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Influences of Agricultural Technology on the Size and Importance of Food Price Variability

Julian M. Alston, William J. Martin, and Philip G. Pardey

1.1 Introduction

Innovation and technological change in agriculture have contributed to profound changes in the structure of agricultural production, markets, and trade. Significant technological changes have been made both on farms and in the industries that store, transport, process, distribute, and market farm products and supply inputs used by farmers (e.g., see Pardey, Alston, and Ruttan 2010).

These changes have affected the size and importance of food price variability in three main ways. First, innovations can change the sensitivity of aggregate farm supply to external shocks—for instance, if farmers adopt improved crop varieties that have higher expected yields but more- or less-variable yields, if individual farmers are induced through innovation to

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become more specialized in particular outputs, or if the adoption of innovations results in less variation among farmers in the timing of farm operations (e.g., the date of planting of crops) or an increase in the geographical concentration of production. Second, technological innovations on or off farms can result in changes in the price elasticity of supply or demand (of both farm inputs and outputs), changing the sensitivity of prices to a given extent of underlying variability of supply or demand or both. This can happen both directly, as a consequence of particular innovations, or indirectly because of the broader economic implications of technological changes—for example, by increasing incomes. Third, food price volatility is less important to richer people and, by increasing the general abundance of food and reducing the share of income spent on food, agricultural innovation has made a given extent of volatility less important.

The recent evidence of a slowdown in agricultural productivity growth in many parts of the world, combined with the rise of biofuels, has coincided with a reversal of the trend of rising abundance of food, and a corresponding increase in vulnerability of a greater number of poor people to food price volatility.[1] Moreover, as poor farmers respond to food scarcity by increasing the intensity of production practices and moving farther into marginal areas, we may see an increase in vulnerability of their production to weather and other shocks for some farmers. This chapter explores these different dimensions of the role of agricultural technology in contributing to or mitigating the consequences of variability in agricultural production, both in the past and looking forward.

1.2 A Simple Model of Technology and Prices

A simple supply and demand model can be used to illustrate the various ways in which changes in technology influence food price variability.[2] In the following model of the farm-level market for a staple food commodity, subscripts s and d refer to supply and demand respectively, Q represents quantity, P represents price, and η represents the absolute value of the elasticity of supply or demand.[3] In each equation, α, the "intercept" comprises a deterministic part and a random part, which is the source of variability:

1. Whether measures of growth of total factor productivity (TFP) or multifactor productivity (MFP) in agriculture are exhibiting a slowdown is the subject of a continuing debate among agricultural economists, but the participants in that debate have agreed that growth rates of partial factor productivity measures such as crop yields have slowed for the world as a whole and for most producing countries (e.g., see Alston, Babcock, and Pardey 2010).

2. Although the general discussion is pertinent to a broader set of circumstances, for concreteness we have in mind a model of the national or global market for a particular food commodity, as represented by aggregate farm-level annual supply and demand. To emphasize the important first-round effects the analysis is mainly partial, although the empirical simulations in section 1.5 explicitly link the farm sector to the broader economy.

3. Some more-detailed results will be conditioned by the use of constant elasticity forms as a local approximation to represent supply and demand equations that could take some other shape, but the main results here will not be sensitive to this approximation, which allows us to represent the key relationships in terms of familiar parameters.

(1) $$\ln Q_s = \alpha_s + \eta_s \ln P_s \text{ (supply)}$$

(2) $$\ln Q_d = \alpha_d - \eta_d \ln P_d \text{ (demand)}$$

Assuming $Q_s = Q_d$ and $P_s = P_d$, solving equations (1) and (2) for market clearing prices and quantities yields:

(3) $$\ln P = (\alpha_d - \alpha_s)/(\eta_s + \eta_d),$$

(4) $$\ln Q = (\eta_s\alpha_d + \eta_d\alpha_s)/(\eta_s + \eta_d).$$

Taking variances of ln P and ln Q in equations (3) and (4) yields:[4]

(5) $$\text{Var}(\ln P) = [\text{Var}(\alpha_d) + \text{Var}(\alpha_s) - 2\text{Cov}(\alpha_d, \alpha_s)]/(\eta_s + \eta_d)^2,$$

(6) $$\text{Var}(\ln Q) = [\eta_d^2\text{Var}(\alpha_s) + \eta_s^2\text{Var}(\alpha_d) + 2\eta_s\eta_d\text{Cov}(\alpha_d, \alpha_s)]/(\eta_s + \eta_d)^2.$$

Hence, price volatility, as represented by the variance of logarithms of prices in equation (5), increases with either (a) increases in the variability of demand or supply, as represented by Var(α_d) and Var(α_s); (b) reductions in the covariance between shocks to supply and demand; or (c) decreases in the elasticity of supply or demand. The corresponding measure of quantity variability in equation (6) increases with increases in variability of supply or demand or decreases in the covariance, but the signs of the effects of the elasticities depend on their relative sizes and the relative sizes of the variance and covariance terms.

Technology enters equations (5) and (6) in several ways, both on the demand side and the supply side. Specifically, the intercepts (α_s and α_d) and elasticities (η_s and η_d) are all functions of technology along with other variables, which are also left implicit, some of which may interact with technology and modify its effects on price volatility. In many contexts, for practical purposes the covariance terms in equations (5) and (6) will be negligible.[5] On the other hand, the mechanization of agriculture, the introduction of chemical fertilizers, and the rise of biofuels have tended to make the supply and demand for agricultural products more elastic (agriculture using a larger share of highly elastically supplied petroleum-based products as inputs makes supply more elastic, and biofuels demand makes demand for agricultural products more elastic unless it is driven by binding mandates). These factors also make agricultural supply and demand potentially more variable (because they are now vulnerable to oil price shocks in a way that was not true in the era of the horse), and the linkage of agriculture to the oil economy

4. Alternative measures of variability were considered. Many studies have used a coefficient of variation to remove the influence of differences in average levels or in units of measurement (e.g., Hazell 1989; Gollin 2006). The variance of log-transformed data has similar characteristics—it is unit-free and invariant to multiplicative transformations of the data—and has the further advantage that statistical tests developed for comparing variances between populations can be applied directly to it, as discussed by Lewontin (1966).

5. Sudden health epidemics, like bird flu or SARS, affect demand and could also affect supply if the affected labor is a major input into agricultural production, as it is in economies with agriculturally oriented economies and labor-intensive farming systems.

makes for a negative covariance between demand shocks and supply shocks (higher oil prices increase demand for biofuels and reduce agricultural supply). Much of the motivation for the present interest in commodity price volatility relates to this nexus. Table 1.1 summarizes the channels by which changes in technology can affect price variability as expressed in equation (5). The discussion that follows puts flesh on these bones.

1.2.1 On-Farm Agricultural Technology and Price Variability—The Supply Side

The primary role of technical change in agriculture has been to increase the supply of farm commodities, which we can think of as a decrease in the intercept of the supply equation, α_s in equation (1), reflecting a downward (or outward) shift in supply stemming from the use of new and better farming techniques or inputs.[6] As a result of innovations of this nature, global growth in supply over the second half of the twentieth century significantly outpaced growth in demand, arising mainly from growth in population and income, to the extent that since 1975 real prices of cereals have fallen by roughly 60 percent (see appendix A). These changes in turn have changed the implications for farm and nonfarm families of a given extent of price variability, an issue to which we will return later. They may have also served to change the extent of price variability as discussed next.

More variable supply of farm outputs? Clearly on-farm innovations (and other changes, some of which were not simply changes in technology, such as a change in the structure, size, and specialization of farms) have profoundly changed the supply function. As well as changing the position of the supply function, the same innovations may have entailed changes in the vulnerability of farm production to biotic and abiotic stresses, reflected as changes in $\text{Var}(\alpha_s)$. A widespread view of technological innovation is that it leads to the introduction of monocultures that—while higher yielding—are more vulnerable to output shocks from disease or other sources. Some economists have proposed that "Green Revolution" technology, for instance, increased cereal yields on average but also led to increases in relative yield variability for individual producers or in aggregate (e.g., Hazell 1989).[7] However, more recent studies have tended to find that Green Revolution technol-

6. Much of what we refer to here as "on-farm" technology is developed and produced "off-farm" for adoption by farmers. These on-farm innovations (including seeds, chemical fertilizers and pesticides, machinery, and methods not embodied in physical inputs) themselves reflect important changes in technology used by the agribusiness firms that supply inputs used by farmers—including everything from ballpoint pens and telephones through to satellite navigation systems, the Internet, and everything in between, which are also used by farmers. Off-farm technologies also include the technologies to process farm output, which may change the composition of and intensity of farm output used in food, fiber, feed, and fuel products.

7. Even if yield variance does not increase for individual farmers, an increased covariance of yield (or yield risk) among farmers implies an increase in variance of production and prices globally.

Table 1.1 **Channels through which agricultural and other technology affects food price variability**

Parameter in equation 5	Effect on price variability	Type of technological change and examples
Variability of supply of farm product: $Var(\alpha_s)$	+	*On-farm technology* • New crop varieties: e.g., Bt maize is less vulnerable to extreme pest pressure • Green Revolution technologies using modern varieties with modern inputs (fertilizer, irrigation) have less-variable yields • Integrated pest management allows better-informed decisions that reduce vulnerability to pests and diseases • Mechanization reduces vulnerability to farm labor shortages; increases vulnerability to some weather shocks • Other technology-induced changes in input mix may increase importance of inputs with more variable supply • Intensive livestock production may be more vulnerable to disease contagion but better able to contain outbreaks *Technology-induced changes in location of production* • Shift of geographic locus of production to places with different climate or other factors that influence variability *Pre-farm technology* • New technology (e.g., transportation, manufacturing) may influence variability of supply of factors to farmers
Elasticity of supply of farm product: η_s	–	*More elastic supply of farm products could result from changes in pre-farm or on-farm technology* • Increased use of more elastically supplied inputs—e.g., intensive livestock production uses feed grains • Induced reductions in relative importance of home consumption reduce the elasticity of supply of marketable surplus • Improved on-farm storage technology increases elasticity of supply to the market
Variability of demand for farm product: $Var(\alpha_d)$	+	*Changes in post-farm technology (storage, preservation, transport, handling, processing, food manufacturing, marketing)* • Improved storage and preservation technology likely to reduce variability of demand *Technology that allows markets to be better-integrated over space and time* • Can make market vulnerable to government intervention (trade barriers, "stabilization" policies) • May increase the risk of volatility from effects of invasive pests and diseases
Elasticity of demand for farm product: η_d	–	*Changes in post-farm technology could make demand for farm products more elastic* • Technology that allows markets to be better integrated over space and time makes demand more elastic *Changes in on- or off-farm technology could make demand for farm products less elastic* • Technology that contributes to increases in per capita incomes makes demand for food commodities less elastic
Covariance of supply and demand shocks: $Covar(\alpha_d, \alpha_s)$	–	*Various technologies increase the strength of the link between agriculture and oil prices and increase the covariance between demand and supply shocks affecting agriculture* • Increased use of mechanical technologies and petroleum-based inputs such as chemical fertilizers • Increased production of biofuels

Note: The symbol + indicates a positive effect of an increase in the parameter on variability of food prices, and the symbol – indicates a negative effect.

ogies reduced the relative variability of maize and wheat yields over time (e.g., as suggested by Gollin 2006).

A more subtle but still substantial influence is that changes in technology have contributed to changes to where production takes place—for instance, enabling wheat production to shift from the eastern United States into the Great Plains states and north into Canada (e.g., see Olmstead and Rhode 2002, 2010)—with implications for variability of yield and production.[8] More recently Beddow (2012) estimated that from 1899 to 2007 the centroid of corn production—essentially the geographical pivot point of US corn production—moved about 440 kilometers in a northwesterly direction. In 1899 the centroid of production was located in central Illinois; by 2007 it had migrated to southeastern Iowa.

On the other hand, some new technologies have equipped farmers to better match technology to environments, to make them potentially less vulnerable to stresses, or to be more resistant to some types of stress. The most recent revolution in crop varietal technology uses genetically modified (GM), herbicide-tolerant (HT), or insect-resistant (IR) varieties that substitute for chemical pesticides. These varieties change the yield profile of the crops in ways that have specific implications for variability of production. In particular, insect-resistant varieties avoid the severe yield losses that can arise with conventional technology in seasons with extreme pest pressure, especially in those areas where access to chemical pesticides is limited. Unlike the chemical pesticide technologies they substantially replace in many settings, yields of genetically engineered insect-resistant crop varieties are less vulnerable to insect damage because the technology does not rely on farmers anticipating pest problems and spraying in advance or observing infestations and spraying when they are under way (Qaim and Zilberman 2003; Hurley, Mitchell, and Rice 2004).[9] The insecticide is inherent in the plant.

In a similar vein, integrated pest management (IPM) technologies involve monitoring pest populations and applying pesticides at an optimal rate and time according to pest pressure, rather than according to the calendar. These and other information technologies allow farmers to apply inputs more flexibly and more precisely in ways that can reduce vulnerability to both biotic and abiotic stresses. Further, thinking more broadly about the change in paradigms associated with technological advance, we have improved methods for the early detection and management of pests and diseases using both

8. Beddow et al. (2010) document dramatic shifts in the location of agricultural production around the world during recent decades.

