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ABSTRACT

Over the past 50 years and longer, the supply of food commodities has grown faster than the effective market demand, in spite of increasing population and per capita incomes. Consequently, the real (deflated) prices of food commodities have steadily trended down. The past increases in agricultural productivity and production, and the resulting real price trends, are attributable in large part to technological changes enabled by investments in agricultural R&D. Evidence is beginning to emerge of a slowdown in the long-term path of agricultural productivity growth. These productivity patterns mirror a progressive slowing down in the growth rate of total spending on agricultural R&D and a redirection of the funds away from farm productivity that began 20-30 years ago.

> Many of the more serious economic difficulties that confront agriculture are born out of [a] difference in the pace of agriculture and industry. The plowman's tread does not allow running for a stretch and then walking or even stopping altogether. Agriculture has a steady gait, while other producers in the economy sometimes run and at other times simply stand still. Farmers, in the main, stay in full production regardless of the effects of business fluctuations upon the demand for farm products and in spite of governmental efforts to reduce output. This assures consumers of a large and steady supply of food and other farm products, but it means great instability in farm prices and farm income.
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> T.W. Schultz *Agriculture in an Unstable Economy*, 1945, p. 12.

Mendel versus Malthus: Research, Productivity and Food Prices in the Long Run

1. Introduction

We are living in turbulent economic times with important consequences for food and agriculture. In recent months we have seen soaring food and commodity prices globally and an increase in the dismal tally of hungry people in the world.[1] This paper uses graphical approaches in conjunction with newly compiled data to provide long-term perspectives on the recent turbulence in food commodity markets.

The price of Brent crude oil reached an all-time high of almost $145 per barrel in July 2008—almost twice the value in July 2007, which itself was historically high.[2] Driven in part by the demand for biofuels, and stimulated by high and rising oil prices and government responses to them, prices of maize and soybeans also rose rapidly to historical highs (at least in nominal terms) in early 2008. The rising prices of these and other staple crops, in particular wheat and rice, were also stimulated by the growing demand for food in India and China fuelled by the general economic growth that had contributed to a rundown of grain stocks over the previous several years. These factors combined with some unfavorable weather in important wheat-producing regions in Russia and Australia constituted the "perfect storm" that gave rise to the spike in grain prices in mid 2008.

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[1] In September 2008 the United Nation's Food and Agriculture Organization released a provisional set of estimates (FAO 2008c) indicating "…that the number of undernourished people in 2007 increased by 75 million over and above FAO's estimate of 848 million undernourished in 2003-05, with much of this increase attributed to high food prices. This brings the number of undernourished people worldwide to 923 million in 2007, of which 907 million [are] in the developing world." More recently, FAO (2009a) estimated that an additional 100 million people are now undernourished, increasing the total to over one billion.

[2] The oil price cited here was obtained from http://www.eia.doe.gov/emeu/international/prices.html on November 16, 2008.

In a reversal of the rapid rise in the beginning of 2008, between July and November of that year the price of oil fell back to around $50. Prices of food and feed crops have also fallen significantly. Consequently, and especially in view of financial and stock market events since mid-September 2008, attention of many commentators has shifted from the food price crisis to the global financial crisis. Nevertheless, food commodity prices remain high relative to the experience of the past several decades, and concerns continue to be raised about the future prospects for food prices. In December 2007, the *Economist* magazine published a briefing note titled "Cheap No More" with the leader "Rising incomes in Asia and ethanol subsidies in America have put an end to a long era of falling food prices." This view has been echoed in a range of other media and at a host of symposia on the causes and consequences of the so-called "food price crisis." Concerns about global food prices have not dissipated, although the focus has mostly shifted away from spikes to trends in prices (see, for example, Economist 2009 and OECD-FAO 2009).

Most of the discussions have focused on the demand side of the story, emphasizing the role of economic growth in the fast-growing economies of Asia coupled with the new demand for biofuels, treating the supply side as given. In this paper we consider the nature of the long-term growth in the supply of food and its principal determinants to see what may be implied for the availability and price of food over the coming decades.[3] We document a slowdown in growth of agricultural productivity and crop yields, and thus in the long-term downward trend of

[3] Economists have long been interested in analyzing commodity price trends and the sources of change in these trends. Among the earliest such studies in the U.S literature are articles by Veblen (1892 and 1893) on (relative) wheat price trends and a 1922 article by Taylor titled "The Decline of Prices of Cereals." In his 1945 book *Agriculture in an Unstable Economy* Schultz explored the nature and causes of commodity price instability during the first half of the 20th century, notably in a chapter titled "The Unequal Growth of the Supply and Demand for Farm Products." Johnson (1948 and 1975) addressed similar themes and Hathaway (1959) revisited Schultz's 1945 work. Tomek and Robinson (1977) provided a comprehensive review of the literature on agricultural prices to that point in time.

real food commodity prices, and we link those developments back to shifts in funding for agricultural R&D.[4]

2. Price Trends and their Possible Causes

Useful insights into the future can be gleaned by a careful consideration of past patterns. Over the past 50 years and longer, the supply of food commodities has grown faster than the demand, in spite of increasing population and per capita incomes. Consequently, the real (deflated) prices of food commodities have steadily trended down. Figure 1 shows long-term trends in indexes of average annual U.S. prices of major food and feed commodities (rice, wheat, corn, and soybeans) for the period 1924 to 2008, with an insert to show monthly price movements over recent months. These U.S. price indexes can be used as indicators of world market prices of these commodities.[5]

The commodity price indexes generally move together over the long term, but with significant differences over shorter periods, especially for rice. These indexes all start at 100 in the base year of 1924. After a great deal of movement over the next 45 years, by the late 1960s the prices of wheat, soybeans, and maize had roughly returned to a nominal value of 100, but the rice price remained much higher. The intervening years included a period of a general downward trend during the 1920s and through the early 1930s (including the effects of the Great Depression), and some rapid growth during the latter 1930s and early 1940s (including the effects of World War II), after which the prices fluctuated around a relatively flat trend. The

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[4] In making this assessment we drew on a range of evidence and used the graphical techniques recommended by Waugh (1966), who wrote "Fancy, super-refined mathematics and electronic computations are wonderful things, but they are of little practical use unless they describe relationships that actually exist in the real world. One of the main ways to find out about these relationships is through graphics (p. 1)." Evident structural changes, especially in the price and crop yield series, limit the applicability of formal econometric approaches to analyzing these trends.

[5] However, the Economist (2009) presents evidence that the U.S. price spikes were less pronounced in intensity and duration than those experienced in some countries.

commodity price spike in the early 1970s brought about a discrete shift in the pattern.[6] Following that price spike the trends were again essentially flat in nominal terms but at a higher level than before 1970 (perhaps slightly trending down) until the recent price spike. Since 1975 the prices of all four commodities have tended to move together more closely than in the previous decades.

[Figure 1: *Nominal U.S. prices of maize, rice, soybeans, and wheat, 1924-2008*]

Figure 2 shows the price indexes for wheat, maize, and soybeans over the period 1924 to 2008, expressed in real terms by deflating using an index of prices paid by farmers. (Rice was omitted to improve the clarity of the figure. The rice prices follow a similar overall pattern to the commodity prices shown here.) The deflated series provide some perspective on the latest price spike, in which grain prices roughly doubled in real terms, compared with the 1970s and mid-1930s, when they more than doubled. Moreover, in the recent spike, real commodity prices fell well short of the prices that prevailed during the previous price spikes. In the case of maize, for example, in real terms the average price in 2008 was 70 percent below the average price in 1974, and over 80 percent below the average prices in both 1936 and 1947. While the latest price spike has passed its peak, questions remain about whether the general path of the previous price trend will be restored.

The longer trends are of interest, too. In real terms, grain and oilseed prices trended up generally (albeit with some major fluctuations during and after the Great Depression) from 1929 through the end of World War II after which they have trended generally down. This downward trend was interrupted by the major price spike in the 1970s and again at the end of the series by

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[6] Eckstein and Heien (1978) examined the food price inflation of 1973 and concluded that in approximate rank order of importance the causes were domestic monetary policy, government acreage restrictions, the Soviet grain deal, world economic conditions, devaluation of the dollar, and price control policies. Our emphasis in this paper is on the long-term trends rather than the short-term deviations from these trends.

the latest price spike. The trend lines in the figure show the real prices declining at different rates during the period 1950-1970, as they converged towards equality. Then following the 1970s price spike, over the period 1975-2008, they trended down at roughly equal rates.

[Figure 2: *Real U.S. prices of maize, soybeans, and wheat, 1924-2008*]

Table 1 includes measures of rates of change in real and nominal prices of the four commodities over the entire period and several sub-periods. The long-term trend in deflated prices has been remarkable.[7] Over the 58 years between 1950 and 2008, in real terms rice prices declined at an average annual rate of 1.9 percent, wheat prices by 1.8 percent per year, soybean prices by 1.6 percent per year, and maize (or corn) prices by 2.3 percent per year. After the jump in the early 1970s, over the 33 years between 1975 and 2008, in real terms rice prices fell at an average rate of 2.1 percent per year, wheat prices by 2.2 percent per year, soybean prices by 2.3 percent per year, and maize prices by 2.9 percent per year. These long-term changes in prices of staple commodities are cumulative and enduring. [8]

[Table 1. *Average annual percentage changes in U.S. commodity prices, 1866-2008*]

It is useful to split the period 1975-2008 into two sub-periods, before and after 1990. This break point was identified in other work by Alston et al. (2010) looking at U.S. productivity patterns. For all four commodities the real rate of decline of prices was substantially slower over

[7] As Hulten (1985) and Roeger (1995) illustrate, under certain conditions, the rate of decline of an output-input price ratio such as the deflated commodity price series presented here corresponds to a dual measure of the rate of multifactor productivity growth, and so the declines in these deflated price trends reflect substantial and rapid productivity growth. The correspondence is closer if the deflator corresponds more closely to the appropriate price index for the inputs used to produce the output. Deflating by the implicit GDP deflator or the consumer price index rather than the index of prices paid by farmers for inputs in practice results in generally similar patterns of change overall in the real price trends for each commodity (but with differences in some of the details).

