WORLD AGRICULTURE IN A DYNAMICALLY-CHANGING ENVIRONMENT:
IFPRI'S LONG-TERM OUTLOOK FOR FOOD AND AGRICULTURE UNDER ADDITIONAL DEMAND AND CONSTRAINTS

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SUMMARY

In this paper, we explore the nature of several key drivers of change in food systems, and examine a number possible entry points for policy intervention, in order to determine their effect on food prices and other market-driven outcomes. Among the drivers of change that we discuss are those of policy-driven growth in biofuel production, which has had a role to play in the rapid increase in food prices, along with other factors. We demonstrate the off-setting impact that supply growth could have on the socio-economic impacts of biofuels, both in terms of price changes, as well as changes in nutrition status. We also look at some evidence that points towards the significant impact that climate change could have on the agriculture and agricultural prices in the future. Combining our quantitative experiments with cited evidence from other studies, we suggest a range of policy interventions that could be instrumental in offsetting the negative impacts of food prices, and helping to promote those benefits in situations where they might exist. Among these suggestions, we encourage increased investments in the agricultural sector, so as to reverse the steadily declining growth of research and development spending and change decades of counter-productive agricultural trade and national-level sector policies.

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1. INTRODUCTION

The sharp increases in food prices that have occurred in global and national markets over the last several years, has sharpened the awareness of policy makers and agricultural economic analysts to the stresses facing global food systems and the ecosystems that support them. The rapid increases in prices of key food commodities such as maize, wheat, rice, soybeans - among others - has mirrored the increase in prices of energy products, and has strengthened the perception that energy and agricultural markets are becoming more closely linked (Schmidhuber, 2006). In the last six years, the international market prices of basic grain commodities have more than doubled, whereas the prices of wheat and rice have tripled. While this might represent a different impact upon the consumer price index in various countries, due to the share of these commodities in total consumption – this represents a significant and sharp change in market conditions, nonetheless. While many see the reversal of historically declining real prices of agricultural commodities as an opportunity for the agricultural producers in both developed and developing countries – others remain concerned about the implications of high food prices and increased volatility in food markets on the welfare and well-being of vulnerable populations who consist of mostly net consumers of these products, and who largely reside in the poorest regions of the developing world (Evans, 2008; FAO, 2008).

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During the same period, prices of oil have increased four-fold, and have caused second-round prices effects on all other goods and services that depend significantly on fossil fuels as inputs to production – including agriculture. Looking forward, into the future, a number of researchers project the continued elevation of world prices for agricultural goods above past historical trends, despite a leveling off in the near-term period from the current highs. The medium-term projections generated by the joint OECD-FAO modeling effort show that a prevailing tightness remains in most major agricultural markets, so as to keep price levels significantly above historical trends (OECD-FAO, 2008). The world market price projections of the International Food Policy Research Institute (IFPRI) show that world grain prices will further increase 30-50% before 2050, and that, in the same period, meat prices will increase an additional 20-30% beyond current high levels (von Braun, 2008).

The underlying factors to the rapid increases in food prices are varied – both in nature, and in their relative strength in driving the market dynamics across various commodities. A number factors have been attributed to the rapid increase in food prices, both within the published literature as well as within the press, and range from the rapid increase in first-generation, food-based production of biofuels (Oxfam International, 2008; Runge and Senauer, 2008) to the increase of cereal and meat demand from East and South Asia – or the increase in speculative activity in food markets. Several comprehensive discussions of this issue have appeared in recent literature, and try to assess the relative merit of each of these factors – while also including an overview of the global macro-economic picture, and the relative decline of the dollar, in relation to other currencies (Abbot *et al.*, 2008). The steady decline in the level of cereal stocks, globally, as a result of the private sector taking over the operation of cereals stocks from government, and adopting a more 'just-in-time' management orientation (Trostle, 2008), has also been cited as a factor that has reduced the ability of national governments to stabilize consumer and producer prices (OECD, 2008). Most authors, however, do not isolate a single cause as being to blame for the current world food situation, but cite a complex interaction between several coincident factors.

The challenges and increased stresses that face global food production and distribution systems, in the present economic climate, are particularly acute and pressing for Sub-Saharan Africa, where persistent levels of food insecurity already exist. To illustrate, roughly thirty-three percent of the population of Sub-Saharan Africa lives with insufficient food supplies (FAO, 2005) and an even greater proportion, forty-three percent, lives below the international dollar poverty line (Dixon *et al*., 2001). The constraints that lie in the way of Africa benefiting from higher producer prices of agricultural commodities on the world market are myriad, and include the fact that most of Sub-Saharan Africa's agricultural production relies on rainfed cultivation, and receives lower input levels of improved seed technology and fertilizer applications than other regions. Additionally, the area affected by land degradation within the region is expanding and is thereby causing a decline in soil fertility that reduces yield levels and increases the difficulty in maintaining sufficient production levels, especially when considering the lack of technological innovation and fertilizer use (FAO, 2005).

In this paper, we examine the key environmental, technological and socio-economic drivers that underpin the global world food situation, and evaluate the potential role of alternative policy interventions that might address it. We discuss these policy interventions in terms of the role they can play in enhancing market stability, food security and human well-being, in the face of the increasing stresses that continue to be placed upon global agricultural markets and food systems. We look, specifically, at the role that biofuels might play in raising food prices, and the role that agricultural technology investments might have in counter-acting these effects. Based on this analysis, we conclude with some final recommendations for both policy intervention and further research.

2. DRIVERS OF CHANGE IN FOOD SYSTEMS

The upward pressure on key commodity prices that were mentioned in the previous section, can be accounted for due to a number of underlying factors or 'drivers of change' that are diverse in nature. These 'drivers' range from environmental to socio-economic and from slow to fast-moving, affecting outcomes differently in both the short- vs. the long-term. There a number of underlining factors driving the long-term trends in food supply and demand that have also contributed towards 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 from agricultural feedstocks. Figure 1 illustrates the interactions between the various key 'drivers' of change in global food systems, and their linkage to other components of the food economy and to important outcomes of human well-being – such as nutrition. While this schematic is not completely exhaustive of all the major factors of importance, it incorporates the main elements of global environmental and economic change in food production and consumption systems, that we hope to address in this paper.

Socio-economic change, in the form of increasing growth in population numbers and total income, are among the major drivers that change the economic behavior of consumers, in terms of their demand for food and energy products. Urbanization, which is related to these demographic changes, is another factor that also has an impact on consumption patterns and the transformation of consumer preferences for both food, fibre and energy products. These changes in consumption and consumption preferences introduce increased stresses on food and energy systems from the demand side, while other environmental factors might restrain the supply side of food systems from responding readily – as a result of either resource scarcity or degraded land and water quality. Reduced investments in crop and energy technology, over time, could also lead to a longer-term slowdown in the expansion of supply – which eventually leads to higher prices, as demand begins to grow faster.

Taking these factors into account, as they have been described and presented in Figure 1, we see a variety of entry points for policy or technological intervention that present themselves. These offer a menu of options for the policymaker to consider, when deciding how best to cope with the current stresses on food or energy systems, or how to mitigate the severity of such stresses in future. Now, following, we can discuss a few of these various components and drivers of the food system in more detail, as we put them within the context of food and energy supply and demand systems.

2.1 Socio-economic factors

Both demographic growth and socio-economic change – in the form of overall income growth, rates of urbanization or changes in the incidence of poverty in the population over time – are key factors that determine the patterns of food consumption and nutrition outcomes that are observed. Since the oil crisis in the 1970s, there has been notable socio-economic progress and growth in the various regions of the world, in terms of human welfare. Despite population growth, the number of malnourished people in developing countries has declined over time – although at various rates. According to the 2006 State of Food Insecurity report (FAO, 2006a), the decrease of 37 million over the period of 1970-1980 was followed by a decrease of almost 100 million over the 1980-1990 – but only followed by a decrease of 3 million in the period since the 1990-1992 period set as a baseline for the 1996 World Food Summit to the present.. Food has become more affordable, as it is now less than half as expensive in real terms as it was in 1960. The decline in cost of food can be attributed to a large increase in food production, where even in per capita terms, the world now produces 40% more food than forty years ago (MA, 2005). Nonetheless, these positive trends might reverse themselves in the future, if the major tipping points of climate change and accompanying degradation of land and water resources are to intensify in future.

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, according to the UN medium variant projections (UN, 2004). In addition, 84 percent of the population increase from 1995 to 2025 in developing countries is expected to localize in urban areas. Incomes, measured by GDP per capita, are expected to grow strongly in recently industrialized nations and most rapidly in East Asia and the Pacific, according to the projections of growth used by a number of key policy centers (World Bank, 2007a; UNEP, 2007). Taking the rates that are used in IFPRI's IMPACT model projections (von Braun, 2008), GDP per capita in China is expected to increase 5.2 percent per year from 1995 to 2025, while Republic of 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 which are generously land-endowed, find it easier to covert forest and other land cover for agricultural production rather than disseminate yield-enhancing technologies – especially where extension services are limited or non-existent. 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, 2006b).

These agricultural land requirement projections assume that 70 percent of food needs will be met through yield enhancements (FAO, 2006b). 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 (Alston and Pardey, 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 (Alston and Pardey, 2006). Therefore, better technology diffusion and more public money dedicated to developing country research programs are critical to meet growing food needs.

2.2 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.*, (2005) 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.

2.3 Policy-based drivers

In addition to the socio-economic and environmental processes which are described above, there are other factors that can help create the kind of "tight" market environment that we have observed in the recent months. These include the decline in cereal stocks and unilateral trade actions by individual countries, as they both restrict supply in the market. For example, world wheat stocks-to-use ratios have declined from over 40% in 1970 to 20% today – below the oil crisis level. Corn stocks-to-use ratios have declines from their peak in their 45% peak on the 1980s to about 12%, a level also previously only seen during the world oil crisis. We have also witnessed increasing levels of private capital invested in grain markets (as well as other commodity markets) in search of portfolio diversification and as a response to the recent poor performance of the stock market. Lastly, unfavorable macroeconomic developments (such as the dollar devaluation) can further complicate the situation for some consumers.

