Biofuels, Growth and Agricultural Development

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1. Introduction

As global energy resources become increasingly scarce in the face of growing energy demand for transport fuel and other productive uses, many countries have begun to turn to the possibilities that biofuels from renewable resources could offer in supplementing their domestic energy portfolio. While much of the recent literature has focused on the growth of biofuels in the developed world, there has been growing interest in biofuel production expressed by developing nations as well (Worldwatch, 2006). Currently, Brazil and the US represent nearly 90 percent of ethanol production, while 90 percent of biodiesel production is concentrated within the EU; however, China and India are expected to have a growing share of production in these biofuels categories in the coming decades (Fulton *et al.*, 2004).

While a number of other developing countries find the prospect of biofuels attractive, the degree to which they invest in building capacity for their own domestic production remains uncertain, given the fluctuating price of fossil-based energy and the inevitable long-term commitment of governments to support fledgling biofuel-producing industries through subsidies, tax credits, and other producer (and consumer) incentives. There are a number of countries in both Sub-Saharan Africa, South and Southeast Asia, and Latin America which have suitable climates and agro-ecological conditions for growing the required feedstock crops needed for biofuel production, as well as having the needed land area and water resource base (World Bank, 2005; Fulton *et al.*, 2004). The degree of infrastructure development in these countries, however, varies widely, which may facilitate the large-scale production of biofuels in some countries, while leaving other countries non-competitive. Furthermore, the degree to which some developing countries would need to divert scarce resources away from other important development projects and their wider growth agenda serves as an argument against the adoption of biofuel technologies in the immediate- to near-term period.

One principal concern in directing agricultural resources away from food and feed production is the long-term impact on prices. Recent outlooks to 2016 attribute biofuel production as the principal driver in long-term trends in commodity prices (OECD/FAO, 2007). This increase in prices may be strong enough to shift consumption patterns for the world's poor, rendering more people food insecure. While this may be welcome news to farmers who have faced years of low commodity prices, the full picture of how energy, growth, and consumption are interrelated may show a wider range of winners and losers. For example, while countries like China are becoming viewed as less of a 'developing' nation, and seems well on its way to meet important Millennium Development goals of reducing poverty and hunger – there is still concern that developing countries like India, which have rapidly growing economies, but continuing high levels of poverty and food insecurity, might jeopardize their development goals of improving human wellbeing for the poorest, if agriculturally-based production of biofuels is pursued aggressively.

While much of the current literature focuses on the development of high-value, liquid biofuels (like grain- or sugar-based ethanol and oil-based biodiesel), which are primarily used to satisfy the demand for transportation energy, not as much attention has been given to lower-value forms of bioenergy, such as those used for domestic heating, cooking and lighting purposes. These types of uses get closer to the needs of the rural poor, and have strong implications for gender-specific health and welfare, as women are likely to be the largest beneficiaries of cleaner alternatives to dirty coal- or wood-based domestic fuels. Although we will not deal explicitly with these types of biofuels, the reader should keep in mind their importance for rural welfare and human wellbeing.

In this chapter, we address the body of literature that looks at the rapidly-growing biofuels production and demand within both the developed and developing world and the potential for adverse impacts on global food economies. We discuss both the micro and macro-level linkages that connect energy to agricultural markets, and the implications that exist for the ability of food systems to deliver needed services, such as human energy and nutrition. We use a simple illustration of energy-driven economic growth, and examine the linkages between agricultural production, food and feed consumption, human welfare and the implications of trying to meet the energy needs of the economy with crop-based biofuels. Through this we can also see the tradeoffs in land use, and the implications that arise for food growing capacity. By taking this approach, we can observe how the dynamics of 'food-versus-fuel' could play out under alternative growth paths for biofuels and the resulting policy implications. Through this exercise we lay out a framework which can allow both policy makers and researchers to better understand how programs which expand biofuel production can synergize with investment and development strategies aimed at strengthening the function of food systems.

2. Overview of Current Literature

In this section, we provide a brief overview of the current literature that addresses the food-versus-fuel issue for biofuels, and summarize the key insights that have been gained, into the nature of the underlying tradeoffs. This overview will help to orient the policy experiment that will be carried out in the subsequent section, which will illustrate the key components that make up this policy question.

