Agriculture in the Global Economy†

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Agriculture is diverse and full of contradictions. The sector accounts for a comparatively small share of the global economy, but remains central to the lives of a great many people. In 2012, of the world's 7.1 billion people, an estimated 1.3 billion (19 percent) were directly engaged in farming, but agriculture (including the relatively small hunting/fishing and forestry sectors) represented just 2.8 percent of overall income (World Bank 2012). However, in today's middle- and low-income countries, where most of the world's farmers are to be found, agriculture accounts for a much greater share of national income and employment—for instance, in India, agriculture represents 18 percent of national income and 54 percent of employment.[1]

Looking beyond direct employment, in 2010 about 2.6 billion people around the world depended on agriculture for their livelihoods, either as actively engaged workers or as dependents, while about half of the world's population lived in rural

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[1] Throughout this paper we group countries by geographic region or based on per capita Gross National Income in 2010 based on the World Bank's (2012) classification, which designated countries to be low-income if their average per capita income was $1,035 or less; lower-middle-income, $1,036–$4,085; upper-middle-income, $4,086–$12,615; and high-income, $12,616 or more.

areas and, of these, about three-quarters were estimated to be living in agriculturally based households (FAOSTAT 2013). Agriculture supplies much more than food for direct human consumption: it produces significant amounts of feed (for livestock), fuel (for transportation, energy production, including household kitchen fires), fiber (for clothing), and, increasingly, agricultural biomass used to produce a host of industrial chemical and material products.

Agricultural production takes up a lot of space—indeed, about 40 percent of the world's land area is occupied by agriculture—and the nature of the space varies in ways that are relevant for the choice of inputs, outputs, and technology, which is often very site-specific. Partly because of differences in climate and natural resource endowments around the world, farms and farming are enormously diverse—in terms of size of farms, products produced, technology used, inputs employed, farm incomes, and other economic outcomes.

Many of the world's poor still live in rural areas, although even that is changing, albeit slowly, as poverty becomes an increasingly urban phenomenon. According to Ravallion, Chen, and Sangraula (2007), in 2002 (the latest year of data they report), around three-quarters of the estimated 1.2 billion people with incomes of less than $1.08 per day (in 1993 purchasing power parity US dollars) resided in rural areas. Many are subsistence farmers, operating very small farms using very little in the way of marketable inputs other than the land they farm and their own family labor. At the same time, some farmers are relatively wealthy and earn relatively high incomes, especially in today's high-income countries where agriculture typically represents less than 2 percent of national income and employment. This diversity reflects country-specific differences in the broader economic context in which agriculture operates, as well as differences specific to agriculture, which is changing rapidly in some places.

Much of agricultural economics is concerned with understanding these patterns and how they change over time. In this article, we first look at how the high-income countries like the United States represent a declining share of global agricultural output while middle-income countries like China, India, Brazil, and Indonesia represent a rising share. We look at the differing patterns of agricultural inputs across countries and the divergent productivity paths taken by their agricultural sectors. We then look at productivity more closely and at the evidence that the global rate of agricultural productivity growth is declining—with potentially serious prospects for the price and availability of food for the poorest people in the world.

In thinking about future productivity growth in agriculture, we look at patterns of agricultural research and development efforts. While high-income countries spend a lot on agricultural research relative to the value of agricultural output, much of that spending is focused on issues other than raising agricultural productivity. Meanwhile, the middle-income countries have a rising share of global spending on agricultural research, which over time should reinforce their growing dominance in global agricultural production. Indeed, the future of global agriculture—including the question of how agriculture will feed the world's growing populations with their rising per capita incomes, and what that means for the world's poorest people—is

likely to be increasingly determined by developments in the agricultural sectors of middle-income economies like China, India, Brazil, and Indonesia.

The Shifting Locus of Global Agricultural Production

Over the past half-century or so, growth in agricultural output far outstripped the rise in population, with a relatively modest increase in land. In 1961, the world produced $746 billion worth of agricultural output (in 2004–2006 prices converted at purchasing power parity) on 4.5 billion hectares of land, using 768 million workers in agriculture, to feed 3 billion people. Over the subsequent half century the world's population grew by 1.69 percent per year, more than doubling from 1960 to reach 7.0 billion people in 2011. But agricultural output increased more than threefold in real terms—growing by 2.25 percent per year—to total $2.4 trillion in 2011. Farm prices in inflation-adjusted terms declined from 1960 to 2010, so this rise in the value of agricultural output represents an even larger increase in the quantity of output. Over this time, land in agriculture increased by a measurable but much more modest 0.22 percent per year to reach 4.9 billion hectares: 31.6 percent of which was in crops, the rest used for raising livestock.

Agricultural Outputs

Farming is enormously diverse around the world: in farming systems, technologies, farm sizes, the mixture of outputs produced, the types of inputs used to produce them, and input proportions. Some of these differences reflect differences in soils and climate or infrastructure that influence agricultural possibilities, while others reflect differences in the relative prices of inputs and outputs and other factors that determine comparative advantage, as well as government policies that dampen its relevance. Some places can grow bananas and pineapples, others can grow lettuce and strawberries, and some can at best graze cattle at less than one beast per square mile. As well as affecting what can be grown, and what it is economic to grow, location affects yield and quality of production, and susceptibility to pests and diseases.[2]

The growth in agricultural output has been very uneven, as shown by the changing shares of total global production in Table 1. Today's high-income countries produced 43.8 percent of total agricultural output in 1961, and although production by the high-income countries almost doubled by 2011, their share of the global total shrank to 24.6 percent. The region comprising Eastern Europe and the former Soviet Union produced 13.8 percent of global food output in 1961, but by 2011, it was producing only 6.5 percent of the global total. Conversely, the global

[2] The concern with "terroir" in wine production exemplifies the phenomenon. Within California, prices for wine grapes in 2010 ranged from an average of over $3,000 per ton in the Napa Valley (and in some instances more than $10,000 per ton) to an average of less than $300 per ton in some crush districts in the southern San Joaquin Valley, 250 miles south (Fuller and Alston 2012).

Table 1
Global Value of Production by Region, 1961 and 2011

Region	1961 Output (2005 PPP$ billion)	1961 Share (percent)	2011 Output (2005 PPP$ billion)	2011 Share (percent)
High income	327	43.8	591	24.6
Eastern Europe and former Soviet Union	103	13.8	155	6.5
Asia and Pacific	178	23.9	1,070	44.7
Latin America and Caribbean	69	9.2	307	12.8
Middle East and North Africa	28	3.7	125	5.2
Sub-Saharan Africa	42	5.6	149	6.2
World	**746**	**100**	**2,397**	**100**

Source: Authors' calculations based on FAOSTAT (2013).
Notes: Countries are grouped according to World Bank (2012) schema, which means that high-income countries are excluded from each geographical region. For example, that Asia and Pacific excludes Japan and Singapore, and Middle East and North Africa excludes Qatar and United Arab Emirates. PPP$ are purchasing power parity dollars.

share of agricultural production increased for all other regions. In particular, the Asia and Pacific region increased its share from 23.9 percent of global agricultural output in 1961 to 44.7 percent in 2011.

To a great extent, food is produced close to where it is consumed, so patterns of production broadly reflect population patterns, albeit with some exceptions for specific farm products that are shipped from other areas. For example, wheat, soybeans, and bananas are examples of commodities for which international trade is comparatively important, and rice is an example of a commodity for which international trade is comparatively thin. Like other staple food crops, much of the world's rice is produced and consumed within the same household. In addition, many farm outputs are physically heavy and perishable, and produced in places that are economically distant from markets.

Global agricultural production has been dominated for a long time by a short list of relatively large and populous countries, but the relative importance of these countries in aggregate and in production of particular farm commodities has been shifting—in particular reflecting a decline in the relative importance of the high-income countries. In 2009–2011, just ten countries accounted for 55.8 percent of the world's cropland, and five (India, the United States, the Russian Federation, China, and Brazil) had 42.1 percent of the total. In contrast, the 100 countries with the smallest shares made up only 0.78 percent of the world's cropland area. Production is even more spatially concentrated, with more than half the world's agricultural output coming from only five countries, and almost three-quarters of the total output produced by just 20 countries.