Looking at productivity growth more closely, we find that yield growth rates for major grains have been declining in the last decades (World Bank, 2007b) and have dropped by roughly 50% since their highs during the 1960s and late 1970s. One of the causes of this decline is no doubt a fall in the growth of public agricultural R&D spending, both in the developing and developed world (World Bank, 2007b). On a global level, R&D spending growth has declined 51% in real terms in the two decades since the 1980s, in the developed world, and the developing world has taken a larger share of the world's agricultural research spending than the developed world, since the 1990s (Alston and Pardey, 2006). This is especially troubling since IFPRI projects that future production growth will stem from yield improvements, rather than area expansion, as has been found in past assessments of global agricultural futures, such as the Millennium Ecosystem Assessment (MA, 2005). In fact, some regions of the world, such as East Asia, Europe and North America, will need to increase production even as agricultural area shrinks.

2.4 Characterizing the drivers of change

Given the rather complex interplay of factors that have been described both in this paper, as well as in the wider literature, it is useful to try and separate the slower-acting, long-term drivers of change from the faster-moving ones that might have more of an impact in the short-term period. Population growth and income growth tend to act relatively slowly and steadily over time, and evolve in a rather predictable fashion – given the nature of the drivers which underlie demographic and economic growth, and the experience we've observed in the past. There are also long-term shifts in climatic conditions at play, that also tend to unfold more gradually over a period of time – compared to the shorter-term manifestations of climatic variability that might be manifest in weather events that occur within the cyclical progression of seasons. Finally, when considering the catalog of slow-moving changes, we can cite the gradual slowing-down of crop yield growth that has been observed over time, relative to the rate of food demand growth which is occurring, and driven by socio-economic changes. In contrast to these types of slow-moving drivers of change are the faster-moving ones, which can take the form of sudden climatic and environmental shocks that can cause seasonal losses of harvest. While food demand tends not to surge upwards, over short periods of time, we have observed relatively rapid increases in the demand for energy – especially that which is driven by transportation energy needs – which manifests itself in the increasing demand for fossil-based fuels as well as for renewable substitutes such as biofuels. The demand for biofuels, such as ethanol and biodiesel, tends to be strong when fossil-based fuel prices are high, and when national fuel policies push for increased levels of blending to reduce the cost of fuel imports. This has been the case in a number of countries around that world, and is a major determinant in the rapid expansion of biofuel production which has been observed in the past 6 years.

Given the various drivers of change that are cited in both the literature, and in the previous sections, it is worthwhile to consider their characteristics so as to better understand their relative importance in explaining the tightening of market conditions that we have observed in global food markets in recent times. Despite some of the fairly comprehensive overviews and discussions of high food prices – in terms of their causes and consequences – relatively little effort has been made to distinguish between their dynamic characteristics of change, so that their relative importance in explaining short-term versus long-term phenomena can be appreciated. Having such a distinction is helpful, not only in being able to identify the most urgent issues to address first, from a point of view of policy, but also help to identify which types of issues are of a more temporary nature, and which might persist into the future and prevent market and food system characteristics from returning to a stable equilibrium, or which might cause prices to rise even further, later on.

While Figure 1 does show how the various drivers of change interact with each other, and where the critical feedback loops might be – it does not provide us with the type of distinguishing characteristics that can explain short-lived and longer-lived effects on food systems. Figure 2, however, does more to make this distinction, and shows where some key drivers of change lie in relationship to each other, with respect to their dynamic characteristics – which is a combination of the speed with which they act, as well as the degree to which they explain short-term or long-term phenomena. Taking the end of the spectrum that contains both fast-acting drivers that help to explain short term effects, we see that market speculation stands out as a factor that might explain the 'bubbles' that might form in markets, due to expectations about short- to medium-term trends, but which might reverse themselves fairly rapidly on the basis of economic conditions and fast-changing market information. This type of activity has been cited as a factor that explains the spikes that developed in some markets, even contrary to the indicators provided by the supply and demand fundamentals that usually determine price formation (von Braun *et al.*, 2008).

On the other end of the spectrum, relatively slow-moving phenomena that will play a part in determining the long-term evolution of food systems and the performance of the underlying ecosystems that support them, is climate change – which encapsulates the changes in long-term means of temperature, precipitation and even atmospheric content, that impact crop growth potential and the characteristics of key agro-ecological systems. Climate change, as a phenomenon, should be distinguished from effects of climate variability and extreme incidents of weather that are presently made manifest in many regions and which act over a much quicker time scale. These types of weather shocks drive the supply-side of the food equation and lead to sudden drops in output that can push up market prices, whereas sudden surges from the demand side of the equation (like those due to growth in crop-based biofuel production) might tighten market conditions and contribute towards similar price increases.

Other drivers of supply and demand change which operate on a slower-moving trajectory are those of growth in demand for key consumer food products, such as cereal and meat (which also have implications for feed demand), as well as trends for crop yield growth which determine how well the supply side can adjust to increases in demand. Changes in demand for food and fibre products tend not to 'surge' as rapidly as those for energy-intensive products, such as petroleum for transport, but represent a component of food system change that will continue to keep prices at an elevated level into the future, as has been cited by the OECD in their projections of agricultural production and prices to 2017 (OECD-FAO, 2008), as well as for longer-term projections (von Braun, 2008).

2.5 Entry points for policy

Given the various drivers of change that we have discussed, above, we might consider several possible entry points for policy intervention, which might address the current global food situation. As is shown in Figure 1, there a number of entry points for intervention that can be considered – both from the supply and the demand side. Looking at the demand side first, we see that policies that govern the use of food-based feedstocks for biofuel production could be altered, such that the overall quantities that come from food and feed sources are substituted for other non-food feedstocks or feedstock conversion technologies. Other policies which might affect direct food and feed use of grains would rely on the alteration of consumer preferences for food products (including meat), and are not as straightforward to address within the analytical framework we will discuss in this paper. Therefore, our attention will focus on the use of food crops in biofuel production.

From the supply side, there are a number of interventions which we will consider. The first is to boost the output of cereals by raising yield levels over time – through policies that accelerate the improvement of crop technologies, such that the higher growth rates of yield are realized. This can be done directly through improved seed technologies, which might enhance the productivity and hardiness of plant varieties, or through the expansion of area under irrigated production, which has a higher yield than rainfed alternatives, typically. Improved seed technologies can even reduce the loss in productivity that occurs when irrigated crops become water-logged or subject to increased salinity and submergence – thus allowing the expansion of irrigated area to be even more effective in raising overall production levels.

Another supply-side intervention would be that of improving the management of grain storage, so that there are sufficient quantities on hand to provide adequate buffer when there are shocks in either production or supply that cause prices to spike. This has been discussed at length in the recent literature, without a great deal of analysis being applied to it. We will pay a considerable amount of attention to this aspect of policy within the analytical framework that we now present, in the following section.

3. QUANTITATIVE OUTLOOK TO 2050

In this section we show some forward-looking outlooks for food production and consumption, that are based on IFPRI's IMPACT model (Rosegrant *et al.*, 2001, 2002, 2005), and also outline the implications that we see for long-term food security. These simulations will help us to show the impact of policy-based and socio-economic drivers on the evolution of agricultural prices – as well as the role that technological interventions and investments can play. These simulations will also help to illustrate the types of entry points that are possible to help stabilize food prices and improve human well-being outcomes, in the face of the various drivers of change that we have discussed, so far.

3.1 Description of model

To examine the potential impact of biofuel production growth on country-level and domestic agricultural markets, a partial-equilibrium modeling framework is adopted to capture the interactions between agricultural commodity supply and demand, as well as trade, at global level. The model used is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which was developed by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand and food security to year 2020 and beyond (Rosegrant *et al.*, 2001). The IMPACT model is a partial equilibrium agricultural model for crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. It is specified as a set of 115 country and regional sub-models, within each of which supply, demand, and prices for agricultural commodities are determined. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock, and other uses.

3.2 Baseline model projections

Production growth

The profile of production in cereal over time is shown below in Figure 3, where we see steady trends of output growth to 2050. Cereal production is projected to grow steadily across all seven regions, with North America and Europe leading the regions in cereal production volume. If we look at these trends on a per capita basis, however, we see a somewhat more static picture, in terms of how the various regions are projected to maintain production levels, relative to their populations (Figure 4). In this case, we see that North American, European and Central Asia regions make significant increases in production, relative to their own population growth, and are able to provide the surpluses that are able to supply the food and feed needs of the rest of the world. The

Middle East and North Africa region is able to increase its per capita production levels, as is the Latin America and Caribbean region, over the projections period. By contrast, the South and East Asian regions decrease their per capita production over time, as does sub-Saharan Africa.

Demand growth

In terms of demand growth over the fifty-year period, total food demand for cereals is projected to increase in all regions with North America and Europe, and East Asia leading all other regions in total volume. Table 1 shows how the total demand for cereals is divided into its largest two components (food and feed uses). In terms of food use, the region that shows the strongest demand growth for cereals is sub-Saharan Africa, even though other regions like South Asia, East Asia and the Pacific and Latin America exceeds it in terms of food consumption volume. The Middle East/ North Africa region has similar food demand growth for cereals as South Asia, and those regions with the lowest levels of growth are Eastern Europe and Central Asia, as well as the East Asia and Pacific regions. In terms of feed uses of cereals, the North American and European regions lead the world in total volume of feed consumption, followed by East Asia, Latin America and the Caribbean as well as the Middle East and North Africa aggregate regions.

If we look at the patterns of food demand in per capita terms, then we get a more comparable basis on which to examine the changes in consumption patterns across regions (Figure 5). Looking at the demand for cereals, we see that East and South Asia fall in per capita cereal consumption, compared to the rest of the world. In terms of the demand for meat (Figure 6), which is the main driver of feed demand for cereals, we see that East Asia far outstrips other regions, which is in keeping with its rapid growth in per capita income, compared to other developing and developed regions. Other regions that show large increases in per capita consumption of meat are North America and Europe, which has a far higher level of consumption compared to South Asia and Sub-Saharan Africa, which grow steadily from relatively low levels, due to their steady income growth over this period.

Long-term trends in malnutrition

Given the patterns of supply and demand that have been highlighted, above, the IMPACT model infers a trend in levels of malnourished among the most vulnerable demographic of the population – those aged zero to five. The determinants of malnutrition are derived primarily from four key indicators – per capita calorie availability, access to clean drinking water, rates of secondary schooling among females, and the ratio of female-to-male life expectancy. The link between malnutrition and these determinants were established in the work of Smith and Haddad (2000), who used them as explanatory variables to account for changes in levels of child malnutrition across the developing world, between 1975 and 1995. According to their work, a greater share of the reduction in child malnutrition levels, over this period, can be accounted by improvement in female schooling and clean water access, than in just calorie availability. This finding is in keeping with the four-pillared concept of food security that underlies FAO's conceptual framework – where availability, is only one of the factors that accounts for food security status among vulnerable populations, and must be evaluated along with access, utilization and stability. The methodology used for tracking child malnutrition in IMPACT, therefore, covers aspects of availability, access and utilization – where the concept of access is grounded in the price response of consumption to market conditions, and the utilization aspect is touched upon by access to clean water, which is a major determinant of human health and the ability of the body to absorb and utilize available and accessible nutrients.

