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Future Yield Growth: What Evidence from Historical Data

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Future Yield Growth: What Evidence from Historical Data?

Xavier Gitiaux[*], John Reilly[†] and Sergey Paltsev[†]

Abstract

The potential future role of biofuels has become an important topic in energy legislation as it is seen as a potential low carbon alternative to conventional fuels. Hence, future yield growth is an important topic from many perspectives, and given the extensions of the period over which data are available a re-evaluation of yields trends is in order. Our approach is to focus on time series analysis, and to improve upon past work by investigating yields of many major crops in many parts of the world. We also apply time series techniques that allow us to test for the persistence of a plateau pattern that has worried analysts, and that provide a better estimate of forecast uncertainty. The general conclusion from this time series analysis of yields is that casual observation or simple linear regression can lead to overconfidence in projections because of the failure to consider the likelihood of structural breaks.

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1. INTRODUCTION

The second half of the century has been characterized by a rapid increase of crop yields in most countries. However, there is debate about the sustainability of such growth rates amid some evidence that yield growth may be slowing. Limits on yield growth and implications for food supply have been concerns that seem to repeat on a cycle of a decade or so. As of the mid 1990s there had been a decade or two of relatively low commodity prices, and some evidence of slowing yield growth. This led to various efforts to investigate yield growth and debates on either side. Borlaug and Dowswell (1993) and Bump and Dowswell (1993) saw significant yield gaps between high productivity regions and other regions as evidence for much opportunity for further improvement if lower productivity regions could just adopt best varieties and practices. Oram (1995) and Brown (1994) both saw slowing yield growth. Rosegrant (2001) accepted evidence on the then recent slowdown but offered reasons why it might be temporary, suggesting policy measures (environmental regulation on fertilizers and pesticides, reduction of cereals stocks, scaled back price supports), declining world prices in the 1980s, and, in the case of developing

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countries, lack of incentives to apply inputs needed to sustain yield gains combined with natural resource issues (water shortage, soil salinity, and decline in soil nitrogen).

Statistical examination of trends in the U.S. data around this time showed little support for a plateau assumption, whether the regression was performed against time alone (Reilly and Fuglie, 1998; for 1939-1994 U.S. field crops) or when controlling for weather conditions and nitrogen consumption (Offutt *et al.*, 1987; for U.S. corn, 1931-1982 at the farm, state and county level).

Since then commodity prices have firmed and 2006 marked the start of another agricultural market crisis in 2006, with commodity prices rising dramatically as they had in the early 1970s. That run-up in prices may be attributable to a number of factors but some authors point a finger strongly to a boom in ethanol production in the U.S. that diverted a large portion of the U.S. corn crop (Mitchell, 2008). The potential future role of biofuels has become an important topic in energy legislation as it is seen as a potential low carbon alternative to conventional fuels. However, the impact of biofuels on agricultural markets as it affects commodity prices, land use, and emissions associated with land use change may undermine their value as a low carbon alternative (*e.g.*, Searchinger *et al.*, 2008). As shown by Tyner *et al.* (2010), continuing yield growth can reduce estimates of the indirect emissions of GHGs associated with biofuels expansion. Hence, future yield growth is an important topic from many perspectives, and, given the extensions of the period over which data are available, a re-evaluation of yields trends is in order.

Of course yield growth is almost certainly some function of economic factors. In the short run, higher crop prices might be expected to provide incentives for additional management using known technologies (more careful nutrient and pest management, optimized choice of varieties, irrigation, *etc.*), and in the longer run research and development has clearly contributed to increasing yields. In one way or another such R&D is likely motivated by economic incentives (or somewhat equivalently, concerns about food shortages). However, given the long and variable lags in these processes, and difficulty of identifying expectations that drive longer term investments in R&D it is very difficult to statistically relate yields to economic incentives for increasing them.

Our approach is thus, to focus on time series analysis, and to improve upon past work by investigating yields of many major crops in many parts of the world. Instead of comparing the goodness of fit of different types of regression, here we measure how large is the uncertainty around the forecasts of future yields that we can derive from these models. We contribute to the literature first, by applying time series techniques that show how standard time regressions may end up with misleading predictions, as most of the crop yields exhibit a unit root. Although papers looking for trend in crop yields are abundant (see articles cited above), the literature has been quite silent on the unit root issue; exceptions are Liu and Shumway (2008) at the state level in the U.S. for corn, Lin and Seavey (1978) for 19 crops in the U.S., Chen and Chang (2005) in Taiwan. Here, we test for the presence of unit root more comprehensively, as we include many crops in many regions of the world. Secondly, we conclude from our analysis of historical data for the period 1961-2006 that the behavior of crop yields is partly driven by a random component that obscures any long-term forecast. This analysis sheds new light on the evaluation of yields trend; for example, we infer that a current plateau is not a robust indication of a persistent slow-down.

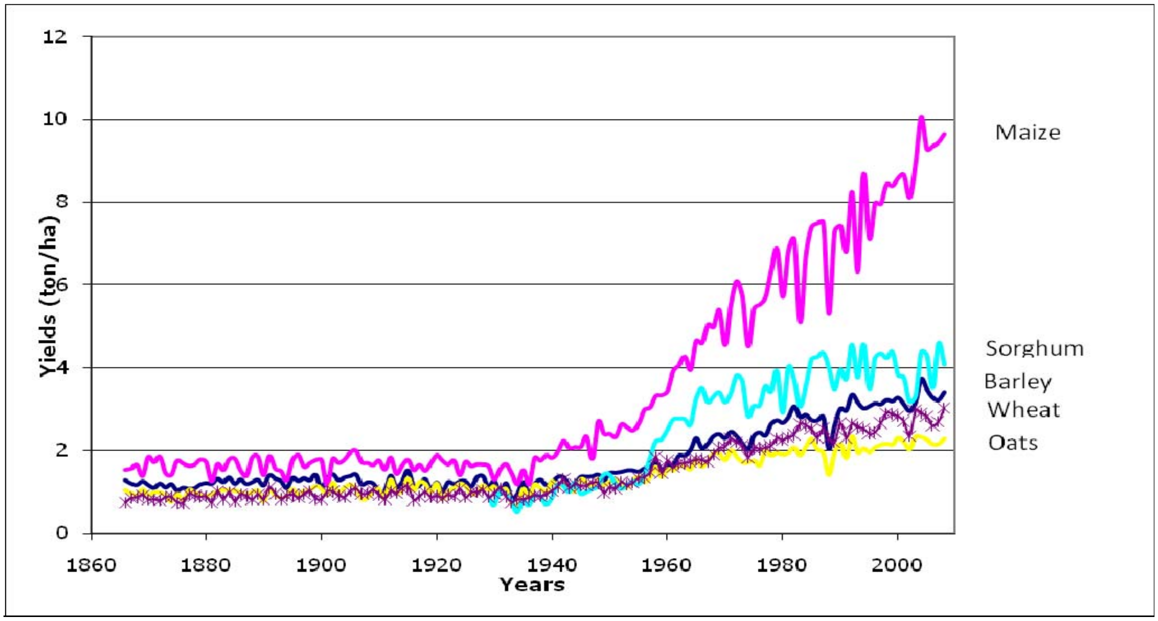
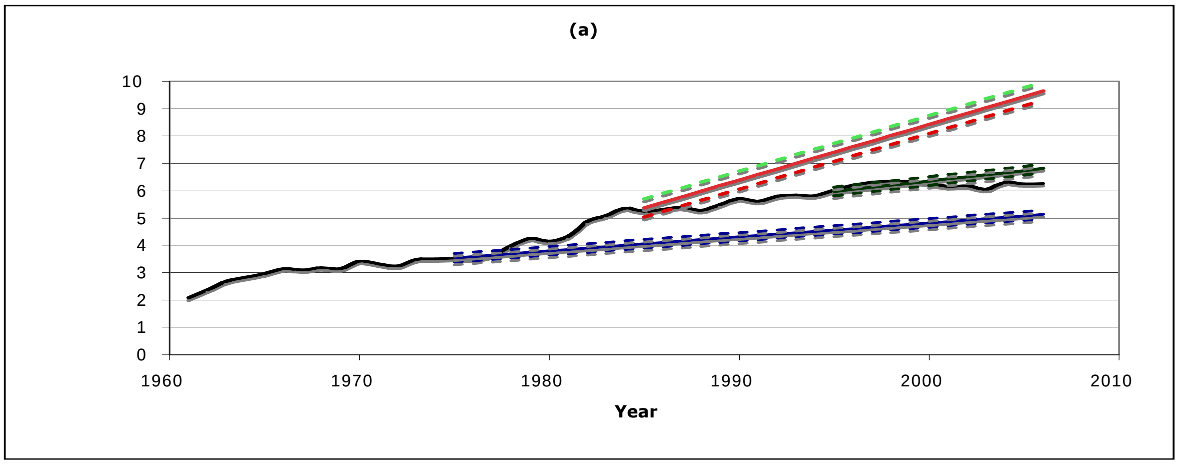


Figure 1. U.S. maize, barley, oats, sorghum and wheat yields. Source: NASS (2008).

