Bursting the Bubble:

A Long Run Perspective on Crop Commodity Prices

by

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GTAP Working Paper No. 80

2014

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Abstract

Contrary to the opinions expressed by many commentators, the recent price spike in agricultural commodities is a transitory phenomenon. Using projections from SIMPLE – a global model of the farm and food system – we argue that, in the long run, food prices will most likely resume their historical downward trend. We begin with an evaluation of the historical period 1961 to 2006 wherein the growth in agricultural productivity outpaced that of global crop demand, the latter being fueled by rising population and incomes. As a consequence, we observed a historical decline in global crop prices, which the SIMPLE model faithfully reproduces. Moving forward to 2051, we establish a set of projections in global crop prices given expected developments in population, incomes, agricultural productivity and biofuel use. We project that global crop prices will continue their long run decline in the coming decades, albeit at a slower pace. However, we recognize that, under some circumstances, global crop prices could still increase by mid-century. To formally assess the likelihood of future price changes, we conduct Monte Carlo simulations given distributions in the growth rates of both drivers and economic responses. Results show that 72% of the realizations produce price declines from 2006 to 2051.

Keywords: crop commodity prices, long run projections, population growth, income growth, biofuels, crop productivity

JEL: Q11, Q12, Q18

1. Introduction

As recently as 2013, there appeared to be wide spread agreement that international agricultural commodity prices had ceased their secular decline and are now on a new trajectory, owing to biofuels, rapid growth in many developing economies, and slowing productivity growth. The World Bank (2013b) has stressed that "...high and volatile food prices have become the "new normal"...". The Food and Agriculture Organization of the United Nations (FAO Media Centre, 2013) notes that "In the past century ... real food prices declined steadily... . In the beginning of this century that long-term trend has been reversed..." The OECD/FAO (2013) noted that "prolonged periods of low agricultural prices driven by ever increasing productivity improvements… seem now a feature of a bygone era". Strong supply response in the current crop year has subsequently altered this view of the world. The most recent OECD/FAO (2014) outlook for the 2014-2023 period envisions price declines for the next two years, followed by a leveling off of crop prices.

Nonetheless, there remains a strong belief that the future holds higher crop prices in store – particularly when climate change impacts are factored into the analysis. Oxfam (2012) reported that "...the average price of staple foods... could more than double in the next 20 years compared with 2010 trend prices" in the wake of climate change. The International Food Policy Research Institute projected that the rise in the price of food grains such as rice, maize and wheat from 2010 to 2050 might be has high as 92% to 64% under current agricultural technologies (Rosegrant et al., 2014). A recent MIT study (Paltsev, 2012) suggests that global agricultural prices from 2010 to 2050 may increase by more than 20%-30% if GHG mitigation policies are implemented. The idea that future commodity prices will rise seems pervasive in the public discourse.

We believe that this 'consensus' is misguided. Observers have been overly influenced by the 2007/08 and 2010/11 spikes in commodity prices, which have largely been driven by transitory phenomena, including record low stocks, an exceptional build-up in the U.S. and European Union biofuels programs, and a succession of adverse weather events (Abbott, Hurt, & Tyner, 2011; Piesse & Thirtle, 2009). Meanwhile, they have not paid sufficient attention to long run structural changes, including slowing population growth, the changing composition of global income growth and recent growth rates in agricultural productivity. When these underlying drivers of change are taken into account, we find that long run crop commodity prices will most likely resume a downward trend.

This is not the first time agricultural commodity prices have spiked over the past century. Figure 1 reports CPI-deflated corn prices in the United States since 1900, which are broadly indicative of real agricultural commodity prices[1]. In the early 1970's, food supply and trade shocks drove real food prices to levels not seen since the 1940's. However, over time, an expansion of supplies, coupled with the rebuilding of commodity stocks, led to prices resuming their long run downward trend. Indeed, Timmer (2010) has argued that regular food crises every three decades are to be expected as governments and private investors cycle through periods of low prices/disinterest into periods of high prices and strong supply response. Is the current experience

[1] Dorward (2013) points out that the U.S. CPI is not the right deflator to use if one is interested in the impact on purchasing power of the poor in developing countries. We choose CPI-adjusted US corn prices in order to have the longest possible time series in this figure.

a repeat of the 1970's? Will prices resume their decline over the coming decades? In order to systematically explore this question, we conduct a series of experiments designed to assess the long run changes in global food prices using the Simplified International Model of agricultural Prices, Land use and the Environment (SIMPLE) (Baldos & Hertel, 2013).

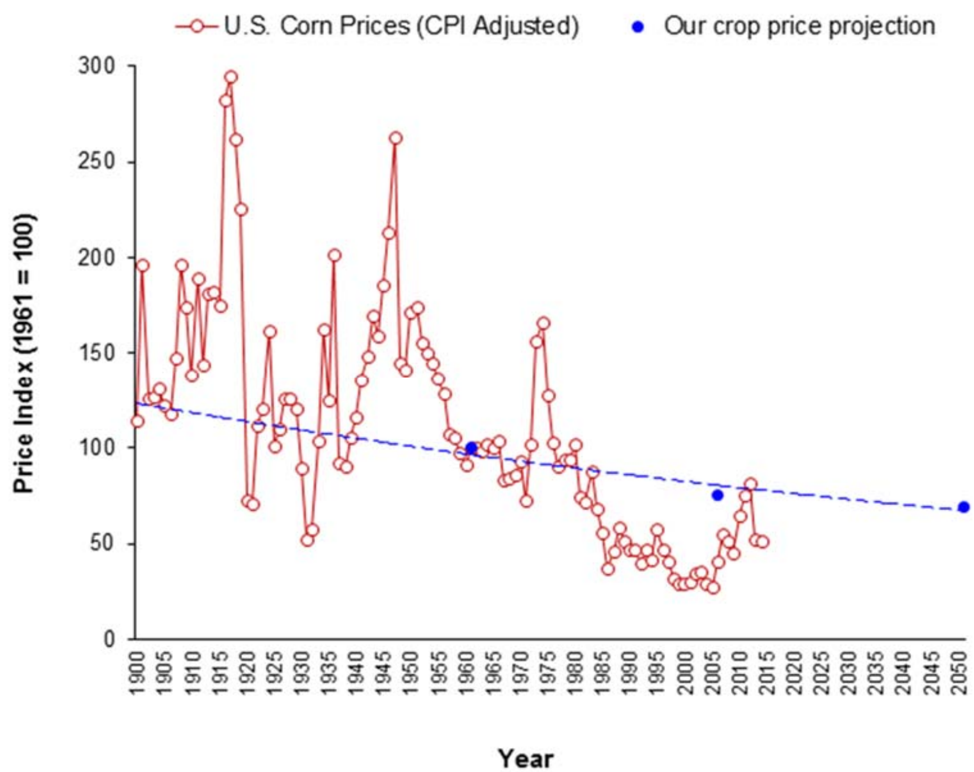

Figure 1. Real crop prices: 1900-2051. Open red circles correspond to the historical evolution of annual U.S. corn prices, adjusted using U.S. consumer price indices (CPI). Blue points report the historical and projected 45-year global crop prices based on simulations of the SIMPLE model. Blue dashed line connecting these points is a simple exponential trend line of these simulations based on the SIMPLE model.

The rest of the paper is organized as follows. In the next section ("Model and Methods"), we discuss the economic framework underlying the SIMPLE model and the set of experiments used in this study to examine the historical as well as future trends in global food prices. We then discuss the estimated food price changes in the following section ("Results and Discussion") with careful attention to changes in the relative contribution of the key drivers of the global farm and food system. Finally, the last section ("Conclusions") summarizes findings of the paper and offers some key conclusions regarding the future of global food prices.