[8] The trends through 2008 include the partially offsetting effects of the recent price spike. Excluding the recent years, the trends were more pronounced. Over the 55 years between 1950 and 2005, in real terms rice prices fell by 2.5 percent per year, wheat prices by 2.2 percent per year, soybean prices by 1.6 percent per year, and maize (or corn) prices by 2.6 percent per year. Over the 30 years between 1975 and 2005, in real terms rice prices fell by 3.7 percent per year, wheat prices by 3.3 percent per year, soybean prices by 2.6 percent per year, and maize prices by 3.9 percent per year.

the period 1990-2008 than for the previous period 1975-1990 and for the 33-year period 1975-2008. This reduction in the rate of price decline was more pronounced for the food grains, wheat and rice (with the real price of both these commodities actually increasing over the period 1990-2008), than for the feed crops, maize and soybeans, consistent with a faster rate of productivity growth in the feed crops that have disproportionately benefited from private research by biotech firms and seed companies. Toward the end of the period, the rate of decline of real prices slowed even more—in fact, from 2000 forward, prices increased in real terms for all four commodities.

In summary, the period since World War II includes three distinct sub-periods. First, over the 20 years 1950-1970, prices for rice, maize, and soybeans declined relatively slowly, while wheat prices declined fairly rapidly. Next, following the price spike of the early 1970s, over the years 1975-1990, prices for all four commodities declined relatively rapidly. Finally, over the years 1990-2008, the rate of price decline slowed for all four commodities, especially towards the end of that period.

Figure 3 shows some comparable price indexes for field crops, specialty crops, and livestock products over the period 1949-2004 for which detailed index numbers are available from the work of Alston et al. (2010). Panel a shows the nominal indexes. The prices of specialty crops have grown both absolutely and relative to field crops and livestock products, which have had fairly static nominal prices for the 20 years prior to 2004 in spite of general cost inflation. As discussed by Alston, Sumner and Vosti (2006), some of these price increases for specialty crops might reflect premia for changes in quality, variety, or seasonal availability that were not fully addressed in the indexing procedure. Figure 3, Panel b shows the same price series deflated by an index of prices paid by farmers for inputs. Real prices received by farmers for all crop categories trended down, but at different rates. Over the period 1949-2004 in real terms prices for field crops fell by 64.5 percent, prices for livestock fell by 42.7 percent, and prices for specialty crops fell by 5.3 percent (8.6 percent for vegetables, 3.0 percent for fruits and nuts, and 0.2 percent for nursery and greenhouse).

[Figure 3: *U.S. prices of specialty crops, field crops, and livestock, 1949-2004*]

These price trends reflect the fact that global supply has been growing faster than global demand, and that supply and demand have been growing at different rates for the different categories of products. Here we are focusing on the supply side. Growth in supply reflects the increased use of some inputs, especially increases in land, water, and chemical inputs (including fuels, fertilizers, and pesticides), balanced partly by labor savings in many places, combined with increases in productivity of inputs. Major increases in productivity and changes in input combinations around the world and over time have been associated with changes in technology along with other changes that contributed to enhanced efficiency of production.

3. U.S. Agricultural Production and Productivity in the Long Run

A range of measures of agricultural productivity growth for the United States show some consistent patterns in terms of secular shifts, including indications of a recent slowdown in growth, that mirror the corresponding patterns in relative prices.

Crop Yields

Figure 4, Panel a shows the remarkable growth in yields for selected U.S. crops over the long run—beginning in 1866 for wheat and corn, 1895 for rice, and 1924 for soybeans. Between 1866 and 2008 average yields of maize increased by a factor of 6.3, while wheat yields increased by a factor of 4.1. Over the past 113 years rice yields grew by a factor of 6.0, while soybean yields grew by a factor of 3.9 over the past 84 years. For all four crops most of the yield gains were made in the latter half of the 20th century, with annual average rates of growth for rice, wheat, and maize since 1950 typically one to two percentage points greater than the previous longer-run rates of growth—spanning the period 1866-1950 for wheat and maize and 1895-1950 for rice (Table 2). However, we see evidence of a slowdown in yield growth during the 1990s and the first decade of the 21st century; rates of yield growth during the 18 years, 1990-2008 were uniformly and markedly below the rates that prevailed during the 40 years, 1950-1990: maize yields grew at an average rate of 1.45 percent per year over 1990-2008 compared with 2.40 percent for 1950-1990; wheat yields grew at an average rate of 0.71 percent per year during 1990-2008, compared with 1.73 percent for 1950-1990; and the rates of growth in rice and soybean yields were also substantially slower during 1990-2008 then during 1950-1990.

[Figure 4: *U.S. crop yields in the long run, 1866-2008*]
[Table 2: *Rates of growth of yield of selected U.S. crops, 1866-2008*]

Figure 4, Panel b provides a different perspective on the long-run pattern of average yield growth in the United States. The plots indicate the doubling times for U.S. crop yields of maize, wheat, rice, and soybeans, measured as the number of previous years required for yields to double to their present levels. Looking back from 1955, it took 20 years from 1935 for maize yields to double and reach their 1955 levels. The doubling times for maize yields trended down until the late 1960s (so that maize yields in 1968 were double the average observed just 14 years previously). Thereafter doubling times steadily increased such that it took 42 years for maize yields to double and reach their 2006-2008 U.S. average of 151 bushels per acre.[9] Similarly, the doubling times for U.S. average wheat, rice and soybean yields have also trended significantly upwards since the mid 1950s. It took about 50 years for soybean, rice and wheat yields to double by 2008. Since the middle of the 20th century, the doubling times for yields have generally been

[9] The doubling times are calculated using a three-year moving average around the indicated year. For example, the yield for 2007 is benchmarked on the average national yield for 2006, 2007 and 2008.

shorter for U.S. maize than for other crops. Doubling times for soybean yields were the longest of all the crops in virtually all the years since 1961, with doubling times for rice and wheat increasing along similar paths, especially since the mid-1970s.

Labor, Land and Multifactor Productivity

Conventional (primal) measures of productivity are obtained by expressing measures of output relative to measures of inputs. Partial factor productivity measures express output relative to a particular input (like land or labor).[10] Multifactor productivity measures express output relative to a more inclusive metric of all *measurable* inputs (including land, labor and capital, as well as energy, chemicals, and other purchased inputs). Here we consider developments in estimates of aggregate land, labor, and multifactor productivity for U.S agriculture stretching back almost a century.

In 2002, in aggregate terms, U.S. agriculture produced more than five times the quantity of agricultural output produced in 1910. The 1.82 percent per year increase in output over 1910-2002 was achieved with only a 0.36 percent per year increase in the total quantity of inputs. The mix of inputs also changed markedly. Most notably, since 1911, labor use declined by an estimated 1.27 percent per year while land use grew by 0.09 percent per year. Use of inputs purchased from farm origin (especially feed for traction animals and the land, labor and other inputs involved in producing that feed) declined generally, especially in the first half of the 20th century (Alston et al. 2010). Consequently, between 1911 and 2002, U.S. agricultural land productivity (output per unit of land) increased by a factor of 4.4, labor productivity increased by a factor of 15.3 and, accounting for all measurable inputs, multi-factor productivity increased by a factor of 4.1 (Figure 5).

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[10] Crop yields represent a particular partial productivity measure wherein the physical output for a particular crop is expressed relative to land input.

[Figure 5: *U.S. labor, land and multi-factor productivity, 1911-2002*]

Impressive as the long-run productivity gains undoubtedly are, they mask a more-recent slowdown in the rates of productivity increase. The 20th century productivity paths can be divided into three phases that closely correspond in both form and timing to the three phases of yield growth and price trends, noted above. Prior to the 1950s, U.S. land, labor, and multifactor productivity grew comparatively slowly (Table 3). The average rates of productivity growth picked up considerably during the subsequent four decades 1950-1990, averaging 4.08 percent per year for labor productivity, 1.96 percent per year for land productivity, and 2.12 percent per year for multi-factor productivity. A third phase, beginning in 1990 (and in this instance running to 2002, the last year for which our productivity estimates are currently available), saw a sharp downturn in the rates of growth of all three productivity measures. Notably, during the period 1990-2002 labor productivity and multifactor productivity grew at half, or less than half, the corresponding rate for the period 1950-1990.[11]

[Table 3: *U.S agricultural productivity growth rates by period, 1911-2002*]

4. Global Productivity Patterns

The long-run evidence on U.S. crop yields and productivity tells a consistent story: measurable but comparatively sluggish growth prior to 1950, historically rapid growth for the subsequent four decades 1950-1990, and then a substantial slowdown in the rates of growth for all the crop yield and productivity series reported here from 1990 forward. How do these U.S. developments square with the yield and productivity paths observed for agriculture worldwide?

[11] The slowdown in multi-factor productivity growth was also pervasive throughout U.S. agriculture. Alston et al. (2010) report that all but four of the 48 contiguous states in the United States had substantially lower rates of multifactor productivity gains for the period 1990-2002 compared with the preceding four decades.

