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Agricultural Production, Productivity and R&D over the Past Half Century: An Emerging New World Order

by

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ABSTRACT

Recent trends in farm productivity and food prices raise concerns about whether the era of global agricultural abundance is over. Agricultural R&D is a crucial determinant of agricultural productivity and production, and therefore food prices and poverty. In this paper we review past and present agricultural production and productivity trends and present entirely new evidence on investments in public agricultural R&D worldwide as an indicator of the prospects for agricultural productivity growth over the coming decades. The agricultural R&D world is changing, and in ways that will definitely affect future global patterns of poverty, hunger and other outcomes. The global picture is mixed. In the world as a whole crop yield growth has slowed. In high-income countries productivity growth has slowed significantly, and real spending on agricultural R&D is being reduced. In China, and other middle-income countries, spending on agricultural R&D is being ramped up and productivity growth has not slowed. The overall picture is one in which the middle-income countries are growing in relative importance as producers of agricultural innovations through investments in R&D and have consequently better prospects as producers of agricultural products.

Global Agricultural Production, Productivity and R&D over the Past Half Century:
An Emerging New World Order

The 1960s saw a chorus of concerns over the imminent prospects of global food

shortages and mass starvation. In *The Population Bomb* (1968, p. xi) 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…" William and

Paul Paddock's 1967 *Famine 1975! America's Decision: Who Will Survive?* had a similar

message and advocated a triage approach to foreign aid. 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. The Club of Rome's 1972 volume *The Limits to Growth*

(Meadows et al. 1972, p. 23) declared that "If the present growth trends in world population,

industrialization, pollution, food production and resource depletion continue unchanged, the

limits to growth on this planet will be reached sometime within the next one hundred years."[1]

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 to aid, that recognized that countries like India had exceeded their "carrying" capacity.

Some of the widely cited thinkers of the day saw a Malthusian nightmare as all but

inevitable, only to be proven wrong by the subsequent dramatic increases in agricultural

productivity. During the half century since 1960, the growth in food supply surpassed

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[1] Meadows et al. (1972, p. 145) also noted "We have shown that in the world model the application of technology to apparent problems had no impact on the *essential* problem, which is exponential growth in finite and complex systems…even the most optimistic estimates of the benefits of technology did not prevent the ultimate decline of population and industry... (emphasis in original)." Beckerman (1972) provided a vigorous critique of this report. He observed that "There are certainly terrible problems, such as those relating to violence, crime, drugs, race, poverty, disease, prejudice, and, in many parts of the world, population. But many of them are age-old problems and, if anything, economic growth has alleviated some of them (p. 344)."

population and per capita income growth, contributing to substantial declines in the share of poor and hungry people worldwide. Chen and Ravallion (2012) estimated that 52.5 percent of the developing world's population lived below $1.25 per day (2005 PPP) in 1981; dropping to 22.4 percent by 2008. FAO (2012) reported that 26 percent of the developing world's population was undernourished in 1969–71 compared with 13 percent in 2006–08. Laudable as these measured gains may be, with the world's population increasing by 3.9 billion people from 1960 to 2010 the total number of poor and hungry people remained stubbornly and tragically high.[2] While there is much left to do to end global hunger, the specter of a widespread systematic surge in famine did not materialize.

Recently, however, anxieties over affordable access to food have resurfaced, precipitated by recent food price spikes coupled with longer-term concerns about structural changes in climate, ever-tighter supplies of water for irrigation, and degrading soil and other natural assets that sustain global agriculture production. Some suspect the decades-long decline in real commodity prices is now over, signaling the end of an era of agricultural abundance. U.S. drought-induced spikes in agricultural commodity prices in the summer of 2012 are just the latest in a series of price spikes to affect global agricultural commodity markets since 2007–2008 (World Bank 2012). On top of everything else is the new competition from biofuels for feed and food commodities.

Against these developments, The Club of Rome (2012) recently declared "Humanity has a forty-year window to avoid the most serious negative consequences of its decades-long

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[2] In 2008, a total of 1,289 million people were still living on less than $1.25 (2005 PPP) per day according to Chen and Ravallion (2012), 649 million (49.7 percent) less than the 1,938 million who eked out a living at this income level in 1981. FAO (2012) report little movement in the number of hungry people: 878 million in 1969–71, 853 million in 1979–81, and 850 million in 2006–08. The disjuncture between these two measures—notably a halving of the number of poor people while the number of hungry people was essentially unchanged—speaks, in part, to the difficulties in forming consistent estimates of these metrics at global scales. See the chapters in NRC (2012) for an examination of these measurement issues.

overconsumption splurge" and "The process of adapting humanity to the planet's limitations may be too slow to stop planetary decline." Lester Brown (2012) recently wrote "Time is running out. The world may be much closer to an unmanageable food shortage replete with soaring food prices, spreading food unrest, and ultimately political instability than most people realize."

Are we returning to the poverty and hunger patterns of the past, or are the implications of recent food price spikes being mis-interpreted? Relatedly, are we witnessing a structural shift in the trends in agricultural production and productivity with implications for the future path of global food prices, rates of poverty, and the vulnerability of the poor? A key to understanding global poverty and, especially, hunger prospects is a clear understanding of past, present and prospective agricultural production patterns, and their consequences for food supplies. In the past, a significant share of increased agricultural production came from expanding the area in agriculture and increasing the intensity of use of agricultural land. Looking forward, with comparatively limited scope for increasing the land available for agriculture, and signs of degradation of land already in production, future increases in agricultural output will be even more reliant on increases in agricultural productivity than they were in the past.[3]

In this paper we review past trends in agricultural production and productivity, and present entirely new evidence on investments in public agricultural research and development (R&D) worldwide. R&D affects agricultural productivity with long lags (see, for example, Alston et al. 2010), and so estimates of agricultural R&D investments over the past half century are presented to help calibrate and understand the R&D-productivity relationships, with their inherent implications for agricultural productivity growth over the coming decades. Measuring research is at least as difficult as measuring hunger or poverty. We briefly review the nature and history

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[3] Many years ago, Schultz (1951) foresaw the continued decline in the economic importance of land in agriculture, particularly as the technical changes affecting agriculture enabled other inputs (like fertilizers, improved seeds and machinery) to substitute for land while increasing agricultural output in total and per unit of land.

of the past R&D estimates and provide some context for the new compilation presented in this paper. The agricultural R&D world is definitely changing, and in ways that will definitely affect future global patterns of poverty, hunger and other outcomes.

1. Agricultural Production and Productivity Patterns

In 1961 the world produced $746.4 billion (2004–2006 PPP prices) worth of agricultural output, on 4.46 billion hectares of land, using 1.53 billion workers in agriculture, to feed 3.0 billion people (Figure 1, Panel a). Over the subsequent half century (49 years to be exact), agricultural output grew in real terms by 2.25 percent per year to total $2.26 trillion in 2009, land in agriculture increased by a measurable but much more modest 0.24 percent per year to total 4.89 billion hectares (31.4 percent of which was in crops, the rest used for raising livestock), the number of agricultural workers grew by 1.22 percent per year to 2.6 billion people, and the world's population grew by 1.69 percent per year to 6.8 billion people. Thus, contrary to the pessimists of the 1960s, the value of agricultural output per capita increased from $242.4 per person in 1961 to $331.0 (2004–06 PPP prices) per person in 2009, with the most pronounced growth being among today's upper-middle income countries (Figure 1, Panel b).

[Figure 1: *World population, agricultural output and land in agriculture, 1960 and 2009*]

The Shifting Global Structure of Agricultural Production

Agriculture is a physically expansive sector. Ramankautty et al. (2008) estimated that that world's 15 million square kilometers of cropland occupied about 12 percent of the total ice-free land mass in 2000. However, although every country in the world is engaged in agriculture in some fashion, that engagement is nowhere near equally spread throughout the world. Table 1 provides cumulative totals for selected countries and country groupings. In 2008–10, just ten countries accounted for 56.4 percent of the world's cropland (with India, United States, Russian Federation, China and Brazil alone having 42.6 percent of the total), while the 100 countries with

the smallest shares made up only 1.05 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. Notably, with 8.1 percent of the world's cropland (and 10.7 percent of its agricultural area, including pasture and grazing land), China produced almost 23 percent of the entire world's agricultural output in 2008–10.

[Table 1: *Country concentration of agricultural land and value of production, 2008-10*] Agriculture is an inherently spatial process, with yields (and hence output) being greatly influenced by local factors such as weather and climate, soils, and pest pressures. Consequently, agricultural production and productivity are especially sensitive to spatial and inter-temporal variations in natural factors of production. Agriculture is also continually on the move, and this spatial shifting has profound (but hitherto largely ignored) implications for how productivity metrics can and should be interpreted (Beddow 2012). For example, the location of worldwide wheat production has moved markedly, even since the early 1960s. During the three-year period 1961–63, Russia accounted for 15 percent of the world's wheat production (35.4 million metric tons) and ranked first among wheat producers worldwide. By 2008–10, Russia had slipped to the world's fourth-ranked wheat producer, accounting for 8.3 percent (55.7 million metric tons) of world wheat production during those years. The massive increases in production by India and, especially, China saw their combined share of world wheat production increase from 11.8 to 28.8 percent over this same period.

Productivity Concepts

Much has been written by economists on how to measure productivity and how to interpret the measures (e.g., Jorgenson and Griliches 1967; Alston et al. 1998; Morrison Paul 1999). Different concepts and corresponding measures of productivity may be appropriate for different

purposes, though they all express some measure of output relative to some measure of input. The simplest measure of all is a measure of output of a single commodity per unit of a single input, such as yield in tons per hectare of wheat per year. This measurement seems straightforward. However, even such a seemingly simple and intuitive measure is prone to conceptual and measurement problems. For instance, land quality varies such that individual hectares are quite unequal in their productive capacity. Do economists use planted or harvested areas (that exclude abandoned areas or areas that fail to produce a measurable grain yield) and measure seasonal or annual acreages when forming measures of yields? Should the units of land be adjusted for quality to make the individual hectares more nearly comparable? If not, how should changes in observed yields that may reflect changes in the intensity of use or average quality of the land input be interpreted?

Similarly, on the output side, wheat quality varies significantly, depending on protein content and other attributes that are not independent of the physical yield—in particular, higher yield tends to be associated with lower quality (James 2000). What should be done about changes in output quality? If nothing is done to correct for variations in the quality mix over space and time, how should the measures be interpreted? Further complications arise from the implicit aggregation over time. For instance, in some cases multiple crops are grown on the same fields within one year; in other places a crop is grown in a multiyear rotation with other crops or with fallow years. How should the measures of yield per hectare per year be adjusted to allow for these characteristics of the production process so as to make the measures comparable over space and time?

Individual grain yield is an example of a partial factor productivity (PFP) measure. It is "partial" in the sense that it only accounts for changes in the amount of land used in production. It does not account for changes in the quantities of other inputs—such as labor, capital, fertilizer,

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rainfall, or irrigation—that also affect production. By the same token, grain yield per hectare of

a particular crop also does not account for changes in other outputs that might be associated with

the crop in question, such as crop biomass or other by-products. Thus yield and other partial

measures can be seen as partial with respect to their treatment of outputs as well as inputs.