The Food and Agriculture Organization of the United Nations (FAO) offers country-level statistics on production of crops like maize (corn), wheat, rice, cassava,

pulses (a group of crops that includes beans and "grain legumes"), and soybeans, as well as for livestock including dairy, beef, pork, and poultry. Using these data, China is the first-ranked country for total agricultural output with 23.0 percent of all global agricultural output by value, which it produces using 8.0 percent of the world's cropland (and 11.7 percent of the world's agricultural area, including pasture and grazing land). China is also top-ranked in output for wheat, rice, pork, all crops, and all livestock; second-ranked for maize and poultry; and third-ranked for dairy and beef. China is among the top four producers of every commodity listed above except cassava.

The United States is second-ranked for total agricultural output at 10.1 percent of global output; first-ranked for maize, soybeans, beef, and poultry; and second-ranked for the other livestock products, dairy, and pork. India is third-ranked overall at 9.9 percent of global output: first-ranked for pulses and dairy, and second-ranked for wheat and rice. Brazil is fourth-ranked overall at 6.0 percent of global agricultural output by value; second-ranked for cassava, soybeans, and beef; and third-ranked for pulses and poultry. Indonesia is fifth-ranked at 2.5 percent of global agricultural output. Thus, four of the top five countries in global agricultural output, including the top one, are not high-income countries.

Agricultural Inputs

Patterns of input use vary systematically among countries according to their stage of development as measured by per capita income, as demonstrated in Table 2. In 1961, today's high-income countries accounted for 43.8 percent of total global agricultural output but only 23.8 percent of global population, 27.3 percent of global agricultural land use, and 8.4 percent of global agricultural labor. However, the high-income countries accounted for 78.1 percent of the world's use of fertilizer and 81.1 percent of the world's stock of tractors used in agriculture. By 2010, today's high-income countries accounted for just 25.5 percent of global agricultural output, and even further reduced shares of global population, global agricultural land use, and global agricultural labor. The high-income countries have increased their use of fertilizer by 73.2 percent, but even so, their share of the global total use has shrunk considerably; they almost doubled their stock of tractors, while their share of the respective global total also shrunk. High-income agriculture continues to make significantly greater use of modern land- and labor-saving inputs compared with agriculture in middle- and especially low-income countries.

Land-labor ratios differ enormously among countries. In 2010, the quantity of arable and permanent cropland ranged from an average of 10.9 hectares per capita of agricultural population (22.2 hectares per capita of agricultural labor) in the high-income countries down to an average of 0.24 hectares per capita of agricultural population (0.45 hectares per capita of agricultural labor) in the countries of the Asia and Pacific region. These disparities have been growing over time, as land-labor ratios have been rising in the high-income countries (as well as in Eastern Europe and the former Soviet Union), but falling elsewhere as low- and middle-income countries have intensified their use of farm labor.

Table 2
Use of Agricultural Inputs, 1961 and 2010

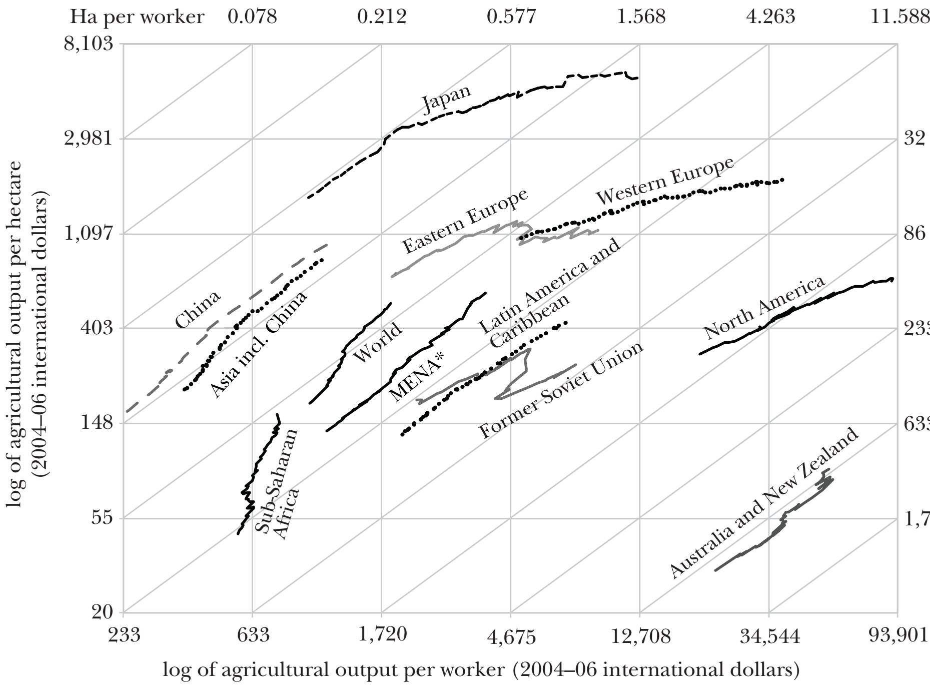
		Countries by income class				
Variable	*Unit*	*High*	*Upper middle*	*Lower middle*	*Low*	*World*
1961						
Agricultural labor	million	64.8	382.8	229.6	90.3	767.5
Agricultural land	million ha	1,107.4	1,657.3	816.0	469.9	4,050.5
Fertilizer	million ton	24.9	5.4	1.3	0.2	31.9
Tractors	million	9.2	2.0	0.1	0.1	11.3
Animal traction	million HP	16.1	61.8	63.7	11.1	152.7
Cropland per agricultural labor	ha per person	6.3	1.4	1.4	1.2	1.8
2010						
Agricultural labor	million	17.2	594.9	463.1	231.0	1,306.2
Agricultural land	million ha	1,094.1	2,009.7	973.3	562.0	4,639.2
Fertilizer	million ton	43.1	81.8	44.1	3.4	172.5
Tractors	million	16.6	7.0	3.7	0.2	27.5
Animal traction	million HP	15.0	66.1	126.1	25.1	232.3
Cropland per agricultural labor	ha per person	22.1	1.0	0.8	0.7	1.2

Source: Authors' calculations based on IFA (2013) and FAOSTAT (2013).
Notes: Countries grouped based on per capita income in 2010 according to World Bank classification (see footnote 1). Agricultural labor represents economically active population in agriculture; agricultural land is the sum of permanent pasture and harvested area; cropland is the sum of arable and permanently cropped land; fertilizer represents nitrogen, phosphate, and potash in tons of plant nutrients consumed; tractors is the number of agricultural tractors in use. According to FAOSTAT (2013) agricultural tractors "generally refers to total wheel, crawler, or track-laying type tractors and pedestrian tractors used in agriculture." Animal traction represents the stock of buffaloes, horses, asses, mules, and camels. We converted the stock of live animals to horsepower using conversion factors from Craig, Pardey, and Roseboom (1997). The abbreviation "ha" means "hectares."

Figure 1 uses the graphical technique developed by Hayami and Ruttan (1971) to track land and labor productivity movements globally and for various regions of the world. The horizontal axis is a measure of labor productivity and the vertical axis is a measure of land productivity, both plotted on a natural log scale for the period 1961–2011. Because the horizontal axis is output per worker and the vertical axis is output per hectare, it is possible to construct 45-degree lines representing constant land/labor ratios measured by hectares per worker. The lines on the graph plot a series of points from 1961 to 2011 for each region or country shown, moving generally from the lower left to the upper right over time as productivity improves.