2. Model and Methods

2.1. The SIMPLE Model

Figure 2 outlines the underlying economic framework in SIMPLE. As its name suggests, this has been designed around the principle that a model should be no more complex than is absolutely necessary to understand the basic forces governing the global supply and demand for crops. In this model, the regional crops sector is conceptualized as one in which land is combined with non-land inputs in order to produce crop output to satisfy domestic and global demands, including direct consumption, feedstuff demand, raw inputs to processed foods, and biofuel feedstock use. Food demands are price sensitive, and, over time, they are driven by growth in population and per capita incomes. Rising incomes cause consumers to diversify their diets, which, at lower income levels, means adding relatively more livestock and processed foods. Production of both these commodities requires crop inputs – the demand for which can be altered by technological progress in those sectors (e.g., more feed efficient livestock). Income also has an implicit effect on food demand response, as high income households typically spend less on food relative to non-food commodities; therefore are less responsive to changes in both income and food prices (Muhammad, Seale Jr., Meade, & Regmi, 2011). In contrast, households in regions with low per capita incomes are more responsive to high food prices (larger absolute value for the price elasticity of demand), since food makes up a relatively large share of their budget. Additional crop demands in SIMPLE come from the exogenously specified feedstock use by the global biofuels industry.

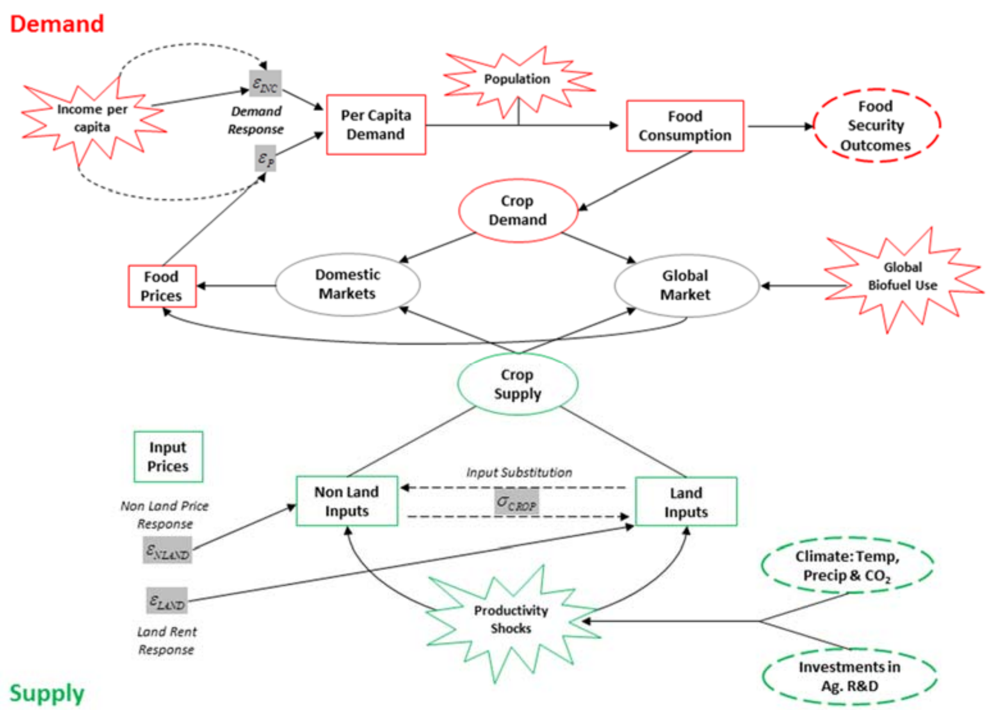

Figure 2. Overview of the Simplified International Model of agricultural Prices, Land use and the Environment

On the supply side, substitution of non-land inputs (e.g., fertilizers, farm labor and machinery) for land in crop production offers scope for endogenous intensification of production, even in the absence of technological change. Agricultural productivity is exogenous to the model. We expect such productivity growth to be driven by investments in agricultural research and development, changes in agricultural and trade policies, and by changes in climate, among other things. On the extensive margin, the supply of land to crops is also price-sensitive, as cropland is bid away from competing uses, with the size of this area response varying considerably across geographic regions. SIMPLE's historical projections of global crop production, area, yield and prices have been validated at global scale (Baldos & Hertel, 2013) and the model has been used in studies focusing on climate change mitigation and adaptation (Lobell, Baldos, & Hertel, 2013) and long run food security analysis (Baldos & Hertel, 2014). In this paper, we utilize a version of the model which explicitly differentiates between access to domestic and international crop markets. This permits us to incorporate the type of market segmentation which has prevailed in agricultural markets over the past century (Figure A1, Supplementary Figures).

2.2. Experimental design for historical and future simulations

To understand the future, one must look back at history. We start by simulating the historical experience (i.e. 1961 to 2006) to examine how well the SIMPLE model reproduces the decline in global crop prices over this historical 45-year period (see also Baldos and Hertel (2013)). The historical simulation allows us to validate SIMPLE and establish confidence regarding our projections for the future. Equally important is the historical decomposition of the relative contribution of the major drivers of global agricultural prices. With this historical experience in hand, we project changes in global crop prices between the 45 years: 2006 – 2051, under several alternative scenarios which are summarized, in Table 1, along with the 'Historical Simulation' scenario. The growth rates for the historical scenario are calculated using population data from the U.N. World Population Prospects (2013) and real gross domestic product (GDP) data from the World Development Indicators (2011). In SIMPLE, productivity growth is represented by increases in total factor productivity (TFP) – an index of output per unit of a composite of all inputs. Historical TFP growth rates for the crop, livestock and processed food sectors are taken from Fuglie (2012), Ludena et al (2007), and Griffith et al. (2004), respectively.

Table 1 also summarizes the growth rates between 2006 and 2051 for each future scenario. The first of these forward-looking scenarios adopts a very simplistic view of the future wherein past trends persist ('Historical Rates for Key Drivers'). This entails imposing the historical growth rates on future decades. Following this scenario, we then establish our baseline for 2051 ('Future Baseline'). For this baseline simulation, we use growth rates calculated from the following sources: medium fertility population projections from the U.N. World Population Prospects (2013), real GDP projections from Fouré, Bénassy-Quéré, & Fontagné (2013), historical global TFP growth rate from Fuglie et al (2012) for the crop sector, projected TFP growth rates from Ludena et al (2007) for the livestock sector and historical TFP growth rates from Griffith et al. (2004) for the processed food sectors. Compared to the historical rates we see that, in the future, population growth is expected to slow down globally and per capita income growth will rise faster in developing regions such as South Asia and China. Future TFP growth

