THEME OVERVIEW: AGRICULTURAL PRODUCTIVITY AND GLOBAL FOOD SECURITY IN THE LONG RUN

Julian M. Alston and Philip G. Pardey

The relative rates of growth in the supply and demand for food, feed and fiber have far-reaching economic and social consequences, most readily observed through changes in commodity prices. Over the past 50 years and longer, the supply of food commodities has grown faster than the demand, in spite of increasing population and rising per capita incomes. As a consequence, the real (deflated) prices of food commodities have trended down over many years, contributing significantly to the alleviation of hunger and poverty worldwide.

Figure 1 illustrates the long-term trends in global commodity prices, using U.S. price indexes for wheat, maize, and soybeans over the period 1924 to 2008, expressed in real terms by deflating with the index of prices paid by farmers. These indexes all start at 100 in the base year of 1924. While rice was omitted to improve the clarity of the plots, rice prices follow a similar overall pattern to the commodity prices shown here. These price patterns reflect the fact that supply has been growing faster than global demand generally, albeit at different rates for the different products.

In real terms, commodity prices trended up generally, albeit with some major fluctuations during and after the Great Depression, from 1929 through the end of World War II after which they have trended generally down. This downward trend was interrupted by the major price spike in the 1970s and again at the end of the series by the latest price spike. The trend lines in the figure show the real prices declining at different rates during the period 1950-1970, as they converged towards equality. Then following the 1970s price spike, over the period 1975-2005, they trended down at roughly equal rates.

The period since World War II includes three distinct sub-periods. First, over the 20 years 1950-1970, wheat prices declined fairly rapidly, while prices for rice, maize, and soybeans declined at a slower rate. Next, following the price spike of the early 1970s, over the years 1975-1990, real prices for all four commodities declined relatively rapidly. Finally, over the years 1990-2005, the rate of price decline slowed for all four commodities, especially towards the end of that period.

Recent turbulence in food commodity markets garnered attention in the popular press. Policymakers and others have been reminded that ever-declining food prices are not guaranteed and that food prices influence the welfare of many people in the world, with rising prices having disproportionately adverse consequences for the world's poorest and most vulnerable people. Beginning in early 2008, food and commodity prices soared globally and the dismal tally of hungry people in the world increased. Driven in part by the demand for biofuels, stimulated by high and rising oil prices and government responses to them, as well as tight inventories, prices of staple commodities also rose rapidly to historical highs (at least in nominal terms) in early 2008. The peak was short-lived. By November 2008 the price of oil had fallen back to around $50 from an all-time high of almost $145 per barrel in July 2008. Crop production has increased and prices of staple food and feed commodities have also fallen significantly. Still, the experience of 2008 raised questions about the long-term future prospects for food prices.

Figure 1. Real U.S. Prices of Maize, Soybeans, and Wheat, 1924-2008
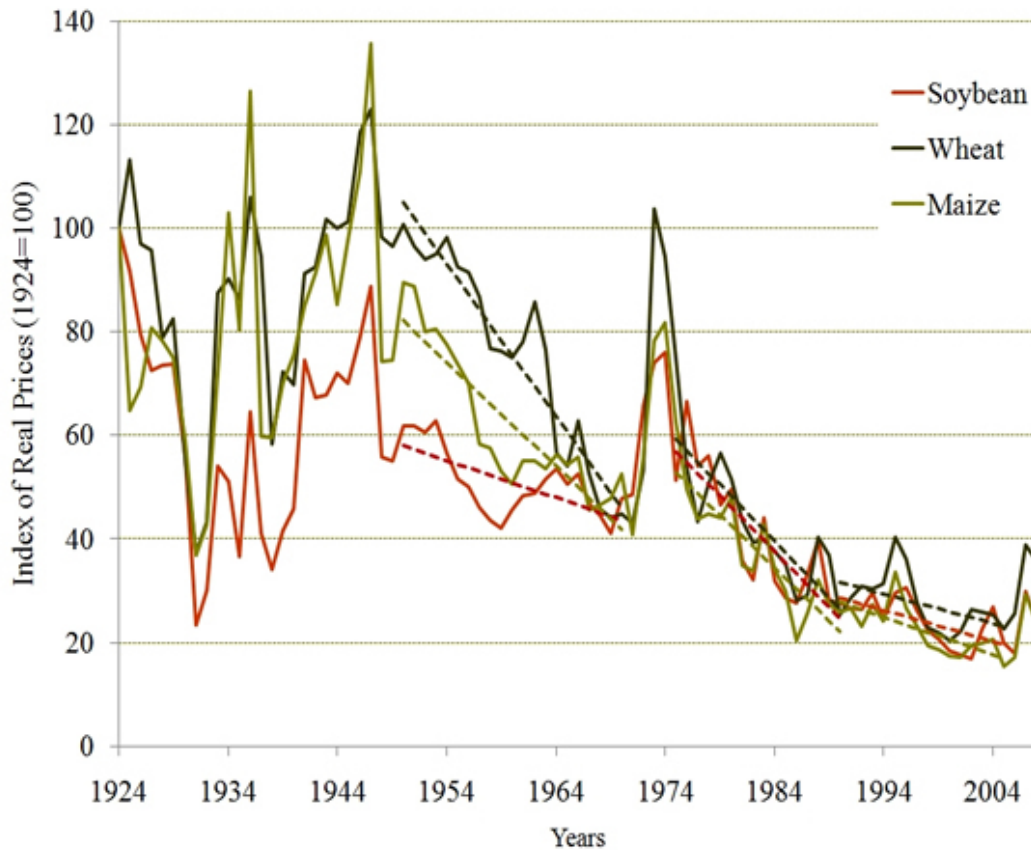
Source: Compiled by the authors with data cited in Alston, Beddow and Pardey (2009b).

Notes: Nominal prices were deflated using the real farm price index. Dashed trendlines represent ordinary least squares regression lines of best fit where the respective commodity price was regressed against a linear time trend during each of the periods 1950-1970, 1975-1990, and 1990-2008.

The demand side of the question is relatively straightforward and uncontroversial. Global population is projected to increase by 2.3 billion people, about one-third, to 9.1 billion people by 2050. The FAO recently estimated that demand for food would increase by 70% by 2050, reflecting the effects of both population growth and rising per capita incomes. The supply side is less straightforward. The past growth in supply reflects the increased use of some inputs—especially land, water, and chemical inputs including fuels, fertilizers, and pesticides—balanced partly by labor savings in many places, combined with technology-driven increases in productivity.

While increases in inputs were important in many places, agricultural productivity growth was the key driver of the extraordinary growth in agricultural supply in the 20th century that enabled the world to feed many more people, better and at lower cost to the natural resource base than would have been necessary otherwise. With increasing environmental and urban competition for land and water resources, an even greater share of future growth in agricultural supply will have to come from growth in productivity.

Will the next 50 years mirror the pattern of the past 50 years, or is the era of ever-increasing agricultural abundance coming to an end? The answer turns on the future path of agricultural productivity. The papers collected under this Choices theme explore recent past patterns in agricultural productivity growth in different parts of the world, with particular attention to the United States (James et al.), China (Rozelle et al.), and a set of countries comprising the former Soviet Union (or FSU) and Eastern Europe (Swinnen et al.) buttressed with an overview of global patterns (Beddow et al.). These papers are all drawn from a more comprehensive

analysis reported in greater detail in the book on the same subject, edited by Alston, Babcock, and Pardey (2010).

Such a review of the recent past is a useful first step towards answering questions about the likely future path of agricultural productivity and what may be implied for the availability and price of food over the coming decades. The papers reveal several interesting points. First, institutional changes in China, the FSU and Eastern Europe during the 1990s have had substantial impacts on global productivity patterns. China has had continuing high rates of productivity growth, pulling the global average up, while the countries of the FSU and Eastern Europe have had a dismal record of productivity, especially during the initial years of transition, pulling the global average down. The effects of these essentially one-shot, institutional changes might have realized much of their supply stimulating effects, so it is not straightforward to extrapolate from the recent past to the future. Second, among developed countries generally, agricultural productivity growth appears to have slowed significantly during the most recent 10-20 years, possibly reflecting an earlier slowdown in growth of spending on certain types of productivity enhancing agricultural R&D.

If they are sustained for more than a few years, these diverging patterns of productivity growth can be expected to have very significant implications for international competitiveness and comparative advantage in agriculture among nations, and among regions of the world. The long-term outcomes will turn on the influences of determinants of productivity patterns that cannot be controlled in the near term, such as climate change, and other determinants that can, such as private and public investments in agricultural science and technology.

For More Information

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. (2010)Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending. New York: Springer, (in press).

Alston, J.M., B. A. Babcock and P.G. Pardey, eds. (2010). Shifting Patterns of Agricultural Production and Productivity Worldwide. CARD-MATRIC Electronic Book. Ames, IA: Center for Agricultural and Rural Development, (forthcoming).

Alston, J.M., J.M. Beddow, and P.G. Pardey. (2009a, September). Agricultural Research, Productivity, and Food Prices in the Long Run. Science 325(4), 1209-1210.

Alston, J.M., J.M. Beddow, and P.G. Pardey. (2009b, revised September) Mendel versus Malthus: Research Productivity and Food Prices in the Long Run. Department of Applied Economics Staff Paper No. P09-01, St Paul, University of Minnesota.

FAO (Food and Agriculture Organization of the United Nations). (2008, September). Hunger on the Rise: Soaring Prices Add 75 Million People to Global Hunger Rolls. FAO Briefing Paper Rome: FAO. Available at http://www.fao.org/newsroom/common/ecg/1000923/en/hungerfigs.pdf. Accessed November 2008c.

FAO (Food and Agriculture Organization of the United Nations). (2009). 2050: A Third More Mouths to Feed. Available at http://www.fao.org/news/story/en/item/35571/icode/.

Pardey, P.G., J.M. Alston, and R.R. Piggott, eds. (2006). Agricultural R&D in the Developing World: Too Little, Too Late? Washington D.C.: International Food Policy Research Institute.

Von Braun, J. (2007, December). The World Food Situation: New Driving Forces and Required Action. IFPRI Food Policy Report. Washington D.C.: International Food Policy Research Institute.

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THE SHIFTING GLOBAL PATTERNS OF AGRICULTURAL PRODUCTIVITY

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Growth in supply of agricultural commodities is primarily driven by growth in productivity, especially as land and water resources for agriculture have become more constrained. Hence, the future path of agricultural productivity will be the key determinant of the future of the world food equation. Here we present and assess trends in agricultural productivity growth over recent decades as a first step to informing views about likely agricultural supply and food security outcomes worldwide over the decades ahead.

Our emphasis is on global trends in selected partial factor productivity measures that express output relative to a particular input such as land or labor. These include crop yields, which measure the quantity produced of a particular output relative to a particular input, land. Descriptions of more-complete measures of productivity for selected key agricultural countries or regions of the world, including Canada, China, the former Soviet Union (FSU) and Eastern Europe, and the United States, are presented in the articles that follow. These agricultural economies are each quite distinctive (Table 1), and productivity developments within them have global consequences, given that they collectively produce around one-half of the world's agricultural output value.

Table 1

Attributes of Agriculture in Canada, China, the Former Soviet Union, and the United States, circa 2008

	United States	Canada	China	FSU & E. Europe	Global Total
Population (million)	304.10	33.30	1325.60	379.30	6692.00
Rural population (million)	55.60	6.50	754.30	138.20	3339.60
GDP (billion/year)	14204.30	1400.10	4326.20	3521.60	60585.30
Ag GDP (billion/year)	153.40	30.80	489.30	192.00	1793.30
Per capita GDP ($/year)	46715.50	42030.40	3263.50	9285.20	9053.40
Ag GDP as percent of total GDP (%)	1.08	2.20	11.31	5.45	2.96
Per capita Ag GDP ($/year)	504.53	924.67	369.10	506.31	267.98
Agricultural land area (1,000 sq. km.)	4147.80	675.00	5563.30	6133.40	49556.60
Ag land as share of total land area (%)	45.270	7.42	59.64	26.43	38.17
Top 5 crops by value	Maize (31.2)	Wheat (30.2)	Rice (14.7)	Wheat (24.8)	Rice (12.1)
Share in parentheses (%)	Soybeans (17.3)	Rapeseed (17.5)	Maize (6.0)	Potatoes (16.9)	Wheat (9.3)
	Cotton (9.3)	Barley (9.6)	Wheat (5.8)	Cotton (5.9)	Maize (7.7)
	Wheat (8.6)	Maize (7.4)	Cotton (5.1)	Maize (5.5)	Cotton (5.0)
	Tomatoes (3.8)	Potatoes (5.3)	Potatoes (4.1)	Barley (5.4)	Potatoes (4.4)
Output value per labor (2005/6 value)	66601	63237	749	4975	1205
Growth rate 1961 - 2005/6 (%/year)	2.92	4.35	3.03	2.27	1.20
Output value per hectare (2005/6 value)	541	532	678	253	354
Growth rate 1961 - 2005/6 (%/year)	1.70	1.95	3.39	0.41	1.96
Land /labor ratio (2005/6 value)	123.0	118.9	1.1	19.7	3.4
Growth rate 1961 - 2005/6 (%/year)	1.23	2.41	-0.36	1.86	-0.76

Source: Commodity value and productivity values are calculated using an IFPRI extraction of FAO data, and are based on average 1999-2001 prices. Other values are from the World Development Indicators database (World Bank, extracted October, 2009) and are for the most recent year available, usually 2008.

Productivity Patterns

Measuring and interpreting productivity and its rate of growth is difficult enough, let alone changes in productivity growth rates. The substantial annual variation in input use and uncontrolled factors such as weather together drive the year-to-year variation in aggregate output. This makes it difficult to discern the onset, magnitude, and duration of any structural shifts in agricultural productivity trends (Figure 1). Year-to-year variations in measured productivity growth might reflect the influences of short-term, transient factors such as weather impacts or policy changes; they might also be the result of measurement errors such as those associated with variable utilization rates of capital or land. In addition, measured growth rates are sensitive to the choices of starting and ending dates, and more so when the intervals are shorter.

Figure 1

Assessing Growth in *Average* Crop Yields

The interpretation of average global crop yields is problematic for several reasons. It can be especially difficult to disentangle the effects of changes in technologies, such as improved crop cultivars, from changes in the use of inputs like fertilizer, pesticides, and irrigation. Moreover, year-to-year fluctuations in weather have direct and measurable yield consequences that are typically pronounced for smaller versus larger areas, for example, a national versus regional versus global average.

More subtly, 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. Consequently, reporting yields on the basis of harvested area would understate the rate of growth in crop yields compared with crop yields measured on the basis of arable area if the intensity of crop plantings per year had increased over time.

Another confounding factor when interpreting changes in global or regional yield aggregates, as well as national aggregate yields for that matter, is the effect of the changing spatial location of production. Changes in location of production imply changes in average productivity reflected in yields to the extent that different locations have different endowments of soils and climate, different incentives, and different technological opportunities. Thus, for example, a country's average yield of a commodity may decrease if production expanded into marginal areas. The average yield decrease in this case results from the fact that land is not a homogenous input. However, it is not straightforward to sort out how land characteristics and other aspects of location affect productivity.

