the economy depending on the size of the biofuel industry (Ewing and Msangi 2009). For example, wages in the sugarcane and ethanol industries in Brazil have risen with the expansion of ethanol over the past few decades (Smeets et al. 2008), as have human development indicators in regions where sugar and ethanol processing have become major activities (Martinelli et al. 2011). The degree to which agricultural commodity prices influence rural wages, and in turn poverty alleviation and food security in the developing world depends on the share of agriculture and biofuels processing in the region's economy, labor mobility, employment conditions and contracts, and the rate of food price increase affecting inflation-adjusted earnings and food access for low-income households. Although biofuels growth can enhance rural incomes, it can also decrease food supplies and access for the poor (Rosegrant et al. 2008; Timilsina et al. 2012).

Biofuels development in food insecure countries

There are clearly pros and cons to biofuel expansion in countries that have persistently high rates of hunger, virtually all of which are agrarian economies. On the one hand, high and volatile prices hurt low-income net consumers in rural and urban areas who spend the majority of their income on food. In addition, high agricultural prices in international markets create fiscal challenges for governments in net grain and oilseed importing countries. On the other hand, developing a domestic biofuels sector can help countries achieve greater energy security, and can promote rural development, agricultural employment, and income growth. The main problems with an agricultural development strategy based on domestic biofuels growth are: 1) it can displace crop production for direct food consumption; 2) it can increase local food prices and land values, and induce speculative activity in domestic land markets ("land grabs"); and 3) it can create opportunity costs with respect to development spending on alternative objectives such as health and education, and it can alter current account balances with wide-reaching macroeconomic effects (Arndt et al. 2010; Mitchell 2010).

Any welfare assessment of biofuels in food insecure countries should thus consider both micro- and macroeconomic aspects of development, and clearly identify the strategy of development that is being pursued. Mitchell (2010) outlines three distinct phases of biofuel development in low-income countries, each of which requires different levels of policy support, institutional capacity, trade activity, and regulatory oversight. The first phase entails the production of agricultural feedstocks for export and for limited use in local transportation and small-scale stationary energy uses. For example, countries might invest in sugar production for export to ethanol refiners, or in jatropha production for export as straight (unprocessed) vegetable oil (SVO) for the biodiesel industry or for local energy use. Projects at this stage are focused mainly on export crop promotion, rural income enhancement, and seasonal risk management of incomes; however, such projects might impose tradeoffs in local resource use (land, water, nutrients) with food crops for domestic consumption. The second phase of development revolves around the production and export of processed biofuels, with the aim of filling gaps in renewable fuels mandates in other countries, and taking advantage of preferential trade access that might be available to U.S., EU, and other markets. A portion of the biofuels production, most likely in the E5-10 and B5 range, might also be allocated to domestic fuel use. Projects at this stage require more direct involvement of the private sector and more thorough development of supply chains, fuel quality regulation, and infrastructure than in the case above. The third stage includes the production and retail sale of biofuels for domestic transportation use at larger scale, and requires significant institutional capacity, infrastructure development, and government support. In order to promote domestic fuel security and rural agricultural investments, the blending target might be set at E85 and B85 depending on domestic resource availability.

How do these different strategies play out in terms of food security and rural income growth? Arndt et al. (2010) present a useful framework for evaluating biofuels projects in developing countries, with a specific eye on sub-Saharan Africa (Table 1). Starting at the household level, the consequences of biofuels development on human welfare depend on trade-offs between feedstock and food production, seasonal income earning opportunities for families engaged in the biofuel sector, and household labor allocation—particularly for women who dominate the farm sector and play a pivotal role in household food production (UNDP 2012; Arndt et al. 2012). At the farm or firm level, successful investments in biofuel feedstock and refining activities depend on production costs (including the value of family or hired labor), seasonal labor requirements and constraints, market profitability, international competitiveness, and price volatility. These variables, in turn, are a function of infrastructure, supply chain development, and agricultural policy.

Table 1: Framework for evaluating biofuels investments

Level of analysis	Consideration
Household	Income, poverty, labor allocation, and food security
Farm or Firm	Production costs, international competitiveness
	Profitability, price volatility
Macroeconomic	Taxes, public investments, and fiscal balances
	Employment, resources, and growth linkages
Environment	Water use, wildlife corridors, GHG emissions

Source: Adapted from Arndt et al. (2010)

Moving from the micro- to the macro- level, interest rates, exchange rates, and factor mobility (labor, credit) play a key role in the success of biofuels investments, as do public investments in infrastructure (e.g., roads and ports), fiscal policy (tax exemptions and budget balances), and trade agreements. For example, attracting international investments in the biofuels industry is likely to entail large public sector investments, as well as tax exemptions on fuels and exports—all of which could deplete government revenues that might otherwise be used for the smallholder agriculture sector, domestic water infrastructure, health clinics, and other development priorities.[34] Finally, at the local to national scale, the ability to meet land and water requirements is critical for the success of biofuels development. How access rights are designed and enforced for land and water use have major implications for production capacity and income distribution. Moreover, the structure and enforcement of wildlife corridors and environmental regulations (e.g., water pollution from refining, air pollution from burning) are important for human health, ecosystems, and tourism revenues. Given these wide-ranging consequences for human welfare, government budgets, and the environment, strategies to promote rural development and energy security through the biofuels industry must be analyzed with great care, particularly for food insecure countries.