The baseline trends for malnutrition are shown in Figures 7 and 8, where we see variation in the rates of change in malnutrition. The decline in malnutrition prevalence, across the various sub-regions of Africa and Asia (Figure 7), shows a steeper decline for the Asian region, compared to sub-Saharan Africa, in the period up to 2025, after which a number of the African sub-regions also show steady declines. The South Asia region has the highest overall levels of prevalence, but is able to make significant reductions by 2050, compared to Southeast Asia and Western sub-Saharan Africa, which are able to decrease the overall levels of prevalence only slightly. East Asia, which already begins with the lowest levels, is able to draw these levels down even further in the longer-term, to achieve single-digit levels of prevalence, which no other region can match. The complete picture of child malnutrition, however, is completed when one looks at the total numbers of malnourished (Figure 8), which shows the Asian region, as a whole, to be the most aggressive in reducing its overall levels of malnutrition, which remain the highest in the world, even in 2050 – compared to sub-Saharan Africa which sees on overall increase in numbers, before the acceleration of production and per capita income levels allow it to reduce its numbers in future. In total numbers, however, the count of malnourished children in Sub-Saharan Africa remains nearly the same in 2050 as compared to year 2000 – even though it represents a smaller share of the overall population. This picture helps to illustrate the challenge that remains in combating hunger and improving human well-being outcomes in the developing world, in the long-term, given the impending pressures that environmental and policy-driven shocks will have on the world food system.

In the following sub-sections, we go into greater detail to discuss the nature of these challenges, and their implications for future food security.

3.3 The role of biofuels

An illustrative counterfactual

Given the complex nature of the various drivers of change that we have described, and the way in which they interact within global agricultural and non-agricultural markets, it is not easy to isolate the effect of biofuels from the other important factors. Nonetheless, in an attempt to do precisely that, we set up a simple counterfactual experiment with the IMPACT model that is designed to show the contrasting impact on cereal prices that the observed historical trends of biofuels growth would exert – if we considered the periods between 1990 and 2000, as well as that between 2000 and 2007, when most of the rapid growth in global biofuels production was realized. In this experiment, we try to see how much global cereal prices would deviate from their observed baseline levels if biofuel production growth were reduced from the actual rates of growth that were observed between 2000 and 2007 and, instead, remained on the trajectory of the previous 1990-2000 period.

As a result of this experimental design, our simulation results produced a rate of growth in average grain prices that is 30% lower than actual rate of increase in world prices over the 2000-2007 period. Following up on this counterfactual experiment, we also carried out a forward-looking set of projections with IMPACT, in which we hold (or 'freeze') the biofuel feedstock demand constant at the observed 2007 levels, rather than continuing along the trend suggested by current policy and plans for future expansion in various key biofuel-producing regions. By carrying out this scenario, we generate results that show grain, oils and cassava prices at least 4% lower than baseline levels in 2015, as well as maize prices that are 14% lower than baseline in 2015. Moreover, as a result of this "freeze" on biofuel growth at 2007 levels, we also see that per-capita levels of calorie availability are 3% higher than baseline levels in 2015, in many developing regions, while regions like Sub-Saharan Africa (where crops like maize are relied upon heavily for staples) would have per-capita levels of calorie availability that are 6% higher than baseline levels in 2015.

Quantifying the implications of renewable fuel targets

We can also look at specific policies, such as the renewable fuel targets that have been set by various countries, for meeting blending and replacement rates of fossil fuels over a given time horizon. Taking the renewable fuel targets of the United States of America, for example, which sets a target in 2022 for 1st generation biofuel production of 15 billion gallons, under the Energy Independence and Security Act (EISA). The additional amount of maize feedstock that is needed to meet this target is considerable, and requires an additional level of yield growth, shown in figure 9, in order to offset the impacts that it would otherwise have on food security. In other words, the future growth of cereal yields would have to go from an annual average rate of 1.3% to 1.8% in order to equate the implied trends in malnutrition. This translates into an additional 1% of yield growth in the developing world, and an extra 0.5% growth in the developed world – presuming that higher yield gains can be made in less developed countries, where there might still be significant opportunities for closing yield gaps that could be exploited The impact of this offsetting yield increase is shown in Figure 10, where we see the increases in malnutrition in 2025, due to the US policy, being offset by the additional cereal yield growth described above.

These scenarios illustrate the impact of biofuels on global food prices in a fairly clear way, and lead to immediate implications for food security and human well-being. In order to illustrate the way in which specific technological innovations can ameliorate the situation and reduce the pressure that crop-based biofuel production growth poses to global food systems, we carry out some further simulation-based experiments that are described in the next section.

3.4 Yield-enhancing technology and policy

An important policy intervention that can be made to alleviate the trade-offs that are embodied in the competing demands for land area to produce the necessary food, feed, fibre and even fuel needs is that of technology – especially in the form of productivity-boosting technologies. Enhancing the yield of food, feed or fibre products per unit area of land, has the effect of not only increasing overall availability of these products (and lowering their market prices, as a result) – but also increasing the availability of land that is available for non-agricultural uses, such as forestry or wildlife habitat, or even for the provision of fuel, in the form of plantation-style biofuel systems. Conversely, increasing the yield of biofuel production systems, through improvements in the productivity and energy yield of the underlying conversion technologies could also have a land-saving effect that increases the area available for growing food and feed products, or other non-agricultural uses.

In some of the global assessments that have been carried out, in the recent past, to assess the future trade-offs between food, feed, and energy needs, and the health of the environment and the ecosystems it supports, some of these very same effects have been noted. In the Millennium Ecosystem Assessment (MA 2005), the scenario that had the highest levels of technology adoption and high income growth (the "Global Orchestration" scenario), also had the highest levels of biofuels production. This arose from the fact that greater investments in increasing agricultural productivity reduced the competition with food-producing land, thereby making more land available for biofuel plantations – and resulting in lower prices for both food and biofuel products. Conversely, the scenario with the lowest levels of income growth and technology adoption – the "Order from Strength" scenario – also had the greatest competition for land under food production (due to lower agricultural productivity and investments), and less biofuels production – resulting in higher food and energy prices. The assessment scenario results also showed that forest land decreased due to the higher levels biofuels – whereas under more extensive agricultural land use patterns, a similar encroachment on forest land would also exist. Both of these results underscore the persistent trade-off s that exist between maintaining ecosystem health and meeting the demands for food, feed, and fuel that exist in all of the scenarios that are considered. Even though there is a difference in the way in which various drivers of change evolve under these scenarios – acting either through increased demand for food, feed, fibre or fuel – there is competition in land uses, and some encroachment upon land that would otherwise remain unmanaged.

The fourth Global Environmental Outlook (GEO-4) of the United Nations Environment Program (UNEP), was a similar global assessment to the MA study, which showed that increased emphasis for meeting targets on greenhouse gas reductions (under either the 'Sustainability First' or 'Policy First' scenarios) could also lead to increased biofuel production and decreases in area under forest (UNEP, 2007). These same scenarios also embodied (in a way that is parallel to the 'Global Orchestration' case in the Millenium Ecosystem Assessment) higher rates of income growth and technology adoption – thereby making agricultural growth more intensive and less extensive in nature, and allowing for more land to be used for non-agricultural uses (including biofuel production). In a similar way, the prices for both food and energy tended to be lower under these high-growth scenarios, due to the higher production of both food and energy products. At the same time, the area of land that is vulnerable to erosion risk also increases, as a result of biofuel production – with the 'Policy First' scenario being the highest one, given that less attention is given to soil conservation and improved land management as under the 'Sustainability First' case.

Given the effects that have been noted the results of the global assessments, we now turn to some biofuel-specific scenarios that will be carried out. In these scenarios, we note both the impact of biofuel production growth on food prices, through demand side effects, as well as the land-saving impact of increased technology growth, which has an effect on the supply side of the agricultural market equation.

As has been done before with IMPACT-based simulations (Rosegrant *et al*., 2001), the "business-as-usual" or 'reference' run describes slowly declining rates of growth in agricultural research (and extension), along the same trend-lines that have been observed in the past. As an alternative to the reference case, we consider a case where levels of agricultural knowledge, science and technology are enhanced – which we call the "high AKST[1]" case. In this variant, we have elevated levels of investments in agriculture over the period 2005-2050. As a result of accelerated investments in agricultural technologies, we have elevated crop yield and livestock numbers growth. A further variant of this considers the implications of even more aggressive growth in agricultural R&D together with advances in other, complementary sectors that provide key infrastructure and social services. Such other sectors include investments in irrigation infrastructure (represented by accelerated growth in irrigated area and efficiency of irrigation water use and by accelerated or reduced growth in access to drinking water, and changes in investments of secondary education for females, an important indicator for human well-being.

3.5 Implications for Malnutrition

In the scenarios mentioned above, the increase in crop prices resulting from expanded bio-fuel production is also accompanied by a net decrease in availability and access to food. Calorie consumption is estimated to decrease across regions under the two bio-fuel scenarios compared to baseline levels.

In the case of enhanced AKST levels, we get a significant improvement in food security status and human well-being levels, due to the reduction of price for important tropical staple crops like cassava and maize. In Figure 11, we see that the availability of calories is greatly enhanced, over time, by the acceleration in yield growth and production, realized under higher AKST levels. The effect is particularly strong in SSA, where the improvements in maize and cassava yield have a big impact on calorie availability, given the compositions of diets in that region – and the fact that maize and cassava are important starch foods.