9. From the evidence presented by Hurley, Mitchell, and Rice (2004) it is evident that *Bt* corn technologies unambiguously reduced the relative variability of crop yields. However, the effects on the variability of corn supply could be ambiguous, depending on the fee charged for the use of the *Bt* technology. Qaim and Zilberman (2003) reported significant reduction in pest damage and higher average yield for *Bt* cotton in India; their results would also appear to imply reduced variance of yields.

current technology on farms and induced adaptive innovation as private and public research institutions respond to information about pest and disease threats.

More elastic supply of farm outputs? Second, technical change on farms may have resulted in changes in the elasticity of supply of agricultural outputs and the food, feed, fuel, and fiber products derived from agricultural outputs. One way this can happen is if new technologies emphasize the use of inputs that are relatively elastically supplied, such as agricultural chemicals, energy inputs, seed, or agricultural machinery (or, more precisely, the services from them), rather than inputs that are comparatively inelastically supplied, such as land and water, and in some cases, labor (see, for example, Schultz 1951). If relatively elastically supplied inputs represent an increased share of the cost of production, then the elasticity of supply will be greater (e.g., see Muth 1964); likewise, supply will be made more elastic if an innovation allows greater substitutability among inputs.

In the US poultry and hog industries, for instance, the introduction of intensive production systems made supply comparatively elastic. The primary inputs are feed grains and oilseeds, which are highly elastically supplied to each of these industries; there are not really any constrained specialized factors of production, and the producing units are replicable at efficient size such that the industry is characterized by constant returns to scale. In the richer countries at least, this industrial structure replaced an industry based on smaller, less-specialized operations, in which hogs and poultry were often raised as sidelines on dairy and grain-producing farms. As documented by Key and McBride (2007) and MacDonald and McBride (2009), livestock agriculture in the United States has undergone a series of striking transformations that affected the structure of the industry and the nature of supply response. Production has become more specialized, such that nowadays farms usually confine and feed a single species of animal, often with feed that has been purchased rather than grown on site, and they typically specialize in a specific stage of production. The scale of operations has increased, and economies of scale have contributed along with technological innovations to rapid growth of productivity. Contracting over production and the use of hired labor have both grown in importance.[10] Similar innovations have taken place in many other countries and are underway in others. These innovations that have tended to make livestock supply in these markets more elastic (at least over the medium to long run), might at the same time have made production more (or less) vulnerable to shocks such as

10. These technical changes have coincided with the move toward the pervasive use of contract farming and vertically integrated structures in most rich-country livestock supply chains. These institutional and structural developments may have muted short-run quantity responses to changes in market prices for farm commodities because of fixities in these complex supply systems, while enabling greater medium- to long-run response to price changes.

disease epidemics that may be spread more rapidly within closely confined systems, but they might also be easier in some cases to prevent, detect, and contain for similar reasons and given the use of better hygiene and access to improved veterinary medicines and practices.

Another way in which changes in technology on farms may have affected the elasticity of supply to the market is by changing the cost of on-farm storage or by causing (through effects on incomes, the extent of specialization, or other variables) changes in the importance of farm-household consumption as a share of the total use of farm output. The elasticity of supply of marketable surplus is an inverse-share-weighted average of the elasticity of farm production response with respect to price and the (absolute) elasticity of farm-household consumption response to price, such that changes in technology that reduce the relative importance of farm-household consumption will tend to reduce the elasticity of supply to the market.

In principle, changes in technology in the agribusiness sector that supplies inputs used by farmers might affect the variability in supply of key inputs, or the elasticity of supply of key inputs, to an extent that either the elasticity of farm output supply or the variability of farm output supply would be affected. For example, the rise of genetically engineered proprietary seed technologies represents an instance where a change in the technology of crop varieties (i.e., genetic engineering) has given rise to a substantial change in the conditions of input supply to the industry. Seed costs now represent a significant share (say, 10 percent) of total costs in North American corn, cotton, canola, and soybean production (e.g., see Alston, Gray, and Bolek 2012), with the technology supplied by a relatively concentrated sector with monopoly privileges. These developments in the conditions of seed supply might have implications for variability in supply in addition to those implied by the seed technology itself given their important consequences for the cost shares of different categories of inputs and the process by which input prices are determined.

1.2.2 Postfarm Agricultural Technology and Price Variability

Changes in technology in the postfarm agribusiness sector might change the elasticity of demand or the variability of demand, or both, as well as contributing to the growth of demand for farm outputs. The characteristics of demand for the farm product might also be affected by *on-farm* changes in technology that have had profound effects on incomes of the poor, which would be expected in turn to contribute to increases in demand for most farm products (though with a shift in the balance toward livestock products), and to make demands for farm commodities generally less elastic, and perhaps less variable.

The main factors driving growth in demand for farm products have been changes in the share and structure of on- versus off-farm consumption (associated with increases in farm size and specialization, part-time farming and urbanization), and increases in population and per capita incomes. The same factors have influenced the structure of demand. As per capita incomes rise, a greater share of food is consumed away from home or in more-processed and more-convenient forms for within-home consumption (e.g., Senauer, Asp, and Kinsey 1991). This reduces the farm component of retail food costs, thus muting the food price effects of fluctuations in farm-level commodity prices. All of these factors have been driven to some extent by on-farm innovations, which made food much cheaper while increasing farm incomes and freeing up labor, hitherto used on farms, for other pursuits. Complementary changes in technology off the farm have included improved technology for processing, storing, preserving, and handling food products, which, from the farmers' perspective, are also manifest as increases in demand.

Transportation and storage (notably refrigeration) technologies that increased demand for farm commodities also served to integrate markets over space and time.[11] Our simple market model abstracts from these relationships, but we can easily imagine what would happen if we expanded it from one country to two countries. In a two-country model, if we introduce trade (as a result of improved technology, increasing effective price transmission) we will make the effective demand (and supply) for food commodities facing each country more elastic, and we will make the prices in each country less variable, compared with the autarky prices, unless the shocks that are the sources of variability are perfectly correlated between the two countries. From this perspective, technology that improves transportation, facilitating interregional and international trade, would be expected to serve to reduce price variability unless it somehow increases the correlation of shocks between countries.[12]

While freer international trade in commodities does allow arbitrage to play its role in buffering prices from supply or demand shocks, it also facilitates the international movement of pests and diseases that could contribute to increases in volatility—for instance, the losses already experienced from the citrus greening disease *Huanglongbing* (known as HGB, and spread by the Asian citrus psyllid), which is already a serious problem in Brazil and now threatens the US citrus industry. Of course, the Columbian Exchange was necessary to create the possibility of "antigains" from trade in citrus

11. Information technologies that make for more efficient markets, including futures and options markets as well as spot markets, should play a complementary role in facilitating markets to better anticipate and absorb or accommodate shocks, and in enabling individuals to cope better generally with variability.

12. However, closer market integration means prices of individual inputs and outputs are more closely correlated spatially and this may have contributed to an increased covariance in prices of outputs both of the same crops among places and across crops. In turn this would add to the variance of production and prices.

and other crops by North America today, so the counterfactual is not easy to make sensible, but the point is that trade has sometimes made food prices both less volatile in the normal short-run sense and potentially more volatile in a longer-run sense because of the concomitant increases in the risk of losses from exotic pests and diseases.[13]

A more subtle implication is introduced when we consider the role of government. While international and interregional trade enabled by innovations in product preservation and transport technologies may have reduced on- and off-farm price variability ceteris paribus, it also creates new possibilities for government intervention in trade. Government intervention can make price variability worse, and it can do so in ways that are particularly damaging (such as active interventions in times of price spikes—e.g., see Martin and Anderson [2012]). The combined effect of trade and government could conceivably make volatility worse compared with autarky, an outcome that would not have happened without the creation of trade facilitated by technology. A similar argument applies in the context of improved storage technologies, which enable prices and consumption to be smoothed over time, and thereby generate net social benefits. But the development of storage technologies also enabled governments to introduce buffer stock schemes, which have historically proven to be very expensive policies. The Australian wool industry fiasco in the late 1980s is a telling example. Massy (2011) estimated that the collapse of the wool reserve price scheme in 1991 imposed social costs worth at least AU $12 billion at today's prices, more than five times the recent annual gross value of Australian wool production. Of course, the main issue here is not the storage or transport technology itself; rather, it is the unhappy decisions made by governments. But technology is involved and conditions the possibilities for damaging or desirable government policies.

Much could be said about technologies for food processing and preservation, but we will restrict attention here to fermentation technology (see Zilberman and Kim 2011). Fermentation has served as a means of converting perishable food products—such as fruit, grain, milk, and vegetables—into less perishable, more palatable, and safer forms—such as wine, beer, cheese, yogurt, sauerkraut, and kimchi among others. It also has enabled the transformation of food commodities into biofuels products. The net implications of these manifold changes are difficult to decipher, but of great immediate interest is the consequential linking of food commodity markets to fossil fuel and thus the broader economy in new ways that surely will have implications for food price volatility.

13. The widespread exchange of animals, plants, culture, human populations, communicable disease, and ideas between the American and Afro-Eurasian hemispheres following the voyage to the Americas by Christopher Columbus in 1492 is known as the "Columbian Exchange."

1.3 Effects of Technology on the Implications of Price Variability

As noted, the most important effects of changes in technology are through their cumulative effects on reducing the expected value of prices, rather than their impacts on price variability. By increasing real incomes through higher producer incomes at any given price and lower costs of living, and by inducing and enabling some people to leave production agriculture, technology changes the welfare implications of agricultural variability. A simple heuristic model can be used to illustrate how this works.

1.3.1 Elements of Benefits and Determinants of Beneficiaries

Productivity-enhancing changes in technology for the production of a staple crop give rise to benefits (B_i), accruing to the *i*th household, approximately equal to

(7) $$B_i = -P_iC_i\Delta\ln P_i + (k_i + \Delta\ln P_i)P_iQ_i,$$

where P_i is the price paid by the household for its consumption, C_i (and received for its production, Q_i) of the crop, and k_i is its household-specific proportional cost reduction associated with the improvements in technology giving rise to the proportional price change, $\Delta\ln P_i < 0$. The first element of the equation represents the consumer benefit. Households that consume but do not produce the crop obtain a benefit equal to the reduction in their cost of consumption—a real income effect of the research-induced price fall. The second element represents the producer benefit. Households that produce but do not consume the crop obtain a gain equal to the difference between their proportional cost reduction and the proportional fall in price ($k_i + \Delta\ln P_i$) times the value of their production.

More generally, households that both produce and consume the good receive a net gain equal to the sum of two gains, as shown in the following version of the above equation:

(7′) $$B_i = k_iP_iQ_i - (P_iC_i - P_iQ_i)\Delta\ln P_i.$$

The first term in equation (7′) is the household's cost saving on production (their proportional cost saving times their value of production). The second is their gain from the reduction in their *net* costs of food purchases (the difference between their expenditure on consumption and the value of their production) resulting from the fall in price. The size of the first term in equation (7′) will depend on the nature, as well as the size, of the shift in technology (Martin and Alston 1997). For food deficit households, the fall in price means a benefit; for food surplus households, it means a loss. Gainers include all households who produce less of the good than they consume, regardless of whether they adopt the new technology or not. Potential losers are those surplus households (i.e., who produce more than they consume) that are not able to achieve a per unit cost reduction equal to the market-wide reduction in price associated with the technology. Among these, in this analysis, those surplus households that are unable to adopt the technology are the only sure net losers. Some of these households might be induced to leave agriculture and find employment elsewhere.[14]

The above analysis might be interpreted as a medium-term or partial analysis. A more general or longer-run analysis could take more explicit account of linkages with the broader economy and this might change the story. Gardner (2002, 328–333) presented evidence that, over a thirty-year period 1960 to 1990, changes in average county-level US farm household incomes were not related to changes in agricultural productivity (or any other agriculture-specific variable). The general idea is that, given enough time for adjustments of employment to take place, it is expected that incomes of farm households will be determined by their education, skills, and other endowments and economy-wide prices of factors, notably the opportunity cost of household farm labor. In the US example, agriculture is now such a small share of the total economy that the economy-wide factor prices can be taken as exogenous (with the possible exception of agricultural land). In less-developed countries, events in agriculture may change the economy-wide prices of factors as well, but the general point remains relevant: linkages with the rest of the economy through the integration of labor and capital markets (e.g., through changes in occupational choice, migration to the cities, and remittances) mean that events in agriculture are not the sole determinants of farm household incomes.

1.3.2 Effects of a Change in Technology on the Distribution of Household Incomes

In what follows we have in mind a model in which changes in agricultural technology induce changes in the distribution of income among households through a multitude of direct and indirect effects and the optimizing responses of the households. These optimizing responses include the choice of whether to adopt the technologies in question and how best to respond to the consequences of others having adopted the technologies. The consequences are reflected both in the income distribution of the households—incomes of all producers are affected regardless of whether they adopt the new technology—and in the purchasing power of that income, since the technological innovations change the consumer cost of food.