Crop Yields

Figure 2 includes yield growth rates for selected U.S. crops—including maize, wheat, rice, and soybeans—for various time periods. For maize, wheat, and rice, yield growth rates accelerated in the second half of the 20th Century relative to the first half; in the second half of the century wheat and maize yields grew at around three times the growth rate in the first half century. For soybeans, in contrast, the rate of growth of yields after 1950 was half that for 1924-1950. However, for all four crops, the average annual rates of yield growth were much lower in 1990-2008 than in 1950-1990. For example, maize yields increased by 2.83% per year during

1950-1990, but only 1.45% per year thereafter, while the growth in wheat yields slowed from 2.18% per year to just 0.71% per year.

Figure 2. U.S. Maize, Rice, Wheat, and Soybean Yield, 1900-2008
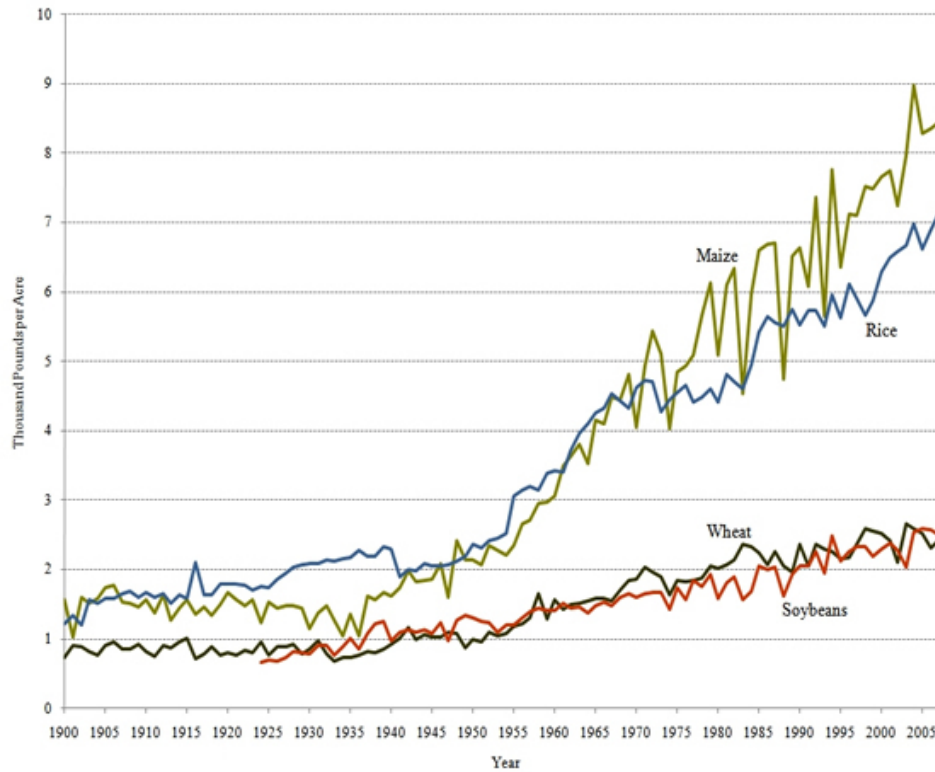
Global annual average rates of yield growth are reported in Table 2, which includes separate estimates for high-, middle-, and low-income countries and the world as a whole, for two sub-periods: 1961-1990 and 1990-2007. The slowdown evident for the global averages (Table 2) mirrors the slowdown in U.S. crop yield growth (Figure 2), although beginning from comparatively low yields, low-income countries had increasing rates of growth in wheat and rice yields since 1990. Thus low-income countries gained some ground since 1990, however the rebound in yield growth in this part of the world failed to fully make up for the comparatively low growth rates they experienced in 1961-1990. Consequently, significant yield gaps persist: the low-income-country versus world relativities of average maize, wheat, and rice yields in 2007 have fallen below the corresponding 1961 relativities. Low-income countries had average soybean yields that were about 50% of the world average in 1961, and that same gap persisted through to 2007.

Table 2

Global Yield Growth Rates for Selected Crops, 1961–2007

Group	Maize		Wheat		Rice		Soybeans	
	1961-90	1990-07	1961-90	1990-07	1961-90	1990-07	1961-90	1990-07
	Global yield growth rates (% per year)							
World	2.20	1.77	2.95	0.51	2.19	0.96	1.79	1.08
Low Income Countries	1.07	0.65	1.32	2.15	1.46	2.16	2.63	0.00
Middle Income Countries	2.39	2.10	3.22	0.82	2.54	0.81	3.21	2.08
Lower-Middle	3.51	1.79	4.30	1.63	2.62	0.69	2.57	0.66
Upper-Middle	1.35	2.58	2.63	-0.25	1.18	2.98	3.39	2.41
High Income Countries	2.34	1.48	2.47	0.06	1.07	0.54	1.14	0.02

Source: The yield data used to calculate growth rates are from the FAOSTAT database (FAO, extracted June 2009), with some adjustments by the authors.

Notes: Low-income countries are those with 2008 per-capita gross national income (GNI) of $975 or less, high-income countries are those with a per-capita GNI greater than $11,905 and middle-income countries are those with per-capita GNIs that fall between these values in line with World Bank practice. Middle income countries are further subdivided into lower-middle and upper-middle depending on whether their per-capita GNI is above or below $3,855.

For all four commodities, in both high- and middle-income countries—collectively accounting for between 78.8 and 99.4% of global production of these crops in 2007—average annual rates of yield growth were lower in 1990-2007 than in 1961-1990. The growth of wheat yields slowed the most and, for the high-income countries as a group, wheat yields barely changed over 1990-2007. Global maize yields grew at an average rate of 1.77% per year during 1990-2007 compared with 2.20% per year for 1961-1990. Likewise rice yields grew at less than 1.0% per year during 1990-2007, less than half their average growth rate for 1960-1990. Again, paralleling productivity developments in the United States, the slowdown in crop yields is quite pervasive. In more than half of the countries that grew these crops, yields for rice, wheat, maize, and soybeans grew more slowly during 1990-2007 than during 1961-1990. More critically, the slowdown was generally more widespread than among the top ten producing countries worldwide.

The slowdown is also pervasive and even more pronounced when countries are aggregated in terms of harvested area. Looking at the period after 1961, the growth in yields of wheat, rice, and soybeans slowed after 1990 in countries accounting for more than 70% of the world's harvested area; for corn around 65% of harvested area was in countries with slower yield growth after 1990. Latin America is the only continent where countries accounting for more than half the harvested area for all four crops had yields growing at more rapid rates after 1990 than before. Notably, countries accounting for more than 90% of the harvested area among the high-income countries saw the pace of growth of maize and rice yields slow after 1990, while all of the high-income countries had wheat and soybean yields growing at a slower rate in the more recent period.

Land and Labor Productivity

Moving beyond crop yields to more broadly construed productivity measures, global productivity trends show a 2.4-fold increase in aggregate output per harvested area since 1961, equivalent to annual average growth of 2.0% per year. Accompanying this increase in land productivity was a 1.7-fold increase, or 1.2% per year

growth, in aggregate output per agricultural worker (Table 3). These productivity developments reflect global agricultural output growing relatively quickly compared with the growth in the use of agricultural land and labor—0.3% and 1.1% per year, respectively.

Table 3

Growth in Agricultural Land and Labor Productivity Worldwide, 1961-2005

Group	Land Productivity		Labor Productivity	
	1961-90	1990-05	1961-90	1990-05
	Growth rates (% per year)			
World	2.03	1.82	1.12	1.36
excl. China	1.90	1.19	1.21	0.42
excl. China & FSU	1.91	1.57	1.13	0.73
Latin America	2.07	2.71	2.11	3.38
excl. Brazil	2.09	2.21	1.51	2.10
Asia	2.56	3.01	1.83	2.72
excl. China	2.45	1.83	1.69	1.24
China	2.81	4.50	2.29	4.45
Africa	2.18	2.21	0.68	0.90
Low Income Countries	2.00	2.39	0.46	1.03
Middle Income Countries	2.35	2.30	1.51	2.02
excl. China	2.18	1.37	0.39	0.81
High Income Countries	1.61	0.72	4.26	4.18

In parallel with the global crop yield evidence presented above, the longer-run growth in land and labor productivity masks a widespread—albeit not universal—slowdown in the rate of growth of both productivity measures during 1990-2005 compared with the previous three decades. China and Latin America are significant exceptions, both having considerably higher growth rates of land and labor productivity since 1990. Among the top 20 producing countries according to their 2005 value of agricultural output, land and labor productivity growth was substantially slower in 1990-2005 than in 1961-1990 once the large, and in many respects exceptional, case of China is set to one side. After setting aside the top 20 producing countries, on average across the rest of the world, the slowdown is even more pronounced: for this group of countries land productivity grew by 1.83% per year during the period 1961-1990, but by only 0.88% per year thereafter; labor productivity grew by 1.08% per year prior to 1990, but barely budged during the period 1990-2005.

Worldwide, after 1990 the growth rate of land productivity slowed from 2.03% per year to 1.82% per year, whereas the growth rate of labor productivity increased from 1.12% per year for 1961-1990 to 1.36% per year for 1990-2005. Once again these world totals are distorted by the significant and exceptional case of China. Netting out China, global land and labor productivity growth has been slower since 1990 than during the prior three decades. The same period relativities prevail if the former Soviet Union (FSU) is also netted out, although the magnitude of the global productivity slowdown net of China and the FSU is less pronounced because both partial productivity measures for the FSU actually shrank after 1990.

R&D Spending Patterns

The published literature has documented a strong association between lagged R&D spending and agricultural productivity improvements. Among other things, the past and present pace and orientation of agricultural R&D will substantially influence the future rates of yield increase and productivity growth more generally (Alston, et al. 2000). Worldwide, public investment in agricultural R&D increased by 35% between

1981 and 2000, growing from an estimated $14.2 billion to $20.3 billion in 2000 international dollars (James, Pardey, and Alston 2008). It grew faster in less-developed countries, and the developing world now accounts for about one-half of global public-sector spending—up from an estimated 41% share in 1980. However, developing countries still account for only about one-third of the world's total agricultural R&D spending when private investments are included.

A notable feature of the trends was the contraction in support for public agricultural R&D among developed countries. From 1950 to 2007, in inflation-adjusted terms, total U.S. public spending on agricultural research grew by 2.16% per year; but from 1980 to 2007, spending growth slowed to only 0.79% per year. Similar shifts in agricultural research spending have been observed in at least some other countries. Public agricultural R&D was massively reduced in Japan (and also, to a lesser degree, in several European countries) towards the end of the 1990s, leading to a reduction in the rate of increase in developed-country spending as a whole for the decade.

The more recent data reinforce the longer-term trends. Namely, support for publicly performed agricultural R&D among developed countries is being scaled back, or slowing down, and R&D agendas have drifted away from productivity gains in food staples towards concerns for the environmental effects of agriculture, food safety and other aspects of food quality, and the medical, energy, and industrial uses of agricultural commodities. See, for example, Alston, Anderson, James, and Pardey (2010) for detailed information on the changing orientation of U.S. public agricultural R&D.

Interpretation and Inferences

Throughout history, commentators have waxed and waned about the relative rate of growth of food supply versus demand and the ability of the world to feed itself. In the face of stagnant or slowly growing crop yields and on the back of several seasons of widespread drought—notably in South Asia and especially in large and rapidly growing countries like India—the prevailing mood in the early 1960s was one of Malthusian pessimism (Figure 3). The subsequent several decades saw a turnaround in crop yield and productivity trends in many, but by no means all, parts of the world as the Green Revolution took hold. Pessimism gave way to complacency as the Green Revolution gains were largely carried forward throughout the 1970s and 1980s.

Malthus Misery

"Famine seems to be the last, the most dreadful resource of nature. The power of population is so superior to the power in the earth to produce subsistence for man that premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation. ...should they fail in this war of extermination, sickly seasons, epidemics, pestilence and plague, advance in terrific array, and sweep off their thousands and ten thousands. Should success be still incomplete, gigantic inevitable famine stalks in the rear, and with one mighty blow levels the population with the food of the world."

Thomas Malthus. *An Essay on the Principle of Population* 1798 (1st edition, end of Chapter 7).

Contemporary Pessimists and Optimists

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

Monsanto Seeks Big Increase in Crop Yields	*DuPont Leader Discusses Agricultural Productivity at USDA Agricultural Outlook Forum*
"Monsanto, the leader in agricultural biotechnology, pledged Wednesday to develop seeds that would double the yields of corn, soybeans and cotton by 2030 and would require 30 percent less water, land and energy to grow." Andrew Pollack, New York Times (June 2008)	"We expect the traits and technologies in our product pipeline to help meet that demand by doubling the rate of genetic gain – targeting a 40 percent yield increase in our corn and soybean products over the next 10 years." Paul Schickler, Pioneer-Dupont (February 2008)

Relative to past performance, the claims by Monsanto and DuPont about potential yield gains seem very optimistic. The claims imply a sustained 10-20 year compound growth rate of about 3.4% per year, a rarity in recent history. In the United States, the rates of yield gain realized in farmers fields would have to match the highest ever, as recorded in the 1960s and 1970s, and recent yield growth rates have not been nearly so fast. Further, average growth in crop yields for maize, wheat, rice, and soybeans never exceeded the 3.4% per year threshold for any decade period ending after 1990. While it is feasible to sustain growth rates that would achieve the Monsanto and Du Pont targets, the future must be substantially different from the recent past if these goals are to be accomplished.

However, on the heels of a recent rapid run-up in global food commodity prices, old doubts have resurfaced

about our collective ability to sustain increases in global food supplies that outstrip the growth in demand. As in the past, how the world's food equation will be balanced depends in large measure on the rate of agricultural productivity growth in the decades ahead. The evidence presented here is indicative of a structural shift in the rate of productivity growth such that in many countries and in the world as a whole agricultural productivity has grown at a slower rate in the 1990s and the first decade of the 21st Century compared with earlier decades.

We suspect that a substantial share of past agricultural productivity growth resulted from agricultural R&D, and, notably, in the high-income countries the growth in R&D spending has slowed the most and so too has the growth in yields of the four important crops presented above. Consistent with that view, and the fact that research affects agricultural productivity with a long time lag, we also suspect that substantial shares of the reduced growth in productivity observed during the past decade or two are attributable in significant part to a slowdown in the rate of growth in R&D spending on agricultural R&D a decade or two previously (Pardey, Alston, and Piggott, 2006).

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

Agricultural science has much to offer, and many significant innovations are in progress if not already in the pipeline, especially in the area of biotechnology. Such prospects might provide grounds for optimism about the potential of agricultural supply to more than keep pace with demand (Figure 3). But even if the technology possibilities can be realized and widely adopted, there are big differences between what is possible in the laboratory and what happens worldwide in farmers' fields. We have to remember that the regulatory approval process is long and expensive and is getting longer and more expensive for new biotech crop varieties, so the rates of innovation will be slower in farmers' fields than in laboratories. And much of the world has not even begun to adopt biotech or otherwise improved varieties because of perceived market resistance or other political and economic barriers, so the benefits from any rapid yield gains in modern crop varieties, including biotech, will accrue only on a fraction of farmers' fields around the world in the short to medium term. While it may be hard to attribute a slowdown in productivity unequivocally to a prior slowdown in research spending, it is not hard to make a case that an increase in spending on farm-productivity-oriented research is warranted if we want to see even a partial return to the rates of productivity improvement enjoyed during the 1970s and 1980s.

For More Information

Alston, J.M., Andersen, M.A., James, J.S., and Pardey, P.G. (2010). Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending. New York, NY: Springer.

Alston, J.M., Beddow, J.M., and Pardey, P.G. (2009). Agricultural Research, Productivity, and Food Prices in the Long Run. Science, 325(4), 1209-1210.