Table 1. Average annual growth rates used in selected scenarios

Scenarios	Eastern Europe	North Africa	Sub Saharan Africa	South America	Australia/ New Zealand	European Union+	South Asia	Central America	Southern Africa	Southeast Asia	Canada/US	China/ Mongolia	Middle East	Japan/Korea	Central Asia	World[a]
Historical Simulation (Historical Rates for Key Drivers)																
Population	0.40	2.20	2.75	2.04	1.39	0.38	2.19	2.12	2.32	2.15	1.03	1.60	2.75	0.85	2.40	1.79
Per Capita Income	1.66	2.29	-0.26	1.42	1.96	2.39	2.39	1.69	0.39	3.14	2.23	6.83	2.30	3.32	1.66	1.66
Biofuels																5.75
Total Factor Productivity																
Crops	0.37	1.97	0.71	1.70	1.43	1.58	1.16	0.97	1.38	1.50	1.70	2.02	1.61	2.11	0.37	0.95
Livestock	0.58	0.17	0.39	0.80	0.92	0.92	0.53	0.80	0.39	0.86	0.92	0.86	0.17	0.92	0.58	1.03
Processed Food																0.89
Future rates for key drivers + Biofuels																
Population	-0.42	1.06	2.45	0.64	1.00	0.09	0.83	0.94	0.57	0.79	0.66	0.09	1.02	-0.22	1.47	0.80
Per Capita Income	4.83	3.58	3.78	2.51	1.75	1.40	4.84	2.55	2.76	3.62	1.06	5.55	2.38	2.17	5.03	2.09
Biofuels																5.75
Total Factor Productivity																
Crops	1.31	1.22	0.62	1.31	0.81	0.94	0.76	1.30	1.14	1.27	1.16	1.59	1.00	1.27	1.31	0.95
Livestock	1.04	-0.30	0.43	2.64	0.42	0.42	1.71	2.64	0.43	2.38	0.42	2.38	-0.30	0.42	1.04	2.10
Processed Food																0.89
“Low” Price Scenario																
Population	-0.78	0.72	2.17	0.29	0.72	-0.19	0.48	0.58	0.17	0.44	0.37	-0.22	0.70	-0.50	1.14	0.48
Per Capita Income	4.83	3.58	3.78	2.51	1.75	1.40	4.84	2.55	2.76	3.62	1.06	5.55	2.38	2.17	5.03	2.09
Biofuels																5.75
Total Factor Productivity																
Crops	1.77	1.66	0.88	1.76	1.13	1.30	1.07	1.75	1.55	1.72	1.58	2.10	1.38	1.72	1.77	1.59
Livestock	1.04	-0.30	0.43	2.64	0.42	0.42	1.71	2.64	0.43	2.38	0.42	2.38	-0.30	0.42	1.04	2.10
Processed Food																0.89
“High” Price Scenario																
Population	-0.08	1.38	2.71	0.98	1.27	0.36	1.16	1.28	0.94	1.11	0.93	0.39	1.32	0.04	1.78	1.10
Per Capita Income	4.83	3.58	3.78	2.51	1.75	1.40	4.84	2.55	2.76	3.62	1.06	5.55	2.38	2.17	5.03	2.09
Biofuels																5.75
Total Factor Productivity																
Crops	1.00	0.92	0.46	0.99	0.60	0.70	0.56	0.98	0.86	0.96	0.87	1.22	0.75	0.96	1.00	0.72
Livestock	1.04	-0.30	0.43	2.64	0.42	0.42	1.71	2.64	0.43	2.38	0.42	2.38	-0.30	0.42	1.04	2.10
Processed Food																0.89

Notes: Population growth rates are taken from the 2012 UN World Population Prospects (2013). Future rates use Medium fertility projections while “Low” (“High”) price scenario uses the Low (High) fertility projections.
Historical income growth rates are taken from World Bank’s World Development Indicators (2014) while Future rates are taken from Fouré, Bénassy-Quéré, & Fontagné (2013).
Historical and future TFP growth rates in the livestock sector are based on Ludena et al. (2007).
TFP growth rate in the processed food sector is based on Griffith et al. (2004).
Historical TFP growth rates in the crop sector are taken from Fuglie (2012). Future rates are based on global TFP growth rates from Fuglie (2012) for the period 1961-2009 using regional scalars calculated from TFP rates for the period 1991-2009. For the “Low” (“High”) price scenario, the global TFP growth rates are taken from Fuglie (2012) based on projected annual rates for the period 1991 to 2009 (1971 to 1990)
Biofuel growth rates are based the “Current policies” projections from the IEA’s World Energy Outlook (2008, 2012)
[a]To facilitate comparison across scenarios, global growth rates for population, per capita incomes and TFP in the livestock and crop sectors are added in the table

in the crops sector is constructed from the historical global rate (Table 1) and regional scalars (Table 3) which captures recent regional trends in productivity growth. We also consider the global growth rate in biofuel feedstocks taken from the projections of the International Energy Agency (2008, 2012b) under the "Current policies" scenario which assumes that future biofuel demand will be driven by recently enacted energy and transportation policies. We will further discuss the plausibility of these projections below.

2.3. Incorporating uncertainty in future projections

Of course there are many uncertainties with regard to future growth rates in the key drivers of the global food system. We are also uncertain regarding the values of the parameters governing the responsiveness of the global farm and food system to prices and incomes. To illustrate the potential range in global crop price changes in the coming decades, we begin by conducting a simple bounding analysis in which two extreme scenarios are constructed by varying the growth rates for population and agricultural productivity, the main historical drivers of food demand and supply, respectively. The last two scenarios in Table 1 show our assumptions for this bounding analysis of future global crop prices. The "low price" scenario is based on the low fertility projections from the U.N. World Population Prospects (2013), combined with Fuglie's (2012) estimate of high global agricultural TFP growth observed during the period 1991-2009. Relying on the same data sources, we construct a "high price" scenario using population growth rates based on the high fertility projections, combined with the historically low rates of crop TFP growth estimated over the 1971-1990 period.

While this bounding analysis is instructive, it is not a systematic approach to uncertainty quantification. Towards this end, we formally undertake a Monte Carlo analysis wherein both model parameters and drivers are varied across their full range of potential values. Inputs to each simulation are drawn from independent triangular distributions of 11 global economic parameters and exogenous drivers of change as reported in Table 2. Construction of each distribution of parameters and shocks requires assumptions about the mode, minimum and maximum values. For both parameters and drivers, the modes are set equal to the 2006-51 baseline values. Due to limited empirical evidence, the max and min of all *parameter* distributions are constructed using the assumption that these are +/- 30% away from the mode. For *uncertainty in exogenous shocks*, we rely on the range of available projections. For population growth, we use the high and low fertility projections from the U.N. World Population Prospects (2013). For biofuels, the minimum is based on "no biofuels growth" while the maximum is based on the projections from the "New Policies" scenario by the IEA (IEA, 2008, 2012b). For TFP growth in the crops sector, the maximum and minimum are taken from Fuglie (2012) using the rates for the 1991-2009 and 1971-1990 periods, respectively. For the livestock sector, the maximum and minimum rates are based on Ludena et al. (2007) using estimates for the periods 2001 to 2010 and 2031 to 2040, respectively. Lacking better information for TFP in the processed food sector, we apply the +/- 30% assumption. Lastly, uncertainty in per capita income growth is based on our review of available forecasts. When combined with the uncertainty in biofuels production, this generates considerable uncertainty in global crop demand. Some of these drivers and parameters are converted from global scale to regional values using

Table 2. Triangular distributions of selected parameters and shocks

	MODE	MAX	MIN
Parameters			
Demand Elasticities			
Income Elasticities: Regression Intercept			
Crops	0.88	1.15	0.62
Livestock	1.05	1.36	0.73
Processed Foods	1.20	1.56	0.84
Price Elasticities: Regression Intercept			
Crops	-0.74	-0.52	-0.96
Livestock	-0.83	-0.58	-1.07
Processed Foods	-1.17	-0.82	-1.52
Non-land supply response	1.34	1.74	0.94
Land supply response	0.28	0.36	0.20
Elasticity of substitution: Crop	3.00	3.90	2.10
Elasticity of substitution: Livestock	1.16	1.51	0.81
Armington Elasticities	2.50	5.00	1.25
Exogenous Shocks (p.a. rates)			
Population	0.80	1.10	0.48
Per capita income	2.09	2.50	1.50
Biofuels	5.75	6.25	0
Total Factor Productivity			
Crops	0.95	1.59	0.72
Livestock	2.10	2.75	1.61
Processed Foods	0.89	1.16	0.62

Source: Authors' construction.