Consider the effects of a productivity-enhancing innovation in the pro-

14. The calculations in equations (7) and (7′) refer to what de Janvry and Sadoulet (2002) termed the "direct" welfare effects of agricultural innovation. The first term in equation (7′) will capture the aggregate welfare impacts of the change except where it changes the volumes of trade passing over existing distortions (Martin and Alston 1994) while induced changes in prices and general equilibrium adjustments influence the distribution of the resulting benefits. See also Byerlee (2000).

duction of staple crops. We can write a reduced-form equation for the "full income" accruing to the *i*th farm household in the population of interest as:[15]

(8) $$Y_i(\tau) = Y(H_i, P, W \mid \tau),$$

where τ is an index of the *available* technology, H_i is a vector of characteristics of the household including its endowments of physical as well as human assets, P is a vector of prices of inputs and outputs, and W is a vector of environmental factors influencing production, including abiotic factors like weather and biotic factors such as pests and diseases. The elements of P and W are random variables, some of which may be contingent on the technology. The particular ex post outcome reflects the household's optimizing choices given the available technology and its assets and its expectations of prices and environmental factors, as well as the actual outcomes for prices and environmental factors.

Hence the household faces an ex ante probability distribution of income, Y_i, that is conditional on the state of available technology, regardless of whether the household does or does not adopt a new technology when it becomes available. Using equation (8) we can consider the probability distribution of income for the *i*th farm household in two states: under a baseline technology set, τ_0 (e.g., traditional grain varieties and related technologies as in 1962), and under an alternative technology set, τ_1 (e.g., modern high-yielding grain varieties and related technologies and other innovations introduced over the subsequent fifty years, as they apply in 2012). The new technology regime may imply a larger or smaller expected value of income for a particular farmer; likewise, the variance of income may be larger or smaller depending on whether the farmer is a technology adopter, among other things.

Even if agricultural technology has no direct effect on household incomes, it affects food security or poverty through its effects on the price of food. Figure 1.1 compares two stylized distributions of ex post household income across households, conditional on the state of technology, and assuming all realized values of random environmental variables and prices are at their expected values for each technology scenario. In each case the income distribution reflects a particular random draw of exogenous factors held constant between the scenarios and the resulting ex post prices, which differ between the scenarios.

The ex post income distribution across households, given technology τ_0, is denoted Y_0^e. Associated with this distribution, and defined by the corresponding prices is a "poverty line," reflecting the cost of a minimal quantity of food (or food calories) and other necessities, drawn at L_0^e. We wish to

15. Here, "full income" refers to total consumption by the household, including market goods and services, home-produced goods and services, and leisure, plus net savings. It reflects, as an accounting identity, endowment income plus variable profits—the total value of production minus costs of variable inputs (including household labor).

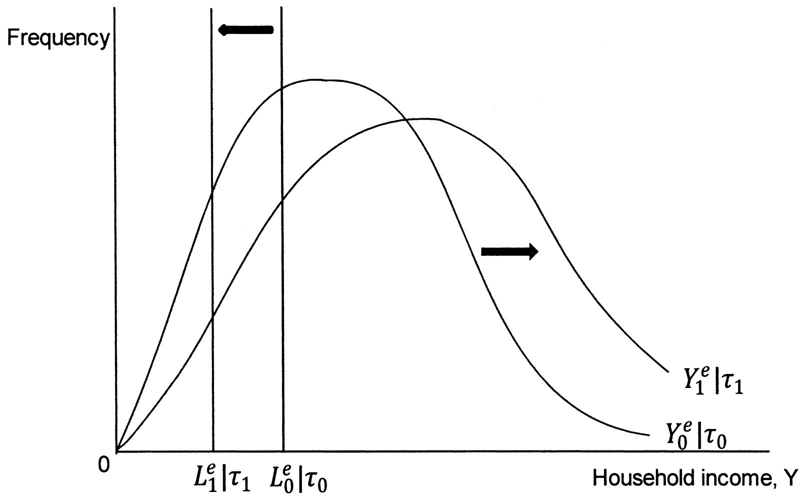

Fig. 1.1 Agricultural technology and household income distributions

compare this outcome with its counterpart under the alternative technology scenario, τ_1, given the same draw of the random environmental factors. Under the new technology, food prices are lower and the poverty line is shifted to L_1^e, reducing the fraction of the population living in poverty for a given income distribution. This can be a big effect if we have a big change in the price of food (say, a 50 percent increase from the present price if the past thirty-five years of research-induced productivity gains were eliminated—see appendix A), even with no direct changes in household incomes. In addition, if the distribution of income shifts to the right from, say, Y_0^e to Y_1^e as a result of shifting from technology regime τ_0 to τ_1, then the fraction of the population living in poverty is further reduced.[16]

1.3.3 Consequences of Income Effects of Technology for Implications of Variability

Richer people are affected less by a given shock to prices of staple grains. When the distribution of incomes has shifted substantially to the right, fewer people will suffer severe consequences from a given price shock. This idea is illustrated in figure 1.2, which shows the distribution of household income under two alternative technologies, Y_0^e and Y_1^e under τ_0 and τ_1, with the corresponding poverty lines, L_0^e and L_1^e—all conditional on a particular draw

16. Even though some farmers will be made worse off (if, for instance, they are surplus producers and cannot adopt the new technology), the distribution generally shifts to the right, as drawn, reflecting the general improvement in incomes for households although some have shifted to the left within the distribution.

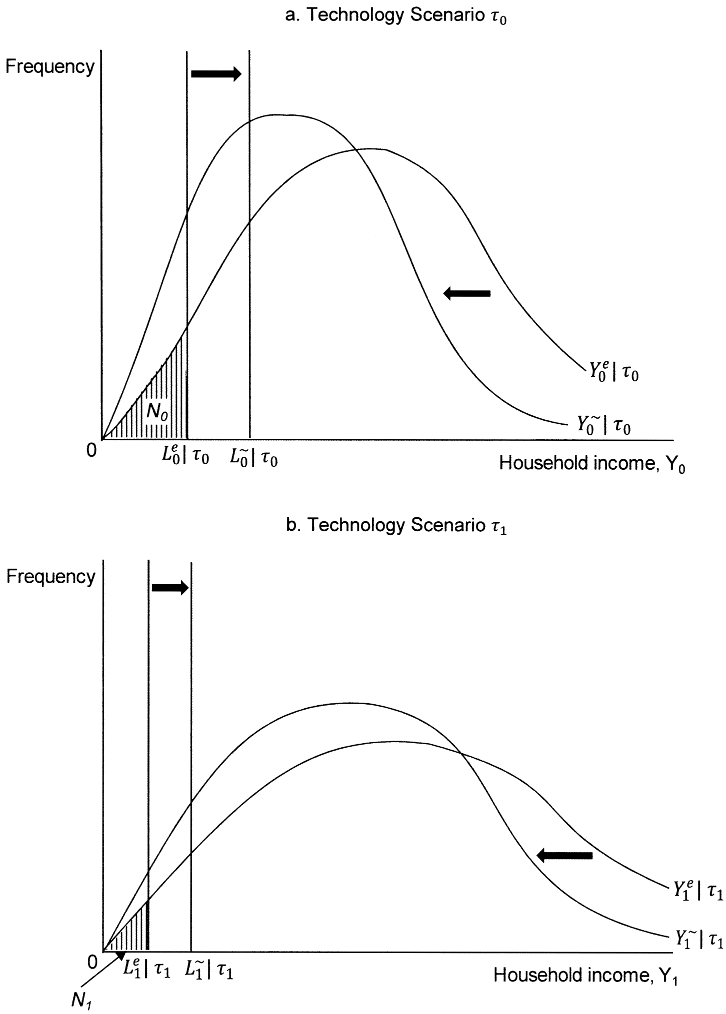

Fig. 1.2 Consequences of a negative shock under alternative technology scenarios

of exogenous environmental factors that gives rise to particular price outcomes, P_0^e and P_1^e. The corresponding numbers of people in poverty are indicated by the shaded areas, N_0 and N_1, with $N_0 > N_1$.

Now, suppose we have a negative environmental shock to the agricultural economy, such as a widespread drought, which under either technology scenario shifts the distribution of income to the left, to $Y_0^{\sim}$ and $Y_1^{\sim}$, and shifts the poverty line to the right, to $L_0^{\sim}$ and $L_1^{\sim}$. Intuitively, the consequences are expected to be much smaller under technology τ_1 because (a) a smaller number of people were already poor, (b) staple food commodities represent a smaller share of incomes generally such that the proportion of the population driven into poverty is smaller under technology τ_1, and (c) farmers represent a smaller share of the population such that the direct effects on farm incomes from the shock are less important for the overall picture.

In section 1.5 of this chapter, we explore these aspects using a computable general equilibrium model. Before doing that, in section 1.4 we consider recent past agricultural innovations, their consequences for technologies and productivity, and their implications for variability. In this work, we take the view that the relevant concern is not with day-to-day price variability, but some other form of variability that is more important for human outcomes, such as year-to-year, multiyear or secular price shifts representing substantial changes in the odds of serious food poverty.

1.4 Agricultural Technology: Past Accomplishments and Consequences

In this section we speculate about the implications for variability stemming from some particular past changes in agricultural technology. We begin with an overview of changes in the structure of agriculture before turning to trends in productivity and prices and what they might imply for poverty and vulnerability.

1.4.1 Changes in the Number of Farmers

A major consequence of technological change has been to reduce the total amount of labor employed in farming and people living on farms. In the United States, the total farm population peaked at 32.5 million people, 31.9 percent of the total US population in 1916. Since then the US population has continued to grow while the farm population declined to 2.9 million in 2006, just one percent of the total population of 299.4 million (Alston, Andersen, James, and Pardey 2010). With less than 1 percent of Americans now on farms, the consequences of farm price variability are very different than when a third of the population was on farms, one hundred years ago. Now, 99 percent of Americans are affected only as consumers, and most of them are rich enough to be relatively unconcerned by relatively large fluctuations in prices of comparatively cheap staple foods. This effect of changes in farming technology on the implications of price variability, through reducing the number of farmers while making food generally much more affordable, is comparatively significant. This transformation of agriculture in the United States, reflecting technological change in the rest of the economy pulling labor off farms as well as on-farm labor-saving innovations, was mirrored in other higher-income countries. In many low-income countries this transformation is still in progress, and often still in its early stages, but it is well advanced in middle-income countries such as Brazil and China.

Currently, the majority of the world's poor are rural. In many parts of the world farmers and consumers of staple crops are relatively insulated from world markets—price transmission is at best partial (see, for example, Minot 2011)—and the effects on world trading prices resulting from changes in agricultural technology elsewhere have limited effects on poverty for poor producers and consumers in the hinterland where the economic (and physical) distance from reasonably sized markets is high. Over the coming decades, an increasing proportion of the world's poor will be found in cities in Asia and Africa, and the numbers of rural poor will shrink in relative if not absolute terms. For the urban poor, unless governments intervene to prevent it, price transmission is relatively good. In addition, changes in technology and improvements in infrastructure will enhance the effectiveness of price transmission to those places that are relatively insulated at present.

Given an improvement in the effectiveness of price transmission to the poor and with an increasing proportion of the poor not being engaged directly in farm production, the predominant way in which agricultural innovations will reduce poverty in the long run will be through shifting the poverty line in a secular fashion by making food generally more affordable. At the same time, the poor will be more exposed to the effects of shorter-term changes in world market prices, transitory shifts of the poverty line.

1.4.2 Longer-Term Changes in Prices and Productivity

The World Bank (2012, 1) noted that "In 2011 international food prices spiked for the second time in three years, igniting concerns about a repeat of the 2008 food price crisis and its consequences for the poor." These recent events represent a reversal of the longer-term trends. Over the past fifty years and longer, the supply of food commodities has grown faster than the demand, in spite of increasing population and per capita incomes. Consequently, the real (inflation-adjusted) prices of food commodities have generally trended down. We use US commodity price indexes as indicators of world market prices. Table 1.2 includes measures of rates of change in real and nominal prices of maize, wheat, and rice over the entire period 1950–2010 and several subperiods.[17] Figure 1.3 plots the same prices in real and nominal terms, in levels and logarithms. The period since World War II includes three distinct subperiods. First, over the twenty years between 1950 and 1970, deflated prices for rice and maize declined relatively slowly while wheat prices declined fairly rapidly. Next, following the price spike of the early 1970s, over the years 1975 to 1990, prices for all three grains declined relatively rapidly and more or less in unison. Finally, over the years 1990 to 2011, prices increased for all three commodities, especially toward the

17. The measures in this table are averages of annual percentage changes, and therefore sensitive to end-points. Trend growth rates imply slightly different patterns.