Much of the current literature has focused on the impacts of increased biofuel production on crop prices and land use. For major food exporters, Ludena *et al,*. (2007) determines that producers in Latin America have enough excess land to meet food requirements and displace 5 percent of liquid transport fuel demand. For OECD countries, between 30 and 70 percent of the current cropland would have to be dedicated to biofuel production to offset 10 percent of domestic transport fuel demand (OECD, 2006). Concerning prices, OECD (2006) also predicts that the additional demand for ethanol could increase the world price of sugar 60 percent by 2014. Msangi *et al.* (2007), however, demonstrate that the positive prices effects on feedstock commodities are lessened as second generation technologies come on-line. Other studies (Schmidhuber, 2006) note the difficulty in determining whether increasing producer price incentives will be substantial enough to overcome escalating production costs as a result of higher oil prices.

The price effects have also been found to differ depending of the commodity. Ludena *et al.* (2007) in their study of Latin America found differing price effects for bioenergy crops, traditional crops, and bioenergy production by-products, like soy meal. Indeed, Schmidhuber (2006) observes strong negative price effects for protein rich feedstocks, like soybeans and cereals, which have protein-rich by-products that can be sold as livestock feed. While the underlying mechanisms dictating commodity price effects may yet to be elucidated, there still remains strong interest in determining how biofuels may affect food security. Ludena *et al.* (2007), Schmidhuber (2006) and Runge *et al.* (2007) warn that countries that import both food and fuel are at the largest disadvantage. This is because net food exporters have the potential to produce both food and fuel, while net importers would have to decide whether to import food and produce bioenergy or vice versa. Schmidhuber (2006) points out those countries that have strong export markets in non-food related sectors, such as tourism in Jamaica, may be able to absorb higher import costs. Similarly, urban households that purchase both food and fuel may have a considerable disadvantage compared to rural residents who are able to produce for their own consumption.

While higher agricultural prices may give rural producers access to world energy markets, few studies investigate the impacts on food consumption and nutrition. For example, in Latin America Ludena *et al.,* (2007) have determined that sugarcane and cassava provide the most viable feedstocks for ethanol production. Rosegrant *et al.,* (2006), however, predict that a rise production of cassava-derived bioethanol may cause a near tripling of its world price by 2020, posing a serious threat to many rural poor who depend on it as a staple food and crops.

In order to test directly how the rural poor may respond to changing prices, a quantitative exercise may provide a clearer understanding. In the next section we develop a conceptual model that exhibits the linkages between agricultural production, growth and well-being, and demonstrate how technology adoption has the ability to create synergies between bioenergy and food production, thereby mitigating the possible effects of food insecurity.

3. Drivers of change in food systems

There a number of underlining factors contributing to long-term trends in food supply and demand that have contributed to a tightening of global food markets during the past decade. These trends are driven by both environmental and socio-economic changes, as well as by agricultural and energy policy, including those encouraging biofuel production. In this section the key drivers are examined in detail in order to characterize the dynamic global food system.

Socioeconomic factors

The main socio-economic factors that drive increasing food demand are population increases, rising incomes, and increasing urbanization. Global population is set to increase from approximately 6 billion in 1995 to 8 billion in 2025, with over 98 percent of this increase in developing countries

(IMPACT projections based on UN (1998) medium scenario). In addition, 84 percent of the population increase from 1995 to 2025 in developing countries is expected to localize in urban areas (ibid). Incomes, measured by GDP per capita, are expected to grow most rapidly in recently industrialized nations. GDP per capita in China is expected to increase 5.2 percent per year from 1995 to 2025, while Korea, Thailand, and India grow at approximately 4.5 percent per year. In general, growth rates in Asia will be the highest, ranging from 2.1 to 5.2 percent per year, while Eastern European incomes will rise by 4.1 percent per year. On the other hand, rapid population growth in Sub-Saharan Africa is projected to depress per capita growth rates to approximately 0.8 to 1.7 percent per year.

