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Non-Linear Catching-up and Long-Run Convergence in the Agricultural Productivity of US States

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Abstract

This note investigates convergence of agricultural total factor productivity (TFP) for 48 contiguous states in the US. This is carried out using a recently developed methodology which allows for a clear delineation between catching-up and long-run convergence as well as for the presence of non-linearity in TFP differentials. According to the empirical results, the state TFP dynamics are predominantly long-run converging.

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1. Introduction

A number of recent empirical studies have investigated convergence of total factor productivity (TFP) in the US states with mixed results. McCunn and Huffman (2000) and Ball *et al.* (2004) using Barro's regressions (the so called formal cross-section approach) found no empirical support for absolute (unconditional) β-convergence. They could not, however, reject the hypothesis of conditional β-convergence. Fousekis (2006) using the time series approach, proposed by Bernard and Durlauf (1995 and 1996), found evidence of multiple long-run equilibria each of them attracting a rather small number of US states.

The formal cross-section approach with its dominant focus on the behavior of the "average/representative" economic entity (country, region, state) is not quite informative about convergence or divergence (e.g. Quah, 1993, and 1997; Friedman, 1994; Oxley and Greasley, 1995). Moreover, β-convergence (absolute or conditional) is only a necessary but not a sufficient condition for convergence (e.g. Sala-i-Martin, 1996). The time series approach by Bernard and Durlauf (1995 and 1996) and Hobjin and Franses (2000) involves tests for level or for zero-mean stationarity of productivity differentials. As noted by Oxley and Greasley (1995), however, rejection of level or of zero-mean stationarity should not be necessarily taken as evidence of divergence. The reason is that the economic entities under consideration may be out of their long-run equilibrium (they have not reached their steady states) meaning that the convergence process may has yet to be completed. At the same time, the level or zero-mean stationarity tests typically assume that the long-run relationship between the variables of interest is linear. The occurrence of non-linearities is known to reduce the power of standard stationarity tests (like the ADF) preserving, thus, the false null of presence of a unit root in a differential (stochastic divergence).

This work considers the issue of convergence of agricultural TFP levels in the US states using recent developments in time series analysis which allow for: (a) a clear delineation between catching-up (a transition process) and long-run convergence (a completed process) and (b) the presence of non-linearities in TFP differentials. In what follows, Section 2 presents the analytical framework and Section 3 the data and the empirical results. Section 4 offers conclusions.

2. Analytical Framework

Let TFP_{it} be the total factor productivity in the agricultural sector of state i at time t. Let also TFP_{Lt} be the same series for the "leading" (highest productivity) state. Catching-up and long-run convergence can be determined from the properties of the logarithm of the TFP ratio, denoted by $y_{it} = \ln(TFP_{it} / TFP_{Lt}) = \ln(TFP_{it}) - \ln(TFP_{Lt})$. For Oxley and Greasley (1995) and Robinson (2007) the natural route for investigating the properties of y_{it} involves Dickey-Fuller type tests based on the model

$$\Delta y_{it} = \mu + \delta y_{it-1} + \varphi T + \sum_{j=1}^{p} \rho_j \Delta y_{it-j} + \varepsilon_{it} \qquad (1).$$

In (1), μ, δ, φ, and ρ_j are parameters to be estimated, Δ is the difference operator, T is a deterministic linear time trend, and ε_{it} is a white noise error term.

The notion of long-run convergence refers to the attainment of long-run steady-state equilibrium in a TFP differential. As such, it requires both the absence of a unit root and the absence of a deterministic time trend in y_{it}. The notion of catching-up refers to the tendency of a TFP differential to narrow over time. Catching-up, therefore, requires absence of a unit root as well as a downward deterministic time trend in y_{it}. In other words, catching-up is consistent with y_{it} being stationary around a deterministic time trend, provided that the deterministic trend is downward. Stationarity of y_{it} around a deterministic but upward trend implies that there is no catching-up; the two TFP series diverge from each other in a deterministic way. Obviously, the notion of long-run convergence is stronger than that of catching up since the former implies that the catching-up process (if any) has been already completed.

With reference to model (1), if $\delta = 0$ (a unit root is present), then the TFP levels diverge stochastically over time; if $\delta < 0$ (a unit root is not present), there is either long-run convergence or deterministic convergence (catching-up) or deterministic divergence. The long-run convergence is consistent with $\varphi = 0$. Given that the TFP differential is computed relative to the "leading" (highest productivity) state, catching-up is consistent with $\varphi > 0$, while deterministic divergence is consistent with $\varphi < 0$.

