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Climate Change and the Future of Global Agriculture

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Abstract

Many factors will shape global agriculture looking ahead. On the food demand side the world is likely to witness a slowing of population growth, and in some regions absolute decline, but this may be partially offset by rising incomes and a shift in food demand towards meat and dairy and fruits and vegetables. The emergence of biofuels has increased the demand for agricultural commodities and linked these markets to fossil energy markets, inducing food-bio-energy trade-offs whose long-term consequences are not yet fully delineated. On the supply side productivity gains have been in decline over the last decade and production may be limited by land and water availability. Could this mean the end of the trend of a relative decline in agricultural prices? How will these various trends play at a country and regional scale? Will countries facing increasing reliance on imports implement policies to insure some level of ‘food security’? This paper will illustrate the impacts of various different assumptions linked to both the demand and supply side using the World Bank’s ENVISAGE dynamic global applied general equilibrium model.

JEL classification: Q54, Q12, Q17

Keywords: Agriculture, international trade, global warming, productivity, global computable general equilibrium model

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1. Introduction

Many factors will shape global agriculture looking ahead. On the food demand side the world is likely to witness a slowing of population growth, and in some regions absolute decline, but this may be partially offset by rising incomes and a shift in food demand towards meat and dairy and fruits and vegetables. Whatever changes may occur to per capita demand for food, the world in any event must be prepared to feed an additional 3 billion persons by the year 2050 according to most population projections. The emergence of biofuels has increased the demand for agricultural commodities and linked these markets to fossil energy markets, inducing food-bio-energy trade-offs whose long-term consequences are not yet fully delineated. On the supply side productivity gains have been in decline over the last decade and production may be limited by land and water availability. Could this mean the end of the trend of a relative decline in agricultural prices? How will these various trends play at a country and regional scale? Will countries facing increasing reliance on imports implement policies to insure some level of ‘food security’?

Into this complex mix shaping the future of global agriculture is the looming, if not already present, impact from a changing climate as the accumulation of greenhouse gases in the atmosphere is warming the planet and changing climate and growing patterns. The most serious impacts may not simply reflect a change in average temperature or precipitation, but a more dramatic change in the variability of weather—such as the change in the arrival of the monsoon or longer periods of droughts. Existing studies suggest that those countries already under the greatest stress in terms of agricultural self-sufficiency, such as much of Sub-Saharan Africa and parts of South Asia are also the regions that will be most negatively impacted by climate change.

This paper focuses on some of the following key issues:

- Under a plausible baseline scenario what will be the future role of agriculture in the global economy? Will agricultural prices continue to fall as they have done for most of the past century?

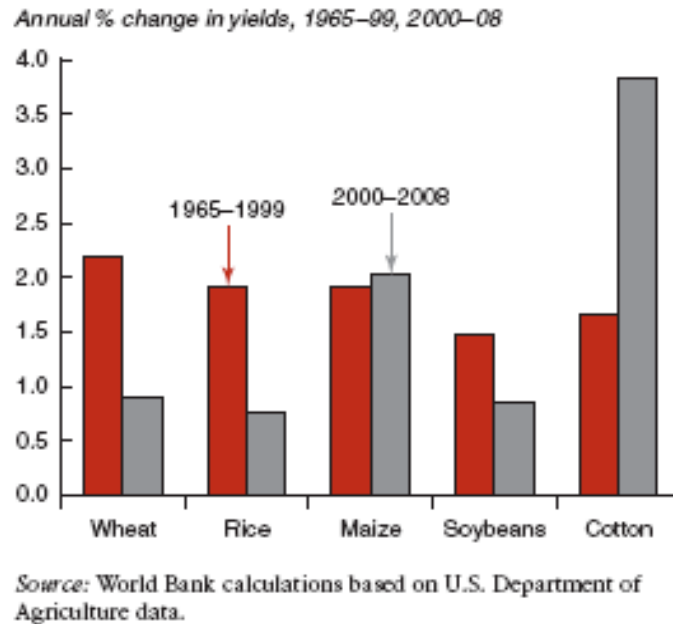
- How will current estimates of the damage to agricultural productivity induced by climate change shape global agriculture? How will climate change affect world agricultural prices? Which countries/regions will benefit from greater trade opportunities? Which will lose?
- More broadly, how will greenhouse gas mitigation policies affect global agriculture? For example, the rise in energy and fertilizer prices and their impact on the cost structure? Or the interactions between carbon taxes on fossil fuels and the competitiveness of alternative fuels such as biofuels. Climate change could accentuate the current food versus fuel debate.

2. Background

Agricultural productivity

Global agricultural productivity has been slowing down in recent decades (Cline). Cline has documented the slow down in yield growth among major crops producers. Agricultural yield growth provides a measure of agricultural technical progress with some caveats. It provides useful snapshots of the evolution of technical improvements in agriculture as realized in fields. For all major crops, yield growth observed during 1961-1983 and then between 1984-2001 shows that global yield growth has been cut drastically, from 3.46% to 1.49% for wheat, from 2.28% to 1.38% for rice, from 2.77% to 1.83% for maize/corn, and from 2.08% to 1.62% for soybeans (Cline). USDA data for 1965 to 1999 and then for 2000 to 2008 suggest nearly similar conclusion with the exception of corn which has shown a slight increase in yield growth rates in the last 9 years (see Background Figure 1).