The combination of rising income and urbanization is also changing the nature of diets. Rapidly rising incomes in the developing world has led to the increase in the demand for livestock products. In addition, it has been shown that urbanized populations consume less basic staples and more processed foods and livestock products (Rosegrant *et al.,* 2001). Diets with a higher meat content put additional pressure on land resources for pasture and coarse grain markets for feed, including maize. As a result of these trends, it is predicted that by 2020 over 60 percent of meat and milk consumption will take place in the developing world, and the production of beef, meat, poultry, pork, and milk will at least double from 1993 levels (Delgado *et al.*, 1999).

Increasing urbanization compounds the pressure on adjacent areas to meet the demand of large, concentrated populations. While urbanized areas themselves do not require a large portion of land, the actual the terrestrial and water resources necessary to support the population can overwhelm existing rural-urban linkages. Many developing countries are land endowed and cash strapped, making it easier to covert forest and other land cover for agricultural production rather than disseminate yield enhancing technologies. It is estimated that an additional 120 million hectares of cropland will need to be converted to agriculture in order to meet food demands in developing countries over the next 30 years, with seven countries in Latin America and Sub-Saharan Africa providing most of the land potential (FAO, 2002).

These agricultural land requirement projections assume that 70 percent of food needs will be met through yield enhancements (FAO, 2002). Yet, agricultural research dedicated to productivity enhancement of staple crops has declined over the years. As the United States and other developed regions have shifted their research focus to reflect consumer preferences for processed, organic, and humane products, the diffusion of more relevant yield enhancing technology in developing countries has slowed (Pardey *et al.*, 2006). Only one-third of global, public agricultural research in the 1990s was in developing countries, over 50 percent was concentrated in Brazil, China, India, and South Africa (ibid). Therefore, better technology diffusion and more public money dedicated to developing country research programs are critical to meet growing food needs.

Environmental drivers

Increases in population and income increase pressure on natural resources to meet domestic, agricultural, and industrial demand. Many large water basins, including the Yellow River and Ganges, are expected to pump relatively less water for irrigation over the next 20 years due to unfavorable competition from other sectors. As a result, irrigated cereal yields in water scarce basins are expected to decline between 11 and 22 percent in 2025 over 1995 levels (Rosegrant et al., 2005).

Climate change and increasing demand for water resources will impact growing conditions, significantly impacting food production in the future. Integrated assessment models of have shown that climate change effects on temperature and rainfall will having positive yield effects in cooler climates, while decreasing cereal yields in low latitude regions—the geographical location of most developing countries (Easterling *et al.*, 2007). Specifically, developing countries will have a 9 to 21 percent decline in overall agricultural productivity due to global warming, while industrialized countries will face a 6 percent decline to an 8 percent increase, depending on the offsetting effects that additional atmospheric carbon could have on rates of photosynthesis (Cline, 2007). As a result of these differentials in predicted production capabilities, some regions will benefit from increases in yield while others will be left to importing an increasing amount of food to meet demand. Fischer *et al.,* (2002) estimate that cereal imports will increase in developing countries by 10 to 40 percent by 2080. While there is a large variation in the prediction, the combined effects of rapid population growth, lower yields, and increasing reliance on trade policy for food imports could leave between an additional 5 to 170 million additional people malnourished in 2080—with up to 75 percent of the total in Africa—depending on the projection scenario (Schmidhuber and Tubiello, 2007). Parry *et al.,* (2005) have shown that the regional variation in the number of food insecure is better explained by population changes than climate impacts on food availability. As a result, economic and other development policy—especially policy pertaining to agricultural research and technology—will be critical in influencing future human well-being.

A myriad of policy, including rural development and agricultural research and technology, has not been able to encourage the necessary supply response needed to meet the food and feed demands of a growing population in the developing world. How exactly can biofuel policy be better designed to encourage the types of investments necessary to both enhance food security, and generate income necessary to purchase imported food? These questions will be explored in the next section.

4. Quantitative Illustration of Biofuels Impacts on Food

We present a simple numerical example to illustrate the impact of rapid biofuels growth on global food prices, and to highlight the kinds of interventions which can help to mitigate these effects. Taking the basic baseline results of IFPRI's IMPACT model (Rosegrant *et al.*, 2001), we construct a simplified system of equations which captures the basic interactions in the model, and which allows us to insert some illustrative parameters with which we do experiments.