These productivity paths exhibit clear patterns. All regions show growth in productivity over time, but at varying rates, with a longer path moving generally

Figure 1
Land and Labor Productivity by Region, 1961–2011



Source: Authors' calculations based on FAOSTAT (2013).
Notes: Diagonal lines represent constant hectare-per-agricultural worker ratios. The ratios corresponding to each diagonal line are labeled along the top and right sides of the graph in units of hectares (ha) per worker. Output is an estimate of the total value of agricultural production (spanning 192 crops and livestock commodities) expressed in 2004–06 average purchasing power parity agricultural prices from FAO (2012). Land is a measure of harvested and permanently pastured area, and labor is a head count of the total number of economically active workers in agriculture. Neither of these measures takes account of differences in land and labor quality among places and over time. Countries are grouped based on per capita income in 2010 according to World Bank classification (see footnote 1).
*Middle East and North Africa

north and east reflecting a faster rate of productivity growth over the period (see, for example, the section of the graph showing China, and Asia including China). But the starting points and the slopes of the paths vary. Over the entire period, the low- and middle-income countries as a group have much lower agricultural land-per-worker ratios than the high-income countries (that is, they are on higher diagonal hectare-per-worker lines). In 1961, both land and labor productivities in the high-income group of countries were substantially greater than the corresponding partial factor productivities in the low- and middle-income groups. Fifty years later, the disparities in measured land productivity (on the vertical axis) have become less pronounced, while the disparities in measured labor productivity (on the horizontal axis) have become more pronounced—the high-income

countries produce much more output per measured unit of agricultural labor than the rest of the world.

This combination of changes suggests that productivity paths are following two distinct patterns. In the higher-income regions like Japan, Europe, the former Soviet Union, and North America, the productivity paths are comparatively flat, which means that agriculture has become less labor-intensive. In today's high-income countries, with their comparatively high wages, a major consequence of technological change and responses to relative factor prices has been to reduce the total amount of labor employed in farming and the number of people living on farms, with commensurate increases in farm sizes (Kislev and Peterson 1981). However, in other regions and for the world as a whole, the productivity patterns are relatively steep, reflecting an intensification of the use of labor relative to land in agriculture in many places. The differences in labor intensity in Figure 1 do not reflect differences in labor quality associated with differences in skill, specialization, and formal education, nor do they reflect differences in land quality. If we could adjust for these dimensions, the international divergences would be smaller: the pattern would be compressed as we revealed in Alston and Pardey (1996, pp. 156–157) for example. Still, the essential story would remain much the same.

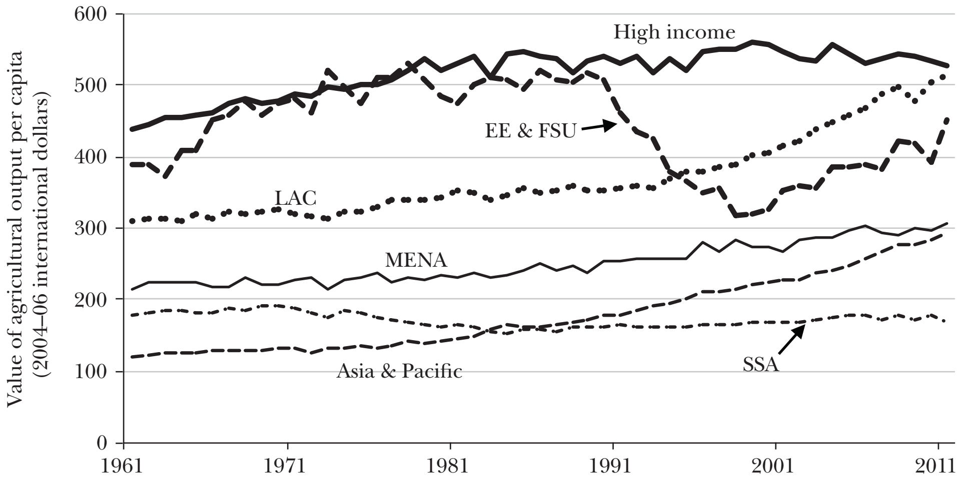
A Closer Look at Agricultural Productivity Growth

Throughout history, until relatively recently, ongoing growth in demand for food, driven both by growth in population and by generally rising per capita incomes, has been met mainly by expanding the resource base for agriculture, in particular, land. Olmstead and Rhode (2009) document the importance of biological innovation, which enabled land productivity to be sustained while land use was increasing. But during the past 100 years, and especially during the past 50 years, in most regions of the world agricultural production has been expanded mainly by increasing the output per unit of land against a relatively slowly growing land base. As noted earlier, over the period 1961 to 2011, global agricultural land use grew at a slow and shrinking rate of less than 0.22 percent per year, while population grew at about 1.7 percent per year and the real output from agriculture grew by about 2.3 percent per year.

These increases in land productivity have been accomplished by intensifying the use of "modern" inputs—in particular machinery, fertilizers, and irrigation—combined with improved genetic material and methods of production derived from organized scientific research, itself a relatively recent innovation (for a discussion in this journal, see Ruttan 2002). Along with increases in quantities of land, labor, irrigation, and fertilizer inputs, this growth reflected improvements in input quality, including new and better machines, new varieties of crops and livestock, and better-educated farmers, as well as institutional change and other changes in technology not embodied in inputs (Pardey, Alston, and Ruttan 2010; World Bank 2011).

While per capita agricultural output has grown generally, the growth has been uneven among regions and over time, as shown in Figure 2. In today's high-income

Figure 2
Per Capita Agricultural Production by Region, 1961–2011

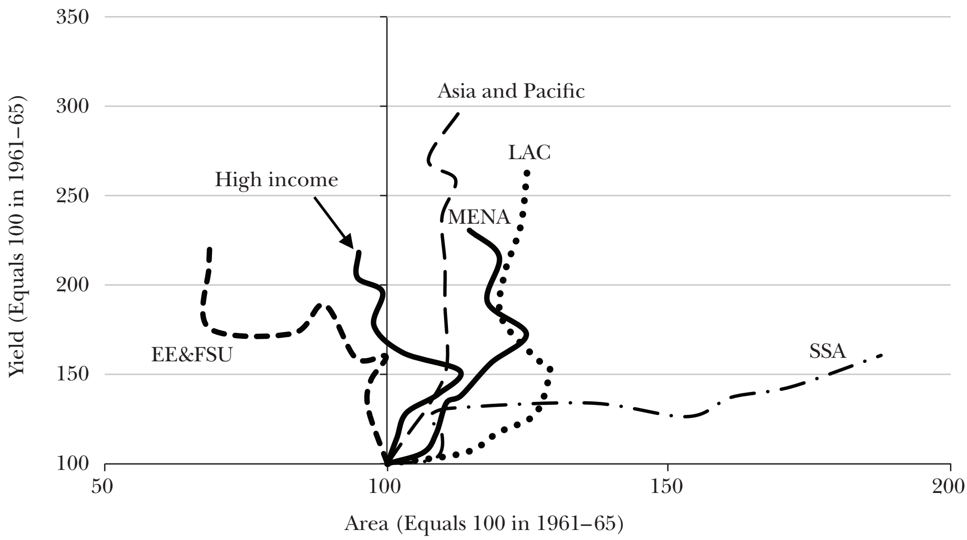


Source: Authors' calculations based on FAOSTAT (2013).
Notes: Countries are grouped according to World Bank classifications. "LAC" is Latin America and the Caribbean. "EE & FSU" is Eastern Europe the former Soviet Union. "MENA" is the Middle East and North Africa. "SSA" is sub-Saharan Africa.

group of countries, per capita agricultural output has been essentially flat since 1980. In the group of countries comprising the former Soviet Union and Eastern Europe, agricultural production collapsed following the dissolution of the Soviet Union in 1989 (Swinnen, Van Herck, and Vranken 2010) and has not yet fully recovered. However, in many of today's middle-income countries—including the regions Latin America and the Caribbean, Asia and Pacific, and Middle East and North Africa—production per capita has grown rapidly, even with reasonably rapid population growth. The picture is comparatively dismal for sub-Saharan Africa, with a decline in the real value of agricultural output per capita of 0.17 percent per year from 1961 to 2011; this decline reflects a reasonably rapid rate of growth in real output (2.6 percent per year), but it is outstripped by a more rapid growth in population (2.8 percent per year).