Under higher AKST levels, we see a significant reduction of malnourishment in small children, over time, as a result of the increase in calorie availability in various regions (Figure 12), as well as due to other improvements in socio-economic conditions embedded in the high AKST scenario assumptions. In Figure 12, we see that the level of malnourishment among small children drops strongly, over time, in both sub-Saharan and North Africa, as well as in Latin America. The poorer regions of West Asia and North Africa benefit as much as the tropical regions do, from enhanced access to water, better female schooling rates, and lower food prices – due to the rather poor state of social services in some of those regions. The rates of change are much faster in those regions, even compared to East Asia and the Pacific, or South Asia, and appear to have a stronger progression, even compared to the improvement in calorie availability. This illustrates the importance of other socio-economic factors, besides just food availability, which underlie malnutrition, and how the various 'pillars' of food security – availability, access, utilization and stability –start to interact to produce an effect that might even be greater than the sum of the individual components. While not all of the components of food security can be captured within our modeling framework – those of availability and access (which is closely connected to food prices) are best captured here. Some elements of utilization are captured in the way in which we relate access to clean water to levels of malnutrition, according to the empirical work of Smith and Haddad (2000). In that work, they found that 43% of the decrease in child malnutrition between 1975 and 1995 was due to female schooling, and was the leading determinant – followed by calorie availability (26%).

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[1] "AKST" refers to Agricultural Knowledge, Science and Technology – which was a broad concept of agricultural technology and capital that was conceptualized in the recent International Assessment of Agricultural Science and Technology for Development (IAASTD) global assessment. Various scenarios that embody differing levels of AKST were quantified, using a number of models including IMPACT. We have chosen the 'high' case from among those scenario specifications, to use in our illustration.

3.6 The added challenge of climate change

In addition to the scenarios that we have presented, that are driven by energy policy, we must also begin to reconcile our accounting of future food balances with the added challenges that climate change will represent to the global food system. It must be said that the ultimate impacts of climate change – both in terms of magnitude and regional specificity – remain somewhat uncertain, as there is a wide spectrum of modeling results that show various degrees of impact for the same regions of the world. A great part of this uncertainty in the results of the Global Circulation Models (GCMs) lies in the fact that each of them models the interactions between the atmosphere, the ocean and terrestrial systems differently, which results in greater divergences in model results as one moves out in time. For this reason, the Inter-governmental Panel on Climate Change (IPCC) tried to portray the wide variance in model results in both its 3rd and 4th assessment reports, and we have chosen to take the more "extreme" of those examples, to include in our model results.

We must also report, at this juncture, that the methodology that we have used to account for climate change "shocks" within our modeling framework, is still under revision and is subject to change in the near future. The main challenge lies in the reconciliation of biophysical modeling results – which are run at a relatively micro-level scale of resolution – with the workings of an aggregate-level, market equilibrium-driven policy model, such as IMPACT, which has to take the average of crop level effects across space. The marriage of these two elements – the biophysical process-driven elements, and economic equilibrium-driven mechanisms – is complex, and is a subject of continuing research. We have also not fully attributed the possible effects that carbon fertilization could have on future crop yields, due to the uncertainty that still exists in trying to quantify this result for various agronomic zones, where on-the-ground reality could differ significantly from carbon fertilization experiments in the laboratory.

Notwithstanding these difficulties, we have elected to present some preliminary results that show the overall magnitude of climate change impacts on global agricultural markets, so that we can begin to discuss the implications of this, in terms of both national and household-level economic effects. For our illustration, we have taken the more extreme "A2a" climate scenario, which represents that socio-economic scenario in which there is higher emphasis on fossil-based fuels, and less cooperation and (clean) technology-sharing across the globe. This type of outcome is similar to the less favorable scenarios of both the Millenium Ecosystem assessment, as well as the UNEP GEO-4 assessment, in terms of portraying a less harmonious, cooperative and purely growth-driven kind of world geopolitical atmosphere.

Figures 13, 14 and 15 show the projected impact of climate change on global prices, for three major cereal commodities that are of key importance to both food and feed uses. The more than doubling of the global market price for maize in 2050 due to climate change (Figure 13), implies strong effects for the livestock industry, which rely on maize for food, as well as for those food consumers of maize, in Sub-Saharan Africa. The less dramatic, but equally important increases in rice and wheat prices have a stronger implication for food uses than for feed uses, and would likely be propagated widely throughout the world food system. Granted that these increases do not necessarily represent sudden spikes in price that occur in 2050, but a gradual accumulation of price pressures that build over time in response to the steady and constant tightening of supplies, as the suitability for crop growth is reduced in various key cereal-growing regions of the world. Nonetheless, these differences do demonstrate that the added pressure on global food supplies would be significantly increased if the environmental drivers embedded in these climate change scenarios were to be realized, and that responsive policy action and adaptation would have to occur, in order to offset these effects. These adapative actions are not, actually, embedded in our results, as the endogenous technology choices of agents is not fully represented in our model. These types of adaptations and technology choices would have to be introduced by scenario, in order to account for the possibility of improved seed variety and other adaptive on-farm improvements, which are not endogenous within our framework. We plan to do these types of adaptation-focused scenarios in further work.

We also show the implications for these climate-driven changes in world food prices, in terms of the effect on child malnutrition outcomes. Looking at the Asian region (Figure 16), we see that the overall progress towards the reduction of malnourishment levels is not greatly hindered in the Asian region, because of these climate pressures, but that there is still an appreciable difference between the 2050 outcomes that are with and without climate change. Given that calorie availability is only one component of the food security measure that we use, this illustrates the fact that it is important to keep the other important socio-economic components of household food security on track, if we are to avoid being seriously derailed, in future, by the additional stress that global climate change poses to our collective food futures.

4. IMPLICATIONS FOR FOOD SECURITY AND POLICY

Now we will discuss the implications suggested by the scenario results that we have seen in the previous section, in light of the current global food situation. In particular we would like to discuss the implications for household-level welfare.

4.1 Micro-level impacts and household welfare

Price changes in food and energy markets influence households directly through market prices or indirectly via cost of production or transportation for other marketed goods. Net sellers and net buyers are affected differently, and even though net sellers gain from price increases, there gains may not be enough to offset the negative impacts that net buyers undergo. From FAO data, we see that in some of the poorest countries, a relatively small share of households are net sellers of the staple foods that are experiencing the strongest price effects. A country like Bangladesh would only have slightly under 16% of all households as net sellers of staples, according to year 2000 data, compared to a country like Vietnam which showed a share slightly over 40% in 1998 (FAO, 2008). Developing countries like Madagascar, which had almost 51% of their households in 1993 as net sellers, would be unusual, compared to countries like Guatemala and Malawi which had slightly over 10% and almost 12% in 2000 and 2004, respectively.

The recent working paper of Ivanic and Martin (2008), showed that the impacts of high food prices had a differential effect on poverty rates and incidence, depending upon this very question of net seller and buyer position of various households. In their analysis, a country like Vietnam could (and probably did) experience a net reduction in poverty rates, due the fact that increased rice prices put those rural households who were net sellers into a much better position than before. Likewise, Peru might also get poverty reductions, due to the fact that increased maize prices would favor those rural households who were in a net seller position. The benefits in Madagascar would arise from maize and dairy, whereas those in Pakistan arise from rice, dairy and wheat. So the impacts vary according to region and commodity, and depend upon the particular structure of the national economy, and the agricultural economy, in particular. Most of the positive benefits that Ivanic and Martin document are in rural areas, whereas urban households tend to bear the negative impacts of higher prices, across the board. In their study they did account for the wage effects, which will be more pronounced (and positive) for the rural households who sell their labor to the agricultural sector.

The means by which households adjust their production and consumption, in response to economic shocks is shown in Figure 17, which illustrates the various dimensions of response that can be undertaken to adjust. Given that a number of expenses might be quasi-fixed, such as rent (especially for urban-dwellers), a good deal of adjustment must come from the food consumption side, often leading to poorer diets and lower levels of essential nutrient intake. For those households with other assets, they can dis-invest to the extent that is possible, in order to smooth consumption in the short-term. Often, however, these dis-investments do not get reversed in future periods, when economic conditions ease, resulting in reduced endowments and enhanced vulnerability to future shocks. The tendency to pull children – especially girls (Schultz, 2002) – from school in times of hardship leads to longer-term effects that arise from decreased investments in human capital and reduced earning capacity and productivity in future.

Some might argue that biofuels, despite causing increases in food prices, could lower the costs of energy to households, and generate some benefits that might not otherwise be accounted for. The specific outcome depends on the shares of household income that go towards food and energy purchases and these shares vary by income level. From the data that we can observe on household level expenditure patterns, we see that those household which lie at the poverty line tend to spend upwards of 50% of their household income on food – whereas that spent on energy is much smaller (Ahmed *et al.,*2007).

4.2 Policy implications

From the evidence and experimental results that we have presented, a number of policy recommendations come to the fore, as being especially pertinent to addressing the world food situation, and its implications for current and future levels of human welfare. Some are of a technological nature, while other pertain more to policy-level interventions, which are both at the national- and global-level.

In terms of specific technological interventions that can address the decline in productivity of key staple crops that have been observed, there are a wide range of improved crop varieties that can be adopted in regions that have relied mostly on traditional but lower-yielding varieties. Some of this varietal improvement will be necessary, just to maintain yields at current levels, in the face of increasingly adverse environmental conditions – such as those brought on by elevated temperature levels, decreased rainfall or increased incidence of crop pests and diseases (which often move over space as a result of changes in the aforementioned temperature and rainfall conditions). A key agricultural technology that was instrumental in allowing the south Asian green revolution to take off was that of irrigation, which is drastically under-invested in certain regions of the world, like sub-Saharan Africa. These increases in irrigation, however, would have to be accompanied by corresponding investments in installing adequate drainage facilities, so that problems of salinity are avoided. In those regions with existing (and increasing) levels of soil salinity, improvement of drainage might also have to be accompanied by adoption of more salt-tolerant crop varieties, in order to maintain yields at the needed levels of for future supply growth.

Some of the obvious policy interventions that are related to the use of agricultural feedstocks for 'first-generation', conventional biofuel production, are those of limiting or perhaps even avoiding the use of food crops in the production of biofuels like ethanol and biodiesel. There are a variety of policy instruments that support biofuels production, such as direct support to biofuel producers and blenders, as well as national blending targets or mandates – as well as trade instruments, which might raise the barriers to imported biofuels from other regions (or encourage their export from others). Technology adoption will largely remain a private industry-driven dynamic, but can be helped from a policy level by increased spending on research and development that is aimed at pushing forward the next generation of conversion technologies and feedstocks. While there are a number of trade-related policy instruments need to be addressed at the country-level, there is also a need for policy (and political) coordination at the global level, in order to effect multi-lateral agreements that can lead toward the liberalization of international trade. As far as biofuels are concerned, trade policy has a large influence on trade and prices through biofuel feedstock and more importantly, trade of biofuels themselves. In practice, allowing for freer trade in ethanol means that gasoline can more easily be replaced by renewable fuels whenever energy prices rise. In addition, if designed poorly, tariffs, tax credits, subsidies and mandates can lead to perverse effects – such as the possibility of actually increasing fossil fuel consumption, as noted by De Gorter and Just (2007).