Model Specification

Figure 2 shows the key interactions between food and energy markets that we try and capture in our numerical illustration. The key relationships can be summarized in the following set of equations

$$yld_{cerl} = f(p_{cerl}, a_{irr}, \tau)$$
$$area_{cerl} = f(p_{cerl}, yld_{cerl}, popn)$$
$$pcfood_{cerl} = f(p_{cerl}, pcInc)$$
$$pcfeed_{cerl} = f(p_{cerl}, prod_{meat})$$
$$prod_{meat} = f(p_{meat}, p_{cerl})$$
$$demd_{meat} = f(p_{meat}, urban_{share}, pcInc)$$

Where the yield, area and price of cereal commodities are represented by $area_{cerl}$, yld_{cerl} and p_{cerl}, respectively, and their per-capita levels of food and feed consumption are, respectively, $pcfood_{cerl}$ and $pcfeed_{cerl}$. The global levels of production, demand and price of meat products is given by $prod_{meat}$, $demd_{meat}$ and p_{meat}, respectively, and the global level 'drivers' of population and per-capita income are given as $popn$ and $pcInc$. A key driver of yield growth, for cereals[1], is the share of total area under irrigation a_{irr}, and a key demographic driver of meat consumption is the share of the total population living in urban areas ($urban_{share}$) – which captures the diet change that is implicit in lifestyle differences between rural and urban populations. A necessary condition for market closure is given by the following two equations

[1] An additional driver of yield growth is time-dependent technological progress, which is captured by the parameter τ. This will be varied under policy experiments, later in the paper.

$$prod_{meat} = demd_{meat}$$
$$area_{cerl} \cdot yld_{cerl} = popn \cdot \left(pcfood_{cerl} + pcfeed_{cerl} \right) + fsdemd_{bioF}$$

Which require that supply of meat is equal to its demand, globally – and that the sum of food, feed and biofuel demand for cereal feedstocks ($fsdemd_{bioF}$) is also balanced with total cereal production. Given the global nature of our numerical example, issues of trade are neglected for the moment, and prices of cereal and meat products (p_{cerl} , p_{meat}) are the key endogenous variables that allows the global system to remain in balance over time.

Baseline Results with Biofuels

Table 1 shows the results of the baseline run from year 2000 to 2030, which shows the change in the basic indicators of global agricultural supply and demand. The steady demand for meat products (which grows at an annual rate of 0.6% over that period in per capita terms), which is driven by steady changes in per capita income (growing globally at an annual average rate of 2%), is matched by an increase in feed demand for cereals (at 2% annually), but a small decrease in per capita levels of food demand for cereals. Nonetheless, the steady 1% growth in global population implies that the total consumption of cereals in all uses grows at 1.1%, and causes an increase in the global price of cereals, over time, which rises at an average rate of 0.6%. The growth in cereal supply is realized mostly through yield growth, which increases at a much faster rate (1.1%, compared to that of cereal area (0.02%, annually). The steady increase in meat demand also causes a similar 0.6% rate of annual growth in the global meat price, over the same period. These trends point to the importance of maintaining constant yield growth, in order to supply the necessary food and feed products to supply the needs of the global food system, as key socio-economic drivers of population and income evolve, and as demographic shifts of urbanization also occur.

Now adding to this the additional demand from cereals, that comes from feedstock demand for crop-based biofuels, we see an even higher increase in the demand for cereals, and the resulting change in the indicators, shown above, over time. Table 2 shows how the indicators shown in Table 1 differ from the baseline run, when the biofuels targets implied by the US Renewable Fuel Standards (RFS)[2] are met, with respect to conventional "1st generation" crop-based biofuels – which peak at a target of 15 billion gallons (or 56.8 billion liters) by 2015. We assume that this production comes entirely from grains at an average feedstock conversion rate of 400 liters of ethanol per metric ton of cereal feedstock. As would be expected, the most dramatic changes in prices, under this scenario, occurs for global cereals prices, which increase by 18% over baseline levels by 2015 (when the target is met), and up to 19% by 2030. Due to the increased cost of cereals, and its implications for animal feed costs, the prices of meat products also goes up slightly , although a much more sizable difference is seen in the levels of per capita feed demand, which decrease by just over 5%, by 2030[3]. The impact on per capita food demand is also sizable, and decreases by up to 3% by 2030. The overall decrease in food and feed demand, however, is offset by the increase in biofuel feedstock demand, which causes the total consumption of cereals, from all uses, to increase by just over 3% by 2030 – thereby causing the increase in cereal prices. This price increase occurs despite the increases in cereal area and cereal yield, which both respond to price – with the total cereal area responding more strongly[4].