Table 1.2 Average annual percentage changes in US commodity prices, 1950–2011

	Commodity			Commodity		
Period	Maize	Wheat	Rice	Maize	Wheat	Rice
	(average annual percentage change			*(trend growth rate, percent per year)*		
Nominal prices						
1950–2011	2.25	2.15	1.59	1.73	1.79	1.26
				(8.78)	(8.86)	(6.21)
1950–1970	–0.67	–2.04	0.08	–1.53	–2.65	–0.07
				(–3.71)	(–7.99)	(–0.36)
1975–2005	–0.87	–0.20	–0.29	–0.49	0.07	–0.90
				(–1.48)	(0.22)	(–1.82)
1975–1990	–0.72	–2.05	–1.47	–0.61	–0.19	–2.68
				(–0.61)	(–0.19)	(–2.06)
1990–2011	4.62	4.99	3.32	2.78	3.23	3.03
				(3.07)	(3.98)	(2.99)
2000–2011	10.70	9.70	7.86	9.75	8.71	11.27
				(6.37)	(6.20)	(6.35)
Deflated prices						
1950–2011	–1.63	–1.73	–2.29	–2.46	–2.40	–2.94
				(–15.85)	(–15.00)	(–14.58)
1950–1970	–2.67	–4.04	–1.92	–3.10	–4.22	–1.64
				(–8.96)	(–11.30)	(–8.55)
1975–2005	–4.32	–4.07	–4.94	–3.61	–3.04	–4.01
				(–11.41)	(–9.09)	(–7.95)
1975–1990	–5.89	–7.22	–6.64	–5.44	–5.02	–7.51
				(–6.66)	(–6.11)	(–6.56)
1990–2011	1.19	1.56	–0.10	–0.48	–0.03	–0.23
				(–0.65)	(–0.04)	(–0.27)
2000–2011	5.92	4.92	3.08	4.76	3.71	6.27
				(3.41)	(2.86)	(3.76)

Notes: Values in parentheses are *t*-statistics. Deflated prices were computed by deflating nominal commodity prices by the Consumer Price Index.

end of that period. This reflected a generally slowing rate of price decline throughout the period prior to the price spike in 2008—in fact, essentially from 2000 forward, prices increased in real terms.

These three crops provide about two-thirds of all energy in human diets (Cassman 1999). Data from the Food and Agriculture Organization of the United Nations (FAO 2013) for 2009 (Food Balance Sheets) show a global total food supply of 2,831 kcal/capita/day of which 43 percent was in the form of wheat, rice, and maize, but this does not include the contribution of feed grains to dietary energy through livestock. The direct contribution of these three crops to dietary energy stays reasonably constant in absolute terms but declines in proportional terms as incomes grow, total food con-

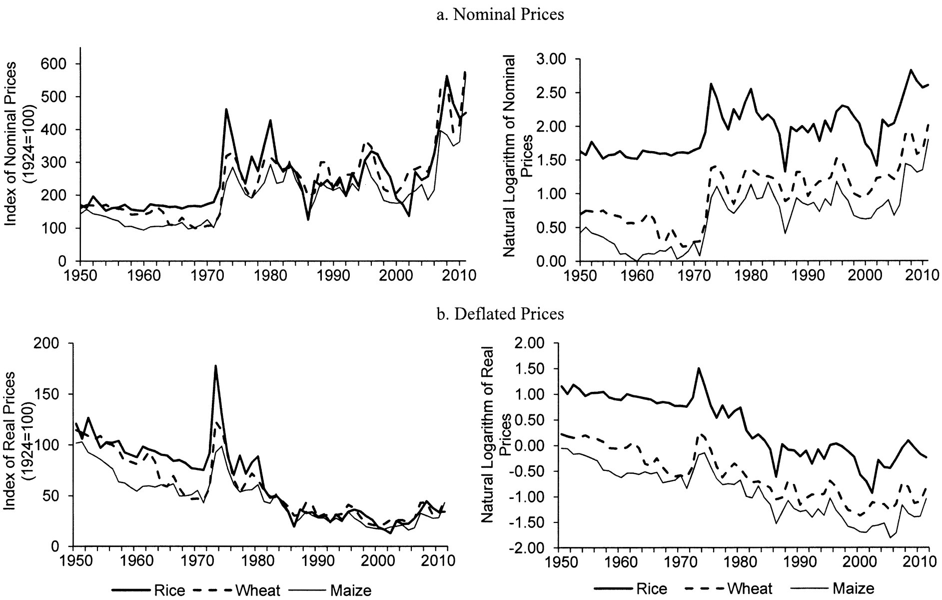

Fig. 1.3 US prices of maize, wheat, and rice, 1950–2011

Note: Nominal prices were deflated using the US Consumer Price Index.

sumption increases, and the share from livestock increases. For the "least-developed countries" group the total food supply for 2009 was 2,298 kcal/capita/day, of which 47 percent was from wheat, rice, and maize, and for India and China the shares were 52 percent and 47 percent, respectively. For high-income countries (such as the United States or the European Union) total caloric consumption was greater (3,688 or 3,456 kcal/capita/day) and the share of calories *directly* in the form in the form of wheat, rice, and maize was smaller (more like 25 percent), but the share of calories from grain-fed livestock is much larger. In 1961 global per capita energy consumption was lower (2,189 kcal/capita/day), but the share from cereals at 41 percent was similar to that in 2009.

Growth in agricultural productivity, fueled by investments in agricultural research and development (R&D), has been a primary contributor to the long-run trend of declining food commodity prices and the slowdown in the decline of real commodity prices since 1990, itself a dual measure of productivity growth, reflected a slowdown in the rate of growth of crop production and yields, among other things. Global annual average rates of crop yield growth for maize, rice, wheat, and cereals are reported in table 1.3, which includes separate estimates for various regions and for high-, middle-, and low-income countries, as well as for the world as a whole, for

Table 1.3 **Global and regional yield growth rates for selected crops, 1961–2010**

	Maize		Wheat		Rice, paddy	
Group	1961–1990	1990–2010	1961–1990	1990–2010	1961–1990	1990–2010
			percent per year			
World	2.33	1.82	2.73	1.03	2.14	1.09
Geographical regions						
North America	2.19	1.75	1.38	0.98	1.22	1.33
Western Europe	3.73	1.32	3.21	0.83	0.62	0.70
Eastern Europe	2.54	1.93	3.19	0.18	0.51	3.49
Asia & Pacific (excl. China)	1.96	2.88	2.96	1.39	1.83	1.49
China	4.39	0.81	5.76	2.05	3.06	0.64
Latin America & Caribbean	2.01	3.22	1.67	1.52	1.39	3.10
Sub-Saharan Africa	1.30	1.70	2.88	1.84	0.83	1.03
Income class						
High income	2.24	1.68	2.02	0.68	1.03	0.79
Upper middle (excl. China)	1.85	3.04	2.22	1.19	0.99	2.23
China	4.39	0.81	5.76	2.05	3.06	0.64
Lower middle income	1.79	3.06	3.27	1.42	2.36	1.36
Low income	1.19	0.36	2.08	2.02	1.50	2.18

Source: Pardey, Alston, and Chan-Kang (2013).

two subperiods: 1961 to 1990 and 1990 to 2010. In both high- and middle-income countries—collectively accounting for between 78.8 and 99.4 percent of global production of these crops in 2007—average annual rates of yield growth for cereals were lower in 1990 to 2010 than in 1961 to 1990. The growth of wheat yields slowed the most and, for the high-income countries as a group, wheat yields barely changed over 1990 to 2010. Global maize yields grew at an average rate of 1.82 percent per year during 1990 to 2010 compared with 2.33 percent per year for 1961 to 1990. Likewise, rice yields grew at 1.03 percent per year during 1990 to 2010, less than half their average growth rate for 1960 to 1990.

1.4.3 Global Crop Yield Variability, 1960 to 2010

Green Revolution varieties of wheat and rice (and other crops) combined with complementary fertilizer and irrigation technologies contributed to very significant growth of grain yields in the latter part of the twentieth century. Did they also contribute to greater variability of yields, production, and prices? And what is the appropriate measure of variability in this context? Competing views have been published on this question.[18] The earlier studies tended to find an increase in variability associated with the adoption of modern varieties. However, more-recent studies have reported that the predominant effect has been to reduce variability of yields and production, as documented in detail by Gollin (2006). Gollin (2006) combined country-level data on the diffusion of modern varieties (MVs) of wheat and maize with corresponding data on aggregate production and yields over the period 1960 to 2000. Using these data he depicted changes in national-level yield variability for wheat and maize across developing countries, and related these changes to the diffusion of MVs.[19] He found "the outcomes strongly suggest that, over the past 40 years, there has actually been a *decline* in the relative variability of grain yields—that is, the absolute magnitude of deviations from the yield trend—for both wheat and maize in developing countries. This reduction in variability is statistically associated with the spread of MVs, even after controlling for expanded use of irrigation and other inputs." (Gollin [2006], 1, emphasis in original).

In our broader context, given an interest in price variability, we are interested in whether changes in technology affected variability of yield per unit area and production as they affect prices, including yield and production in high- and middle-income countries as well as in the low-income countries emphasized by Gollin (2006). A first step toward answering that question is to ask whether yield variability has changed. Table 1.4 provides some more up-to-date measures of variability corresponding to those reported by Gollin (2006), based on data from FAO (2012).[20] The measures in table 1.4 are ten-year moving variances of logarithms of global total annual production and average yields (computed as total annual production divided by total harvested area), whereas Gollin (2006) computed ten-year moving coefficients of variation, but they are otherwise similar in concept. The last two columns of the table include the coefficient from regression of this measure of variability against a linear time trend, and the corresponding t-statistic.

As can be seen in table 1.4, variability of global production and average yields trended down over the half century ending in 2010 (the trend coefficients are all negative numbers, and all statistically significantly different from zero). The decade-by-decade figures in the table also tend to

18. For example, see Hazell (1989); Anderson and Hazell (1989); Singh and Byerlee (1990); Naylor, Falcon, and Zavaleta (1997); Gollin (2006); and Hazell (2010).

19. Gollin (2006) presented various measures of variability, including ten-year moving coefficients of variation, but his main results rest on measured changes over time in the relative variability of yields calculated as the change in the absolute deviation of yields relative to a trend value derived using a Hodrick-Prescott filter.

20. Appendix B contains more detailed results, by crop and region of production. It also includes plots of first differences of logarithms of production, yield, and prices, which provides an alternative, visual indication of the changes in variability over time.

Table 1.4 **Variability of global production and average crop yields, 1961–2010**

	10-year moving variance, logarithms, 10 years ending					Trend regression	
	1970	1980	1990	2000	2010	coefficient	*t*-stat
Production							
Wheat	0.0173	0.0101	0.0055	0.0022	0.0047	–0.0003	–10.99
Maize	0.0128	0.0134	0.0107	0.0081	0.0152	–0.0002	–4.49
Rice	0.0140	0.0071	0.0057	0.0032	0.0044	–0.0002	–10.41
Cereals	0.0116	0.0065	0.0035	0.0019	0.0056	–0.0002	–8.67
Yield							
Wheat	0.0121	0.0053	0.0078	0.0020	0.0023	–0.0003	–10.18
Maize	0.0074	0.0081	0.0059	0.0055	0.0040	–0.0002	–7.08
Rice	0.0057	0.0032	0.0043	0.0012	0.0020	–0.0001	–4.03
Cereals	0.0081	0.0042	0.0037	0.0029	0.0032	–0.0001	–9.67

Notes: Entries are ten-year moving variances of logarithms of global total production or logarithms of yield (total production divided by total harvested area), with the ten years ending on the year shown in the column heading. The time-trend coefficient is from the regression of the annual observations of the ten-year moving variance against a linear time trend, and the *t*-stat is for the test of the null hypothesis that the coefficient is zero.

decline with time, although the variability of production increased (roughly doubling) for every crop between 2000 and 2010. Variability of yield also increased in the last decade in table 1.4 for wheat, rice, and cereals as a group (though not for maize), but generally by a smaller proportion than the corresponding increase in variability of production.

The global aggregate figures mask some interesting regional variation in these measures. Figure 1.4 graphs the annual observations of the ten-year moving variances for the global measure of production (panel a) and yields (panel b), along with counterpart observations for the low-income countries as a group (panels c and d). In the world as a whole, variability of both production and yields trended down, but in the low-income countries the converse was true, especially since 1990: the measures of variability of production increased four- to fivefold between the mid-1990s and 2010. The reasons for this dichotomy between patterns in the higher- versus low-income countries remain uncertain, but a significant factor might have been slower growth of the means of yield and production in the low-income countries. The pattern everywhere changed toward the end of the series. The variability of global production of cereals increased after 2007 (panel a) but the variability of yields did not increase nearly as much (see panel b). The difference probably reflects supply response to commodity prices that became more variable in the same period.