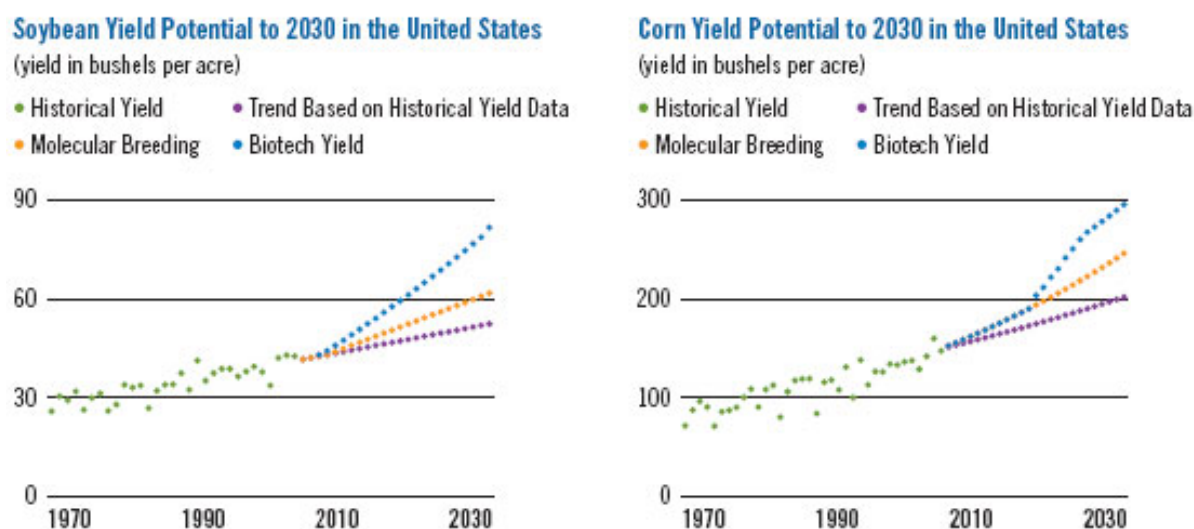
Figure 1. Yield growths have been decelerating



These global averages over time and countries hide much variation across countries and time due to weather shocks and new technologies. China has exhibited the steepest decline in yields between these two periods despite the strong incentives provided by the post 1978 agricultural policy reforms. The latter provided strong incentives to intensify Chinese agriculture as land in private hands was limited. The observed declines in Chinese yield growth were caused by biological limits reached on chemical intensification (fertilizer use).

On the upside, GMO technology may allow for higher yield growth. For example, Monsanto is predicting a doubling of U.S. corn yield the next decade and a near doubling of U.S. soybean yield using molecular breeding combined with biotechnology (Monsanto) (see Background Figure 2). Maize yields in recent years have shown resilience to drought as exemplified by U.S. corn yield. This increasing resistance to precipitation variability may also contribute to global yield growth. Despite these industry conjectures, the conventional view is that global yield may exhibit little growth in the coming decades (Cline).

Figure 2. Projected yield gains in U.S. agriculture (Monsanto)



Technical progress varies by agricultural activity and country. Several factors influence this progress. The suitability of technology developed elsewhere, intellectual property rights on seed innovations, the availability of complementary inputs, farm and food policies that may hinder or ease the adoption of some technology. Maize is a special crop with a remarkable history of yield growth, resistance to drought, etc. Not all crops have had the growth record as maize. For example, yields of sugar cane, another major feedstock for biofuel, have been much more stagnant than grain yields. Among grains, maize/corn has exhibited stronger gains than other coarse grains, principally because of the substantial public and private R&D expenditures going into maize rather than barley, sorghum, or oats.

An important consideration is the positive feedback of carbon fertilization occurring with global warming. This effect is uncertain and depends much on temperature increases as well as on crop type (Cline). Initially, global warming and increase CO₂ concentrations can be beneficial for increases of 1 to 2 °C. Beyond that the effect may be negligible. Initial measures of this carbon fertilization effect estimated large magnitudes. New evidence gathered in fields show more modest effects on yield improvements. Cline (2007) summarizes this debate quite effectively. The estimated impacts of global

warming on agriculture can be reversed in terms of directions and magnitude when comparing impact with and without carbon fertilization. Carbon fertilization could increase yields by as much as 15% with a doubling of CO₂ concentrations (Cline). Given the uncertainty about carbon fertilization, two cases are considered in our analysis, one with and one without carbon fertilization. Many of these climate effects will come into play after 2030.

Will agricultural prices fall in the future?

Farmers do respond to higher commodity prices and adopt cost saving and yield improving technology as long as they are profitable in the short run. In the long run, competitive pressure and the technology treadmill have induced lower commodity prices. The extremely high agricultural prices observed in the summer of 2008 are unlikely to come back as they represent the outcome of a “perfect storm” combining supply shocks, strong exchange rate movements, rising speculative demand feeding back in physical markets, structural change in demand with the emerging feedstock demand, and negative policy reactions to restrict exports. These price levels are even less likely to be sustained. The supply response would be dramatic if such price increases were sustained for more than a growing season.

So would agricultural prices resume their secular decline? A substantial structural change has occurred in agricultural commodity markets with the new demand for feedstock in the bio-fuel industry. This new demand is here to stay as long as policy makers in various countries pursue the development of biofuel markets. As a result, agricultural prices have settled to a higher price level, reflecting this stronger demand and higher land value. Land becomes the residual claimant of higher commodity prices and associated profits. For example, world corn prices have settled to a new and higher equilibrium level following the expansion of the U.S. ethanol industry from roughly \$2/bushel in around 2000 to \$3.5 to \$4.0 in 2009. As long as U.S. borders remain closed to Brazilian ethanol and as long as U.S. policy incentives and mandates remain in place, corn prices will not go back to the lower levels of the early 2000s. Over time, new technology could of course offset part of this price increase as it did in the past.

Global warming is likely to generate supply shocks and price variability. Climate change is likely to increase crop failures via floods and droughts (Stern; Garnaut; and Cline). According to the global warming literature, supply shocks and crop failures will be occurring more frequently in Africa, Asia, in major agricultural regions of Australia (See Cline for a review; and Garnaut). These shocks when combined to a rising demand for feedstock from biofuel production could lead to serious price hikes.