The Dickey-Fuller tests, however, are known to have very low power when the relations of interest (here the TFP differentials) are non-linear (e.g. Michael *et al.*, 1997; Kapetanios *et al.*, 2003). To address this problem, Chong *et al.* (2008) combined the approach of Oxley and Greasley (1995) with that of Kapetanios *et al.* (2003) on incorporating Smooth Transition Autoregressive (STAR)-type non-linearity in Dickey-Fuller tests. In particular, Chong *et al.* (2008) propose the estimation of the following model

$$\Delta y_{it} = \mu + \delta y^3{}_{it-1} + \varphi G(T) + \sum_{j=1}^{p} \rho_j \Delta y_{it-j} + \varepsilon_{it} \qquad (2),$$

where *G*(*T*) is a trend component of a specific functional form (either linear trend or the square of the linear trend). The statistical interpretation of (2) is analogous to that of (1). If $\delta < 0$ (a non-linear unit root is not present), there is either non-linear long-run convergence (consistent with $\varphi = 0$) or non-linear catching-up (consistent with $\varphi > 0$) or non-linear deterministic divergence (consistent with $\varphi < 0$). If $\delta = 0$ (occurrence of a non-linear unit root) the TFP levels of the states are said to diverge stochastically over time. The statistical significance of δ and φ can be tested using *t*-type statistics. Critical values for conducting the tests are provided by Chong *et al.* (2008).

Prior to the estimation of (2) one should verify whether a productivity differential is non-linear. This task can be performed following Luukkonen *et al.* (1988) who proposed the estimation of the model

$$y_{it} = \theta_0 + \sum_{k=1}^{p} (\theta_{1k} y_{it-k} + \theta_{2k} y_{it-k} y_{it-d} + \theta_{3k} y_{it-k} y^2{}_{it-d}) + \theta_4 y^3{}_{it-d} + v_{it} \qquad (3),$$

where *k* stands for the autoregressive lag length, *d* for the delay lag length, while v_{it} is a white noise error term. From (3), the null hypothesis of linearity ($\theta_{2k} = \theta_{3k} = \theta_4$ for all k) can be tested using an *F*-type statistic against the alternative of non-linearity. In case that linearity is rejected, catching-up and long-run convergence are investigated using model (2). Otherwise, they are investigated using model (1).

3. The Data and the Empirical Results

The data for the empirical analysis have been obtained from the Economic Research Servive (ERS) of the United States Department of Agriculture (USDA).[1] The ERS/USDA

[1] Available at www.ers.usda.gov/Data/AgProductivity/Table19.xls; full documentation is provided at www.ers.usda.gov/Data/AgProductivity/methods.htm.

database contains TFP levels for 48 contiguous states over the period 1960-2004 all expressed relative to the TFP level of Alabama in 1996.[2] We note that the same database (for the period 1960- 1999) has been used in the earlier studies of Ball *et al*. (2004) and Fousekis (2006).

TFP differentials of 47 states have been computed relative to FL which is the state with the highest (on the average) TFP level over the sample period. To conduct the tests for linearity, the autoregressive lag length k and the delay lag length d have been selected from $k \in \{1,2,3,4\}$ and $d \in \{1,2,3,4\}$ such that the F-type statistic for the maintained hypothesis is optimized. Then, the marginal significant value (msv) for the implied F-type statistic is bootstrapped. Table I presents the test results. We observe that linearity has been rejected at the 10 percent level for 35 states, at the 5 percent level for 26 states and at the 1 percent level for 6 states. Therefore, there is considerable evidence in favor of non-linear TFP differentials is the US agriculture.

Table I. Linearity Tests on the TFP Differentials

State	k	D	F-Statistic	Bootstrap msv[1]	State	k	d	F-Statistic	Bootstrap msv
AL	1	2	2.31	0.055***	ND	4	1	1.516	0.194
AR	4	3	2.483	0.034**	NE	4	1	4.272	0.01*
AZ	4	1	2.136	0.115	NH	1	1	1.757	0.133
CA	4	2	2.645	0.031**	NJ	2	2	2.484	0.047**
CO	2	1	5.523	0.001*	NM	1	2	2.035	0.106
CT	1	4	2.517	0.052***	NV	4	3	2.249	0.064***
DE	4	4	1.665	0.133	NY	4	1	2.956	0.053***
GA	4	2	3.176	0.012**	OH	1	4	1.008	0.418
IA	4	2	2.529	0.039**	OK	3	1	3.021	0.042**
ID	1	2	1.524	0.262	OR	1	2	3.363	0.036**
IL	3	4	2.224	0.065***	PA	4	1	3.667	0.021**
IN	1	1	2.115	0.093***	RI	4	3	2.609	0.026**
KS	1	1	1.867	0.121	SC	2	1	3.061	0.034**
KY	4	4	2.671	0.025**	SD	4	1	1.574	0.185
LA	1	1	4.266	0.015**	TN	2	1	5.005	0.005*
MA	3	2	1.399	0.253	TX	1	1	3.907	0.022**
MD	4	1	1.915	0.122	UT	4	2	2.696	0.027**
ME	3	2	2.276	0.059***	VA	4	1	2.968	0.033**
MI	4	3	2.802	0.021**	VT	3	1	1.256	0.265
MN	1	4	2.599	0.016**	WA	3	1	4.082	0.009*
MO	4	3	1.736	0.099***	WI	1	3	3.013	0.025**
MS	1	2	4.075	0.004*	WV	1	3	2.658	0.021**
MT	1	1	2.330	0.068***	WY	3	1	3.491	0.019**
NC	3	1	6.401	0.001*					