Biofuels development in sub-Saharan Africa

The biofuels sector may be an attractive target for development in sub-Saharan Africa for several reasons. There are large untapped land holdings available for further agricultural development throughout the continent, and there is a desire by many countries to promote export crops for foreign exchange earnings. More generally, the biofuels sector provides

[34] Fiscal balances are an important component of the welfare outcome. In many countries, transportation fuel is taxed heavily and adds to government revenue, but biofuels investors often demand tax exemptions for blending and distributing fuel, as has been the case in the U.S.

an opportunity to enhance agricultural investments and develop supply chains for rural income growth and improved food security. It also provides an avenue for countries to meet their large and rising fuel needs. Much of sub-Saharan Africa remains energy insecure for transportation, cooking, lighting, heating and cooling, and production activities (Nussbaumer et al. 2012). Fuel prices throughout the continent are roughly double those in other competitive regions (and even higher for landlocked countries), and the demand for transportation fuel is expected to grow by more than 5 percent per annum through 2020 with continued population and income growth (Mitchell 2010).

Several African countries have adopted biofuels blending targets or mandates, and provide subsidies at different stages in the value chain (IEA 2011; Gerasimchuk et al. 2012). There are a wide variety of crops that can be used for biofuels in the region, including sugar (cane and molasses), maize, cassava, sweet sorghum, jatropha, castor beans, and palm oil. Some of these crops, especially maize and cassava, have large tradeoffs with food consumption and are not widely used as fuels. The two leading biofuel feedstocks in the region are molasses and jatropha, neither of which is a staple food commodity (jatropha is toxic for human consumption).[35] Africa has a long history of sugar production with supply chains already in place in several countries, and investments in sugar-based ethanol benefit from decades of technological development in Brazil. Sugar tends to be a water-intensive crop, however, which limits production and imposes major opportunity costs with respect to staple food production given that less than five percent of agriculture in sub-Saharan Africa is currently irrigated. Jatropha, on the other hand, can be grown under marginal, drought-prone conditions by smallholders. The drawbacks are that there is no history of crop breeding in jatropha, very little experience in jatropha-based biodiesel production, and no human consumption value to the crop if the fuel market fails. Moreover, although the crop can be grown under marginal conditions, yields are substantially higher when fertilizers, irrigation, and other inputs are used (Ewing and Msangi 2009; Altenburg 2011). Labor requirements for jatropha production are also very high because the seeds ripen throughout the year and need to be picked by hand. As a result, labor availability and costs are often the major constraint on growth of the jatropha industry (Mitchell 2010).

The implications of biofuels development for food security in sub-Saharan Africa revolve around a few key issues. First, the level of government support needed to attract foreign investments for commercial-scale growth in feedstock and biofuel production often involves commitments to build infrastructure and provide tax exemptions or subsidies that diminish budget revenues for other development priorities that might enhance food security. A related issue is that large-scale expansion of feedstocks requires land and water, which raises a series of thorny questions about property rights and access to resources. Much of the unoccupied land on the continent is state-owned, and individual countries have different statutes related to customary land rights and the ability to own or lease real property on crown land. The ambiguity in and high potential value of land

[35] Molasses is one of the lowest-cost commodities that can be used as an export or in domestic production of ethanol, but it is not as high yielding as sugarcane. The latter has higher trade-offs as a food commodity and also higher production costs. See Mitchell (2010) for further details on production practices and costs of alternative feedstocks and biofuels in Africa.

ownership has led to widespread land acquisitions (also referred to as "land grabs") by foreign companies, global financial companies trading land-based assets, and individuals within and outside of Africa who see land as a lucrative investment—especially since other financial investments have lost value since 2008 (Kugelman and Levenstein 2012). The International Land Coalition estimates that over 31 million ha of land was sold in sub-Saharan Africa between 2000 and 2011; the largest regional purchaser was Asia (38%), followed by Africa and Europe (each ~20%) and North America (~10%).[36] During the past five years, the main targeted use for this acquired land (~40%) has been biofuels (Schoneveld (CIFOR) 2010), although only a portion has been cultivated to date. There is clearly a speculative component to land transactions in Africa that differs from the more structural factors influencing land market sales in the U.S. and other fully developed agricultural systems.[37] How these land acquisitions affect smallholder production in Africa—and particularly the ability of poor households to secure land assets, water, and other inputs such as fertilizer relative to larger landholders coming into the region—is a critical factor influencing food security in the region (as discussed in the paper by Jayne et al. in this series).