We computed ten-year moving variances of the real and nominal prices of maize, rice, and wheat as counterparts to the measures of variability of yield and production thus discussed, and these are plotted in figure 1.5 and

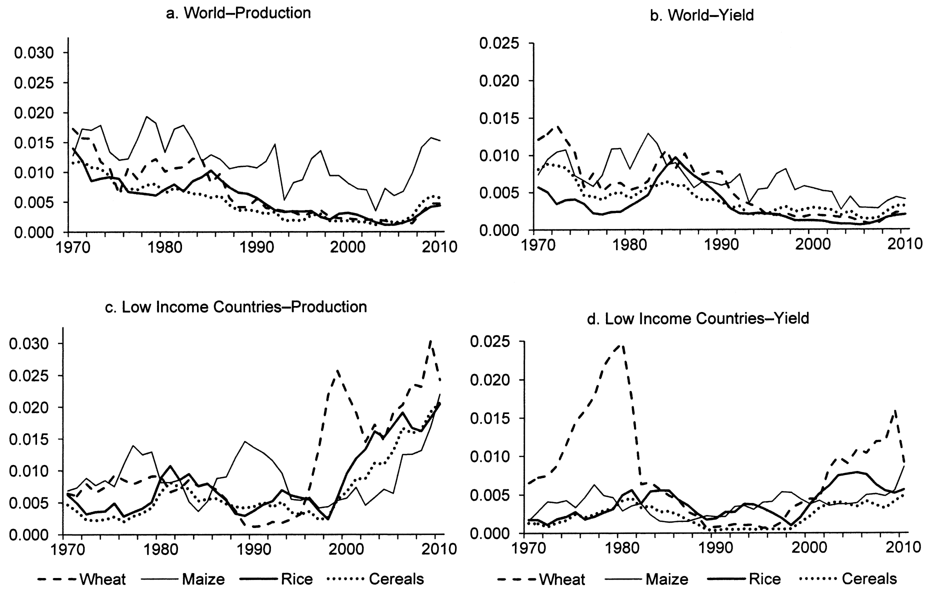

Fig. 1.4 Variability of grain production and yield, ten-year moving variances of logarithms, 1970–2010

Note: See table 1.3 and associated text for details.

summarized in table 1.5. As can be seen in figure 1.5, in both nominal and real terms, prices were comparatively stable through the 1950s and 1960s. The pattern changed in the 1970s, reflecting the price spike and its aftermath. Thereafter the patterns for wheat and maize are quite similar but rice is more distinct, with generally higher variability and greater variation in variability over time. Variability of deflated prices was lower in the 1990s than in the 1980s for all three grains but then increased in the early twenty-first century—especially for rice. The changes in price variability—especially in the mid-1970s and in the mid to late years of the first decade of the twenty-first century—do not appear to be clearly associated with changes in technology; they are more likely linked to other market phenomena that have been widely documented and discussed (see, for example, Wright 2011).

Of course, these prices of grain commodities are different from final consumer prices of food that may or may not include grain as an ingredient. Using data from FAO (2013) we computed the country-specific variances of the logarithms of annual average food Consumer Price Indexes (CPI) for the ten-year period of 2001 to 2010 (conceptually comparable to the variances of logarithms of annual average commodity prices in table 1.5, in the column labeled 2010). If we include only the variances for the 172 countries for which we have data for every year, the mean of the logarithmic variances across countries is 0.12, but the median is 0.025 (the distribution

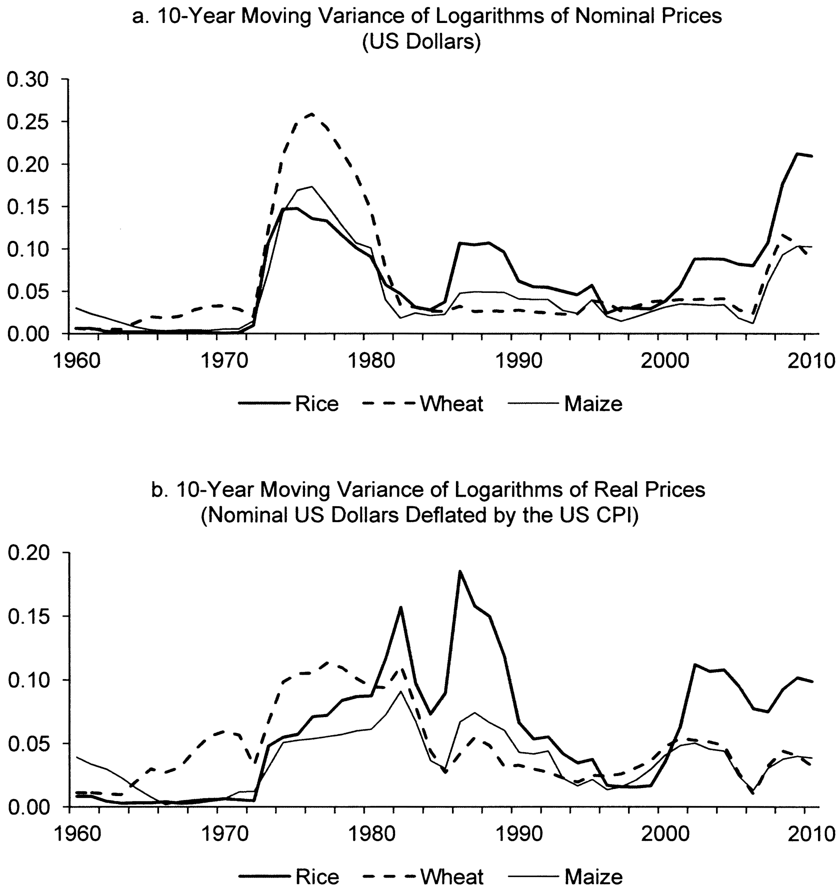

Fig. 1.5 Variability of prices of maize, wheat, and rice, 1951–2010

Source: These are based on updated versions of prices reported by Alston, Beddow, and Pardey (2009).

Note: The ten-year moving variance is plotted against the last year of the corresponding ten-year period, such that a shock in 1971 is reflected in the measures for 1971 through 1980.

is very skewed to the left, and for 75 percent of the countries the variance is less than 0.06); this remains true if we exclude a few extreme outliers from either end of the distribution. The corresponding variances of logarithms of international (US) prices of rice, wheat, and maize in table 1.5 are 0.21, 0.09, and 0.10, somewhat larger generally than the counterparts for food CPIs. We would expect domestic prices to be less variable than international prices for grains, depending on country-specific price transmission relationships, and we would expect food prices to be less variable than grain prices. Our general observations are consistent with this expectation. However, the variability of CPIs varies tremendously among countries and, while the pat-

Table 1.5 **Variability of prices of rice, maize, and wheat, 1951–2010**

Crop	Ten-year moving variance of logarithms of prices, 10 years ending						Time-trend coefficient (*t*-values in italics)	
	1960	1970	1980	1990	2000	2010	1960–2010	1980–2010
				A. Nominal values				
Rice	0.0061	0.0005	0.0906	0.0620	0.0380	0.2095	0.0019	0.0026
							4.22	*3.00*
Wheat	0.0062	0.0327	0.1456	0.0277	0.0386	0.0875	–0.0002	0.0007
							–0.23	*1.09*
Maize	0.0302	0.0052	0.1010	0.0409	0.0312	0.1027	0.0003	0.0006
							0.61	*1.20*
				B. Deflated values				
Rice	0.0082	0.0064	0.0874	0.0664	0.0361	0.0988	0.0015	–0.0013
							3.76	*–1.48*
Wheat	0.0111	0.0595	0.0946	0.0328	0.0475	0.0325	–0.0003	–0.0013
							–0.88	*–3.11*
Maize	0.0392	0.0063	0.0612	0.0431	0.0409	0.0387	0.0003	–0.0012
							1.24	*–3.55*

Notes: Entries are ten-year moving variances of logarithms of prices, with the ten years ending on the year shown in the column heading. The time-trend coefficient is from the regression of the annual observations of the ten-year moving variance against a linear time trend, and the *t*-value is for the test of the null hypothesis that the coefficient is zero.

terns of variation among the country-specific measures of variability seem generally plausible and consistent with expectations (e.g., very low for Japan and Switzerland), to say anything more specific would require a substantial dedicated research effort.

1.5 Implications of Alternative Productivity Paths

As discussed above, recent evidence indicates that agricultural productivity growth rates have slowed significantly in many (especially rich) countries over the past twenty years or so (e.g., see Alston, Beddow, and Pardey 2009, 2010; Alston, Babcock, and Pardey 2010), especially in the higher-income countries. In addition, rates of growth in investment in productivity-enhancing agricultural R&D that slowed earlier have turned negative in many (especially high-income) countries, suggesting a worsening of the agricultural productivity slowdown in years to come, given the long R&D lags (e.g., see Pardey and Alston 2010; Pardey, Alston, and Chan-Kang 2013). Both the slowdown in agricultural productivity patterns generally and the divergent patterns among countries in rates of research investments and productivity will have implications for future paths of agricultural prices, price variability, and consequences of variability. These outcomes might be moderated by a restoration of research investments and revitalization of productivity growth. To explore these possibilities we conducted simulations using a computable general equilibrium framework.

1.5.1 The Model and the Simulations

Our analysis uses a model and approach developed and applied by Ivanic and Martin (2012) (see also Ivanic and Martin 2008; Ivanic, Martin, and Zaman 2011) to evaluate the impacts of agricultural productivity growth on poverty. Using this model, we extend the analysis of Ivanic and Martin (2012) to evaluate the effect of agricultural productivity growth on vulnerability of the poor. To do this we simulate the global economy from 2010 to 2050 under two alternative agricultural technology scenarios: (a) a pessimistic (slower growth) scenario, with equal productivity growth rates in agriculture and other sectors; and (b) an optimistic (faster growth) scenario, with agricultural productivity growing by one percentage point per year faster than in the rest of the economy. The higher growth scenario involves global average rates of agricultural productivity growth that are broadly in line with the projections of Fuglie (2008). Then, for each scenario we simulate the effects of a negative agricultural shock and compare the impacts on the number of people in poverty in a selection of less-developed countries between the optimistic and pessimistic productivity scenarios.

Here we provide a summary description of the key features of the model, which is described in more complete detail by Ivanic and Martin (2012). The simulations were carried out using an aggregated version of the latest Global Trade Analysis Project (GTAP) model that contains the geographical regions defined by the World Bank (East Asia and Pacific, Europe and Central Asia, Developed, Latin America, Sub-Saharan Africa, the Middle East, and South Asia). The thirty-four nonagricultural and nonfood GTAP commodities were aggregated into five categories relevant for this work (agricultural farm output, energy, nondurables, durables, and services). The food-related sectors remain disaggregated. Because most of our simulations relate to long-term changes, we applied a long-run closure that allows complete flexibility of employment of capital and labor and limited flexibility of land use. Poverty assessment is based on the household survey data sets collected at the World Bank for twenty-nine developing countries that span the developing world, but notably exclude China. All of the surveys used in this study are relatively recent, and they contain detailed information on the patterns of households' incomes from and expenditures on agricultural products.[21] Behavioral responses of the households in the model are represented using

21. The information on household consumption expenditures, including any own-produced consumption, was separated into seven broad categories: agricultural (food) products, nondurables, energy goods, durables, services, financial expenses, and taxes and remittances paid by the household. The category of agricultural products was further divided into thirty-nine individual commodities, which roughly follow the GTAP commodity classification with some additional crops that may be important to the poor, such as sorghum, cassava, coffee and tea, and potatoes.

expenditure functions to characterize consumption responses, and profit functions to represent output decisions and input responses.[22] When prices change, we identify those households whose cost of living less any changes in income moved them across the poverty-line level of utility. We then recalculate the poverty rate for each country following each simulation and the income and expenditure shares that are the primary determinants of the impacts of price and productivity shocks. Of specific interest is the difference in the effects of a commodity supply shock on poverty outcomes between the optimistic and pessimistic productivity growth scenarios.

1.5.2 The Simulation Results

The baseline projections are intended not as forecasts but as a plausible backdrop against which to examine policy alternatives. These particular results appear to be consistent with the widespread view that substantial growth in agricultural output will be required over the next forty years to meet increasing demand. Under the pessimistic scenario of uniform productivity growth across the agricultural and nonagricultural sectors, the prices of many foods rise substantially: food prices at the household level increase by an average of 48 percent by 2050 (63.3 percent in developing countries). Under the optimistic scenario, with productivity growing 1 percent per year faster in agriculture than in other sectors, food prices rise by a modest 1.4 percent over the same period (8 percent in developing countries).[23]

Table 1.6 shows the total population in column (1) and the initial baseline percentage poverty rate (at US$1.25 per person per day) in each of the twenty-nine countries of interest in column (2). The next two columns show the effects of 1 percent higher productivity growth over forty years, 2010 to 2050, in reducing the poverty rate in column (3) and the number of people in poverty in column (4). The new poverty rate under the high-productivity growth scenario is shown in column (5). Thus, for example, in India the initial poverty rate of 43.83 percent applied to a population of 1.17 billion implies a total of some 513 million people in poverty. If global agricultural productivity grew by 1 percent per year faster for forty years, this number would be reduced by 89 million and the poverty rate would be reduced by 7.6 percentage points. The reductions in poverty rates would be even more pronounced in some countries. Across all of the countries in this sample poverty rates would be reduced by an average of 4.75 percentage points and a total of more than 135 million people would be lifted above the poverty

22. The consumer expenditure functions of the households were calibrated to make the elasticities of demand derived from them consistent with those in the macro model. The profit functions were similarly calibrated to ensure that the elasticities of supply that they imply are consistent with those in the macro model.

23. Ivanic and Martin (2012) also examined a scenario with one percent per year higher productivity in agriculture in developing countries only, under which food prices increase by 13.5 percent (19.2 percent in developing countries). This highlights the importance of productivity growth in developed countries for prices and poverty in less-developed countries as well as showing the central role of productivity growth in less-developed countries.