1: *, **, and *** denote statistical significance at 1, 5, and 10 percent level, respectively.

[2] The 48 contiguous states considered in this study are: AL(Alabama), AR(Arkansas), AZ(Arizona), CA(California), CO(Colorado), CT(Connecticut), DE(Delaware), FL(Florida), GA(Georgia), IA(Iowa), ID(Idaho), IL(Illinois), IN(Indiana), KS(Kansas), KY(Kentucky), LA(Louisiana), MA(Massachusetts), ME(Mein), MI(Michigan), MN(Minnesota), MO(Missouri), MS(Mississippi), NC(North Carolina), ND(North Dakota), NE(Nebraska), NH(New Hampshire), NJ(New Jersey), NM(New Mexico), NV(Nevada), NY(New York) OH(Ohio), OK(Oklahoma), OR(Oregon), PA(Pennsylvania), RI(Rhode Island), SC(South Carolina), SD(South Dakota), TN(Tennessee), TX(Texas), UT(Utah), VT(Vermont), VA(Virginia), WA(Washington), WV(West Virginia), and WY(Wyoming).

On the basis of the above results, the non-linear unit root test has been subsequently applied to the 35 states for which linearity has been rejected at the 10 percent level (or less). The optimal lag length has been selected using the Bayesian Information Criterion. Table II presents the test results from model (2) with a constant and a linear trend. The null of a non-linear unit root has been rejected at the 10 percent level (or less) for 25 out of 35 states. CA, CT, LA, NJ, NV, NY, RI, UT, WI, and WV are the states which appear to diverge stochastically from FL because of the presence of a non-linear unit root. Non-linear long-run convergence has been attained for 20 out of the above 25 states; AR, MI, and OR appear to have been in a non-linear catching-up process with FL, while two states (OK and WY) have been diverging deterministically over the sample period. The introduction of the square of the linear trend in the place of the linear trend (Table III) has not had any notable impact on the results.

Table II. Tests for Non-Linear Long-Run Convergence and Catching-up

(with Constant and Linear Trend)

State	k	t-statistic[3]		State	k	t-statistic[3]	
		δ^1	φ^2			δ^1	φ^2
AL	1	-4.258*	-0.701	NE	0	-3.676**	1.250
AR	0	-6.497*	3.013**	NJ	1	-1.533	1.202
CA	1	-1.938	-0.092	NV	1	-2.567	-0.507
CO	0	-4.223*	-0.481	NY	0	-2.303	0.208
CT	0	-2.561	1.785	OK	0	-4.343*	-2.864***
GA	1	-4.336*	2.557	OR	1	-3.998**	2.993***
IA	0	-3.781**	0.695	PA	0	-3.223***	1.003
IL	1	-3.379***	0.763	RI	1	-2.925	1.146
IN	3	-3.503**	2.509	SC	0	-6.017*	1.237
KY	0	-4.281*	1.247	TN	0	-4.185*	-1.611
LA	1	-2.703	-0.096	TX	1	-4.567*	-2.091
ME	0	-3.661**	0.945	UT	1	-2.403	0.175
MI	0	-4.464*	3.596**	VA	0	-3.665**	1.333
MN	0	-4.526*	1.717	WA	1	-3.259***	1.415
MO	1	-3.531**	-0.016	WI	0	-2.609	0.653
MS	2	-4.724*	0.799	WV	0	-2.878	0.388
MT	0	-5.347*	-1.844	WY	0	-5.053*	-3.861*
NC	1	-3.166***	1.837				

1: Critical Values for δ are -4.05, -3.38, and -3.06 at the 1, 5 and 10 percent level, respectively

2: Critical Values for φ right (left) tail are 3.76, 3.02, and 2.62 (-3.78, -3.07, and -2.63) at the 1, 5 and 10 percent level, respectively

