Beta-Convergence of Crop Yield across Countries: A Modern Panel Data Analysis

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Abstract

This study examines the state of beta-convergence in three major crop yields l in the world namely rice, wheat and maize in terms of consumption and production for the period 1961 to 2016 using modern panel data approach concerning beta convergence. The study has applied modern panel data analysis including panel unit root tests on demeaned series and staticpanel regression. The conventional sigma convergence indicators namely, standard deviation and coefficient of variation show convergence for wheat for the period of1986 to 2016 showing a downward trend and thus indicating sigma-convergence, But the results of panel unit root and panel regression establish beta convergence for all the crop yield. This result also shows that economies converge to different steady states.

Key words: *rice; wheat; maize; modern time seres; multiple structural break*

1. Introduction

Over the last fifty years global population has increased at a lower rate compared to the growth of major cereals production (2.1% on an average) (Beddow et al., 2014). This growth in cereal production has been possible due to unprecedented growth of crop yield (Pandey et al., 2012). This has been highly possible due to technological change and large investment in research & development in agriculture (Alston et al., 2013)). But, this duration of cereal abundance at the global level may face sustainability problem from ecological perspective including extreme weather events like tropical cyclones (Beer, 2018). In such studies, the ultimate impacts of extreme weather events through complex link of atmosphere and food security has been presented. In view of rising population combined with increased income, non-food demand for cereals such as bio fuels demonstrate a rising demand in a significant way for cereals. Therefore, there are obvious issues to understand how and where this additional burden of cereals demand can be met in the presence of several natural (land and water) and environmental constraint (climate change). There are some works where emphasis has been given to meeting yield gap to resolve food scarcity issue. However, in our approach we intend to find out the state of convergence of major crop yield and thus focus on the possibilities of increasing yield rates of the low yield countries through technological and innovative measures so that the food security problem can be resolved on earth. Again, agriculture is still the mainstay of economic life for millions of rural population leaving in major parts of the poor countries. The World Bamk in its report published in 2014 stated that overall 29.5% of global employment is contributed by agriculture, where this contribution goes up to 68.5% in low income countries. Agriculture growth has been found to be pro-poor as per the World Bank report, 2008. The report also mentioned that in comparison to growth in other sectors of the economy such as service and/or manufacturing, agriculture more effectively reduces poverty. It essentially leads to understanding the issue of reducing cross country differences in aggregate productivity by reducing agricultural productivity. So policies towards reducing agricultural productivity differences can be highly effective in reducing regional inequality across countries. Considering the combined harvest of around 2.5 billion tonnes, rice, wheat and maize are the world's most widely cultivated crops and the foundation of world food security. In human diet these three crops contribute around 42% of the world's calorie supply. The contribution to protein supply is the second largest (around 37%) after Fish and livestock products (FAO, 2016). Geographically, except Latin America these cereals provide with more protein than meat, fish, milk and eggs combined. Historically, agriculture has played significant role, particularly these cereals in building and collapsing of several great civilizations of the humanity. In modern time to meet the growing challenges of ever-increasing population, high increases in productivity were achieved through the use of heavy farm machinery powered by fossil fuel, along with high-yielding crop varieties, irrigation and agrochemicals(FAO, 2011).As agriculture has played a pivotal role in the development of human history being the major economic activity before the industrial revolution (See for details, Yuan et al.(2021)), its significant role in alleviating rural poverty cannot also be ignored. (Thirtle et al. 2003; World Bank 2007; Chen and Gong 2021). Many scholars believe that higher agricultural productivity can enhance economic development through human capital accumulation, reallocation of labor forces and increasing comparative advantage in an open economy set up. Thus, understanding the state of dynamic path of yield-gap across the countries is very important considering the key role of agriculture in overall economic development.

So, considering the importance of cross-country agricultural productivity or yield differences in terms of food security, poverty reduction and removal of overall inequality, we attempt to understand the state of cross-country crop-yield differences over time.

Literature Review

Empirical Analysis of agricultural productivity growthhas considered two paths: one on convergenceanalysis and the other on frontier productivity approach based on data stochastic frontier analysis (SFA) and data envelopment analysis (DEA) (See, Ruttan 2002; Coelli and Rao 2005)). We follow the convergence analysis based on time series and panel data approach discussed below.