Despite the focus on land acquisitions in sub-Saharan Africa, there are many opportunities for smallholders to engage in biofuel activities, either as outgrowers selling their product to a central processing firm, or as employees on larger estates. In some locations, farmers also lease their land to biofuel producers, or grow and process small amounts of oil from jatropha or other oil seeds such as castor beans for small-scale local use. There are several case studies of biofuel operations in eastern and southern Africa showing the outcomes of various value chain arrangements (see for example, Ewing and Msangi 2009; Mitchell 2010; Arndt et al. 2010; Negash and Swinnen 2012). In virtually all cases, these operations are foreign owned, and they either employ agricultural workers or have some sort of contracting arrangement with smallholders. The latter can provide additional income on a year-round basis and thus reduce seasonal risks of income loss; they can also lead to the creation of supply chains that have positive spillover effects on local staple crop systems (Negash and Swinnen 2012). One of the main lessons from these studies, however, is that supply chains are commonly the limiting factor for success. It is often difficult to achieve sufficient expansion for economies of scale, and the ability of outgrowers to remain profitable is frequently constrained by their lack of credit and other inputs (Mitchell 2010). Although government support is usually strong for these projects, the institutional capacity is often insufficient to manage risks, ensure stable prices, and enhance smallholder productivity. But the industry is at a nascent stage, and some of these constraints could be overcome in the future.

Biofuels development in India

Like sub-Saharan Africa, India continues to experience widespread food and energy insecurity despite rapid income growth. In order to encourage the production and use of

[36] See the Anseeuw et al. (2011) report on "Land Rights and the Rush for Land", http://www.landcoalition.org/cpl/CPL-synthesis-report, accessed July 19, 2012.
[37] For a discussion on the structural features of U.S. farmland values, see Gloy et al. (2011).

renewable fuels as the demand for transportation fuel escalates, the Government of India approved a National Biofuels Policy in December 2009 (Aradhey 2011). This policy establishes an indicative blending target of 20 percent for both ethanol and biodiesel by 2017—it is suggestive (not a hard mandate) because the country has struggled to supply sufficient feedstocks to meet its target in the past (*ibid.*). The policy also includes a suite of support prices for feedstocks and biofuels, as well as various tax exemptions. Given the state of food insecurity in India (as discussed by Binswanger and Banziger in this series), the aim of the policy is to develop non-edible feedstocks—mainly sugar and jatropha and other native tree-based oilseeds.

Despite good intentions, the country faces some major challenges in meeting its biofuels targets over the next five years. India is the world's second largest sugar producer after Brazil (Aradhey 2011), but its production has been highly volatile during the past two decades (Landes 2010). Sugar production is dominated by small-scale producers who often have limited access to inputs and thus variable yields. Land ownership laws in the country prevent vertical integration (e.g., refining mills cannot own land or invest directly in feedstock production), and prices offered by blenders are often too low to cover feedstock production costs. At the same time, the sugar industry (and the molasses sub-industry) is heavily regulated, with government controls on prices, mill capacity, domestic consumption, and trade. The combination of production volatility and widespread inefficiencies in the sector has limited India's ability to meet its ethanol targets to date (Raju et al. 2009). Moreover, the share of sugar area that is irrigated is between 90-100 percent in most regions where it is grown (Landes 2010), which raises serious questions about the allocation of scarce water supplies for fuel versus food. If sugar remains the target feedstock for ethanol production in the future, its drain on available water resources could have large impacts on the nation's food security, particularly in light of climate change (see Lobell's paper in this series).

In addition, growth in India's biodiesel sector has been dependent in the past on imported soy and palm oil from Southeast Asia and South America, which has implications for the country's foreign exchange reserves, as well as for tropical deforestation and climate change. Foreign investments are now being encouraged to support domestic jatropha production as a feedstock.[38] However, most of the production is occurring under marginal conditions, and as in the Africa case, producers experience poor yields, low prices, and high labor costs. It is unlikely that jatropha will become cost-competitive with fossil diesel or imported vegetable oils in the future. As a result, the prospects for commercial jatropha-based biodiesel to generate rural economic growth and improve food security are limited.