Both the decrease in per capita consumption levels of cereals, and the increase in price of cereals, for both food and feed, imply that food security is likely to be compromised by the pursuit of

[2] The RFS aims for 36 billion gallons of ethanol by 2022 from all sources, of which the production of 'conventional'reaches a peak of 15 billion gallons by 2015. This is the particular aspect of the RFS target that has been modeled here.
[3] This effect does not take into account, however, the mitigating effect of by-products from ethanol production, such as dried distiller's grains (DDGs), which can also be used for animal feed, up to a certain proportion.
[4] The empirical literature does not always distinguish clearly between area and yield response, when trying to explain the price-induced expansion of supply. Therefore, we rely on those few studies that have documented a modest response of yield to output price, which is also embedded in the supply responses of the IFPRI IMPACT model (Rosegrant *et al.*, 2001).

the stated targets for 1st generation, conventional, crop-based biofuels – such as ethanol from maize, especially for those who rely on cereals for a large share of their calorie intakes, and for whom food represents a large share of their household expenditure. Many of the world's poor fall into this category, as do others who lie near the poverty line or within the lower and lower-middle income strata of the world's economy. While there are some increases in agricultural wages and income that result from the expansion of crop-based biofuels, those gains will not permeate widely or deeply enough to offset the loss in human welfare that occurs from sharp increases in the price of basic staple foods.

Impacts of Yield Improvements

By undertaking some simple policy experiments, we can examine the impact that price and policy-driven investments in yield growth can have on the outcomes that we have described, under rapid crop-based biofuels expansion. By returning to the relationship that governs yield, in our simple model, $yld_{cerl} = f(p_{cerl}, a_{irr}, \tau)$, we see that there are several avenues through which yield improvements can be brought about. Cereal yields can be boosted by either increasing the share of cultivated area under irrigation (a_{irr}), or increasing the rate at which yield improvements are made over time, which is captured by the parameter τ. Table 3 shows the impact on the key indicators of supply and demand, when the annual rate of increase in irrigated area (a_{irr}) is increased by 2% over the time horizon of the simulation. We see a small, but steady decrease in cereal prices across all time periods, and see the corresponding expansion in the supply of cereals (at the expense of area growth), and the consumption of cereals as both food and feed.

To demonstrate the impact of market forces on agricultural innovation, we make the parameter for yield growth (τ) endogenous to the model, so that it responds positively to price changes – such that investments in agricultural R&D are increased under higher prices, according to the relationship

$$AgR\&D = \theta_0 + \theta_1 \cdot p_{cerl} \qquad \theta_0, \theta_1 > 0$$

In this case, we would expect to see an acceleration of investment levels, when prices are high, such that they begin to have a cumulative effect on yield growth, and enable supply to expand in future and, subsequently, bring the price levels down. We know that the effect of investments on yield is not instantaneous, and cumulates over a period of time, with time-variant effects over a fairly long horizon (Alston *et al.*, 1998), and so we model the effect of agricultural research and development on yield according to a similar shape described by Alene and Coulibaly (2009), such that we obtain the shape shown in Figure 1[5]. Using this framework, we then simulate the effect of price-endogenized agricultural research and yield growth, on the overall results of our model.