The literature on convergence empirics is very comprehensive (See for details Quah, 1996)). Intuitively, convergence in a multi-object context suggests that the probability density of an indicator y describing objects tends to the delta function over time ($\delta(y - y^*) = 0$ for all y except for $y = y^*$, where ($\delta(y - y^*)$ $= \infty$, and $\int_{-\infty}^{\infty} \delta(y - y^*)dy = 1$; y^* stands for a uniform long-run value of y_is). The simplest testable version may be checking whether a statistic of the distribution that measures dispersion (standard deviation, coefficient of variation, Gini index, Theil index, etc.) diminishes over time. Such an approach had been known long before Barro and Sala-i-Martin, who gave it name "sigma-convergence" in the context of economic growth.

Following these seminal contributions of Barro (1990) and Mankiew etal.(1992), a large number of empirical cross-country analysis of growth and development have taken place. The standard cross-country growth regression framework and its panel cousin have been used in the econometric literature although the 'growth regression approach' came under attack from several corners but it still has life in it.

There have been series of works in understanding convergence in income, crop yield, industrial output, social outcome etc. in several country level and cross- country level studies. These studies are useful in understanding the state of dynamics of regional-gap across regions and countries which is very important for policy prescription and decision making at appropriate level in the long –run. However, studies relating to convergence considering very large set of data at the world level for agricultural crop yield are very few.

It may be relevant to mention in this context that in a comprehensive study, Mukhopadhyay (2021) observed 'sigma convergence' while revealing convergence of crop yield between countries of the world covering 86 to 130 countries and 56 years for three major crop in the world namely, rice, wheat and maize. The study found that the rice and wheat yield gaps remain on average constant during 56 years, and the maize yield gaps tend to increase across countries in the world.

There exists another version of convergence in the literature called 'beta convergence' which statistically examines whether the partial correlation between income over time and its value is negative (Yong et al., 2008). In other words, the opinion that a negative correlation between initial levels of an indicator and its growths evidences convergence ("regression towards the mean") counts almost a century and half. It is also known as Galton's fallacy. Again, Barro and Sala-i-Martin revitalized it under the name "beta-convergence." The literature also states that if 'sigma convergence' hold then 'beta convergence' adds nothing. Since in our study stated earlier we have not obtained any 'sigma convergence', we now like to examine the state of 'beta convergence' in the present study, by following a panel data approach including a series of panel unit root tests on demeaned series for the three major crops in the world in terms of production and consumption covering the period 1961 to 2016 using the crop yield data of the Food and Agricultural Organization (FAO). In addition, although no significant 'sigma convergence' was achieved in Mukhopadhyay(2021), we now examine the state structural break by following multiple structural break test of Bai-Perron in the standard indicators of 'sigma convergence' namely, standard deviation, coefficient of variation and Gini-coefficient.This study will enable us to understand whether countries have achieved the steady state in yield growth over the long run.The rest of the sections indicate data and methodology in section 2, empirical results in section 3 and summary and conclusions in section4.

2. Data and Econometric Methodology

In this section, the data sources and the methodological issues are elaborated. As stated earlier, this study examines the state of beta convergence on a long time series data of 56 years from 1961 to 2016 for three major crops using panel data approach at the global level consisting of the countries having continuous available data for the study period. We first define the study variable i.e., crop yield for each crop. The crop yield has been defined as the output per unit of harvested land here, hectogram per hectare of land area. The data are collected from the website of the Food & Agricultural Organization (FAO) website (http://www.fao.org/faostat/en/#data/QC). This study uses rice yield data for 99 countries, wheat yield data for 86 countries and maize yield data 130 countries.

The rice data include the countries namely Afghanistan, Algeria, Angola, Argentina, Australia, Bangladesh, Belize, Benin, Bhutan, Bolivia, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Chile, China, China (mainland), China(Taiwan Province), Colombia, Comoros, Congo, Costa Rica, CÃ´te d'Ivoire, Cuba, Democratic People's Republic of Korea, Democratic Republic of the Congo, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, France, French Guiana, Gabon, Gambia, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, Iraq, Italy, Jamaica, Japan, Kenya, Lao People's Democratic Republic, Liberia, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mexico, Morocco, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Portugal, Republic of Korea, Romania, Senegal, Sierra Leone, South Africa, Spain, Sri Lanka, Eswatini, Thailand, Timor-Leste, Togo, Trinidad and Tobago, Turkey, Uganda, Tanzania, USA, Uruguay, Venezuela, Vietnam and Zimbabwe