Finally, and perhaps most important, the National Biofuels Policy was approved at the federal level, but it must be implemented at the state level. Political and institutional

[38] Jatropha is also commonly planted as a boundary hedge crop to protect crops and prevent soil erosion, which provides modest additional income to farmers without tradeoffs to agriculture and livestock systems. More dispersed plantings of jatropha in forest systems or along rail lines have not contributed much to feedstock production, because even very poor households find the labor requirements too high and the returns too low to collect the seeds (Altenburg 2011).

conditions vary highly among states, as do socioeconomic variables and the nature of biofuel value chains (Altenburg 2011). Individual states also have different norms and goals surrounding the biofuels sector, varying sets of favored constituencies, and distinct realms of political power and organization. These factors result in a wide array of prices and tax structures, and complications in interstate trade of feedstocks and biofuels (*ibid*.). At the federal level, regulatory oversight of the biofuels industry is complex, involving at least five ministries (Raju 2009; Evans 2010). India's success in meeting its renewable fuel targets through first generation biofuels—to say nothing about enhancing rural incomes and food security—hinges in large part on resolving these inconsistencies between state and federal directives. Even if they were resolved, the complicated socio-political context underpinning biofuel activities at the state level is still likely to constrain biofuel expansion in the future (Altenburg 2011).

Conclusion

The wide range of food security and policy issues reviewed in this paper suggest that the global expansion of liquid biofuels (ethanol and biodiesel) is indeed changing the nature of agricultural demand and rural development. Three main themes emerge from the chapter. The first theme surrounds the issue of uncertainty that dominates any discussion of future biofuels growth. Given the tight linkages between the agriculture and energy sectors, the realm of uncertainty is vast. It includes, for example, fluctuating trends in energy supplies and prices, particularly in light of natural gas investments in the U.S. and political tensions in the Middle East; uncertainties in global financial systems, economic growth, and energy demand; unclear trajectories for the commercial viability of advanced (second and third generation) biofuels; and extreme heat waves and droughts that cause crop prices—and hence first-generation biofuel feedstock prices—to spike. Volatility in crop and energy prices creates additional uncertainties in the policy domain. In the case of the U.S., the world's largest biofuel producer and supplier of grains to the international market, such volatility could lead to important changes in renewable fuel mandates, blending requirements, waivers, and regulations on biofuel production—all of which would affect global food prices and food security.

The second main theme relates more specifically to government policies and the development of supply chains that such policies have supported. One of the key lessons from the U.S. ethanol and EU biodiesel examples is that there is no such thing as a "clean slate" when it comes to agricultural policy. Biofuel subsidies and mandates have created new price dynamics in international grain and vegetable oil markets, but they follow from an already distorted global food economy that has been characterized by subsidized production, surplus dumping, and high levels of trade protection in many industrialized countries. The downward trend in real prices that dominated international agricultural markets during the second half of the 20th century—viewed by many analysts as the leading disincentive for global agricultural investment in developing countries—was reversed in the first decade of the 21st century with rapid growth in biofuel demand (Swinnen 2011). Whether this shift is good or bad for global food security remains hotly contested and depends largely on the time frame of analysis and assumptions on agricultural investments and yield growth in response to changes in crop prices. But one underlying condition is clear: the 21st century biofuel boom would not have occurred without substantial government subsidies and without the prior existence of supply chains that could support the ethanol and biodiesel sectors in the U.S., EU, and Brazil. In particular, policies that led to the emergence of strong private sector involvement in the agricultural and energy sectors were critical for the successful development of biofuel industries that were capable of capturing potential economies of scale.

The third and final theme draws on these points and addresses the question: Given the uncertainties and public sector costs surrounding the development of liquid biofuels, should developing countries facing high rates of food and energy insecurity invest in the industry? There is no universal answer to this question; each country must evaluate its own economic and resource situation, and its institutional capacity. This evaluation must be done with skill and great care, because the stakes for rural development, hunger, resource depletion, and inequality are high. Adopting a strategy for biofuel growth as a means of stimulating the agricultural economy, addressing domestic transportation fuel needs, and enhancing foreign exchange reserves will require the creation of well-functioning supply chains that can generate economies of scale. To date, small isolated plants with new sources of feedstocks (e.g., jatropha) have thus far been too costly. Public investments in agricultural productivity and infrastructure, as well as fuel mandates and tax exemptions for private companies that are needed to build supply chains and ensure long-run demand for biofuels, will have large opportunity costs in terms of fiscal expenditures, land and water resources, and political capital.

Arguably the most prominent opportunity cost related to biofuels development is the trade-off with domestic food supplies that support local and regional markets. This trade off involves land and water resources as well as labor allocation. In many cases, the reallocation of family land, domestic water supplies, and women's labor (which constitutes the majority of agricultural labor in sub-Saharan Africa) from food crops into biofuel feedstocks leads to a reduction in household food production and deteriorating health for family members. The sum of losses at the micro-level could thus erode well-intentioned development targets at the macro-scale. Increased biofuel production and improved food security will be a very delicate marriage for most developing countries. There are already many signs—highlighted by worsening resource inequality in several nations—that the marriage may not be blissful and lasting.

References

Abbott, P., Hurt, C., and W. Tyner. 2008. What's driving food prices? July 2008 Update. Farm Foundation Issue Report. Available online from: http://www.farmfoundation.org/webcontent/Farm-Foundation-Issue-Report-Whats-Driving-Food-Prices-404.aspx. Accessed July 19 2012.