The policy response to high prices is the next component of price shocks. Supply or price shocks induce policy responses. For example, the 2007-08 commodity price hikes showed that the policy responses of several governments were globally inappropriate. Export bans and other forms of export restrictions were imposed to attempt to deflate domestic market prices. This worked domestically to some extent, but with the negative consequence of exacerbating world price movements by reducing the available supply on world markets (Brown et al.; Dollive; Nogues; and Piermartini). Such policies particularly affected the world rice market in the last 2 years and have resulted in higher and more volatile world prices (World Bank; Mitchell; and Timmer).

Are higher farm prices bad? In the long term, predictable higher prices will generate higher farm and rural income, although they hurt the urban poor and the rural net-buyer. The income-generating effects depend on the ability of the agricultural sector to respond to these prices. The better the infrastructure, access to credit and technology, the stronger the output response will be (World Bank). Targeted policies can be put in place to alleviate the burden on the poor such as means-tested food stamps or cash transfers.

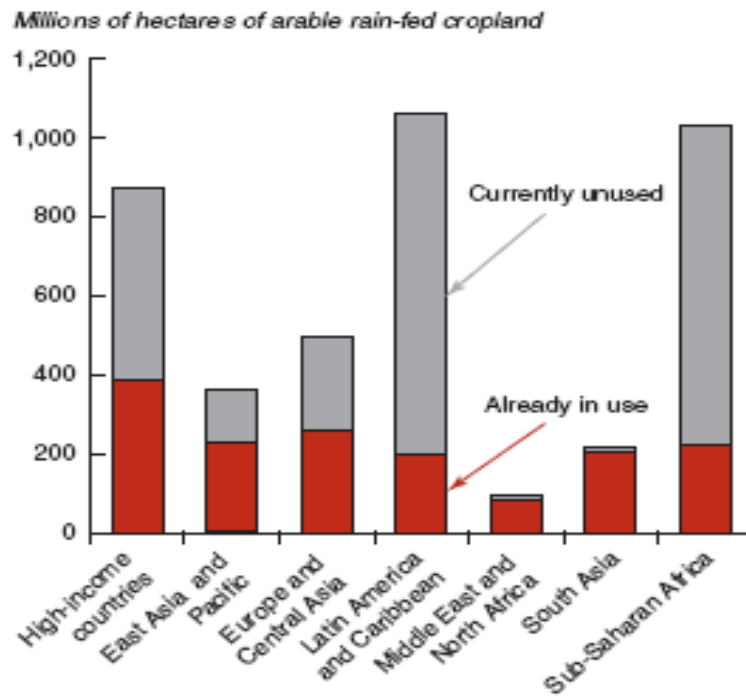
Land expansion

Globally, the most productive land has been put in production. Vast reserves of unused land remain in Brazil, and some land in the U.S. and the EU has returned from agriculture to forest or has been idled because of environmental fragility. With this qualifier, readily available, high quality arable land is scarce globally. However, there is a large supply of lower quality land which has not been tapped, including idled land under farm programs in the EU and the US, land in Africa, and land in the former

USSR (see Background Figure 3). Putting some of this land in profitable production would require some new infrastructure expenditure, especially in Africa. Any major expansion of a crop on existing high quality land may come at the cost of reducing other crops or reducing high quality pasture such as in Argentina.

Global warming through droughts, rising temperature, and salinity issues is likely to make some land inappropriate in Africa, parts of Asia and Australia. For example, Garnaut reports that there is a 10% probability that most of the Murray-Darling river basin might become unsuitable for wheat, rice, and other major crops grown in the bread basket of Australia because of extremely high temperature, drought, and salinity.

Figure 3. Stock of land available world wide



Source: Food and Agriculture Organization.

Agricultural and trade policies

One of the achievements of the Uruguay Round (UR) agreement signed in 1994 was to bring the discipline of the GATT/WTO to the agricultural sectors that had largely been left aside in the previous trade rounds. Despite this achievement, the discipline placed on agricultural support—either through domestic subsidies or trade restrictions—has proven weak at best. There was minimal market access opening as the invention of tariff rate quotas (TRQs) essentially capped trade to a minimal level. Other barriers persist as well, notably sanitary and phyto-sanitary standards. Despite the relatively small share of agriculture in total GDP, most quantitative assessments of potential gains from trade show that the greatest benefits to be had from further liberalization of world trade would be generated by more substantial removal of trade restrictions in agricultural and food trade¹, though the political economy of trade policy reform makes this the most difficult sectors to touch.

There has been some success in the negotiations under the Doha Development Agenda on the agricultural side—though reaching consensus on a final package has eluded the negotiators up until now. One of the critical issues is the designation of so-called special and sensitive products that would most likely be left up to individual countries to define. Even allowing for a narrow band of exemptions could effectively negate an agreement. On the other hand, reducing substantially the current gap between applied and bound rates would limit backsliding on trade liberalization as witnessed last year during the food price crisis or in the current situation where memories of the tariff escalation of the 1930's is still a cautionary tale of what could go seriously wrong.

As mentioned previously, the widespread use of export restrictions and bans during the recent food price hike showed how detrimental the lack of discipline on export restrictions can be. Future negotiations should incorporate discipline on export restrictions to minimize disruption on world markets and increase reliance on trade to smooth out supply shocks.

¹ Most of these assessments leave out the substantial gains that could be garnered from liberalization of the services sector. Measuring trade barriers in services remains a difficult if urgent task.

Net trade and policies

The recent applications of export taxes and bans in many countries show the importance of bringing these policies under a tighter multilateral discipline to reduce the shallowness of world markets and the resulting price sensitivity to policy shocks in these world markets. These markets respond strongly to export restrictions. The rice market is a perfect illustration. No rice-producing country produces primarily for the export market but rather uses world markets to smooth excess supply. Export bans have dramatic effects in this context and raise the price on world markets, penalizing net importing countries. The initial price hike is exacerbated on world markets and it also dampens the supply response in countries implementing the restrictions.