The wheat yield data include the countries namely, Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria, Bangladesh, Bhutan, Bolivia, Brazil, Bulgaria, Burundi, Canada, Chad, Chile, China, China (mainland), China(Taiwan Province), Colombia, Cyprus, Democratic People's Republic of Korea, Democratic Republic of the Congo, Denmark, Ecuador, Egypt, Finland, France, Germany, Greece, Guatemala, Honduras, Hungary, India, Iran, Iraq, Ireland, Israel, Italy, Japan, Jordan, Kenya, Lebanon, Lesotho, Libya, Malawi, Mali, Malta, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Niger, Nigeria, Norway, Oman, Pakistan, Paraguay, Peru, Poland, Portugal, Republic of Korea, Romania, Rwanda, Saudi Arabia, South Africa, Spain, Sweden, Switzerland, Syrian Arab Republic, Tunisia, Turkey, United Kingdom, Tanzania, USA, Uruguay, Venezuela, Yemen, Zambia and Zimbabwe.

The Maize yield data include the countries namely, Afghanistan, Albania, Algeria, Angola, Argentina, Australia, Austria, Bahamas, Bangladesh, Barbados, Belize, Benin, Bhutan, Bolivia, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cabo Verde, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, China (mainland), China(Taiwan Province), Colombia, Comoros, Congo, Costa Rica, CÃ´te d'Ivoire, Cuba, Democratic People's Republic of Korea, Democratic Republic of the Congo, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, France, Gabon, Gambia, Germany, Ghana, Greece, Grenada, Guam, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Hungary, India, Indonesia, Iran, Iraq, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Lao People's Democratic Republic, Lebanon, Lesotho, Libya, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Caledonia, New Zealand, Nicaragua, Niger, Nigeria, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Republic of Korea, RÃ©union, Romania, Rwanda, Saint Vincent and the Grenadines, Sao Tome and Principe, Saudi Arabia, Senegal, Sierra Leone, Somalia, South Africa, Spain, Sri Lanka, Suriname, Eswatini, Switzerland, Syrian Arab Republic, Timor-Leste, Togo, Trinidad and Tobago, Turkey, Uganda, Tanzania, USA, Uruguay, Vanuatu, Venezuela, Vietnam, Yemen, Zambia and Zimbabwe.

The countries from the Former USSR have not been taken along with some countries where there was no scope for the continuous data of the study period.

Econometric Methodology

The growth empirics highlighted on the convergence hypothesis based on two concepts, namely, sigma convergence and beta-convergence. The sigma convergence occurs when any indicator (standard deviation/ coefficient of variation/ Gini-coefficient/ Theil index) of crop yield across countries declines over time. But since our analysis uses a long series of 56 years, it would highly be worthwhile and noteworthy to examine structural break in these dispersion series. We have followed the standard methodology of structural break due to Bai-Perron multiple break point tests (Bai-Perron, 1998, 2001) to see whether convergence has been achieved after technological change in agriculture worldwide since mid-1980s.

The beta-convergence occurs here when low-crop yield country tends to 'catch up' the high crop-yield country yield.

Researchershave argued that beta convergence is necessary but not sufficient for sigma convergence (Sala-i-Martin, 1996); Paas and Schlitte, 2006). Furthermore, Monfort (2008, p.3), points out that "either because economies can converge towards one another but random shocks push them apart or because, in the case of conditional Beta-convergence, economies can converge towards different steady states."

This study examines unconditional or absolute beta-convergence implying structurally similar cross section units (countries, in this study). For the purpose of testing unconditional beta convergence, we now discuss panel unit root tests. Considering y_{kit} to be ln(Y_{kit}) where Y_{kit} is the crop yield of the k th crop(k=1,2,3 for rice, wheat and maize , respectively) in the i th country at tth time point(i.e., year), the panel unit root tests on the demeaned series($\tilde{y}_{kit} = y_{kit} - \bar{y}_{kt}$) of y_{kit} ,where $\bar{y}_{kt} = \frac{1}{n}\sum_{i=1}^{n} y_{kit}$, proposed by Levin *et al*. (2002) , Im*et al*. (2003), and Maddala and Wu (1999) , have been considered (see, Mukhopadhyay and Sarkar , 2015) for a brief description of these tests).

We have followed the static panel regression approach for testing conditional beta convergence in the kth (k=1,2,3) crop yield as follows:

$$\ln(\frac{Y_{kit}}{Y_{ki,t=1}}) = \mu_{ki} + \beta \ln Y_{ki,t-1} + +\varepsilon_{kit}, k = 1,2,3 \qquad (1)$$

where kth crop yield in the country i at time t is represented by Y_{kit} .

The negative statistical significant value of β leads to holding of beta convergence.

The standard testing procudre of Wu-Hausman test for judging the suitability of fixed effect and random effect model are also applied. The estimation results take care of heteroscedasticity by following White's test.