By endogenizing the parameter for yield growth (τ), in addition to the acceleration in irrigated area growth, we get the results shown in Table 4, which shows a further decrease in cereal prices to nearly the same magnitude as they were increased from the original baseline case (in Table 1) by the rapid growth in crop-based biofuels. The decrease in total cereal area that is give in both of these cases occurs simultaneously with the increase in area, which means that rainfed area is converted to irrigated area with less of a need for expansion in total cultivated area, in order to boost supply growth. This result is much in line with the general trend that has been observed in many countries in South and East Asia, which have increased supply mostly through yield growth, which has been largely driven by increases in irrigation, besides other technological improvements in seed and production technologies and practices.

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[5] The author acknowledges the insight provided by Simla Tokgoz in pointing out this facet of the literature, and providing invaluable advice.

5. Implications for Food Security and Policy

Many of these country-level investments coincide with those that we might consider necessary, in general, for the improvement of food production, distribution and delivery systems in developing agricultural economies. In the scenarios we considered, the addition expansion of net irrigated area[6] necessary to offset the negative food production impacts of expanded biofuels production, amounts to 170.1 million hectares under the scenario with accelerated irrigation growth, and 159.1 million hectares under the scenario with irrigation expansion and added technological progress[7]. Many of the environmental stresses that could stand in the way of crop production for biofuel feedstocks, in terms of soil quality or other critical resource endowments, such as water, are the very same stresses that put pressure on the production of food for domestic consumption and export. Indeed, a great many of the "pre-conditions" that one could list for the establishment of an efficient and well-functioning domestic biofuel program, in terms of the agricultural production and delivery systems, are the very same ones that policy makers and researchers consider when trying to define the necessary conditions for food security and the reliable delivery of food-based services to developing country populations.

In light of the analysis that we have done, it might be argued that the "food-for-fuel" trade-off that some policy analysts use to characterize the prospects for large-scale expansion of biofuel production need not always occur, if the appropriate investments and efficiency improvements are made in advance. To be sure, there is certainly a tension that exists between the provision of food and fuel from agricultural production systems – especially when the manufacture of one is supported by

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[6] We consider net irrigated area, to take into account the fact that there is multiple cropping in some regions, which might overstate the actual surface area under irrigation, if we were to simply add up the statistics of harvested area under irrigation.

[7] The irrigation area increase is decreased when additional technological progress is introduced, due to the 'land-saving' effects of added yield growth and productivity, as well as the effect induced by generating additional supply, and thereby dampening the price increases that would otherwise stimulate area expansion over time.

policies that might distort the true cost structure or put up barriers to free trade in either the feedstock or the finished product. Many of the arguments that support liberalization of trade in agricultural base and finished products might hold as well for fuel products as well as food products, themselves. Indeed, the very investments that might enhance food security, through the strengthening of food production and delivery systems could be the very ones that ensure the healthy operation of a nascent biofuel industry, and prevent the kind of sharp trade-off that some see as inevitable. Without doubt, there will be market-level price effects when there is large-scale expansion of production from a feedstock commodities that also has sizeable food and feed use value – and, to be sure, those who are most vulnerable to price increases could be adversely affected. Therefore, we feel that the need for continued policy analysis in this area is clearly evident, and should remain a priority for researchers.

6. Conclusions

In this papser, we have explored the possible dimensions in which biofuel production could intersect with agricultural production, economic growth and overall development and welfare. Through use of a simplified conceptual and quantitative model which shows some of the key linkages between agriculture and energy, we have illustrated the important technological factors that could affect the long-term prospects for biofuels and its impact on the wider economy. Development and long-term economic growth will inevitably lead to more capital and energy-intensive patterns of production, over time, and it remains the role of technological efficiency improvements – in both industry and agriculture – to relieve the pressures that this growth will place on the natural resource base, and on the landscape. A food-focused economy would need much more agricultural land (barring any productivity improvements) than one which is more capital and energy-intensive –

however the linkage between growth, consumption and energy needs will inevitably put greater pressure on production systems, and on the natural resources and ecosystems that support them.

Therefore maintaining a focus on agricultural productivity, and technological innovation (both within agriculture and in other sectors) can help avoid (or at least mitigate) the kind of 'food-versus-fuel' tradeoff that is frequently discussed in the literature. The 'duality' of biofuel capacity growth and agricultural development can create some synergy between these goals – such that more efficient and productive agricultural production, processing, storage and distribution processes can lead to better outcomes in terms of both food security and the productive capacity of the biofuel industry that may rely on them. By examining biofuel capacity, agricultural development and economic growth, in this way, we can achieve a multitude of important human well-being and development goals with a common set of technologies, policy instruments and interventions.