It is challenging to partition growth of agricultural productivity among different possible sources because the available data for many countries are very limited, especially for inputs and, within that aggregate, especially for capital inputs. Certainly the growth in output has reflected a combination of changes in the total quantity and mix of inputs as well as changes in productivity, and the importance of these different elements has varied tremendously over time as well as among countries at a point in time. For a vivid example, consider the time paths since 1961–65 of indexes of regional cereal yield as shown on the vertical axis in Figure 3 plotted against a corresponding index of land planted to cereals. During the period 1961–2010, growth in cereal production in sub-Saharan Africa was almost entirely attributable to growth in area, with very slow yield growth. In contrast, in the Asia and Pacific region and the Latin America and Caribbean region, both area and especially yield

Figure 3
Expansion in Yield versus Area of Cereal Production, 1961 to 2010



Source: Authors' calculations based on FAOSTAT (2013).
Notes: Figure 3 presents the time paths since 1961–65 of indexes of regional cereal yield as shown on the vertical axis plotted against a corresponding index of land planted to cereals. The plots represent five-year averages, starting with 1961–65, which is set to 100. The terminal value for each plot is the 2006–2010 average. Countries are grouped according to World Bank classifications. "EE&FSU" is Eastern Europe the former Soviet Union. "LAC" is Latin America and the Caribbean. "SSA" is sub-Saharan Africa. Cereals include the following commodities: barley, buckwheat, canary seed, fonio, maize, millet, mixed grain, oats, quinoa, rice, rye, sorghum, triticale, wheat, and other cereals.

grew very rapidly, while for Eastern Europe and the former Soviet Union and the high-income countries, yield increased somewhat but land area declined.

An Agricultural Productivity Slowdown

The measured growth rate of crop yields—that is, the total quantity of crop produced per unit of land area harvested per year—has been slowing generally:[3] worldwide aggregate cereal yields have been growing linearly, which implies diminishing proportional growth rates.[4] This slowdown in yields is widespread and pervasive, occurring across most geographical regions and across countries with

[3] Measurement issues abound in this context. For example, even something as apparently obvious as measuring the growth in crop yield requires care in defining the numerator (for example, harvested versus marketed grain, how to adjust for quality or types such as durum versus winter versus spring wheat), the denominator (for example, area sown versus area harvested, and how to accommodate crop failures), and the time unit of the analysis (annual versus seasonal, properly matching the numerator to the denominator, and allowing for the fact that in some cases more than one crop per year is grown on a particular piece of land).
[4] Production and area data were aggregated into geographical and income groupings prior to calculating yields. Cereals include the following: barley, buckwheat, canary seed, fonio, maize, millet, mixed grain, oats, rice, rye, sorghum, triticale, wheat, and other cereals.

high, medium, and low per capita income.[5] Our own calculations based on data from FAOSTAT (2013) find that global average maize yields grew at an average annual rate of 2.33 percent for the period 1961–1990, but then by 1.77 percent for the period 1990–2011; wheat yields grew 2.72 percent per year for 1960–1990, but 1.09 percent per year for 1990–2011; rice (paddy) yields grew 2.14 percent per year for 1961–1990, and 1.06 percent per year for 1990–2011; soybean yields grew by 1.72 percent per year for 1961–1990, but 1.21 percent per year for 1990–2011; and for cereals, yields grew by 2.35 percent per year for 1961–1990, but 1.48 percent per year for 1990–2011.

Measures of land and labor productivity growth exhibit mixed patterns among countries and over time. For the low-income countries, both of these partial productivity measures grew at rates that were consistently below the rates recorded for the middle-income group of countries, although in more recent years the average rates of growth in the low-income countries appear to have risen relative to the other groups of countries. Likewise, the growth rates of land and labor productivity appear to have risen for all other country groups relative to those for the high-income countries. Table 3 clarifies the structure of pre- and post-1990 growth rates. Taking China out of the world picture, both land and labor productivity growth rates were slower after 1990 than before. The same was true for the group of 154 countries that each had a small share of the global value of agricultural production, and which combined produced only 20 percent of the 2011 total value of output from the 183 countries excluding China. In both instances, the slowdown was more pronounced in labor productivity than land productivity.

No one disputes the evidence that growth rates of crop yields and land and labor productivity have slowed for the world as a whole excluding China. We see some evidence that also points to a slowdown in more comprehensive measures of multifactor productivity (MFP), which some call total factor productivity (TFP).[6] But the evidence on either measure of productivity is much less complete, the measures that do exist are much more open to question, and the issue is somewhat controversial.

[5] Various approaches might be used to compute average annual growth rates, as discussed by the World Bank (2013). The main alternatives are the "exponential growth rate," which is determined entirely by the starting and ending points and the "least-squares growth rate," which is obtained by regressing the natural logarithm of the measure of productivity against time. The slope coefficient from this regression is an estimate of the rate of productivity growth. Compared with the exponential growth rate, the least squares growth rate is less sensitive to starting and ending points of subperiods but more sensitive to other outliers in the sample. This method is also subject to bias from specification error, if the true path of productivity growth is not exponential, or from other failures of the linear regression model. All yield growth rates reported here were calculated using the least-squares method.

[6] Total factor productivity (TFP) is conceived as a measure of the aggregate quantum of *all* outputs divided by the aggregate quantum of *all* of the inputs used to produce those outputs. As we observe in Alston, Babcock, and Pardey (2010, p. 452): "TFP is a theoretical concept. All real-world measures omit at least some of the relevant outputs and some of the relevant inputs, and therefore it is more accurate to refer to the real-world measures as multifactor productivity (MFP) measures. Particular MFP measures differ in the extent to which they fall short of the counterpart ideal TFP measure because of methodological differences as well as differences in the consequences of incomplete coverage of the inputs and outputs."

Table 3
Land and Labor Productivity Growth before and after 1990

	Land productivity growth			Labor productivity growth		
Grouping	*1961–90*	*1990–2011*	*Difference*	*1961–90*	*1990–2011*	*Difference*
			(percent per year)			
World (184 countries)	2.04	2.22	0.18	0.93	1.71	0.79
China	2.89	4.00	1.11	2.03	4.13	2.10
World minus China						
Total (183 countries)	1.92	1.78	−0.14	1.09	0.92	−0.17
Top 29 countries	1.91	1.85	−0.06	1.15	1.26	0.12
Bottom 154 countries	1.89	1.65	−0.24	0.93	0.12	−0.81

Source: Authors' calculations based on FAOSTAT (2013).
Notes: The 29 countries that account for 80 percent of total agricultural production from the 183 countries, comprising the world excluding China, are represented in the second to the last row of the table. The last row represents the productivity of the remaining 154 out of 183 countries. All aggregates are formed as weighted averages. Difference is given as the rate for 1990–2011 minus the rate for 1961–90.

Using FAO data for 171 countries for 1961–2009, Fuglie (2012, p. 356) has undertaken an extensive analysis of agricultural productivity patterns and concludes: "[T]here does not seem to be a slowdown in sector-wide agricultural productivity growth. If anything, the growth rate in agricultural TFP [total factor productivity] accelerated in recent decades, in no small part because of rapid productivity gains achieved by developing countries, led by Brazil and China, and more recently because of a recovery of agricultural growth in the countries of the former Soviet Union and Eastern Europe." Other studies based on the same data resources have tended to find similar results (for a selection of such studies, see the chapters in Fuglie, Wang, and Ball 2012). These findings of accelerating growth in multifactor or total factor productivity are somewhat surprising given relatively constant or slowing growth in crop yields and broader partial productivity measures. We suspect that the underlying issue here lies in a host of data and measurement problems, many of which have long been discussed in the agricultural economics literature.[7] Fuglie (2012) is aware of these issues and spent considerable effort trying to address them; in particular, he notes some weaknesses of the proxy measures used to measure capital, material, or other inputs. Butzer, Mundlak, and Larson (2012) raise specific concerns about the measures of capital and their implications.

[7] Many of these data and measurement issues were identified initially by Schultz (1956) and Griliches (1963) and have been the subject of continuing efforts in the more recent literature. For instance, in Alston, Anderson, James, and Pardey (2010), we demonstrated the considerable sensitivity of their US multifactor productivity 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 multifactor productivity measures on an international scale with incomplete, inconsistent, and inaccurate measures of agricultural input quantities and prices.