Alston, J.M., Dehmer, S., and Pardey, P.G. (2006). International Initiatives in Agricultural R&D: The Changing Fortunes of the CGIAR. In P.G. Pardey, J.M. Alston, and R.R. Piggott (Eds.), Agricultural R&D in the Developing World: Too Little, Too Late? (313-360).Washington, DC: International Food Policy Research Institute.

Alston, J.M., Marra, M.C., Pardey, P.G., and Wyatt, T.J. (2000). A Meta Analysis of Rates of Return to Agricultural R&D: Ex Pede Herculem? (IFPRI Research Report No 113). Washington, D.C.: International Food Policy Research Institute.

Ehrlich, P.R. (1968). The Population Bomb. New York, NY: Ballantine Books.

Hardin, G.J. (1977). The Limits of Altruism: An Ecologist's View of Survival. Bloomington, IN: Indiana University Press.

James, J.S., P.G. Pardey, and J.M. Alston. Agricultural R&D Policy: A Tragedy of the International Commons. Department of Applied Economics Staff Paper No. P08-08, St Paul, University of Minnesota, September 2008.

Malthus, T. (1993). An Essay on the Principle of Population. Oxford, UK: Oxford University Press. (Original work published 1798).

Paddock, W., and Paddock, J. (1967). Famine 1975! America's Decision: Who Will Survive? Boston, MA: Little, Brown.

Pardey, P.G., Alston, J.M., and Piggott, R.R. (Eds.). (2006). Agricultural R&D in the Developing World: Too Little, Too Late? Washington, DC: International Food Policy Research Institute.

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STRUCTURAL CHANGES IN U.S. AGRICULTURAL PRODUCTION AND PRODUCTIVITY

Jennifer S. James, Julian M. Alston, Philip G. Pardey, and Matthew A. Andersen

The structure of U.S. agricultural production changed dramatically during the 20th Century. Major technological innovations transformed the relationship between agricultural inputs and outputs, and contributed to rapid increases in agricultural productivity. However, evidence is mounting that suggests we have entered a new era, with substantially lower rates of productivity growth. In this article, we examine trends and spatial patterns in agricultural input use, production of outputs, and productivity. We focus on productivity growth over the period 1949–2002, and find a statistically significant slowdown in productivity growth after 1990.

The analysis presented here is based on the book by Alston, et al (2010), which provides complete details on the data, sources, and analysis. The InSTePP (International Science and Technology Practice and Policy Center, University of Minnesota) production accounts that underpin this analysis consist of state-specific measures of the prices and quantities of 74 outputs and 58 inputs for the 48 contiguous U.S. states. In developing the InSTePP data, special attention was given to accounting for variation in the composition of input and output aggregates, with particular reference to the quality of inputs and outputs and the spatial dimensions.

Input Use

Inputs are grouped into four broad categories: land, labor, capital, and materials inputs. During the 20th Century, technological advancements transformed inputs such that their quality has generally increased over time. Our measures of input use account for major quality changes within the four broad categories, and the changing composition of the aggregate. The apparent decline in the use of agricultural inputs is offset somewhat when we account for these changes.

Over the period 1949–2002, the aggregate quantity of input fell at an average rate of 0.11% per year for the United States as a whole, but rates of change in input use were widely dispersed around this average. State-specific annual average rates of growth ranged from -1.99% in Massachusetts to 1.18% in Florida. While input use declined in most states, it increased in 15 states, primarily in the Pacific, Mountain, and Northern Plains regions. Table 1 presents the annual average rate of growth in input use by region and input category, as well as additional measures corresponding to growth in the quantity of output and productivity, described later. In addition to the spatial variation in overall input use, we also see very different patterns in the four input categories.

Land inputs consist of three broad categories—pastureland, nonirrigated cropland, and irrigated cropland. For the United States as a whole, agricultural land use decreased by 0.07% per year over 1949–2002. After adjusting for quality and compositional changes, notably those brought about by the growth in irrigated acreage, measured land use grew by 0.25% per year in the Northern Plains, 0.08% in the Pacific region, and 0.02% in the Mountain region. These increases were offset by decreases in land use in the Central, Southeast, and Northeast regions.

The labor data consist of 32 different categories, including family labor, hired labor, and 30 categories of

operator labor, specified by age and education cohort. The quality change of the labor aggregate is particularly pronounced, because farmers are much better educated and more experienced on average compared with 50 years ago. Nonetheless, quality-adjusted labor use decreased in every state over the period 1949–2002, and decreased by 1.74% per year for the United States as a whole. The Pacific region, dominated by developments in California, had the smallest rate of decline in labor use, while reductions were much more pronounced in eastern states, especially in the northeast.

Capital inputs consist of seven categories of physical capital and five categories of biological capital. We adjusted inventories of physical capital classes to reflect quality changes over time, in particular factoring in the changes in vintage, durability, and size of machines used on farms. For the United States as a whole, quality-adjusted capital use decreased by 0.10% per year, and decreased most dramatically in the Northeast and Central regions. Capital use increased in 23 states, with the largest increases occurring in the Pacific and Mountain regions.

The materials input category consists of 11 different categories, including pesticide, seed, feed, fuel, electricity, rented machines, repairs, miscellaneous inputs, and three types of fertilizer. This is the only input category that increased for the nation as a whole (1.88% per year over the period 1949–2002). Use of materials inputs increased most rapidly in the Pacific region (2.58% per year) and most slowly in the Northeast region (0.65% per year).

After aggregating among all measured inputs, the quantity of total input use in U.S. agriculture changed little in well over half a century. In contrast, the composition of input use changed dramatically, with U.S. agriculture now much more reliant on materials inputs purchased off farm and less reliant on labor. Total use of land and capital inputs was fairly constant, although the composition of specific inputs within these two broad classes of inputs changed markedly.

Agricultural Production

U.S. agricultural production has grown rapidly since 1949, with concomitant marked changes in the composition and location of production. The total nominal value of U.S. agricultural production grew from $29.9 billion in 1949 to $223.5 billion in 2006, equivalent to a compound growth rate of 3.6% per year. Deflating by the implicit GDP deflator, the real value of U.S. agricultural production grew from $183.0 billion in 1949 (2000 prices) to just $191.5 billion in 2006. The value of U.S. agricultural production has varied over space and time, reflecting the impacts of changes in prices and quantities of inputs and outputs, changes in technologies, and a host of factors that directly or indirectly affect these variables.

While the value of agricultural output grew during the 20th Century, regional and state shares did not change much until the post-WWII years. Changes in domestic and export demand as well as changes in off-farm technology contributed to changes in the composition of demand for U.S. agricultural output, which in turn contributed to changes in the composition and location of production. Major structural changes, such as the shifting geography of population and the substantial migration of labor off farms—combined with improved communications, electrification, transportation, and logistical infrastructure—meant that perishables and pre-prepared foods needed to and could be moved efficiently over much longer distances. This contributed to the changing spatial patterns of production in the second half of the 20th Century. Technological innovations on- and off-farm underpinned many of these changes.

The output data cover the period 1949–2006. Aggregate output quantity increased by an average of 1.68% per year over this period for the United States, so that output in 2006 was 2.6 times the output in 1949. At the same time, production tended to shift south and west. In 1949, Iowa and Texas were the largest states in terms of agricultural production, with 8.0% and 7.5% of the 1949 value of U.S. production, respectively, and the Central region produced more than one-third of the entire U.S. agricultural output value. California was the fourth-ranked state in 1949, producing 5.8% of national production. By 2006, the regional distribution of production had shifted substantially. The Central region's share of U.S. production value decreased to 30.8%, while the Northeast region's share fell from 9.6% in 1949 to 5.7% in 2006. The big increase was in the Pacific region, whose share roughly doubled over the 57-year period, from 8.3% of U.S. agricultural output value in 1949 to 16.3% of the 2006 total. As shown in Table 1, the output quantity index grew faster in the Pacific, Northern Plains, and Mountain regions than the nation as a whole.

Not only did the spatial composition of production change, the mix of outputs changed as well. The 74

different categories of outputs can be grouped into the broad classifications of livestock, field crops, specialty crops, and miscellaneous outputs. The livestock category includes 9 commodities, and the aggregate quantity of livestock produced increased by 1.39% per year, which is the slowest rate of growth of the three output categories included in Table 1. Furthermore, the value of livestock as a share of agricultural production trended down over the past 50 years, declining from about half of the value of U.S. production in the 1950s to around 45% in more recent years. A significant amount of livestock production moved out of the Central and Northeast regions to become increasingly concentrated in the Southern Plains and Southeast regions.

The field crops output category consists of 17 different crops, and the total quantity produced in this category grew at about the same rate as all outputs combined, but with a great deal of regional variation. Growth in field crop production was particularly pronounced in the Northern Plains and Central regions at 2.60% and 2.29% per year, respectively, and quite modest in the Southeast, Northeast, and Pacific regions. The value share of field crops jumped to more than 40% of the U.S. total value of production in the 1970s and 1980s when commodity prices were historically high. Aside from this period of time, the share of agricultural output value coming from field crops fluctuated around a generally downward trend, declining from approximately 40% of the total value of agricultural output in 1949 to around 30% in recent years.

The specialty crop output category includes 18 fruits, 4 nuts, 22 vegetable crops, and an aggregate greenhouse and nursery products category. Production of specialty crops has increased dramatically since 1949, both in quantity and value. Output quantity in this aggregate increased by 3.5-fold, or 2.21% per year on average, and the value share of total U.S. production increased from less than 10% in the 1950s to more than 20% in the 2000s. The value shares for vegetables and fruit and nuts followed very similar paths over the latter half of the 20th Century–each increasing from about 3.5% in 1949 to 6.5% in more recent years. The value share of greenhouse and nursery products increased more rapidly, from less than 1.5% in 1949 to around 8% in 2006. Production of these crops tends to be spatially concentrated. For example, only 11 states contributed more than 1% of the value of production of fruits and nuts, and the top four producing states accounted for about 80% of the total U.S. value of production. Similarly, 18 states each contributed more than 1% to the value of production of vegetables, and the top four producing states accounted for just over half of the total U.S. value of production. In 2006, roughly half of the value of nursery and greenhouse production was concentrated in the top four producing states—California, Florida, Texas, and Oregon. The increased production and spatial concentration of these high-value crops help explain some of the spatial shifts in the value of production described above.

U.S. Agricultural Productivity

The changes in agricultural inputs and outputs are reflected in multi-factor productivity (MFP), which is measured as the ratio of the index of aggregate output quantity to the index of aggregate input quantity. Measures of MFP growth were developed for each state, region, and the nation. Maps in the first column of Figure 1 indicate the state-specific rates of growth in input use, outputs, and productivity over the period 1949–2002. Some states, such as California and Florida, had both inputs and outputs growing and some, such as Massachusetts and Rhode Island, had both falling, but the majority had output growing against a declining input quantity.

The annual average rates of growth in MFP are shown in Table 1 by region, and the state-specific growth rates are indicated by the shading in the last map in the first column of Figure 1. During the period 1949–2002, all states had positive productivity growth, with substantial variation among the states. Productivity growth was most rapid in the Southeast region, with several states in the Northern and Southern Plains also experiencing above-average productivity growth.

The pattern of MFP growth has varied widely over time. Year-to-year variations in measured productivity growth might reflect the influences of short-term factors such as weather impacts or policy changes; they might also be the result of measurement errors such as those associated with variable capital utilization rates; however, long-term changes in patterns of productivity growth are of more serious concern in the present context. In particular, accumulating evidence suggests that the rate of U.S. agricultural productivity growth may have slowed in recent years, perhaps as a reflection of a slowdown in the growth of total spending on agricultural R&D starting in the late 1970s, or a reduction in the share spent on productivity enhancing agricultural research and development (Alston, Beddow and Pardey 2009; Alston et al. 2010). It is not a trivial matter to detect structural changes in the process of productivity growth, given the substantial year-to-year movements and spatial differences, but our detailed data make it possible to test for structural

changes.

Evidence of a recent productivity slowdown can be seen in Figure 2, which shows distributions of multi-factor productivity growth rates by decade since 1949. Each of the distributions refers to a particular period, and the data are the state-specific averages of the annual multi-factor productivity growth rates for the period, a total of 48 growth rate statistics in each panel. By inspection, it can be seen that the general shape and position of the distribution of state-specific multi-factor productivity growth rates seems reasonably constant across periods until the last one, 1990–2002, when it shifts substantially to the left, indicating a widespread slowdown in productivity growth.

A visual inspection of the MFP data reveals an apparent natural break in the data around 1990; therefore, we calculated and compared rates of productivity growth for the period 1949–1990 and for the remaining period, 1990–2002. Table 1 includes the U.S. and regional growth rates for each period. Over the period 1949–1990, multi-factor productivity grew positively in all 48 states, whereas during the period 1990–2002, multi-factor productivity growth was negative for 15 states, mostly in the northeast. Multi-factor productivity grew faster in the more recent period compared with the earlier one in only four states; with 44 states experiencing lower rates of productivity growth. U.S. aggregate agricultural productivity grew on average by just 0.97% per year over 1990–2002 compared with 2.02% per year over 1949–1990. The simple average of the 48 state-specific MFP growth rates indicates a larger difference between the periods, a paltry rate of 0.54% per year for 1990–2002 compared with 2.02% per year for 1949–1990.

The maps in the right-hand column of Figure 1 depict the state-specific annual average input, output and multi-factor productivity growth rates for 1990–2002. Aggregate input growth was generally higher in the period 1990–2002 compared with the period 1949–2002, and notably so for most western states, whereas output growth generally slowed in the more-recent period. The combination of these reinforcing input and output trends resulted in the pervasive slowdown in multi-factor productivity growth that is especially evident in comparing the two maps at the bottom of the figure.

We also conducted more formal statistical tests for a productivity slowdown using the state-specific MFP data for 1949–2002, and comparing growth rates for various sub-periods. Cognizant of the possibility that different measures of MFP growth may imply different findings, we started by calculating state-specific MFP growth using two different methods. The first method used the simple average of the annual state-specific estimates of MFP growth. The second used a regression of each state-specific MFP index in logarithms against a time trend such that the estimated coefficient on the time trend provides an estimate of the average growth in the index of MFP. We computed these alternative measures for each state and for various time periods defined in Table 2. Finally, we conducted paired t-tests for statistically significant differences in the state-specific growth rates before and after the split points.

The entries in Table 2 refer to proportional growth in MFP, measured either as the average of year-to-year growth rates or the slope coefficient from a regression of the logarithm of the index against a time trend variable. In every case with either measure, the tests indicate a substantial and statistically significant (at the 10% level of significance in every case, and in most cases at a level of significance well less than 1%) slowing of productivity growth for any period that includes the years 1990–2002 compared with any prior period. The slowdown is most pronounced for 1990-2002 compared with 1949–1990.

Finally, our most recent data on agricultural outputs ending in 2006 indicate that in the years 2000–2006, the annual average growth in aggregate output was 0.80% per year, which is less than half of the long run average of output growth of 1.68% per year over 1949–2006. Unless there was a large decrease in the quantity of inputs used in production for 2000–2006, the lower rate of output growth implies that average productivity growth was also substantially lower for this period. The evidence presented here supports the view that the recent productivity slowdown in agriculture is not a temporary cyclical event but more structural and sustained.