Table 3. Regional scalars for selected parameters and shocks

Regions	Land Supply Response	Population	Per Capita Income	TFP: Livestock	TFP: Crop
Eastern Europe	2.00	-0.40	4.77	0.38	1.53
North Africa	0.39	1.42	2.51	-0.08	1.39
Sub Saharan Africa	2.00	4.59	2.79	0.14	0.62
South America	2.00	0.78	1.33	1.44	1.52
Australia/New Zealand	2.00	1.32	0.77	0.13	0.83
European Union+	0.39	0.10	0.56	0.13	1.00
South Asia	1.00	1.05	4.80	0.74	0.78
Central America	1.00	1.21	1.36	1.44	1.50
Southern Africa	1.00	0.68	1.56	0.14	1.27
Southeast Asia	1.00	0.98	2.57	1.21	1.46
Canada/US	1.00	0.80	0.39	0.13	1.30
China/Mongolia	1.00	0.10	6.73	1.21	1.97
Middle East	0.39	1.34	1.22	-0.08	1.08
Japan/Korea	0.39	-0.22	1.06	0.13	1.46
Central Asia	2.00	2.15	5.26	0.38	1.53

Source: Authors' construction. For the land supply response, the scalars are calculated relative to the regional value for the North America region. Scalars for the rest are calculated relative to the global growth rate.

regional scalars (Table 3). This reflects the notion that (e.g.) if the true land supply response in one region is higher than in the base case, then the true values for all of these elasticities are also higher – since these are derived from the same global study. Our sample size is 1000 experiments.

3. Results and Discussion

3.1. Understanding the historical decline in commodity prices

Over the 45 years leading up to the most recent commodity price boom, the World Bank's international index of food grain prices fell by 30%. This finding is reflected in the SIMPLE model's historical validation experiment as reported in the first bar of Figure 3 which shows a predicted price decline of 32% based solely on historical growth rates in population, per capita income and agricultural productivity as reported in Table 1. The model also captures key changes in historical crop output, crop yield and cropland use at the global level (Figure A1, Supplementary Figures). For example, observed crop production rose by 218% over this period, with 187% of this coming from increased yields. The SIMPLE model predicts a 199% output rise with 157% coming from yield increases. These results give us some confidence that we can use SIMPLE in order to simulate global long run changes in price, output, yield, and crop land at global scale.

The SIMPLE model also allows for a decomposition of these historical drivers of the global crop price index (colored areas in Figure 3, with their respective contributions read off the right hand axis). As can be seen from the first bar in Figure 3, rising population was by far the most important driver of historical food demand, followed by growth in per capita income. However, agricultural productivity growth during this period outpaced the increase in food demand. For example, global yields for maize, rice and wheat increased by 1.8% to 2.2% annually. Overall global crop production more than tripled (FAO, 2011). A number of factors have helped contribute to the steady rise in crop yields, including development and adoption of new crop varieties, increased use of pesticides and fertilizers, and improved access to irrigation (Burney, Davis, & Lobell, 2010). Indeed it is estimated that for the period 1965-1998, the average yield growth due to the genetic improvements in modern crop varieties for key grains and root crops was around 0.72% per annum (Evenson (2003) as cited in Renkow and Byerlee (2010), p 393)**.** This strong productivity growth is what drove the observed decline in crop prices since the 1960s.

3.2. Population and income: The main drivers of future food demand

As we look forward to 2051, our first forecast is a 'naïve' one which assumes that historical growth rates for population, incomes and agricultural productivity will continue into the future, resulting in the second bar of Figure 3. While the absolute contributions of each driver are larger in the future – due to the larger economic base in 2006 as opposed to 1961 – the relative contributions are the same as in the historical period, resulting in a comparable percentage decline in the global crop price (-28%) over the next 45 years. However, this is clearly a poor prediction, since it does not avail itself of what we know about (e.g.) the impacts of declining fertility rates and slower growth in life expectancy in much of the world (Bloom, 2011; Ezeh, Bongaarts, & Mberu, 2012). While the predicted rise in world population to 9 billion in 2050 will still place additional pressure on world food production, the slower *global growth rate* (Table 1) means that population will have less impact on future food prices (third bar, Figure 3 - red area).

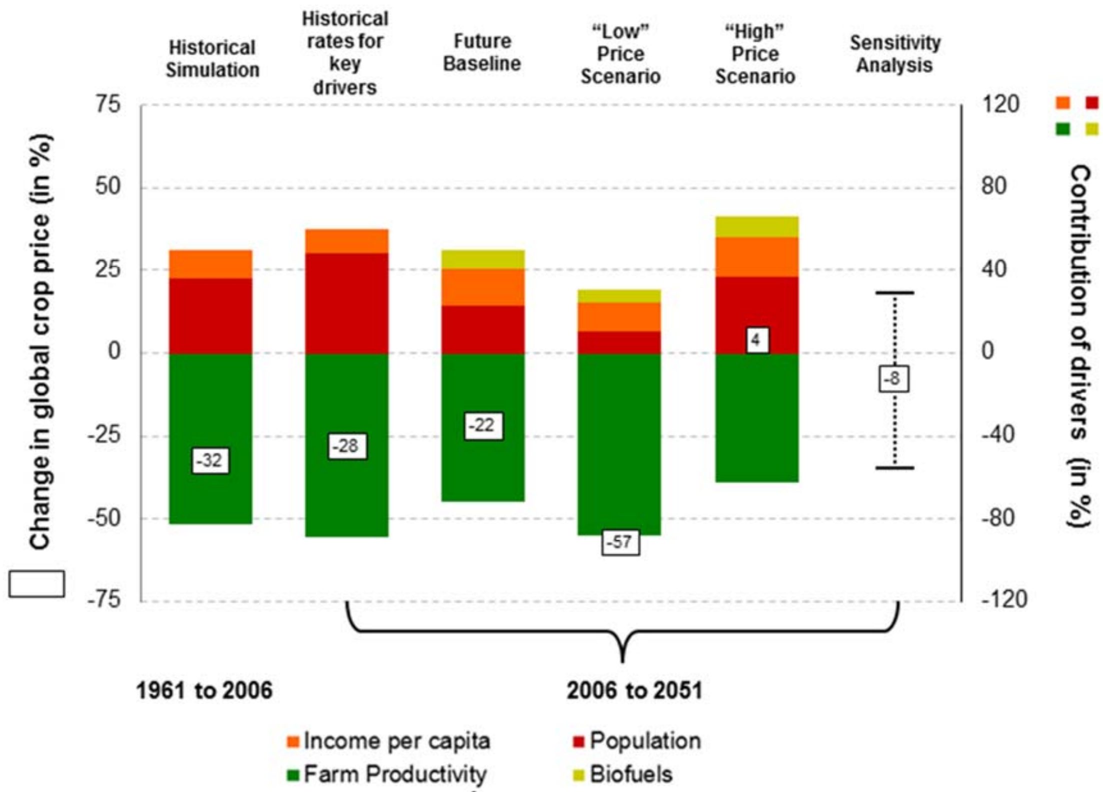

Figure 3: The future of global crop prices: projection and decomposition. Long run changes in crop prices are read off the left-hand axis and % contribution of drivers of change are read off the right hand axis. The left-most bar describes results for the historical period 1961 to 2006 while the rest are for the period 2006 to 2051. These projections include (from left to right): continuation of historical growth rates for key drivers, our baseline with future growth rates for key drivers plus biofuels, bounding analysis showing both a "low price" scenario and a "high price" scenario, and finally, the mean price change and 95% confidence interval from a Monte Carlo analysis in which both model parameters and drivers are varied. Drivers include population (red area), per capita incomes (orange area), agricultural productivity (green area) and biofuels (tan area). The bounding analysis is constructed using min-max assumptions on population and agricultural productivity growth.