Yield growth is a phenomenon of the last 50 to 80 years. **Figure 1** shows little change in yields in U.S. wheat, maize and barley from 1866 until a take-off period for yield growth beginning in the 1930-1940s: since then, maize yields display a more than fivefold increase from 2 ton/ha to 10 ton/ha and wheat and barley an almost threefold increase, respectively from 1.0 ton/ha to 2.7 ton/ha and from 1.2 to 3.2 ton/ha. U.S. improvements have spread across the world to Europe and through the Green Revolution in India and China (*e.g.*, Griffon, 2006). From 1961 to 2006, maize yields increased in Europe from 2.8 ton/ha to 8.7 ton/ha, in China from 1.2 ton/ha to 5.4 ton/ha; wheat yields from 1.9 ton/ha to 5.9 ton/ha in Europe, from 0.9 ton/ha to 2.6 ton/ha in India, from 0.5 ton/ha to 4.5 ton/ha in China; rice from 2 ton/ha to 6 ton/ha in China, from 1.5 ton/ha to 3 ton/ha in India.

Figure 1 suggests that sharp breaks have characterized by the evolution of crop yields over the last hundred and fifty years in the U.S. Second, the presence of a plateau may be due to the choice of the period of interest; if we select end points carefully, we actually see the plateau behavior in the period from about 1985 through 2000 that worried analysts of the time. The post-2000 evidence seems to suggest a resumption of yield growth. Thereby, because of sharp changes in the behavior of yields, a specific pattern for a limited time span might not be very informative about future yields. The problem with a simple time trends approach is the failure to account for structural changes in the behavior of crop yields. If the crop yields are modeled as stationary processes about a deterministic trend as in most past work, the variance of the forecast error is bounded in the far future by the in-sample variance of the residuals provided by the regression. Then, we show that this may underestimate uncertainty, even if the fit is very good. To illustrate, we develop best linear fits for sub-periods of historical data and produce out of sample forecasts that can be compared against actual data. For example, in **Figure 2**, the upper panel estimates trends in China's rice yields based on 1965-1975, 1975-1985, and 1985-1995 data and then uses these trends to forecast ahead to 2006. Figure 2, the lower panel, uses data for the full 1965-1995 to forecast ahead to 2006. The forecasts err in being either too high or too low depending on the period over which the model is estimated. Moreover, the forecast error, shown by the dashed line, fails to provide an indication of the true forecast error. The error ranges from all of these approaches do not include the true value, and error bars from the different periods do not overlap. At issue is the failure to capture the next plateau or resumption of yield growth, or at least to account in the forecast error for such sharp changes. The objective of the remaining sections is to construct appropriate error estimates that reflect this feature of the data.



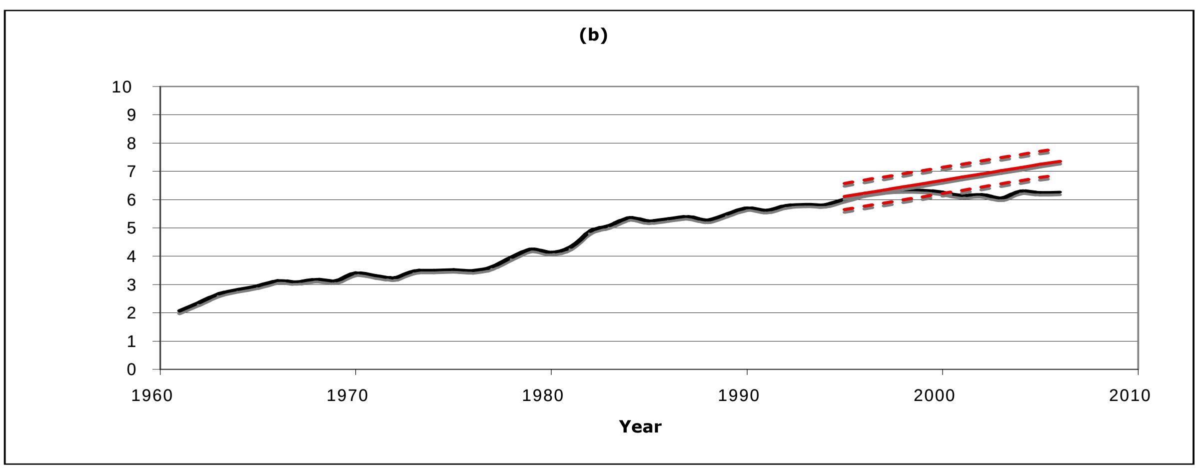


Figure 2. Rice yields in China. Source: FAO (2008). The straight solid lines represent the long-run linear projections for yields using data from 1965-1975, 1975-1985, 1985-1995 (panel (a)) and from 1961-1995 (panel (b)). The forecasts result from the extrapolation of a linear deterministic trend. The dotted lines represent a long run 95% confidence interval for the respective rice yields forecasts.

The remaining sections of this paper are organized as follows. Section 2 tests for the presence of unit roots in crop yields and provides evidence for modeling them as stochastic trends. That is why section 3 decomposes crop yields as the sum of a stationary component and a random walk component and then, estimates the size of the random walk component that may represent the shift in the long-term trend. Based on these estimates, section 3 also builds forecast intervals and shows that historical data do not allow us statistically to discriminate between models with constant growth rate growth or without growth.

2. TESTING FOR UNIT ROOT IN CROP YIELDS

2.1 Data

The analysis is based on FAO data (FAO, 2010) provided from 1961 to 2009. We aggregate countries following Rosegrant (2001). Specifically, we single out two countries, China and the U.S., and two political identities for convenience: the European Union with 15 countries (as in 1995) and the former soviet block (USSR). Other countries are aggregated in South Asia (dominated by India), Latin America, South-East Asia, Western Asia and Northern Africa (WANA), Sub-Saharan Africa and Eastern Europe. Details about this aggregation are given in Appendix A. The USSR numbers come from the former Soviet Union until 1991 and since then, result from the aggregation of the data from countries formerly part of the USSR. As for the crops, we only investigate the yields of the major crops (in terms of acreage) in each region. **Table 1** summarizes the data considered in this paper.

Table 1. Regions and crop aggregation

Regions	Crops
USA	Barley, Maize, Oats, Seed cotton, Sorghum, Soybean, Wheat
South America	Maize, Rice, Seed cotton, Sorghum, Soybean, Sunflower, Wheat
Sub-Saharan Africa	Maize, Millet, Rice, Seed cotton, Sorghum, Wheat
Western Asia[1] / North Africa (WANA)	Barley, Maize, Seed cotton, Sorghum, Sunflower, Wheat
South Asia	Maize, Millet, Rapeseed, Rice, Seed cotton, Sorghum, Soybean, Wheat
South-East Asia	Maize, Rice
China	Maize, Millet, Rapeseed, Rice, Seed cotton, Soybean, Wheat
USSR	Barley, Maize, Millet, Oats, Rye, Sunflower, Wheat
EU15	Barley, Maize, Oats, Rapeseed, Rye, Sunflower, Wheat
Eastern Europe	Barley, Maize, Oats, Rapeseed, Rye, Sunflower, Wheat

[1] Excluding former Soviet Republics (Azerbaijan, Armenia and Georgia).

2.2 Unit Root Tests

Most of the crop yields exhibit strong trends that are not stationary. Stationarity can be achieved either by regressing the dependent variable on time or by taking its first difference. The former transformation produces a stationary process for time series that results from movements along a time trend. The latter transformation works only for time series that contain a unit root, *i.e.* whose model should include a random walk, possibly with drift).

In most previous work, as in Reilly and Fuglie (1995) or Brown (1994), crop yields have been assumed to be trend stationary, but no evidence have been provided to support this assumption. However, it should be one of the primary concerns when dealing with crop yields as time series. This is the powerful message of Granger and Newbold (1974):

"In our opinion the econometrician can no longer ignore the time series properties of the variables with which he is concerned - except at his peril. The fact that many economic levels are near random walks or integrated processes means that considerable care has to be taken in specifying one's equations."

Indeed, unit root processes and trend stationary processes have very different implications in terms of analysis of time series. On one hand, if a crop yield is trend stationary, it exhibits a long run growth with short-term transitory shocks that are dampened over time. Effort to extract a trend in crop yields are fruitful and are rewarded with bounded forecast intervals. On the other hand, if crop yields' behavior reflects a unit root, shocks have a permanent effect: a decrease in the current yields implies that forecasts should be decreased for an indefinite future. Then, trending techniques are misleading and any future extrapolation is complicated, as forecast intervals are now growing unbounded.