Conclusion

U.S. agricultural production changed remarkably during the past 100 years. Changes in production and productivity were enabled by dramatic changes in the quality and composition of inputs, important technological changes resulting from agricultural research and development, and wholesale changes in the structure of the farming sector. While the quantity of U.S. agricultural output grew nearly 2.5-fold during the

period 1949–2002, the measured quantity of aggregate input use has declined marginally, reflecting rapid growth in productivity. While U.S. agricultural productivity grew quickly through the 1980s, mounting evidence indicates a substantial, sustained, systematic, structural slowdown in the growth rate of U.S. agricultural productivity since then. Over the most recent 10–20 years of our data the annual average rate of productivity growth was half the rate that had been sustained for much of the 20th Century. Compounding over decades, the difference will have serious implications. Unless other countries with competing agricultural production experience comparable slowdowns in agricultural productivity growth, the United States will suffer a widening competitiveness gap. On the other hand, if other countries do experience comparable slowdowns in agricultural productivity growth, the consequences will be felt in a widening gap of a different sort: between growth in global supply and growth in global demand for agricultural products, with serious consequences for food security, especially among the world's poor.

For More Information

Alston, J.M., M.A. Andersen, J.S. James, and P.G. Pardey. (2010). Persistence Pays: U.S. Agricultural Productivity Growth and the Benefits from Public R&D Spending. New York: Springer.

Alston, J.M., J.M. Beddow, and P.G. Pardey. (2009). Mendel versus Malthus: Research, Productivity and Food Prices in the Long Run. Department of Applied Economics Staff Paper/InSTePP Paper P09-1. St Paul: University of Minnesota (revised September 2009).

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AGRICULTURAL PRODUCTION AND PRODUCTIVITY IN CANADA

Terrence S. Veeman and Richard Gray

Agriculture in Canada was substantively transformed in the past century. In absolute terms, agricultural production increased considerably. For example, production of wheat, a major Canadian crop, based initially on the improved variety Marquis, trebled from 1908 to 2008. New crops, such as canola—improved varieties of rapeseed—on the Prairies and soybeans in Ontario, are now widely grown. Similarly, the numbers of livestock on farms have greatly increased since World War I, the number of cattle and calves nearly doubling, the number of pigs growing about four-fold, and the number of chickens trebling (Statistics Canada, 2009).

In relative terms, however, primary agriculture's share of the Canadian economy has shrunk to account for 1% to 2% of GDP and some 2% of national employment. Such structural change has been common in developed nations. Associated with economy-wide changes in the structure of agriculture, agricultural productivity has increased considerably over time, whether measured in terms of increases in crop yields, livestock gains, or growth in overall—total factor—productivity.

An Overview of Canadian Agriculture

Agriculture uses only 7% of Canada's land mass and is concentrated in the southern portion of the country, chiefly in the Canadian prairies and the southerly reaches of Ontario and Quebec. The current Canadian farmland area of 67.8 million hectares (mha) has remained relatively constant since World War II, although the area in crops has crept upwards to some 36 mha (Statistics Canada, 2007). In western Canada, since the 1980s, while individual farms have become more specialized, aggregate agriculture has diversified away from cereal and coarse grains, mainly wheat and barley, to higher-valued crops such as oilseeds, chiefly canola, and pulses such as field peas and lentils. In terms of cropped area in Canada, despite having lost ground spring wheat still leads, followed by hay and other fodder crops, with canola now ahead of barley, in third place.

The 2006 Census of Agriculture counted 229,000 farms in Canada reflecting a steady decline in farm numbers that began in 1941 (Statistics Canada, 2007; Mitura, 2007). Average farm size recorded in 2006 was 295 ha, ranging from more-intensive 100 ha farms in Ontario and Quebec to more-extensive farms in Saskatchewan, averaging nearly 600 ha. Farm size has also increased in terms of livestock numbers, most notably in hog farming where the number of pigs per farm rose by more than twentyfold from approximately 70 in 1971 to 1450 in 2008 (Statistics Canada, CANSIM 2009).

Agricultural production is increasingly concentrated on specialized larger farms. In 2005, some 5,900 farms had gross receipts exceeding one million dollars. These "million dollar" farms represented only 2.6% of all farms in Canada but earned nearly 40% of total receipts. In contrast, farms with less than $100,000 (Canadian, currently $94,000 U.S.) in farm receipts comprised 65.6% of all farms and generated only 9.9% of all farm receipts (Mitura, 2007).

Nearly 40% of Canadian farms are designated as crop farms, followed by beef farms at 26.6% of all farms. The mix of agricultural commodities varies among the provinces (AAFC, 2005). Production of red meats, along with dairy, is most important in Ontario and Quebec. Red meats, grains and oilseeds typically account for over 80% of market receipts in the prairie provinces of Alberta, Saskatchewan and Manitoba. In British

Columbia, fruits and vegetables are important, while in Atlantic Canada, potatoes and dairy predominate. In 2006, nearly 7% of Canadian farms reported growing organic products for sale but only one-quarter of these were actually certified.

Farm operators in Canada are getting older, now averaging 52 years of age (Statistics Canada, 2007). The economic well-being of farm households is increasingly linked to the nonfarm economy with nearly half of all farms reporting off-farm income. In 2006, 57% of Canadian farms were sole proprietorships, 27% were partnerships, and 16% were incorporated—a rising share but still largely family incorporations. Trade, particularly with the United States, is very important to Canadian agriculture. The red meat sectors, in particular, became increasingly integrated within the North American market in the past 15 years.

Crops and Livestock in Canada: Shifting Patterns over Time

Canada is ranked eighth in world cereal production and tenth in world meat production (Statistics Canada, 2009). From 1999 to 2008, an average of 48% of total farm cash receipts in Canada came from livestock receipts, 41.3% from crop receipts, and the remaining 10.7% from government program payments (Statistics Canada, CANSIM 2009). Livestock receipts generally exceeded crop receipts during this decade, although 2007 and 2008 were notable exceptions reflecting stronger grain prices and adverse red meat fortunes. Government payments increased, often on an ad hoc basis, in years of drought, animal disease, border problems, and financial stress.

The pattern of crop receipts has changed considerably over time, as shown in Figure 1. The large share of the "other crops" category, which rose until 2004, reflects increasing diversification of Canadian crop production. Relative shares of wheat, excluding durum, and barley declined significantly whereas canola increased in importance. Corn and soybean shares both rose, but they still only contribute 6% and 5%, respectively, to Canadian crop receipts. Corn for bio-fuel production is not currently significant in Canada.

Figure 1 Shares of Total Crop Receipts Canada, 1971-2008
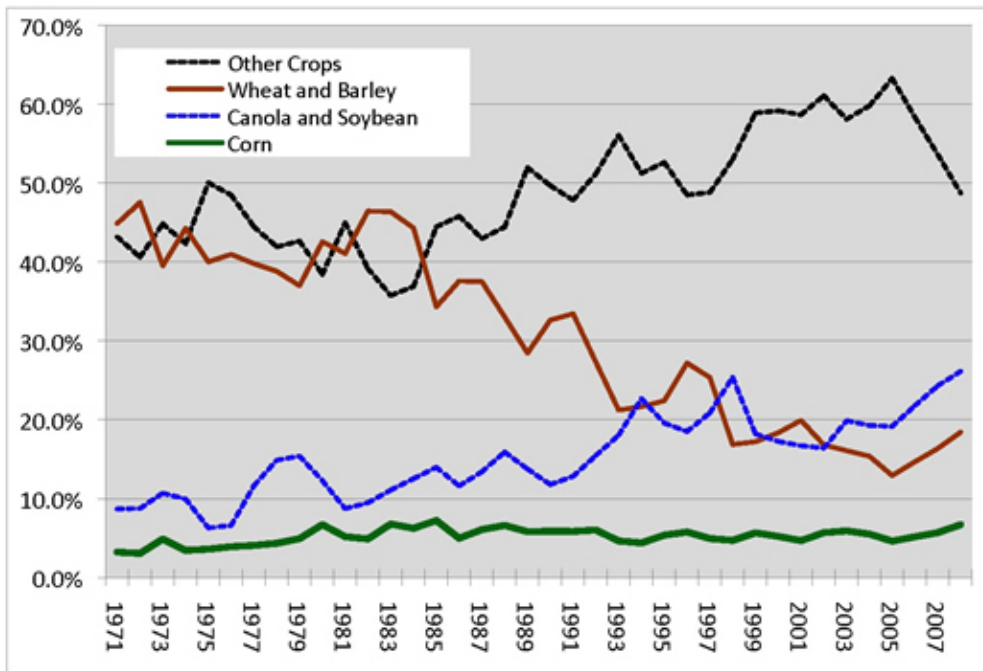
Source: Authors' calculations from Statistics Canada, CANSIM.

Livestock receipts in Canada from 1971 to 2008 also portray shifting production patterns. In the last decade of this period cattle and calves contributed nearly 33% of total livestock receipts in Canada, with hogs

providing 19%, dairy 26%, and chickens and hens 9%. The share of livestock receipts from cattle and calves dropped over time, while the hog share increased from the 1990s until 2004.

Partial Productivity Measures for Canadian Agriculture

Changes in crop yields are the most readily available measures of productivity gains in Canadian agriculture. Despite long-term declines in real crop prices, the output of the crops sector has increased through improvements in productivity evidenced in rising crop yields. Changes in technology have contributed to this productivity improvement.

Yields of the major field crops grown in Canada—wheat, barley, canola, corn, soybeans, and peas—the most important of which are shown in Figure 2, all increased from the 1960s until the present. Several features are noteworthy, including the volatile nature of yields even at the national level, highlighting the important continuing role of weather in influencing annual yields. Further, indexed against a base of the 1960-64 average, yields of all these crops follow a similar trend, increasing by about 60% during the forty-seven year period to the point that statistical testing could not reject an identical linear trend coefficient for corn, wheat, canola, and peas. This is remarkable considering the varying locations, biological properties, farming systems, and research institutions associated with each crop. The linear trend suggests a constant absolute growth in yields, which implies a declining proportional growth rate, since the same absolute increase per year is a smaller percentage of the growing base—in fact, a 60% decline in the proportional rate of growth over the period.

Figure 2 Canadian Crop Yield Indexes, 1960 to 2007 (Base 1960: 1964 = 100).
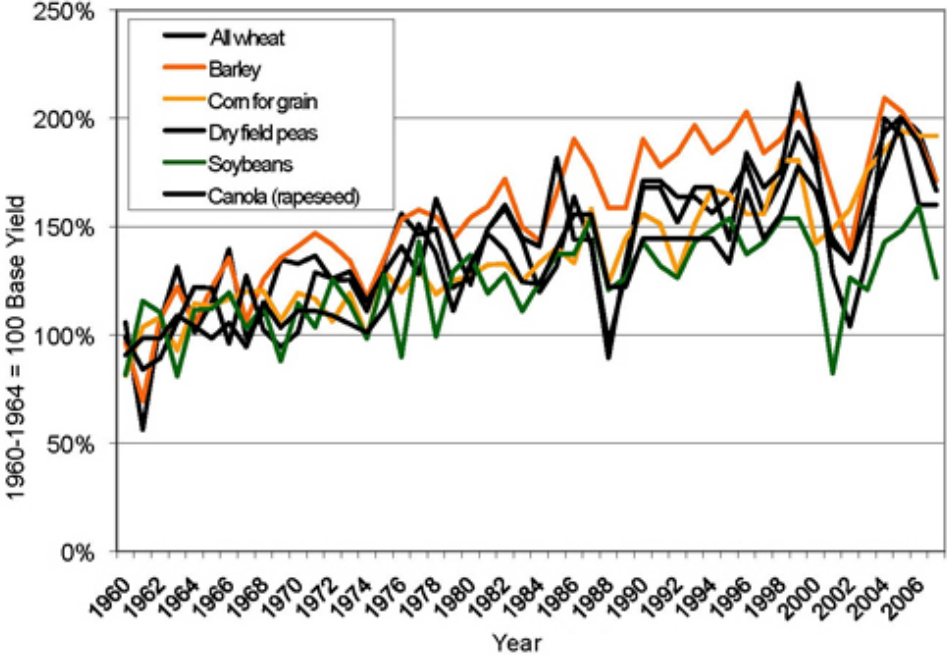
Source: Statistics Canada, CANSIM.

The yields shown in Figure 2, based on yield per seeded acre, do not reflect the changes in cropping intensity that have occurred in western Canada since the 1960s. As a result of the decline in summer fallow area, annual cropping intensity in western Canada has increased from 62% to 87% of cultivated area. If this increase in cropping intensity were to be reflected in yields, yield growth for wheat, barley, canola, and peas would be closer to 100%, rather than 60%, over the 47 year period.

In contrast to trends in average actual farm crop yields, research trial yield indexes diverge markedly among Canadian crops. Both wheat and durum yields in experimental trials exhibited slow linear trends, increasing to 122% of the 1960-64 base yield over the period to 2006. However, canola yields in experimental trials

grew unevenly, but quite rapidly, reaching 180% of base yields by 2006, while trial pea yields accelerated since 1994, achieving 148% of the base. Further analysis is needed to reconcile the differences between these growth patterns in experimental yield indexes and the patterns in Canadian average realized yields of the various crops.

Many of the crops have also shown important changes in quality that increase value but are not captured in the yield figures. Spring wheat varieties were confined to hard red spring wheat in the 1960s. While hard red spring wheat still dominates plantings, new classes of wheat have been introduced with each wheat class made up of varieties that can be visually distinguished from other classes. Durum wheat now includes extra-high-gluten varieties. Canola was transformed from rapeseed in the early 1970s by a decade of public breeding that reduced the level of glucosinolates and erucic acid. In the mid 1990s herbicide tolerant and hybrid canola was introduced. Since 2000, new canola varieties high in oleic acid have been introduced. While feed is the primary use of barley, plantings continue to be dominated by two-row malting varieties, which replaced earlier six-row malting varieties.

Discussion of productivity enhancement in cropping systems would be incomplete without noting the dramatic change in tillage systems. In the 1960s, fields were tilled extensively during the summer fallow period in much of western Canada, and tilled again prior to seeding. In the more-humid regions of central Canada, land was tilled with a moldboard plough to bury the stubble residue from the previous crop. Beginning in the 1970s, some farmers and industry groups began developing seeding systems and weed control systems that required less tillage. By the 1990s, very effective low-disturbance seeding systems had been developed and were rapidly adopted, especially in the prairie region. The new cropping systems reduce the demand for diesel, fuel, and labor, while increasing the demand for glyphosate herbicide and nitrogen fertilizer. They have reversed the long term decline in soil organic matter, increased carbon sequestration, made better use of available moisture, and significantly reduced both water and wind erosion.

Livestock productivity gains have also been achieved from improved genetics, feed conversion, and management practices, as well as the exploitation of economies of scale in intensive production systems. Important livestock productivity gains include: an increase in cattle carcass weights of some 34% between 1980 and 2003; a 38% rise from 1990 to 2003 in production per sow due to larger litter sizes, more litters per year, and heavier carcass weights (AAFC, 2005); and a 43% increase in milk production per cow between 1991 and 2007.

Finally, labor productivity in Canadian crop and animal production grew very rapidly from 1961 to 2005 at 4.7% per year, an estimate based on Statistics Canada data. Indeed, labor productivity growth in agriculture has been greater than in other sectors of the Canadian economy. However, labor productivity growth considerably overstates the total productivity gains overall in agriculture, given the substantive increases in the use of material inputs and the historical capital-for-labor substitution in production.

Total Factor Productivity Measures for Canadian and Prairie Agriculture

Partial productivity measures, such as yield per unit of land, can certainly be informative, as seen above. However, a much better indicator of productivity performance, if available, is total factor productivity (TFP). TFP or multi-factor productivity is the ratio of aggregate output to aggregate input, in which as many inputs in the production process as possible, rather than just a single input, are counted in evaluating productivity performance.