In terms of social protection of the most vulnerable sections of the population, there is a lot that can be accomplished through policy-driven strengthening of national social 'safety net' programs, that allow for relief for those who are most threatened by escalating food prices, while avoiding 'blanket' policies like price controls, which are easier (and cheaper) for governments to enact – but which have the perverse effect of reducing the producer response that could otherwise soften the price rises through increased output. The main challenge of policy, in this case, is to maintain a balance between maintaining producer incentives, and not introducing distortions that might counteractively dampen the self-correcting responses that are needed, while still supporting human welfare through protecting the most vulnerable. The careful targeting of interventions to those most in need requires deliberate and careful policy design, which is often lacking in indiscriminate food subsidy-type schemes, which might still benefit a lot of the poor (especially if they're the majority consumers of the targeted staples), but might also benefit the better-off households who have other degrees of adjustment (or assets) to exploit.

5. CONCLUSIONS

In this paper, we have explored the nature of several key drivers of change in food systems, and examine a number possible entry points for policy intervention, in order to determine their effect on food prices and other market-driven outcomes. Among the drivers of change that we discuss are those of policy-driven growth in biofuel production, which has had a role to play in the rapid increase in food prices, along with other factors such as global climate change. We demonstrated the off-setting impact that supply growth could have on the socio-economic impacts of biofuels, both in terms of price changes, as well as changes in nutrition status. We also make the argument that it is important to be cognizant of all the components of food security – and not just focus on the one of food production and output – in order to maintain progress towards reducing levels of malnutrition and improving human well-being.

Based on the discussion above, this paper argues that certain policy responses should be avoided in dealing with high prices. These include export bans (akin to a 'starve-your-neighbor' policy), import subsidies, restoration of production subsidies, subsidies for the vocal middle class, policing and threatening traders and attempting to curb food price inflation with macroeconomic policies. On the other hand, the following three broad policy areas would represent desirable and effective tools in fighting the challenges and negative side-effects posed by high food prices: trade, agricultural growth and protection of the vulnerable.

The pressures of high food prices can be alleviated by eliminating trade barriers and export bans and by better enabling international institutions to raise the financing and mobilize the resources needed to effect emergency food imports for the neediest countries. Agricultural growth can be revitalized by expanding aid for rural infrastructure, services, agricultural research and technology. Finally, the vulnerable can be shielded from the worst effects of high food prices by expanding food and nutrition related aid, including safety nets, child nutrition and employment programs.

In summary, a two track approach is needed in developing countries. It should include a global and national food, health, and nutrition security initiative focused on the vulnerable as well as an agricultural productivity initiative focused on small farmers.

Combining our quantitative experiments with cited evidence from other studies, we suggest a range of policy interventions that could be instrumental in offsetting the negative impacts of food prices, and helping to promote those benefits in situations where they might exist – in order to encourage increased investments in the agricultural sector, and reverse the steadily declining trend of research and development spending and decades of counter-productive agricultural trade and national-level sector policy.

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APPENDIX: FIGURES & TABLES

Figure 1: The interrelationships between key drivers of change in food systems and their connection to human well-being

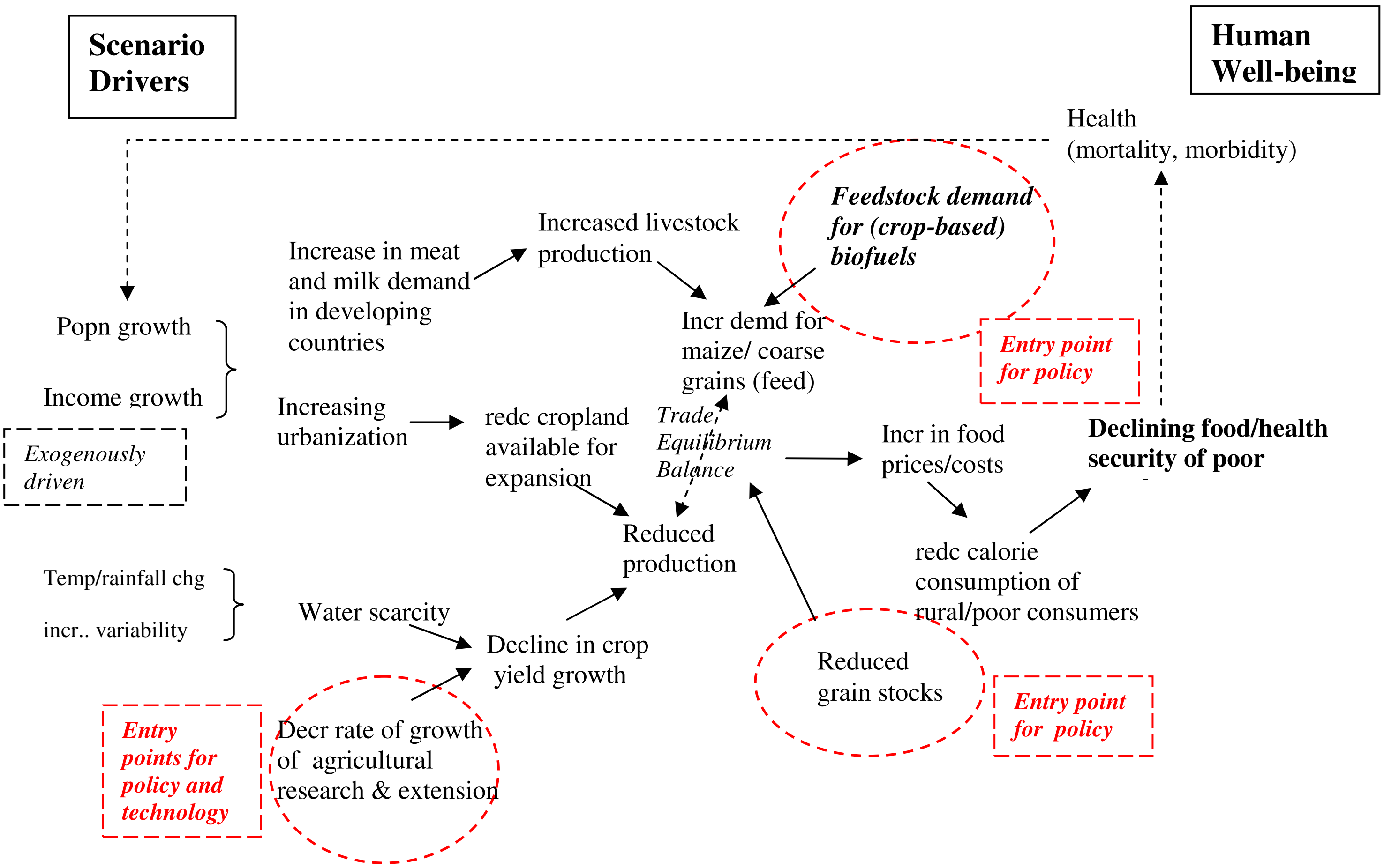


Figure 2: Characteristics of various drivers of change in food systems

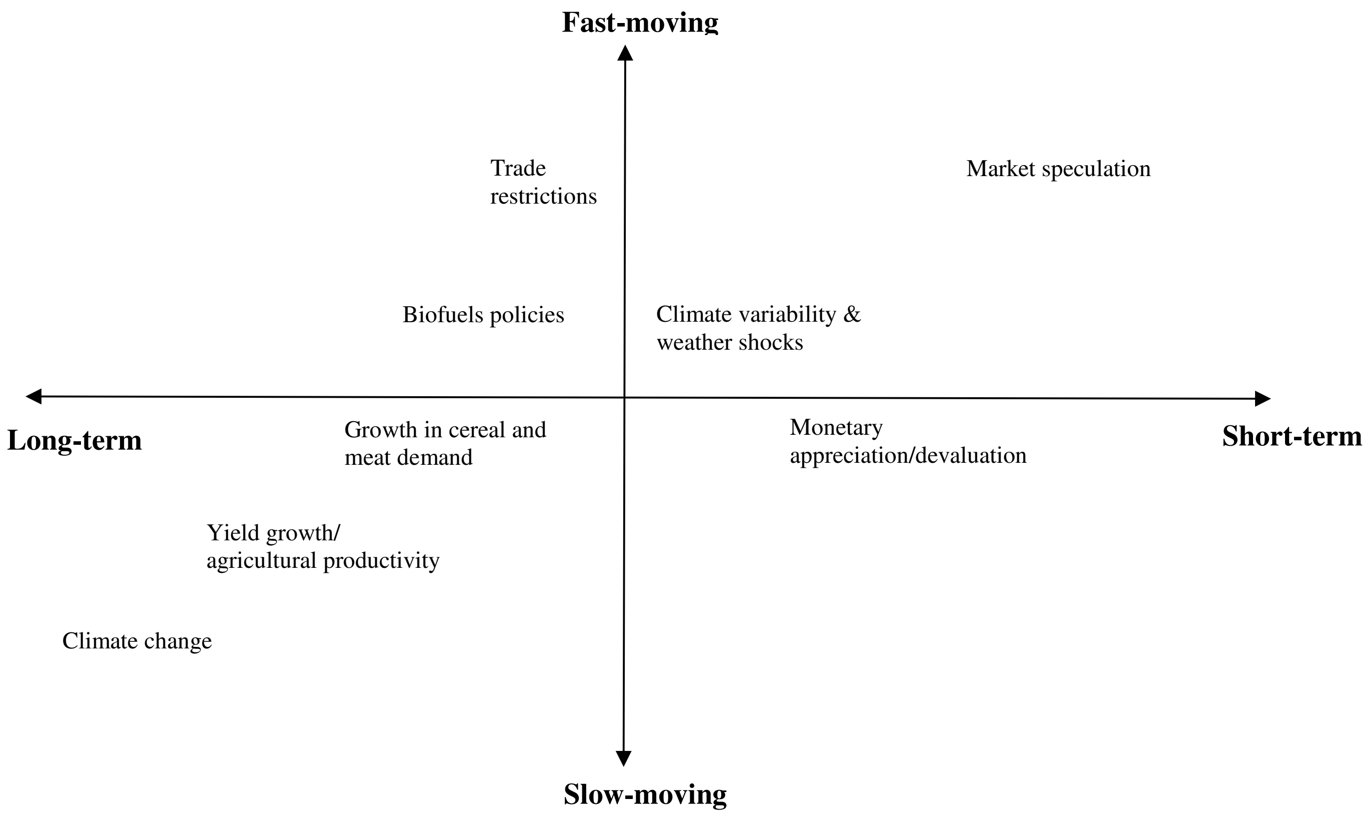
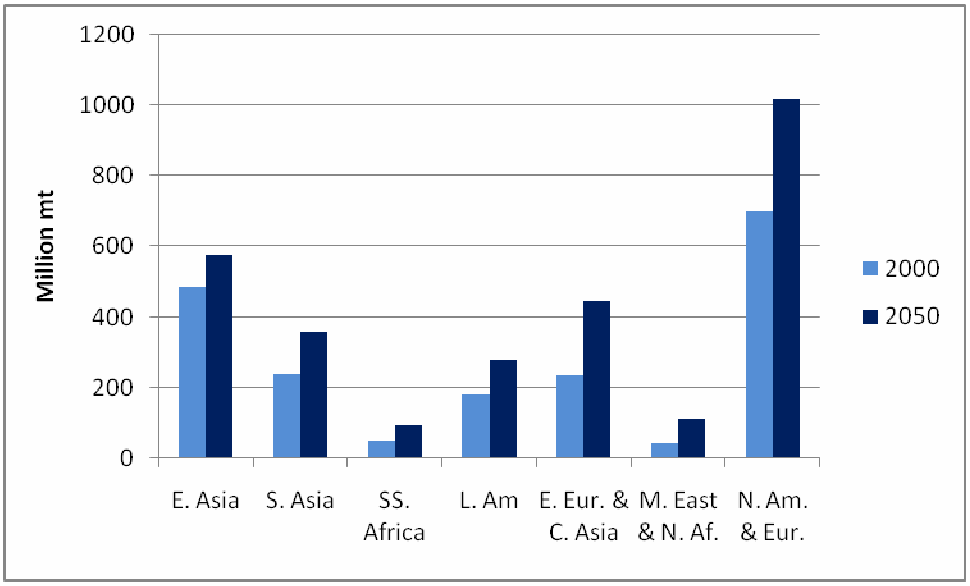