Therefore, it is crucial to first determine to which regimes the crop yields pertain, before projecting yields in the future. We test the presence of unit root against one of the two following hypotheses: a trending behavior or a stationary behavior. We use the procedure proposed by Elliot, Rosenberg and Stock (1996) to conduct this test. Crop yields Y_t are first detrended (demeaned, if we test the presence of a unit root against a stationary process) by generalized least squares:

$$Y_t^{GSL} = Y_t - \beta^T Z_t \, .$$

For detrending, $Z_t = (1,t)^T$ and β is obtained by regressing $(Y_1, Y_2 - \alpha Y_1, ..., Y_{49} - \alpha Y_{48})$ on $(Z_1, Z_2 - \alpha Z_1, ..., Z_{49} - \alpha Z_{48})$, where $\alpha = 1 - 13.5/49$, given that we dispose of 49 observations. For demeaning, $Z_t = (1)^T$ and the same regressions as previously are run with $\alpha = 1 - 7/49$. The values of α are from Stock (1994). Then, we apply a standard augmented Dickey-Fuller regression, using the transformed series Y_t^{GSL}. That is, for the crop yields that do not exhibit a clear trend, we test the null hypothesis $\gamma = 0$ in the regression:

$$\Delta Y_t^{GLS} = \mu + \gamma Y_{t-1}^{GLS} + \sum_{j=1}^{k} c_j \Delta Y_{t-j}^{GLS} + \varepsilon_t \ ,$$

where Y_t^{GSL} has been demeaned only. For crop yields with a trending behavior, we use the regression

$$\Delta Y_t^{GLS} = \mu + \beta t + \gamma Y_{t-1}^{GLS} + \sum_{j=1}^{k} c_j \Delta Y_{t-j}^{GLS} + \varepsilon_t \ ,$$

where Y_t^{GSL} has been detrended. In both formulations, $\Delta Y_s^{GLS} = Y_s^{GLS} - Y_{s-1}^{GLS}$ and k is the order of the autoregressive process necessary to accommodate serial correlations of the disturbances and whiten the errors. In the first approach, this truncation lag is determined by sequentially examining the t statistic on the coefficient of higher order. We test the null hypothesis of the absence of a unit root by considering a t test on γ, with a set of critical values proposed in Elliot, Rosenberg and Stock (1996).

The column "Model I" of **Table 2** shows results for this procedure. Out of 63 crops, the presence of a unit root can be rejected at the 99% level for only 17 crops (at 95% for 22 crops). At first glance, there is no clear pattern across countries or crops. Although in the U.S. all the crops but cotton seeds do not appear to exhibit a unit root, we cannot infer that crop yields in developed countries, are more likely to be trend stationary, as the null hypothesis is mostly not rejected in Europe. From Table 2, the key message is that for two thirds of the crop yields considered, we cannot statistically reject the presence of a unit root and that great care is necessary before regressing historical data on time.

Table 2. ERS Unit root test. Truncation lags are chosen in Model I by a sequential t-test on the coefficient of higher order; in Model II, by a MAIC criterion; in Model III, by a SIC criterion. t-ratios in bold characters indicate that the null hypothesis is rejected at the 99% (95% in italics) confidence level.

Region	Crops	DM or DT[2]	Model I		Model II		Model III	
			k	t-ratio	k	t-ratio	k	t-ratio
USA	Barley	DT	0	**-4.209**	1	**-4.012**	2	*-3.266*
	Maize	DT	0	**-8.465**	1	**-5.224**	9	-1.249
	Oats	DT	0	**-6.309**	1	**-4.574**	1	**-4.574**
	Seed cotton	DT	1	-2.834	1	-2.834	2	-2.094
	Sorghum	DT	0	**-6.037**	1	*-3.564*	6	-1.648
	Soybeans	DT	0	**-6.975**	1	**-4.034**	9	-0.977
	Wheat	DT	0	**-4.899**	1	**-3.773**	1	**-3.773**
Latin America	Maize	DT	2	-0.711	1	-1.403	2	-0.711
	Rice	DT	7	-1.136	1	0.268	1	0.268
	Seed cotton	DT	8	-1.622	1	-2.77	1	-2.77
	Sorghum	DT	5	-2.053	1	-2.667	4	-1.554
	Soybeans	DT	2	-0.348	2	-0.348	2	-0.348
	Wheat	DT	0	**-3.89**	1	-2.702	3	-1.708
Sub Saharan Africa	Maize	DT	0	**-5.488**	1	**-4.347**	2	-2.801
	Millet	DT	7	-2.505	1	-1.859	2	-1.208
	Rice	DT	3	-2.151	1	-2.379	2	-1.728
	Seed Cotton	DT	5	-1.756	1	-2.038	4	-1.15
	Sorghum	DT	0	*-3.392*	1	-2.824	2	-2.338
	Wheat	DT	2	**-5.486**	1	**-5.687**	7	-1.562
Western Asia / North Africa (WANA)	Barley	DT	9	-1.821	1	**-4.496**	1	**-4.496**
	Maize	DT	5	-0.778	1	-1.246	1	-1.246
	Seed cotton	DT	0	-2.75	1	-2.792	1	-2.792
	Sorghum	DT	2	-1.481	2	-1.481	2	-1.481
	Sunflower seed	DT	9	-1.506	1	-3.13	8	-1.097
	Wheat	DT	0	-5.292	1	-3.142	3	-1.977
South Asia	Maize	DT	9	-0.955	1	-1.322	2	-0.511
	Millet	DT	9	-0.922	1	-3.79	6	-0.533
	Rapeseed	DT	4	-1.164	1	-2.55	4	-1.164
	Rice	DT	2	-1.182	1	-1.858	2	-1.182
	Sorghum	DT	4	-2.842	2	-2.097	2	-2.097
	Soybeans	DT	0	**-3.811**	1	-2.514	1	-2.514
	Wheat	DT	6	-1.172	2	-1.18	2	-1.18
South-East Asia	Maize	DT	5	-0.911	5	-0.911	5	-0.911
	Rice	DT	7	-1.27	1	-1.801	1	-1.801
China	Maize	DT	2	-1.103	2	-1.103	2	-1.103
	Millet	DT	1	-2.272	1	-2.272	1	-2.272
	Rapeseed	DT	5	**-4.42**	1	-2.845	1	-2.845

[2] DM: demeaned; DT: detrended.

	Rice	DT	0	-1.372	1	-1.128	1	-1.128
	Seed cotton	DT	7	*-3.163*	1	-2.421	1	-2.421
	Soybeans	DT	4	-2.559	1	-2.095	2	-1.645
	Wheat	DT	6	-1.753	1	-2.44	1	-2.44
USSR	Barley	DT	0	**-5.873**	1	*-3.533*	3	-2.287
	Maize	DT	9	*-2.901*	1	-1.824	3	-1.319
	Millet	DM	0	**-5.967**	1	-2.48	4	-1.234
	Oats	DT	6	-2.333	1	**-4.216**	6	-2.333
	Rye	DT	5	-2.427	1	-2.985	4	-1.869
	Sunflower seed	DT	0	*-3.211*	1	-1.814	1	-1.814
	Wheat	DT	0	-5.538	1	*-3.307*	2	-2.666
EU15	Barley	DT	0	**-5.872**	1	*-3.343*	5	-1.368
	Maize	DT	0	**-4.403**	1	-3	2	-2.302
	Oats	DT	5	-0.51	2	-0.951	2	-0.951
	Rapeseed	DT	7	-1.79	1	-2.308	4	-1.439
	Rye	DT	7	*-3.656*	1	-3.013	2	-2.416
	Sunflower seed	DM or DT	0	-1.667	1	-0.952	1	-0.952
	Wheat	DT	1	-1.824	5	0.82	1	-1.824
Eastern Europe	Barley	DM	7	-1.479	1	-1.71	2	-1.288
	Maize	DM	8	-0.937	1	-1.607	2	-1.176
	Oats	DM	10	-0.456	1	-1.611	2	-1.16
	Rapeseed	DT	0	**-5.23**	1	*-3.248*	2	-2.535
	Rye	DT	0	**-4.203**	1	-2.568	5	-1.3
	Sunflower seed	DM	3	-0.954	1	-1.469	3	-0.954
	Wheat	DM	7	-0.831	2	-0.732	8	-0.599

We look at the robustness of our findings in relation to the sample size and the choice of the truncation lag. First, the number of observations (1961-2009) provided by the FAO is small, especially because truncation lags should be selected at an order high enough to avoid serial autocorrelation in the ERS procedure. With a truncation lag order equal to 5, the number of no overlapping data is reduced to between 9 and 10. Such a small number may cast doubt on the solidity of our previous results in Table 1, especially on the power of the unit root test. We test the unit root hypothesis with the much longer time series for U.S. data provided by NASS (2008). Two sets of data are considered: barley, maize, oats from 1866 to 2008; barley, maize, oats and sorghum from 1929 to 2008. With this expanded dataset, the ERS procedure concludes that all crops but oats between 1929 and 2008 behave as a unit root. Therefore, not only does a longer time horizon not contradict the presence of unit root, it also reinforces this pattern, at least in the U.S., since we did not find a unit root for maize, barley and oats previously with the shorter time series.