At the opposite end of the spectrum are measures of total factor productivity (TFP), the

aggregate quantum of all outputs divided by the aggregate quantum of all of the inputs used to

produce those outputs. 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. Sometimes we are

interested in partial productivity measures and sometimes PFP measures or MFP measures are

used as proxies for TFP. 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.

In the present context, as in many others, we are most interested in TFP since it is an

encompassing measure that represents the full quantity of resources used to produce the total

quantity of output produced. How well does an MFP or PFP measure approximate TFP? The

main ideas can be illustrated with some simple mathematics. Let us define total output Q as the

sum of the quantities of outputs *included* in MFP, Q_i, and the outputs *excluded* from MFP, Q_e

(where $Q_e / Q = q_e$), and total input X as the sum of the quantities of *included* inputs, X_i, and

excluded inputs, X_e (where $X_e / X = x_e$), such that the measures of TFP and MFP are

$$MFP = \frac{Q_i}{X_i},$$

(1)

$$TFP = \frac{Q}{X} = \frac{Q_i + Q_e}{X_i + X_e}.$$

(2)

Taking logarithmic differentials of equations (1) and (2) gives measures of growth rates of MFP and TFP. Taking the difference between the logarithmic differentials gives an equation for the difference between growth in TFP and growth in MFP as follows:

$$d \ln TFP - d \ln MFP = d \ln \left(Q_i + Q_e \right) - d \ln \left(X_i + X_e \right) - d \ln \left(Q_i \right) + d \ln \left(X_i \right)$$

$$= q_e \left(d \ln Q_e - d \ln Q_i \right) - x_e \left(d \ln X_e - d \ln X_i \right).$$

(3)

Thus the discrepancy depends on the relative importance of the excluded quantities of outputs and inputs (q_e and x_e), and on the differences in the growth rates between the included and excluded quantities of outputs and between the included and excluded quantities of inputs. Importantly, if the excluded quantities of outputs and inputs are growing at the same rates as their included counterparts, the MFP measure grows at the same rate as the TFP measure. If the growth rates are different, however, the MFP growth rate will be different, with the difference increasing with the relative importance of the excluded outputs and inputs unless by chance the distortions in the outputs and inputs offset one another.

In what follows, we briefly review the evidence on partial-factor productivity developments in agriculture over the past half a century using the range of measures at our disposal. Measures of crop yields (or total productivity of land) will tend to overstate TFP growth if the use of the aggregate of labor, capital and other purchased inputs has intensified over time relative to land; they will understate TFP growth if use of other inputs has declined relative to land. Likewise, measures of labor productivity will tend to overstate TFP growth in those places where labor has been leaving agriculture and other inputs have increased relative to labor.

Crop Yields

During the almost 50-year period from 1961 to 2010, global average maize and wheat yields rose worldwide by 1.96 and 2.03 percent per year respectively (Table 2). Average rice and soybean yields rose more slowly, growing respectively at 1.76 percent and 1.50 percent per year on

average. Notably, yields for the top 20 producing countries worldwide rose more rapidly than the world average for maize, wheat, rice and cereals: for soybeans yields for the top 20 countries as a group grew at about the same pace as the world average, which is to be expected given that the top 20 countries accounted for almost all (98.9 percent on average) of global soybean production over this period. In sub-Saharan Africa long-run (1961–2010) growth of crop yields was slower than the world average for all crops other than wheat and soybeans (although the region accounted for only 0.91 and 0.54 percent of world wheat and soybean production respectively in 2010). Notably, for North America (a top 20 producer of all crop categories in Table 1) average annual growth rates since 1961 were below the world average rate of growth for all three crops and the cereal total.

[Table 2: *Yield growth rates for selected crops, 1961–2010*]

These longer-run changes mask a worrisome feature in the pattern of crop yield growth. Crop yield growth was generally slower in the post-1990 period (see bolded entries in Table 2), and in some instances substantially slower, than before 1990.[4] For example, nearly all of the top 25 wheat-producing countries in the world had slower growth in average yield in the period 1990–2010 than in the period 1961–1990 (Table 3). Likewise, 56 percent of the top 25 rice producers and 76 percent of the leading soybean producers had slower post- versus pre-1990 growth. The exception is maize, a crop subject to substantial private-sector research interest and a continuing stream of new technologies, where yield growth post-1990 exceeded the pre-1990 rate for more than half the leading producers.

[Table 3: *Countries with slower yield growth since 1990*]

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[4] These comparative yield growth rates are sensitive to choices of end-points. Splitting the data in years other than 1990 changes the specifics of the growth rates, but splitting the data at different years around this date does not alter the general finding of a widespread (but by no means universal) slowdown.

As Alston, Pardey and Beddow (2010) pointed out, the interpretation of average global and regional crop yields is problematic for several reasons. One of the most confounding (but often ignored) factors is that 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.[5] In addition, in the yield data used here (and those used by most other observers) yields are reported on the basis of harvested area, which will count the same land 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 crop plantings per year had increased over time.

Partial Productivity

Figure 2 uses the graphical technique developed by Hayami and Ruttan (1971) to track land and labor productivity movements globally, and for the United States, China and all the world's countries grouped into income per capita classes. The horizontal axis is a measure of labor productivity and the vertical axis a measure of land productivity for the period 1961-2010. These partial productivity measures were formed by taking a ratio of the real value of aggregate output and the respective quantities of land and labor inputs. Output is an FAO estimate of the total value of agricultural production (spanning 192 crops and livestock commodities) expressed in 2004–06 average purchasing power parity agricultural prices (FAO 2012). Land is a measure

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[5] Wood et al. (2000) developed measures of cropping intensities worldwide that expressed the annual harvested area as a proportion of total cropland (including land in use and fallowed land). In 1997, the global average annual cropping intensity was estimated to be about 0.8 (Wood et al. 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 range of 0.6 to 0.7. The estimated intensity for sub-Saharan Africa was 0.9.

of harvested and permanently pastured area, and labor is a head count of the total number of economically active workers in agriculture.

[Figure 2: *Land and labor productivity, 1961–2010*]

These productivity paths exhibit clear long-run structural patterns. The low- and middle-income countries as a group have much lower agricultural land per worker ratios than the high-income countries. Moreover, 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. Almost 50 years later, the disparities in land productivity were much less pronounced, although the high-income group still produced much more output per measured unit of agricultural labor than the rest of the world.

Figure 3 plots (moving average) changes in agricultural labor and land productivity for the world and various per capita income groups for the period 1961–2010. Labor productivity growth has reflected a combination of labor leaving agriculture and the remaining labor becoming much more productive, in a sustained pattern. In the high-income countries the growth rate of labor productivity declined to around 3.2 percent per year during the 1980s, with some substantial swings but no clear trend thereafter. This is a markedly faster than the rate of TFP or MFP growth in those countries where it has been measured during the past 50 years or so. The rate of growth of land productivity roughly halved for the high-income group during the sample period, from a decade average of 2.10 percent per year during the 1960s (and 1.38 percent per year during the 1970s) to 0.81 percent per year from 2000 to 2010. The pattern of land productivity in these countries is quite comparable to the pattern of TFP or MFP for those countries where it has been measured, such that land productivity might be a reasonable proxy for TFP or MFP.[6]

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[6] U.S. MFP growth rates that were approaching two percent per year in the period 1960–1990 have fallen to about one percent per year for the years since 1990 (see Alston, Andersen, James and Pardey 2010). Similar slowdowns

This observation gives us some confidence in using crop yield evidence as a broader indicator of agricultural productivity trends, while we remain conscious of the fact that partial productivity measures such as crop yields can sometimes diverge substantially from MFPs. On average, agricultural labor productivity in the rich countries grew at about double the rate of land productivity over the past 50 years.

[Figure 3: *Rates of growth of land and labor productivity, ten-year moving average, 1961–2010*]

Comparative trends in the growth of land and labor productivity for the low- and middle-income countries are a mixed bag. For the low-income countries, both of the partial productivity measures grew at rates that were consistently below the rates recorded for the middle-income groups 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 country groups represented in the Figure. Likewise, the growth rates of land and labor productivity for all other country groups appear to have risen relative to those for the high-income countries.

Table 4 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 166 countries that each had a small share of the global value of agricultural production and combined produced only 20 percent of the 2010 total value of output. In both instances, the slowdown was more pronounced in labor productivity than land productivity.

[Table 4: *Countries with slower partial productivity growth since 1990*]

The general pattern we see in the available crop yield and partial-factor productivity evidence is one of a widespread (but by no means universal) slowing down in the rates of growth of these productivity metrics. Specifically, global average maize, wheat, rice, soybean and cereal yields

have been observed in other high-income countries such as Australia and New Zealand, Canada, and the United Kingdom (e.g., see Alston, Babcock, and Pardey 2010).

grew more slowly after 1990 than before it and, setting aside China, so too did the rest-of world land and labor productivities. This perspective on productivity growth is contrary to Fuglie's (2008) finding that "…I find no evidence of a general slowdown in sector-wide agricultural TFP [total factor productivity], at least through to 2006. If anything, the growth rate in agricultural TFP accelerated in recent decades." Fuglie's TFP estimates are unavoidably subject to distortions whose magnitude and direction are difficult to decipher, especially when testing differences in growth rates between periods to determine a slowdown, because of the incomplete and inaccurate data (and the methods) used to construct them,. As Alston, Babcock and Pardey (2010, p. 465) concluded, Fuglie's "TFP" estimates (or any similar such estimates reliant on FAO data) "…should be used carefully, given the many constraints that data and measurement realities and choices place on generating accurate estimates, and especially in relation to the question of a slowdown in productivity given that we have little basis for assessing their accuracy for that purpose."

Looking forward, the issue of interest is not whether productivity growth has slowed but rather what can we expect given recent trends in public investments in R&D. While technical changes arising from investments in R&D and changes in multi-factor productivity are not synonymous, there is strong empirical support for the notion that an accumulation of past and present R&D spending plays a big part in stimulating present and future productivity growth. It is the magnitude and nature of that R&D spending to which we now turn our attention.

2.   Measuring R&D for Food and Agriculture

Bob Evenson and colleagues can take credit for the first comprehensive compilation of national estimates of investments in agricultural R&D.[7] Their efforts over a number of years culminated

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[7] The U.N. Food and Agriculture Organization produced a great deal of published and unpublished agricultural research system reviews, directories of agricultural research organizations, regional overviews of national

in a 1975 volume by Boyce and Evenson (1975) titled *National and International Agricultural Research and Extension Programs*.[8] This publication included time-series data on research and extension spending and personnel from the early 1960s (although in some instances 1950 and 1959 figures were also provided) through to 1973. Two subsequent publications (Judd, Boyce, and Evenson 1983 and 1986) built upon these prior studies and reported "constructed time-series" for 106 countries for three time periods: 1959, 1970 and 1980. Drawing directly on this body of work and other sources, Oram and Bindlish (1981) developed annual agricultural R&D expenditure estimates for 51 developing countries for the period 1970 to 1980.