Better targeted measures do exist to avert the negative poverty consequences of high world commodity prices (Brown, Laffan, and White; and Nogués). Similarly, the targeting principle suggests narrower policies to promote some value added activities in infant domestic industries.

3. Modeling approach

The quantitative analysis in this paper relies extensively on the World Bank's dynamic global computable general equilibrium model, ENVISAGE.² Underlying the model is the 2004-based Release 7 of the GTAP³ database that divides the world economy into 113 countries/regions (of which 95 are countries) and 57 commodities. For modeling purposes the underlying database is typically aggregated to a more manageable set of regions and sectors with a focused selection of both depending on the objectives of the particular study. In the case of the current study the focus has been on the agriculture and food sectors, but energy as well to capture the emergence biofuels and the linkage between energy and agriculture. ENVISAGE has been designed for climate change studies and therefore the standard GTAP data is supplemented by several satellite accounts. These satellite accounts include energy data in volume,

² The acronym stands for the ENVironmental Impact and Sustainability Appplied General Equilibrium Model. See van der Mensbrugghe 2009 for a more exhaustive description of the model [Energy Policy web URL?].

³ More on the GTAP data can be found at www.gtap.org.

carbon emissions linked to the burning of fossil fuels, and emissions from the other Kyoto greenhouse gases, i.e. methane (CH₄), nitrous oxides (N₂O), and the fluorinated gases (F-gases).⁴ The other GHG differ from carbon emissions. First, they have a more exhaustive set of drivers since they can be associated with all intermediate inputs, not simply fossil fuels, as well as factor inputs (for example land in the case methane generated by the production of rice) and output. Second, there exist abatement technologies that are more complex than in the case of fossil fuel-based carbon emissions. With current technologies, the latter can only be abated by either lowering consumption of fossil fuels or substitution into lower- or zero-emission fuels. In the case of the other GHG, abatement technologies may exist that involve different production methods, though presumably at a higher cost.

Separately, we have supplemented the GTAP data with a more exhaustive set of electricity activities—splitting the single GTAP electricity sector into five production activities that include coal fired, oil and gas fired, nuclear, hydro-electric and other (including all existing renewables).⁵ For long-term scenario analysis we also introduce several new energy technologies that initially have low penetration, but that under certain circumstances could potentially replace conventional technologies. These new technologies include first and second generation biofuels as potential substitutes in the transport sector, and coal and gas carbon capture and storage (CCS) in the power sector.

In most respects ENVISAGE is a rather classical recursive dynamic global CGE with a time horizon spanning 2004-2100. Production is based on the capital-labor substitution with capital and energy near-complements in the short-term and substitutes in the longer-term. A vintage production structure is employed that allows for partial capital mobility across sectors in the short-term, or a putty-semi-putty technology. Vintage capital is associated with lower production flexibility, whereas new capital is more

⁴ The non-greenhouse gas dataset that is associated with GTAP was produced for the 87-region 2001 based Release 6 of the GTAP data. This was updated to Release 7 using a 2-step procedure. In the first step, new regions were assigned emissions proportional to the emissions from their previous aggregate region. In a second step, the 2001-based emissions were ‘aged’ to 2004 based on GDP growth rates. These estimates will be refined as more GHG inventory data becomes available for more recent years.

⁵ To keep aggregation flexibility, the data has been constructed at the GTAP 113-region level of aggregation. The basic data for the split comes from a combination of IEA and EIA data sources [reference?]. The cost structure of the final data is based on cost data from only a handful of countries and will need to be refined.

flexible thus aggregate flexibility depends on the share of vintage capital in total capital, with greater flexibility associated with those economies with the highest savings rate. Factor payments accrue to a single representative household in each region and the latter allocates income between savings and expenditures on goods and services. The model allows for significant flexibility in specifying consumer demand. The top level utility function can be specified using one of three demand systems—constant difference in elasticities (CDE)⁶, extended linear expenditure system (ELES)⁷, and AIDADS⁸. The top level utility function can be specified at a different commodity aggregation than production. A transition matrix—that allows for commodity substitution—converts consumer goods to produced goods. Energy demand is specified as a single bundle for each agent in the economy. Energy demand is then split into demand for specific types of energy using a nested CES structure. Trade is specified using the ubiquitous Armington assumption⁹—though the model allows for homogeneous commodities as well. Government plays a relatively passive role—collecting taxes and spending on goods and services.¹⁰ The government’s fiscal balance is fixed in any given year (and declines towards 0 from its initial position by 2015), and the household direct tax schedule shifts to achieve the fiscal target.¹¹ The latter implies that changes in indirect taxes (e.g. import tariffs or carbon taxes) are recycled in lump-sum fashion to households. Investment is savings driven and savings rates are influenced by the overall growth rate as well as demographic factors such as dependency ratios. The current account balance for each region is fixed in any given. The base year balances converge towards zero at some date (currently set to 2025). An ex ante shift in either import demand or export supply influences the real exchange rate. Thus, for example, if a country is forced to import more food due to climate damages to its agriculture, this would normally entail a real exchange rate depreciation that increases demand for its exports in order to pay for the additional food imports.

⁶ See Hertel 1997.

⁷ Lluch 1973.

⁸ Rimmer and Powell 1992.

⁹ See Armington 1969.

¹⁰ Fixed relative to GDP in the baseline and fixed to baseline values in policy scenarios.

¹¹ The base year imbalance converges towards zero at some later date currently set at 2015.