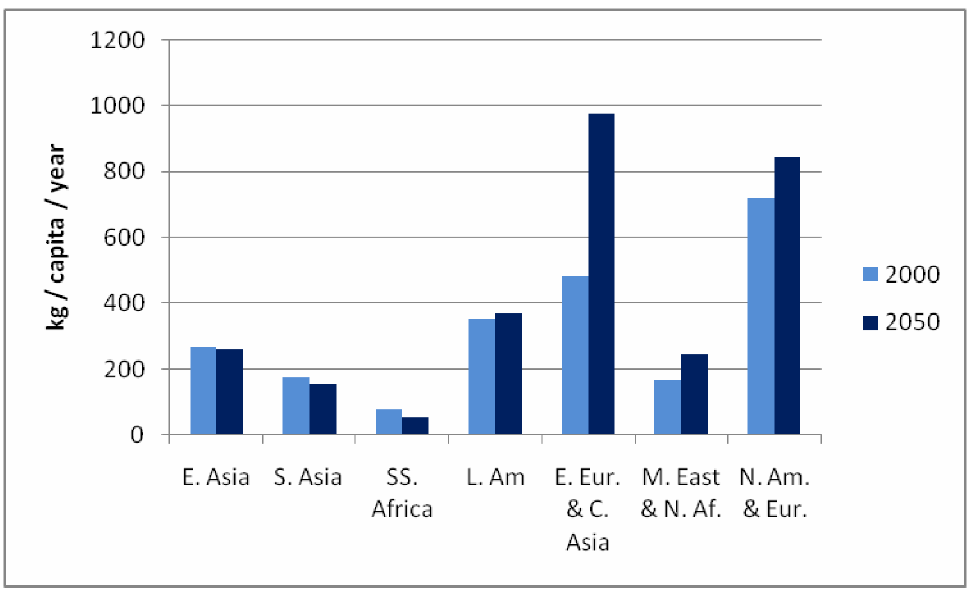
Figure 3: Total Cereal Production to 2050 (millions of metric tons)



Source: IFPRI IMPACT projections.

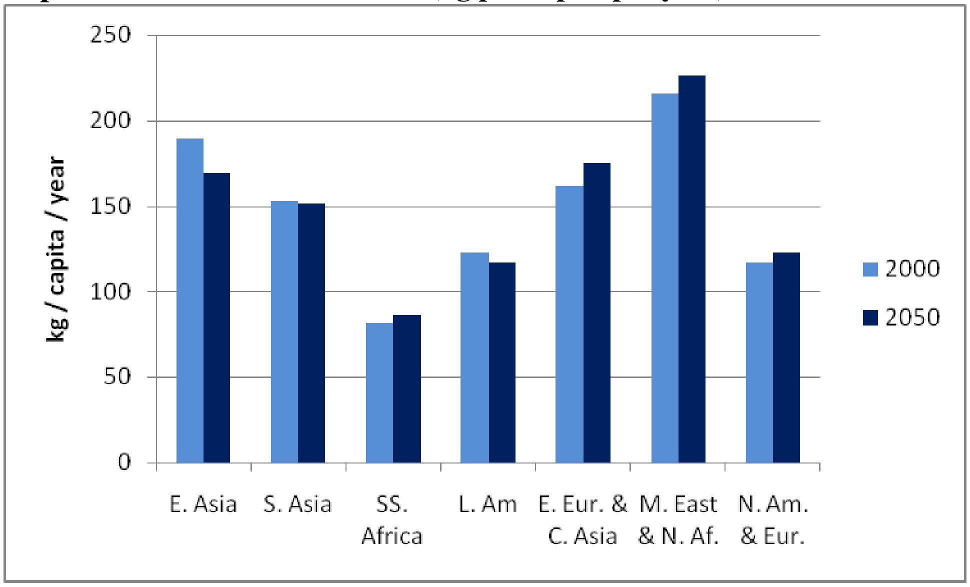
Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

Figure 4: Per Capita Cereal Production to 2050 (kg per capita per year)



Source: IFPRI IMPACT projections.
Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

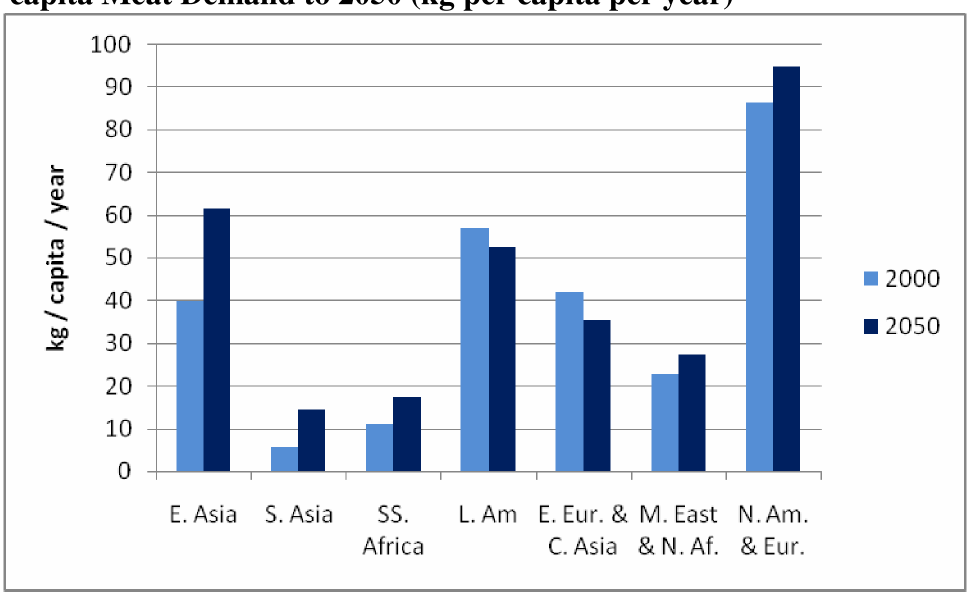
Figure 5: Per capita Cereal Demand to 2050 (kg per capita per year)



Source: IFPRI IMPACT projections.

Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

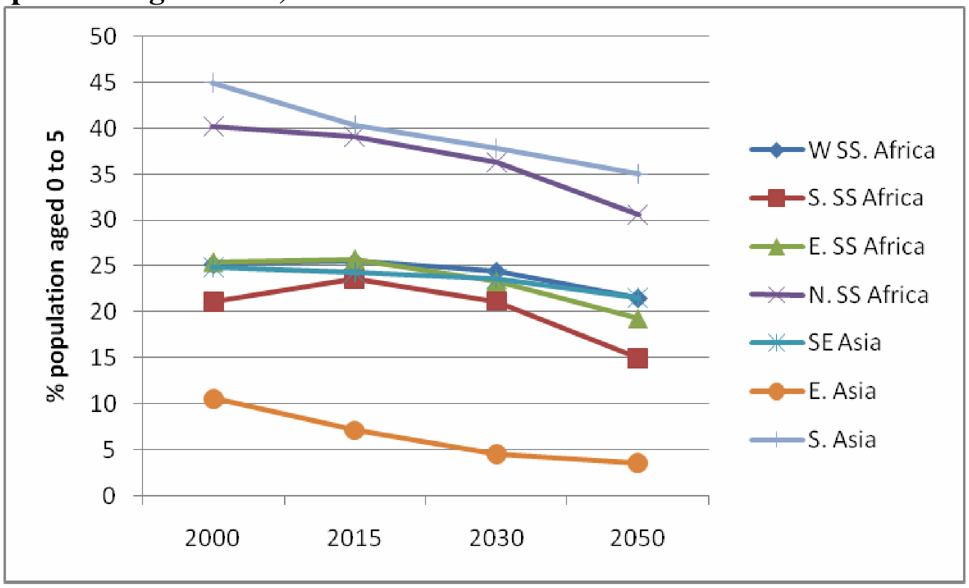
Figure 6: Per capita Meat Demand to 2050 (kg per capita per year)



Source: IFPRI IMPACT projections.

Note: Nrt Am & Eur = North America and Europe, SS Africa = Sub-Saharan Africa, S Asia = South Asia, C&W Asia N Af = Central and West Asia & North Africa, L Am & C = Latin America & the Caribbean, SE Asia & P = SouthEast Asia & Pacific.