Table 3. Unit root test for U.S. crops from 1866 to 2009 and from 1929 to 2009. Truncation lags are chosen in model I by a sequential t-test on the coefficient of higher order; in model II, by a MAIC criterion; in model III, by a SIC criterion. t-ratios in bold characters indicate that the null hypothesis is rejected at the 99% (95% in italic) confidence level.

	Crops	DM or DT	Model I		Model II		Model III	
			k	t-ratio	k	t-ratio	k	t-ratio
1866 -2008	Barley	DT	9	-0.284	2	-0.866	2	-0.866
	Maize	DT	11	-0.848	11	-0.848	4	0.488
	Oats	DT	8	-0.988	6	-0.829	2	-1.576
1929-2008	Barley	DT	10	-1.279	10	-1.279	1	-3.81
	Maize	DT	10	-1.108	4	-1.021	4	-1.021
	Oats	DT	0	**-6.902**	6	-1.946	1	**-4.21**
	Sorghum	DT	1	-2.531	5	-1.438	1	-2.531

Secondly, Ng and Perron (2001) argue that the choice of a truncation lag may distort the size of the ERS test. Specifically, they show that small k may be inadequate and lead to an over-rejection of the null hypothesis. To improve the size of the test, they propose to choose the truncation lag k that minimizes a modified Akaike's information criterion (MAIC) defined by:

$$MAIC(k) = \ln(\sigma_k^2) + \frac{2(\tau_k + k)}{49 - k_{\max}},$$

where $\sigma_k^2 = \frac{\sum_{k_{\max}+1}^{49} \varepsilon_t^2}{49 - k_{\max}}$, $\tau_k = \frac{\gamma^2 \sum_{k_{\max}+1}^{49} (Y_{t-1}^{GLS})^2}{\sigma_k^2}$ and $k_{\max} = 12 * \left(\frac{49+1}{100}\right)^{0.25}$.

Results from the ERS procedure using this criterion are reported in the column "Model II" of **Table 2** and **Table 3**. The unit root hypothesis is rejected for only 9 yields at the 99% confidence level (at 95% for 13 yields). Therefore, an improvement in our selection of truncation lags turns out to reinforce our previous conclusion that crop yields contain a unit root. It does not come as a surprise, as the MAIC procedure is designed to increase the size of the test. The last column of Table 2 and Table 3 relies on another selection criterion, the Schwarz information criterion (SIC) that determines k, as the lag that minimizes:

$$SIC(k) = \ln\left(\frac{\sum_{k_{\max}+1}^{49} \varepsilon_t^2}{49 - k_{\max} - K}\right) + (k + K)\frac{\ln(49 - k_{\max} - K)}{49 - k_{\max}},$$

with $K = 1$ if the yields are demeaned only, and $K = 2$ if they are detrended. Our key results still hold, as the unit root hypothesis is rejected in only 3 situations at the 99% level.

2.3 Can We Explain Unit Root Behavior as a Consequence of Structural Break?

Looking back at Figure 1, one of the most striking features is a sharp change in the behavior of crop yields in the U.S. at the beginning of the 1930s for maize, barley and oats and at the end of the 1950s for sorghum. It may give us a reasonable interpretation for the presence of unit roots in crop yields. Intuitively, a structural break implies one permanent shock that masks a collection of permanent small innovations and therefore biases the ERS procedure toward a non-rejection of the unit root. Following Zivot and Andrews (1992), we consider these jumps as realizations from the tail of the distribution of the underlying data-generating process. Thereby, the null hypothesis of a unit root model should be tested against the alternative hypothesis of a trend-stationary model with one structural break occurring at a date determined endogenously. We consider the regression

$$\Delta Y_t = \mu + \beta t + \chi DI_t(t_B) + \delta DS_t(t_B) + \gamma Y_{t-1} + \sum_{j=1}^{k} c_j \Delta Y_{t-j} + \varepsilon_t$$

where k is a truncation lag defined as in section 2.2, t_B is the time of the break. DI_t is the indicator dummy variable for shift in the intercept occurring at time t_B: $DI_t = 0$ for $t < t_B$ and $DI_t = 1$ otherwise. DS_t is the corresponding trend shift variable such that $DS_t = t$ if $t > t_B$ and zero otherwise. We test for the presence of a unit root with a null $\gamma = 0$. The alternative hypothesis is a trend stationary process with a break in the intercept and the slope at time t_B. The date of this structural change is allowed to vary from $t_B = 2$ to $t_B = 48$, therefore we do not allow break at the beginning and the end of the period. Zivot and Andrews (1992) select the break point that least favors the null hypothesis *i.e.* that minimizes the t-ratio corresponding to the coefficient γ. Critical values corresponding to this t-ratio are from Zivot and Andrews (1992). In **Table 4**, we report the results of this procedure: for 31 crop yields, the unit root hypothesis can be rejected at the 99% (at 95% for 34 crop yields) level. When we admit structural break, we have less support to conclude that crop yields behave as a unit root process. It is particularly true for the former Soviet Union (USSR), the EU15 and Eastern Europe, where out of 21 crops, only 4 yields are not trend stationary. Moreover, in the former communist regions (USSR and Eastern Europe), the date of break coincides with the change of regime (beginning of the nineties), which was followed by a restructuring in the agriculture sector. However, our procedure provides still little support for a trend stationary model of crop yields in the developing countries: out of 34 crops, the presence of a unit root is rejected for only 11crops at the 99% level (13 crops at the 95% level). One of the likely reasons is that we allow for only one structural break. Lumsdaine and Papell (1997) argue that considering one break may be insufficient and leads to a loss of information if there is actually more than one break in the data generating process.

Table 4. ERS Unit root test. Truncation lags are chosen by a sequential t-test on the coefficient of higher order. t-ratios in bold characters indicate that the null hypothesis is rejected at the 99% (95% in italic) confidence level.

Regions	**Crops**	**t_B**	**k**	**t-statistic**
USA	Barley	1985	0	-4.81
	Maize	1988	0	**-9.874**
	Oats	1987	0	**-7.322**
	Seed cotton	1981	1	-4.345
	Sorghum	2001	0	**-7.391**
	Soybeans	1990	0	**-8.202**
	Wheat	1986	0	*-5.554*
Latin America	Maize	1991	2	**-5.687**
	Rice	1988	1	-2.992
	Seed cotton	1982	0	-3.565
	Sorghum	1979	0	-5.927
	Soybeans	1995	2	-2.482
	Wheat	1969	0	-5.213
Sub Saharan Africa	Maize	1976	**0**	**-7.588**
	Millet	1991	2	-3.098
	Rice	1984	2	-2.805
	Seed Cotton	1985	0	**-5.874**
	Sorghum	1974	0	-4.255
	Wheat	1970	**2**	**-7.591**
West Asia/North Africa (WANA)	Barley	2002	0	**-8.405**
	Maize	1984	0	-3.955
	Seed cotton	2000	0	**-6.022**
	Sorghum	1983	2	-5.03
	Sunflower seed	1990	0	**-7.326**
	Wheat	1986	0	**-6.199**
South Asia	Maize	1987	2	-3.094
	Millet	1985	0	**-9.124**
	Rapeseed	1984	0	**-7.547**
	Rice	1983	0	**-7.932**
	Sorghum	1974	2	-3.059
	Soybeans	1979	1	-4.606
	Wheat	1995	2	-3.999
South-East Asia	Maize	1991	1	-1.775
	Rice	1980	2	-4.712
China	Maize	1990	2	-3.833
	Millet	1993	1	-4.201
	Rapeseed	1981	0	-4.309
	Rice	1982	0	*-5.122*
	Seed cotton	1992	0	-3.775
	Soybeans	1993	1	-4.463
	Wheat	1982	0	*-5.153*

USSR	Barley	1995	0	**-7.362**
	Maize	1992	0	**-5.85**
	Millet	1991	0	**-6.875**
	Oats	1972	0	**-5.95**
	Rye	1998	0	**-6.503**
	Sunflower seed	1993	0	-4.796
	Wheat	1994	0	**-7.146**
EU15	Barley	1984	*0*	**-7.797**
	Maize	1996	0	**-5.741**
	Oats	1995	2	-4.294
	Rapeseed	1984	0	**-5.92**
	Rye	1995	0	**-6.552**
	Sunflower seed	1970	2	-4.466
	Wheat	1984	1	-4.575
Eastern Europe	Barley	1992	1	**-6.46**
	Maize	1987	0	**-5.661**
	Oats	1991	0	**-6.248**
	Rapeseed	1992	0	**-6.532**
	Rye	1992	0	**-6.884**
	Sunflower seed	1992	0	**-5.669**
	Wheat	1992	2	-4.825

In practice, with finite samples, it is nearly equivalent to consider a unit root process with fat tail disturbances or a trend stationary process with structural break. The key consequence of both interpretations is that a part of the long-run response of crop yields is driven by current shocks, which complicates any predictions of future yields based on the extrapolation of past or current trends.