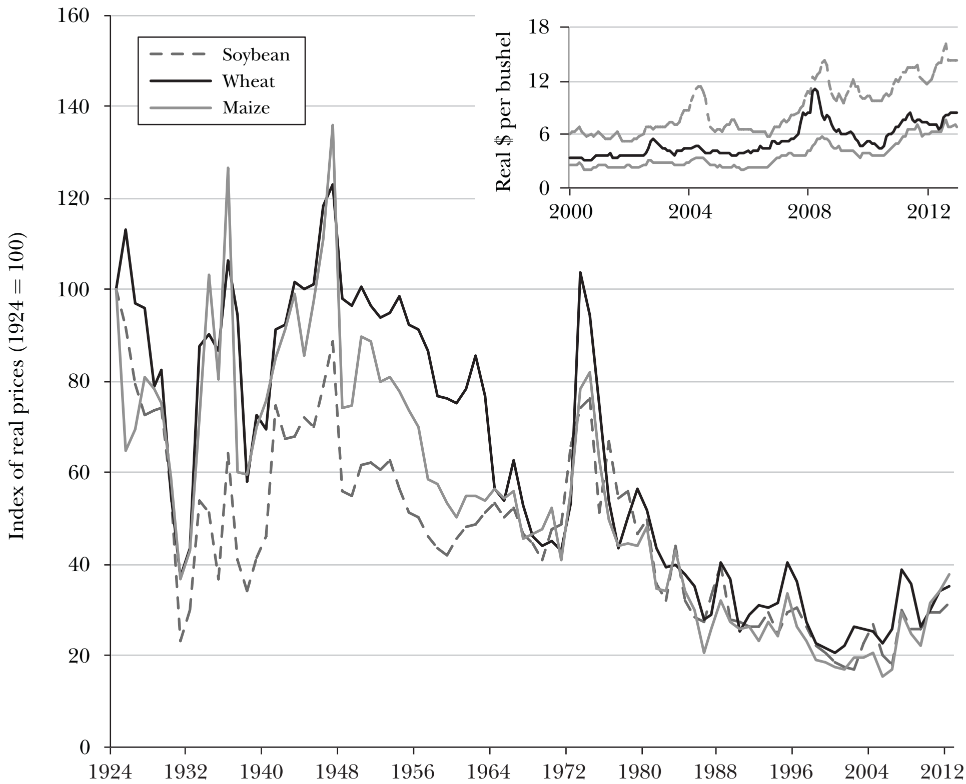
In Alston, Babcock, and Pardey (2010), we discuss the measurement issues more broadly and suggest that caution should be exercised in particular in using total factor productivity measures based on the FAO data to test for a slowdown in productivity growth because the nature of the likely index number biases is particularly damaging in that context. In some countries, much more complete and more detailed nationally sourced data permit the computation of measures of multifactor or total factor productivity that are less prone to index number biases and other measurement problems compared with studies based on FAO estimates of various agricultural inputs. For example, in Pardey, Alston, and Chan-Kang (2013), we estimated multifactor productivity growth for the US agricultural sector for 1949–2007 using the InSTePP data.[8] The results are quite different from Fuglie's.

Fuglie (2012) reported an acceleration of US agricultural productivity growth from 1.21 percent per year in the 1960s to 2.25 percent per year in 2001–2009. In contrast, in Pardey, Alston, and Chan-Kang (2012), we identified a pronounced slowdown in US agricultural productivity growth, a pattern that is consistent with the observed slowdown in US crop yield growth and other measures of US partial factor productivity growth. Likewise, using a completely different set of measures of aggregate US total factor productivity, Ball, Schimmelpfenning, and Wang (2013) also report evidence of a slowdown in agricultural productivity growth, albeit with different timing. In earlier work using US state-level InSTePP data 1949–2002, in Alston, Andersen, James, and Pardey (2010), we conducted a variety of statistical tests that comprehensively suggest that agricultural multifactor productivity growth slowed substantially after 1990, returning to a longer-term trend rate in the range of 1 percent per annum.

What should we believe about the pattern of agricultural productivity? We conclude that agricultural productivity growth generally has slowed in much of the world, both because it is the story told by crop yields and other partial productivity measures and because it is the story told by the limited set of more reliable estimates of multifactor productivity based on the detailed national-level data. Index number biases from using incomplete and ill-measured input quantities (especially for capital and materials inputs), failure to adjust for input quality improvements (especially for labor and capital), or the use of inappropriate input shares might account for the discrepancies. Thus, we have reservations about the use of measures of total factor productivity estimated using the FAO data, particularly in relation to the question of a slowdown in productivity growth over time. But the timing, extent, and likely persistence of the slowdown in agricultural productivity growth around the world are lively research topics, with crucial implications for how the food supply can expand to meet the growth in worldwide demand stemming from future increases in population and per capita income.

[8] These represent an updated version of the data we used in Alston, Andersen, James, and Pardey (2010). Details on data sources and methods used to compute the indices can be found at http://faculty.apec.umn.edu/ppardey/data-agprod.html.

Figure 4
Real US Prices of Maize, Soybeans, and Wheat, 1924–2012



Source: Beddow and Pardey (2013) and US Department of Agriculture, National Agricultural Statistics Service (2013).
Notes: The main figure plots annual average US prices received by farmers deflated by the US implicit price deflator for GDP for the period 1924 to 2012, indexed to 1924 = 100. The inset plots are real monthly prices for the period 2000–2012, expressed in 2012 values.

Prices, Productivity, Policy

The past patterns of growth in productivity and production have had important implications for food security and for poverty especially through their consequences for prices (Alston, Beddow, and Pardey 2009). During the 20th century, growth in agricultural supply more than kept pace with growth in agricultural demand—which was fueled by growth in population, income per capita, and more recently as a feedstock for biofuels—to the extent that farm commodity prices trended down significantly relative to prices generally in the economy, as illustrated for maize, soybeans, and wheat in Figure 4. But this trend has been slowing (as can be seen in Figure 4) if we set aside the period around the price spike of the early 1970s. In fact, prices have trended up since around 2000, a trend that was exacerbated by the commodity price spikes of 2007 and since, that were associated with a confluence

of influences, including the rise of biofuels—encouraged by ethanol blending mandates and subsidies in the United States and elsewhere, in conjunction with high oil prices (for example, de Gorter and Just 2009; Lapan and Moschini 2012; Wright, this issue). However, the recent price rise is more properly seen as simply the last step in a progressive slowing of the rate of decline of real commodity prices over the 40 years since 1970, which is consistent with the evidence of a slowdown in growth of primal measures of agricultural productivity. Long-term trends in real prices for farm commodities are indicative of the evolving path of worldwide agricultural productivity, since the ratio of an index of input prices to an index of output prices is itself a dual measure of total factor productivity—though less useful for that purpose in short-run comparisons when relative price movements might not reflect long-run equilibrium relationships (Jorgenson and Griliches 1967).

The rise in agricultural prices in recent years reminded policymakers that agriculture plays several roles relative to food security and poverty in high- and low-income countries alike. Among the world's very poor, subsistence farmers are especially vulnerable to the effects of weather and other supply shocks that affect both their individual production and the prices they face. However, increasingly the world's poor are not farmers; nevertheless, their real incomes depend directly on the availability and price of food. Changes in agricultural technology that increase productivity or reduce susceptibility of production to weather and other shocks can contribute to the welfare of the farm and nonfarm poor by increasing abundance and lowering the real cost of food—in effect, by shifting the consumption-based poverty line—as well as by increasing net farm incomes and by reducing the variability of prices, production, and income (Alston, Martin, and Pardey forthcoming). These are all elements of the food security question that is an increasingly important part of the agricultural policy agenda. Agricultural innovation, driven increasingly by organized agricultural science, has played a large and growing role in driving agricultural development and the balance of the world food equation—as acknowledged, for example, when Norman Borlaug was awarded the Nobel Peace Prize in 1970 for his role in developing "Green Revolution" technologies.