3. Results and Discussion

Now, we report the results of structural break tests on the above estimated regressions in Table 1by following Bai-Perron multiple structural break test . The multiple structural break test results based on the $UD_{\max}$ and $WD_{\max}$ show that the test statistics are significant at 5% level of significance implying presence of structural break in the standard deviation and coefficient variation of rice and wheat yield . But the multiple break test result shows no break for maize series for both standard deviation and coefficient of variation. There are two break corresponding to rice yield series and one break in wheat series aaaaaas far as the standard deviation(SD) and coefficient variations(CV) are concerned.

The regression results are presented in table 2 below after the determination of structural break in table 1. The regression results clearly indicate that both the standard deviation and coefficient of variations for wheat series move downwardly during 1986 to 2016 implying presence of significant 'sigma convergence' for the wheat series. No such convergence is achieved for rice series.

Table 1: Results of UD_{max}andWD_{max}Tests

Series	UD_{max}statistic value		WD_{max}statistic value	
	SD	CV	SD	CV
Rice yield	31.804*	31.947*	54.285*	54.956*
Wheat yield	52.824*	43.817*	52.82*	43.817*
Maize yield	8.415	8.348	10.917	10.910

*Note: * shows significant value at 5% level.*

Table 2: Results of Regression on linear trend

Time period (Break year)	Rice Yield Standard Deviation(Cross sectional) Adj. R^2=0.794			
	Regressors	Value of coeff.	*Value of t*-statistic	*p*-value
1961-1985(1986)	Constant	0.552	68.763	0.000
	Linear trend	0.002	3.237	0.002
1986-1994(1995)	Constant	0.402	5.609	0.000
	Linear trend	0.006	2.289	0.027
1995-2008(2009)	Constant	0.198	3.843	0.000
	Linear trend	0.010	8.273	0.000
2009-2016	Constant	0.319	2.108	0.040
	Linear trend	0.006	2.139	0.038
Time period (Break year)	Rice Yield Coefficient of variation(Cross sectional) Adj. R^2=0.629			
	Regressors	Value of coeff.	*Value of t*-statistic	*p*-value
1961-1985(1986)	Constant	0.056	62.198	0.0000
	Linear trend	0.0001	1.753	0.086
1986-2008(2009)	Constant	0.038	15.401	0.000
	Linear trend	0.0006	8.374	0.000
2009-2016	Constant	0.033	1.934	0.059
	Linear trend	0.0006	1.675	0.100
Time period (Break year)	Wheat Yield Standard deviation(Cross sectional) Adj. R^2=0.595			
	Regressors	Value of coeff.	*Value of t*-statistic	*p*-value
1961-1985(1986)	Constant	0.570	44.549	0.000
	Linear trend	0.007	7.543	0.000
1986-2016	Constant	0.737	29.523	0.000
	Linear trend	-0.001	-1.835	0.072
Time period (Break year)	Wheat Yield Coefficient of variation(Cross sectional) Adj. R^2=0.440			
	Regressors	Value of coeff.	*Value of t*-statistic	*p*-value
1961-1985(1986)	Constant	0.061	45.367	0.000
	Linear trend	0.0006	5.973	0.000
1986-2016	Constant	0.077	29.135	0.000
	Linear trend	-0.0002	-2.979	0.004

Notes: Trimming parameter value is 0.15.

It may be pointed out at this stage that under beta convergence low crop yield countries tend to grow faster than high crop yield countries. The panel unit root results are presented in table 3. In the panel unit root test, the null hypothesis assumes unit root i.e., nonstationarity of the panel. The test statistic values of the LLC (due to Levin et al. (2002)) test statistic for crop yield of rice, wheat and maize are -7.939, -18.295 and -7.947, respectively, which are highly significant at 1% level of significance, and hence the null of nonstationarity is rejected in favour of stationarity in the demeaned series for all these three crops. Thus it is concluded that based on the results of this test, crop yield shows convergence across the globe for all the three principal cereal crops. The same conclusion is also drawn from the IPS(due to Im et al. (2003)) test, the Fisher's chi-square (ADF version), and Fisher's chi-square(PP version) tests since values of all these test statistics are highly significant. In all these tests we have used Schwartz's Bayesian information criterion (BIC) for lag selection. Thus all the panel unit root tests infer stationarity in the demeaned series of the logarithm of crop yield of rice, wheat and maize. Hence we conclude that beta-convergence in cereal yield holds across the globe.