The impact of income growth on food demand is complex. As incomes rise, Engel's Law suggests that consumers will shift their expenditure pattern in favor of nonfood products and services. At the same time, the composition of food consumed is also influenced by income growth – particularly amongst households at the lower end of the income spectrum – as per capita consumption of meats and dairy products increases and diets are upgraded and diversified (Cranfield, Preckel, Eales, & Hertel, 2002). Indeed, this dietary upgrading has contributed significantly to the growth in global agricultural demands in recent years (Pingali, 2007). Recall that these consumption trends are incorporated into SIMPLE via the food demand response to changes in prices and incomes (i.e. demand elasticities). Going forward to 2051, the implications of dietary upgrading is particularly important since per capita incomes in the developing countries are projected to grow at a relatively higher rate in the coming decades (Table 1), even as growth rates in the high income economies such as the U.S. and the European Union weaken (Fouré et al., 2013).

Rapid income growth in the developing world – particularly in Asia – has been an important element of recent projections of higher commodity prices (Nelson et al., 2010; OECD/FAO, 2013), although this assertion has been questioned, since income growth as a driver of food demand tends to be a gradual phenomenon (Piesse & Thirtle, 2009). Increased food demand by lower income households will lead to increased production by the livestock and food processing industries, which in turn translates to greater derived demand for crops. Indeed, we find that nearly all the growth in volume of food consumption comes in the form of livestock and processed food products (Figure A2, Supplementary Figures). When combined with steady population growth in the lower income regions, as discussed above, greater incomes translate into strong growth in global demand for crops. Indeed, based on this analysis, we find that the contribution of income growth to the global crop price (third bar, Figure 3 - orange area) is projected to rival that of population (red area) for the first time in history.

However, it is also the case that as lower income regions become wealthier, the responsiveness of food consumption to additional income increments is diminished (Muhammad et al., 2011) and studies which do not factor this into their projections will inevitably overstate the potential for future demand growth (Baldos & Hertel, 2013). Thus, even with income becoming a more significant driver of future food demand than population, this driver is not strong enough to compensate for the slower population growth.

3.3. Biofuels as a driver of future demand

The remarkable growth in biofuels demand over the past decade has also prompted analysts to suggest that world food markets have entered a “new normal”. Indeed over the two crop year period from 2005/06 – 2007/08, half of the global increase in cereal consumption was absorbed by U.S. ethanol production (Westhoff, 2010). Similarly, one-third of the increase in vegetable oil use from 2004-2007 is estimated to have gone into biodiesel production (Mitchell (2008) , cited in Piesse and Thirtle (2009), p. 127). There is little doubt that growth in first generation biofuels – namely those that utilize food crops as their feedstocks – has contributed to higher crop prices over the past decade (Abbott et al., 2011) and many studies suggest that biofuels will place significant pressures on future crop demand and prices (Fischer, Hizsnyik, Prieler, Shah, & Velthuizen, 2009; Msangi, Ewing, & Rosegrant, 2010; Piesse & Thirtle, 2009). Whether or not these projections are realized depends critically on oil prices. Some studies suggest that corn ethanol production will continue to expand, even without government support, as long as oil prices remain above $100 (Miranowski & Rosburg, 2013; Tyner, 2008). However, recent increases in oil and gas supplies suggest that earlier projections of rising energy prices may be misleading (U.S. Energy Information Administration, 2013).

In the absence of strong growth in oil prices, subsidies and mandates will be critical to the growth of the biofuel industry. However, government support for this industry has been recently eroded due to concerns about the global environmental impacts of indirect land use change induced by biofuels (National Research Council, 2011; Searchinger et al., 2008). As a consequence, the current trend in Europe and the U.S. has been to trim back such support in the face of budget austerity and concerns about competitiveness (Babcock, 2013; European Commission, 2012). Second generation biofuels, which compete with food crops only indirectly through land use, might be influenced by greenhouse gas (GHG) mitigation policies, as they offer significant GHG savings over conventional fuels (National Research Council, 2011). However, these biofuels are not yet commercially viable, and most studies do not envision them playing a significant role until mid-century (Rose et al., 2012; Steinbuks & Hertel, 2013).

In short, it is hard to predict how biofuel demands will evolve in the coming decades. Accordingly, in our baseline we simply opt for the 'business as usual' projections of biofuel growth by the International Energy Agency (2012b). This is based on simulations of the World Energy Model – a dynamic partial equilibrium model focusing on final energy consumption, energy transformation and energy supply from renewable and non-renewable sources (IEA, 2012a). Among the projections available, we use those generated under the 'Current Policies' scenario which takes into account all policies enacted as of mid-2012, although we do consider other scenarios (including "no-growth") in our Monte Carlo analysis (Table 2). From Figure 3 it can be seen that, under the current policies scenario, biofuels add modestly to our projections of future crop demand (bars 3-5, tan area at the top of the column).

3.4. Agricultural productivity remains a key to food prices and output growth

As in the past, agricultural productivity will play a key role in shaping future crop prices. If historical productivity growth rates were to continue into the future, food prices would most certainly fall, given the more modest rate of population growth projected to 2051. Total factor productivity can also be directly related to future output growth. Figure 4 reports the results from Fuglie's (2012) land-based decomposition of output growth which apportions the drivers of total growth in output into the expansion of land area and the growth in yields per hectare of crop land. The latter can, in turn, be attributed to one of two sources: intensification of production, via the application of more non-land inputs such as fertilizer and labor, and productivity growth due to improved technologies. The first bar in this Figure decomposes the model's output predictions from 1961-2006. Here, we see once again that nearly all the growth in crop output over this historical period was due to higher yields. Of this yield growth, roughly 40% was due to the intensification of production and 60% due to improved technology. If the underlying drivers remained unchanged over the period 2006-2051, this decomposition would look quite similar (second bar in Figure 4). However, that is not the case when future drivers are in place. With slower global population growth, there is less incentive to intensify production and expand land area, and so productivity growth as a driver of output change becomes relatively more important (third bar in Figure 4). Sustainability of meeting future food demand also hinge on productivity growth. In regions with relatively flat TFP growth (Figure A3, Supplementary Figures), such as Sub Saharan Africa, increases in output will be supported by expansion of cropland use and intensive application of non-land inputs which could potentially harm the environment.