ENVISAGE has been developed as an integrated assessment model (IAM). Emissions of the greenhouse gases generated by the economic part of the model lead to changes in atmospheric concentrations. A simple reduced form atmospheric model converts changes in the stock of atmospheric concentrations into changes in radiative forcing and global mean temperature.¹² The resulting changes in global mean temperature feedback on the economy through damage functions that affect various economic drivers. In the current version of the model the only feedback is through changes in agricultural productivity. The agricultural damage functions have been calibrated to the estimates from the recent study by Cline 2007.¹³

4. Baseline

A degree of prudence is needed when undertaking economic scenarios much beyond the near future, say 2015, but climate change is a long-term process and the linkages between the economic drivers and the carbon cycle is a complex relation with significant built-in lags. This section describes the business-as-usual (BaU) scenario, alternatively referred to as baseline or reference scenario, which runs from 2004 through 2100.¹⁴ It is named the BaU scenario because it assumes that by and large all existing policies remain in place, particularly those linked to energy prices and investment.

ENVISAGE, as most other comparable models, has three key drivers at the heart of its scenarios. The first is demographics, which describe the growth of total population as well as the labor force. Like many others, our baseline uses the medium variant from the UN populations forecast, with the growth of the labor force equated to the growth of the working age population (defined as those between 15 and 65 years of age). The second key driver is savings and investment that determines the overall level of the capital stock (along with the rate of depreciation). In ENVISAGE the savings function is partially

¹² The climate module is largely derived from the MERGE model that has a similar configuration of greenhouse gases (Manne et al. 1995 and also available at <http://www.stanford.edu/group/MERGE/m5ccsp.html>).

¹³ Work is ongoing to develop damage functions for other sectors of the economy.

¹⁴ The baseline and other scenarios are solved over this time horizon in varying intervals. Between 2004 and 2015, the model is solved for each year, between 2015 and 2050 in five-year increments, and between 2050 and 2100 in ten-year increments.

determined by demographics with savings rising as dependency ratios (both under 15 and over 65) fall. The third driver is productivity. In our scenarios we differentiate productivity across broad sectors: agriculture, energy, manufacturing, and services. The exogenous component of productivity growth in agriculture is calibrated to 2.1 percentage points per year, consistent with recent trends (World Bank, 2008). The endogenous component of agricultural productivity growth comes from a linear damage function, which links increases in global temperature to declines in agricultural TFP and is calibrated with an average of Cline's estimates with and without carbon fertilization (Cline, 2007). Productivity in other sectors is unaffected by climate change, and is calibrated through 2015 to match the World Bank's medium- and long-term forecast. After 2015, productivity growth in the US is calibrated to achieve a long-term average (2004-2100) growth in real GDP per capita of 1.2 percent per year—with faster growth in the first half of the century—while productivity in other countries/regions is calibrated based on simple convergence assumptions. For the purposes of climate analysis the model runs through 2100, however for the purposes of this paper the focus will be on the period that ends in [2030].

Global population reaches [8.0] billion by 2030, though with a rapidly decline in the population growth rate between 2005 and 2030 (Result Figure 1). Today's developing countries are responsible for nearly 100 percent of this increase, as population in high income countries rises by only 40 million through 2030. This raises the population share of the developing world from 83 percent in 2004 to 86 percent in 2030.

At market exchange rates there is a clear rotation of economic activity towards developing countries by 2030 (Result Figure 2). Their share in global activity doubles by 2030—from around 20 percent to 40 percent, based on significantly greater growth rates for developing countries even if the scenario assumes some leveling off of the rapid growth over the last decade.¹⁵

¹⁵ The current crisis has significantly lowered growth prospects for 2009, but the World Bank's current forecast is for a relatively short crisis and rapid return to potential growth. The long-term impacts are expected to be negligible.

Our emissions profile is significantly higher than most of those that form the basis of the climate change analysis as presented in the recently released Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC 2007). The scenarios in AR4 were generated around 2000 and largely underestimated both output and emission growth over the last decade. Our baseline scenario, calibrated to actual growth over the last decade shows much greater emission growth, and, if this pattern continues, puts the world on a trajectory with much higher temperature changes than the AR4 median of around 3 °C by the end of the century. The potential for high agricultural damages, particularly as it affects developing countries, is great as we explore further below.

Global agricultural production in the baseline grows at close to 3 percent per annum with high growth in the higher value added commodities notably fruits and vegetables and livestock (Result Figure 3). Grain production growth is more modest reflecting a number of factors including improved feeding efficiency and expansion of range feeding. Under the demand and supply assumptions of the baseline, agricultural prices are largely stagnant (compared to manufacturing prices—the model’s numéraire), with some variations across sector. Compared to recent history where prices have fallen roughly 1 per cent per annum (prior to the recent price boom) this reflects rapid income growth in developing countries where over 80 percent of the global population resides and somewhat more modest productivity growth (Result Figure 4). The net agricultural trade position will also evolve over time with demand outpacing production in most developing countries, particularly East Asia and Pacific led by China with its high income growth and low expansion potential (Result Figure 5). For developing countries as a whole, the net agricultural trade position deteriorates by around 1 percent of GDP by 2015 and nearly 2 percent in 2030 (relative to the base year). Latin America and the Middle East and North Africa regions are the exceptions among developing regions. Sub-Saharan Africa which used to be a big net exporter sees some slight deterioration, but decelerating as population growth slows down significantly in the later period.

5. Alternative scenarios

The importance of productivity

The baseline productivity assumptions for agriculture may be overly optimistic, if not on a global basis, perhaps regionally. Research and development expenditures have stagnated, water stress is high in many regions, acidity and salinity are affecting productivity and many consumers (and therefore countries) have shunned GMO-based crops. In the medium term rising concentrations of atmospheric carbon may induce plant growth, but the so-called carbon fertilization effect is still under scrutiny—particularly as controlled experiments and open-air field experiments suggest contrasting results.

We test the sensitivity of the baseline results to different assumptions on agricultural productivity. In one scenario we assume that lower productivity only affects developing countries and impose a TFP of 1.2 percent per annum rather than the baseline 2.1 percent. In a second scenario, we assume that all agriculture is affected by the TFP slowdown.