Evenson's pioneering work notwithstanding, much of the data to this point were fragmented in scope and coverage, difficult to access, uneven in quality, and varied markedly in the degree of documentation. With initial input and on-going guidance from Howard Elliott and Eduardo Trigo, the International Service for National Agricultural Research (ISNAR) launched an undertaking in late 1984 led by Philip Pardey and co-executed by Han Roseboom, to expand the available agricultural R&D data while also striving to standardize both the data collected and the way they are treated. Where possible, data were collected and compiled in adherence to *Frascati Manual* (OECD 2002) guidelines to increase the compatibility of the agricultural R&D indicators with other R&D series reported by the Organisation for Economic Cooperation and Development (OECD), the United Nations Educational, Scientific and Cultural Organization (UNESCO), among others.[9]

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agricultural research activities, conference and workshop reports, and so on that included data on investments and scientific personnel as well as institutional information on national agricultural research efforts. However, no comprehensive cross-country compilation of agricultural R&D spending data appears to have existed prior to the work led by Evenson, although the United Nations Educational, Scientific and Cultural Organization (UNESCO), and several collaborating agencies, did (and still do) produce *Statistical Yearbooks* and other reports and maintain on-line data repositories that contain relevant information.

[8] Evenson and Kislev (1975a and b, Appendix 1) reported research and extension expenditure and personnel estimates for 84 countries for circa 1965.

[9] The latest incarnation of these guidelines is the 2002 version of the *Frascati Manual*, which had its beginnings in a June 1963 meeting convened by the OECD at the Villa Falcioneri in Frascati, Italy.

This led to the Pardey and Roseboom (1989) publication, *ISNAR Agricultural Research Indicators Series*, an extensively documented compilation of statistics on basic spending and (full-time equivalent) personnel employed by national agricultural research systems (NARSs) that drew on three benchmark ISNAR surveys (which yielded usable data for nearly 70 developing-country NARSs) plus information from almost 900 additional data sources. The series includes data on 154 developed and developing countries spanning the period 1960–86 (although complete data for all countries for all years were not available). This series, like the one published by Oram and Bindlish (1981), encompassed agriculture, forestry and fisheries research undertaken by public agencies. Boyce and Evenson's 1975 series sought to exclude forestry and fisheries research.[10]

Different series used different methods to standardize the units in which research spending data are reported, and these differences can have substantive empirical implications. Judd, Boyce and Evenson (1983, p. 3) noted that "… [research] expenditures were converted to U.S. dollars using official exchange rates and were then inflated to 1980 dollars using a [U.S., presumably] general wholesale price index." Although it is not possible to determine with any certainty, it seems plausible that the same method was used for the other compilations published by Evenson and colleagues around that time. Pardey, Roseboom and Craig (1992) evaluated the conceptual and practical implications of casting research spending aggregates into comparable units. The key analytical decisions involve the choice of an appropriate approach to convert currencies and adjust for inflation, including which currency exchange rate and which deflator to use, and whether to convert-first-then-deflate (as did Judd, Boyce and Evenson 1973) or vice a versa. The Pardey and Roseboom (1989) series—and all subsequent versions of this series—opted for a deflate-first-then-convert method, using a purchasing power parity approach for the currency

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[10] Pardey, Roseboom and Anderson (1991b, p. 268) estimated that in 1981–85 about 7.3 percent of the research in developing countries was related to forestry and 5.7 percent to fisheries.

conversions to express R&D spending from all countries for all time periods in base period international dollars.[11]

During the 1990s, ISNAR (in collaboration with the International Food Policy Research Institute, IFPRI) evolved its on-going country survey and data compilation work into the Agricultural Science and Technology Indicators (ASTI) initiative. This involved a second round of survey effort undertaken by Philip Pardey, Han Roseboom and Nienke Beintema, data from which were used to form the regional and global summaries for the period 1976–1995 published in Pardey and Beintema (2001). Since 2002 the ASTI initiative has been led by Nienke Beintema at IFPRI. Pardey et al. (2006) updated the regional and global summaries for the period 1981–2000, to which data for selected countries and regions were added in the 2010 report by Beintema and Stads. In addition to this "global" update, the ASTI initiative has continued to maintain a large number of country-specific series, with accompanying country briefs and regional summaries for 64 developing countries.[12]

InSTePP Global Compilation 1961–2009

In this paper we describe and interpret an entirely new compilation of agricultural R&D spending estimates spanning 126 developed and developing countries for the period 1960–2009 summarized in Pardey, Chan-Kang and Dehmer (2012).[13] The estimates refer to publicly performed R&D oriented to food and agriculture reported on a by-performer basis (which means the expenditures are reported according to where in the world the research was done, rather than

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[11] These series (and the one reported here) use national implicit GDP deflators to adjust for inflation and GDP purchasing power parity indexes to convert currencies. Pardey, Chan-Kang and Dehmer (2012) revisit these deflation and conversion issues for the new series summarized in this paper.

[12] The more recent regional summaries are for sub-Saharan Africa (Beintema and Stads 2011), Latin America & Caribbean (Stads and Beintema 2009), and Asia & Pacific (Beintema and Stads 2008). The ASTI country reports and data can be downloaded from http://www.asti.cgiar.org/home.

[13] Appendix Table 1 lists the regional groupings of these 126 countries.

from where in the world the funds for research flowed).[14] In constructing these estimates, all the previously available sources (including all those mentioned above, as well as unpublished data that underpinned a number of these earlier compilations) were used in addition to an entirely new compilation of agricultural R&D spending estimates for the OECD countries reported in Pardey and Chan-Kang (2012).[15]

Table 5 summarizes the sources-cum-methods used to develop this series for each decade since 1960 and for the entire sample period. The left-hand side of the table indicates the share of observations from each source for each decade and overall; the right-hand side of the table shows the shares of R&D spending by source. The basis for the estimates in the data series changes over time. For a substantial share of the entries (specifically 24.4 to 42.1 percent, depending on the time period), proximate agricultural research intensities (i.e., agricultural R&D spending relative to agGDP) were used in conjunction with corresponding annual, country-specific measures of agGDP to develop estimates of the amount of agricultural R&D spending per country per year. However, estimates formed in this fashion often pertain to the smaller R&D countries in the sample and, for the entire 1960-2009 sample period, accounted for less than 10 percent of the estimated amount of spending. Comparatively solid sources of data were used to form the estimates for a sizeable share of the countries in our sample, and especially the larger R&D spending countries. For example, data from the sources-cum-methods reported in rows 1,

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[14] The series also includes food and forestry research conducted by national agencies (i.e., excluding research performed by international agencies such as the centers of the Consultative Group on International Agricultural Research, CGIAR). The "by performer" versus "by funder" distinction is quantitatively important. Many developing counties, especially in the earlier years and especially those in sub-Saharan Africa, were heavily reliant on loan and grant funds from rich countries and international agencies such as the World Bank and the Inter-American Development Bank for significant shares of their agricultural research funding. For example, Pardey, Roseboom and Anderson (1991, p. 371) estimated that in 1981–85 around 35 percent of all publicly performed agricultural R&D in sub-Saharan Africa was funded by donor agencies, 26 percent in Asia & Pacific, and around 16 percent of all developing-country agricultural R&D.

[15] The data reported in and used to develop the various OECD country series in Alston, Pardey and Smith (1999) were also used, along with the developing-country evidence in Pardey et al. (2006). For summary details of the sources used by Pardey and Roseboom (1989) see Chapter 3, and, especially, Table 3.1 in that publication.

2, and 3 of Table 5 accounted for around 58 percent of the reported global spending total, and about 77 percent of the total if data from rows 4 and 6 are also included.

[Table 5: *Summary of data sources and methods by decade and overall, 1961-2009*]

3.   Measures of Public Agricultural R&D

Over the past half century, the preponderance of technical changes affecting productivity growth in food and agriculture worldwide arose from public and private investments in formal forms of R&D. While our empirical handle on private investments in food and agricultural research is far from certain, available evidence indicates that (a) the private share of global agricultural R&D is in the 35 to 41 percent range, (b) the lion's share of that research (89 to 94 percent) took place in the high-income countries, and (c) for the rich countries at least, well over half of that research was concerned with producing off-farm, primarily food processing, innovations (Pardey and Pingali 2010).[16] Important as private agricultural R&D has been, at least in rich countries, for most of the world the greatest part of the agricultural R&D effort that will drive farm productivity growth in the coming decades has been in the public domain. Here we present an entirely new, long-run perspective on investments in publicly performed R&D.

General Trends

Over the past half century, and especially during the past decade or so, the global pattern of public agricultural R&D spending has undergone a seismic shift.[17] In 1960, just $5.5 billion (2005 PPP prices) was spent on public agricultural R&D worldwide (Figure 4, Panel a). By 2009 that total had climbed to $33.5 billion: an average rate of (inflation-adjusted) growth of

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[16] Pardey and Beintema (2001, Table 2) estimated that the private share of global agricultural R&D was almost 35 percent in circa 1995, and about 94 percent of that research occurred in developed countries. Beintema and Stads (2008, Figure 4) put the private share of the total at 41 percent in 2000, of which 94.4 percent took place in high-income countries. Fuglie et al. (2011, Table 1.2) estimated the private share of total to be 39 percent for 2000, with the high-income country share of total private food and agricultural R&D being 89 percent.

[17] The data presented here revise, update, and thus supersede the global public-sector data presented in Pardey and Pingali (2010), Alston et al. (2010), and Pardey and Alston (2012).

3.31 percent per year.[18] We have seen big, and of late accelerating, geographical shifts in the location of performance of this R&D. In 1960 the high-income countries—classified according to average per capita incomes in 2009—accounted for 58 percent of the world's total: almost 50 years later, in 2009, that share had dropped to 48 percent. The United States has lost significant global market share, accounting for 21 percent of the total in 1960 but just 13 percent in 2009. If recent trends continue the U.S. position will continue to shrink. Pardey, Alston and Chan Kang (2012) show that the growth in real public-sector agricultural R&D spending (i.e., intramural spending by the United States Department of Agriculture, USDA, and the state agricultural experiment stations, SAESs) has transitioned from an extended period of slowing down to one of none or negative growth.[19]

[Figure 4: *Global trends in public agricultural R&D spending, 1960-2009*]

Sub-Saharan Africa has also lost market share, declining from 9 percent of the world's total in 1960, to 6 percent in 2009. So too has the Latin America & Caribbean region, although Brazil's share increased from 3 percent to 5 percent while the rest of that region lost ground relative to the rest-of-the-world. The notable expansion in market share was in the Asia & Pacific region: China's share grew from 13 percent in 1960 to 19 percent in 2009, while India's grew from 2 to 6 percent. In 2009, 31 percent of the world's public agricultural R&D took place in the Asia & Pacific region compared with just 20 percent in 1960.

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[18] Pardey, Chan-Kang and Dehmer (2012) report a preliminary 2008 estimate for public agricultural R&D conducted in the Former Soviet Union (FSU) and Eastern European countries of $1.14 billion (2005 PPP prices). This figure includes estimates for, the Czech Republic, Hungary, Poland, Romania, the Russian Federation and 23 other countries from this region.

[19] Using an implicit GDP deflator to adjust for inflation (as we do for almost all of the R&D data reported in this paper) indicates that real spending on publicly performed agricultural R&D in the United States flat-lined since 2004. Using a purpose built U.S. agricultural R&D deflator (which grew at an annual average rate of 3.46 percent per year from 2004-2009, compared with 2.37 percent per year growth for the implicit GDP deflator) indicates a cut back in real spending since 2004.