3. PERSISTENCY IN CROP YIELDS AND FORECAST INTERVALS

3.1 A Measure of Persistency: The Variance Ratio

The presence of unit root in crop yields shows that at least a part of the shocks has a permanent effect on crop yields. Therefore, we follow Cochrane (1988) and decompose our time series into a stationary component and a random walk component[3]: the latter represents permanent changes and the former temporary fluctuations. It can be shown that in the presence of a unit root, such decomposition does not add any structure. As in Cochrane (1988), we propose a measure of persistency that considers at lag k the variance ratio:

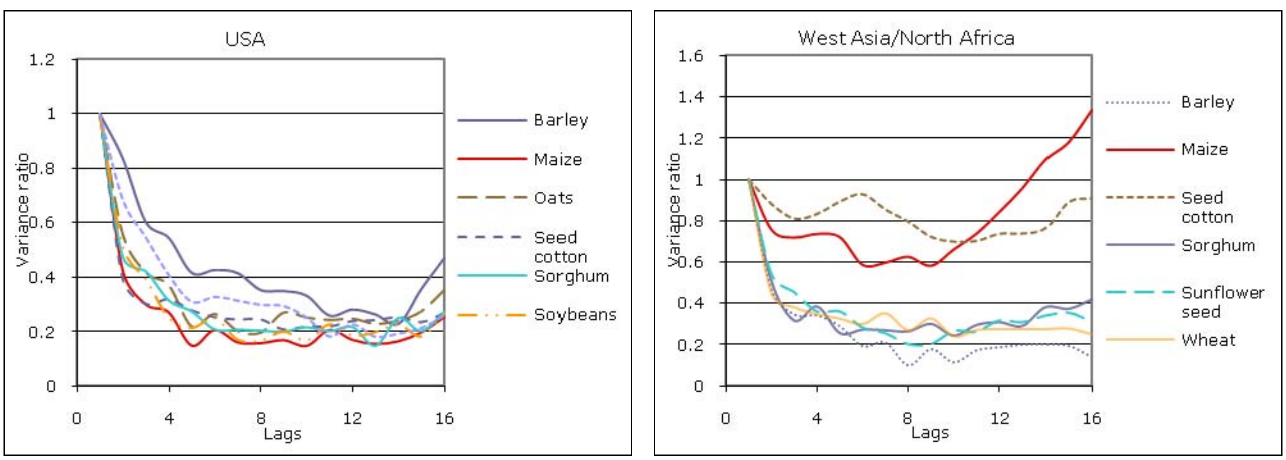
$$VR(k) = \frac{\mathrm{var}(Y_t - Y_{t-k})/k}{\mathrm{var}(Y_t - Y_{t-1})}.$$

[3] The decomposition is not unique; however, Cochrane argues that the innovation variance of the random component does not depend on the decomposition.

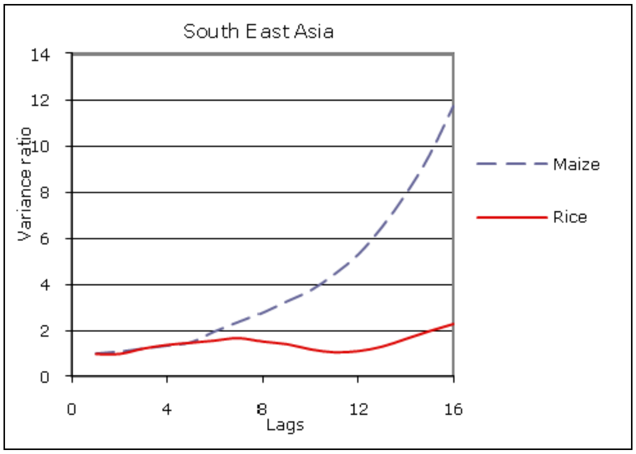
Then, we exploit the fact that on one hand, if a crop yield Y_t is a pure random walk, the variance of its $k-$differences grows linearly with the lag k and $\lim_{k->\infty}\frac{\operatorname{var}(Y_t - Y_{t-k})}{k} = \sigma_\varepsilon^2$, where σ_ε^2 is the variance of the random walk component. Hence, the variance ratio converges to unity. On the other hand, if Y_t is stationary about a trend, the variance of its $k-$differences converges to a constant when k increases, and the variance ratio converges to zero. In an intermediate case, if the fluctuations in crop yields are partly temporary and partly permanent, the variance ratio converges to the fraction of the variance in the crop yields that is explained by the random walk component[4]. A value larger than one suggests that crop yields exhibit more shock persistence than a random walk. In contrast, values significantly lower than one indicate that the time series is mostly mean reverting.

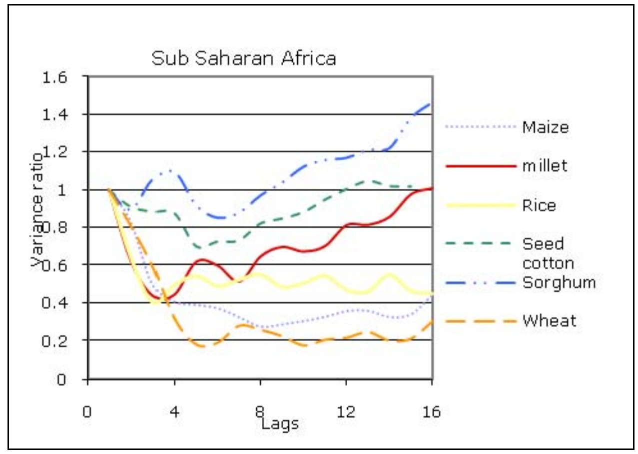
To avoid small sample bias, we estimate the variance ratio by: $\overline{VR(k)} = \frac{\bar{\sigma}_k^2}{\bar{\sigma}_1^2}$, where

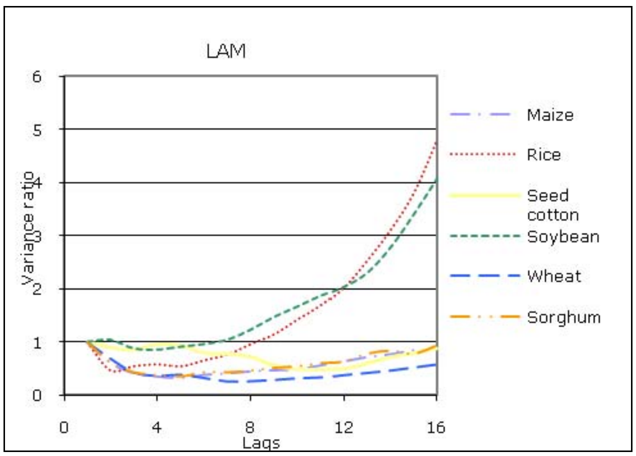
$\bar{\sigma}_k^2 = \frac{T}{k(T-k)(T-k-1)}\sum_{j=k}^{T}\left[Y_j - Y_{j-k} - k\mu\right]^2$, $\bar{\sigma}_1^2 = \frac{1}{(T-1)}\sum_{j=2}^{T}\left[Y_j - Y_{j-1} - \mu\right]^2$ and μ is the sample mean of the first difference $Y_t - Y_{t-1}$.

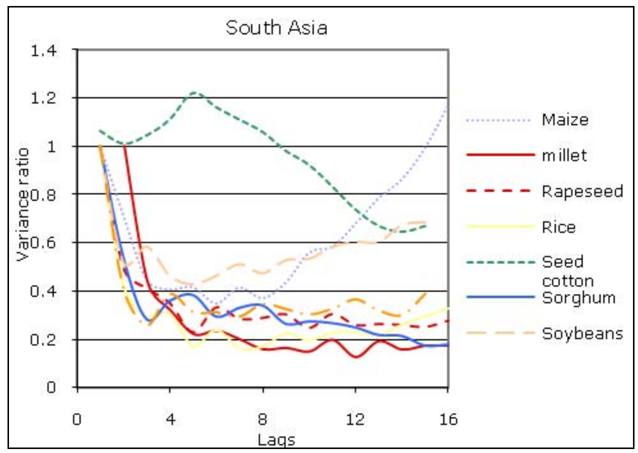


[4] Provided that the random walk component and the stationary component are not correlated.