Abbott, P., Hurt, C., and W. Tyner. 2009. What's driving food prices? March 2009 Update. Farm Foundation Issue Report. Available online from: http://www.farmfoundation.org/issuereports.aspx. Accessed 19 July 2012.

Abbott, P., Hurt, C., and W. Tyner. 2011. What's driving food prices in 2011? Farm Foundation Issue Report. Available online from: http://www.farmfoundation.org/issuereports.aspx. Accessed 22 June 2012.

Altenburg, T. 2011. Interest groups, power relations, and the configuration of value chains: The case of biodiesel in India. *Food Policy* 36(6): 742-748.

Anseeuw, W., Wily, L.A., Cotula, L., and M. Taylor. 2011. Land rights and the rush for land: Findings of the global commercial pressures on land research project. Rome: International Land Coalition.

Aradhey, A. 2011. India biofuels annual (GAIN Report No. IN1159). New Delhi: Global Agricultural Information Network, United States Department of Agriculture Foreign Agricultural Service.

Arndt, C., Msangi, S., and J.Thurlow. 2010. Are biofuels good for African development? Working Paper No. 2010/110. Helsinki, Finland: World Institute for Development Economics Research.

Arndt, C., Benfica, R., and J. Thurlow. 2012. Gender implications of biofuels expansion in Africa: The case of Mozambique. Working paper. Washington, D. C.: The World Bank and International Food Policy Research Institute.

Babcock, B. 2012. Preliminary assessment of the drought's impacts on crop prices and biofuel production. Center for Agricultural and Rural Development (CARD) Policy Brief 12-PB7. Ames, Iowa: Iowa State University.

Barros, S. 2011. Brazil sugar annual 2011 (GAIN Report Number BR110006). Global Agricultural Information Network. The Hague: United States Department of Agriculture Foreign Agricultural Service.

Blandford, D., Josling, T., and J. Bureau. 2011. Farm policy in the U.S. and EU: The status of reform and the choices ahead. Washington, D.C.: International Food and Agricultural Trade Policy Council.

Campbell J.E., Lobell D.B., and C.B. Field. 2009. Greater transportation energy and GHG offsets from bioelectricity than ethanol. *Science* 324(5930): 1055-1057.

Cassman, K., Eldman, V., Simpson, E., Berger, L., Loomis, R., Walsh, M., Peterson, T.A., and E. Runge. 2006. Convergence of agriculture and energy: Implications for research and policy. Lincoln, NE: USDA Agricultural Research Service.

Congressional Budget Office. 2012. The Supplemental Nutrition Assistance Program. Available online from: http://cbo.gov/publication/43173. Accessed 19 July 2012.

de Gorter, H. and D.R. Just. 2007. The law of unintended consequences: How the U.S. biofuel tax credit with a mandate subsidizes oil consumption and has no impact on ethanol consumption. Working Paper 2007-20. Cornell, NY: Cornell University Department of Applied Economics and Management.

de Gorter, H., Drabik, D., and D.R. Just. 2011. The economics of a blender's tax credit versus a tax exemption: The case of U.S. 'Splash and Dash' biodiesel exports to the European Union. *Applied Economic Perspectives and Policy* 33(4): 510-527.

Duffy, Michael. 2011. The current situation on farmland values and ownership. *Choices* 26(2).

European Union (EU) 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources. *Official Journal of the European Union*.

Evans, Martin. 2010. Key requirements for successful biofuel sector development in Senegal: A summary assessment. Biofuels and the Poor. Gates Foundation, Stanford University, and IFPRI.

Ewing, M. and S. Msangi. 2009. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. *Environmental Science and Policy* 12: 520-528.

Fargione, J., Hill, J., Tilman, D., Polasky, S., and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Science* 319(5867): 1235-1238.

Flach, B., Lieberz, S., Bendz, K., and B. Dahlbacka. 2011. EU-27 Annual Biofuels Report (GAIN Report No. NL1013). Global Agricultural Information Network. The Hague: United States Department of Agriculture Foreign Agricultural Service.

Gerasimchuk, I., Bridle, R., Beaton, C., and C. Charles. 2012. State of play on biofuel subsidies: Are policies ready to shift? Manitoba: International Institute for Sustainable Development (IISD).

Gloy, B., Boehlje, M.D., Dobbins, C.L., Hurt, C., and T.B. Baker. 2011. Are economic fundamentals driving farmland values? *Choices* 26(2).

Greenstone, M., Koustas, D., Li, K., Looney, A., and H. Marks. 2012. Farming memo: Energy policy opportunities and continuing challenges in the presence of increased supplies of natural gas and petroleum. The Hamilton Project.

Hertel, T. W. and J. Beckman. 2012. Commodity price volatility in the biofuel era: An examination of the linkage between energy and agricultural markets. In Zivin, J.G. and Perloff, J.,eds., *The intended and unintended effects of U.S. agricultural and biotechnology policies*. NBER and University of Chicago Press.