Crop Yields

Figure 6 plots average global yields for maize, rice, and wheat (in metric tons per harvested hectare) since 1961 (the earliest year for which global yield estimates are reported by the U.N. Food and Agriculture Organization, whence most of these data were drawn). Maize and wheat yields each grew by a factor of 2.6 from 1961 to 2007; over the same period, rice yields increased by a factor of 2.2 and soybean yields increased by a factor 2.0.

[Figure 6: *Average global yields for selected crops, 1961-2007*]

Corresponding annual average rates of yield growth are reported in Table 4. Separate estimates of average growth rates of yields are reported for developing countries, developed countries (further subdivided into Western Europe, Eastern Europe, and North America), and the world as a whole, for two sub-periods 1961-1990 and 1990-2007. The slowdown evident for U.S. crop yield growth since 1990 is mirrored in the global averages. For all four crops, in both developed and developing countries, average annual rates of yield growth were lower in 1990-2007 than in 1961-1990.[12] The growth of wheat yields slowed the most and, for the developed countries as a group, wheat yields actually declined over the period 1990-2007. Global maize yields grew during 1990-2007 at an average rate of 1.77 percent per year compared with 2.20 percent per year for 1961-1990. Likewise rice yields grew at less than 1.0 percent per year after 1990, less than half their average growth rate for the period 1961-1990.

Table 4 also reveals that yields of wheat, maize and soybeans grew more rapidly in China than in the rest of the world during both 1961-1990 and 1990-2007. However, while rice yields grew more rapidly in China than in the rest of the world during 1961-1990, the converse was true during the latter period, 1990-2007. As a consequence of these differences, and the large scale

[12] However, the rate of growth in rice yields in developed countries decreased only slightly.

of China's production, the inclusion or exclusion of China had a significant influence on the global averages. The countries of the Former Soviet Union (USSR) had a relatively small impact on global maize, rice and soybean yield growth rates—largely because the USSR accounts for a small percentage of global production of these commodities. However, decreases in USSR wheat yields during 1990-2007 depressed global average yield growth for wheat such that for the global total excluding the USSR, wheat yields grew by 0.73 percent per year compared with 0.52 percent per year when the USSR is included. These issues are further explored in Section 4.

[Table 4: *Global yield growth rates, 1961-1990 vs. 1990-2007*]

Again, paralleling productivity developments in the United States, the slowdown in crop yields is quite pervasive. In more than half of the countries growing each crop, yields for rice, wheat, maize and soybeans grew more slowly during 1990-2007 than during 1961-1990 (Table 5). More critically, the slowdown was more widespread among the most important producers (i.e., the top ten producing countries worldwide) than among all producing countries.

[Table 5: *Percentage of countries with slower yield growth since 1990*]

The interpretation of average global crop yields is problematic for several reasons. For one, countries located in tropical and temperate regions of the world differ considerably in terms of their propensity to plant multiple crops per year, and cropping intensities have changed considerably over time for certain regions of the world.[13] The yield data used here (and by most other observers) report yields on the basis of harvested area, which will count the same land

[13] Wood, Sebastian and Scherr (2000) developed measures of cropping intensities worldwide that expressed the annual harvested area as a proportion of total crop land (including land in use and fallowed land). Swidden agriculture, for example, relies on maintaining a significant share of production in fallow every year (thus having a cropping intensity of less than one) whereas some irrigated areas in the tropics can produce up to three crops a year from the same physical area (thus having a cropping intensity of 3). In 1997, the global average annual cropping intensity was estimated to be about 0.8 (Wood, Sebastian and Scherr 2000, p.23). In South Asia, with its extensive use of irrigation, the average intensity was 1.1, whereas in Western Europe and North America the intensities were in the 0.6 to 0.7 range.

twice if it is cropped twice in a given calendar year. An alternative is to report yields on the basis of arable area, which will count the land area only once per year regardless of how often it is cropped. Reporting yields on the basis of harvested area would understate the rate of growth in crop yields compared with crop yields measured on the basis of arable area if the intensity of crop plantings per year had increased over time.[14]

Another confounding factor when interpreting changes in global or regional yield aggregates (as well as national aggregate yields for that matter) is the effects of the changing spatial location of production. Table 6 illustrates that the location of worldwide wheat production, for example, has moved markedly, even since the early 1960s. During the three-year period 1961-1963, Russia accounted for 15 percent of the world's wheat production (35.4 million metric tons) and ranked first among wheat producers worldwide. By 2005-2007 Russia had slipped to the world's fourth-ranked wheat producer accounting for 7.8 percent (47.4 million metric tons) of world wheat production during those years. The massive increases in production by India and, especially, China are particularly evident in Table 6. These changes in location of production imply changes in average productivity (yields) to the extent that different locations have different endowments of soils and climate, different incentives, and different technological opportunities.[15]

[Table 6: *Changing spatial location of global wheat production, 1961-63 and 2005-07*]

Land and Labor Productivity

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[14] For example, if rice yields averaged 2 tons per harvested hectare in 1961 and doubled to 4 tons per harvested hectare by 2007, that would be equivalent to an average annual yield growth of 1.5 percent per harvested hectare per year. In contrast, if yields per harvested area doubled from 2 to 4 tons per hectare from 1961 to 2007 while the cropping intensity also increased from one to two crops per calendar year, yields reported on the basis of arable area would have grown from 2 to 8 tons per arable hectare, or 3.1 percent per year.

[15] Olmstead and Rhode (2002) discuss and document this phenomenon in the context of the early development of the U.S. wheat industry. Beddow et al. (2009) provide a brief synopsis of the concordance between broad agro-climatic zones, national per capita income rankings, and yields.

Moving beyond crop yields to more broadly construed productivity measures, global productivity trends show a 2.4-fold increase in aggregate output per harvested area since 1961 (equivalent to annual average growth of 2.0 percent per year) and a corresponding 1.7-fold increase (or 1.2 percent per year growth) in aggregate output per agricultural worker. These productivity developments reflect a comparatively faster rate of growth in global agricultural output against relatively slower growth in the use of agricultural land and labor (0.3 and 1.1 percent per year, respectively).

In parallel with the global crop yield evidence presented above, the longer-run growth in land and labor productivity mask a widespread slowdown in the rate of growth of both productivity measures in 1990-2007 compared with the previous three decades. Among the world's top 20 producers (according to their 2005 value of agricultural output), compared with 1961-1990, land and labor productivity growth slowed considerably during 1990-2007 once the large, and in many respects exceptional, case of China is set aside (Table 7). Across the rest of the world (i.e., after setting aside the top 20 producing countries), on average, the slowdown was even more pronounced. For this group of countries land productivity grew by 1.74 percent per year during 1961-1990, but only 0.88 percent per year thereafter; labor productivity grew by 1.00 percent per year during 1961-1990, but barely changed over the period since then.

[Table 7*: Growth rates of agricultural land and labor use and productivity, by region, 1961-2005]*

Worldwide, land productivity grew at a slower pace in 1990-2007 (1.82 percent per year) than during earlier decades (2.03 percent per year), whereas labor productivity increased at a faster rate from 1990 to 2008 than it did from 1961 to 1990 (1.36 percent versus 1.12 percent per year). Once again these world totals are distorted by the significant and exceptional case of China. Netting out China, global land and labor productivity growth was slower in 1990-2007 than during the prior three decades. The pattern is similar if the former Soviet Union (USSR) is also netted out, although the magnitude of the global (net of China and USSR) productivity slowdown is less pronounced because both land and labor productivity declined in the USSR during 1990-2007.[16]

5. Agricultural Research and Development

The increases in agricultural production and the resulting real price trends over the past 50 years and longer are attributable in large part to improvements in agricultural productivity achieved through technological changes enabled by investments in agricultural R&D. Similarly, the recent slowdown in productivity growth may be linked to an earlier slowdown in the growth rate of total spending on agricultural R&D and a redirection of the funds away from farm productivity. From 1950 to 2007, in inflation-adjusted terms, total U.S. public spending on agricultural research grew by 2.16 percent per year; but from 1980 to 2007, spending growth slowed to only 0.80 percent per year. Similar shifts in agricultural research spending and productivity growth have been observed in at least some other countries (Alston et al. 2010).

Worldwide, public investment in agricultural R&D increased by more than 40 percent in inflation-adjusted terms between 1981 and 2000; from an estimated $14.2 billion to $20.3 billion in 2000 international dollars. It grew faster in less-developed countries, and the developing world now accounts for about half of global public-sector spending—up from an estimated 41 percent share in 1981. However, developing countries account for only about one-third of the

[16] While notable in their own right and of significance in terms of global totals, developments in the USSR and China are exceptional, with unique, essentially one-off attributes. The impacts on agricultural productivity growth and downsizing of agriculture in the USSR economies following the break-up of the former Soviet Union are documented and discussed by Mathijs and Swinnen (1998), Macours and Swinnen (2002), and Brooks and Gardner (2004) among others. The massive institutional changes in China (notably the introduction of the household responsibility system into Chinese agriculture in the late 1970s) also had a sizable, one-shot, albeit enduring, effect on productivity developments in that country (see for example, Lin 1992 and Fan and Pardey 1997).

world's total agricultural R&D spending when private investments are included, and agricultural research intensities (expressing agricultural R&D spending as a percentage of agricultural gross domestic product) in developing countries are static and remain much lower than in the developed countries.