South East Asia
Variance ratio
Lags
Maize
Rice


Sub Saharan Africa
Variance ratio
Lags
Maize
millet
Rice
Seed cotton
Sorghum
Wheat


LAM
Variance ratio
Lags
Maize
Rice
Seed cotton
Soybean
Wheat
Sorghum


South Asia
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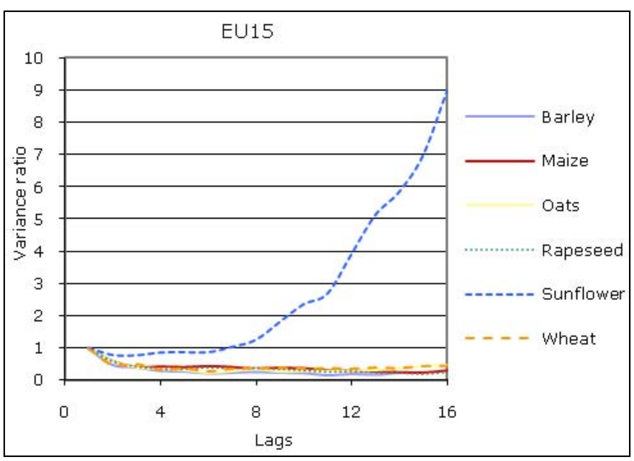
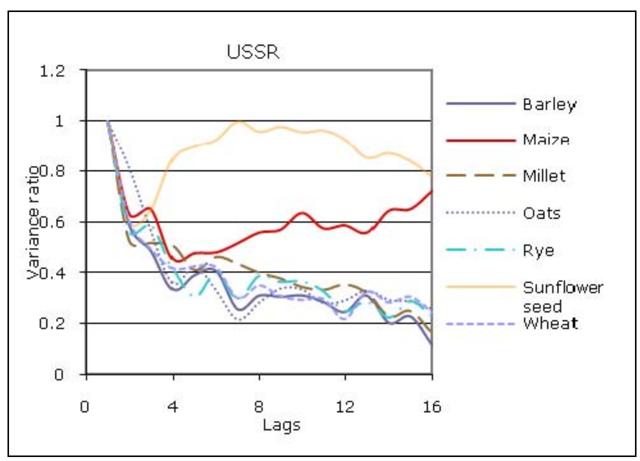
Seed cotton
Sorghum
Soybeans


EU15
Variance ratio
Lags
Barley
Maize
Oats
Rapeseed
Sunflower
Wheat


USSR
Variance ratio
Lags
Barley
Maize
Millet
Oats
Rye
Sunflower seed
Wheat

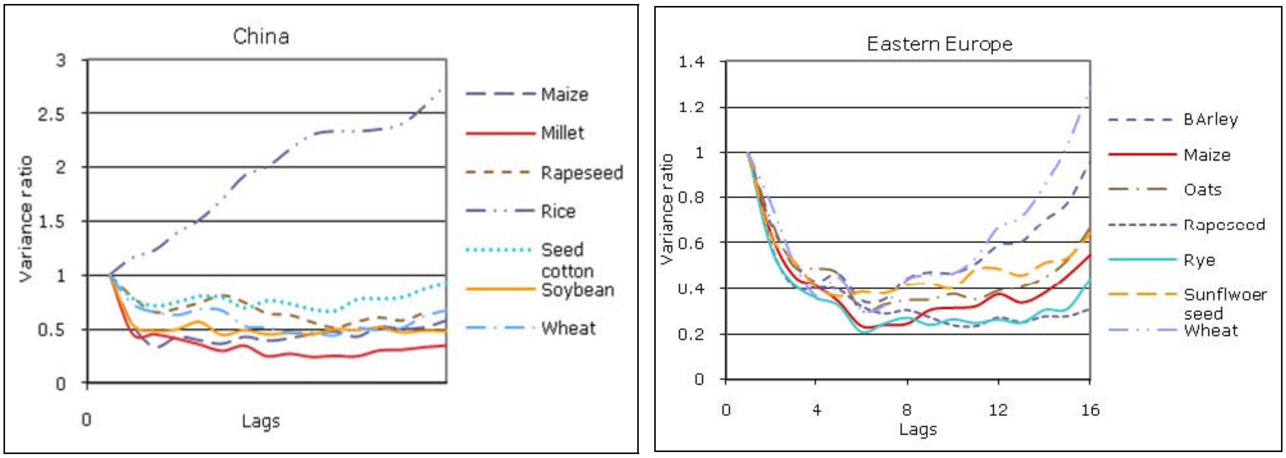


Figure 3. Estimates of variance ratio.

Table 5. Variance ratio computed at lag 16.

Regions	**Crops**	σ^2_{16}	$VR(16)=\sigma^2_{16}/\sigma^2_1$
USA	Barley	0.0352	0.472
	Maize	0.2994	0.256
	Oats	0.0195	0.352
	Seed cotton	0.0175	0.269
	Sorghum	0.1045	0.273
	Soybeans	0.0185	0.264
	Wheat	0.0123	0.258
Latin America	Maize	0.0605	1.003
	Rice	0.1514	4.804
	Seed cotton	0.0436	0.879
	Sorghum	0.0977	0.945
	Soybeans	0.1048	4.075
	Wheat	0.0288	0.583
Sub Saharan Africa	Maize	0.0177	0.443
	Millet	0.0036	1.008
	Rice	0.0024	0.449
	Seed Cotton	0.0018	1.105
	Sorghum	0.0042	1.46
	Wheat	0.0117	0.302
West Asia / North Africa (WANA)	Barley	0.0085	0.141
	Maize	0.0651	1.336
	Seed cotton	0.0098	0.907
	Sorghum	0.0101	0.42
	Sunflower seed	0.0068	0.312
	Wheat	0.0061	0.249
South Asia	Maize	0.026	1.17
	Millet	0.0046	0.243
	Rapeseed	0.0034	0.277
	Rice	0.0092	0.328

	Sorghum	0.0023	0.18
	Soybeans	0.0249	0.785
	Wheat	0.0027	0.379
South-East Asia	Maize	0.0658	11.751
	Rice	0.0072	2.263
China	Maize	0.0587	0.581
	Millet	0.0245	0.343
	Rapeseed	0.012	0.759
	Rice	0.0688	2.782
	Seed cotton	0.0655	0.935
	Soybeans	0.0076	0.487
	Wheat	0.0277	0.674
USSR	Maize	0.0587	0.581
	Millet	0.0245	0.343
	Rapeseed	0.012	0.759
	Rice	0.0688	2.782
	Seed cotton	0.0655	0.935
	Soybeans	0.0076	0.487
	Wheat	0.0277	0.674
EU15	Barley	0.0245	0.221
	Maize	0.0766	0.292
	Oats	0.0432	0.462
	Rapeseed	0.0653	0.959
	Rye	0.0536	0.249
	Sunflower seed	0.2708	8.991
	Wheat	0.067	0.447
Eastern Europe	Barley	0.1542	0.963
	Maize	0.6434	0.548
	Oats	0.0559	0.668
	Rapeseed	0.0447	0.308
	Rye	0.0453	0.444
	Sunflower seed	0.0357	0.648
	Wheat	0.3154	1.285

Figure 3 suggests three different behaviors: for most of the crops, the ratio settles between 0.2 and 0.4 for large k, indicating that the random walk component explains only between 20% and 40% of the total variation; for some crops (cotton in West Asia/North Africa, millet and cotton in Sub Saharan Africa, cotton and soybeans in South Asia, cotton in China, maize and sunflower seeds in USSR), the variance reaches a plateau at the variance ratio closer to unity, showing evidence for a stronger random walk component; finally, yields for rice and soybean in LAM, maize in West Asia/North Africa, sorghum in Sub Saharan Africa, maize and rice in South East Asia, maize in South Asia, sunflower seeds in EU15, rice in China, barley and wheat in Eastern Europe, appear to be mean averting, in the sense that they exhibit more shocks persistence than a random walk. At lag 16 most of the variance ratios do settle down; the ones that do not, exhibit an explosive behavior that would not be likely to be moderate at larger lags anyway. Moreover, the larger the lags, the smaller the size of the sample we analyze: with a lag 16, the sample is already reduced to 33 observations. Hence, results obtained with large lags may be doubtful, due

to potential distortions arising in small samples. Beyond lags 16, it might be reasonable to assume that temporary shocks have been sufficiently dampened and that resilient shocks operate through the random walk component. Therefore, the figures reported in **Table 5** at lag 16 should be an approximation of the size of this component. They suggest that there are substantial differences across regions and crops with a variance ratio varying between 0.117 and 11.751.