Table 1.6 Baseline scenario: Changes in poverty from 1 percent per year higher agricultural productivity growth over 2010–2050

Country	Population (1)	Initial poverty rate, percent (2)	Change in poverty: Percentage points (3)	Change in poverty: Headcount (4)	New poverty rate, percent (5)
	number	*percent*	*percent*	*number*	*percent*
Albania	3,204,284	0.85	–0.13	–4,104	0.72
Armenia	3,092,072	10.63	–1.27	–39,176	9.36
Bangladesh	148,692,100	50.47	–4.29	–6,372,561	46.18
Belize	344,700	33.50	–1.73	–5,962	31.77
Cambodia	14,138,260	40.19	–18.96	–2,680,020	21.23
Cote d'Ivoire	19,737,800	23.34	–3.94	–777,204	19.40
Ecuador	14,464,740	15.78	–3.27	–473,067	12.51
Guatemala	14,388,930	12.65	–5.02	–722,634	7.63
India	1,170,938,000	43.83	–7.59	–88,868,501	36.24
Indonesia	239,870,900	7.50	–1.54	–3,682,462	5.96
Malawi	14,900,840	73.86	–12.71	–1,894,637	61.15
Moldova	3,562,062	8.14	–4.04	–143,983	4.10
Mongolia	2,756,001	22.38	–6.30	–173,642	16.08
Nepal	29,959,360	55.12	–4.46	–1,337,469	50.66
Nicaragua	5,788,163	45.10	–5.62	–325,177	39.48
Niger	15,511,950	65.88	–2.10	–326,292	63.78
Nigeria	158,423,200	64.41	–3.47	–5,493,147	60.94
Pakistan	173,593,400	22.59	–6.97	–12,094,064	15.62
Panama	3,516,820	9.48	–1.94	–68,181	7.54
Peru	29,076,510	7.94	–1.77	–514,516	6.17
Rwanda	10,624,010	76.56	–2.26	–239,671	74.30
Sri Lanka	20,859,950	14.00	–3.20	–668,386	10.80
Tajikistan	6,878,637	21.49	–8.67	–596,488	12.82
Tanzania	44,841,220	67.87	–3.62	–1,621,932	64.25
Timor-Leste	1,124,355	52.94	–3.29	–37,033	49.65
Uganda	33,424,680	51.53	–6.78	–2,267,582	44.75
Viet Nam	86,936,460	13.70	–2.10	–1,824,816	11.60
Yemen	24,052,510	17.53	–5.25	–1,263,621	12.28
Zambia	12,926,410	61.87	–5.30	–684,590	56.58

Notes: In the "low-productivity" scenario, productivity grows at the same rate in agriculture as in the rest of the economy; in the "high-productivity" scenario, productivity grows 1 percent per year faster in agriculture than in the rest of the economy in all countries. The changes in poverty in this table reflect 49 percent higher productivity in agriculture as a result of 1 percent higher growth over forty years.

line under the faster productivity growth scenario. Results such as this are the focus of the study by Ivanic and Martin (2012). Our purpose here is to explore the implications of the same difference in baseline productivity growth rates for the vulnerability of people to changes in food markets, as represented by price shocks.

Table 1.7 shows the impacts of a substantial externally generated (say, drought- or crop-pest-induced) price shock on poverty rates under the pes-

Table 1.7 **Changes in poverty rates resulting from a supply shock in the industrial countries causing agricultural commodity prices to double**

	Low productivity state of the world		High productivity state of the world		Reduction in poverty impact: High versus low productivity state	
	Initial rate (1)	Change (2)	Initial rate (3)	Change (4)	Rate (5) = (2) – (4)	Headcount (6)
			percentage points			*thousands*
Albania	0.85	0.11	0.72	–0.26	0.37	11.9
Armenia	10.63	0.92	9.36	0.14	0.78	24.1
Bangladesh	50.47	1.74	46.18	0.06	1.68	2,498.0
Belize	33.50	2.43	31.77	0.44	1.99	6.9
Cambodia	40.19	–2.85	21.23	–3.09	0.24	33.9
Côte d'Ivoire	23.34	–0.26	19.40	–0.63	0.37	73.0
Ecuador	15.78	2.25	12.51	0.19	2.06	298.0
Guatemala	12.65	6.59	7.63	0.42	6.17	887.8
India	43.83	4.70	36.24	1.74	2.96	34,659.8
Indonesia	7.50	0.77	5.96	0.15	0.62	1,487.2
Malawi	73.86	1.14	61.15	–0.59	1.73	257.8
Moldova	8.14	3.99	4.10	0.55	3.44	122.5
Mongolia	22.38	2.31	16.08	0.57	1.74	48.0
Nepal	55.12	–0.67	50.66	–1.27	0.6	179.8
Nicaragua	45.10	3.16	39.48	–0.35	3.51	203.2
Niger	65.88	–0.75	63.78	–1.29	0.54	83.8
Nigeria	64.41	0.32	60.94	–0.10	0.42	665.4
Pakistan	22.59	3.02	15.62	0.73	2.29	3,975.3
Panama	9.48	1.20	7.54	–0.42	1.62	57.0
Peru	7.94	0.93	6.17	–0.50	1.43	415.8
Rwanda	76.56	0.49	74.30	0.21	0.28	29.7
Sri Lanka	14.00	2.45	10.80	0.72	1.73	360.9
Tajikistan	21.49	6.14	12.82	0.37	5.77	396.9
Tanzania	67.87	1.61	64.25	0.05	1.56	699.5
Timor-Leste	52.94	0.00	49.65	–0.43	0.43	4.8
Uganda	51.53	–0.07	44.75	–0.95	0.88	294.1
Viet Nam	13.70	–0.58	11.60	–0.84	0.26	226.0
Yemen	17.53	3.35	12.28	0.33	3.02	726.4
Zambia	61.87	0.77	56.58	–0.27	1.04	134.4
Average	34.18	1.56	29.43	–0.15	1.71	39,460.4

Notes: In the "low-productivity" scenario, productivity grows at the same rate in agriculture as in the rest of the economy; in the "high-productivity" scenario, productivity grows one percent per year faster in agriculture than in the rest of the economy in all countries. The external price shock is represented by a 100 percent increase in the prices of all agricultural commodities. The numbers in column (6) are derived by applying the rates in column (5) of table 1.6 to the total population given in column (1) of table 1.5.

simistic agricultural productivity scenario (columns [1] and [2]) and the optimistic scenario (columns [3] and [4]). In most cases the price shock causes an increase in the poverty rate (positive signs on entries in columns [2] and [4]) but in other cases—where there are many poor net-selling households—the price shock causes a decrease in the poverty rate (negative signs on entries in columns [2] and [4]). However, in every case the entry in column (2) is more positive than the entry in column (4), such that the difference (in column [5], given by column [2] minus column [4]) is positive—the poverty rate increases by less (from a lower base) or decreases by more in the high-productivity scenario, compared with the low-productivity scenario. This means that the effect of the price shock on poverty is always more favorable given the high-productivity scenario than the low-productivity scenario. On average across countries in the high-productivity scenario, the external price shock results in a *reduction* in poverty by 0.15 percentage points, whereas in the low-productivity scenario, the poverty rate increases by 1.56 percentage points. The difference reflects a benefit from higher productivity in providing some insulation against the impoverishing effects of price variability, and—in most cases—reductions in the proportion of the population vulnerable to poverty.

In general, we find that the high-productivity scenario leaves households less vulnerable to price shocks. Higher productivity growth lowers real prices and—given the small price elasticities of demand for staple foods—leaves households with smaller shares of their income spent on food. The high-productivity scenario also leads to a decline in the global share of income from food production given the low price elasticities of demand. For most countries, the reduction in poverty associated with higher productivity reduces the fraction of the population vulnerable to poverty. This is not always the case, however. In countries like Malawi, where the poor fraction of the population was initially more than half, the reduction in the poverty rate may increase the fraction of the population near the poverty line. The numbers are substantial. As shown in column (6) of table 1.7, across the twenty-nine countries, a total of 39.5 million fewer people would be cast into poverty by a doubling of food commodity prices in the high-productivity growth scenario compared with the low-productivity growth scenario. This total benefit—that is, the reduced poverty impact of the price change in the high-productivity growth scenario—reflects the effects of (a) having a smaller shift of the income distribution induced by the price change in the high-productivity state, and (b) generally having a smaller share of the population close to the poverty line as illustrated in the heuristic analysis using figures 1.1 and 1.2.

1.6 Conclusion

Technological change in agriculture can affect the variability of food prices both by changing the sensitivity of aggregate farm supply to external shocks and changing the sensitivity of prices to a given extent of underlying variability of supply or demand. At the same time, by increasing the general abundance of food and reducing the share of income spent on food, agricultural innovation makes a given extent of price variability less important. This chapter has examined these different dimensions of the role of agricultural technology in contributing to or mitigating the consequences of variability in agricultural production, both in the past and looking forward.

A review of patterns of production, yields, and prices for the major cereal grains—wheat, maize, rice, and corn—over the period since World War II indicates that technological change has contributed significantly to growth of yields and production and to reducing real prices, but has probably not contributed to increased price variability. Rather, it seems more likely that technological changes in agriculture may have contributed to an underlying trend of production, yield, and prices that was generally less variable—as measured by moving averages of variances of logarithms of real prices, production, and yields—with other factors giving rise to periodical increases in variability, such as in the early 1970s and late in the first decade of the twenty-first century. The patterns are not uniform across countries and regions. In particular, production and yields have become more variable in the low-income group of countries during the past decade or so, in contrast to the high- and middle-income groups of countries, with some variation among countries within the groups and across crops. Further work remains to be done to analyze these patterns more formally, and to see whether differences in agricultural technology, or its location-specific impacts, might have contributed to these seemingly systematic differences.

We have emphasized the role of agricultural technology in reducing the importance of food price variability for food security of the poor by reducing the number of farmers, the number of poor, and the importance of food costs in household budgets. An illustrative analysis uses simulations of the global economy to 2050. The results show that the vulnerability of households to poverty is lower following a sustained period of higher productivity growth.

Appendix A

Prices and Productivity

Between 1975 and 2010, deflated US dollar prices of maize, wheat, and rice fell by about 2.8 percent per year (this is a simple average of the individual rates as reported in the text—see table 1.1), a cumulative decline of about 63 percent of the 1975 prices over the period.[24] Over the same interval total global production of cereals (wheat, rice, and coarse grains) grew from about 1,360 million metric tons in 1975 to about 2,430 million metric tons in 2010,

24. The trend growth rate over this period was –2.5 percent per year. Prices fell faster and farther over the interval from 1975 to 2005, after which they increased in real terms.

an increase of about 79 percent relative to 1975 production, and the world's population increased from about 4 billion to almost 7 billion.

Suppose we assume that the medium-term elasticity of supply of grain is $\varepsilon = 0.5$ and the elasticity of demand is $\eta = -0.2$. The proportional growth of supply (g) required to achieve a proportional increase in crop output of $q = d \ln Q$ (= 79 percent), in spite of a negative proportional change in price of $p = d \ln P$ (= –63 percent), is equal to $g = q - \varepsilon p = 79 + (0.5) \times 63 = 110.5$ percent. Now, let us suppose conservatively, for the sake of argument, that half of the past thirty-five years' growth in supply is attributable to research-induced productivity improvements (i.e., in round numbers a proportional increase of $j = 0.5$ such that $100j = 55$ percent is half of $g = 110$ percent growth).

What would the world be like today in the absence of those productivity gains? This can be analyzed by examining the price and quantity effects of a $100j/(1 + j) = 35$ percent reduction in current supply against the given demand. Given $j^* = -0.35$, $\varepsilon = 0.5$ and $\eta = -0.2$, the equations for proportional changes in price and quantity are $p = 100\, j^*/(\varepsilon - \eta) = 50$ percent and $q = -100\, \eta j/(\varepsilon - \eta) = -10$ percent. Hence, eliminating thirty-five years of research-induced productivity gains would imply an increase of the current price of cereals by about 50 percent (19 percent of the 1975 price) and a reduction in the current quantity produced and consumed of about 10 percent (18 percent of the 1975 quantity). These numbers refer to "with" and "without" the research-induced productivity gains. Although they are quantitatively related and of similar orders of magnitudes, they are conceptually different from the price and quantity changes over time, the "before" and "after" figures, which reflect the effects of all the variables that changed.

Appendix B

More-Detailed Evidence on Variability of Production and Yield

The following tables report measures of ten-year moving variances of yield and production and regressions of those measures against a time trend, using data for 1961 to 2010.