A notable feature of the trends was the contraction in support for public agricultural R&D among developed countries. While spending in the United States increased in the latter half of the 1990s, albeit more slowly than in preceding decades, public agricultural R&D was massively reduced in Japan (and also, to a lesser degree, in several European countries) towards the end of the 1990s, leading to a reduction in the rate of increase in developed-country spending as a whole for the decade. The more recent data reinforce the longer-term trends. Namely, support for publicly performed agricultural R&D among developed countries is being scaled back, or slowing down, and R&D agendas have drifted away from productivity gains in food staples towards concerns for the environmental effects of agriculture, food safety and other aspects of food quality, and the medical, energy, and industrial uses of agricultural commodities. Nonetheless, developed countries as a group still account for about one-half of public agricultural R&D worldwide. Given the role of spillovers, a continuation of the recent trends in funding, policy, and markets is likely to have significant effects on the long-term productivity path for food staples in developed and developing countries alike (Pardey, Alston and Piggott 2006).

[Figure 7: *Global public agricultural R&D spending, 1981 and 2000*]

The private sector has continued to emphasize inventions that are amenable to various intellectual property (IP) protection options such as patents, trade secrets (including those associated with hybrid crops), and more recently, plant breeders' rights and other forms of IP protection. The private sector has a large presence in agricultural R&D, but with dramatic differences among countries. In 2000, the global *total* spending on agricultural R&D (including pre-, on-, and post-farm oriented R&D) was $33.7 billion (2000 prices) (James, Pardey and Alston 2008). Approximately 40 percent was conducted by private firms and the remaining 60 percent by public agencies. Notably, 95 percent of that private R&D was performed in developed counties, where some 55 percent of total agricultural R&D was private, a sizeable increase from the 44 percent private share in 1981. This rich-country trend may well continue if the science of agriculture increasingly looks like the sciences more generally. In the United States, for example, the private sector conducted nearly 55 percent of agricultural R&D in 2000, compared with 72 percent of *all* R&D expenditures in that same year (NSF 2005). These increasing private shares reflect increasing industrial R&D by the farm-input supply and the food processing sectors. Around the general trend was much country-specific variation. In developing countries, only 6.4 percent of the agricultural R&D was private, and there were large disparities in the private share among regions of the developing world.

We have access to more detailed data on agricultural R&D in the United States, which we can use to illustrate some trends in the United States that we suspect are also underway in other countries. These trends include a slowing overall growth rate of government funding for public agricultural R&D—with inflation-adjusted growth in public agricultural R&D spending averaging 1.4 percent per year from 1970 to 2007 compared with 3.6 percent per year from 1950 to 1970—and a shifting emphasis of the use of the funds away from research directed at enhancing on-farm productivity. In 1987 around 68 percent of all State Agricultural Experiment Station (SAES) research was directed to maintaining or enhancing farm productivity, but the following two decades saw a sizable and sustained reduction in the productivity orientation of

SAES research and by 2007 only 57 percent of SAES research sought to raise or sustain farm productivity. More detailed discussion of the U.S. agricultural research system and these trends may be found in Alston et al. (2010) from which most of the data in this section are drawn.

6. Implications

In this paper we have presented an array of data indicating a secular slowdown in various measures of productivity growth. All such evidence is subject to measurement error and open to interpretation, and we are aware of some competing views.[17] The truth will be revealed with the passage of time but for now, at least, we are persuaded by the evidence we have presented indicating a slowdown in productivity growth.

The compilation of country-specific studies reported in Alston et al. (2000) reveals a strong association between lagged R&D spending and agricultural productivity improvements. We suspect that a substantial share of the reduced growth in productivity is attributable to a slowdown in the rate of growth in spending on agricultural R&D. Consistent with that view, and the fact that research affects agricultural productivity with a long lag, we suspect that substantial shares of the reduced growth in productivity observed during the past decade or two are attributable in significant part to a slowdown in the rate of growth in spending on agricultural R&D a decade or two previously.

[17] For instance, using FAO data for 171 countries, Fuglie (2008, p. 431) finds "… no evidence of a general slowdown in sector-wide agricultural TFP, at least through 2006." Although we have not fully examined all of the evidence presented, we suspect that this particular finding is driven in significant part by the fact that the input data for many countries are very incomplete such that Fuglie's "TFP" measures are not as reliable as either our multi-factor productivity (MFP) measures for the United States or the partial productivities and crop-specific yield data we have presented that show a clear slowdown. Alston et al. (2010) demonstrate the considerable sensitivity of their U.S. MFP measures to choices of price weights, input quality or compositional adjustments, and measurement methods; sensitivities that are likely to be magnified in efforts to generate MFP measures on an international scale with incomplete and inaccurate measures of agricultural input quantities and prices. Some other differences may be attributable to differences in time periods covered or differences in methods. Fuglie (2008, p. 438) does report a substantial decline in the growth rate of grain yields, from 2.29 percent per year for 1970-1989 to 1.35 percent per year for 1990-2006, consonant with our own findings, but his other partial productivity measures do not indicate a slowdown.

The observed shifts in that research spending away from productivity-oriented research would serve to amplify the slowdown in productivity growth. Reductions in productivity growth imply slower growth in supply against continuing growth in demand (which is driven largely by continuing growth in population and per capita income). Thus, the slowdown in R&D spending is likely to have contributed to the current high commodity prices, though other factors are responsible for most of the recent rapid increases (e.g., von Braun 2007; Trostle 2008).

An implication of our analysis is that a restoration of the growth in spending on agricultural R&D may be necessary to prevent a longer-term food price crisis of a more-enduring nature. This message may be discounted or dismissed on the grounds that, if necessary, science can solve this problem as it did in the 1970s, proving false the prophecy of the doomsayers of the time such as the "Club of Rome."[18] Optimism about the potential for science to contribute to solving our problems may well be justified, but an appropriate investment in science and the translation of that scientific knowhow into technological changes on farms is required to realize that potential—it should not be forgotten that the 1960s and 1970s witnessed a very rapid growth in spending on agricultural science around the world, including the creation of the Consultative Group on International Agricultural research (CGIAR), which played an instrumental role in the Green Revolution (Alston, Dehmer and Pardey 2006).

[18] For example, in *The Population Bomb* published in 1968, just as the Green Revolution spurring rapid crop yield growth was getting underway, the eminent ecologist Paul Ehrlich predicted that in the 1970s "the world will undergo famines—hundreds of millions of people are going to starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate … (p. xi)." William and Paul Paddock's 1967 *Famine 1975! America's Decision: Who Will Survive?* had a similar message. They advocated a triage approach to foreign aid, in which countries in need of food aid should be divided into three groups, as are soldiers injured in battle. The "can't be saved" group, which should receive no aid, included India and the Philippines, both of which have since had years of food surplus from their own harvests. Biologist Garrett Hardin, famous for coining the term "The Tragedy of the Commons" to describe the very real problems that can arise when there is open access to exploitation of a natural resource, published *The Limits of Altruism* in 1977 in support of a "tough-minded" approach that recognized that countries like India had exceeded their "carrying" capacity.

Being able to foretell a tragedy is not the same as being able to prevent it—especially when the very long R&D lags mean that one cannot easily reverse the consequences of current decisions if they turn out to have been misplaced. In this and some other senses, investments in agricultural R&D have some important aspects in common with investments in reductions of greenhouse gas emissions, the benefits from which will accrue mainly to future generations, possibly in countries far away, and will be difficult to ascribe to specific sources. In such circumstances, governments around the world may well fail to anticipate the issue and act quickly and effectively to address it.

Some may suggest that we can count on the private sector to solve the problem. Indeed, if we were to believe relatively recent announcements made by seed and biotech firms about technologies in prospect if not already in the pipeline, the problem may be already solved. For instance, speaking at the U.S. Department of Agriculture's (USDA) Agricultural Outlook Forum in February 2008, DuPont Vice President and General Manager and Pioneer Hi-Bred President Paul Schickler said "We expect the traits and technologies in our product pipeline to help meet that [global food, feed, fuels and materials] demand by doubling the rate of genetic gain—targeting a 40 percent yield increase in our corn and soybean products over the next 10 years." More recently, in an article in the *New York Times* in June 2008, Andrew Pollack reported "Monsanto, the leader in agricultural biotechnology, pledged Wednesday to develop seeds that would double the yields of corn, soybeans and cotton by 2030 and would require 30 percent less water, land and energy to grow."[19]

Such prospects might provide grounds for optimism about the potential of agricultural supply to more than keep pace with demand. But even if the technology possibilities can be

[19] The Schickler quote is available at http://www.pioneer.com/web/site/portal/menuitem.d4f86eb536a8ca24c5892701d10093a0/ and the Pollack article is at http://www.nytimes.com/2008/06/05/business/worldbusiness/05crop.html.

realized (and adopted in some parts of the world) there are big differences between what is possible in the laboratory and what happens in farmers' fields. In addition, crop technologies optimized for growing conditions, say, in the upper mid-west of the United States, must be adapted to conditions prevailing elsewhere in the United States and the world before their widespread use is technically and economically feasible. And even then, we have to remember that the regulatory approval processes are often long and expensive and are getting longer and more expensive for new biotech crop varieties, so the rates of innovation will be slower in farmers' fields than in the laboratories. Moreover, it is still the case that much of the world has not begun to adopt biotech varieties because of perceived market resistance or other political and regulatory barriers, so the benefits from any rapid yield gains in biotech crop varieties will accrue only on a fraction of farmer's fields around the world, especially if these barriers persist.

Relative to past performance, the claims by Monsanto and DuPont about potential yield gains seem very optimistic. The rates of yield gain realized in farmers fields would have to match the highest ever, as recorded in the 1960s and 1970s, and recent yield growth rates have not been nearly so fast. Both claims imply a sustained compound growth rate of about 3.4 percent per year; a rarity in recent history. Figure 8 identifies the number of years for which maize yield growth averaged 3.4 percent per year over the previous decade. This occurred in only 28 instances during the past 133 years, and about half of those instances were for ten-year periods ending in the 1950s and 1960s. In contrast, less than one-sixth of the years during the 1990s and 2000s had maize yield growth rates in excess of 3.4 percent per year over the preceding 10 years. While it is feasible to sustain aggregate growth rates that would achieve the

Monsanto and Du Pont targets it seems improbable, especially given recent trends in crop yields.[20] To do so will mean the future must be substantially different from the more recent past.