The key impacts are illustrated in Result Figure 6. For developed countries, slower productivity growth in developing countries provides an additional boost in agricultural net trade relative to the baseline in 2030 amounting some 0.7 percent of GDP.¹⁶ The added deterioration for developing countries exceeds 1 percent of 2030 GDP—adding substantially to the widening of the agricultural trade gap in the baseline relative to the initial position. And, unlike in the baseline, world agricultural prices rise in this lower productivity scenario by around 0.6 per annum per year translating into an increase of around 19 percent on average in 2030 relative to the baseline. A global decline in agricultural productivity would also tend to worsen the agricultural net trade position of developing countries, but by a somewhat smaller amount than when the lower productivity is limited to developing countries only. Prices, on the other

¹⁶ Note that in the baseline net agricultural trade for developed countries improves by some 0.95 percent of 2030 GDP relative to the base year (figure 5), so the total impact, relative to the base year is around 1.6 percent of GDP in 2030.

hand would increase substantially more—rising by an average of 1.2 percent per annum compared with no change in the baseline and prices some 37 percent higher in 2030 compared to the baseline.

Damages from climate

Part of the deterioration in the net trade position of developing countries comes from the fact that climate induced agricultural damages are uneven across regions with developing regions suffering more on average than developed regions. The baseline estimates of climate damage are calibrated to the estimates described in Cline 2007. We have used the no carbon fertilization estimates—so that we may be overestimating the damages should carbon fertilization prove to be positive—at least in the medium term. The damage functions have also been specified to be linear for technical reasons. This may overstate damages in the short-term, particularly in certain regions where warming could be beneficial, for example the northern latitudes, an understate damages in the long-run as many damage functions in the literature are assumed to be non-linear (see Nordhaus 2007 for example).

In an alternative baseline we assess the impacts of assuming away climate induced damages by simply. In this case agricultural productivity matches the exogenous assumption of 2.1 percent uniform growth with no deviation. The impacts on real income from climate damages even in 2030 could be substantial. South Asia would take the most significant hit—a loss in real income in 2030 of over 2 percent, more than double the loss of the next region Sub-Saharan Africa (Result Figure 7). The relatively large losses in these two regions reflect two factors. First, agriculture remains relatively important for these two regions in 2030 despite relatively rapid growth. And second, the Cline estimates, that summarize a relatively wide body of research, have the largest damages occurring in these two regions. The impact on the high-income countries is negligible in the short-term. Partly, this arises from a terms of trade gain as world prices rise in the with-damage scenario and the net trade position of high-income countries improves. This latter point is illustrated in Result Figure 8 where the net trade position of all developing regions deteriorates in the with-damage scenario, albeit somewhat modestly in 2030, and improves (modestly) for high-income countries. Climate damages are bound to increase over time—both

because the climate will deteriorate and also due to non-linear effects (not currently captured in our model).

Removal of trade barriers and agricultural support

Policy changes—particularly agricultural support and border restrictions will also have long-term impacts on structural changes and relative comparative advantage. There have been a number of quantitative analyses of merchandise trade reform—both partial, as may emerge from a yet-to-conclude Doha Round of negotiations, and full free trade (though typically limited to merchandise trade).¹⁷ The estimates cited herein rely on the relatively new Release 7 of the GTAP database and differ somewhat from estimated impacts based on Release 6. Global free trade would lead to significant changes in trade patterns and raise real income. Our most recent estimate suggests that high-income countries could gain as much as 1 percent of real income on average by 2025 under a free trade scenario (that also includes removal of all domestic support measures). Developing country gains would be somewhat less at around 0.6 percent of income (Result Figure 9). These new results somewhat change the distribution of gains that used to be skewed somewhat more towards developing countries. This reflects in part a new data base with a different base year, a different structure of production and a different pattern of trade restrictions. The latter suggests that there was significant reform between 2001 and 2004 that includes unilateral liberalization on the part of some developing countries (notably through China's WTO accession agreement and further reform under the Uruguay Round agreement that had a 10-year transition period. For both regions the income gains are not insubstantial and could be an underestimate for a variety of reasons including the exclusion of pro-growth dynamic effects, pro-competitive imperfect competition effects and a downward aggregation bias.¹⁸ The net agricultural trade impacts suggest that developing countries could see an improvement of some 0.2 percent (relative to baseline income) in 2025 from full removal of trade distortions—somewhat reversing the long-term trend of deterioration (Result Figure 9).

¹⁷ See for example Anderson, Martin and van der Mensbrugghe, Bouët et al, Hertel et al...[to be completed].

¹⁸ In another paper being presented at this conference, an attempt is made to overcome the aggregation bias using a new methodology—see Laborde, Martin and van der Mensbrugghe 2009.

There is considerable variation across developing regions (not shown here) with Latin America, for example, exhibiting an improvement in net agricultural trade of some 1.6 percent relative to income.

Biofuels

The expansion of ethanol based on grain feedstock is quite different from that of ethanol production based on sugar cane, especially in Latin America. The tradeoff between food and fuel is quite limited in the case of sugar cane based ethanol. Sugarcane expansion would occur primarily in Latin America, then in other countries with low-cost sugar production. Most of this expansion will occur on land for which competition among crops is limited. By contrast, ethanol based on grains has a direct effect on several important competing crops, including oilseeds. The expansion of biodiesel as a strong and direct implication for vegetable oil prices and the feedstock and food demand are in direct competition. A large bio-diesel expansion will push vegetable prices higher. Hence, the expansion of biofuel based on grains and oilseed products is a potential factor of exacerbation of high food prices and could compromise the access to food or the poorest on the planet. The most affected food prices would be grains, vegetable oils, meat, and dairy products which are intensive in feedstocks.