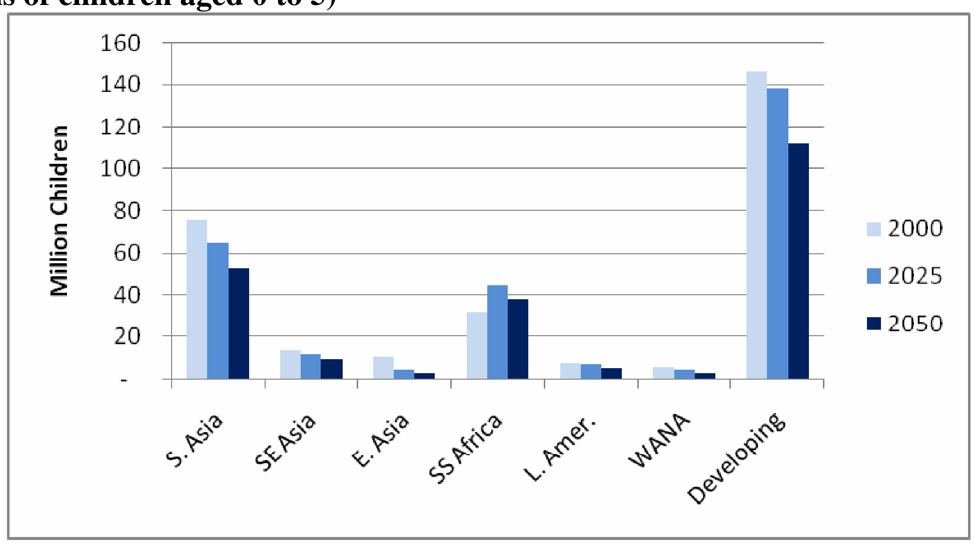
Figure 7: Prevalence of pre-School Child Malnutrition in Asia and Africa (% of population aged 0 to 5)



Source: IFPRI IMPACT projections.

Note: N/S/E/W. SS Africa =Northern/Southern/Eastern/Western Sub-Saharan Africa, S Asia = South Asia, E Asia = East Asia, SE Asia = SouthEast Asia.

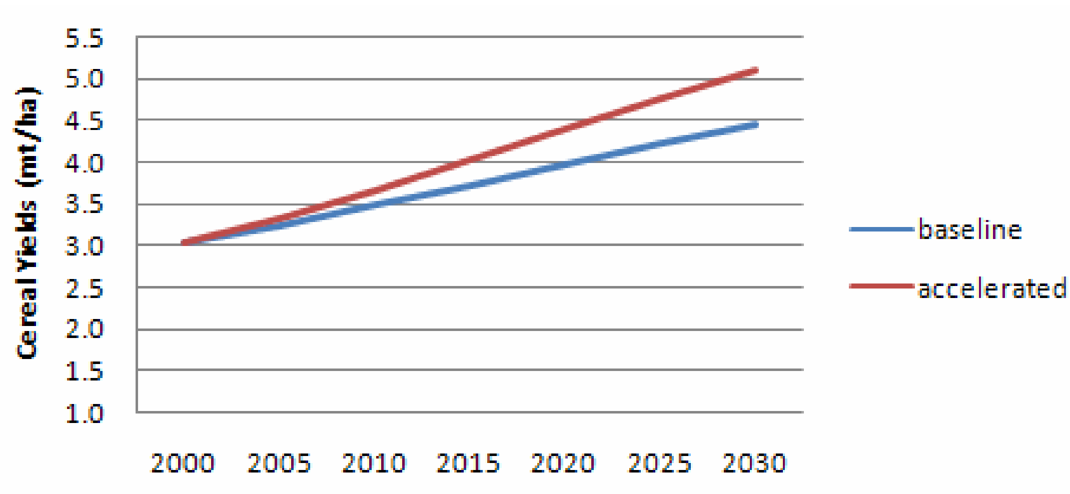
Figure 8: Total Levels of pre-School Child Malnutrition in Developing World (millions of children aged 0 to 5)



Source: IFPRI IMPACT projections.

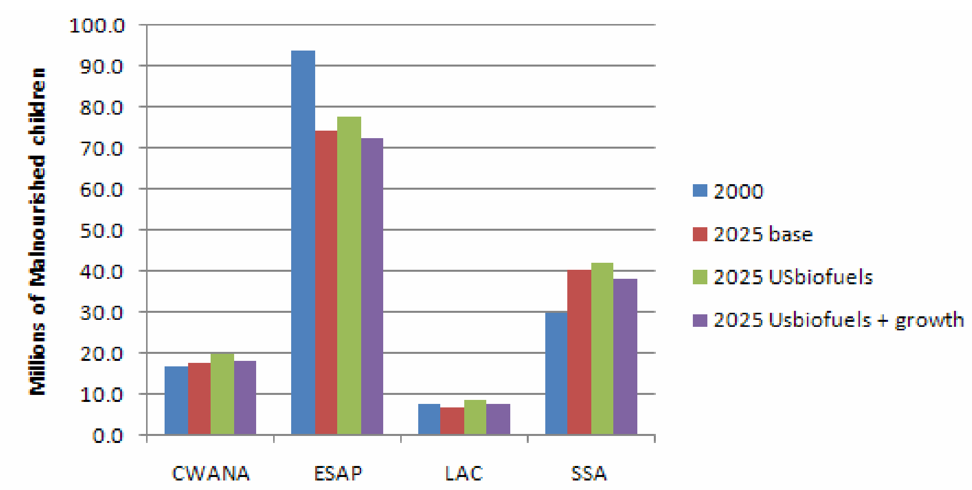
Note: SS Africa = Sub-Saharan Africa, W Asia & N Africa = West Asia & North Africa, L Am & C = Latin America & the Caribbean.

Figure 9: Additional global cereal growth needed to offset impacts of US biofuels target



Source: IMPACT model simulations

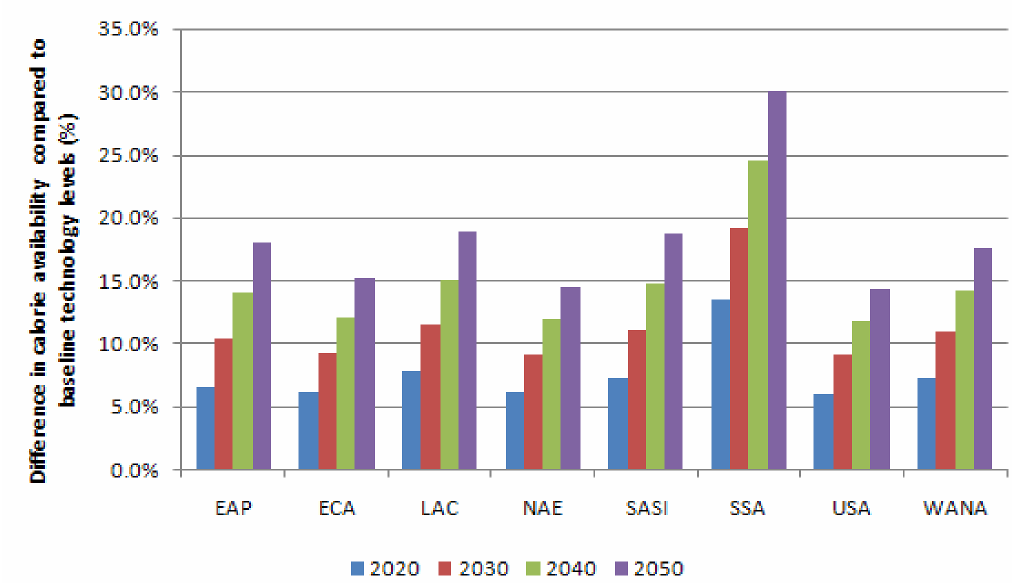
Figure 10: Trends in child malnutrition to 2025 under the baseline case



Source: IFPRI IMPACT projections.

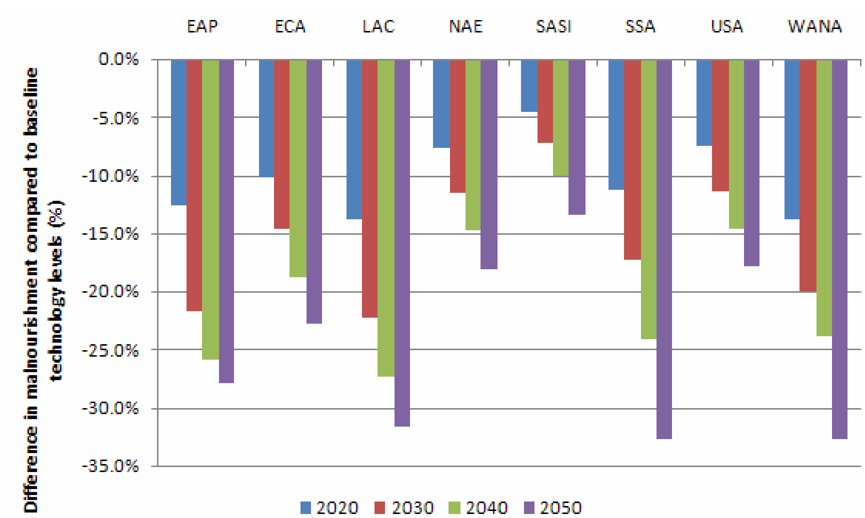
Note: CWANA = Central & West Asia & North Africa, EASP = East Asia & Pacific, LAC = Latin America and Caribbean SSA = Sub-Saharan Africa.

Figure 11: Calorie availability increases compared to biofuel expansion under baseline technology levels (% difference from baseline technology case)



Source: IFPRI IMPACT projections.
Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.