[Figure 8: *Number of ten-year periods when growth in maize yields exceeded 3.4 percent per year, periods ending 1875-2008*]

7. Conclusion

Much of the dramatic transformation of U.S. agriculture over the past 100 years, as well as before that, can be traced to the adoption of new technologies that allowed more to be produced with less. The increases in agricultural productivity have been impressive and enormously valuable. It can be difficult to partition the past productivity growth accurately between elements associated with new technology and elements attributable to other sources (including weather and infrastructure), but technological change has surely been the main source. Technological change itself can come from multiple sources, but organized research undertaken by governments and industry has played a central role, especially over the past 150 years.

The long-term downward trends in real prices of food and feed crops, like their counterpart measures of partial and multifactor productivity, appear to have accelerated in the 1970s and 1980s and then slowed in the 1990s and the first decade of the 21st century. Such patterns are difficult to discern precisely given the effects of temporary fluctuations associated with year-to-year variations in weather, and more-enduring but still temporary departures from trend, such as the price spike in the early 1970s; and measured growth rates are sensitive to the choices of starting and ending dates, and more so when the intervals are shorter.

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[20] The more-recent evidence further lengthens the odds of achieving a 3.4 percent per year worldwide growth rate of crop yields. World average yield growth rates exceeded that target for maize for only two decade periods ending after 1961 (i.e., the decades ending in 1973 and 1979); wheat for six decade periods (three of which terminated in years during the 1970s); and soybeans only once. Rice yields never sustained that average rate of growth for a ten-year period. Moreover, average growth in crop yields for all fours crops never exceeded the 3.4 percent per year threshold for any decade period ending after 1990. Further, the Monsanto claim suggests that yield growth rates in excess of 3.4 percent per year can be sustained over a period of two decades, which, historically, even in the United States has not occurred for any of the 20-year periods ending in the 1970s for maize, wheat and rice, while 20-year U.S. soybean yield growth rates have not exceed 3.4 percent during the 85 years for which data are available.

These caveats notwithstanding, a consistent pattern is evident across the range of different measures of productivity—including crop yields, partial factor aggregate productivities of land and labor, multifactor productivities and their dual counterpart of deflated crop prices—and across countries. We conclude from our graphical analysis of these patterns that agricultural productivity grew relatively rapidly in the second half of the 20th century, and within that period, especially during the first 15 years or so after the price spike of the early 1970s. During the period from 1990 forward, however, our agricultural productivity measures grew at significantly slower rates.

Shifts in the support for agricultural research oriented towards on-farm productivity enhancement over the previous 10-20 years (i.e., beginning in the 1980s and 1990s) may have contributed to the observed slowdown in measured productivity growth. Certainly, the rate of growth in support for public agricultural research around the world has slowed, especially in the more-developed countries, and the focus has shifted away from the farm, at least in those places where information is available on such details. While it may be hard to attribute a slowdown in productivity unequivocally to a prior slowdown in research spending, it is not hard to make a case that an increase in spending on farm-productivity-oriented research is warranted if we want to see a return to the rates of productivity improvement enjoyed during the 1970s and 1980s. Sustained and long-run reductions in the number of poor and hungry people worldwide will depend crucially on revitalizing R&D to reinvigorate productivity growth in agriculture over the long term.

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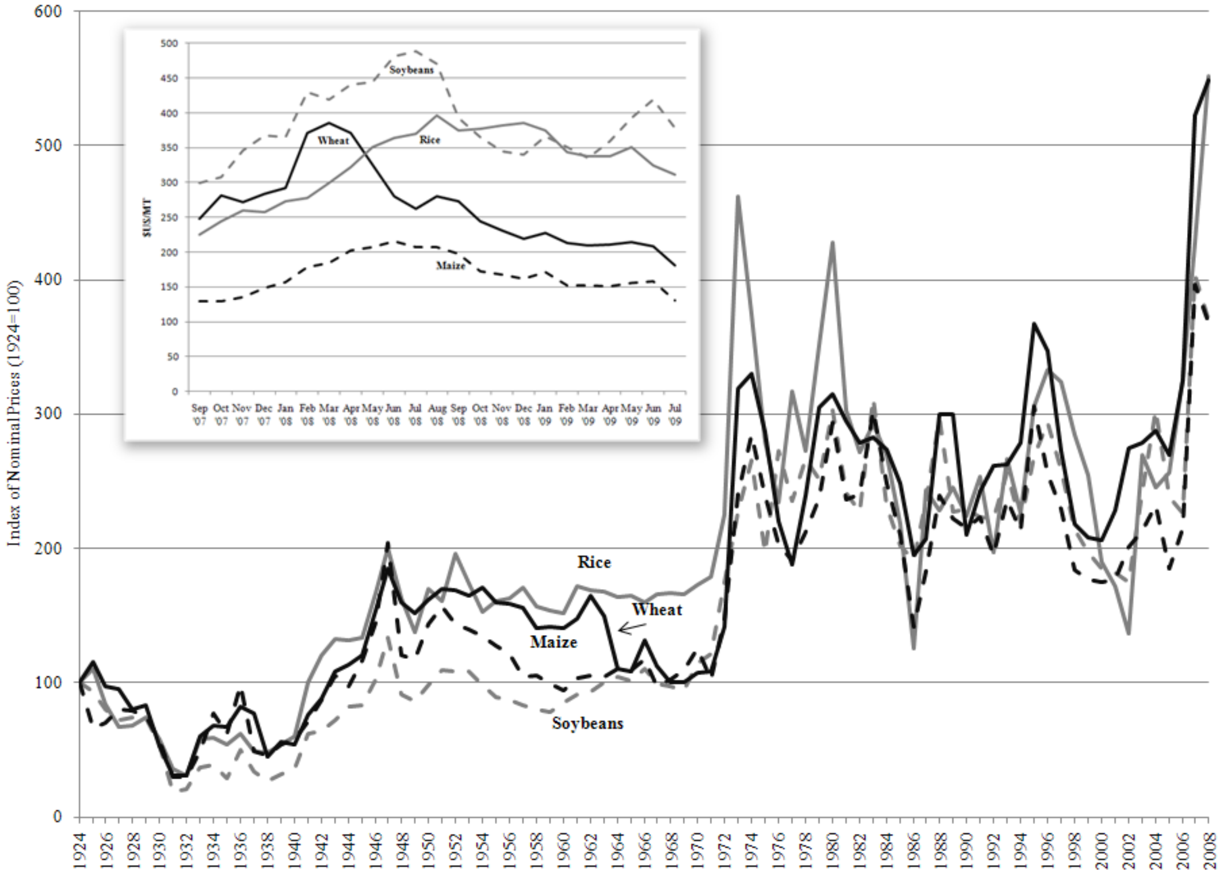
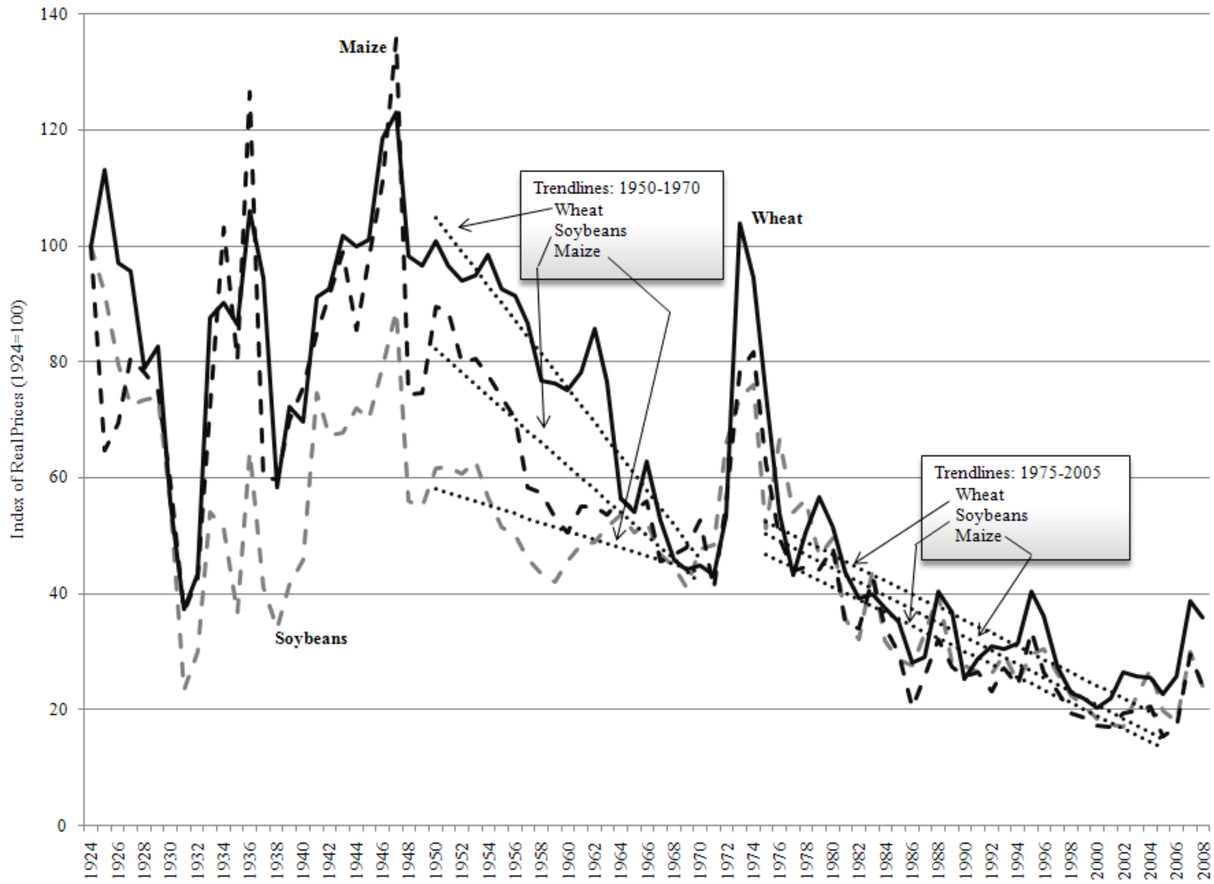
Figure 1: *Nominal U.S. prices of maize, rice, soybeans, and wheat, 1924-2008*



Source: Compiled by the authors with data from Olmstead and Rhode (2006), FAO (2008) and USDA, NASS (2008b).