Figure 5, Panel a plots the trends in real spending from 1960 to 2009 by region. Notably, spending by today's middle income group of countries, which includes Brazil, India and China (BIC), grew rapidly, especially in the past decade or thereabouts, such that by 2009 this group of countries had caught up the high-income countries in terms of their agricultural R&D spending.[20] Both groups of countries spent around $16 billion dollars on public agricultural R&D in 2009. Over this same time period, the 28 countries in today's low-income group (of which 24 countries, 86 percent, are from sub-Saharan Africa) made little headway vis-à-vis the rest of the world. In 2009 they collectively spent just $0.847 billion (2005 PPP) on agricultural R&D, less than 5.2 percent of the corresponding high- or middle-income total that year.

[Figure 5: *Public agricultural R&D spending by income class, 1960–2009*]

Figure 5, Panel b gives a different perspective on these trends. Here countries are grouped into income classes using the contemporary World Bank schema, but with countries allocated to each income category according to their 1960 per capita income levels (versus their 2009 per capita income levels as in Panel a). From this perspective, France, Japan, South Korea and Spain (now all high-income countries), had per capita incomes in 1960 that placed them in the middle-income range (by contemporary World Bank standards) such that this 1960 middle-income category spent substantially more on agricultural R&D in 2009 than the corresponding 1960 high-income cluster. Similarly, the 1960 low-income group includes China and India (now both classified as middle-income countries) and that group also spent more than the high-income cluster on public agricultural R&D in 2009.

Figure 6 highlights key elements in the changing structure of global public agricultural R&D worldwide. The share of total R&D done by China, and thus the BIC aggregate, shrank substantially throughout the 1960s; a response to the turmoil of the Great Leap Forward and the

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[20] As a group the BIC countries spent $10.2 billion (2005 PPP) on public agricultural R&D in 2009, 2.3 times the amount spent by the United States that year.

subsequent Cultural Revolution (and causing the initial decline in the middle-income totals

plotted in Figure 5, Panel a). As Fan and Pardey (1991) described, during 1960–61, one third of

the CAAS (Chinese Academy of Agricultural Sciences) institutes were moved to rural areas or

disbanded and the Academy's total number of staff declined by 70 percent from 7,500 to 620

personnel.[21] From a fifty-year low of 2.9 percent of global agricultural R&D spending in 1968,

China's share of the total grew steadily to 10.7 percent in 2001 and thereafter grew rapidly to

19.5 percent by 2009. The BIC trend followed a similar path, such that by 2009 these three

countries alone accounted for 30.4 percent of the world total and 61.9 percent of the low- and

middle-income total. The flip-side of these developments is a declining share of the world's total

both for today's rich countries as a group, and for most of the countries within this group

(specifically 21 out of 33 countries) as illustrated by the U.S. share plotted in Figure 5.

[Figure 6: *Shifting shares of global public agricultural R&D spending, 1960-2009*]

These changes in the global structure of public agricultural R&D reflect a shifting pattern of

growth in R&D spending among countries and regions of the world. Figure 7, Panel a shows the

average rate of growth by decade since 1960 for five regions of the world. The generally slower

pace of spending growth in Latin America and sub-Saharan Africa compared with the Asia &

Pacific region are especially evident. All three of these regions saw agricultural R&D spending

growth rebound in the past decade of our data, but the recovery is much more marked in Asia &

Pacific than the other two regions. Moreover, the 1980s and 1990s were dismal decades in terms

of spending growth in Africa and Latin America, and especially so in Africa during the 1990s

when overall spending shrank (in real terms). For sub-Saharan Africa and the Latin America &

Caribbean region the recent recovery appears fragile and was not widespread. In sub-Saharan

Africa over half the increase in spending from 2000 to 2009 came from just two countries

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[21] CAAS was established in 1957 (Fan and Pardey 1991, p. 31).

(Nigeria and Angola), while Brazil accounted for more than half the spending gains realized in the Latin America & Caribbean region during this same period.

[Figure 7: *Rates of growth in public agricultural R&D spending by decade, 1960-2009*]

Figure 7, Panel b recasts the growth rate data, grouping the countries by per capita income class. As expected from the regional representations of these data, growth rates in both the lower- and upper-middle income groups have rebounded in the 2000s, with the recovery being greatest in the two middle-income groups. In fact during the 2000s, the upper-middle income countries as a group experienced growth rates commensurate with the rates of increase witnessed for the high-income countries back in the 1960s. The black **X** marks indicate the growth rates that apply to the lower-middle group if India is excluded, and the upper-middle income group if Brazil and China are excluded. They indicate that during the 2000s India's agricultural R&D spending grew at about the same rate as the average for other countries in its income class, while spending in Brazil and China grew faster than the average of the other countries in their income class.

In 1960 the top 10 countries ranked by public agricultural R&D spending accounted for 62 percent of the world's total spending; by 2010 the top 10's share had grown to 66 percent. Not only has the spatial concentration in the conduct of public agricultural R&D become more pronounced over the past half century, the ranking of countries in terms of the amounts spent on public agricultural R&D has also changed markedly. In 1960, the first-ranked United States spent almost three times more than the second-ranked China (Table 6). By 2009 China was spending measurably more than the United States. Germany dropped in the ranking, as did the United Kingdom (4th in 1960 versus 13th in 2009). By 2009 Australia had also dropped out of the top ten (down to 16th). New entrants into the top ten are India (13th in 1960, 4th in 2009), Spain (26th to 9th), and South Korea (14th to 10th). Brazil also moved markedly up the ranking

22

from 10th to 5th. This represents a significant change in the geo-economic order of public agricultural R&D investments, with the historically richer countries ceding ground in more recent years to those with rapidly rising per capita incomes.

[Table 6: *Top ten agricultural R&D spending countries, 1960 and 2009*]

Research Intensities

Countries with larger (smaller) agricultural economies are likely to invest more (less) in agricultural R&D simply because of a congruence effect (Pardey, Kang and Elliott 1989). For this reason, normalizing agricultural research expenditures with respect to the size of the agricultural economies they serve gives one indication of the intensity of research spending. The research intensity ratios summarized in Figure 10 are (weighted) averages by decades of the amount of public agricultural R&D spending relative to the corresponding agricultural GDP (agGDP).

Over the past 50 years, the high-income group has progressed steadily towards an ever-more research-intensive mode of agricultural production. From just 56 cents for every $100 of agricultural output in 1960, these countries invested an average of $3.45 per year into public agricultural R&D per hundred dollars of output in 2009 (Figure 8). This increasing R&D intensity has occurred in spite of a slowdown in the rate of growth of agricultural R&D spending, an indication of an even more pronounced slowdown in the rate of growth of agricultural output in these countries. In contrast, the intensity at which the Asia & Pacific region invests in agricultural R&D has grown much more modestly from 0.43 percent of agGDP in 1960 to 0.52 in 2009. While this region has sustained growth in agricultural R&D spending at a comparatively rapid pace, averaging 5.1 percent per year since 1960, agricultural output has grown at reasonably rapid rate as well (3.71 percent per year). Thus while the growth in spending on agricultural R&D outpaced the corresponding growth in the value of output, the

23

growth rate differentials were comparatively modest such that the region's research intensity

only inched up over time, although increasingly so after the mid-1990s.

[Figure 8: *Agricultural research intensities by region and income class, 1960–2009*]

Of concern are the intensity trends in sub-Saharan Africa. In distinct contrast to the other

developing country regions of the world, research intensities in this part of the world have been

slipping, especially in the past couple of decades. The same pattern is evident in the low-income

countries more generally. According to our data 46.5 percent (20 countries) of the 43 countries

in sub-Saharan Africa had lower research intensities in 2009 than they did in 1980: 46.4 percent

of the 28 low-income countries in our sample have similarly lost ground on this score.

Imminent Implications

The incongruous patterns of agricultural research investments and the value of agricultural

production today will have implications for the patterns of agricultural productivity and

production for decades to come. As we have noted, agricultural R&D is slow magic: research

takes a long time to take effect, and then its effects endure for many years. The dynamics are

complex, because much of the current research spending is required simply to stop productivity

from falling, and this maintenance research—currently perhaps one-half to two-thirds of the total

investment—will become increasingly important as climate change introduces additional

challenges.[22] The fact that much of the world has depended on spillovers from the rich countries

in the past should not be forgotten as we move further into this century with a shifting world

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[22] Attempts to assess the overall importance of maintenance research in the United States—that is research intended
to sustain past productivity gains—include Heim and Blakeslee (1986), Adusei and Norton (1990) and Sparger
(2009). See also Ruttan (1982, p. 60) who was an early commentator on the prospect that sustained productivity
growth would require committing a rising share of agricultural R&D to maintaining past productivity gains.
Olmstead and Rhode (2002) referred to this as the "Curse of the Red Queen" (see also Dalrymple 2004). In Lewis
Carroll's Through the Looking Glass the Red Queen said, "It takes all the running you can do, to keep in the same
place." This colorful metaphor has a parallel in naturally evolving biological systems to which the Red Queen
principle was introduced by Van Valen (1973) who broached the notion that for a species within an evolutionary
system, continuing development is needed to maintain its fitness relative to the systems within which it co-evolve.

order in agriculture and agricultural R&D but no real change in the own-research effectiveness of many of the poorest countries.

4. Closing Comments

Concerns about the future of food today echo similar concerns raised half a century ago, but the worst fears of the 1960s were not borne out. Indeed, rather than an ever-worsening Malthusian nightmare the predominant feature of agricultural commodity markets, since at least the 1950s, has been falling real prices. But that phase may be over. Recent high commodity prices combined with increased price volatility have raised new concerns about whether the price structure has permanently changed, raising the specter that the future will not be like the past in this important respect, unless significant changes in policy are made soon.

The demand side of the world food equation is relatively uncontroversial and reasonably predictable: population and income growth will lead to sustained increases in the demand for food over the next 40 years. Agriculture is no longer just about food. The new demands for biofuels and related policies mean that the total demand for agricultural output is larger and somewhat less predictable. Even so, the long-term issues related to food prices, food security, poverty and hunger turn mainly on the future path of agricultural supply; in particular, the growth of agricultural productivity given increasing constraints on the natural resource base available for food production. In turn, the path of agricultural productivity over the next decades will be determined substantially by investments in agricultural research. Given the long R&D time lags, to some extent the die is already cast, because the relevant research investments determining productivity growth in the next 20 years will be those made in the past decade or two, but a revitalization of R&D spending over the next 10–20 years could significantly shift the path of productivity and prices by mid-century.

Against this background, in this paper we have reviewed the status of agricultural productivity patterns and public agricultural research investments over the past 50 years with a view to the implications for the decades to come. The patterns are interesting and to some extent worrisome. They depict a retreat by the world's richest countries from their historical role as the principal providers of the global public good of agricultural science, and the rise of the middle-income countries to the forefront, in an era of slower and perhaps still slowing agricultural productivity growth.