International Energy Agency (IEA). 2011. Technology roadmap: Biofuels for transport. Paris: International Energy Agency.

International Energy Administration (IEA). 2012. Annual Energy Outlook. Available online from http://www.eia.gov/forecasts/aeo/. Accessed 04 August 2012.

International Monetary Fund. 2012. International Financial Statistics e-Library, Wheat and Maize Commodity Prices and US GDP Deflator. http://elibrary-data.imf.org/DataExplorer.aspx. Accessed 11 July 2012.

Jayne, T.S., Chamberlin, J., and M. Muyanga. 2012. Emerging land issues in African agriculture: Implications for food security and poverty reduction strategies. Stanford Symposium Series on Global Food Policy and Food Security in the 21st Century. Stanford: Center on Food Security and the Environment.

Jayne, T.S., Chapoto, A., and J Govereh. 2010a. Grain marketing policy at the crossroads: challenges for Eastern and Southern Africa. Chapter 6 in Sarris, A. and Morrison, J., eds, *Food security in Africa: Market and trade policy for staple foods in Eastern and Southern Africa*. Northampton: Edward Elgar Publishing (FAO).

Jayne, T.S., N. Mason, R. Myers, J. Ferris, D. Mather, M. Beaver, N. Lenski, A. Chapoto, and D. Boughton. 2010b. Patterns and trends in food staples markets in Eastern and Southern Africa: Toward the identification of priority investments and strategies for developing markets and promoting smallholder productivity growth. Michigan State University, International Development Working Paper No. 104. East Lansing: Michigan State University Department of Agricultural, Food, and Resource Economics.

Kennedy, D. 2007. The biofuels conundrum. *Science* 316(5824): 515.

Knittel, C.R. 2012. Discussion paper 2012-03: Leveling the playing field for natural gas in transportation. The Hamilton Project.

Kugelman, M. and S. L. Levenstein. 2012. The global farms race: Land grabs, agricultural investment, and the scramble for food security. Washington: Island Press (in press).

Kutas, G., Lindberg, C., and R. Steenblik. 2007. Biofuels: At what cost? Government support for ethanol and biodiesel in the European Union. Switzerland: International Institute for Sustainable Development.

Landes, M.R. 2010. Indian sugar sector cycles down, poised to rebound. Washington, D.C.: United States Department of Agriculture Economic Research Service, SSS-M-260-01.

Lobell, D. 2011. Climate change and agricultural adaptation. Stanford Symposium Series on Global Food Policy and Food Security in the 21st Century. Stanford: Center on Food Security and the Environment.

Loarie, S.R., Lobell, D.B., Asner, G.P., Mu, Q., and C.B. Field. 2011. Direct impacts on local climate of sugar-cane expansion in Brazil. *Nature Climate Change* 1: 105-109.

Martin, W. and K. Andersen. 2012. Export restrictions and price insulation during commodity price booms. *American Journal of Agricultural Economics* 94(2): 422-427.

Martinelli, L.A., Garrett, R., Ferraz, S., and R. Naylor. 2011. Sugar and ethanol production as a rural development strategy in Brazil: Evidence from the state of Sao Paulo. *Agricultural Systems* 104(5): 419-428.

McPhail, L., Westcott, P., and H. Lutman. 2011. The renewable identification number system and U.S. biofuel mandates (Outlook No. BIO-03). Washington, D.C.: United States Department of Agriculture Economic Research Service.

Mitchell, D. 2010. Biofuels in Africa: Opportunities, prospects, and challenges. Washington, D.C.: The World Bank.

Mosher, A.T. 1966. Getting agriculture moving. Agriculture Development Council.

Naylor, R. L. 1996. Energy and resource constraints on intensive agricultural production. *Annual Review of Energy and the Environment* 21: 99-123.

Naylor, R.L. and W.P Falcon. 2008. Our daily bread: Without public investment, the food crisis will only get worse. *The Boston Review* September/October.

Naylor, R.L. and W.P Falcon. 2010. Food security in an era of economic volatility. *Population and Development Review* 36(4): 693-723.

Naylor, R.L. and W.P Falcon. 2011. The global costs of American ethanol. *The American Interest* 7(2): 66-76.

Naylor, R.L., Liska, A., Burke, M., Falcon, W.P., Gaskell, J., Rozelle, S., and K. Cassman. 2007. The ripple effect: Biofuels, food security, and the environment. *Environment* 49(9): 30-43.

Negash, M. and J. Swinnen. 2012. Biofuels, poverty and food security: micro-evidence from Ethiopia. Working paper. Belgium: LICOS Center for Institutions and Economic Performance, University of Leuven.

Nussbaumer, P., Bazilian, M., and V. Modi. 2012. Measuring energy poverty: Focusing on what matters. *Renewable and Sustainable Energy Reviews* 16: 231-243.