3.2 Forecast Intervals

The persistency of shocks that we measured in the previous section, is an indicator to what extent crop yields are predictable in the long run. A low variance ratio at lag 16 means that future crop yields could reasonably be extrapolated from past data, since shocks do not affect substantially the long run behavior of the time series. In contrast, a value larger than unity is the sign that a process is highly unpredictable, as future values are mostly built from current shocks that are, in essence, not foreseeable. To illustrate, we show in this section, how the random walk component affects the quality of projections by 2025.

As in section 3.1, we use a decomposition of crop yields into a stationary component and a random walk and look at the width of forecast intervals around projections by 2025. We first consider forecasts that assume no growth from 2009 onward. To derive the size of a 95% forecast intervals, we consider only the variance in the data explained by the random walk component. Specifically, we look at crop yields once purged of temporary fluctuations, and then we compute a forecast interval $[\bar{Y}-1.96\,\bar{\sigma}_{16}\sqrt{17};\bar{Y}+1.96\,\bar{\sigma}_{16}\sqrt{17}]$, where $\bar{Y}$ is the projected crop yield by 2025 and $\bar{\sigma}_{16}$ are from the second column of Table 5. The rationale behind this construction is that $\bar{\sigma}_{16}$ is a consistent estimator of the variance of the random walk component. Although this approach underestimates the true size of the interval, as it discards the variability implied by the stationary component, it has the merit of simplicity and it provides a reasonable idea of how predictable or not crop yields are. The column for Model A of **Table 6** shows the projected value of crop yields by 2025, given our no growth assumption for the average crop yield over the last five years of the time series. The last two columns display the lower and upper bound of the associated forecast interval. On average, the uncertainties on 2025 projections are about $\pm 70\%$ of the forecast. This average hides diverse behaviors among crop yields: rice in Sub Saharan Africa, cotton in West Asia/North Africa, rice and wheat in South Asia, rice in South East Asia, maize in EU15 have less than $\pm 25\%$ of uncertainties on their predicted yields; for soybeans in LAM, sorghum in West Asia/North Africa, soybeans in South Asia, sunflower seeds in EU15, maize and wheat in Eastern Europe, these uncertainties are higher than $\pm 100\%$.

The conclusion is that the historical data imply large forecast intervals. From this foundation and in light of concerns about the slowing growth of yields, we next assess how different assumptions about the functional form of yield growth affect 2025 projections. In addition to our previous projections, two additional projections are considered: we assume that crop yields grow from 2009 to 2025 at a constant rate equal to the average growth rate from 1961 to 2009 in Model B and from 1990 to 2009 in Model C. Model A is an extreme representation of a plateau; Model B is an optimistic perspective that considers sustainable the growth observed in the last fifty years; Model (C) reflects a more recent trend in the growth rate. It can be noticed in Table 6, that Model C is not always more pessimistic than Model B. The striking result is that for 40 crops, projections from Model B (36 crops for projections from Model C) lie within the forecast intervals associated with our projections without growth. This means that for almost two thirds of the crops, we cannot statistically distinguish the projections from a model without growth and the ones from a model with a constant growth rate. Here the random walk extracted from historical data dominates the uncertainties related to the choice of forecast model.

Hence, a slowdown today is not a strong indication of a continued plateau in the future as the uncertainty of crop yields, embedded in the random walk, prevents us from pursuing such an extrapolation. As argued in section 2.3, one of the reasons for this difficulty is that historical data exhibit structural breaks that we cannot rule out in the future. For example, **Figure 4** looks back at the example of rice in China and sheds new light by adding a 95% forecast interval that take into account a random shift in the long run trend. These bands are constructed by using our previous methodology but with two differences: we use only data from 1961 to 1995 and we forecast rice yields in 2009, based on a linear projection. First, this forecast interval performs better than the one provided by a purely deterministic approach. Unlike the latter, the former is wide enough to encompass the actual variations of rice yields between 1996 and 2009. Secondly, despite this width, rice yields cross nearly the lower confidence bound at the end of the period. Random trend shifts do not allow for ruling out completely the possibility for yields to catch up with the linear projections level. But the persistency of the proximity between actual yields and lower confidence bands may indicate that, in the last 14 years, the productivity of rice land is driven by patterns that are not captured in the historical data and that are not taken into account by the amplitude of the past trend shifts. Thirdly, both projections implied by a model without growth and by a model with a constant growth rate based on 1961-1995 data lies within the 95% forecast interval around a linear projection. In comparison, the slowdown pattern is not clear for wheat in India, since the 1996-2009 observations do not escape the 95% forecast intervals. Sharp shifts in trend may be still expected to allow wheat yields to catch up with linear extrapolations.

Table 6. Projections of crop yields by 2025. Model (A) proposes the average from 2005 to 2009 as forecast by 2025; Model (B) assumes a constant growth rate equal to the average growth rate from 1961 to 2009; Model (C) assumes a constant growth rate equal to the average growth rate from 1990 to 2009.

Regions	Crops	Forecasts by 2025			Forecast intervals	
		Model A	Model B	Model C	Lower bound	Upper bound
USA	Barley	3.52	5.13	5.20	2.00	5.03
	Maize	9.69	16.32	14.86	5.27	14.12
	Oats	2.26	2.97	2.96	1.14	3.39
	Seed cotton	2.26	3.04	2.84	1.19	3.33
	Sorghum	4.20	5.93	6.30	1.59	6.82
	Soybeans	2.84	3.82	4.01	1.74	3.94
	Wheat	2.84	3.73	3.99	1.94	3.74
Latin America	Maize	3.90	5.93	6.91	1.91	5.89
	Rice	4.47	6.52	7.92	1.33	7.62
	Seed cotton	1.75	2.47	2.20	0.07	3.44
	Sorghum	3.09	4.34	4.03	0.57	5.62
	Soybeans	2.59	4.53	6.26	-0.02	5.21
	Wheat	2.39	3.32	2.77	1.02	3.76
Sub Saharan Africa	Maize	1.60	2.37	2.04	0.53	2.68
	Millet	0.90	1.15	1.15	0.41	1.38
	Rice	1.74	2.02	1.88	1.34	2.13
	Seed Cotton	0.88	1.32	1.01	0.54	1.23
	Sorghum	1.00	1.20	1.26	0.48	1.53
	Wheat	1.99	3.33	3.29	1.11	2.86
Western Asia / North Africa (WANA)	Barley	1.40	2.56	2.68	0.66	2.15
	Maize	5.65	9.52	8.73	3.59	7.71
	Seed cotton	3.14	4.75	4.56	2.34	3.94
	Sorghum	0.79	0.94	1.29	-0.02	1.61
	Sunflower seed	1.54	2.08	1.76	0.88	2.21
	Wheat	2.30	3.69	3.26	1.67	2.93
South Asia	Maize	2.37	3.42	3.47	1.07	3.67
	Millet	0.91	1.57	1.54	0.36	1.46
	Rapeseed	1.10	1.87	1.66	0.63	1.57
	Rice	3.30	4.44	4.02	2.52	4.07
	Sorghum	0.86	1.31	1.13	0.47	1.25
	Soybeans	1.08	1.86	1.82	-0.20	2.35
	Wheat	2.52	3.86	3.34	2.10	2.94
South-East Asia	Maize	3.35	5.64	6.27	1.27	5.42
	Rice	3.94	5.48	5.06	3.25	4.63
China	Maize	5.30	9.48	7.34	3.34	7.26
	Millet	1.93	2.76	2.65	0.66	3.19
	Rapeseed	1.84	4.22	3.05	0.95	2.72