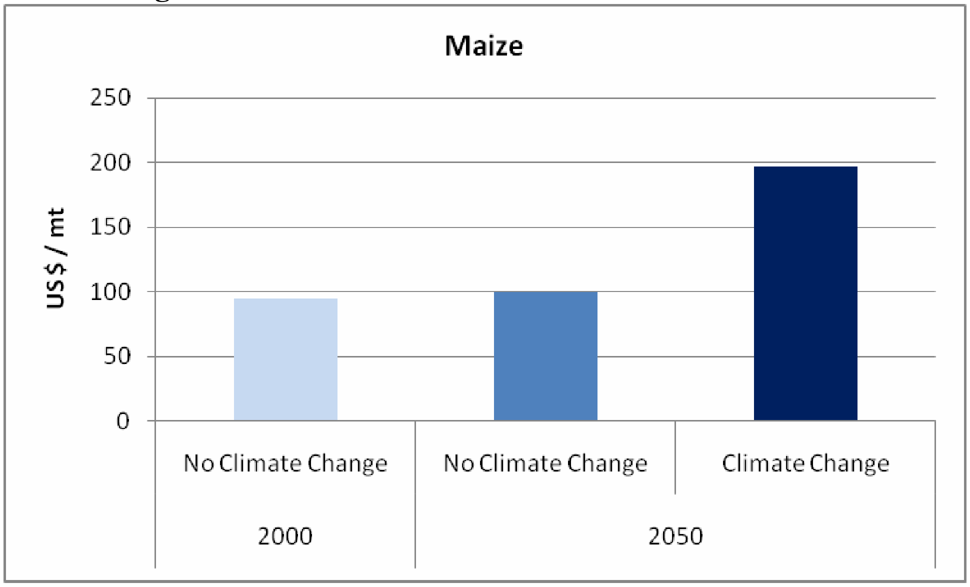
Figure 12: Decreases in numbers of malnourished children compared to biofuel expansion under baseline technology levels (thousands of children)



Source: IFPRI IMPACT projections.

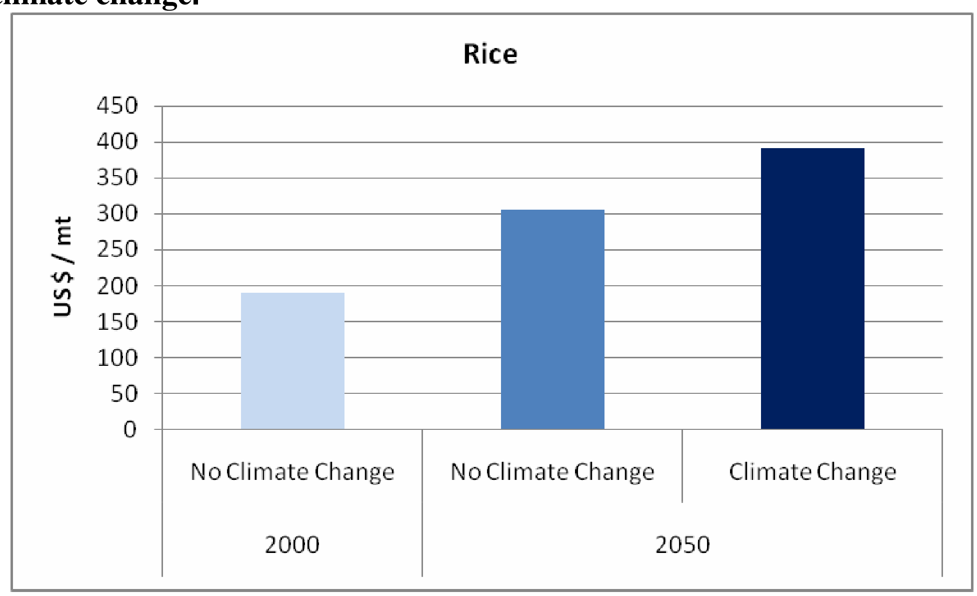
Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.

Figure 13: Global commodity-level maize prices in year 2000 and 2050 under scenarios with and without climate change.



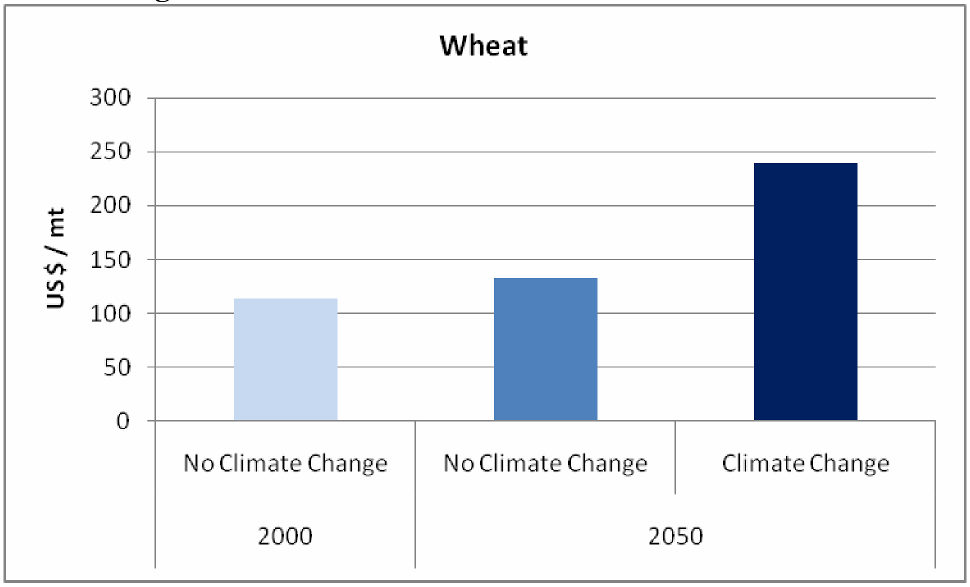
Source: IMPACT model simulations

Figure 14: Global commodity-level rice prices in year 2000 and 2050 under scenarios with and without climate change.



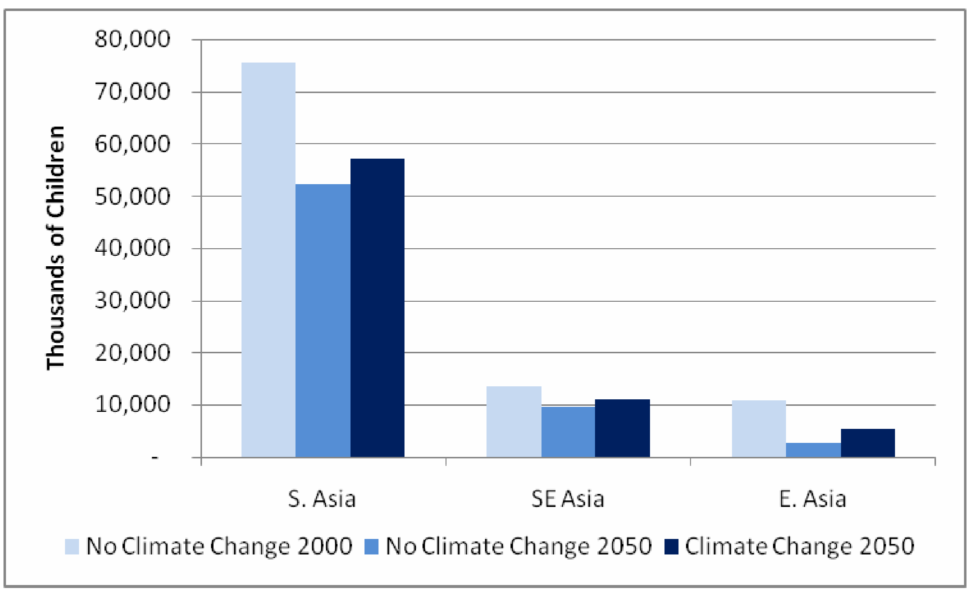
Source: IMPACT model simulations

Figure 15: Global commodity-level wheat prices in year 2000 and 2050 under scenarios with and without climate change.



Source: IMPACT model simulations

Figure 16: Total number of malnourished Children in developing Asia (thousands of children, under 5 yrs of age)



Source: IMPACT model simulations

Figure 17: Schematic of Household Income and Expenditure Adjustments

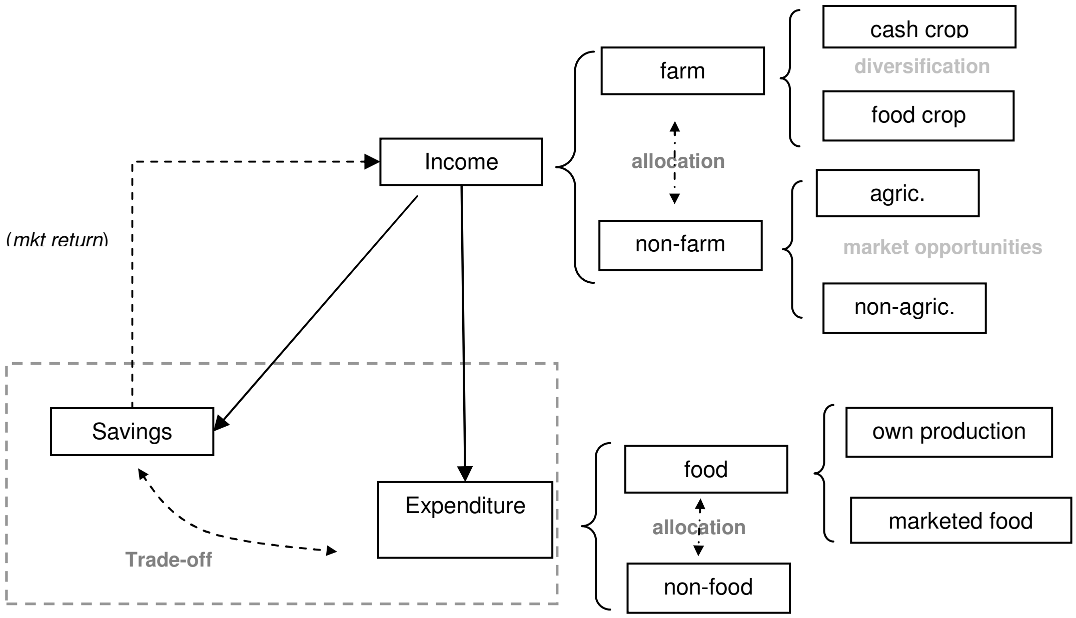


Table 1. Total, Feed and Food Demand for Cereals (millions of metric tons)

	Total			**Food**			**Feed**		
	2000	**2050**	**% chg**	**2000**	**2050**	**% chg**	**2000**	**2050**	**% chg**
South Asia	250	427	71%	218	360	66%	3	12	266%
East Asia and Pacific	524	688	31%	347	376	8%	102	205	100%
Europe and Central Asia	235	267	13%	79	80	1%	108	124	14%
Latin America and Caribbean	180	287	60%	63	88	40%	50	112	122%
Middle East and North Africa	90	182	103%	56	102	83%	23	58	147%
Sub-Saharan Africa	84	243	190%	65	187	189%	7	18	155%
North America and Europe	619	853	38%	114	148	30%	324	401	24%

Source: IFPRI IMPACT projections.

Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.