Productivity is difficult to measure well, even if good data are abundantly available, and it is even harder to detect meaningful structural changes in the rate of growth of productivity. Even so, the various measures that we can muster do appear to signal a significant change in the growth rate of agricultural productivity around the world. The data show a substantial slowdown since about 1990 in growth rates of average crop yields for the world as a whole, and in most parts of the world. We have also seen some slowdown in rates of growth of labor productivity and land productivity, but here the patterns are more mixed among countries, with China as a significant exception such that the world including China shows an increase but the world excluding China shows a slowdown in land and labor productivity growth. These differential productivity patterns are reflected to some extent in differential research spending propensities. Real rates of annual R&D spending have begun to decline in many countries, including the United States, which was once at the forefront. In the high-income countries in spite of compelling evidence of high rates of return and a significant productivity slowdown, support for agricultural science has broadly waned. Moreover, in these countries, of the amounts being spent on "agricultural science," 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 let alone increasing farm productivity. Capacity

of the agricultural science sector in many countries has been run down over decades, infrastructure has been depreciated and the majority of the scientists in many countries are close to retirement age (the median age of scientists in the U.S. NARS is close to 60 years).

On the salutary side we observe the rise of the large, populous middle-income countries: Brazil, India and China together now provide 30.4 percent of the world's public agricultural R&D. And these are the countries with the largest total numbers of farmers and food poor whose lives can be very substantially improved through agricultural innovation leading to more abundant and cheaper food. But we also see continuation of a growing global divide, with the world's poorest countries falling even farther behind and, in an era of increasingly proprietary and local research emphasis, decreasing scope for those countries to capture spillover benefits from research undertaken by other countries on which they have relied in the past.

These systemic seismic shifts in spending patterns for agricultural R&D mean that the world will increasingly depend on the middle-income countries for agricultural innovations. The shifted shares of the world's total agricultural science business will have implications 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, livelihoods of farmers and their families. Absent a reversal of public R&D investment trends in the rich countries, and perhaps even in spite of that, today's middle-income countries 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.

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Figure 1: World population, agricultural output and land in agriculture, 1960 and 2009

Panel a: World population, agricultural area, and value of production
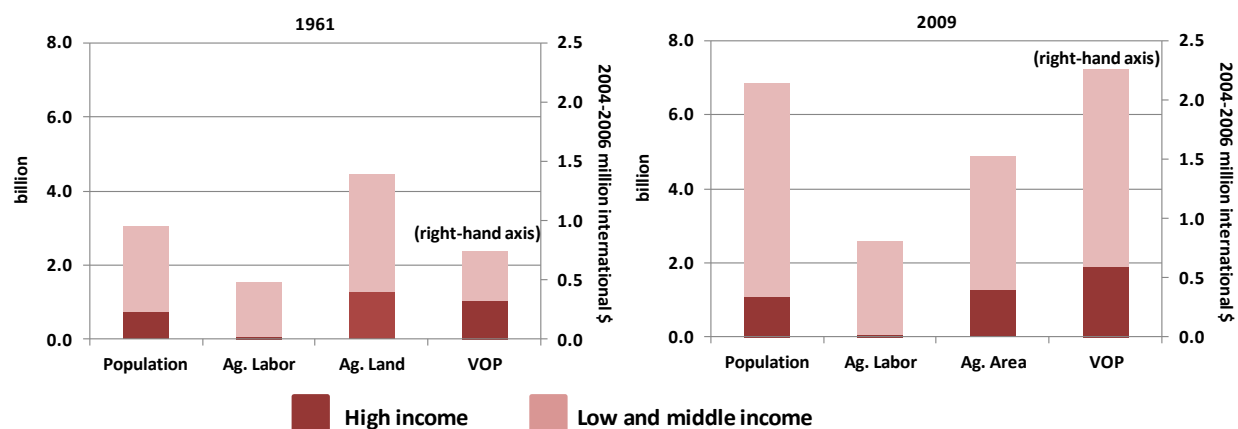
Panel b: Value of agricultural production per capita
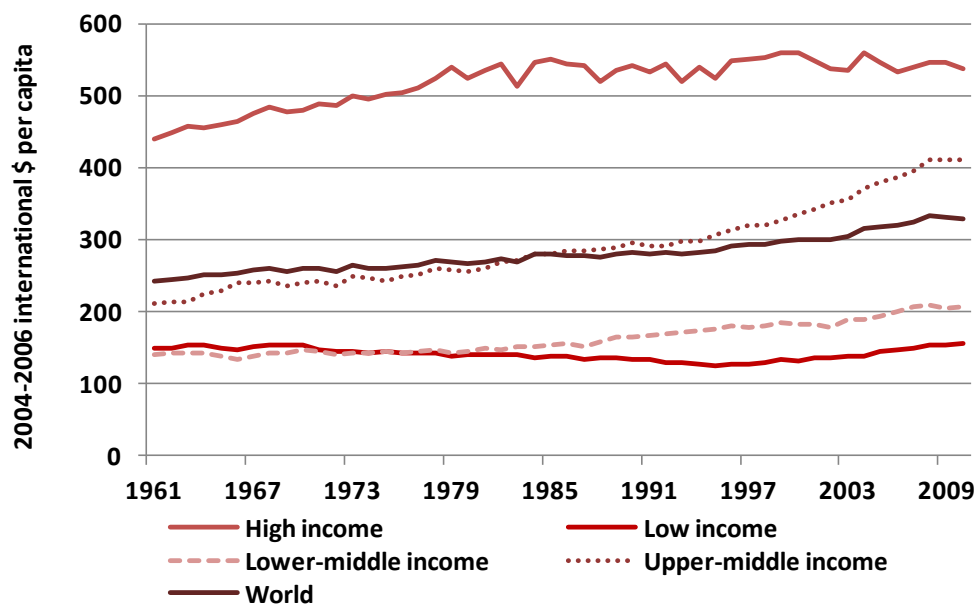
Source: Authors' calculations based on FAOSTAT (2012).

Notes: Agricultural area is in billions of hectares and population and agricultural labor is in billions of persons. VOP is value of agricultural production in billions of 2004-2006 agricultural PPPs. High-income countries are those with 2010 GNI per capita of $12,276 or more; upper middle income countries are between $3,976 and $12,275; lower middle income countries between $1,006 and $3,975; and low income countries below or equal to $1,005 (World Bank 2011, p.389).

Table 1: Country concentration of agricultural land and value of production, 2008–2010 average

		Value of Agricultural Production			Arable and Permanent Cropland		
			Share				Share
Rank	Country	Partial	Cumulative	Country		Partial	Cumulative
			%				%
1	China	22.9	22.9	India		11.1	11.1
2	United States of America	10.4	33.4	United States of America		10.8	21.9
3	India	9.6	42.9	Russian Federation		8.1	30.0
4	Brazil	5.7	48.7	China		8.1	38.1
5	Indonesia	2.6	51.2	Brazil		4.5	42.6
6	Russian Federation	2.2	53.4	Canada		3.4	46.0
7	France	1.8	55.3	Australia		3.0	49.0
8	Argentina	1.8	57.1	Indonesia		2.7	51.7
9	Pakistan	1.7	58.7	Nigeria		2.6	54.2
10	Germany	1.6	60.4	Ukraine		2.2	56.4
	Top 20		73.8				71.1
	Bottom 100		1.2				1.1

Source: Authors' calculations based on FAOSTAT (2012).

Notes: Top 20 and bottom 100 producers groups countries according to their ranking of 2008-10 value of agricultural production.

33

Table 2: Yield growth rates for selected crops, 1961–2010

	Maize			Wheat			Rice, paddy			Soybeans			Cereals		
	1961-2010	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010	1961-2010	1961-1990	1990-2010
	Percent per year														
Geographical regions															
North America	1.77	1.99	**1.75**	1.16	1.38	**0.98**	1.25	1.22	1.33	1.24	1.06	**1.03**	1.86	1.83	2.21
Australia & NZ	2.56	3.44	**0.96**	0.78	0.83	**-0.94**	0.83	0.16	0.28	2.44	4.49	**1.22**	1.01	1.20	**-0.79**
Western Europe	2.72	3.73	**1.32**	2.33	3.21	**0.83**	0.73	0.62	0.70	1.69	2.06	**-0.10**	2.03	2.58	**1.00**
Eastern Europe	1.29	2.54	**1.93**	1.27	3.19	**0.18**	1.21	0.51	3.49	2.01	1.50	3.24	1.19	2.77	**0.74**
USSR	0.74	1.62	1.97	1.42	2.15	**1.23**	0.36	1.75	1.80	2.01	2.40	2.86	1.38	1.94	**1.61**
Asia & Pacific	2.88	3.54	**1.53**	2.96	4.08	**1.42**	1.80	2.26	**1.04**	1.38	2.05	**0.23**	2.36	2.88	**1.47**
China	3.06	4.39	**0.81**	4.01	5.76	**2.05**	2.13	3.06	**0.64**	1.90	2.38	**0.51**	2.90	4.10	**1.24**
Latin America & Caribbean	2.48	2.01	3.22	1.78	1.67	**1.52**	2.31	1.39	3.10	1.87	1.98	**1.61**	2.23	1.98	2.70
Africa	0.99	1.30	1.70	2.55	2.88	**1.84**	0.74	0.83	1.03	2.43	2.34	3.97	0.89	1.27	1.37
Nth Africa [a]	2.78	2.42	2.59	2.47	2.14	**1.99**	1.66	0.73	1.62	1.70	5.23	**1.14**	2.16	1.56	2.09
Income Class															
High income	1.88	2.24	**1.68**	1.55	2.02	**0.68**	0.82	1.03	**0.79**	1.28	1.15	**1.00**	1.68	1.99	**1.32**
Middle income	2.35	2.56	**2.32**	2.33	3.12	**1.28**	1.91	2.41	**1.04**	2.38	3.12	**1.77**	2.22	2.70	**1.67**
Low income	0.56	1.19	**0.36**	1.49	2.08	**2.02**	1.72	1.50	2.18	1.12	3.00	**-0.55**	1.11	1.26	1.57
Countries by production rank															
Top 10	2.16	2.46	**1.82**	2.11	2.84	**1.03**	1.87	2.26	**1.13**	1.47	1.68	**1.10**	2.27	2.64	**1.71**
Top 20	2.08	2.41	**1.98**	2.08	2.74	**1.05**	1.81	2.20	**1.12**	1.50	1.72	**1.17**	2.14	2.54	**1.64**
Other producers	1.42	1.95	**1.49**	1.67	2.69	**0.87**	0.91	1.06	**0.82**	1.32	2.75	**-0.29**	1.03	1.59	**0.87**
World	1.96	2.33	**1.82**	2.03	2.73	**1.03**	1.76	2.14	**1.09**	1.50	1.72	**1.18**	1.91	2.35	**1.45**

Source: Authors' calculation based on FAOSTAT (2012).

Notes: Bolded entries have slower post versus pre 1990 growth. All growth rates were calculated using the least-squares method (i.e., as the slope of a regression of logarithms of variables against trend). Top 10, top 20 and other producers groups countries according to their ranking of 2008-10 value of agricultural production. Production and area data were aggregated into geographical and income groupings prior to calculating yields. Cereals include the following commodities: barley, buckwheat, canary seed, cereal nes, fonio, maize, millet, mixed grain, oats, rice, rye, sorghum, triticale, and wheat. Africa is sub-Saharan Africa

[a] First year of data for soybeans is 1972 therefore the growth rate for the first period spans 1972 to 1990.

Table 3: Countries with slower yield growth since 1990

Grouping	Maize	Wheat	Rice	Soybeans	All Cereals
			(count)		
Total number of countries	139	95	105	49	156
All countries	62	67	58	32	95
Top 10 producers	3	10	6	8	7
Top 25 producers	12	21	14	19	18
			(percent)		
All countries	45	71	55	65	61
Top 10 producers	30	100	60	80	70
Top 25 producers	48	84	56	76	72

Source: Authors' calculations based on FAOSTAT (2012).