There is modest historical literature on productivity growth in Canadian agriculture. However, the extensive body of agricultural-specific productivity analyses undertaken in the United States has not been replicated in Canada at the national level. Some empirical information on TFP in Canadian agriculture can be derived from recent data and work by Statistics Canada on productivity in the Canadian economy.

Over the period 1961 to 2005, TFP based on gross output for crop and animal production in Canada increased by 0.6% per year. In the same time period, TFP based on value added grew somewhat more rapidly at some 1.4% per year. Following Christensen (1975), we prefer TFP measures based on gross output rather than on value added. One possible reason why the TFP growth rate based on gross output is comparatively low is that the annual compound growth rate for all inputs combined in crop and livestock production is 2.4%, a rate considerably higher than in comparable American and Australian studies for

aggregate input use in agriculture.

The prairie provinces of western Canada are the "bread-basket" of Canadian agriculture, containing nearly half of Canada's farms and much larger shares of its cropland and grassland bases. A lengthy time-series study of productivity growth in prairie agriculture, using total factor productivity measures based on Tornqvist-Theil indexing procedures, was recently completed (Stewart, 2006; Stewart, Veeman, and Unterschultz, 2009). Using this detailed case study, we now summarize estimates of output, input, and productivity growth for prairie agriculture from 1940 to 2004, including the disaggregation of this analysis to the crops and livestock sectors.

Prairie agriculture displayed relatively strong productivity performance over this historical period, with a compound annual TFP growth rate of 1.56% (see Figure 3). Aggregate output and aggregate input comprised of land, labor, capital, and materials grew, respectively, at 2.43% and 0.86% per year over the 1940 to 2004 period. Accordingly, productivity growth on a gross output basis accounts a 64% lion's share of the considerable growth in prairie agricultural output over this 65 year period.

### Figure 3 Törnqvist-Theil Indexes of Canadian Prairie Aggregate
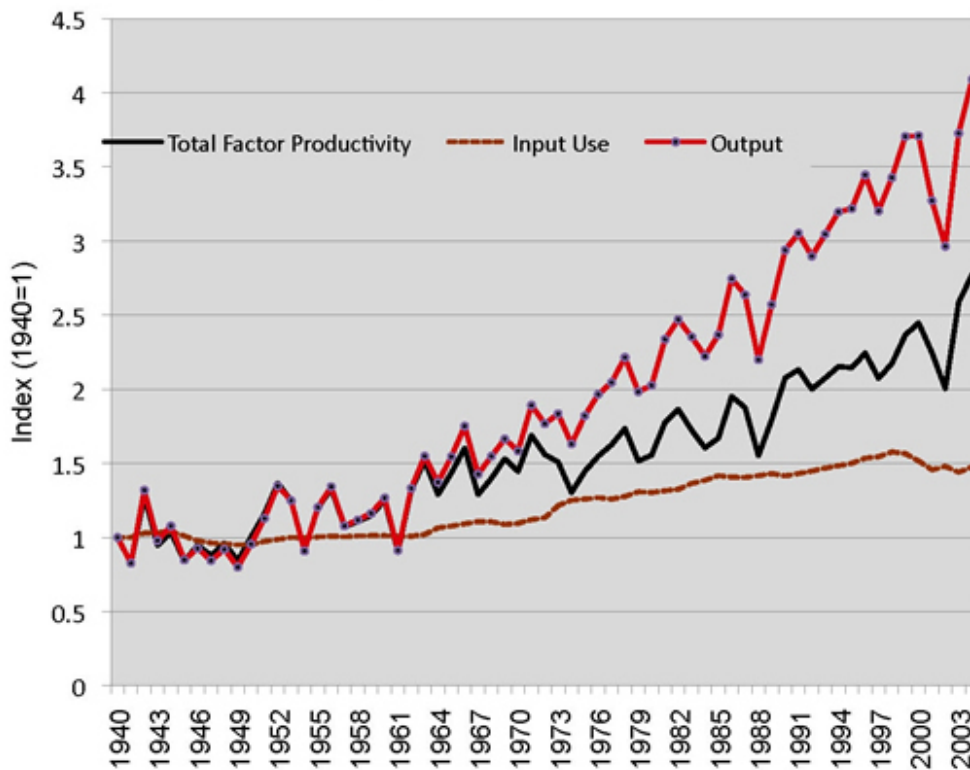
Source: Stewart (2006).

Productivity growth estimates were also obtained for each prairie province, though not reported here, and for each of crops and livestock. As shown in Figure 4, productivity growth in the crops sector at 1.77% per year over the 65-year period is nearly three times higher than that in the livestock sector at 0.65% per year. This general result is also found in the United States (Huffman and Evenson, 1993). While prairie crop productivity growth declined during the final fifteen years of the study, notably in Alberta and Saskatchewan, livestock productivity growth accelerated considerably in Manitoba and Saskatchewan, largely off-setting the crop productivity decline (see Figure 5). Two contributors to the recent increase in livestock productivity growth, at least until 2005, were the major scale economies associated with the shift to intensive livestock operations and the increased attractiveness of livestock feeding in the Prairie region due to the removal in 1995 of the

Crow Rate rail shipping subsidy on grain moving to export position.

Figure 4 Törnqvist-Theil Indexes of Crops and Livestock Total Factor Productivity (TFP) for the Canadian Prairies: 1940-2004.
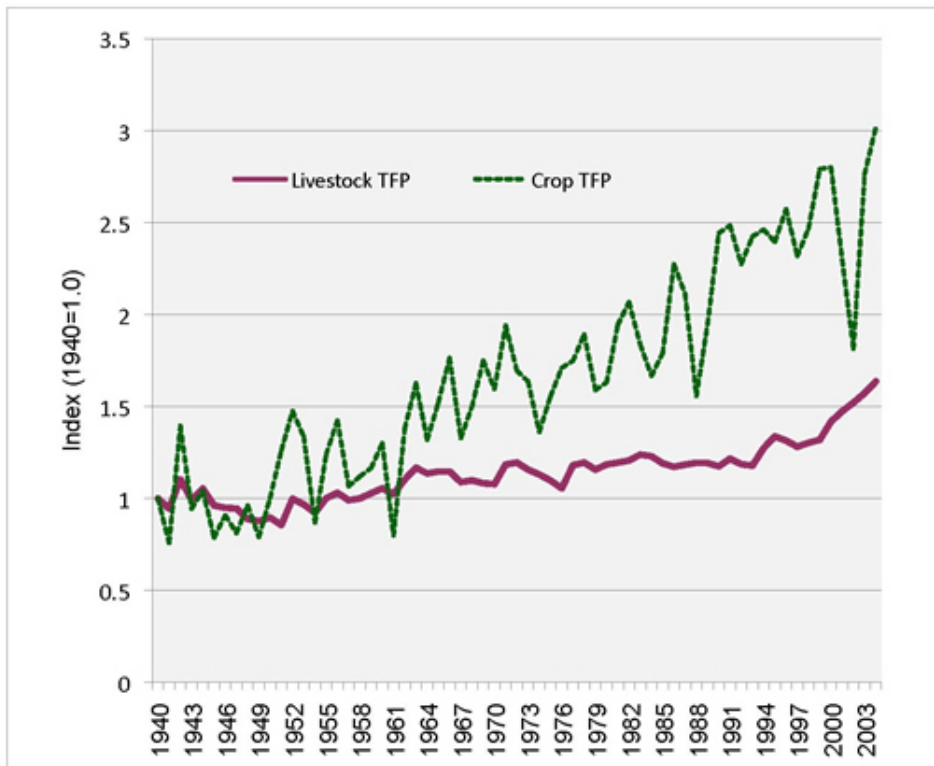
Source: Stewart (2006).

The stronger productivity performance in the prairie crops sector from 1940 to 2004 does not mean, however, that the "profitability" of the crops sector has been better than that in the prairie livestock sector. In fact, the terms of trade—output prices relative to input prices—facing the crops sector has deteriorated more rapidly over time, at -2.57% per annum versus only –0.29% for the livestock sector. The terms of trade for prairie farmers is heavily influenced by productivity growth outside Canada, which drives global relative prices, rather than by the much smaller influence of productivity growth inside Canada. Productivity advance has slightly outpaced cost-price squeeze pressures in the livestock sector over time, but not in the crops sector on the Canadian prairies. By decomposing estimated productivity growth into its constituent parts, technical change was concluded to be critical in the crops sector, whereas the roles of technical change and scale impacts have been roughly equal in the livestock sector (Stewart, Veeman, and Unterschultz, 2009).

Figure 5 Average Annual Growth Rate in Total Factor Productivity (TFP) for the Canadian Prairies: 1940-2004 versus 1990-2004
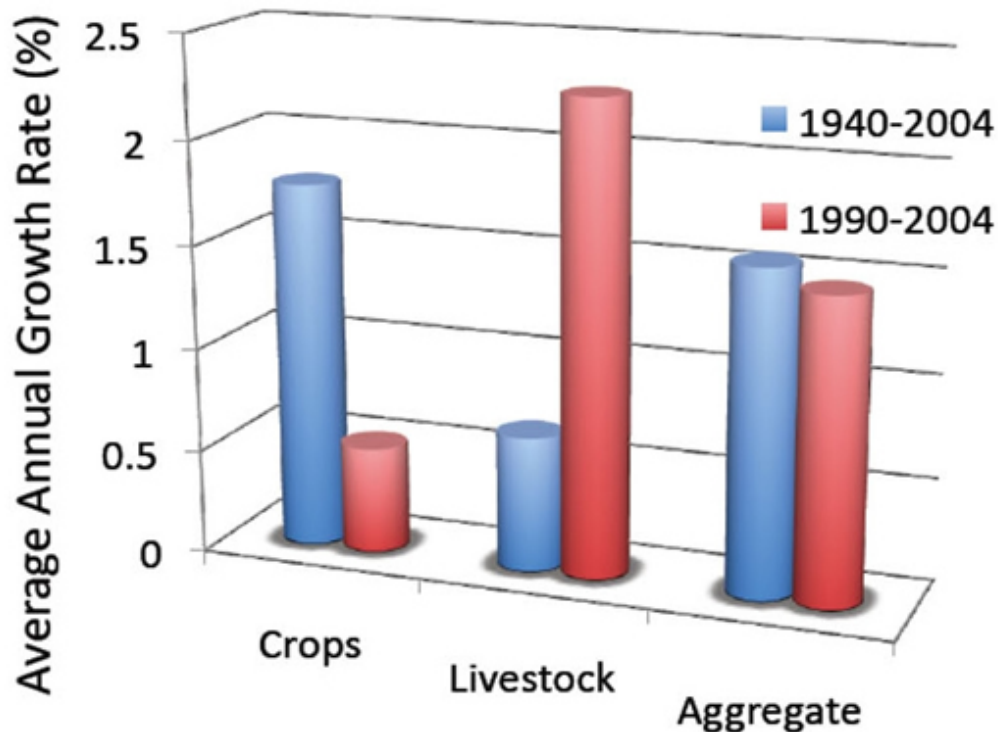
Source: Stewart (2006).

Summary and Implications

Over time, with increasing consolidation and specialization, Canadian primary agriculture has evolved to a sector characterized by fewer farms in number but much larger in size. As in many developed nations, large farms in Canada account for most of the agricultural production. In terms of farm receipts, red meats, grains and oilseeds led by wheat and canola, respectively, and dairy are Canada's most important agricultural commodities. However, Canadian farmers have been diversifying their production mix to reach niche markets, increase value added, and spread risk.

Since the early 1960s, the yields of several major crops have increased by approximately 60 %. Yield trends for corn, wheat, canola, and peas are remarkably similar, exhibiting consistent absolute growth in yields, but declining proportional rates of growth over the period. Labor productivity in crop and animal production in Canada grew rapidly at 4.7% per year from 1961 to 2005. Total factor productivity (TFP) growth for crops and livestock was considerably slower, ranging from 0.6% per year based on gross output to 1.4% per year based on value added. More research on productivity estimation and analysis that is directed explicitly to the Canadian agricultural sector could clarify these differences and strengthen understanding of agricultural productivity at the national level. In western Canada's prairie region, productivity growth estimated at nearly 1.6% per year since 1940, has been very important to the growth of prairie agriculture. Crop productivity growth outpaced that of livestock historically, but not from 1990 to 2004.

Our research indicates that a slowdown in spending on agricultural R & D (Gray 2008) in the past two decades is one contributing factor to slower productivity growth, especially in the crops sector. Stewart (2006), in assessing possible causal factors underpinning productivity growth in prairie agriculture, points to the effects of a stagnant knowledge stock variable, derived from past R&D expenditures, since 1990. Further, in Canada, as in the United States, agricultural R&D has shifted away from direct improvement in crops and

livestock to other societal priorities such as food safety and the environment.

In summary, both the study of Canadian crop yields and the analysis of total factor productivity growth in the crops sector in the prairie region of western Canada indicate a slow-down of productivity growth in crop production since 1990. Increased funding for agricultural research would help to counter the productivity slowdown in crops and to ensure that future livestock sector productivity growth could be based relatively more on technical change and less on scale economies associated with output expansion. Improved productivity performance, led by increased funding for R & D, is critical to the future competitiveness and economic sustainability of Canada's primary agriculture.

For More Information

AAFC (Agriculture and Agri-Food Canada). (2005). *An overview of the Canadian agriculture and agri-food system.* Ottawa, ON.

Christensen, L.R. (1975). Concepts and measurement of agricultural productivity. *American Journal of Agricultural Economics.* 57(5), 910-915.

Gray, R. (2008). Agricultural Research at a Crossroads. *Canadian Journal of Agricultural Economics. 56(1),1-11.*

Huffman, W.E., and Evenson, R.E. (1993). *Science for agriculture.* Ames: Iowa State University Press.

Mitura, V. (2007). *The changing structure of Canadian agriculture.* Presented at the Canadian Agricultural Economics Society annual meeting, Portland, OR, July 31.

Statistics Canada. CANSIM database (accessed June, 2009).

Statistics Canada. (2007). *Snapshot of Canadian agriculture.* Ottawa, ON.

Statistics Canada. (2009). *Human activity and the environment: Annual Statistics (Special feature on "Food in Canada").* Catalogue no. 16-201-X. Ottawa, ON.

Stewart, B. (2006). *Measures and causes of productivity growth in Prairie agriculture: 1940-2004.* MS thesis, University of Alberta.

Stewart, B., Veeman, T.S., and Unterschultz, J. (2009). "Crops and livestock productivity growth in the Prairies: The impacts of technical change and scale." *Canadian Journal of Agricultural Economics,* 57(3), 379-394.

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THE PRODUCTION PERFORMANCE OF CHINA'S TRANSFORMING AGRICULTURE

Songqing Jin, Jikun Huang, and Scott Rozelle

The economic performance of China's agricultural economy in the decades ahead will increasingly rely on the growth of total factor productivity rather than the growth of input use. Total factor productivity, or TFP for short, is positive when one of the following conditions holds: if output increases while inputs stay constant; if inputs fall while output remains the same; or a combination of both the prior conditions. However, the substantial structural changes in production agriculture and the institutions that serve it make it difficult to gauge the nature and sources of productivity growth in Chinese agriculture. Agricultural research spending at times has remained stagnant. At other times the government has invested large amounts of funds into agricultural R&D. Policies to encourage the importation of foreign technologies have been applied unevenly. Structural adjustment policies also triggered wrenching changes in the sector. Horticulture and livestock production has boomed; while the output of other crops, such as rice, wheat and soybeans, has stagnated or fallen. At a time when China's millions of producers are faced with complex decisions, the public extension system is crumbling and farmer professional associations remain in their infancy. In short, there are almost as many reasons to be pessimistic as optimistic about the country's productivity trends in agriculture.