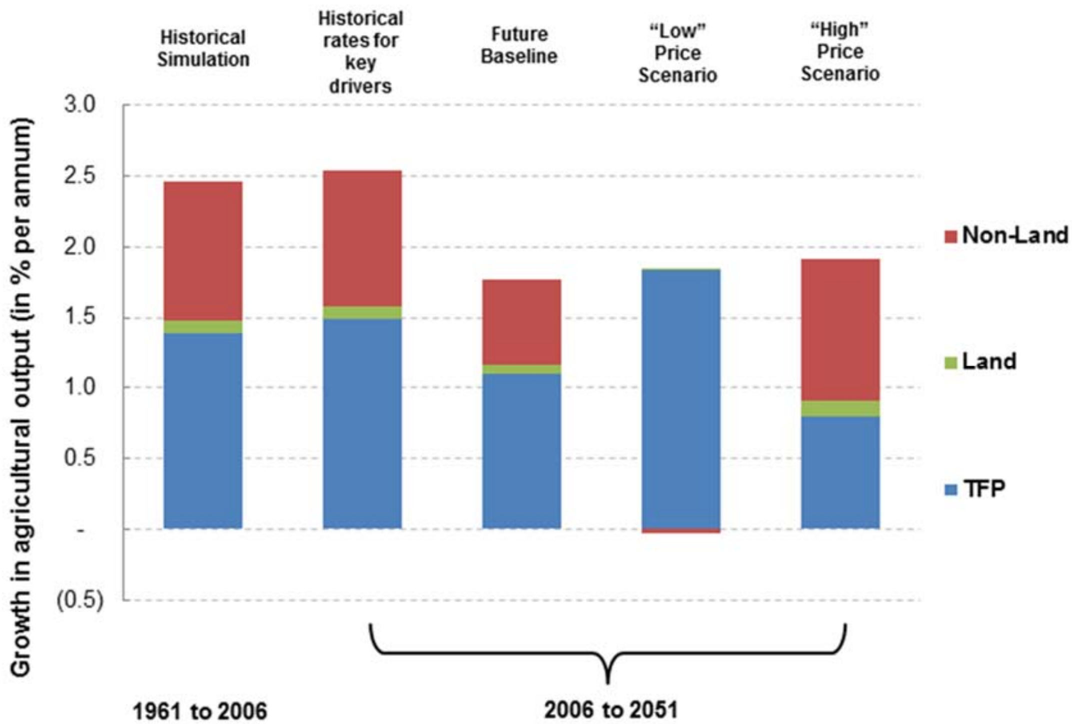

Figure 4. Decomposition of global output growth due to intensive use of non-land inputs, expansion in cropland and total factor productivity growth.

All of this highlights the key role for future productivity projections, yet these remain quite challenging, and therefore a great source of uncertainty. Part of the problem is that – unlike population and income, which are directly observable – there is no consensus about how (unobservable) Total Factor Productivity growth (TFP is output per unit of a composite of all inputs) in agriculture has evolved over the last two decades. Studies focusing solely on yields – a partial measure of productivity which focuses only on land and ignores the role of other farm inputs – find that yields of staples are slowing in key regions (Alston, Beddow, & Pardey, 2009, 2010). However, yields are also sensitive to prices and it is not uncommon to observe falling yields, even as TFP rises (Ludena et al., 2007). This is especially likely following long periods of depressed or flat world prices, as was the case from 1980-2005, or in the wake of domestic policy reforms resulting in lower producer prices, such as those implemented in Europe over the past two decades. Thus it should not be surprising that studies focusing on TFP growth come to rather different conclusions than the yield studies. From 2001 to 2009, regional agricultural TFP growth rates ranged from 1.1% to 3.3% annually, with the exception of Sub Saharan Africa and Eastern Europe where it grew by only 0.5% and 0.8% per annum, respectively (Fuglie, 2012). In light of these considerations, our projections to 2051 draw on historical global TFP growth rates (Table 1) and incorporate recent regional differences (Table 3) in productivity growth. These future rates are generally slower than actual regional rates for the previous 45 years. Nonetheless, these productivity growth rates are still sufficient to result in declining long term crop prices (-22%, white box in the third bar of Figure 3).

It is widely acknowledged that a key factor in sustaining long run productivity growth in agriculture will be investments in research and development (R&D). The global growth rate of public investments in agricultural R&D in high income countries fell slightly over the 1990's (Pardey et al. (2006), as cited in Piesse and Thirtle (2009), p. 125), but recent data suggests that it has picked up strongly since then, with global public and private R&D both rising by roughly one-quarter over the 2000-2008 period (Beintema, Stads, Fuglie, & Heisey, 2012). Moreover, there has been a shift in the pattern of investments, as R&D expenditures have grown faster in developing countries – particularly in Brazil, China and India. Yet despite the growth in other regions, more than half of global spending in agricultural research comes from high income countries wherein the growth rates of R&D expenditures have continued to show signs of slowing. Historically, low income countries have benefitted from the technological spillovers generated from R&D spending in high income countries (Alston, 2002). But with the slowdown in spending in developed regions, developing countries must increasingly rely on their own R&D spending to boost local agricultural productivity. Furthermore, the potential for technological spillovers in the future may be limited as agricultural research in high income countries appears to be moving away from technologies that can be easily transferred to developing countries (Alston & Pardey, 2006) and as the private sector's share of total R&D spending in developed country agriculture has continued to rise (Pardey et al., 2006). Furthermore, the R&D expenditures in richer countries increasingly emphasize environmental and food safety concerns that are not supply-enhancing.

The effectiveness with which R&D expenditures translate into productivity growth will hinge in part on climate change. Depending on the location, management practice, and crop type, temperature and precipitation impacts of climate change may cause potential crop yields to rise or fall (Tubiello, Soussana, & Howden, 2007). Between the two, temperature changes transmit the strongest signal in the context of agricultural impacts (Lobell, Schlenker, & Costa-Roberts, 2011; Wolfram Schlenker & Lobell, 2010), with projected increased frequency and intensity of extreme heat events having a significant adverse impact on crop yields (W. Schlenker & Roberts, 2009). Recent estimates suggest that warming temperatures have slowed yield growth for wheat and maize over the past three decades, while mixed impacts on rice and soybeans have been offsetting at the global scale (Lobell et al., 2011). Another aspect of climate change which could significantly affect agricultural productivity and global food availability is the presence of heightened CO_2 concentrations in the atmosphere. This can directly benefit crop yields through increases in leaf CO_2 levels and reductions in stomatal conductance, thereby boosting the optimum temperature for C3 crops (Long, 1991). However, these CO_2 impacts differ widely across crop types as well as agro-climatic conditions. Moreover, analyses at the regional level show that CO_2 fertilization effects are quite uncertain as the variations in these impacts could be more than half of the variations from temperature and precipitation (McGrath & Lobell, 2013). Overall, most climate/crop model combinations show modest impacts – and indeed sometimes gains – when it comes to crop supplies between the present and 2050 (Rosenzweig et al., 2013). It is only after mid-century, as temperatures continue to rise and CO_2 fertilization effects taper off, that the ensemble of climate-crop models show larger, more systematic declines in yields across all regions (IPCC, 2014).