Notes: Data in the body of the graph represent annual averages of prices paid to farmers. Inset data are corresponding monthly average prices.

Figure 2: *Real U.S. prices of maize, soybeans, and wheat, 1924-2008*

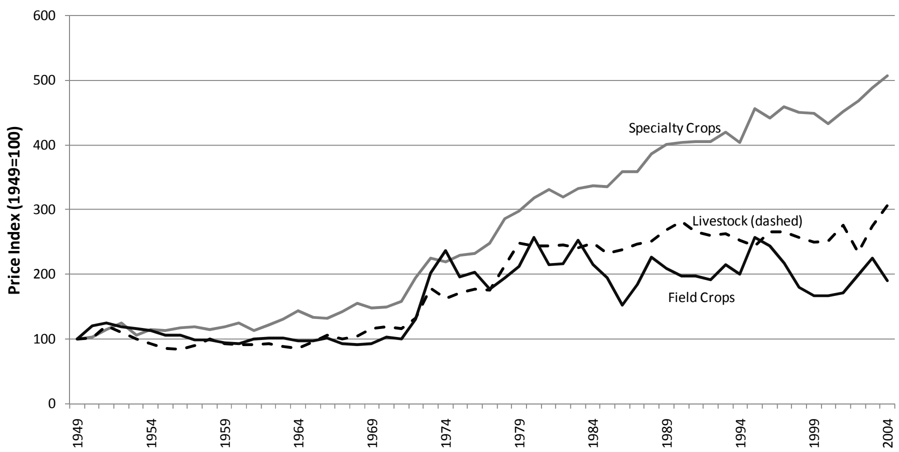


Source: Compiled by the authors with data from Olmstead and Rhode (2006), FAO (2008) and USDA (2008b).

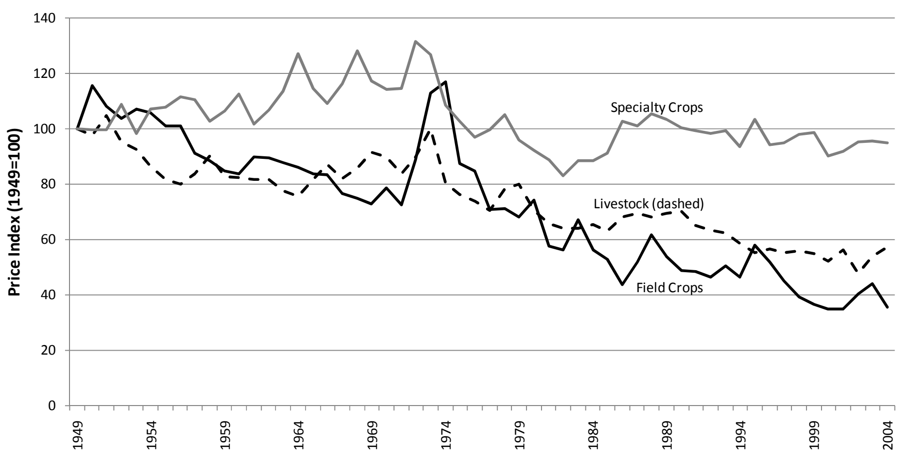
Notes: Nominal prices were deflated using the real farm price index. Trend lines represent lines of OLS best fit where the respective commodity price was regressed against a linear time trend during each period.

Figure 3: *U.S. prices of specialty crops, field crops, and livestock, 1949-2004*

Panel a: Nominal prices



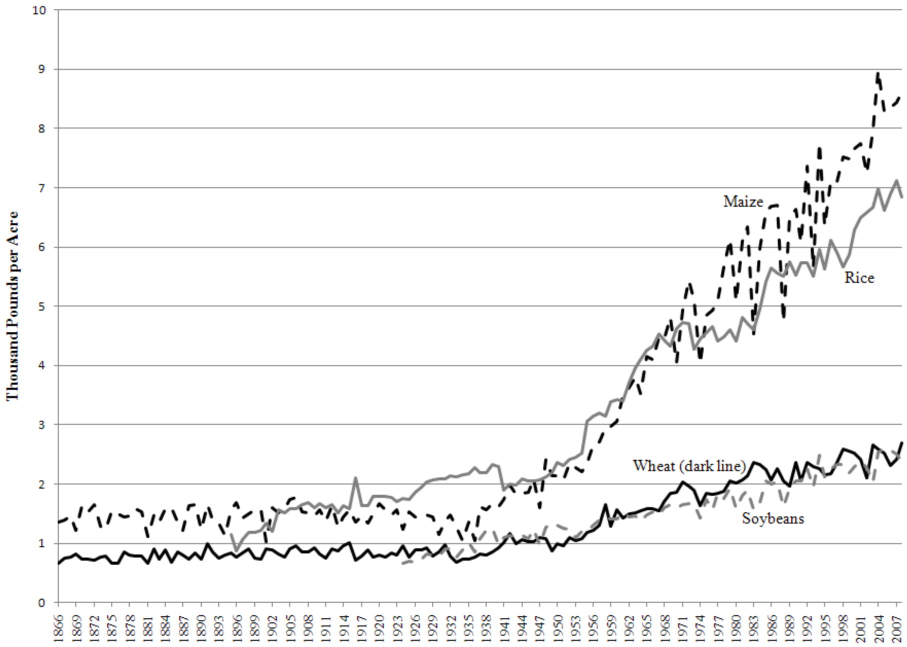
Panel b: Real prices deflated using farm price index



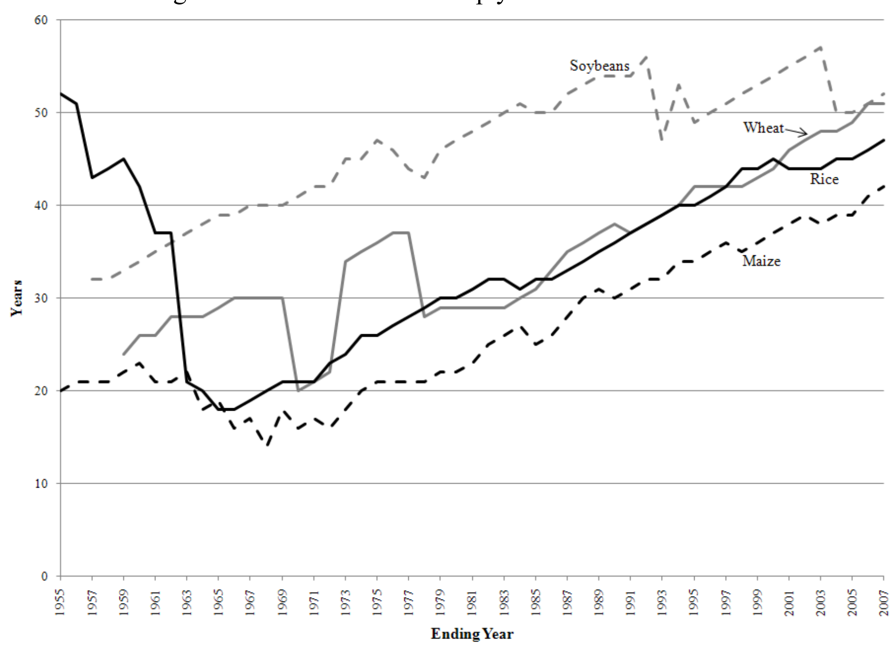
Source: Adapted from Alston and Pardey (2008).