Notes: Total number of countries is a count of those countries with reported crop production. All remaining entries indicate the count and share of reported producers with slower yield growth in 1990-2010 period compared with 1961-1990 period. Top 10 and top 25 producers groups countries according to their ranking of 2008-10 value of agricultural production. For certain countries and crops, the period coverage is as follows due to missing data: 1966–1990 for Antigua and Barbuda (cereals, maize), Uganda (wheat); 1967-1990: Rwanda (rice), Bolivia (soybeans); 1968–1990: Kuwait (cereals), Western Sahara (cereals), Zambia (rice); 1969-1990: El Salvador (soybeans); 19701990: Somalia (rice), Spain (soybeans), Swaziland (wheat); 1971-1990: Qatar (cereals and wheat); 1990-2008: Botswana (wheat).

**Figure 2: Land and labor productivity, 1961–2010**
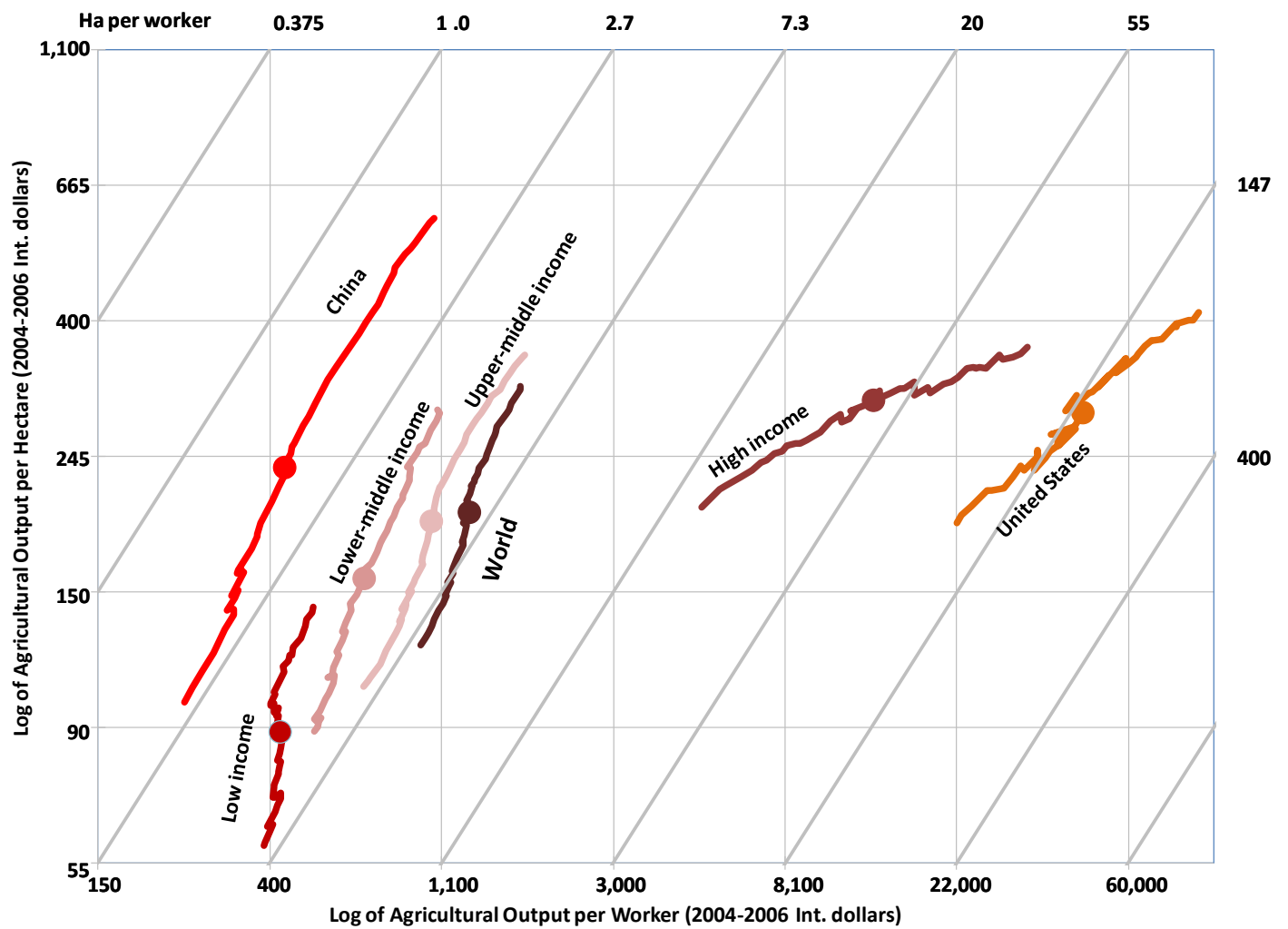
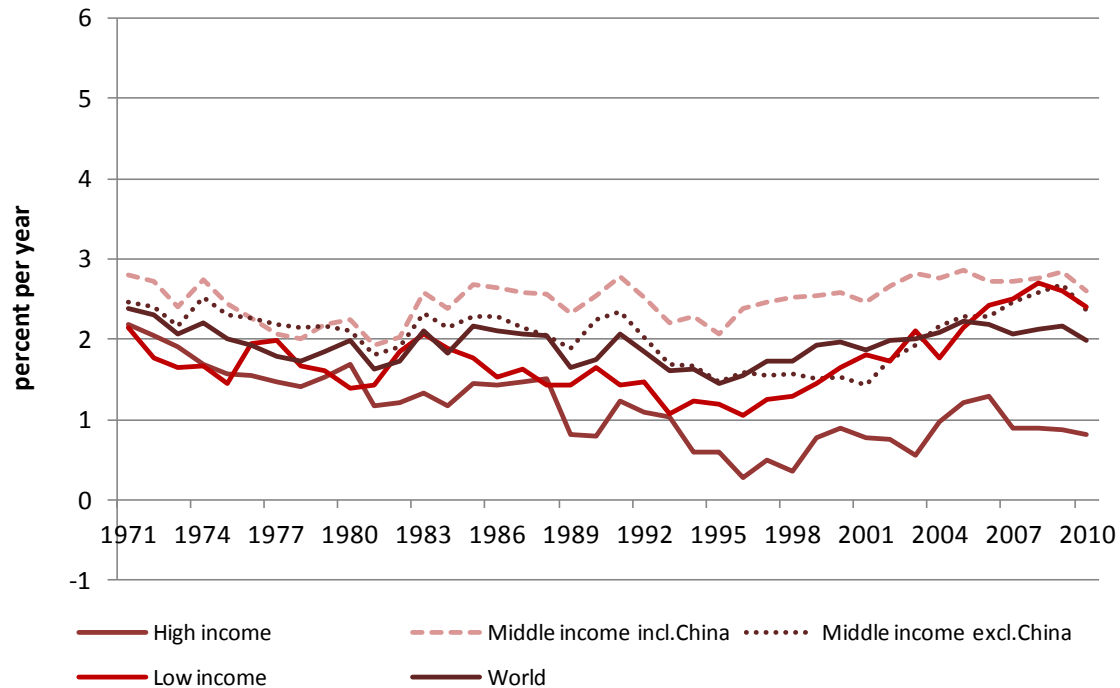Source: Authors' calculations based on FAOSTAT (2012).

Notes: Dot on each productivity locus indicates mid-point of sample period, 1985. Vertical and horizontal axes are scaled in natural logs, but value entries on the axes are in anti-logs.

Figure 3: Rates of growth of land and labor productivity, ten-year moving average, 1961–2010

Panel a: Agricultural labor productivity growth
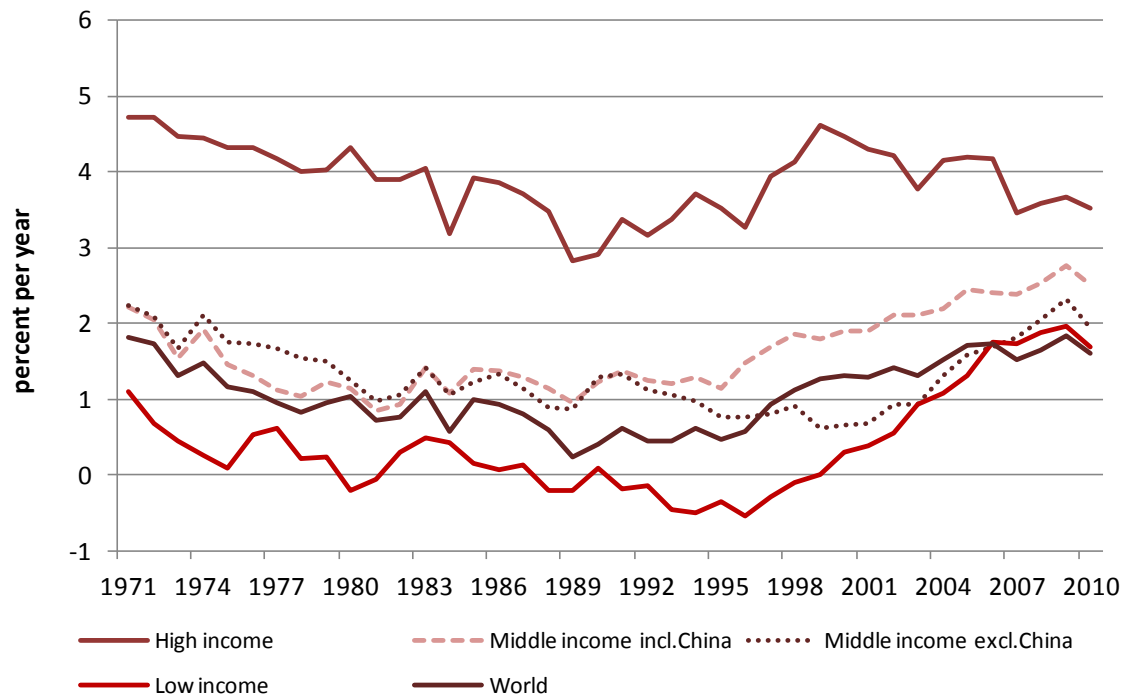
Panel b: Agricultural land productivity growth

Source: Authors' calculations based on FAOSTAT (2012).

Note: Plots represent moving averages over ten years ending in the year of the observation.

Table 4: Countries with slower partial productivity growth since 1990

	Land Productivity			Labor productivity		
	1961-90	1990-10	Difference	1961-90	1990-10	Difference
	(percent per year)					
World (N=190)	1.98	2.07	0.09	0.94	1.58	0.64
World minus China	1.81	1.62	**-0.19**	1.10	0.82	**-0.28**
China	3.22	3.96	0.74	2.01	3.93	1.92
80% excl. China (N=23)	1.78	1.83	0.05	1.05	1.17	0.12
Bottom 20% (N=166)	1.85	1.20	**-0.65**	1.20	0.10	**-1.10**

Source: Authors' calculations based on FAOSTAT (2012).