Somewhat surprisingly perhaps, little effort has been devoted to assessing the productivity performance of Chinese agriculture—especially in the past decade. We describe the productivity trends in the nation's agricultural sector during the reform era that began in the 1980s, with an emphasis on the period 1995-2005. Because our analysis examines TFP growth on a crop by crop basis, we focus primarily on technical efficiency and are not able to assess changes to allocative efficiencies, or those efficiencies that would arise by adjusting crop structure or crop mixes.

Economic Factors, Structural Change and Productivity

The pace of TFP growth is influenced by investments in agricultural research and extension and other factors. Moreover, changes in technologies can have differential impacts on the rate of measured productivity over time.

Technology Development, Extension and Other Factors

After the 1960s, China's research institutions grew rapidly, from almost nothing in the 1950s, to a system that now produces a steady flow of new varieties and other technologies. Yields of Chinese-bred rice, wheat and maize varieties were comparable to the yields that were being produced by varieties in some of the most productive agricultural economies in the world (Stone 1988). After the economic reforms in the late 1970s and early 1980s, a nationwide reform in research was launched in the mid-1980s (Rozelle, Pray, and Huang 1997). The reforms attempted to increase research productivity by shifting funding from institutional support to competitive grants, support research useful for economic development, and encouraged applied research institutes to be more self-supporting by commercializing the technologies they produced (Fan, Zhang, and Qian 2006).

After remaining stagnant in terms of the share of agricultural gross domestic product for more than a decade (between the early 1980s and mid-1990s—Pray, Rozelle, and Huang 1997), investment into R&D finally

began to rise in both absolute and relative terms. Government investment in agricultural R&D increased by 5.5% annually between 1995 and 2000 and by more than 15% annually after 2000 (Hu et al. 2007). Funding was greatly increased for plant biotechnology, although Bt cotton is the only genetically engineered crop that has been commercialized to any significant extent (Huang et al. 2002).

The extension system in China was once known as a system that was effective in moving technology from the experiment station to the farm and for giving farmers advice in combating diseases and insects. With the publicly funded system, there were extension agents at the county and township levels. After the mid-1980s, however, fiscal pressures at all levels of government induced local officials to commercialize the extension system. Extension agents had their salaries reduced by half or more. The extension system—focused on supplying technology and other information to farmers—almost collapsed completely. Surveys found that most cropping farmers rarely, if ever, saw extension agents. Likewise, livestock and horticulture farmers received little support from the formal extension system.

There also are other economic factors affecting the nation's productivity. First, China's agricultural economy has been steadily transforming from a grain-first sector to one producing higher-valued cash crops, horticultural goods, and livestock and aquaculture products. In the early reform period, output growth—driven by increases in yields—was experienced in all subsectors of agriculture, including grains. However, after the mid-1990s, the area sown to rice and wheat production has fallen, as has the domestic production of these two staple food crops. The contraction in grain supply was preceded by a reduction in demand as increasing per capita incomes, rural to urban migration and a reduction in government marketing controls shifted the pattern of consumption away from staple food grains. Like the grain sector, production of cash crops in general and specific crops, such as cotton, edible oils and vegetables and fruit, also grew rapidly in the early reform period. In contrast to staple grain crops, the output of these other crops continued to grow throughout the reform era beginning in the 1980s, some at rates in excess of 5% per year.

The growth in livestock and fishery output outpaced the growth in output from the cropping sector, in total and in most crop subcategories. Livestock production increased by 9.1% per year in the early reform period and has continued growing at between 4.5 to 8.8% per year since 1985. Fisheries production has been the fastest growing component of agriculture, increasing by more than 10% per year during 1985-2000. Today, more than 70% of the world's fresh water aquaculture production occurs in China. At the same time, the combined share of livestock and fisheries in total agriculture rose to 45% in 2005, more than doubling their 1980 share. Dairy production also is rising extremely rapidly (Fuller et al. 2006).

Inputs, Outputs and Productivity Before 1995

After the rapid growth in output and the decline in inputs—involving mostly labor that shifted to off-farm activities—during the early 1980s (McMillan, Whalley, and Zhu 1989; Lin 1992), policy-makers became increasingly concerned about the slowing pace of agricultural output growth. In fact, our data suggest that these concerns were justified in the case of some crops but not others. For example, Figure 1 (Top Panel) demonstrates that output of early and late indica rice, japonica rice, and soybeans grew by less than 2% per year during the decade 1985-1994, substantially below the average rates of growth of the prior decade. For these four crops, input use actually increased by 1.7 to 4.0% per year, depending on the crop, which was faster than the corresponding rate of growth in crop output. In contrast, during the same decade, production of wheat and maize grew by 2.8 and 3.7% per year respectively, generally exceeding the corresponding rate of growth in input use, which averaged about 2% per year.

Figure 1 Annual Growth Rates of Output, Inputs and TFP of China's Major Grain Crops and Cotton (1985-1994)
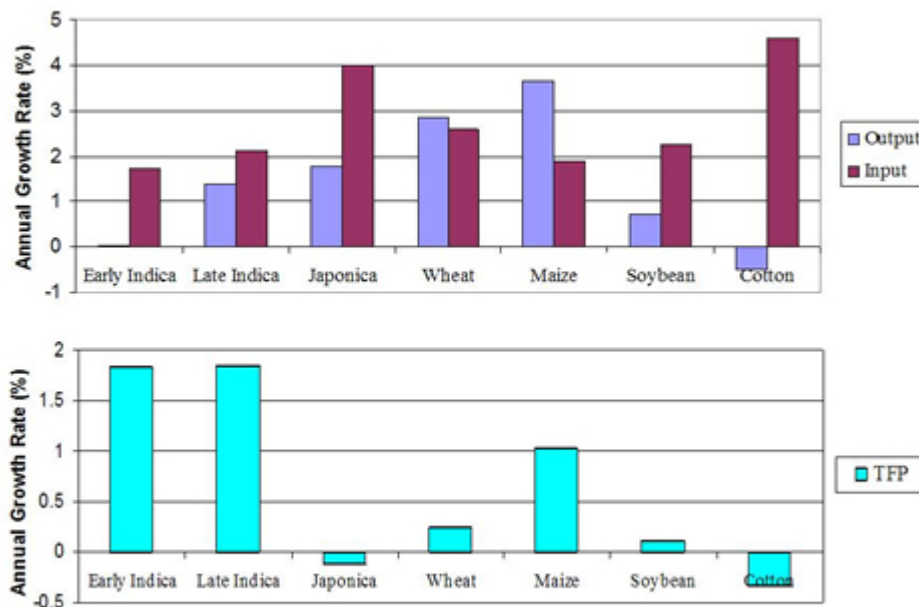
While pre-1995 data for cash crops and livestock production are limited, the record of output and input trends also varied among commodities. Widespread problems with cotton pests meant cotton production contracted by 0.49% per year between 1985 and 1995, while input use in this sector expanded by more than 4% per year. Inputs used in hog production also grew faster than output, whereas output grew faster than inputs for beef production.

TFP Performance before 1995

TFP analysis demonstrates that policy concerns regarding the relatively poor performance by Chinese agriculture during 1985-1994 were justified (Figure 1, Lower Panel). For early and late indica rice and soybeans, our estimates indicate that TFP during this period grew by a relatively modest rate compared with the early 1980s. The growth rates of TFP were even smaller for wheat and maize. Japonica rice productivity actually fell by 0.12% per year from 1985 to 1994.

The record is mixed during this period for nongrain crops. The decline in the rate of growth in cotton TFP shows that China's cotton production sector was becoming less competitive during the decade 1985-1994 (Qiao et al. 2006). Although the research system helped stem the fall by producing some new conventional cotton varieties, production efficiency declined; TFP trends in the hog sector followed a similar path.

**Production Agriculture: 1995 to 2004**

The relatively slow rates of growth of output experienced in 1985-1994, compared with the pace of growth in previous years, raised concerns that the underlying rate of TFP growth had systematically slowed after 1984. Hitherto information has been lacking on the pace of productivity growth for the major grain crops for the decade after 1995. In addition, there has never been a systematic analysis of the productivity performance of rapidly emerging agricultural sectors, such as horticulture, poultry and dairy.

Outputs and Inputs after 1995

Agricultural output growth for most commodities rebounded during the period 1995-2004 (Figure 2, Top

Panel). For 20 of the 23 commodities, for which we have more-complete data, output grew at a faster rate than inputs. This was so for all the grain crops as well as soybeans. Other sectors within agriculture showed similar trends. Cotton production expanded by 2.68% per year, whereas measured inputs declined by 1.90% per year. Most likely, the widespread uptake of Bt cotton—which allowed farmers to dramatically reduce pesticide use and labor for spraying while increasing yields—is a large part of the story. With the exception of the specialized milk sector that is mostly made up of large commercial dairies, the livestock sector also saw output growing faster than inputs during 1995-2004.

Figure 2 Annual Growth Rates of Output, Inputs and TFP of China's Major Grain Crops and Cotton (1995-2004)
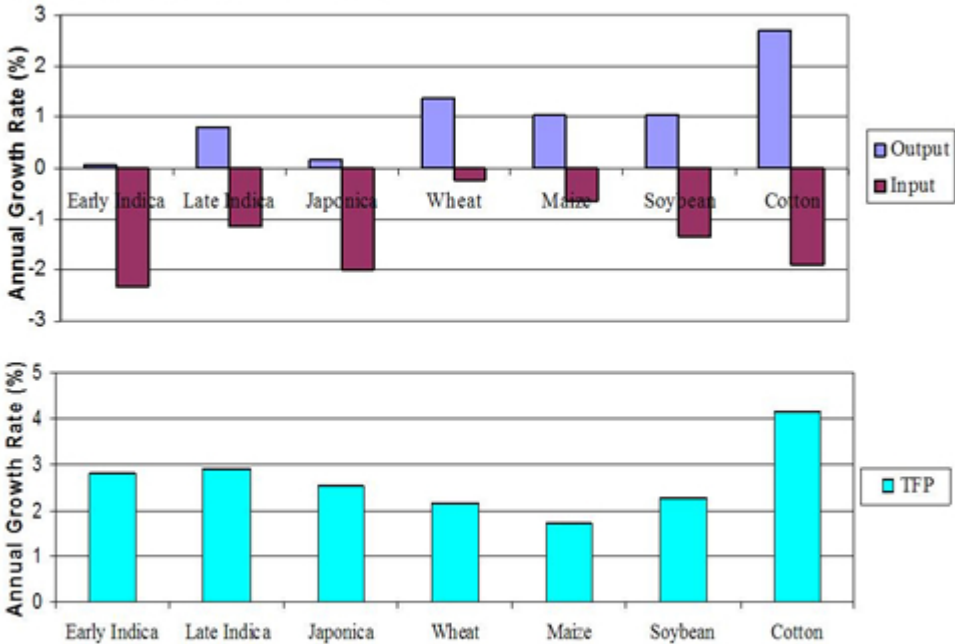
The horticultural sector has a more mixed record (Figure 3, Top Panel). The pace of output growth exceeded the pace of growth in input use for five of the horticultural crops, namely capsicum, field cucumbers, greenhouse cucumbers, greenhouse tomatoes, and mandarins. In contrast, the opposite held for eggplants, field tomatoes, and oranges. The fact that greenhouse tomatoes and other greenhouse vegetables experienced faster output growth relative to input growth—compared with less favorable output-input trends for field tomatoes and some other crops—might reflect the greater farming abilities of those commercial farmers who adopted greenhouse technologies.

TFP in China's Agriculture, 1995-2004

TFP growth during 1995-2004 was positive for all 23 commodities and in all cases was greater than the measured TFP for the pre-1995 period (Figures 2, 3 and 4, Lower Panel). With just a few exceptions, TFP growth for these commodities exceeded 2% per year after 1994. In fact, using the respective value shares of output as weights when aggregating these 23 commodities, the implied rate of growth of TFP for Chinese agriculture exceeded 3% per year between 1995 and 2004. Coupling these estimates with the corresponding TFP estimates for 1978-1994 implies that TFP growth in China over the period 1978-2004 sustained an average rate of growth in excess of 3% per year; a remarkable achievement over a quarter of a century. It also appears that TFP growth accelerated between the late 1980s and 2005.

Some of the highest rates of TFP growth have been in the livestock sector. If one considered the fact that domestic investment into livestock productivity-enhancing research during the 1980s and 1990s was relatively low this might seem surprising. It could be, however, that foreign technologies have played a role in the rapidly increasing TFP growth in the livestock sector after 1995 (Figure 4). During the 1990s, China

encouraged the importation of large amounts of new genetic material for the hog, beef, poultry and dairy industries. The quality of the genetic stock in China's livestock industry has greatly increased through the introduction of new hog varieties from the United States and Japan; new beef and dairy cattle genetics from Canada, New Zealand and Australia; and poultry technology from around the world, including the United States. Apparently these new innovations have found their way into individual farms in China's villages as well as fledgling commercial operations.