Increasing water scarcity is another factor cited by authors suggesting the emergence of a 'new normal' in commodity markets (Rosegrant, Cai, & Cline, 2002). Assuming continued demand growth and no efficiency gains in water use, it has been estimated that one-third of the world's population will live in river basins where demand exceeds accessible, reliable supply by 50% or more (McKinsey & Co, 2009). One response to surface water scarcity in agriculture has been to turn to ground water, which has become an increasingly important source of irrigation over the past 50 years (Burke & Villholth, 2007). This growth has been most pronounced in areas with low recharge rates (Döll & Fiedler, 2007), thereby raising concerns over long run sustainability. In light of the fact that 40% of global crop production comes from irrigated lands, this suggests that water scarcity could indeed be a significant constraint on future supplies. Rosegrant et al. (2013) examine this issue in considerable detail, using a global water model. The authors estimate the Irrigation Water Supply Reliability (IWSR) index in 2000, 2030 and 2050 which depends on growth in food demand, changes in irrigation efficiency, changes in non-agricultural water use, water policies and infrastructure development. Their findings suggest that the IWSR does indeed deteriorate in a number of important river basins – particularly in South Asia and China. However, the largest changes are limited to a few river basins, and their global impact is further mitigated by improvements in IWSR elsewhere. Accordingly, the subsequent impacts on world crop prices has been estimated to be quite modest (Liu, Hertel, Taheripour, Zhu, & Ringler, 2014). Thus water shortages, while critically important at the local and regional level, appear to be less critical when it comes to long run global agricultural supply over the next few decades.

A final source of supply-side uncertainty relates to the potential for closing existing yield gaps, which are particularly pronounced in Sub Saharan Africa, Eastern Europe and parts of Latin America and Asia (Foley et al., 2011). These differences, which can be characterized as the differences between observed yields at a given site and maximum yields obtained under similar agro-ecological circumstances elsewhere in the world, are driven by economic factors in many cases (Herdt, 1979). These can include limited availability of locally-adopted technologies and poor access to markets which leads to high input costs and low output prices. Production risks can also hamper the adoption of existing technologies amongst subsistence farmers (Evans, 1993; Herdt, 1979). In addition, narrowing most of these gaps entails increased fertilizer use which could potentially lead to adverse environmental impacts if proper nutrient management is not practiced (Mueller et al., 2012). But if these gaps can be closed in an economical and sustainable way then this could provide a much needed opportunity to sharply increase global crop production in the future. Indeed, it has been estimated that global production of maize, wheat and rice could be increased by 29% if yields in underperforming areas are increased to 75% of yields in productive areas with similar agro-climatic conditions (Mueller et al., 2012).

3.5. Assessing uncertainty in future commodity prices

As previously noted, we begin our uncertainty analysis with a simple 'bounding analysis' (Table 1), the results of which are reported in Figure 3. The fourth bar in Figure 3 reports a 'low price' future in which population growth is at the low end of future projections, and TFP growth is at the high end of likely outcomes. In this case, crop prices fall about twice as much (-57%) as in the previous 45 year period and there is virtually no incentive to expand crop land or intensify production at the global scale (fourth bar in Figure 4). On the other hand, if population growth is at the upper end of future projections and crop TFP growth is at the lower end, then crop prices will be flat, rising by just 4% cumulatively over the 2006-2051 period (Figure 3, fifth bar). In this case, there is greater incentive to expand crop area and intensify the use of non-land inputs (Figure 4, fifth bar). Our Monte Carlo analysis offers a more systematic assessment of uncertainty by sampling simultaneously from distributions of the economic parameters as well as from distributions of the exogenous drivers (recall Table 2). The final bar in Figure 3 reports the mean price change (-8%) from this Monte Carlo analysis. The associated error bar (dotted line) shows that we cannot rule out the possibility of long run price increases, as observed under our high-price bounding scenario. However, these outcomes are the result of scenarios in which demand drivers and responses are at the high end of their distributions and supply side factors are at the low end. To assess the overall likelihood of price rises or declines, we construct a histogram of global crop price changes from the Monte Carlo simulations (Figure 5). The median value of the price decrease is -9% and it is clear from the figure that the bulk of the simulations result in global crop price reductions. Indeed, we find that 72% of the probability mass lies on the negative side of the price change, thereby substantiating our claim that, *in the long run, crop prices are most likely to resume their downward trend*.

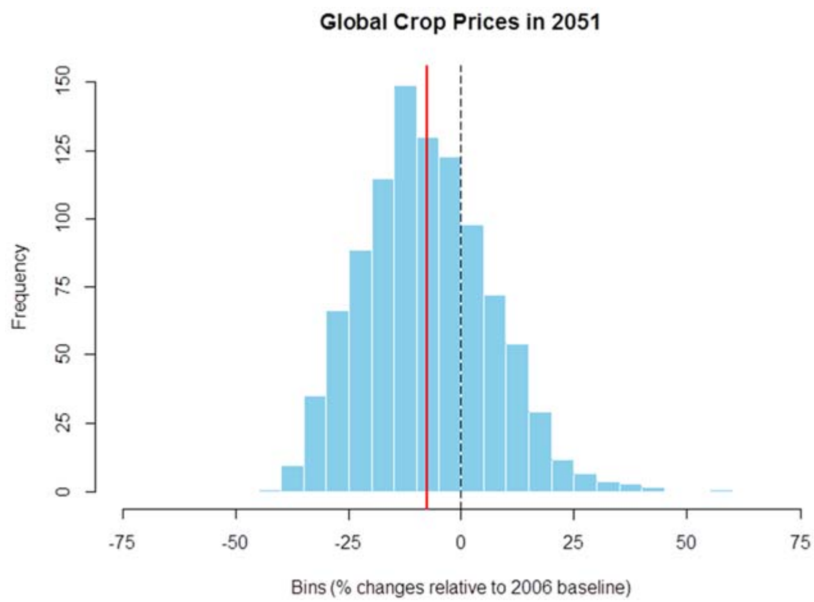

Figure 5. Histogram of global crop prices between 2006 and 2051 (in % change) when both parameters and food system drivers are sampled from the distributions outlined in Table 2 (solid red line: mean = -8%, black dashed line at zero separates negative and positive price change outcomes).

4. Conclusions

In order to understand the future, it is important to study history, and the food crisis of the 1970's offers a valuable perspective on the current state of affairs. In the wake of this earlier crisis, Don Paarlberg (1981) coined the term "Scarcity Syndrome" to characterize mood prevalent at the time. His words are remarkably apropos to today's environment:

> "*Pessimism has arisen about the ability of the Earth to feed its people. Burgeoning population growth…doubts about the adequacy of the agricultural resource base…allegations that discovery of new agricultural knowledge is lagging...misgivings about weather in the years ahead are cited in outlining a dismal food prospect for the poor*

people of the world." (excerpt from the 1981 USDA Yearbook of Agriculture, entitled: 'Will there be enough food?', p 282)

Paarlberg's response to this perceived crisis was concisely summarized in the title to his chapter, which was: "Enough food? Sure, if we don't play it dumb!" He believed that the global food economy would respond to the high prices of the 1970's with increased supplies, and this belief was in fact borne out by a prolonged period of declining/flat food prices over the next two decades.

We believe that the apparent consensus that today's high crop prices will persist over the coming decades is unfounded and is excessively influenced by a 'scarcity syndrome' similar to that noted 30 years ago by Don Paarlberg. Rather, we expect that global food prices will likely resume their downward trend in the coming decades. However, analysis with the SIMPLE model of long term, global supply and demand for crops suggests that the factors behind this price decline will be different in the future. Looking back at history, we see that the increase in food demand was fueled mainly by population growth. This period was also characterized by strong agricultural productivity growth which led to significant gains in food production. Moving forward to mid-century, our analysis suggests that, despite slower productivity growth as well as the rising importance of income growth in the world's poorest countries and the increasing use of crops for biofuels, global food prices will still fall due to the slowdown in global population growth. We do recognize that there is tremendous uncertainty surrounding future food price trends, and therefore provide a bounding analysis wherein we vary the growth rates of population and agricultural productivity – the main historical drivers of food demand and supply. With high population growth and a stagnation of TFP growth in the crops sector, food prices will indeed rise in the future. In contrast, slower population growth and faster crop TFP growth will result in even lower food prices, declining twice as fast as the observed reduction from 1961 to 2006. Our formal uncertainty analysis in which both model parameters and exogenous shocks are systematically varied reveals that more than 72% of the possible future outcomes show declining food prices between 2006 and 2051. Thus, we conclude that current expectations of rising long run food prices in the long run are misplaced.