Figure 4: *U.S. crop yields in the long run, 1866-2008*

Panel a. Average U.S. yields for selected crops



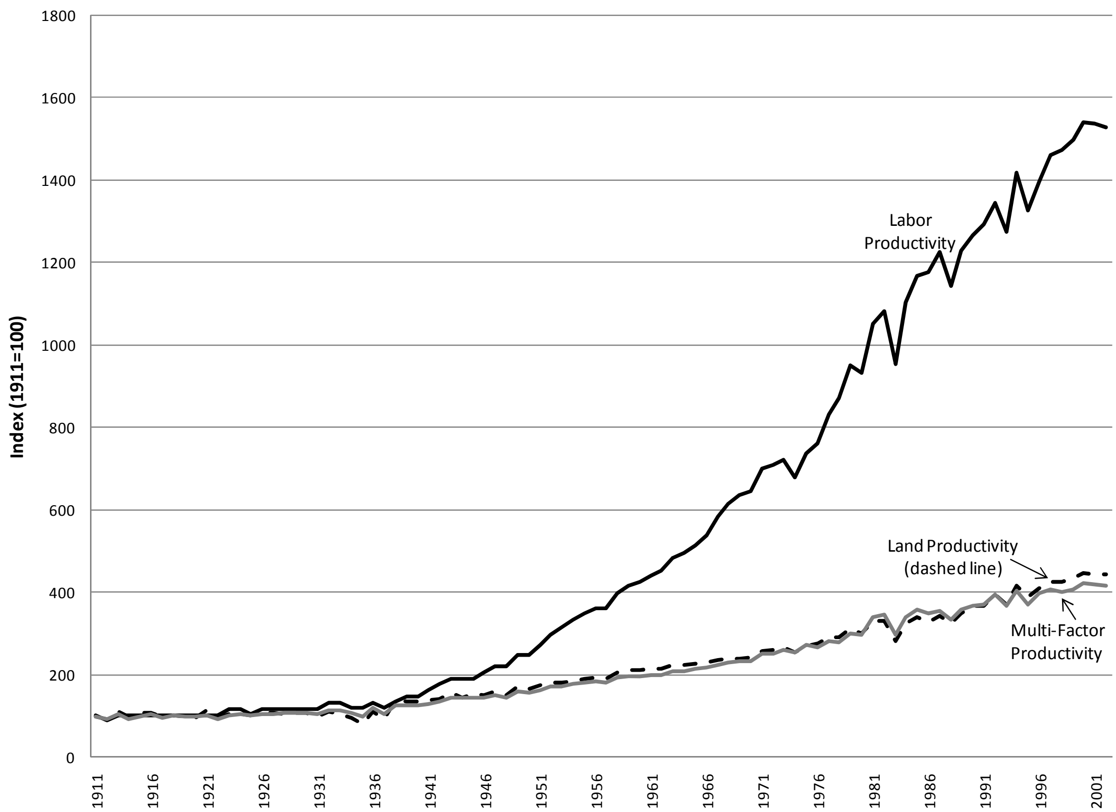
Panel b: Doubling times for selected U.S. crop yields



Source: Adapted from Beddow, Hurley and Pardey (2009).

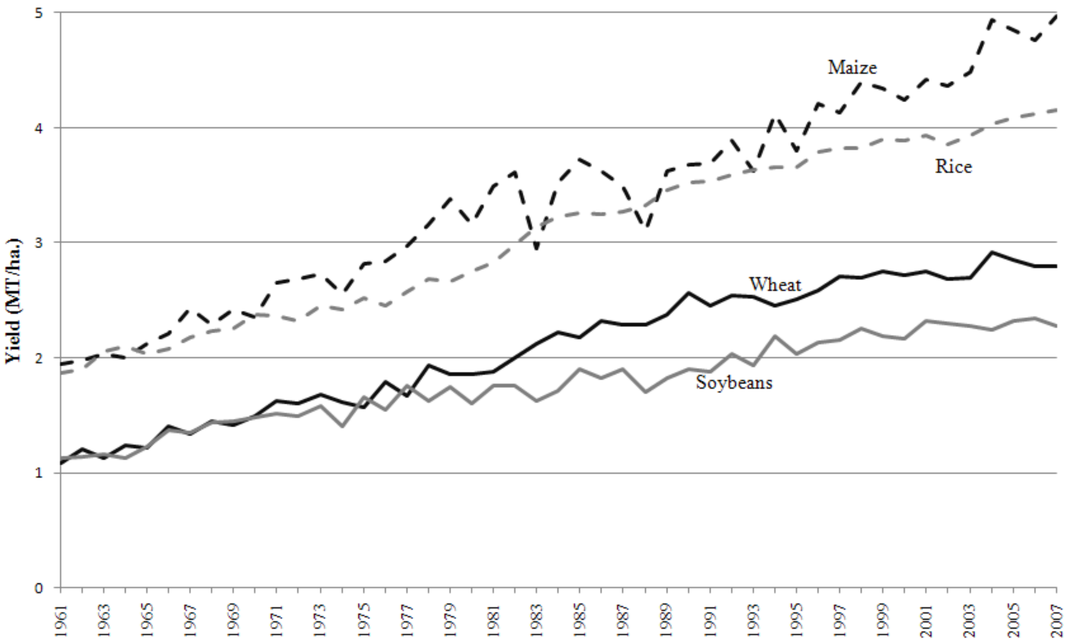
Notes: Doubling times are based on a 3 year moving average of yields, centered on the indicated year. The values in the chart represent the number of years it took to double yields such that they equal yields in the "ending year."

Figure 5: *U.S. labor, land and multi-factor productivity, 1911-2002*



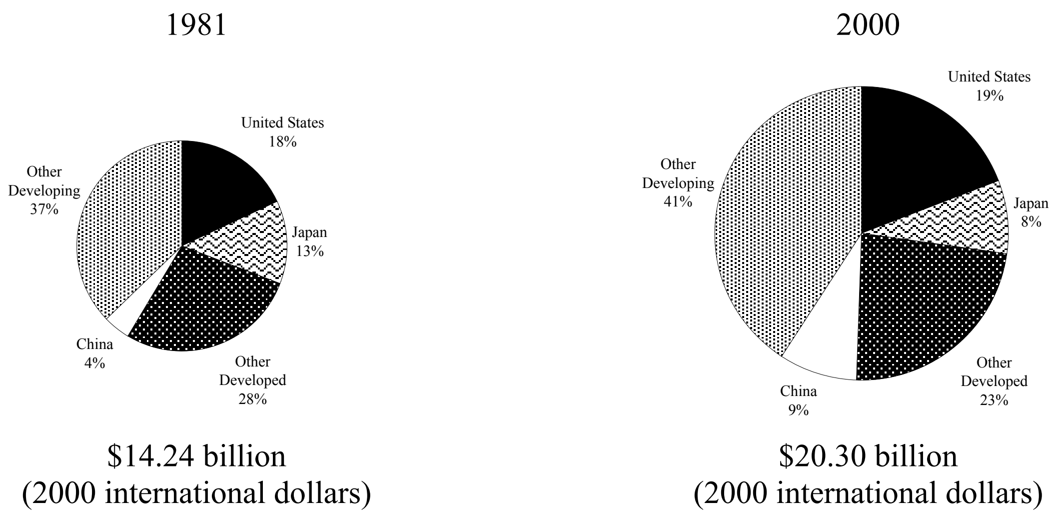
Source: Alston, Anderson, James and Pardey (2010).

Figure 6: *Average global yields for selected crops, 1961-2007*



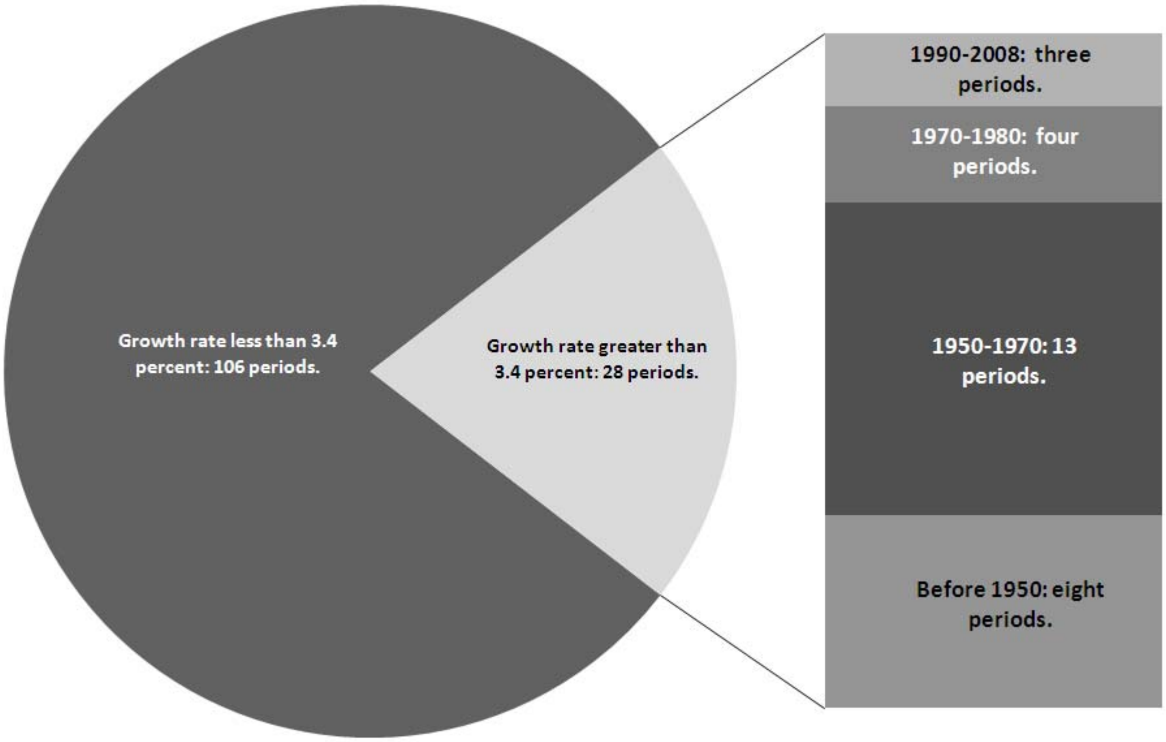
Source: Compiled by the authors from FAO (2008a).

Figure 7: *Global public agricultural R&D spending, 1981 and 2000*



Source: James, Pardey and Alston (2009).

Figure 8: *Number of ten-year periods when growth in maize yields exceeded 3.4 percent per year, periods ending 1875-2008*



Source: Authors' calculations based on data reported by Beddow, Hurley and Pardey (2009), derived from Alston and Pardey (2006) and USDA, NASS (2008a).

Notes: Values are attributed to the end of each ten-year period. For example, the 1950-1970 category includes all ten year periods ending between 1950 and 1970 (thus starting between 1941 and 1960).