	Rice	6.40	9.76	7.49	4.28	8.52
	Seed cotton	3.68	7.97	6.87	1.61	5.75
	Soybeans	1.67	2.58	2.22	0.96	2.37
	Wheat	4.54	10.24	6.76	3.19	5.88
USSR	Barley	2.05	4.30	3.42	1.18	2.91
	Maize	3.89	3.89	5.60	0.80	6.98
	Millet	1.14	1.14	3.64	0.22	2.07
	Oats	1.67	1.67	2.51	0.86	2.49
	Rye	1.96	1.96	2.90	1.01	2.91
	Sunflower seed	1.18	1.18	1.19	0.16	2.20
	Wheat	2.08	2.08	3.03	1.05	3.11
EU15	Barley	4.24	5.51	5.51	2.98	5.51
	Maize	9.10	14.12	14.12	6.87	11.34
	Oats	2.65	3.17	3.17	0.97	4.33
	Rapeseed	3.45	4.62	4.62	1.39	5.52
	Rye	4.03	6.28	6.28	2.15	5.90
	Sunflower seed	1.76	1.70	1.70	-2.45	5.96
	Wheat	5.44	8.32	8.32	3.35	7.53
Eastern Europe	Barley	3.22	4.25	3.09	0.04	6.39
	Maize	3.32	6.10	9.74	-3.16	9.81
	Oats	2.14	2.63	2.81	0.23	4.05
	Rapeseed	2.63	4.37	5.40	0.92	4.34
	Rye	2.50	3.41	3.40	0.78	4.22
	Sunflower seed	1.60	2.19	2.38	0.07	3.13
	Wheat	3.15	4.45	4.56	-1.38	7.69

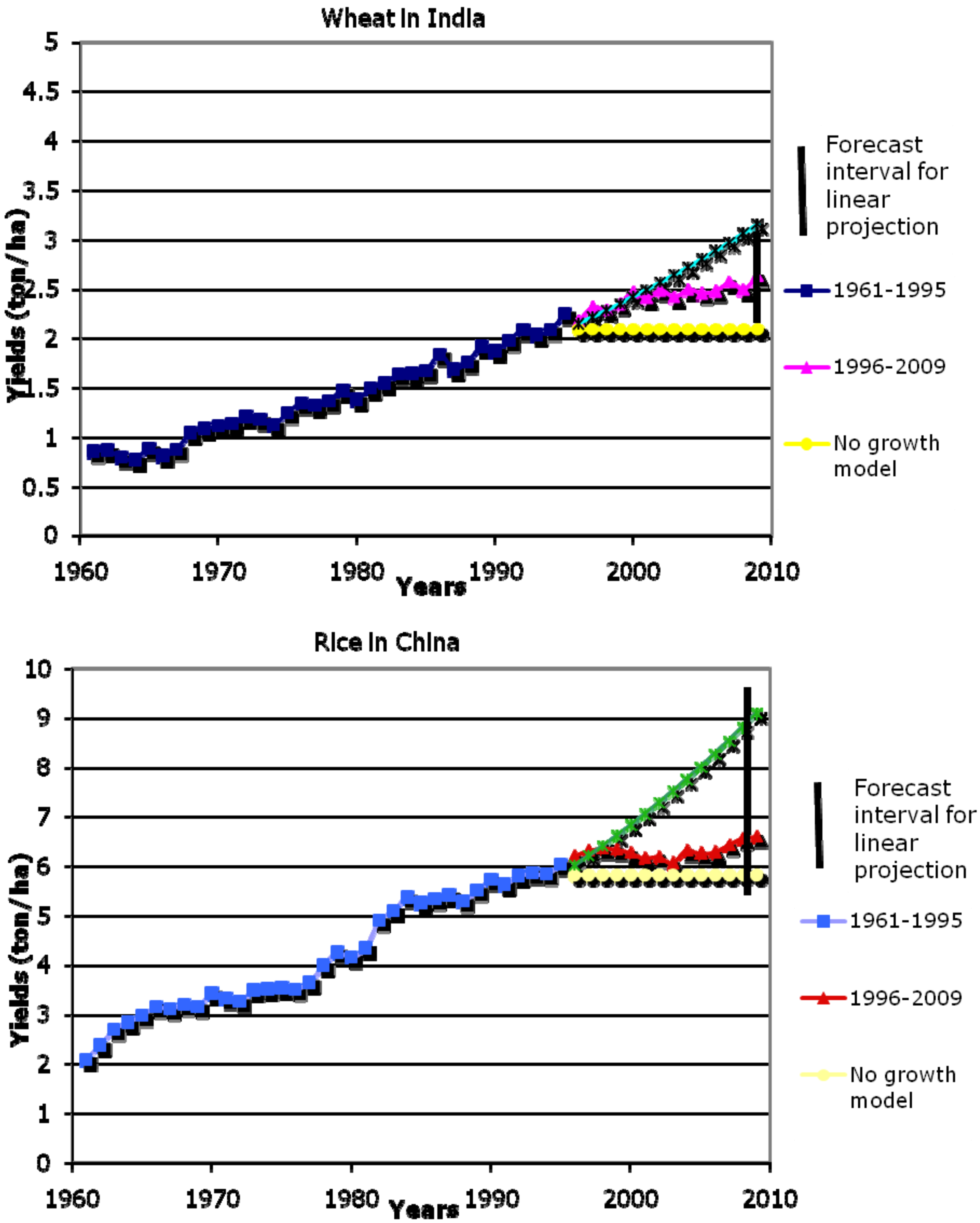


Figure 4. Rice yields in China (lower panel) and wheat yields in India (upper panel). The solid vertical line represents the width of 95% confidence forecast for 2009 based on linear projections from 1961-1995. The model without growth is based on the 1991-1995 yield average; the model with constant growth rate is based on the average growth rate from 1961 to 1995.

4. CONCLUSION

Concerns about a yield plateau and a failure of yield growth to keep up with population growth and other demands have been a recurring issue. In recent times, these concerns arose in the mid-1990s after yield growth rates appeared to slow in the 1980s. These concerns led to fairly pessimistic projections based on a variety of approaches, ranging from expert judgment to regression models. In this paper, we re-evaluate crop yields with a new approach. We do not focus on the determination of the trend that best fits the time series, but instead we wonder how useful such trends are in order to forecast future yields. The main result is that trending these time series may be a misleading technique, since we show that among all the crops we investigated, at least two thirds behave as a unit root. Furthermore, one likely explanation for these unit roots is the failure to account for structural breaks that characterize yields in the last fifty years. What we can learn from past data is that long run behavior of crop yields is shaped by either a multitude of small shocks or by a few structural changes. Given the uncertainty entailed with both types of fluctuations, it seems reasonable to add a random walk component into our representation of crop yields. We introduce a measure of the resiliency of shocks and show that very few crop yields are mean reverting. We also construct forecast intervals to account for the presence of a random walk component into the time series. As a result, for almost two thirds of the crops, historical data do not provide us with any reason to favor a model without growth over a model with a constant growth rate.

Our findings shed new light on the issue of possible slowdown in agricultural yields. Conclusions about a current plateau effect may be reversed in the future by shocks that will affect permanently the long run behavior of yields. In other words, more than future trends, past data suggest that we should use extrapolations with very great caution, given the inherent randomness of crop yields.

The addition of these uncertainties allows us to reconsider the question of whether there is a plateau in yield growth. For most of the crops, forecasts based on a constant growth rate or no annual increment are not significantly different given the uncertainties in these forecasts. Data for the period 1961-2009 do not provide strong support for choosing one model over another. There is no statistical evidence to distinguish the forecasts provided by a model without growth or by a model with constant growth rate, because of our inability to rule out a structural shift from one path of agriculture development to another. The general conclusion from this time series analysis of yields is that casual observation or simple regression can lead to overconfidence in projections because of the failure to consider the likelihood of structural breaks.

Two possible avenues can be suggested to pursue this analysis. The first is to use a Bayesian estimation and prediction procedure, as in Pesaran *et al*. (2006), to allow for possible future breaks over the forecast time horizon, based on the distribution of historical breaks. The second is to provide a causal model of yield growth and thereby explain structural breaks as a function of economic conditions or other factors. The difficulty is that we have a relatively short time series and many potential explanatory variables. Moreover, the lag between the events that might explain changes in yield and the observation of change is likely long and variable. We have taken a first step by simply investigating the time series behavior of yields. The very long time series that exists for the U.S. indicates a very different pattern of yield growth (*i.e.* very little if any) in the period of about 1930-40, followed by rapid growth. The period of rapid growth coincides and is likely explained by advances in plant breeding and the widespread availability of fertilizers and other chemicals. However we mostly have good data only for the period spanning 1960 to the present.

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APPENDIX A

Countries Included in the Analysis

European Union (EU 15): Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

United States

Eastern Europe: Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Hungary, Macedonia, Poland, Romania, Slovakia, Slovenia, and Yugoslavia.

USSR: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russian Federation Tajikistan, Turkmenistan, Uzbekistan and Ukraine

Central and Latin America: Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent, Suriname, Trinidad and Tobago, Uruguay, and Venezuela.

South Asia: Afghanistan, Bangladesh, India, Maldives, Nepal, Pakistan and Sri Lanka.

Southeast Asia: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand and Viet Nam.

China

Sub-Saharan Africa: Angola, Botswana, Benin, Burkina Faso, Burundi, Cameroon, Chad, Central African Republic, Comoros Island, Congo Democratic Republic, Congo Republic, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

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