Notes: Bolded entries have slower post versus pre 1990 growth. All growth rates were calculated using the least-squares method (i.e., as the slope of a regression of logarithms of variables against trend). "80% excl. China" includes the 23 countries that accounted for 80 percent of the 2008-10 value of agricultural production (net of Chinese output). "Bottom 20%" includes the 166 countries that accounted for the remaining 20 percent of global agricultural output.
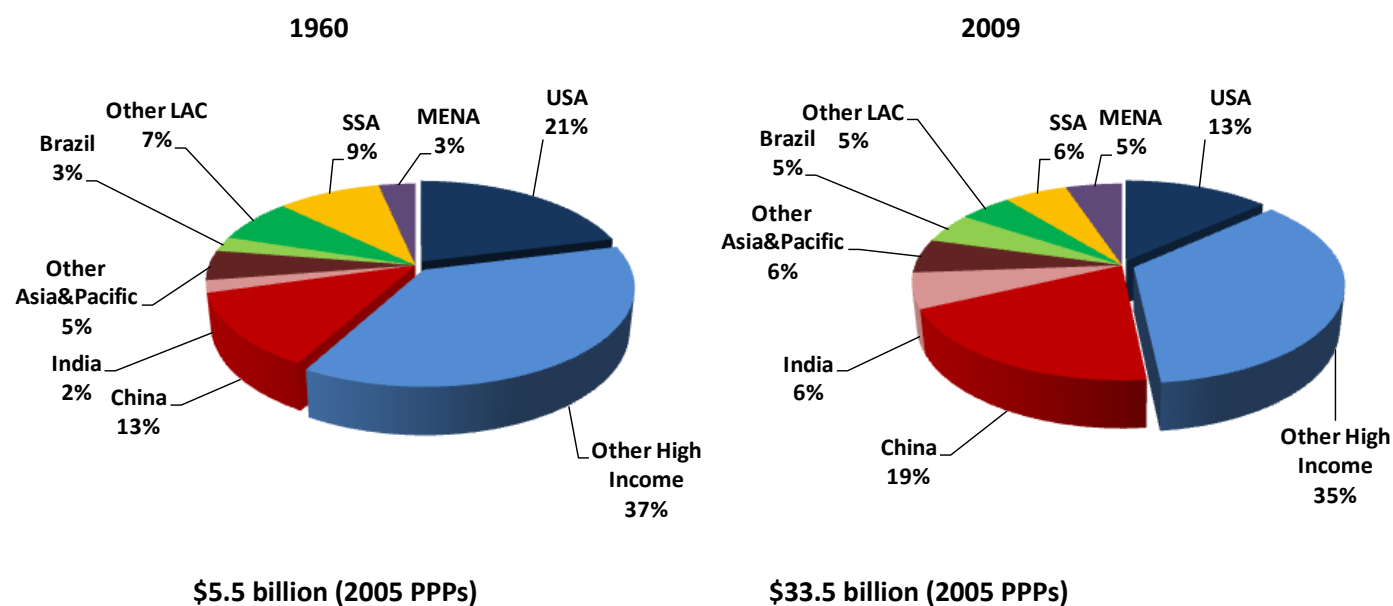
Table 5: Summary of data sources and methods by decade and overall, 1961-2009

		Share of observations						Share of AgR&D spending					
		1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	1960-2009	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	1960-2009
							(percent)						
1	ASTI	0	0	22.9	36.9	32.4	18.4	0	0	13.1	21.5	13.6	12.4
2	OECD based	0.6	0.4	4.6	6.3	9.4	4.3	0.5	0.2	3.2	8.1	11.4	6.4
3	National	4.0	5.8	6.7	9.2	8.3	6.8	28.8	26.3	30.5	47.1	46.6	39.0
4	Various sources	7.7	21.1	14.8	1.7	0	9.1	12.7	19.1	9.7	0.2	0	5.9
5	Interpolate	11.3	14.8	6.4	3.1	2.1	7.6	5.1	5.5	1.9	2.4	0.7	2.4
6	Rate of change	37.8	30.0	8.0	1.1	1.2	15.6	27.1	31.6	20.7	3.2	3.5	12.9
7	ARI based	37.2	24.4	32.5	37.9	42.1	34.8	17.0	3.4	6.7	7.4	13.6	9.4
8	Other methods	1.3	3.5	4.0	3.8	4.5	3.4	8.7	13.9	14.1	10.1	10.7	11.5
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Notes: 1. Data downloaded November 2011 from ASTI (http://www.asti.cgiar.org/); 2. Data based on: (a) Gross Domestic Expenditure on Research and Development (GERD) series downloaded from OECD.Stat (http://stats.oecd.org/), (b) (International) Survey of the Resources Devoted to R&D (OECD, various years); and (c) Science & Technology Indicators, Basic Statistical Series (OECD, various years); 3. Data obtained from national statistical agencies. 4. Data from Pardey and Roseboom (1989), Alston et al. (2002), Pardey et al. (2006), ISNAR Statistical briefs downloaded from http://www.asti.cgiar.org/publications/country-briefs, and data from Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/science_technology_innovation/data/database) downloaded November 2011; 5. Missing values derived by linear interpolation; 6. Series back- or forward-cast using rate of change in relevant agricultural R&D data obtained from various sources, including those cited in 4; 7: Proximate agricultural research intensities (i.e., agricultural R&D spending relative to agGDP) used in conjunction with corresponding annual, country-specific measures of agGDP to develop estimates of the amount of agricultural R&D spending per country per year; 8. Other author estimates based on data obtained from various sources.

Figure 4: Global trends in public agricultural R&D spending, 1960-2009

Panel a: Public Agricultural and Food R&D

1960

Other LAC 7%
Brazil 3%
Other Asia&Pacific 5%
India 2%
China 13%
SSA 9%
MENA 3%
USA 21%
Other High Income 37%

$5.5 billion (2005 PPPs)

2009

Other LAC 5%
Brazil 5%
Other Asia&Pacific 6%
India 6%
China 19%
SSA 6%
MENA 5%
USA 13%
Other High Income 35%

$33.5 billion (2005 PPPs)

Panel b: Spending trends by region
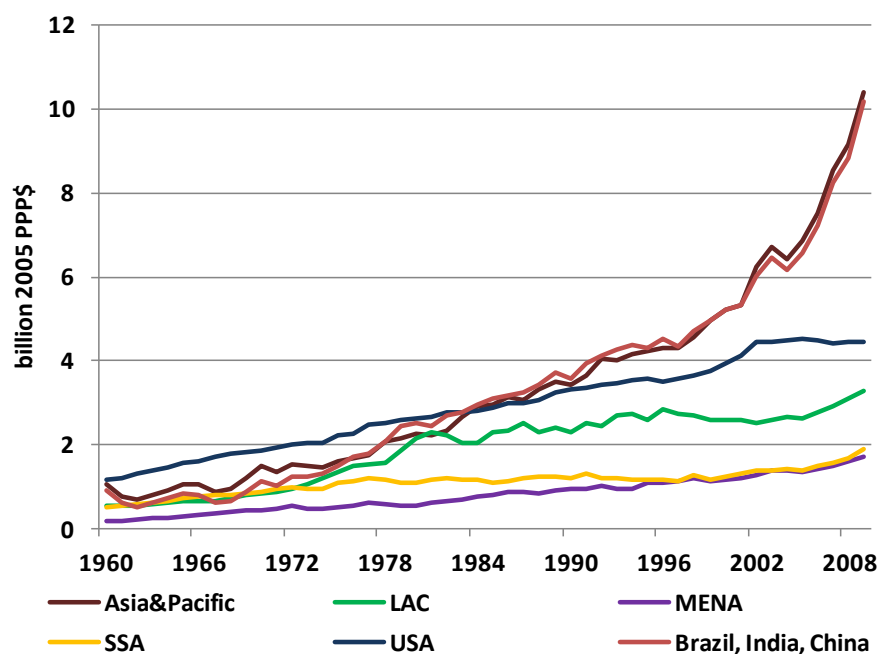
Asia&Pacific — LAC — MENA — SSA — USA — Brazil, India, China

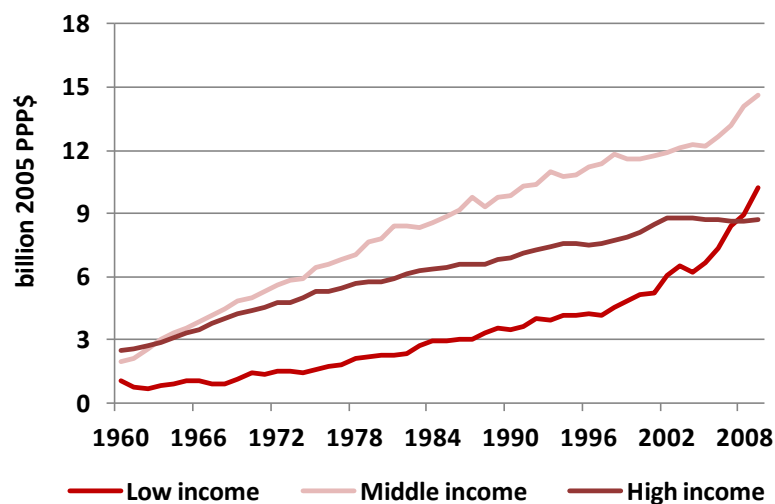*Source*: Pardey, Chan-Kang and Dehmer (2012).

*Note*s: Eastern European and Former Soviet Union countries are excluded. Asia & Pacific includes China and India; LAC (Latin America & Caribbean) includes Brazil. 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. See Appendix 1 for countries grouped into regions.

Figure 5: Public agricultural R&D spending by income class, 1960-2009

Panel a. Countries grouped by 2010 per capita incomes
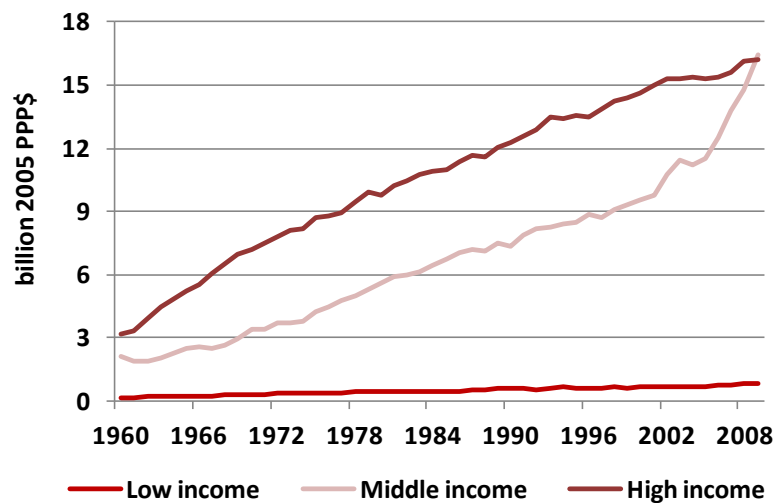
Panel b. Countries grouped by 1960 per capita incomes

Source: Pardey, Chan-Kang and Dehmer (2012).

Notes: Countries grouped intro income classes using contemporary World Bank (2011) schema and each country's 2010 per capita income (Panel a) and 1960 per capita income (Panel b).