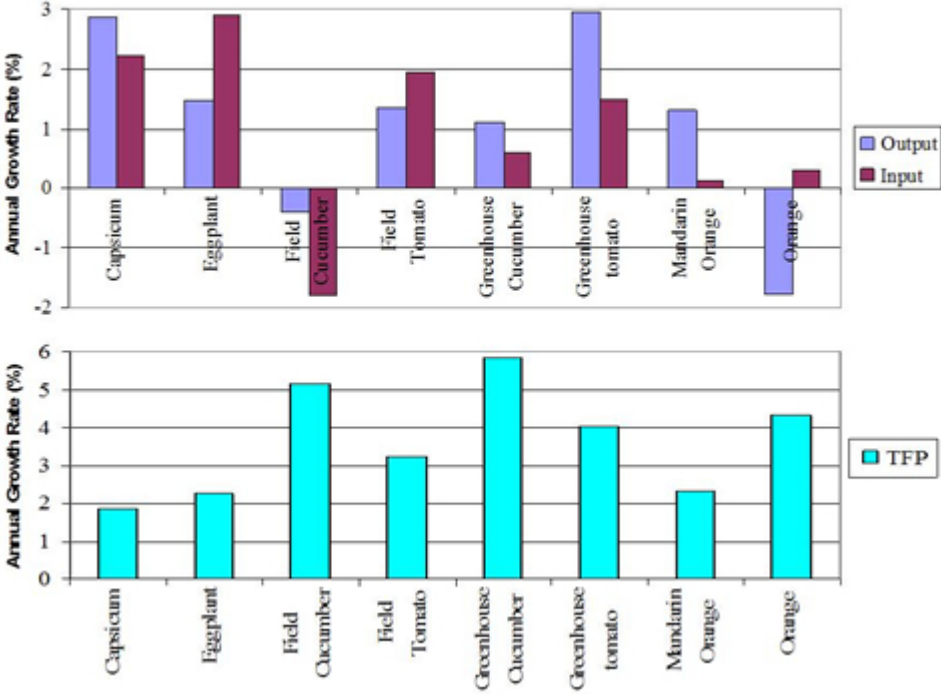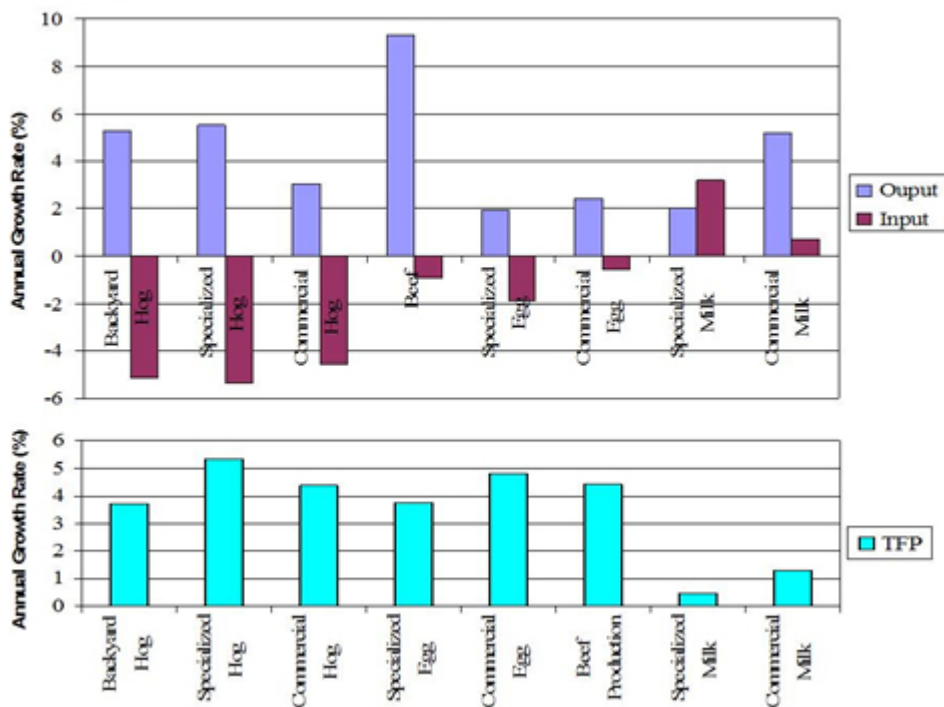**Figure 3 Annual Growth Rates of Outputs, Inputs and TFP of Vegetables and Oranges (1995-2004)**

Figure 4 Annual Growth Rates of Outputs, Inputs and TFP of Livestock and Dairy Products (1995-2004)

Conclusion

Our analysis shows that agricultural TFP in China grew at a relatively rapid rate since 1995 for a large number of commodities. TFP for the staple commodities generally increased by about 2% per year; TFP growth rates for most horticulture and livestock commodities were even higher at between 3 and 5% per year. The rate of increase in agricultural TFP in China over the quarter century, 1978-2004, was high by historical standards and compared with corresponding rates of TFP growth reported for many other countries around the world. We ascribe much of this TFP growth to changes in the technologies flowing to and being used by these sectors. Both domestic and foreign technologies have played a role. Sustained and increasing support of China's agricultural research has been vital to this success, as has an openness to trade in technologies produced by public research agencies in foreign countries and foreign firms.

Rapid TFP growth is important for the competitiveness and national food security in China in the coming years. It is also important to keep China from putting too much pressure on international markets. If China's economic growth continues, its consumers are going to demand increasing quantities of meat, fish, fruits and vegetables. These demands mean that large increases in production will be needed to feed China. Simulation modeling has shown that continued rapid growth of the economy and slow productivity growth would result in extremely large demands for imports. Being such a large country with access to foreign reserves, international prices would feel upward pressure. However, if agricultural productivity growth in China remains strong, simulations clearly demonstrate that its own farmers will be able to produce most of the food that China's consumers will demand. The race between China's future supply and demand of food will be a key determinant of future international trade flows, and in no small part will depend on the future productivity performance of its own farming sector.

For More Information

Fan, S., K. Qian, and X. Zhang. (2006). China: an Unfinished Reform Agenda. Chapter 3 in *Agricultural R&D in the Developing World: Too Little, Too Late?* Eds. P.G. Pardey, J. M. Alston, and R. R. Piggot. Washington DC: International Food and Policy Research Institute.

Fan, S., and Zhang, X. (2002). Production and Productivity Growth in Chinese Agriculture: New National and Regional Measures. *Economic Development and Cultural Change, 50*(4), 819-838.

Fuller, F., Huang, J., Ma, H., and Rozelle, S. (2006). Got Milk? The Rapid Rise of China's Dairy Sector and Its Future Prospects. *Food Policy, 31*(3), 201-215*.*

Hu, R., Shi, K., Cui, Y., and Huang, J. (2007). *China's Agricultural Research Investment and International Comparison* (Working Paper). Beijing, China: Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences.

Huang, J., Rozelle, S., Pray, C., and Wang, Q. (2002). Plant Biotechnology in China. *Science*, *295*(25): 674-677.

Jin, S., Ma, H., Huang, J., Hu, R., and Rozelle, S. (in press). Productivity, Efficiency, and Technical Change: Measuring the Performance of China's Transforming Agriculture. *Journal of Productivity Analysis.*

Lin, J.Y. (1992). Rural reform and agricultural growth in China. *American Economic Review, 82*(1), 34-51.

McMillan, J., Whalley, J., and Zhu, L. (1989). The Impact of China's Economic Reforms on Agricultural Productivity Growth. *Journal of Political Economy, 97*(4), 781-807.

Pray, C. E., Rozelle, S, and Huang, J. (1997). Can China's Agricultural Research System Feed China? (Working Paper). New Brunswick, NJ: Department of Agricultural Economics, Rutgers University.

Qiao F., Huang, J., Rozelle S., and Wilen, J. 2006. Managing Pest Resistance in Fragmented Farms: An Analysis of the Risk of Bt Cotton in China and its Zero Refuge Strategy and Beyond (Working Paper). Palo Alto, CA: Freeman Spogli Institute, Stanford University. Available online: http://iis-db.stanford.edu/pubs/21622/managing_resistance_new_version_3.pdf

Rozelle, S., Pray, C. E., and Huang, J. (1997). Agricultural Research Policy in China: Testing the Limits of Commercialization-led Reform. *Comparative Economic Studies, 39*(2), 37-71.

Stone, B. (1988). Developments in Agricultural Technology. *China Quarterly, 116,* 767-822.

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AGRICULTURAL PRODUCTIVITY IN TRANSITION ECONOMIES

**Johan F.M. Swinnen, Kristine Van Herck, and Liesbet Vranken**

Agricultural output and productivity have changed dramatically in Central and Eastern European countries (CEECs) and the Former Soviet Union (FSU) since the fall of the Berlin Wall, exactly 20 years ago. Initially, market reforms caused a strong decline in agricultural output. The extent to which this output decline was associated with changes in productivity depended on the speed with which labor could exit agriculture and agricultural factor and output markets could develop. These, in turn, depended on the initial conditions and implemented reform policies. As the initial conditions and reform policies were very different across countries in the region, productivity evolved very differently across countries.

In this paper we document the changes in agricultural output and productivity, explain how they were affected by a combination of factors, identify four "patterns" of productivity changes, and then relate these patterns to differences in initial conditions and reform policies. Our review covers more than 20 countries. To keep the discussion more tractable we organized countries into six regional groups. Specifically we distinguish Central Europe (Hungary, Poland, Czech Republic and Slovakia), Baltics (Estonia, Lithuania and Latvia), Balkans (Albania, Bulgaria, Romania, Slovenia), European CIS (Commonwealth of Independent States) (Russia, Ukraine, Belarus), Transcaucasia (Georgia, Armenia, Azerbaijan), and Central Asia (Uzbekistan, Turkmenistan, Kazakhstan, Kyrgyz Republic, and Tajikistan).

Changes in Agricultural Output

Figure 1 shows the evolution of agricultural output in the past two decades. The pattern is similar in all countries. In general, we observe a U effect: an initial decline in agricultural output and a recovery later on.

## Figure 1 Evolution of the Gross Agricultural Output (GOA)
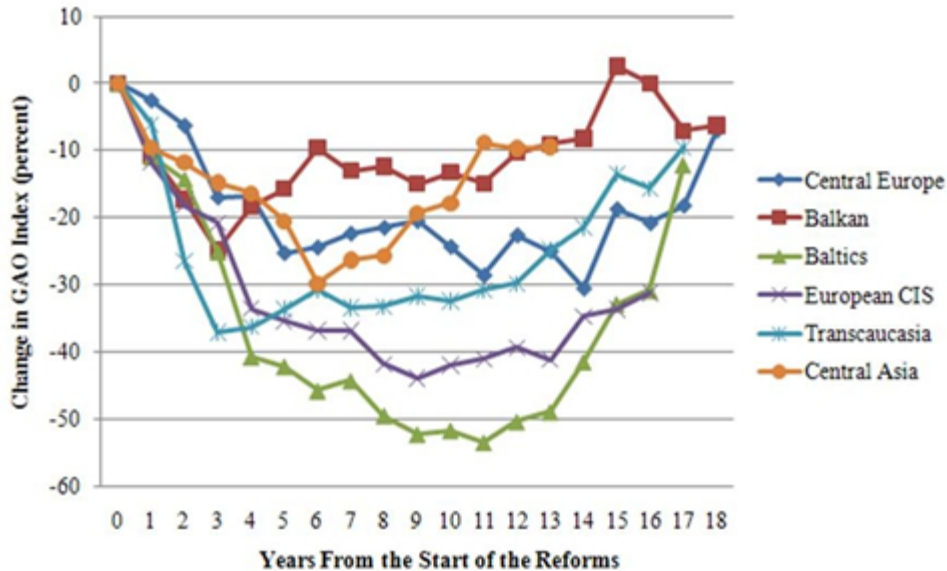
In the first years of transition, gross agricultural output decreased in all countries by at least 20%. The transition from a centrally planned economy to a market orientated economy coincided in all countries with subsidy cuts and price liberalization, which in general caused input prices to increase and output prices to decrease. Purchased inputs were no longer affordable at the new relative prices and the decrease in input use caused a decrease in agricultural output.

In the Baltic states and the European CIS agricultural output decreased to about 50% to 60% of the prereform output. In Central Europe and Central Asia, output declined by 25% to 30%. Output stabilized and started to recover in the mid 1990s in Central Europe and later in the other regions. Currently agricultural output is close to the pre-reform output level in most countries.

Changes in Agricultural Productivity

Figure 2 illustrates the evolution of agricultural labor productivity (ALP), measured as output per farm worker. Despite a decrease in agricultural output in total, output per worker in Central Europe strongly increased during the past two decades. This increase was driven by the dramatic decrease in agricultural employment in the first years of transition from centrally planned to more market-oriented economies. As output stabilized at the end of the 1990s and agricultural employment continued to decline, the increase in ALP continued.

**Figure 2 Evolution of Agricultural Labor Productivity (ALP)**
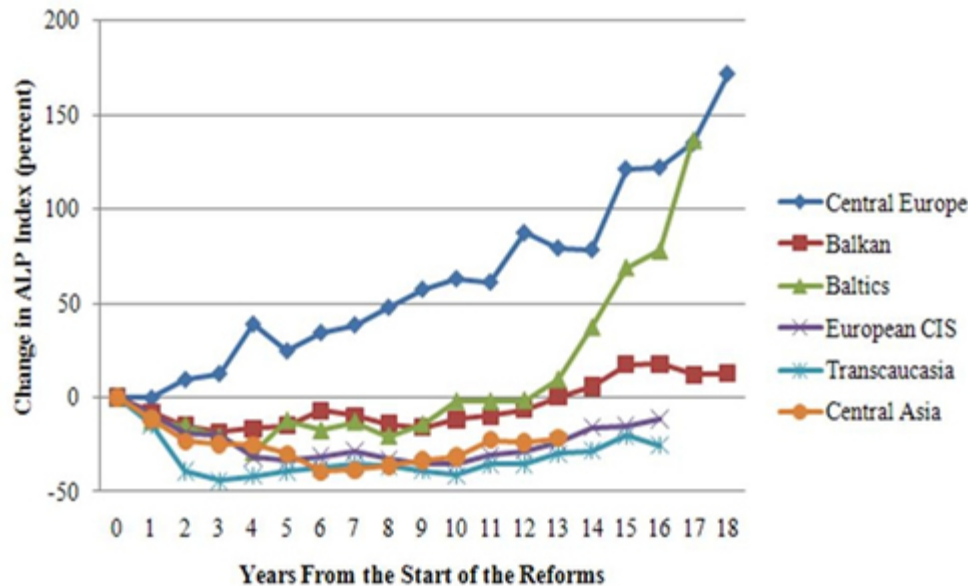
However, this pattern was not followed by other countries. In the Balkan countries the agricultural sector acted as a social buffer and absorbed rural labor in the first years of transition (Swinnen, Dries, and Macours, 2005). ALP decreased initially as much labor was absorbed in agriculture. In the late 1990s labor began to flow out from agriculture and this outflow of labor, in combination with increased investments in the farming and agri-food industry, resulted in a gradual but consistent improvement in ALP.

Farther East, ALP strongly decreased in the first decade of transition. On average, ALP decreased by 33% in the European CIS and 30% in Central Asia in the first five years of transition. The strong decline in ALP was the result of two effects. First, agricultural output declined strongly in both regions and second, the outflow of agricultural labor was limited, and in some regions agricultural employment even increased. From the mid 1990s, however, the decline in ALP started to slow down and since the beginning of the 2000s ALP has recovered slowly.

Figure 3 illustrates the time path of land productivity, which evolved in conjunction with ALP. Everywhere in the region average yields fell during the first years of transition and recovered later. However, the depth and length of the fall differed strongly among countries. Average yields recovered considerably from the mid 1990s onwards in countries such as Hungary, nations with relatively more large-scale farming and investments in the food industry. In contrast, productivity recovered more slowly in countries such as Romania, which has a large number of small-scale family farms with difficult access to inputs. Yields declined the most in the European CIS and Central Asia where yields started to increase only from the beginning of the 2000s. Importantly, the recovery of yields in the European CIS and Central Asia was so slow that they only recently reached their prereform levels.

Figure 3 Evolution of Average Agricultural Yield
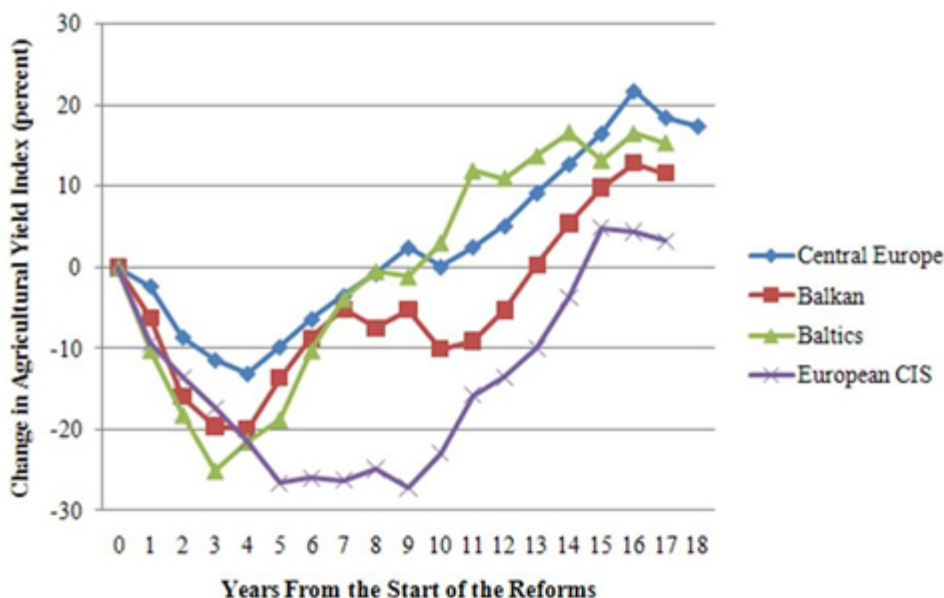
Of course, partial productivity measures might exhibit very different patterns than would be found using measures of total factor productivity (TFP), the most comprehensive measure of productivity. Unfortunately, only a few studies have measured total factor productivity (TFP), and consequently only limited comparisons can be made between countries and over time (Macours and Swinnen, 2000; Swinnen and Vranken, 2009; Lerman, Caski, and Feder, 2004). However, the available evidence on TFP is roughly consistent with the evidence from the partial productivity indicators.