Agricultural Innovation

The domestication of crops initially involved saving seed from one season for planting in subsequent years. Agricultural innovation began when farmers purposefully selected seeds from successful crop varieties and, by repeated selection over many years, began adapting crop genetics to the environment in which the crop was grown. Scientifically bred varieties of crops and livestock have a history of less than 200 years. Collective, more organized, and increasingly scientific forms of agricultural innovation by way of publicly funded research and development undertaken in universities and, eventually, government research agencies took hold in the early 19th century, initially in Germany, then spreading to North and South America and Australasia and, eventually, to today's developing world (for example, Ruttan 1982; Grantham 1984). Along with genetic innovations in crops, this growing body

of scientific knowledge fostered innovations in pest and disease management, animal husbandry, and the like, which accompanied "labor-saving" innovations that augmented and replaced human labor with wind- and watermills, and livestock draft power, eventually to be replaced with tractors and other machines. While technical changes arising from investments in agricultural productivity are not synonymous with changes in multifactor productivity, available empirical evidence strongly supports the notion that an accumulation of past and present research spending plays a big part in stimulating present and future productivity growth in agriculture.

Role of Public and Private Agricultural Research

Some distinctive features of agriculture have shaped the division of labor between the private and public sectors in agricultural science in ways that differ from industrial science more generally. First, agriculture continues to be an atomistic sector, such that individual farm firms have had attenuated incentives to invest in many types of innovations, leaving a larger potential role for government than in industrial research generally. Second, the demands for farming technologies reflect the biological nature of production and the site-specific nature of the production environment. Hence, as well as demanding innovations that save costs or enhance product quality generally, farmers demand innovations that reduce the susceptibility of production to uncontrolled factors. In addition, they have to deal with biological obsolescence: continuing innovation is necessary simply to maintain yields as the climate changes and pests, diseases, weeds, and other aspects of the environment co-evolve.

Reflecting this context, the role of publicly funded and performed agricultural and food research rose in tandem with the growth in private research, especially among the high-income countries during the latter half of the twentieth century. Several broad institutional and market changes contributed to this evolution, reflecting the peculiar features of agriculture and its role in the economy. One contributing factor was general scientific developments, which led to particular innovations such as the development and commercialization of hybrid seeds, beginning with corn in the United States in the 1920s—but now hybrid seeds are common in other crops like canola, rice, and numerous vegetable crops such as cabbage, broccoli, and watermelon. A second critical influence was an expansion in the scope of intellectual property protection to encompass plant and animal innovations. In particular, this reform spurred the rapid expansion of private investment to develop private varieties of crops, including the genetically modified varieties of soybeans, maize, cotton, canola, and other crops that have been widely adopted in the largest agricultural countries since the mid-1990s. A third major influence was the increase in the share of food and beverages being consumed away from the home or prepared and packaged in more convenient forms, which induced innovative activity to service these changing consumer demands. For example, between 1940 and 2011, food consumed away from home rose from 19.7 percent to 48.7 percent of total US food expenditures (USDA, ERS 2012). The various changes in science, institutions (including intellectual property and regulatory realities, as well as changes in the law), and markets have tended to increase the private appropriability of the

benefits arising from agricultural research, thus spurring increased attention from the private sector—especially into mechanical and chemical technologies, and more recently, new varieties for some crops, where intellectual property protection and market incentives are strong—primarily in the higher-income countries.

For the world as a whole, governments continue to outspend the private sector in agricultural research. In 2009, a total of about $35 billion (in 2005 dollars converted at purchasing power parity exchange rates) was spent on public sector agricultural and food research worldwide (Pardey, Chan-Kang, and Dehmer forthcoming). While our empirical handle on private investments in food and agricultural research is far from certain, the available evidence indicates that spending by the private sector on food and agricultural research is in the range of $20–22 billion per year. The lion's share of that research, around 90 percent, took place in the high-income countries and, for the high-income countries at least, almost one-half of that research was concerned with producing off-farm innovations, primarily those related to food processing.[9] In 2009, the United States accounted for around one-third of overall public and private spending by high-income countries on food and agricultural research.

Knowledge and Technology Spillovers

The potential for spillovers of agricultural technologies is mitigated by differences in climate and other aspects of the natural resource stocks that govern agricultural potential. Even so, spatial movement of agricultural technologies has played an important role in the development of agriculture. Before the modern scientific age, great advances in American agricultural productivity resulted from plant prospectors who imported new and improved crop varieties from foreign lands. As early as the mid-1850s, the US government employed "agricultural explorers" to scout the globe for new plant and seed material for shipping back to the United States (Ryerson 1933, p. 117). US Navy expeditions and Consular staff were also regularly used to collect new plant material from countries around the world and ship that material back to the United States (Juma 1989; Olmstead and Rhode 2007). These efforts were particularly fruitful in introducing varieties of wheat and other crops suitable for the relatively arid and harsh conditions on the Great Plains. Countries around the world made similar efforts.

Positive economic spillovers across national borders from research are still of substantial importance to global and US agriculture. For example, foreign entities accounted for 64 percent of all the plant varietal rights in the United States in 2008, compared with just 21 percent in 1984 (Pardey, Koo, Drew, Horwich, and Nottenburg 2013). By the early 1990s, about one-fifth of the total US wheat acreage was sown to varieties with ancestry developed by the International Maize and Wheat

[9] For a discussion of the range of estimates, see Pardey, Alston, and Chan-Kang (2012), where we discuss estimates from Pardey and Beintema (2001); Beintema and Stads (2008); Fuglie et al. (2011); and Beintema, Stads, Fuglie, and Heisey (2012). Pardey and Chan-Kang (forthcoming) report a public and private spending total of $37.3 million (in 2009 prices converted at purchasing power parity) for the high-income countries in 2009, 52 percent of which was performed by the private sector.

Improvement Center (CIMMYT), located in Mexico, and in 1993 virtually all the California spring wheat crop was grown with varieties from CIMMYT or with CIMMYT-based ancestors (Pardey, Alston, Christian, and Fan 1996). The US reliance on wheat varieties from CIMMYT and elsewhere in the world has persisted (Pardey and Beddow 2013, Box 3).

Agricultural research spillovers go well beyond wheat varieties and national borders. In a comprehensive study of the state-by-state returns to *all* the state-specific investments in agricultural research performed in the United States (Alston, Andersen, James, and Pardey 2009), we estimated that, on average, one-third of the economic benefits from research-induced productivity gains in agriculture in each state were attributable to spill-ins from research done in other states or by the federal government. In Alston, Anderson, James, and Pardey (2011), we report that on average across the states, an incremental dollar invested in research carried out by a state agricultural experiment station in the United States returned benefits to that state over 50 years with a real present value of $21, and a value of $32 to the nation as a whole if spillover benefits to other states were added to the own-state benefits.

Formal international collaboration in the development and diffusion of agricultural innovations, designed to enhance the international spillovers of technologies and techniques, crystalized in the first half of the twentieth century. There has been a recent revival in international agricultural research, including research undertaken by the international research centers collectively known as the Consultative Group on International Agriculture (CGIAR). The CGIAR was founded in 1971 as a collective funding instrument to support agricultural research with an explicit international intent. The system spent $20 million (nominal prices) in 1971, growing to $643 million in 2010 (for details, see Pardey and Beddow 2013; Ozgediz 2012; Wright 2012). However, the donor pressures on that system appear to be placing increased emphasis on shorter-term, more development-oriented efforts at the expense of research with longer-run payoffs and larger spillover potentials.

The potential for spillover benefits from an increase in private participation in agricultural research is also uncertain. On the one hand, the business model of multinational companies would support the increased international movement of innovations in the food and agricultural sectors. On the other hand, the cross-country flows of agricultural technologies will be limited by regulatory restrictions, lack of effective legal processes and intellectual property protection, and, especially in many of the world's poorer countries whose economies are still heavily reliant on agriculture, a preponderance of comparatively small, fragmented, and costly-to-service farms.

An Agricultural Research Spending Slowdown

In the high-income countries, in spite of compelling evidence of high rates of return and a significant productivity slowdown, public support for agricultural science has broadly waned.[10] In 1960, $5.4 billion was spent on public food and

[10] Reviewing the rates-of-return to agricultural research literature over the past 50 years, Rao, Hurley, and Pardey (2012) compiled 2,186 evaluations from 359 separate published studies and report an average

agricultural research, and today's high-income countries accounted for 56 percent of the world's total. Almost 50 years later, in 2009, that high-income country share had dropped to 48 percent, with the US share dropping from 21 percent to just 13 percent of global public spending on food and agricultural research over the same period (Pardey, Alston, and Chan-Kang 2013). Real rates of annual public research spending have begun to decline in many countries, including the United States (Pardey, Alston, and Chan-Kang 2013).