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SUPPLEMETARY FIGURES

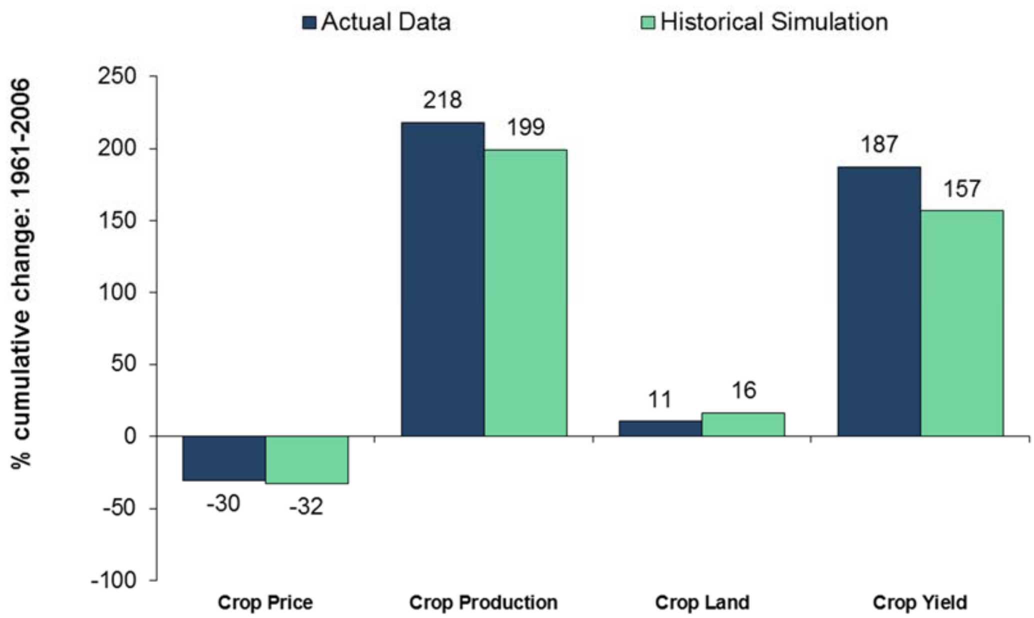

Figure A1. Historical changes in global crop variables: Actual vs. Simulation

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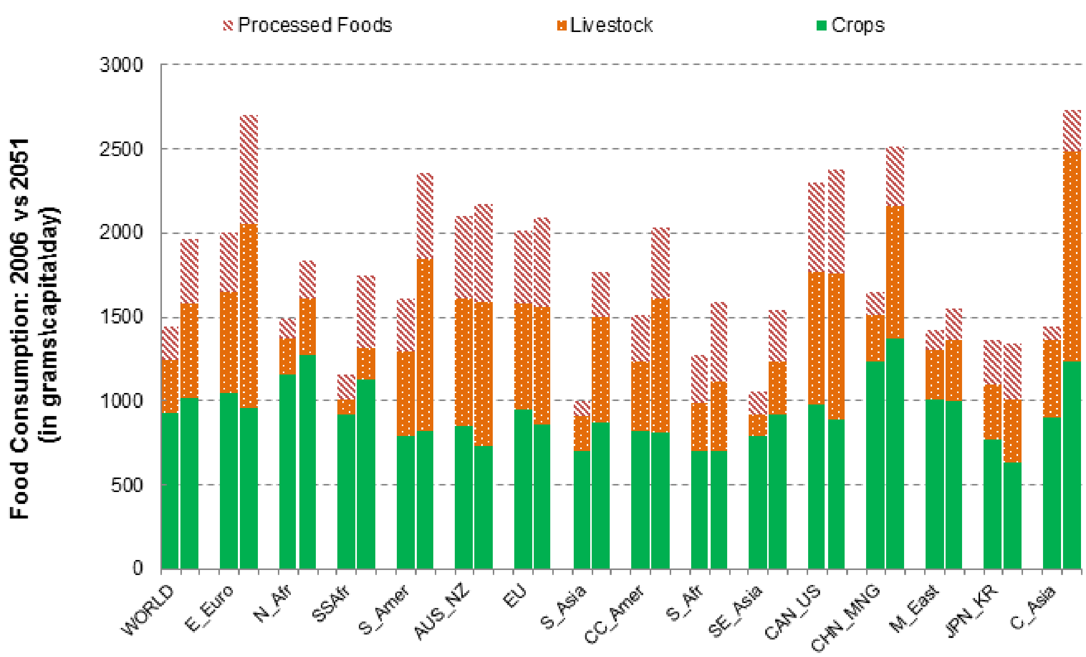

Figure A2. Food consumption in 2006 and in 2051.

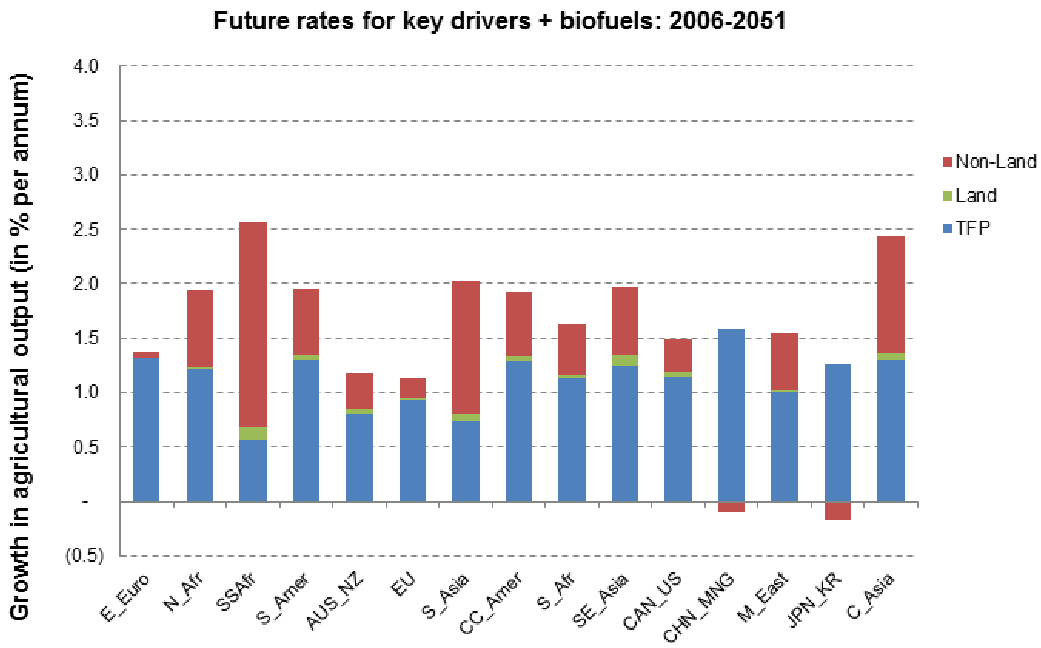

Figure A3. Decomposition of regional output growth due to intensive use of non-land inputs, expansion in cropland and total factor productivity growth.