However, if cellulosic/biomass ethanol can become profitable, this tradeoff between food and fuel may be less important and confined to oilseed based biofuels. The development of biofuels is also determined by their return. The latter is largely determined by fossil energy prices and feedstock prices. Low fossil energy prices will undermine the development of large biofuel sectors and would reduce the tradeoff between food and fuel. Of course large and forced biofuel mandates could change this result. It is difficult to know what policies will prevail in 2050.

5. Conclusion

Many factors will influence agricultural production, trade, and prices over the next 40 years. As the world grows from the present day 6.5 billion towards some 9 to 10 billion by 2050, can the world sustainably feed the additional mouths? If so, at what economic and/or environmental cost? The recent price crisis

was perhaps a wake-up call after a period of complacency regarding agriculture. And shaping this discussion will also be concerns about sustainable agriculture as recent reports on climate change—the Stern Review, the IPPC’s Fourth Assessment Report, the Garnaut review, and even Al Gore’s documentary—so vividly portray. With hunger still prevalent in many parts of the world both issues of affordability and sustainability will go hand-in-hand.

This paper illustrates some of the key elements to both affordability and sustainability. Productivity will be a critical factor—as it has been over the last 100 years. This includes both the ability to move the productivity frontier outwards in the most advanced economies as well as progress by lagging regions to move towards the frontier. The policy implications are different. For the advanced economies it relies mostly on research and development and improving production technologies. In lagging regions it not only includes these policies but as well complementary policies that improve overall supply responsiveness—agricultural extension, investment in access to water, rural electrification, mechanization, access to credit and development of regional and national markets (including roads, storage facilities, etc) that expand the potential markets for farmers and reduce transaction costs.

Our baseline may be overly optimistic as it suggests that the potential is there to affordably feed the next 3 billion (albeit ignoring distributional issues that are highly relevant today and in the future). Moreover, in this paper we do not link the rapid growth in agricultural productivity in the baseline to actual policies and their economic costs [though there is evidence that many of the needed policies have high economic rates of return]. Climate change will make achieving high rates of productivity more difficult and less predictable—and the costs for some regions, often the poorest and most vulnerable could be high.

The expansion of biofuels is a potential factor of exacerbation of high prices and could compromise the access to food or the poorest on the planet. If cellulosic/biomass ethanol can become profitable, this trade off between food and fuel may not be important. If current feedstock (grains) are maintained in temperate countries, the trade-off could become acute unless ethanol trade becomes open and sugar-ethanol is allowed to compete against grain ethanol. The development of biofuels is linked to

their return largely determined by fossil energy prices and feedstock prices. Low fossil energy prices will undermine the development of large biofuel sectors and would reduce the tradeoff between food and fuel. Of course large and forced biofuel mandates could change this result.