Table 1B.1 **Yields**

	Average 2010 yield tonnes/ha	10-year moving variance					Time-trend coefficient	*t*-stat
		1970	1980	1990	2000	2010		
				A. Wheat yield				
World	3.00	0.0121	0.0053	0.0078	0.0020	0.0023	–0.0003	–10.18
Australia & New Zealand	1.67	0.0290	0.0463	0.0486	0.0328	0.0976	0.0012	3.73
North America	3.02	0.0147	0.0033	0.0063	0.0042	0.0099	0.0000	–1.25
Western Europe	6.11	0.0115	0.0084	0.0106	0.0032	0.0036	–0.0003	–6.87
China	4.75	0.0615	0.0295	0.0157	0.0067	0.0087	–0.0011	–6.12
Asia & Pacific (excl. China)	2.56	0.0084	0.0099	0.0060	0.0032	0.0013	–0.0003	–15.10
Eastern Europe	3.61	0.0231	0.0088	0.0082	0.0059	0.0166	–0.0003	–3.15
Latin America	3.33	0.0124	0.0065	0.0100	0.0042	0.0127	–0.0002	–2.16
USSR	1.85	0.0488	0.0237	0.0266	0.0113	0.0097	–0.0006	–5.51
Northern Africa	2.43	0.0198	0.0094	0.0402	0.0105	0.0103	0.0000	0.12
Sub-Saharan Africa	2.05	0.0115	0.0105	0.0212	0.0075	0.0076	–0.0001	–1.46
High income	3.66	0.0080	0.0019	0.0047	0.0021	0.0037	–0.0001	–5.37
Upper middle income	2.79	0.0224	0.0108	0.0140	0.0031	0.0041	–0.0004	–9.41
Lower middle income	2.70	0.0186	0.0053	0.0088	0.0036	0.0013	–0.0006	–8.31
Low income	1.92	0.0065	0.0247	0.0008	0.0044	0.0092	–0.0001	–1.52
				B. Maize yield				
World	5.22	0.0074	0.0081	0.0059	0.0055	0.0040	–0.0002	–7.08
Australia & New Zealand	6.75	0.0197	0.0182	0.0195	0.0069	0.0054	–0.0009	–7.07
North America	9.60	0.0117	0.0118	0.0199	0.0114	0.0051	–0.0002	–2.93
Western Europe	9.42	0.0433	0.0099	0.0039	0.0072	0.0039	–0.0007	–6.76
China	5.46	0.0359	0.0205	0.0120	0.0037	0.0029	–0.0007	–15.16
Asia & Pacific (excl. China)	3.22	0.0027	0.0046	0.0085	0.0036	0.0130	0.0002	5.43
Eastern Europe	5.34	0.0277	0.0111	0.0187	0.0539	0.0396	0.0011	8.18
Latin America	4.21	0.0047	0.0058	0.0009	0.0117	0.0095	0.0002	3.60
USSR	4.08	0.0294	0.0126	0.0104	0.0170	0.0202	0.0004	3.50
Northern Africa	6.10	0.0201	0.0063	0.0169	0.0236	0.0031	0.0001	1.59
Sub-Saharan Africa	1.92	0.0102	0.0134	0.0263	0.0226	0.0077	–0.0003	–3.97
High income	9.44	0.0131	0.0102	0.0138	0.0094	0.0044	–0.0002	–5.20
Upper middle income	4.92	0.0102	0.0106	0.0021	0.0048	0.0066	–0.0001	–4.28
Lower middle income	2.74	0.0027	0.0050	0.0061	0.0117	0.0104	0.0002	8.38
Low income	1.70	0.0016	0.0029	0.0021	0.0038	0.0086	0.0000	2.58

(*continued*)

Table 1B.1 (continued)

	Average 2010 yield tonnes/ha	10-year moving variance					Time-trend coefficient	*t*-stat
		1970	1980	1990	2000	2010		
				C. Rice yield				
World	4.37	0.0057	0.0032	0.0043	0.0012	0.0020	–0.0001	–4.03
Australia & New Zealand	10.84	0.0102	0.0139	0.0227	0.0129	0.0199	0.0001	1.27
North America	7.54	0.0088	0.0010	0.0070	0.0016	0.0012	0.0000	0.13
Western Europe	6.74	0.0045	0.0128	0.0013	0.0031	0.0005	–0.0002	–4.88
China	6.55	0.0234	0.0085	0.0059	0.0020	0.0008	–0.0003	–3.87
Asia & Pacific (excl. China)	3.85	0.0037	0.0031	0.0050	0.0014	0.0029	–0.0001	–2.86
Eastern Europe	4.98	0.0089	0.0238	0.0468	0.0280	0.0139	0.0000	0.11
Latin America	4.55	0.0015	0.0019	0.0100	0.0143	0.0072	0.0003	6.74
USSR	4.30	0.0349	0.0019	0.0015	0.0140	0.0178	0.0002	1.71
Northern Africa	9.38	0.0035	0.0022	0.0074	0.0045	0.0008	0.0001	1.64
Sub-Saharan Africa	2.15	0.0020	0.0006	0.0040	0.0014	0.0111	0.0001	3.10
High income	6.88	0.0027	0.0042	0.0020	0.0045	0.0009	0.0000	–1.26
Upper middle income	5.42	0.0148	0.0044	0.0051	0.0022	0.0010	–0.0002	–3.49
Lower middle income	3.83	0.0072	0.0048	0.0081	0.0014	0.0033	–0.0002	–5.44
Low income	3.61	0.0017	0.0049	0.0019	0.0037	0.0056	0.0001	4.58
				D. Cereals yield				
World	3.56	0.0081	0.0042	0.0037	0.0029	0.0032	–0.0001	–9.67
Australia & New Zealand	1.76	0.0249	0.0321	0.0353	0.0218	0.0682	0.0007	3.24
North America	6.34	0.0113	0.0092	0.0111	0.0100	0.0088	–0.0001	–1.76
Western Europe	5.82	0.0100	0.0055	0.0076	0.0044	0.0026	–0.0002	–6.98
China	5.52	0.0341	0.0147	0.0086	0.0029	0.0028	–0.0005	–6.51
Asia & Pacific (excl. China)	3.06	0.0034	0.0048	0.0056	0.0027	0.0032	0.0000	–3.55
Eastern Europe	3.78	0.0157	0.0044	0.0027	0.0142	0.0157	0.0001	0.92
Latin America	3.97	0.0027	0.0044	0.0008	0.0075	0.0082	0.0001	2.81
USSR	1.96	0.0366	0.0215	0.0220	0.0106	0.0081	–0.0004	–5.07
Northern Africa	2.77	0.0242	0.0075	0.0241	0.0103	0.0055	0.0000	–0.63
Sub-Saharan Africa	1.34	0.0026	0.0073	0.0066	0.0046	0.0044	–0.0001	–5.10
High income	5.32	0.0078	0.0037	0.0054	0.0041	0.0042	–0.0001	–6.46
Upper middle income	3.76	0.0182	0.0065	0.0072	0.0041	0.0041	–0.0003	–8.17
Lower middle income	2.69	0.0055	0.0054	0.0064	0.0033	0.0032	–0.0001	–7.45
Low income	2.07	0.0013	0.0042	0.0003	0.0022	0.0049	0.0000	1.81

Note: Cereals include the following commodities: barley, buckwheat, canary seed, cereal nes, fonio, maize, millet, mixed grain, oats, popcorn, rice, rye, sorghum, triticale, and wheat.

Table 1B.2 Production

	2010 production share	10-year moving variance					Time-trend coefficient	*t*-stat
		1970	1980	1990	2000	2010		
		A. Wheat production						
World	1.00	0.0173	0.0101	0.0055	0.0022	0.0047	–0.0003	–10.99
Australia & New Zealand	0.03	0.0646	0.0783	0.0573	0.1160	0.1229	0.0013	4.35
North America	0.13	0.0159	0.0199	0.0199	0.0020	0.0173	–0.0001	–1.01
Western Europe	0.16	0.0120	0.0088	0.0118	0.0065	0.0060	–0.0002	–2.34
China	0.18	0.0628	0.0475	0.0218	0.0058	0.0121	–0.0013	–7.22
Asia & Pacific (excl. China)	0.24	0.0239	0.0200	0.0088	0.0043	0.0030	–0.0009	–13.99
Eastern Europe	0.05	0.0276	0.0097	0.0186	0.0179	0.0322	0.0002	2.29
Latin America	0.05	0.0246	0.0288	0.0139	0.0177	0.0109	–0.0005	–3.20
USSR	0.13	0.0510	0.0264	0.0147	0.0241	0.0324	0.0001	0.94
Northern Africa	0.02	0.0306	0.0114	0.0474	0.0451	0.0287	0.0010	5.90
Sub-Saharan Africa	0.01	0.0422	0.0041	0.0235	0.0145	0.0153	–0.0005	–2.93
High income	0.36	0.0130	0.0096	0.0046	0.0033	0.0074	–0.0002	–4.56
Upper middle income	0.43	0.0271	0.0129	0.0088	0.0038	0.0082	–0.0003	–5.78
Lower middle income	0.19	0.0463	0.0164	0.0147	0.0084	0.0041	–0.0015	–8.36
Low income	0.02	0.0064	0.0091	0.0012	0.0221	0.0242	0.0004	5.61
		B. Maize production						
World	1.00	0.0128	0.0134	0.0107	0.0081	0.0152	–0.0002	–4.49
Australia & New Zealand	0.00	0.0216	0.0310	0.0232	0.0457	0.0148	–0.0007	–4.26
North America	0.39	0.0132	0.0230	0.0574	0.0233	0.0171	–0.0003	–1.37
Western Europe	0.04	0.0646	0.0145	0.0101	0.0140	0.0062	–0.0015	–6.55
China	0.21	0.0585	0.0487	0.0221	0.0145	0.0250	–0.0008	–5.97
Asia & Pacific (excl. China)	0.08	0.0127	0.0126	0.0175	0.0050	0.0340	0.0003	2.98
Eastern Europe	0.04	0.0225	0.0137	0.0292	0.0448	0.0467	0.0011	7.79
Latin America	0.14	0.0243	0.0054	0.0034	0.0108	0.0200	0.0001	1.48
USSR	0.02	0.0720	0.0207	0.0327	0.0983	0.1223	0.0039	7.67
Northern Africa	0.01	0.0176	0.0113	0.0185	0.0142	0.0065	0.0001	0.75
Sub-Saharan Africa	0.07	0.0155	0.0164	0.0476	0.0233	0.0217	–0.0004	–2.59
High income	0.44	0.0146	0.0194	0.0390	0.0192	0.0126	–0.0004	–3.01
Upper middle income	0.42	0.0153	0.0136	0.0027	0.0069	0.0182	–0.0001	–1.92
Lower middle income	0.09	0.0126	0.0082	0.0325	0.0053	0.0330	0.0003	2.62
Low income	0.04	0.0069	0.0081	0.0136	0.0057	0.0220	0.0000	0.94

(*continued*)

Table 1B.2 (continued)

	2010 production share	*10-year moving variance* 1970	1980	1990	2000	2010	Time-trend coefficient	*t*-stat
				C. Rice production				
World	1.00	0.0140	0.0071	0.0057	0.0032	0.0044	–0.0002	–10.41
Australia & New Zealand	0.00	0.0813	0.1067	0.0380	0.0333	1.9633	0.0214	3.64
North America	0.02	0.0353	0.0380	0.0267	0.0078	0.0053	–0.0007	–5.15
Western Europe	0.00	0.0083	0.0114	0.0155	0.0148	0.0043	–0.0001	–2.31
China	0.29	0.0456	0.0059	0.0050	0.0021	0.0034	–0.0005	–6.28
Asia & Pacific (excl. China)	0.61	0.0074	0.0082	0.0083	0.0048	0.0056	–0.0001	–4.03
Eastern Europe	0.00	0.0435	0.0250	0.0424	0.1513	0.2766	0.0049	2.92
Latin America	0.04	0.0156	0.0213	0.0110	0.0123	0.0079	–0.0001	–1.62
USSR	0.00	0.3507	0.0362	0.0029	0.0535	0.0487	–0.0038	–4.28
Northern Africa	0.01	0.0640	0.0020	0.0120	0.0306	0.0223	0.0003	0.97
Sub-Saharan Africa	0.03	0.0159	0.0077	0.0280	0.0041	0.0314	0.0001	0.56
High income	0.05	0.0043	0.0076	0.0021	0.0047	0.0021	–0.0001	–3.48
Upper middle income	0.39	0.0354	0.0067	0.0037	0.0021	0.0032	–0.0005	–8.01
Lower middle income	0.40	0.0124	0.0106	0.0145	0.0052	0.0049	–0.0003	–6.62
Low income	0.17	0.0062	0.0089	0.0037	0.0095	0.0204	0.0003	6.45
				D. Cereals production				
World	1.00	0.0116	0.0065	0.0035	0.0019	0.0056	–0.0002	–8.67
Australia & New Zealand	0.01	0.0551	0.0515	0.0420	0.0756	0.0798	0.0007	3.01
North America	0.18	0.0105	0.0113	0.0299	0.0099	0.0128	–0.0001	–1.24
Western Europe	0.08	0.0114	0.0060	0.0055	0.0064	0.0038	–0.0002	–5.28
China	0.20	0.0381	0.0137	0.0086	0.0036	0.0091	–0.0005	–8.33
Asia & Pacific (excl. China)	0.27	0.0076	0.0087	0.0076	0.0034	0.0049	–0.0001	–7.08
Eastern Europe	0.04	0.0115	0.0025	0.0030	0.0179	0.0215	0.0003	3.96
Latin America	0.08	0.0175	0.0080	0.0015	0.0077	0.0116	–0.0001	–1.95
USSR	0.06	0.0316	0.0235	0.0115	0.0461	0.0211	0.0003	1.90
Northern Africa	0.01	0.0396	0.0094	0.0289	0.0247	0.0164	0.0002	2.20
Sub-Saharan Africa	0.05	0.0075	0.0059	0.0233	0.0087	0.0143	0.0000	0.13
High income	0.31	0.0091	0.0055	0.0087	0.0053	0.0061	–0.0001	–6.94
Upper middle income	0.40	0.0216	0.0086	0.0043	0.0010	0.0062	–0.0004	–7.70
Lower middle income	0.21	0.0122	0.0076	0.0136	0.0045	0.0055	–0.0002	–5.89
Low income	0.08	0.0047	0.0067	0.0044	0.0067	0.0207	0.0003	6.58

Note: Cereals include the following commodities: barley, buckwheat, canary seed, cereal nes, fonio, maize, millet, mixed grain, oats, popcorn, rice, rye, sorghum, triticale, and wheat.