3: *, **, and *** denote statistical significance at 1, 5, and 10 percent level, respectively

Table III. Tests for Non-Linear Long-Run Convergence and Catching-up
(with Constant and Square of Linear Trend)

State	k	t-statistic[3]		State	k	t-statistic[3]	
		δ^1	φ^2			δ^1	φ^2
AL	1	-4.228*	-0.639	NE	0	-3.684**	1.271
AR	0	-6.726*	3.306**	NJ	1	-1.722	1.448
CA	1	-1.919	0.066	NV	1	-2.475	-0.023
CO	0	-4.208*	-0.095	NY	0	-2.341	0.623
CT	0	-2.868	2.217	OK	0	-4.537*	-3.082**
GA	1	-4.223*	2.403	OR	1	-3.853**	2.853***
IA	0	-3.939**	1.250	PA	0	-3.281***	1.168
IL	1	-3.544**	1.293	RI	1	-3.054	1.449
IN	3	-4.005*	3.137	SC	0	-6.046*	1.313
KY	0	-4.145*	0.855	TN	0	-4.403*	-1.993
LA	1	-2.761	-0.250	TX	1	-4.355*	-1.741
ME	0	-3.875**	1.521	UT	1	-2.073	0.591
MI	0	-3.766**	2.803***	VA	0	-3.564**	1.102
MN	0	-4.771*	2.147	WA	1	-3.377***	1.318
MO	1	-3.538**	0.375	WI	0	-2.781	1.154
MS	2	-4.724*	0.705	WV	0	-2.873	0.325
MT	0	-5.199*	-1.562	WY	0	-4.315*	-3.021**
NC	1	2.746	1.106				

1: Critical Values for δ are -4.07, -3.44, and -3.10 at the 1, 5 and 10 percent level, respectively
2: Critical Values for φ right (left) tail are 3.81, 2.99, and 2.65 (-3.86, -3.02, and -2.66) at the 1, 5 and 10 percent level, respectively
3: *, **, and *** denote statistical significance at 1, 5, and 10 percent level, respectively

Table IV. ADF Tests for Linear Long-Run Convergence and Catching-up

State	k	t-statistic[3]		State	k	t-statistic[3]	
		δ^1	φ^2			δ^1	φ^2
AZ	1	-1.181	1.156	ND	0	-5.710*	2.263
DE	0	-3.814**	-0.311	NH	0	-3.604**	-0.470
ID	0	-2.753	1.935	NM	1	-2.792	1.202
KS	0	-4.888*	-1.785	OH	0	-5.631*	3.599*
MA	0	-2.667	1.793	SD	0	-3.931**	1.498
MD	0	-3.965**	0.656	VT	0	-3.753**	-0.851

1: Critical Values for δ are -4.186, -3.518, and -3.189 at the 1, 5 and 10 percent level, respectively
2: Critical Values for φ are 3.53, 2.79, and 2.47 at the 1, 5 and 10 percent level, respectively (Enders, 1996)
3: *, **, and *** denote statistical significance at 1, 5, and 10 percent level, respectively

For completeness, Table IV presents the relevant statistics from the application of model (1) to the 12 states for which the null of linearity of TFP differentials has not been rejected. Four states (AZ, ID, MA, and NM) appear to diverge stochastically from FL due to the presence of linear unit roots; another seven states (DE, KS, MD, ND, NH, SD, and VT) are long-run converging, while only one state (OH) has been in the process of catching-up with FL over the sample period. Considering non-linear and linear productivity differentials together it appears that there has been long-run convergence in 27 states, stochastic divergence in 14 states, catching-up in 4 states, and deterministic divergence in 2 states.

4. Conclusions

The objective of the present work has been to investigate convergence of agricultural TFP in 48 contiguous states in the US. This has been pursued using a recently developed methodology which allows for a clear delineation between catching-up (a transition process) and long-run convergence (a completed process) as well as for the presence of non-linearity in TFP differentials. The empirical results indicate that the state TFP dynamics are predominantly long-run converging; catching-up has been found in only handful of cases, while divergence (either stochastic or deterministic) has occurred for 34 percent of the states in the panel.

It is widely recognized that agricultural research has been a major factor behind TFP growth in the US agriculture. Convergence and catching-up is affected not only by the research effort undertaken within each state but also by the ease scientific information is transferred and exchanged. The Federal Technology Transfer Act which allows for cooperative research agreements between universities, federal and private laboratories promotes greater sharing of new technologies (research spillins) across geographical areas. This may explain why convergence (either long-run one or catching-up) dominates by far divergence (stochastic or deterministic one).

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