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Result Figures

Figure 1: Baseline population

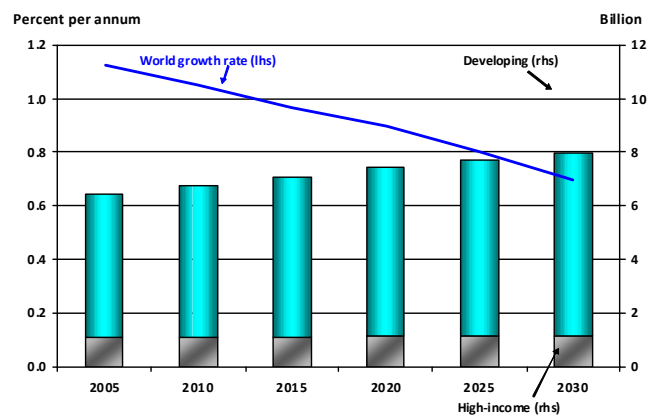


Figure 2: Baseline GDP at constant prices

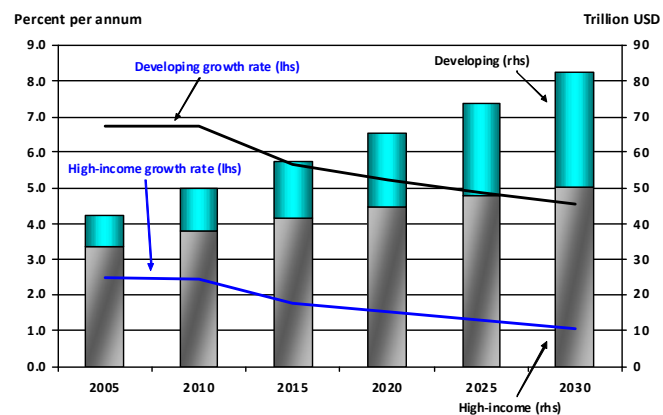


Figure 3: Growth in world agricultural production in baseline scenario

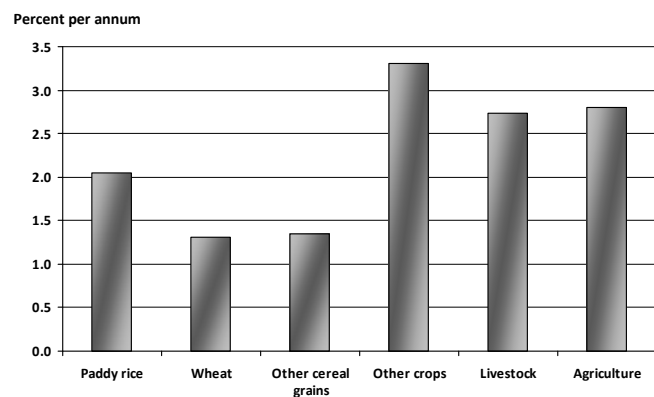


Figure 4: World agricultural prices in baseline scenario

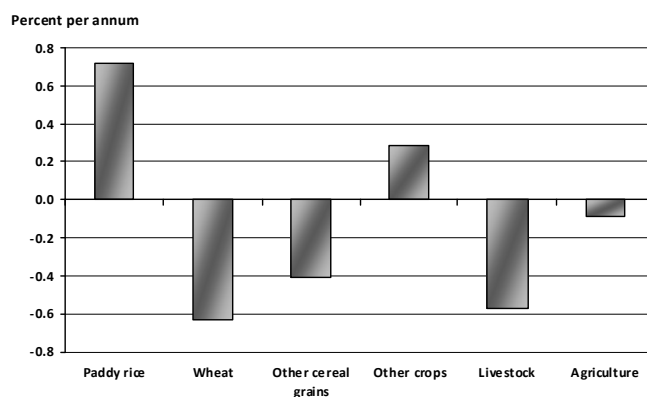
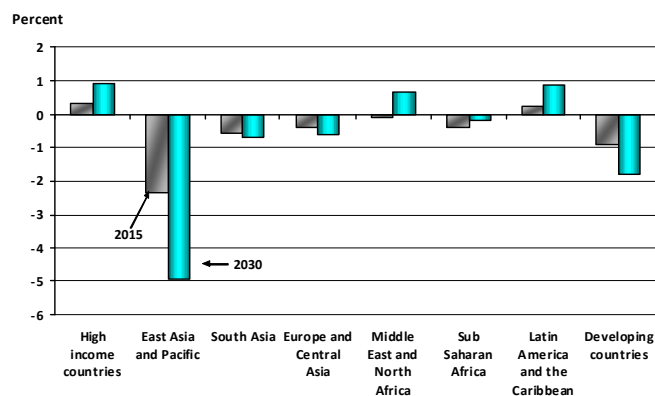
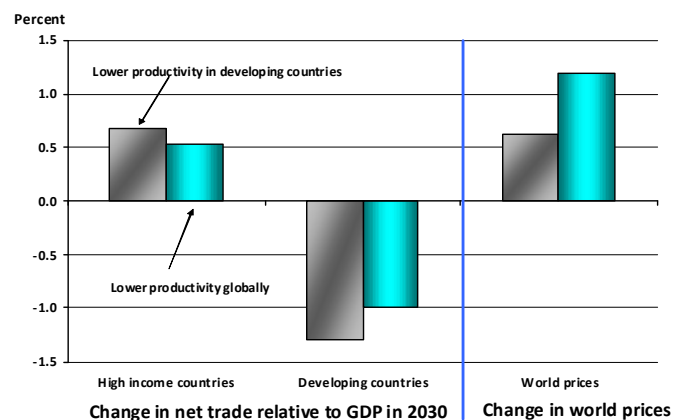


Figure 5: Change in agricultural net trade relative to base year as percent of GDP



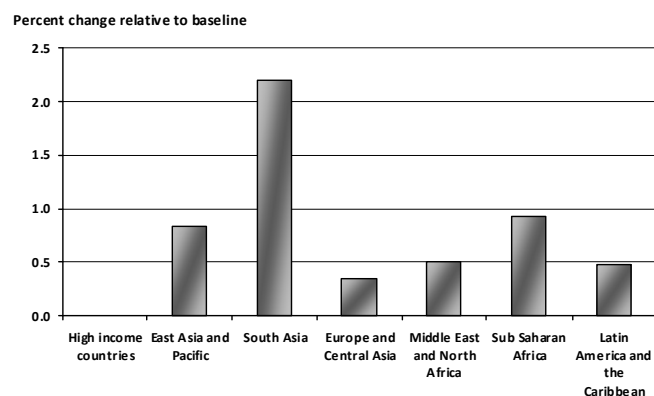
Source: Simulations with ENVISAGE.

Figure 6: Summary impact of changes in agricultural productivity in 2030



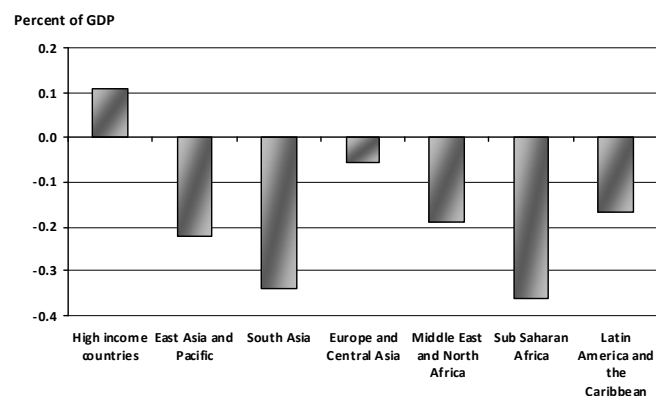
Source: Simulations with ENVISAGE.

Figure 7: Impact of climate damage on real income in 2030



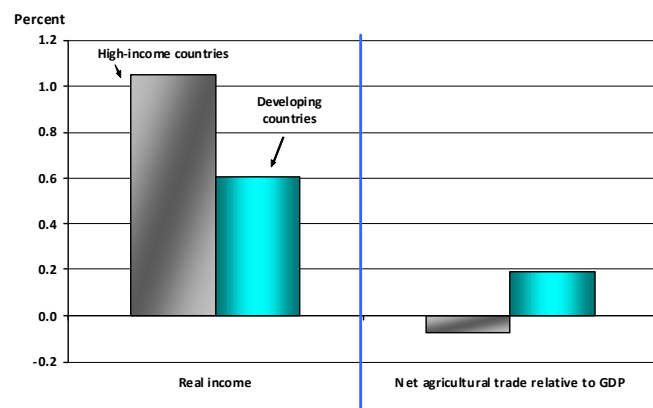
Source: Simulations with ENVISAGE.

Figure 8: Impact of climate damage on agricultural net trade in 2030



Source: Simulations with ENVISAGE.

Figure 9: Summary impact of global free trade in 2025



Source: Simulations with ENVISAGE.