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References

Alene, A.D. and O. Coulibaly. 2009. The Impact of agricultural research on productivity and poverty in sub-Saharan Africa. *Food Policy*, 34: 198-209.

Alston, J. M., Craig, B. J. and Pardey, P. G., 1998. "Dynamics in the creation and depreciation of knowledge, and the returns to research:," EPTD discussion papers 35, International Food Policy Research Institute (IFPRI).

Benjamin, C. and M. Houee-Bigot. 2007. ‘Measuring competition between non food and food demand on world grain markets: Is biofuel production compatible with pressure for food production?’, paper prepared for the American Association of Agricultural Economics Annual Meeting, July 29-August 1, Portland.

Cline, W. 2007. Global Warming and Agriculture: Impact Estimates by Country. Center for Global Development. Washington DC, USA. 250 pp

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, C. Courbois. 1999. Livestock to 2020: The next food revolution. Food, Agriculture, and Environment Discussion Paper #28. Washington, DC: International Food Policy Research Institute.

Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello, 2007: Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 273-313.

FAO. 2006. World agriculture: towards 2015/30. Rome: Food and Agricultural Organization of the United Nations.

Fischer, G., M. Shah, F.N. Tubiello, and H.van Velhuizen. 2005. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080. Phil. Trans. R. Soc. B 360: 2067–2083

Fulton, L., Howes, T. and Hardy, J. 2004. ‘Bio-fuels for Transport: An International Perspective’, International Energy Agency, Paris.

Ludena, C. E., Razo, C. and A. Saucedo. 2007. ‘Biofuels in Latin America and the Caribbean: Quantitative Considerations and Policy Implications for the Agricultural Sector’, paper prepared for the American Association of Agricultural Economics Annual Meeting, July 29-August 1, Portland.

Msangi, S., T. Sulser, M. Rosegrant and R. Valmonte-Santos. 2007. ‘Global Scenarios for Biofuels: Impacts and Implications,’ *Farm Policy Journal* 4 (2).

OECD. 2006. ‘Agricultural Market Impacts of Future Growth in the Production of Biofuels’, Directorate for food, Agriculture and Fsiheries, Committee for Agriculture, Paris, viewed 10 August 2007, http://www.

OECD/FAO. 2007. Agricultural Outlook 2007-2016.

Pardey, P.G., J.M. Alston, and R.R. Piggott, eds. 2006. Agricultural R&D in the developing world: Too little, too late? Washington DC: International Food Policy Research Institute.

Parry, M., C. Rosenzweig and M. Livermore. 2005. Climate change, global food supply and risk of hunger. Phil. Trans. R. Soc. 360: 2125–2138

Rosegrant, M., S. Msangi, T. Sulser, and R. Valmonte-Santos. 2006. ‘Biofuels and the Global Food Balance’, in *2020 Focus 14—Bioenergy and Agriculture: Promises and Challenges*, eds. P. Hazell and R.K. Pachaura, International Food Policy Research Institute: Washington D.C.

Rosegrant, M.W., M.S. Paisner, S. Meijer, and J. Witcover. 2001. *Global food projections to 2020: Emerging trends and alternative futures*. Washington, DC: International Food Policy Research Institute.

Runge, C. F. and B. Senauer. 2007. ‘How Biofuels Could Starve the Poor’, *Foreign Affairs*, vol. 86, no. 3, pp. 41-53.

Schmidhuber, J. 2006. ‘Impact of an increased biomass use on agricultural markets, prices and food security: A longer-term perspective’, paper prepared for the International symposium of Notre Europe, 27-29 November, Paris.

Schmidhuber, J. and F. Tubiello. 2007. Global food security under climate change. PNAS, 104 (5): 19703-19708.

Worldwatch Institute. 2006. ‘Bio-fuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century’. Extended Summary of Report for the German Federal Ministry of Food Agriculture and Consumer Protection (BMELV). Washington, DC.