Moreover, of the amounts being spent on "agricultural science" in high-income countries, an ever-increasing share is being directed towards off-farm issues—such as health and nutrition, food safety, biofuels technology, and the environment—leaving less for research directed at maintaining or increasing farm productivity. In the United States, around 65 percent of the public research conducted by the land grant universities in 1976 was classified as farm productivity research, dropping to just 56 percent by 2009 (Pardey, Alston, and Chan-Kang 2013). Public sector research capacity in the agricultural sciences in many (especially high-income) countries has been run down over decades, infrastructure has depreciated, and the majority of the scientists focused on this research in many countries are close to retirement age.

On the salutary side, agricultural research is on the rise in large, populous middle-income countries: Brazil, India, and China together now provide 31.1 percent of the world's public agricultural research. These countries have among the largest total numbers of farmers and the "food-poor," whose lives can be very substantially improved through agricultural innovation leading to more abundant and cheaper food. By 2007–09, China was spending more than any other country on public sector agricultural research and development, with a budget of $5.8 billion per year in 2007–2009, greater than that of the United States at $4.5 billion per year. But we also see continuation of a growing global divide, with the world's poorest countries falling even farther behind. Notably, the nations of sub-Saharan Africa spent just 6 percent of the world's total public sector agricultural research in 2009, down from a 10 percent share in 1960.

Over the past 50 years, high-income countries progressed steadily towards an ever more research-intensive mode of agricultural production. Compared with just 56 cents for every $100 of agricultural output in 1960, these countries invested an average of $3.59 into public agricultural research per $100 of agricultural output in 2009. Agricultural research intensity has increased in spite of a slowdown in the rate of growth of this spending—reflecting an even more pronounced slowdown in the rate of growth of agricultural output in these countries. As productivity increases, an increasing share of research is required to sustain past productivity gains given the co-evolutionary pressures of pests and diseases that act to undercut the efficacy of

internal rate of return of 49.4 percent per year (after eliminating extreme outliers and a median of 40.7 percent per year). In Alston, Andersen, James, and Pardey (2011), we raised concerns over using internal rates of return as a summary measure of the benefits associated with a given research cost, arguing instead for a benefit–cost ratio or a "modified internal rate of return." Rao, Hurley, and Pardey (2012) report, for the studies they evaluated, an average modified internal rate of return of 11–14 percent, depending on the assumptions used when recalibrating the reported internal rates of return.

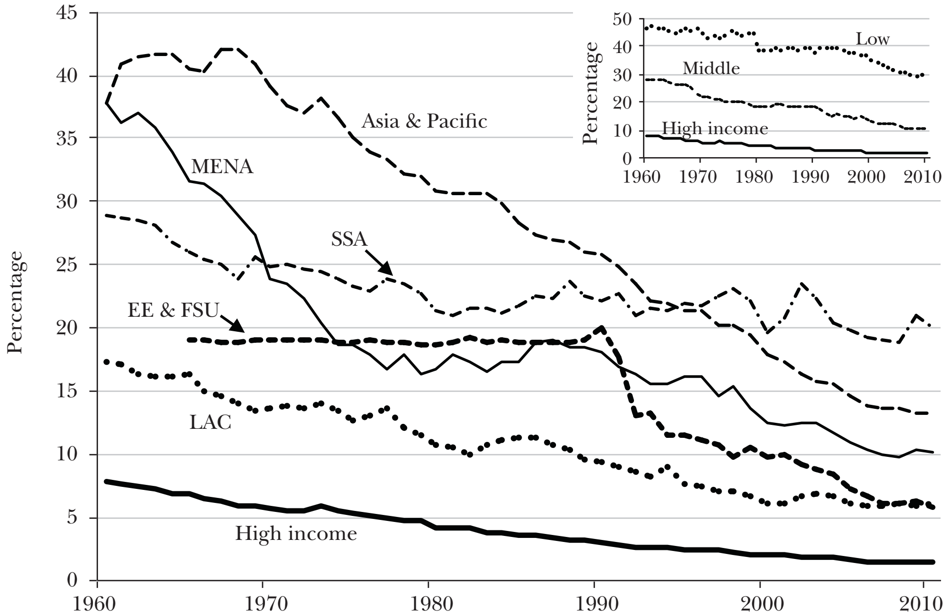
chemical, management, and biological pest-control technologies (Ruttan 1982). In contrast, the intensity with which the Asia and Pacific region invests in agricultural research has grown much more modestly from 40 cents for every $100 of agricultural output in 1960 to 54 cents in 2009. While this region has sustained growth in agricultural research spending at a comparatively rapid pace, averaging a growth rate of 5.1 percent per year since 1960, agricultural output has grown at a reasonably rapid rate of 3.8 percent per year. Thus, while the growth in spending on agricultural research and development outpaced the corresponding growth in the value of output in this region, the growth rate differentials were comparatively modest such that the region's research intensity only inched up over time, albeit increasingly so after the mid-1990s. In sub-Saharan Africa, research intensities have been slipping, especially in the past couple of decades. The same pattern is evident in the low-income countries more generally.

The Transition of Agriculture as Economies Grow

As per capita income rises in a country, the agricultural share of GDP typically falls (Timmer 2009). For example, in 2010, agriculture (again including forestry and hunting/fishing) contributed 29.3 percent of total GDP on average in countries with per capita incomes less than $1,005 (the World Bank 2010 threshold designating low-income countries); while for middle-income and high-income countries, the shares were 10.5 and 1.5 percent respectively. As Figure 5 shows, the agricultural shares of GDP have declined in every region of the world, but unevenly. In the high-income countries of the world, agriculture contributed a relatively small share of total GDP a half-century ago, and this share has dropped even further since then. Over the same time period, in the Asia and Pacific region, the agricultural share began much higher, but declined relatively rapidly, with the region's very rapid rates of economic growth. On the other hand, in sub-Saharan Africa, agriculture's share of GDP was much lower than in the Asia and Pacific region in 1960, but with its relatively slow rate of agricultural and general economic growth, agriculture's share of GDP in sub-Saharan Africa has fallen relatively slowly such that the share of GDP from agriculture is now larger than in any other region.

The cross-sectional evidence using 2005–2010 average data tells a similar story to the time-series evidence. Figure 6 plots country-specific measures of the share of labor in agriculture against GDP per capita (Figure 6A), and the share of GDP from agriculture against GDP per capita (Figure 6B). The individual bubbles represent country-specific average observations for 2005–2010. For a selection of countries, we have also plotted the time path of the share of labor in agriculture versus GDP per capita (in Figure 6A) and the share of GDP in agriculture versus GDP per capita (Figure 6B). The relationship is clearly negative in general—a larger share of total income from agriculture and of total labor engaged in agriculture is associated with a lower per capita income—though not always smooth and monotonic in the time-series plots for particular countries.

Figure 5
Agricultural GDP as Share of GDP (by Region), 1960-2010



Source: Authors' calculations based on World Bank (2012) and Pardey, Chan-Kang, and Dehmer (forthcoming).
Notes: Countries are grouped according to World Bank classifications. High-income countries are excluded from each geographical region. For example, Asia & Pacific excludes Japan and Singapore; MENA (Middle East & North Africa) excludes Qatar and United Arab Emirates. High-income countries are those with 2010 GNI per capita of $12,276 or more; middle-income countries had 2010 GNI per capita between $1,006 and $12,275; and low-income countries had 2010 GNI per capita less than or equal to $1,005 (World Bank 2011, p. 389).