Rabobank. 2012. The future of ethanol- Brazil and U.S. perspectives. *Marketwatch, PR Newswire*, March 1.

Raju, S.S., Shinoj, P., and P.K. Joshi. 2009. Sustainable development of biofuels: Prospects and challenges. *Economic and Political Weekly* 44(52): 65-72.

REN21. 2012. Renewables 2012 Global Status Report. Paris: REN21 Secretariat.

Rosegrant, M.W., Zhu, T., Msangi, S., and T. Sulser. 2008. Global scenarios for biofuels: Impacts and implications. *Applied Economic Perspectives and Policy* 30(3): 495-505.

Schmidhuber, J. 2007. Biofuels: An emerging threat to Europe's Food Security? Notre Europe Policy Paper 27, May.

Schoneveld, George C. 2010. Potential land use competition from first-generation biofuel expansion in developing countries. Center for International Forestry Research Occasional Paper No. 58. Bogor, Indonesia: CIFOR.

Searchinger, T., Heimlich, R., Houghton, R.A., Dong, F., Elobeid, A., Fabiosa, J., Tokgoz, S., Hayes, D., and T. Yu. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land use change. *Science* 319:1238-1240.

Smeets, E., Junginger, M., Faaij, A., Walter, A., Dolzan, P., and W. Turkenburg. 2008. The sustainability of Brazilian ethanol—an assessment of the possibilities of certified production. *Biomass and Bioenergy* 32(8): 781–813.

Swinbank, A. 2009. EU policies on bioenergy and their potential clash with the WTO. *Journal of Agricultural Economics* 60(3): 485-503.

Swinnen, J. 2011. The right price of food. *Development Policy Review* 29(6): 667-688.

Taheripour, F., Hertel, T.W., Tyner, W.E., Beckman, J.F., and D.K. Birur. 2010. Biofuels and their by-products: Global economic and environmental impacts. *Biomass and Bioenergy* 34: 278-289.

Tilman, D., Socolow, R., Foley, J.A., Hill, J., Larson, E., Lynd, L., Pacala, S., Reilly, J, Searchinger, T., Somerville, C., and R. Williams. 2009. Beneficial biofuels – The food, energy, and environment trilemma. *Science* 325(5938): 270-271.

Timilsina, G., Beghin, J., van der Mensbrugghe, D., and S. Mevel. 2012. The impacts of biofuels on land-use change and food supply: A global CGE assessment. *Agricultural Economics* 43: 315-332.

Timmer, P.C. 2009. Management of rice reserve stocks in Asia: Analytical issues and country experiences. Paper presented to the Experts' Meeting on "Institutions and Policies to Manage Global Market Risks and Price Spikes in Basic Food Commodities" by the FAO Trade and Markets Division, 26-27 October, 2009 at FAO Headquarters, Rome, Italy.

Timmer, P.C. 2010. Did speculation affect world rice prices? In David Dawe, ed*., The rice crisis: Markets, policies and food security*. London and Washington, DC: Earthscan, pp. 29-60.

Timmer, P.C., Falcon, W.P., and S.R. Pearson. 1983. *Food Policy Analysis*. Baltimore: Johns Hopkins University Press (The World Bank).

United Nations Development Programme (UNDP). 2012. African Human Development Report 2012: Towards a food secure future. New York: UNDP Regional Bureau for Africa.

United States Congress. 2007. Energy Independence and Security Act of 2007.

United States Department of Agriculture (USDA). 2011. Measuring the indirect land-use change associated with increased biofuel feedstock production: A review of modeling efforts. Washington, DC: U.S. Department of Agriculture, Economic Research Service.

Valdes, C. 2011a. Brazil's ethanol industry: Looking forward. Washington, DC: U.S. Department of Agriculture, Economic Research Service. BIO-02.

Valdes, C. 2011b. Can Brazil meet the world's growing need for ethanol? *Amber Waves* 9(4): 36-45.

Worldwatch Institute. 2012. *Vital Signs 2012: The trends that are shaping our future*. Washington, D.C.: Island Press.

Wright, B. D. 2011. The economics of grain price volatility. *Applied Economic Perspectives and Policy* 33(1): 32-58.

Zivin, J. G. and J. Perloff (eds). 2012. *The Intended and Unintended Effects of U.S. Agricultural and Biotechnology Policies*. NBER and University of Chicago Press.

Core literature on Biofuels, Rural Development, and the Changing Nature of Agricultural Demand

Naylor, R.L., Liska, A., Burke, M., Falcon, W.P., Gaskell, J., Rozelle, S., and K. Cassman. 2007. The ripple effect: Biofuels, food security, and the environment. ***Environment*** **49(9): 30-43.**

This paper provides technical details and economic analysis of the modern crop-based biofuels boom in its early stages of growth. Written by an interdisciplinary team of scholars from Stanford University and the University of Nebraska, it explores the food security and environmental dimensions of the biofuels industry around four case studies: U.S. maize production for domestic ethanol; Chinese cassava imports for domestic ethanol; expansion of Brazilian sugarcane and soy for global ethanol and biodiesel; and Indonesian palm oil growth for global biodiesel. The paper also provides analyses of cellulosic biofuels potential, and of energy yields and greenhouse gas mitigation potential of leading biofuels. Although the biofuels industry has continued to develop since the publication of this piece, it provides a solid framework for evaluating food security and environmental impacts of the sector.