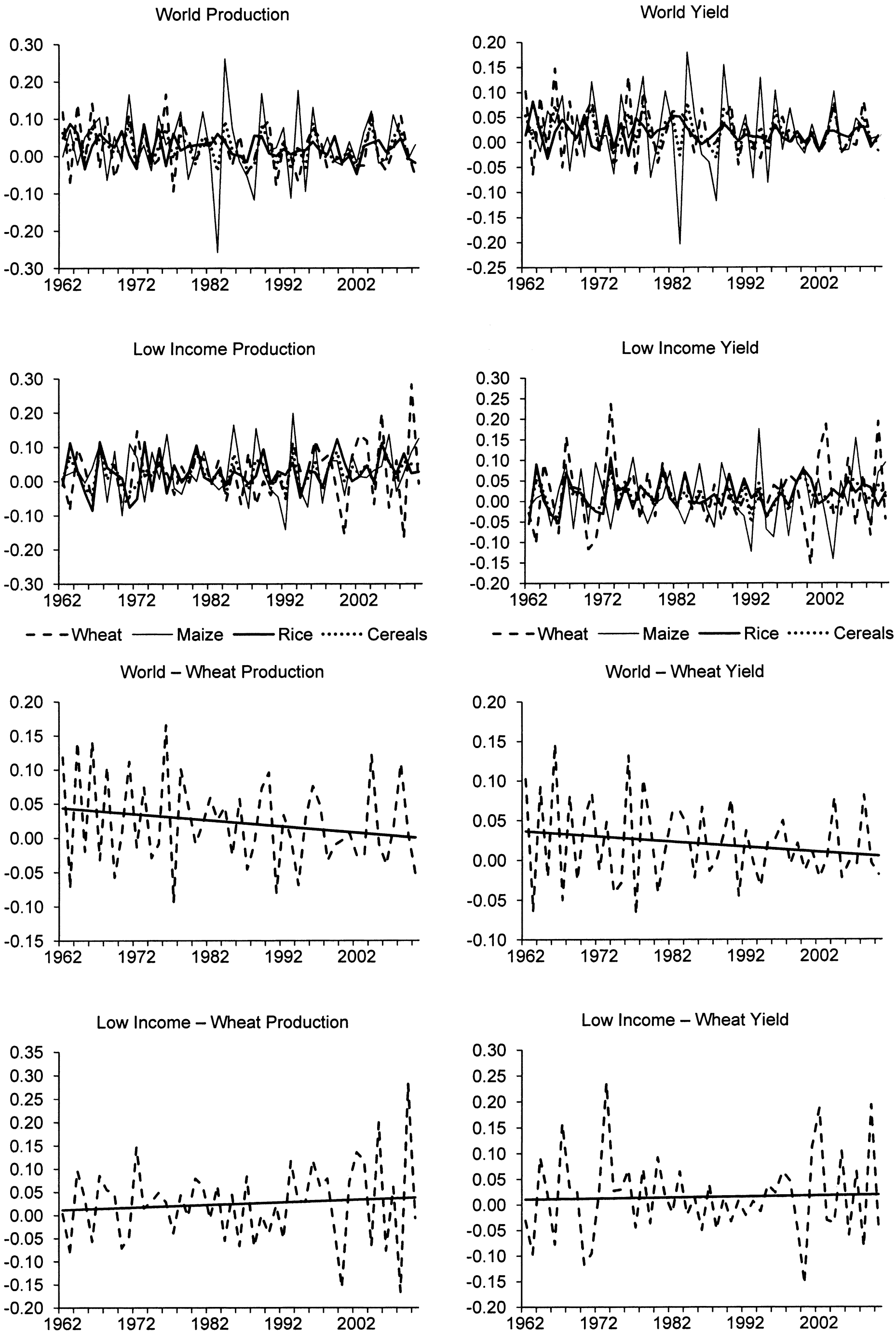

Fig. 1B.1 Variability of grain production and yield, first differences of logarithm of production, yield and prices

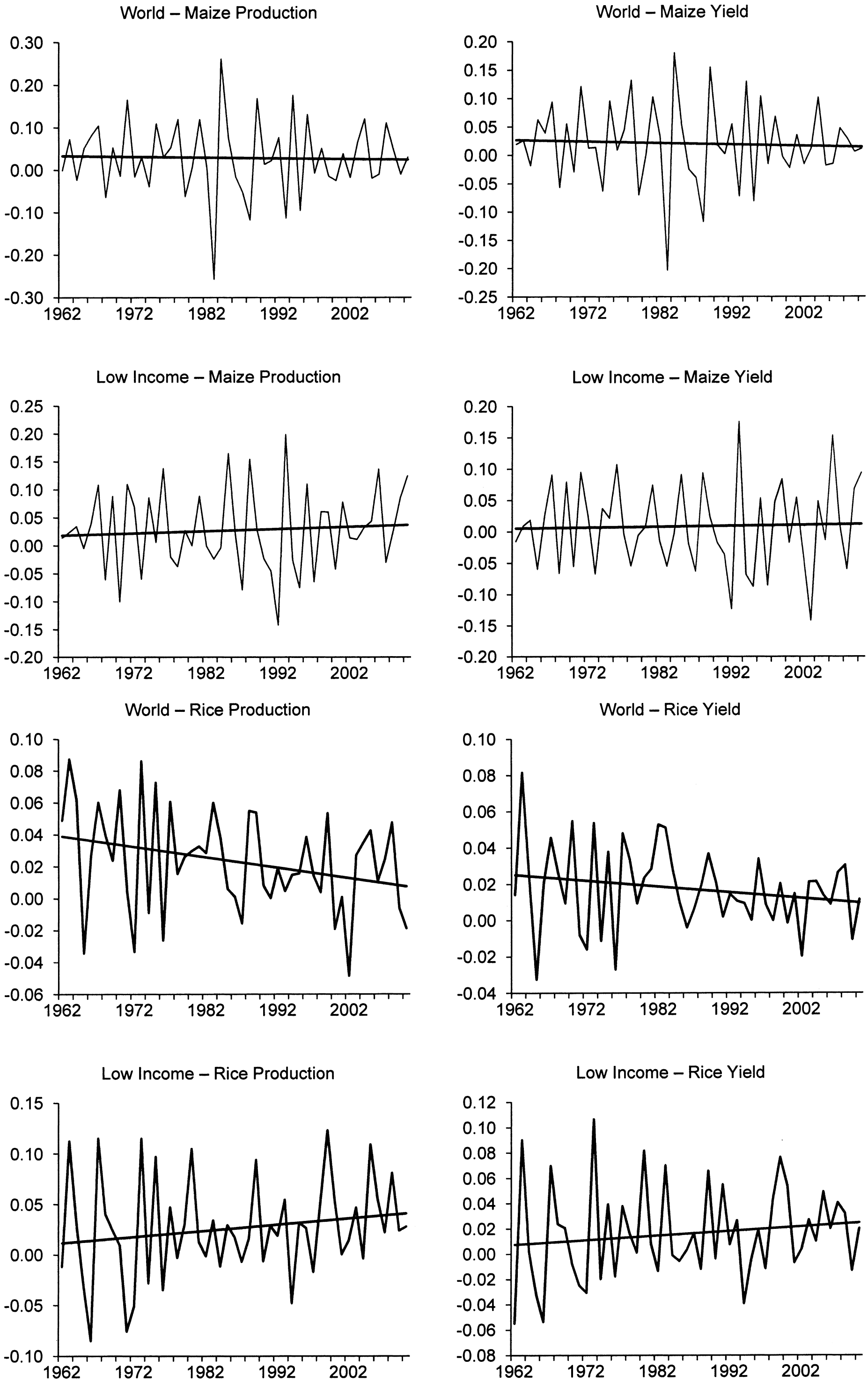
World – Maize Production
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
1962
1972
1982
1992
2002
World – Maize Yield
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
1962
1972
1982
1992
2002
Low Income – Maize Production
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
1962
1972
1982
1992
2002
Low Income – Maize Yield
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
1962
1972
1982
1992
2002
World – Rice Production
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
1962
1972
1982
1992
2002
World – Rice Yield
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
1962
1972
1982
1992
2002
Low Income – Rice Production
0.15
0.10
0.05
0.00
-0.05
-0.10
1962
1972
1982
1992
2002
Low Income – Rice Yield
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
1962
1972
1982
1992
2002

Fig. 1B.1 (cont.)

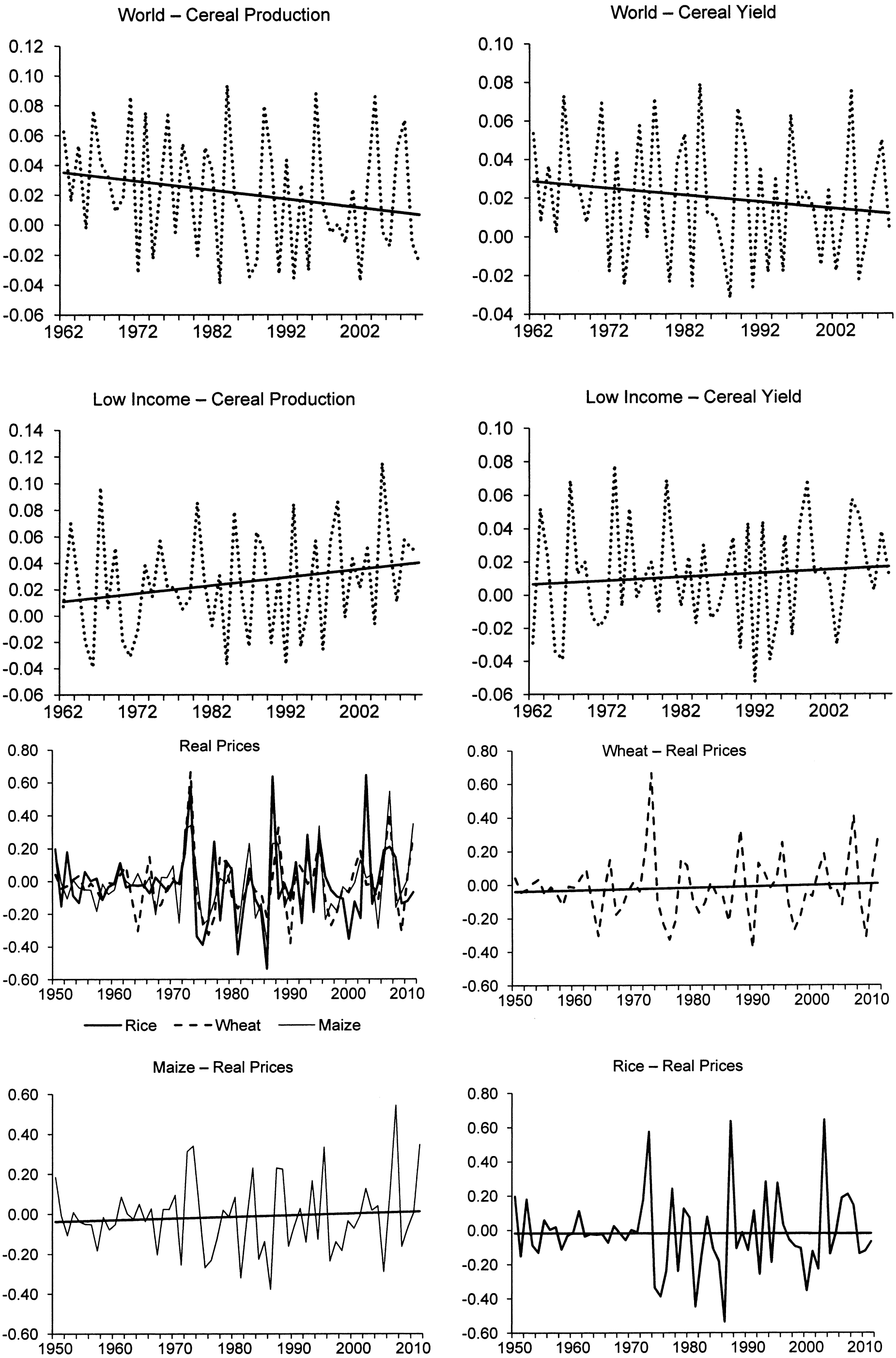
World – Cereal Production
World – Cereal Yield
Low Income – Cereal Production
Low Income – Cereal Yield
Real Prices
Rice
Wheat
Maize
Wheat – Real Prices
Maize – Real Prices
Rice – Real Prices

Fig. 1B.1 (cont.)

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Comment James M. MacDonald

Alston, Martin, and Pardey (AMP) provide a rich and useful framework for thinking about the links among technology, food prices, and the impacts of food price changes on welfare. Innovations in technology work through four channels and can alter:

1. price elasticities of demand and supply for farm commodities, changing the sensitivity of prices to given shifts in supply or demand;
2. the sensitivity of farm supply to external shocks, such as weather or pests, and can therefore influence the degree to which such shocks affect farm prices;
3. agricultural productivity, and the level of farm prices; and
4. economy-wide productivity and real incomes, which leads to falling shares of income spent on food and hence leaves populations less exposed to food price fluctuations.

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