Table 3: Panel unit root test results on demeaned series

Series: Rice Yield (99 Countries; Time 1961-2016)		
Panel unit root test	Test statistic value	*p*- value
Levin-Lin-Chu unit-root test (LLC)	-7.939	0.000
Im-Pesaran-Shin unit-root test (IPS)	-11.198	0.000
Fisher-Chi-square test (ADF)	573.787	0.000
Fisher-Chi-square test (PP)	652.348	0.000
Series: Wheat Yield (86 Countries; Time 1961-2016)		
Panel unit root test	Test statistic value	*p*- value
Levin-Lin-Chu unit-root test (LLC)	-18.295	0.000
Im-Pesaran-Shin unit-root test (IPS)	-32.088	0.000
Fisher-Chi-square test (ADF)	1273.89	0.000
Fisher-Chi-square test (PP)	1801.72	0.000
Series: Maize Yield (130 Countries; Time 1961-2016)		
Panel unit root test	Test statistic value	*p*- value
Levin-Lin-Chu unit-root test (LLC)	-7.947	0.000
Im-Pesaran-Shin unit-root test (IPS)	-12.894	0.000
Fisher-Chi-square test (ADF)	835.180	0.000
Fisher-Chi-square test (PP)	921.652	0.000

The beta convergence results are shown in table 4. The absolute beta convergence uses the regression based on equation(1). To be specific, for the purpose of testing for beta-convergence, where the logarithm of the initial yield level has been taken as the regressor. In Table 4, we first present the panel regression results for rice yield. In this regression the beta coefficient is found to be highly significant and negative (-15.071), implying thereby an inverse relationship in yield growth and its initial level. We also obtained analogous results for wheat and maize yield. The corresponding test statistic values for these two yield crops are -14.555 and -14.172 These findings thus confirm beta convergence. We have also carried out the Hausman specification test for deciding between a fixed effect model and random effect model in the static panel data analysis for each crop yield. We find from Table 5 that the chi-square test statistic values for these three equations are 141.057, 131.685 and 40.262 which are highly significant at 1% level of significance. This implies the rejection of the random effect model in favour of the fixed effect model for each series. Accordingly, the fixed effect model has been used. In order to take care of the possible cross-sectional heterogeneity, we have used White's heteroscedasticity consistent variances and covariances in estimation.

Table 4 : Results on absolute beta convergence

Dependent Variable: $\ln Y_{1it} - \ln Y_{1i,t-1}$				
Variable	Coefficient	Standard error	*t*-statistic	*p*-value
Constant	2.102	0.139	15.09	0.0000
$\ln Y_{1i,t-1}$	-0.206	0.014	-15.071	0.0000
Hasusman Test statistic= 141.057#, Adj. R^2=0.098				
Dependent Variable: $\ln Y_{2it} - \ln Y_{2i,t-1}$				
Constant	3.043	0.208	14.605	0.0000
$\ln Y_{2i,t-1}$	-0.309	0.021	-14.555	0.0000
Hasusman Test statistic= 131.685#, Adj. R^2=0.165				
Dependent Variable: $\ln Y_{3it} - \ln Y_{3i,t-1}$				
Variable	Coefficient	Standard error	*t*-statistic	*p*-value
Constant	2.070	0.146	14.217	0.0000
$\ln Y_{3i,t-1}$	-0.209	0.015	-14.172	0.0000
Hasusman Test statistic= 40.262#, Adj. R^2=0.094				

 # denotes the test statistic is significant at 1% level of significance.

4. Summary and Conclusions

We have examined the beta convergence and structural break in sigma convergence in the crop yield of three important cereals in the world namely rice, wheat, maize for the period 1961 to 2016 across the globe. The modern time series approach including multiple structural break has been followed.

The panel unit root tests strongly demonstrate conditional beta-convergence in the series.

The static panel regression presents an inverse relationship between growth rate and lagged dependent variable implying a conditional beta-convergence in the series.

Finally, this empirical evidence on convergence in crop yield of major cereals demonstrates that these countries converge to their own steady state equilibrium although no negative trend is profoundly present in terms of declining yield-gap across the countries except wheat yield which experiences a downward trend after 1986. Further, analysis of club convergence is necessary for better understanding of this very important issue in world agriculture. It may be pointed out that it is possible to reduce rural poverty in the developing world by reducing productivity gaps in major cereal yield.

Stagnating or declining crop yields along with environmental degradation and climate change are threatening global food security, in particular, in developing regions. But at the same time protecting natural resources are utmost important for sustainable development. Therefore, sustainable crop intensification is need of the hour.

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