Schmidhuber, J. 2007. Biofuels: An emerging threat to Europe's Food Security? Notre Europe Policy Paper 27, May.

Also published at the early stage of 21st century biofuel expansion, this paper provides a European perspective on the implications of crop-based ethanol and biodiesel for agricultural markets, prices and food security. The paper is written by a senior economist at FAO and covers both the theoretical and empirical aspects of agriculture-energy linkages via biofuels. It is particularly useful is describing the process of price transmission and how renewable fuel mandates and energy prices can create a floor and ceiling price for biofuels feedstocks. The economic analysis throughout this report is excellent.

Farm Foundation Series on Global Agricultural Markets
http://www.farmfoundation.org/issuereports.aspx Accessed 8 August 2012.

a) Abbott, P., Hurt, C., and W. Tyner. 2011. What's driving food prices in 2011? Farm Foundation Issue Report (July 2011)

b) Abbott, P., Hurt, C., and W. Tyner. 2009. What's driving food prices? March 2009 Update. Farm Foundation Issue Report (March 2009)

c) Abbott, P., Hurt, C., and W. Tyner. 2011. What's driving food prices? Farm Foundation Issue Report (July 2008)

This series of economic reports written for the Farm Foundation by Philip Abbott, Christopher Hurt, and Wallace Tyner at Purdue University provide a comprehensive overview of how the biofuels sector—and the U.S. ethanol industry in particular—have affected international food prices and land markets since the turn of the century. The reports discuss biofuels in a broader context of factors influencing the dynamics of the world food economy, including agricultural stock adjustments, feed demand, macroeconomic policy and exchange rates, and speculation. The reports provide excellent economic analyses of the issues at a basic level that does not require advanced modeling skills. The Farm Foundation series is thus a "go to" location for up-to-date analyses and insights on biofuels and agricultural markets.

Stanford Center on Food Security and the Environment series on global food price volatility and biofuels: http://foodsecurity.stanford.edu/ Accessed 8 August 2012.

a) Naylor, R.L. and W.P Falcon. 2008. Our daily bread: Without public investment, the food crisis will only get worse. *The Boston Review* September/October.

b) Naylor, R.L. and W.P Falcon. 2010. Food security in an era of economic volatility. *Population and Development Review* 36(4): 693-723.

c) Naylor, R.L. and W.P Falcon. 2011. The global costs of American ethanol. *The American Interest* 7(2): 66-76.

This series of papers by Rosamond Naylor and Walter Falcon at Stanford University's Center on Food Security and the Environment (FSE) provides a sequential analysis of the chaotic nature of global food markets since the early period of the 21st century biofuels era. The first paper describes the 2008 global food crisis, when energy and agricultural prices spiked, causing food riots and agricultural trade restrictions. It is followed by a more in-depth economic analysis of the subsequent drop in prices and ensuing volatility caused by the global financial crash. The third paper discusses the continuing role of U.S. ethanol policy in influencing food price levels and variability throughout this period. The collection of papers is useful in presenting a political economy perspective and providing specific details about policy changes in industrialized and developing countries that accentuate volatility stemming from the biofuels sector. The 2010 piece, in particular, provides a comprehensive economic analysis of food price volatility and its impacts on global food security, moving from international markets to local markets in poor countries.

Ewing, M. and S. Msangi. 2009. Biofuels production in developing countries: assessing tradeoffs in welfare and food security. *Environmental Science and Policy* 12: 520-528.

This paper provides an excellent grounding for understanding the potential economy-wide impacts of biofuels growth on developing economies. It outlines the key energy-agriculture linkages that affect economic growth and food security, and discusses the policy context of biofuel development. The paper is most useful in its construction of an economic framework that provides the intuition for general equilibrium modeling. The authors have subsequently contributed to a series of biofuels papers based on computable general equilibrium (CGE) model analysis (cited in references).

Mitchell, D. 2010. Biofuels in Africa: Opportunities, prospects, and challenges. Washington, D.C.: The World Bank.

This report by Donald Mitchell at the World Bank represents the "book" on biofuels in Africa. In addition to providing a general understanding of the issues (which is synthesized beautifully in the beginning of the report), it provides detailed analyses on feedstock and biofuel production costs, global and regional demand for biofuels, biofuel policies, and excellent case studies from an African context. The report also provides selected demographic and sectoral data for African countries and is filled with interesting figures and information boxes.