Table 1: *Average annual percentage changes in U.S. commodity prices, 1866-2008*

Period	Commodity			
	Maize	Wheat	Rice	Soybeans
Nominal Prices	*percent per year*			
1866-2008	1.25	0.84		
1924-2008	1.55	2.03	2.03	1.56
1950-2008	1.62	2.11	2.03	2.28
1950-1970	-0.67	-2.04	0.08	0.72
1975-2008	1.30	1.97	2.06	1.91
1975-1990	-0.72	-2.05	-1.47	1.03
1990-2008	2.98	5.32	5.01	2.65
2000-2008	9.29	12.22	13.35	8.66
Deflated Prices				
1924-2008	-1.70	-1.22	-1.22	-1.69
1950-2008	-2.27	-1.79	-1.87	-1.62
1950-1970	-2.67	-4.04	-1.92	-1.29
1975-2008	-2.90	-2.23	-2.14	-2.29
1975-1990	-5.89	-7.22	-6.64	-4.15
1990-2008	-0.41	1.93	1.62	-0.74
2000-2008	4.09	7.01	8.15	3.45

Source: Calculated by the authors based on data compiled from Olmstead and Rhode (2006), FAO (2008) and USDA (2008b).

Notes: Deflated prices were computed by deflating nominal commodity prices by an index of farm input prices.

Table 2: *Rates of growth of yield for selected U.S. crops, 1866-2008*

Period	Crop Yields			
	Maize	Wheat	Rice	Soybeans
	percent per year			
1866-2008 [a]	1.30	0.99	1.58	n/a
1900-2008[a]	1.57	1.21	1.60	1.52
1900-1950[a]	0.61	0.60	1.33	2.61
1950-2008	2.40	1.73	1.83	1.04
1950-1990	2.83	2.18	2.12	1.13
1990-2008	1.45	0.71	1.19	0.83

Source: Calculated by the authors based on data reported in Beddow, Hurley and Pardey (2009) derived from Alston and Pardey (2006) and USDA, FAS (2008).

a. Rice yields start in 1895, soybeans in 1924.

Table 3: *U.S agricultural productivity growth rates by period, 1911-2002*

Period	Productivity		
	Labor	Land	Multi-Factor
	percent per year		
1911-2002	3.00	1.64	1.56
1911-1950	2.32	1.32	1.16
1950-2002	3.50	1.87	1.86
1950-1990	4.08	1.96	2.12
1990-2002	1.59	1.58	1.01

Source: Alston, Anderson, James and Pardey (2010).

Table 4: *Global yield growth rates for selected crops, 1961-1990 vs. 1990-2007*

	Maize			Wheat			Rice			Soybeans		
Group	1961-90	1990-07	1961-07	1961-90	1990-07	1961-07	1961-90	1990-07	1961-07	1961-90	1990-07	1961-07
							percent per year					
World	2.20	1.77	2.04	2.95	0.52	2.05	2.19	0.96	1.74	1.79	1.08	1.53
excl. China	1.82	1.92	1.86	2.58	0.23	1.71	1.61	1.38	1.53	0.95	1.01	0.97
excl. USSR	2.27	1.83	2.11	2.97	0.73	2.14	2.19	0.96	1.74	1.75	1.09	1.51
Developing	2.67	2.07	2.45	3.73	1.49	2.90	2.33	0.99	1.84	3.21	2.08	2.79
excl. China	1.59	2.68	1.99	2.62	1.39	2.17	1.77	1.49	1.66	3.04	2.14	2.71
Developed	2.43	1.57	2.11	2.70	-0.25	1.61	0.80	0.79	0.79	1.16	0.00	0.73
Western Europe	3.30	1.81	2.75	3.31	0.63	2.32	0.38	0.55	0.44	1.64	0.05	1.05
Eastern Europe	1.91	0.97	1.57	3.18	-1.69	1.38	-0.41	1.07	0.14	1.90	2.29	2.04
North America	2.20	1.40	1.90	2.23	0.01	1.41	1.67	1.54	1.62	1.05	0.04	0.68

Source: Adapted from Alston, Beddow and Pardey (2009) using FAO (2008a) and USDA, FAS (2008).

Table 5: *Percentage of countries with slower yield growth since 1990*

Grouping	Maize	Wheat	Rice	Soybeans
		percent per year		
All Countries	56	78	56	65
Top 10 Producers	60	100	60	78
Top 25 Producers	60	88	48	71

Source: Authors' calculations based on FAO (2008a) and USDA, FAS (2008).

Note: 155 countries are included for maize, 114 for wheat, 108 for rice and 55 for soybeans. Only countries with area and production data for both periods are included.

Table 6: *Changing spatial location of global wheat production, 1961-63 and 2005-07*

1961-1963				2005-2007			
Rank	Country	Production *(MMT)*	Share *(percent)*	Rank	Country	Production *(MMT)*	Share *(percent)*
1	Russia	35.4	15.0	1	China	103.9	17.0
2	U.S.	31.5	13.4	2	India	71.0	11.6
3	China	16.5	7.0	3	U.S.	53.4	8.7
4	Canada	14.3	6.0	4	Russia	47.4	7.8
5	France	11.3	4.8	5	France	35.2	5.8
Top 5 Total		109.0	46.3	Top 5 Total		310.8	50.9
6	India	11.3	4.8	6	Canada	23.9	3.9
7	Ukraine	10.5	4.5	7	Germany	22.5	3.7
8	Kazakhstan	9.9	4.2	8	Pakistan	22.1	3.6
9	Italy	8.6	3.7	9	Turkey	19.7	3.2
10	Turkey	8.6	3.7	10	Australia	16.3	2.7
Top 10 Total		157.9	67.1	Top 10 Total		415.4	68.0
Top 20 Total		201.8	85.7	Top 20 Total		521.9	85.5

Source: Authors' calculations based on FAO (2008a) and USDA, FAS (2008).

Note: The country designations used in both periods pertain to 2008 geopolitical boundaries. For states that were previously part of a statistical or national aggregation, country-specific values were estimated using a decomposition procedure when reliable sub-national area and production data were unavailable. Sub-national data were obtained for Kazakhstan, Ukraine and Russia. Otherwise, data for a number of countries were estimated using the decomposition procedure, including those of the Socialist Federal Republic of Yugoslavia, the People's Democratic Republic of Ethiopia, Czechoslovakia, Serbia and Montenegro, the Belgium-Luxembourg aggregation and the Former Soviet Union.

Table 7: *Growth rates of agricultural land and labor use and productivity, by region, 1961-2005*

Group	Land Use 1961-'90	Land Use 1990-'05	Land Use 1961-'05	Labor Use 1961-'90	Labor Use 1990-'05	Labor Use 1961-'05	Land Productivity 1961-'90	Land Productivity 1990-'05	Land Productivity 1961-'05	Labor Productivity 1961-'90	Labor Productivity 1990-'05	Labor Productivity 1961-05	Output 1961-'90	Output 1990-'05	Output 1961-'05
							percent per year								
Latin America	0.70	0.39	0.60	0.72	-0.32	0.37	2.17	2.83	2.40	2.15	3.53	2.62	2.88	3.22	2.99
Asia	0.80	1.65	1.09	1.53	0.75	1.26	2.56	1.96	2.36	1.83	2.86	2.18	3.36	3.61	3.44
China	1.30	0.17	0.92	1.82	0.21	1.27	2.81	4.50	3.39	2.29	4.45	3.03	4.12	4.67	4.30
excl. China	0.47	2.55	1.18	1.24	1.28	1.25	2.45	0.24	1.70	1.69	1.50	1.62	2.93	2.78	2.88
Africa	0.20	0.39	0.26	1.70	1.69	1.70	2.18	2.21	2.19	0.68	0.90	0.76	2.38	2.59	2.45
Developing Countries	0.59	0.42	0.53	1.57	0.84	1.32	2.60	2.95	2.72	1.61	2.53	1.93	3.19	3.37	3.25
excl. China	0.44	0.48	0.45	1.40	1.27	1.36	2.42	2.27	2.37	1.46	1.47	1.47	2.86	2.74	2.82
Developed Countries	-0.06	-0.12	-0.08	-2.10	-2.70	-2.30	1.70	0.27	1.21	3.74	2.85	3.43	1.64	0.15	1.13
World	0.35	0.23	0.31	1.26	0.70	1.07	2.03	1.82	1.96	1.12	1.36	1.20	2.38	2.06	2.27
excl. China	0.23	0.24	0.24	0.92	1.01	0.95	1.90	1.19	1.66	1.21	0.42	0.94	2.13	1.43	1.90
excl. China & USSR	0.25	0.26	0.26	1.04	1.10	1.06	1.91	1.57	1.80	1.13	0.73	0.99	2.17	1.83	2.05
Top 20 Producers	0.40	0.13	0.31	1.34	0.52	1.06	2.11	2.16	2.13	1.17	1.77	1.37	2.51	2.29	2.44
excl. China	0.21	0.12	0.18	0.86	0.87	0.86	1.98	1.38	1.77	1.33	0.63	1.09	2.19	1.50	1.95
Other Producers	0.26	0.40	0.31	1.01	1.20	1.08	1.74	0.88	1.45	1.00	0.07	0.68	2.01	1.27	1.76

Source: Authors' calculations based on FAO (2008a) and USDA, FAS (2008).

Note: Labor is measured as economically active workers in agriculture. Land is the sum of area harvested and permanently pastured areas. Output is a value of production measure formed by weighting a time series of country specific commodity quantities (spanning 155 crop-related and 30 livestock-related commodities) by an unpublished 1999-2001 global average of commodity-specific international prices developed by FAO.