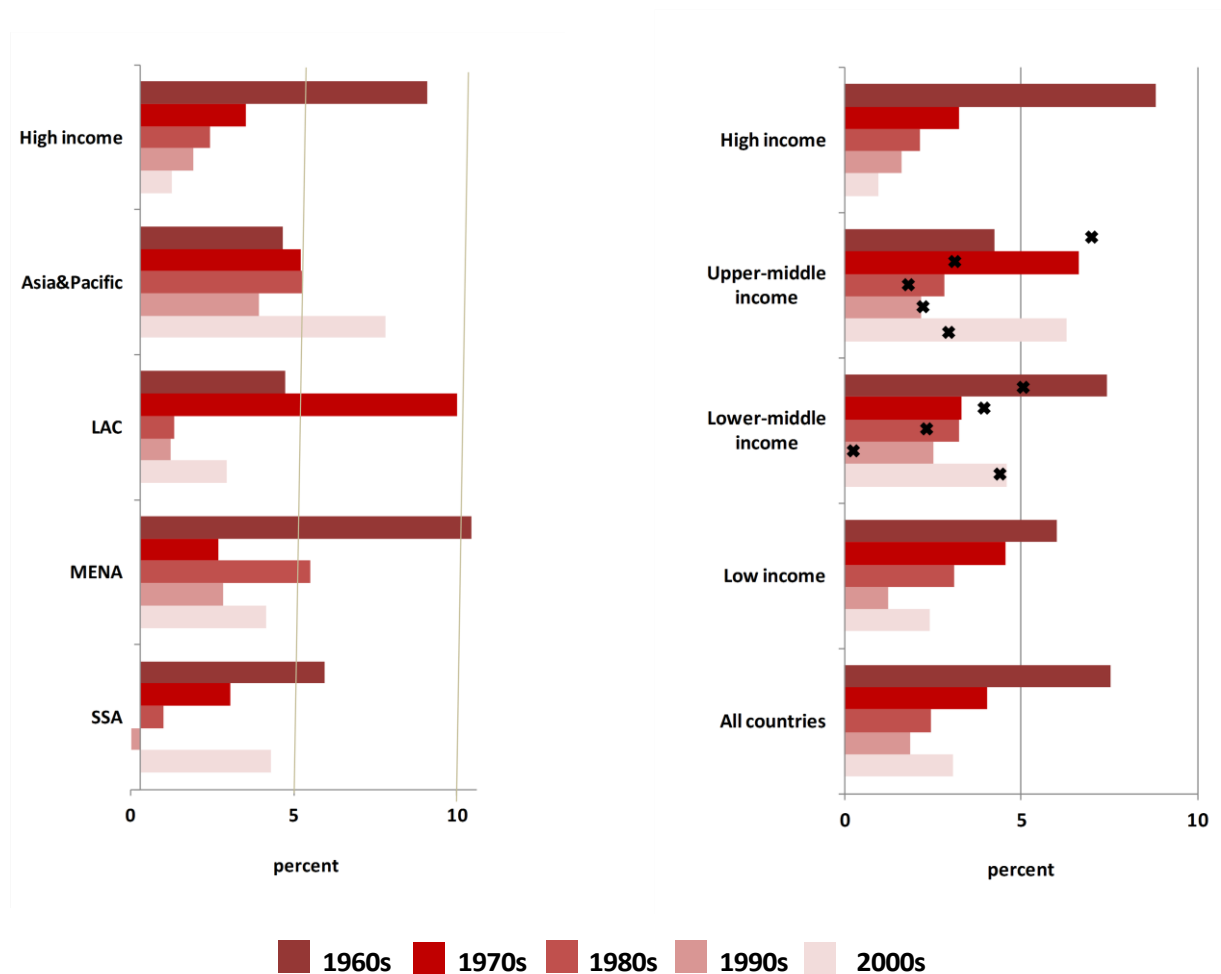**Figure 6: Shifting shares of global public agricultural R&D spending, 1960-2009**
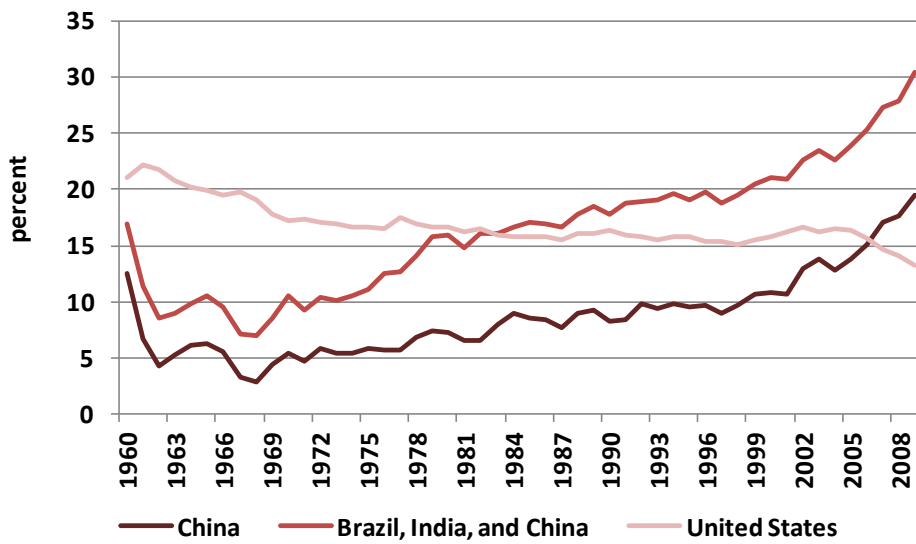
Source: Pardey, Chan-Kang and Dehmer (2012).

Note: Eastern European and Former Soviet Union countries are excluded from the global total used to calculate shares.

Figure 7: Rates of growth in public agricultural R&D spending by decade, 1960-2009

Panel a: Growth rates by region   Panel b: Growth rates by income class

1960s **1970s** **1980s** **1990s** **2000s**

Source: Pardey, Chan-Kang and Dehmer (2012).

Notes: Eastern European and Former Soviet Union countries are excluded. All growth rates were calculated using the least-squares method (i.e., as the slope of a regression of logarithms of variables against trend). See Figure 4 for details on country coverage and groupings. 1960s indicates the period covering 1960—1970, and likewise for other decades. Units of horizontal axis in Panel a is percent per year.

43

Table 6: Top ten agricultural R&D spending countries, 1960 and 2009

| Rank[a]	Country	1960–62	Rank[a]	Country	2007–09
		million 2005 PPP$			*million 2005 PPP$*
1/2	United States	1,214	2/1	China	5,767
2/1	China	433	1/2	United States	4,446
3/6	Germany	378	5/3	Japan	3,202
4/13	United Kingdom	294	13/4	India	1,837
5/3	Japan	290	10/5	Brazil	1,480
6/7	Canada	224	3/6	Germany	969
7/24	South Africa	205	6/7	Canada	872
8/16	Australia	161	15/8	France	868
9/19	Argentina	137	26/9	Spain	793
10/5	Brazil	135	14/10	South Korea	792
Top 10 total		3,471/62%[b]	Top 10 total		21,026/66%
Top 20 total		4,370/78%	Top 20		26,202/82%
Bottom 100 total		979/17%	Bottom 100		4,324/14%

Source: Authors' calculations based on data from Pardey, Chan-Kang and Dehmer (2012).

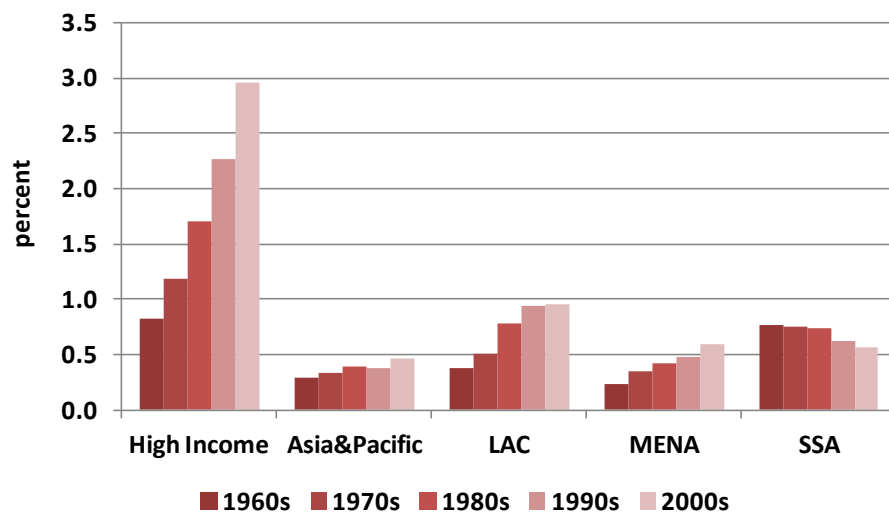[a] A/B where A is the 1960-62 rank and B is the 2007–2009 rank

[b] Percentages indicate the respective group total share of world total..

Figure 8: Agricultural research intensities by region and income class, 1960–2009

Panel a: ARI by income class
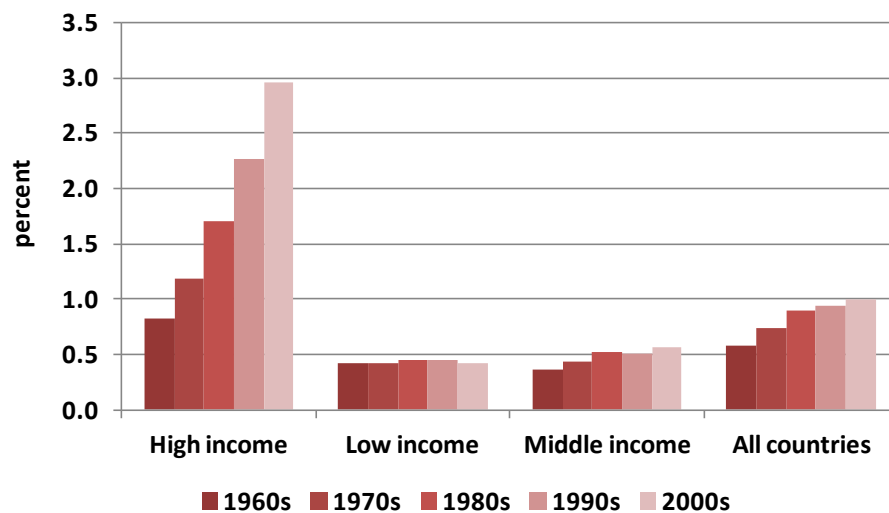
Panel b: ARI by region

Source: Pardey, Chan-Kang and Dehmer (2012).

Notes: ARI (agricultural research intensity) indicates food and agricultural R&D spending relative to ag GDP. See Figure 4 for details on country coverage and groupings.

Appendix table: List of countries by region

Region	Countries
High Income	Australia, Austria, Barbados, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Guam, Iceland, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Puerto Rico, Qatar, Singapore, South Korea, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States, and U.S. Virgin Islands.
Asia and Pacific	Bangladesh, China, Fiji, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Pakistan, Papua New Guinea, Philippines, Samoa, Solomon Islands, Sri Lanka, Thailand, Tonga, Vanuatu, and Vietnam.
Latin America and Caribbean (LAC)	Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Uruguay, and Venezuela.
Middle East and North Africa (MENA)	Egypt, Iran, Jordan, Morocco, Syria, Tunisia, and Turkey.
Sub-Saharan Africa (SSA)	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Democratic Republic of Congo , Republic of Congo, Ethiopia PDR, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

Source: Authors categorization.