Around the world today can be found countries at every stage of the transition that is now largely complete in the high-income countries. In the United States, for example, the total farm population peaked at 32.5 million people, or 31.9 percent of the total US population, in 1916. Since then the US population has continued to grow while the farm population declined to 2.9 million in 2006, just 1 percent of the total population of roughly 310 million. Among today's upper-middle-income countries, China has been transforming its agricultural sector and releasing considerable labor for other employment, but nonetheless the rural and urban labor markets have not fully adjusted. Among today's lower-middle-income countries, in India 48.4 percent of the population is still agricultural and 68.7 percent earn less than $2 per day. Many low-income countries are like Mali, where over 70 percent of the population live on farms and about 80 percent earn less than $2 per day, and have not really begun the process.

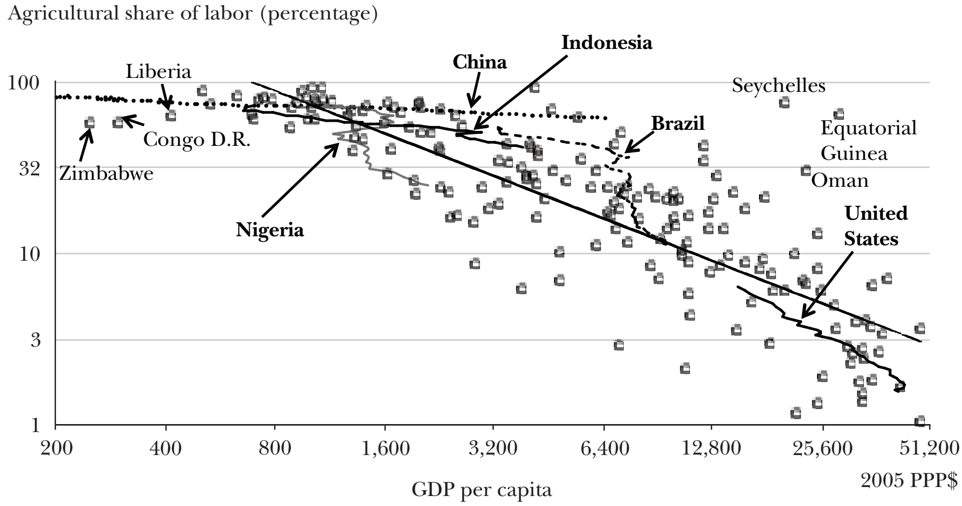
Timmer (2009) observed that the decline in the agricultural share of labor generally lagged the decline in the agricultural share of GDP, reflecting some "stickiness" of adjustments in farm labor. Fifty to 100 years ago, the same phenomenon gave rise

Figure 6

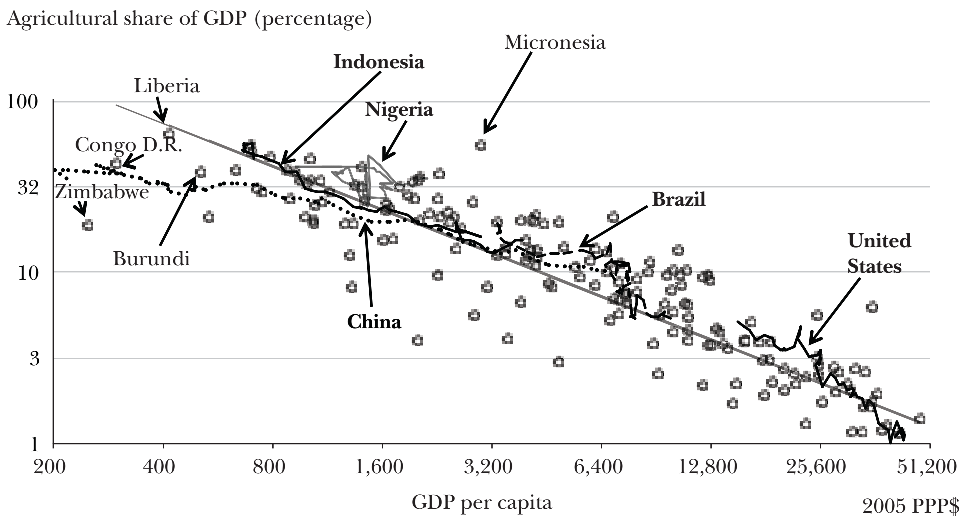
Share of Labor and GDP in Agriculture versus GDP per Capita

(logarithmic scale)

A: Share of Agricultural Labor in Total Labor



B: Share of Agricultural GDP in GDP



Source: Authors' calculations based on World Bank (2012) and FAOSTAT (2013).
Notes: The downward sloping straight line represents an OLS linear best fit. Other line plots represent the time path of annual values of the respective labor and output shares plotted against GDP per capita (both on a logarithmic scale) for the period 1961–2011 for Brazil, China, Indonesia, Nigeria, and the United States.

to the "farm problem" in the United States and other countries, a persistent problem of excess farm labor and low farm incomes that characterized agriculture in transition (for example, Gardner 1983, 2002). The coming decades may see monumental changes in structure of the farm sector in the countries that have barely begun the process of transition. But the evidence from the past suggests that this transition may not be smooth and may involve very substantial costs of adjustment (Timmer 2009).

Although it seems clear that economic growth entails a reduction in the relative importance of agriculture in an economy, the causal mechanisms in the process by which this transformation takes place are not fully clear. This transition away from agriculture seems to involve both relatively rapid growth of the nonfarm sector, and a substantial reduction in the labor intensity of farming. Much has been written about the role of innovation and economic growth in agriculture, in the first instance, as a means of priming the pump for broader economic growth by generating an economic surplus, releasing resources to and demanding inputs from the rest of the economy (for example, World Bank 2007). The hard empirical challenge is to sort out the relative roles of push from agriculture versus pull from growth in the rest of the economy, as contributors to a drift from farm work to part-time farming or nonfarm employment, in a world in which both push and pull processes are at work, synergistically, occurring in conjunction with changes in educational status, per capita incomes, and other changes, as elaborated in Timmer (2009). Sorting out these issues is a classic and still largely unresolved question at the intersection of agricultural economics and growth theory. But there can be no doubt that agricultural innovation plays a crucial role, whether in priming the pump for economic progress or as an induced innovation response to facilitate adjustment when the rest of the economy is bidding resources away from agriculture.

A Changing World Order

The past 50–100 years have witnessed dramatic changes in agricultural production and productivity, driven to a great extent by public and private investments in agricultural research, with profound implications especially for the world's poor. A trend of slowing growth, or real reductions in spending by the high-income countries on agricultural productivity enhancing research, has contributed to a slowdown in their agricultural productivity growth. But over time and among countries, the developments in agricultural production and productivity have been uneven, resulting in seismic shifts in the world table of agricultural production over the past few decades and prospects for continuing shifts over the decades to come.

A half-century ago, today's high-income countries dominated agricultural production and public agricultural research. In the 50 years since then, these countries have shrunk in relative global importance both as agricultural producers and in terms of agricultural research. In counterpoint, the middle-income countries—especially China and Brazil—have grown in importance both as agricultural producers and as performers of agricultural research. These countries have significantly reduced the relative role of agriculture in their own economies while rising to a position of dominance within the

global agricultural economy—mirroring the status of today's high-income countries a half century ago. Meanwhile, many of the world's poorest countries continue to lag behind in agricultural production and productivity, in agricultural research, and in making the overall economic transition away from agriculture.

These uneven developments, and the associated systemic seismic shifts in agricultural production, productivity, and spending patterns for agricultural research mean that the world, especially the world's poor, will increasingly depend on the middle-income countries for agricultural innovations and abundance. The shifted shares of the world's agricultural science will have implications over decades to come for the balance of research undertaken, global patterns of productivity and prices, competitiveness and comparative advantage, the mix and quality of food and other agricultural products produced, and the livelihoods of farmers and their families. Even if we see a reversal of research investment trends in the high-income countries, both toward higher levels of agricultural research spending and toward a renewed focus on sustaining and increasing crop yields and other dimensions of agricultural productivity—which does not seem very likely—today's middle-income countries like China, India, and Brazil will increasingly determine the future path of poverty and hunger in the world and the vulnerability of the poor to food price shocks of the kind experienced in 2008 and 2012. These countries are now poised potentially to play a role in the coming 50 years that was played by today's high-income countries in the past 50 years.

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