Appendix: Tables and Figures

Table 1: Baseline Results for Global Indicators of Food Production and Consumption

	2000	2010	2020	2030	Avg Growth (2000-2030)
World Cereal Price ($/mt)	125.6	131.2	139.8	151.8	0.6%
World Meat Price ($/mt)	593.8	619.9	659.6	705.2	0.6%
Global Cereal Area (millions ha)	662.7	668.1	672.6	665.7	0.015%
per capita meat demand (kg/cap)	36.7	38.3	40.7	43.5	0.6%
Average Cereal Yield (mt/ha)	2.8	3.1	3.5	3.8	1.1%
per capita food demand for cereals (kg/cap)	154.0	153.9	153.8	153.7	-0.01%
per capita feed demand for cereals (kg/cap)	150.9	152.8	155.6	158.1	0.2%
global Cereal production (millions mt)	1855.2	2097.9	2343.7	2551.5	1.1%
Total Food and Feed demand for Cereals (millions mt)	1855.2	2097.9	2343.7	2551.5	1.1%
Total demand for Cereals (millions mt)	1855.2	2097.9	2343.7	2551.5	1.1%
Global Population (millions)	6084.2	6841.3	7574.5	8181.8	1.0%
Global Average per capita income (2000 US$/cap)	5587.7	6502.2	8096.2	10242.5	2.0%

Table 2: Percentage Change from Baseline Results under Biofuels Expansion

	2010	2015	2020	2030
World Cereal Price	8.4%	18.0%	18.4%	19.1%
World Meat Price	0.1%	0.1%	0.1%	0.1%
Global Cereal Area	0.9%	2.0%	2.1%	2.4%
per capita meat demand	0.0%	0.0%	0.0%	0.0%
Average Cereal Yield	0.4%	0.8%	0.8%	0.9%
per capita food demand for cereals	-1.1%	-2.5%	-2.6%	-3.0%
per capita feed demand for cereals	-2.2%	-4.7%	-4.9%	-5.5%
global Cereal production	1.3%	2.8%	2.9%	3.2%
Total Food and Feed demand for Cereals	-1.6%	-3.6%	-3.8%	-4.3%
Total demand for Cereals	1.3%	2.8%	2.9%	3.2%

Table 3: Biofuels Expansion Results with Increased Irrigated Area (% change from results with biofuels expansion and baseline yield growth)

	2010	2015	2020	2030
World Cereal Price	-1.4%	-2.0%	-2.5%	-3.5%
World Meat Price	0.0%	0.0%	0.0%	0.0%
Global Cereal Area	-0.2%	-0.3%	-0.4%	-0.7%
per capita meat demand	0.0%	0.0%	0.0%	0.0%
Average Cereal Yield	0.5%	0.8%	1.0%	1.6%
per capita food demand for cereals	0.2%	0.3%	0.4%	0.7%
per capita feed demand for cereals	0.4%	0.6%	0.8%	1.3%
global Cereal production	0.3%	0.4%	0.6%	0.9%
Total Food and Feed demand for Cereals	0.3%	0.5%	0.6%	1.0%
Total demand for Cereals	0.3%	0.4%	0.6%	0.9%

Table 4: Biofuels Expansion Results with Increased Irrigated Area &Yield Improvement (% change from results with biofuels expansion and baseline yield growth)

	2010	2015	2020	2030
World Cereal Price	-9.1%	-11.8%	-14.5%	-18.2%
World Meat Price	-0.1%	-0.1%	-0.1%	-0.2%
Global Cereal Area	-1.4%	-1.9%	-2.5%	-3.6%
per capita meat demand	0.0%	0.0%	0.0%	0.0%
Average Cereal Yield	3.3%	4.7%	6.1%	8.6%
per capita food demand for cereals	1.3%	2.0%	2.5%	3.5%
per capita feed demand for cereals	2.6%	3.8%	4.8%	6.6%
global Cereal production	1.9%	2.7%	3.4%	4.7%
Total Food and Feed demand for Cereals	2.0%	2.9%	3.7%	5.1%
Total demand for Cereals	1.9%	2.7%	3.4%	4.7%

Figure 1: The marginal impact of agricultural research spending on yield over time