In Central Europe, TFP grew slightly in the first years of transition —0.4% annually between 1989 and 1992— and significantly afterwards: by 2.2% annually between 1992 and 1995 and by 4.4% annually between 1995 and 1998. Studies find a slowdown of TFP growth in the period 1998-2001, probably due to substantial investments in agricultural machinery and capital inputs in this period.

In the Balkan countries, the TFP evolution fluctuates much more. TFP decreased strongly, by 4.1% per year, from 1989 to 1992. Later there was a stronger recovery when TFP increased by 7.5% per year in the period 1992-1995, but it fell again in the late 1990s with bad macro-economic policies resulting in TFP declines of 1.3% annually from 1995 to 1998. After 1998 when a series of important reforms were implemented in the region, there was a strong recovery in productivity: from 1998 to 2001, TFP grew on average by 2.3% per year.

Causes of Productivity Changes

The productivity changes—and the variations in them—were caused by a combination of factors. In this section we review a few of the main drivers.

First, initial conditions affected productivity in two important ways. On the one hand, they directly influenced the impact of reforms; on the other hand, through institutional and political constraints, they also indirectly influenced the choice of the reform policies. For example, the collectivization of agriculture and the introduction of central planning occurred in the 1920s in the FSU, but only after World War II in CEECs. Consequently, rural households in Central Europe had much more experience with private farming than their counterparts in most of the FSU. This difference affected not only the emergence and dynamics of the new private farms, but also the preferences for land reforms: in CEECs households wanted their land back, while in a large part of the FSU households had never owned land since feudalism had directly preceded

collectivist farming.

Another condition that played an important role was that in Central Europe and the Baltic states, countries were generally richer and agriculture was less important in the overall economy, compared to countries in Transcaucasia and Central Asia, which were much poorer with relatively more important agricultural sectors. The general economic situation in a country influenced the extent to which other sectors could absorb surplus labor from agriculture and the development of the social safety net system. Finally, the outflow of surplus agricultural labor was much stronger in Central Europe than in other countries in the 1990s, in part because the social safety net system was much better developed in Central Europe and the agricultural sector was relatively small.

Initial conditions, in particular resource endowments and use of technology, also affected the relative efficiency of farm organizations and thus incentives for farm restructuring. Resource endowments affect the costs and benefits of shifting from corporate farms to family farms. If labor/land ratios are high, as in countries with labor-intensive technologies, such as in Transcaucasia and the Balkans, the benefits from better labor governance by shifting to family farms from corporate farms are larger, while the losses in scale economies of shifting to smaller farms are lower. These productivity incentives resulted in a strong shift to small scale farming. In contrast, in more capital- and land-intensive agricultural systems, such as in the Czech Republic and Slovakia, the benefits from shifting to family farms were lower so that large-scale corporate farming remained more important. In these situations, productivity gains came mostly from laying off corporate farm workers.

Second, reform choices and their implementation also mattered importantly— and they differed by country. For example, price liberalization and the subsequent decline in terms of trade strongly affected agricultural productivity. The decrease in output prices and the increase in input prices caused a decline in the terms of trade. This contributed to a fall in input use at the start of the reforms, which caused a decrease in the productivity of land and labor (Macours and Swinnen, 2000). The implementation of these reforms differed substantially between regions. Governments in Central Europe and the Baltic states dramatically reduced agricultural subsidies in the first years of transition, whereas in some European CIS and countries in Central Asia, reforms were more gradually implemented (Csaki and Fock, 2001).

A very important element of the reform packages was land reform. There were three types of land reform: restitution of land to the former owners; the physical distribution of land to agricultural workers; and the distribution of certificates to agricultural workers (Macours and Swinnen, 2002). The two first types of land reform, restitution and the physical distribution of land, ended up with relatively strong and well-defined property rights. While it was expected that restitution of land would lead to a decrease in productivity because of the fragmentation of land ownership, in many countries restitution contributed to a greater consolidation of land use because many of the former owners were not interested in farming themselves, and rented the land to the privatized cooperative and corporate farms.

In the regions that implemented land reforms by distributing certificates, property rights were less-clearly defined and, at least in the first decade of the reforms, output and productivity were negatively affected as a result. Restrictions were placed on selling and purchasing of land certificates, which significantly slowed down structural changes and thus productivity growth. Second, owners had little incentive to put in effort and undertake investments because property rights on specific plots were not clearly defined. At the end of the 1990s the situation started to improve when land policies were further liberalized, and limited land transactions became possible.

Finally, privatization of farms and agri-food companies led to contracting problems and disruptions all along the agri-food chain. Investments by private processors and the reintroduction of vertically coordinated supply chains have been important in overcoming these hold-up problems and improving output, productivity and quality of agricultural products. Foreign direct investment (FDI) in the agri-food sector played an important role in these developments through spillover effects on farmers and local food companies (Dries and Swinnen, 2004). They have contributed dramatically to productivity and quality improvements and technology transfers.

Figure 4 illustrates the vast differences in the inflow of FDI since the mid-1990s. FDI rose strongly in Central Europe and the Baltic states. In the Balkan states, the inflow of FDI lagged behind. However, after substantial reforms were introduced at the end of the 1990s, FDI started to increase there as well. In the European CIS,

Transcaucasia and Central Asia, FDI inflow has been very low, and increased only in more recent years.

Figure 4 Evolution of FDI per Capita
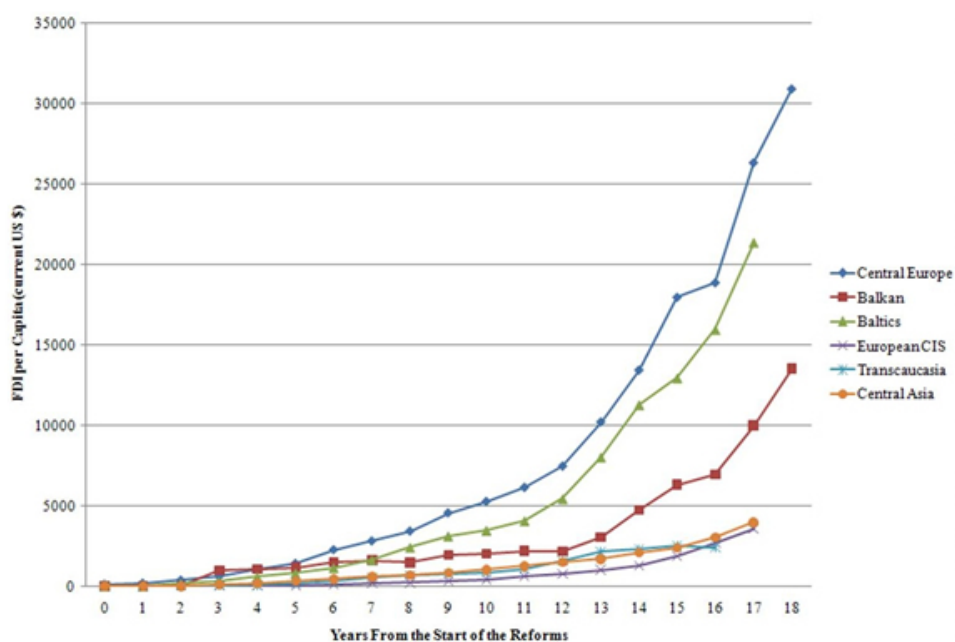
Patterns of Productivity Change

Initial conditions, reform policies and investments had a large impact on agricultural productivity changes throughout the region, but effects varied tremendously among countries and over time. We distinguish four patterns.

The first group of countries are the most economically advanced countries in Central Europe and the Baltics, such as Hungary, the Czech Republic, Slovakia and Estonia which implemented radical reforms. These countries were characterized by relatively high incomes, a capital-intensive agricultural sector and a big-bang approach to reforms and privatization, including restitution of land to former owners. The loss from foregone economies of scale was limited because the restitution of agricultural land to previous owners led to consolidation of land in large farming enterprises. In addition, a massive outflow of agricultural labor occurred early in transition, facilitated by a well-developed social safety net system and radical reforms which stabilized the macroeconomic environment. This outflow of labor caused substantial gains in labor productivity early on in transition. Later, productivity gains were reinforced by spillovers from the large inflow of FDI in the agri-food sector. Investments, through vertically integrated supply chains, improved farmers' access to credit, technology, inputs and output markets.

Another pattern was followed by the poorer CEECs, including Romania, Bulgaria, Lithuania and Poland. These countries were diverse in their initial farm structure. Before transition, Poland already had mainly small, family farms, whereas in Lithuania, Romania and Bulgaria the agricultural sector was concentrated in large corporate farms. However, in all of the countries, labor outflow from agriculture was limited in the first years of transition. In these countries, agriculture served as a social buffer in times when overall unemployment was high and social benefits were low. The restitution of land to former owners constrained access to land for young farmers, since that land was given to older people who started farming to complement their small pensions. Because the agricultural sector in these countries was relatively capital-intensive, the break-up of the corporate farms into small, family farms caused significant losses in economies of scale and yielded only limited gains from the shedding of labor. Initially, both output and productivity declined. In countries such as Poland and Lithuania, output and productivity started to recover in the mid-1990s stimulated by FDI. In Romania and Bulgaria output and productivity recovered only slowly, and at the end of the 1990s they decreased again as a result of the financial crisis. From the beginning of the 2000s the

outflow of inefficient labor and the inflow of FDI started a sustained recovery.

Third, a group of poor Transcaucasian and Central Asian countries, such as Armenia, Azerbaijan, Kyrgyz Republic and Tajikistan, followed yet another pattern. These countries are characterized by their poverty and the absence of a good social safety net system, their labor intensive agricultural systems and their slower progress in overall reforms. In these countries, agriculture also provided a buffer role and a labor sink. Reforms caused a strong shift from large scale towards individual farming—especially when land distribution in kind to households was introduced after the failure of the share distribution system became evident. The reforms also caused a substantial inflow of labor into agriculture, and growth in the importance of more labor-intensive sectors, such as horticulture and livestock. This caused a decrease in labor productivity while land productivity grew. Although there has been substantial growth in yields, labor productivity is still now substantially below prereform levels in Transcaucasia (see Figure 1).

A fourth pattern is followed by a group of middle income FSU countries, including Kazakhstan, Russia and Ukraine. In these countries, there was almost no outflow of agricultural labor and, since output fell substantially in the 1990s, agricultural labor productivity declined strongly. Reforms were implemented only slowly and soft budgets continued, which favoured the large-scale farms and constrained restructuring, with limited efficiency gains. Only after the Russian crisis in 1998 did the macroeconomic situation improve with enhanced competitiveness of the domestic agricultural sector through exchange rate devaluations and the inflow of revenues from increasing oil and mineral prices. This affected in particular Russia and Kazakhstan. Ukraine implemented a series of important reforms in the late 1990s. Since then, agricultural productivity has increased in these countries as liquidity in the economy and investments in agriculture increased. Surplus employment started to decline gradually. An important factor in the growth of productivity in the 2000s was increased investments in the food industry which benefited agriculture through vertical integration. As Figures 2 and 3 illustrate, it has taken more than 15 years in the European CIS for labor and land productivity to recover to their pre-reform levels.

Prospects for the Future

While the recent past has seen positive developments, the future remains uncertain. As documented above, productivity has increased significantly throughout the region in the decade since the Russian crisis in 1998. However, the global financial crisis has hit the CEECs and FSU particularly hard. Due to a combination of factors, some of the countries covered here have experienced declines in output and productivity among the worst in the world (Mitra, Selowsky, and Zalduendo, 2010). Significant declines in demand and reductions in access to finance had important impacts on agriculture (Meyers and Kurbanova, 2009). Governments throughout the region have tried to offset reductions in private finance and investment by the expansion of public support to agriculture.

It is unclear at this point to what extent these more recent setbacks or the offsetting policy stimulus will have a lasting effect on the productivity developments in the sector, or whether they will only cause a temporary interruption in a long run path of productivity growth in agriculture.

For More Information

Csaki, C., and A. Fock. (2001). The Agrarian Economies of Central and Eastern Europe and the Commonwealth of Independent States: An Update. Environmentally and Socially Sustainable Development Working Paper, World Bank, Washington, D.C.

Dries, L., and J.F.M. Swinnen. (2004). Foreign Direct Investment, Vertical Integration and Local Suppliers: Evidence from the Polish Dairy Sector. *World Development,* 32(9), 1525-1544.

Lerman, Z., Kislev, Y., Biton, D., and A. Kriss. (2003). Agricultural Output and Productivity in the Former Soviet Republics. *Economic Development and Cultural Change*, 51, 999-1018.

Lerman, Z., Csaki, C., and G. Feder. (2004). *Agriculture in Transition: Land Policies and Evolving Farm Structures in Post-Soviet Countries.* Lanham: Lexington Books, Lanham.

Liefert, W.M. (2008). Measuring the Success of Agricultural Transition: An Application to Russia. In Csaki, C.,

and C. Forgacs (eds.), *Agricultural Economics and Transition: What was Expected, What We Observed, the Lessons Learned* (pp.44-54). Halle, Germany: IAMO.

Macours, K., and J.F.M. Swinnen. (2000). Causes of Output Decline during Transition: The Case of Central and Eastern European Agriculture. *Journal of Comparative Economics,* 28, 172-206.

Macours, K., and J.F.M. Swinnen. (2002). Patterns of Agrarian Transition. *Economic Development and Cultural Change,* 50(2), 265-294.

Meyers, W., and G. Kurbanova. (2009). *Impact of the Global and Financial Crisis on Food Security in Eastern Europe and Central Asia.* Background Paper for the Conference on Social Impacts of the Economic Crisis in Eastern Europe, Turkey and Central Asia, 7-8 December 2009, Almaty, Kazakhstan.

Mitra, P., Selowsky, M., and J. Zaluendo. (2010). *Turmoil at Twenty: Recession, Recovery, and Reform in Central Eastern Europe and the Former Soviet Union. The International Bank for Reconstruction and Development*, World Bank.

Rozelle, S., and J.F.M. Swinnen. (2004). Success and Failure of Reform: Insights from the Transition of Agriculture. *Journal of Economic Literature*, 42(2), 404-456.

Sedik, D., Trueblood, M., and C. Arnade. (1999). Corporate Farm Performance in Russia, 1991-1995: An Efficiency Analysis. *Journal of Comparative Economics,* 27, 514-533.

Swinnen, J.F.M., Dries, L., and K. Macours. (2005). Transition and Agricultural Labour. *Agricultural Economics,* 32(1), 15-34.

Swinnen, J.F.M. and L. Vranken. (2009). Reforms and Agricultural Productivity in Central and Eastern Europe and the Former Soviet Republics: 1989-2005. *Journal of Productivity Analysis*, forthcoming.

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