Empirical Economics (2002) 27:49–62

EMPIRICAL ECONOMICS

Are U.S. regions converging? Using new econometric methods to examine old issues

Marc Tomljanovich[1], **Timothy J. Vogelsang**[2]

[1] Department of Economics, Colgate University, Hamilton, NY 13346.
E-mail: mtomljanovich@colgate.edu.
[2] Cornell University, Ithaca, NY 14853

First version received: September 2000/Final version received: December 2000

Abstract. Are different regions of the United States experiencing convergence in levels of GDP? Carlino and Mills (1993) examined this question through time-series techniques, and found some evidence in favor of regional convergence. This paper checks the robustness of their results by using new econometric methods proposed by Vogelsang (1998). Our results, together with results from Loewy and Papell (1996), suggest there is stronger evidence in favor of convergence than previously thought based on the results of Carlino and Mills (1993).

Key words: Regional per-capita income, time series models, beta convergence, trend functions, serial correlation.

JEL classification: C32, E10, O40, R00

1. Introduction and motivation

Do poor countries have the ability to catch up to rich countries in standards of living? Solow's (1956) seminal neoclassical model of growth has sparked endless debates on the empirical validity of its convergence prediction. More specifically, the battle has raged over whether countries worldwide are actually converging in terms of levels of GDP, after adjusting for different steady-state parameters. This is known as conditional convergence: due to different savings rates, population growth rates, and depreciation rates, different countries will not necessarily converge to the same steady-state. However, if the parameters are the same, then convergence will occur. This issue has important ramifications on the development front, for if convergence is indeed a myth, then key assumptions and decisions by policy makers must be completely altered. Mankiw, Romer and Weil (1992) claim poorer countries grow faster than richer ones, by augmenting the Solow model with human capital. However, Quah (1993), studying dynamics of per-capita GDP country distributions, found no such convergence. Baumol (1986) also found evidence of convergence, but only within the developed countries. Clearly, the debate is far from over.

Closer to home, this question of convergence in the United States has been carefully examined. For if no clear evidence of convergence exists in the U.S., with its relatively fluid capital and labor markets, then what chance is there for global convergence? Barro and Sala-i-Martin (1992) drew attention to this issue by examining U.S. state data since the mid-eighteenth century. For the U.S. as a whole, as well as globally, they found evidence of β-convergence (defined as a negative relation between the initial levels of relative GDP and relative growth rates).

In contrast to this cross-sectional notion of convergence, a time-series notion has also been examined in recent papers. Initially, optimistic results were not found. Brown, Coulson and Engle (1986) argue that there is no evidence of U.S. state convergence. But other economists, using regional data, have found convergence. Carlino and Mills (1993) point out that Barro and Sala-i-Martin's work leaves open the possibility of individual U.S. regions not converging, despite overall convergence in the United States. They define stochastic convergence as the log of per-capita income in one region relative to that of the national average being stationary. That is, under stochastic convergence, shocks to a region are temporary. They then examine whether the regional series are stationary; if so, then the U.S. region in question displays stochastic convergence. Carlino and Mills state that both β-convergence and stochastic convergence are necessary for actual convergence; the former type means that poorer regions are on average catching up to the U.S. average, while the latter type means that shocks to the region are temporary. They find no evidence of stochastic convergence without including a break in the trends of the series, but upon adding a trend break with break date of 1946, they show that three of eight regions display stochastic convergence. Furthermore, they find β-convergence for the same three regions, indicating that at least part of the U.S. is converging. In addition, they conclude that the bulk of U.S. convergence took place before World War II. However, their econometric approach contains several restrictive assumptions. First, if the serial correlation in the errors does not follow an AR(2) process, as they assumed for all regional series, then their model is misspecified and their results are potentially misleading. Second, they impose the same trend break year of 1946 on each region, when a priori it is but one of several possible choices for a break in trend. While we find that their results are not an artifact of their AR(2) specification, the strength of the evidence for convergence depends on whether the break date is treated as known or unknown.

Loewy and Papell (1996) expand upon Carlino and Mills by testing the unit root hypothesis while allowing a break in the trend at an unknown date. Thus, the break date is chosen endogenously by the data. In the end, they find evidence in support of stochastic convergence in seven out of eight regions. Yet they ignore the β-convergence tests needed to make complete statements on U.S. regional convergence.

We check the robustness of Carlino and Mills's results with respect to β-convergence and extend them to the case of an unknown break date by using new econometric tests proposed by Vogelsang (1997, 1998). These tests have the following useful properties. The tests are asymptotically valid for general serial correlation in the data, including ARMA models, and do not require estimates of serial correlation nuisance parameters (Vogelsang (1997, 1998) showed that the tests also have good finite sample properties when asymptotic critical values are used). The tests are also valid whether the errors are $I(0)$ or $I(1)$ and do not require unit root pre-tests (An $I(0)$ series is one that is stationary around its deterministic trend, while an $I(1)$ series has a unit root in the error term). More importantly, the procedures work well in finite samples for series with errors that have persistent serial correlation. Like Carlino and Mills (1993) we allow a break in the trend function at the date 1946, but we also report results where the break date is considered unknown and is chosen by the data. Therefore, our results provide evidence regarding regional convergence for the case where the break date is treated as unknown. Overall, we find considerable evidence of β-convergence, although the strength of the evidence depends on whether we can treat the break date as known or unknown, and how robust we want to be with respect to persistence of the errors.

The remainder of the paper proceeds as follows. Section 2 describes the time series notion of β-convergence and gives details of the econometric methodology of trend function hypothesis testing. Section 3 reports our empirical results. Section 4 concludes.

2. The econometric model and methodology

Let y_t denote the natural logarithm of relative per-capita income for some region at time t. That is, y_t is the natural logarithm of the ratio of per-capita income of that region to average income (across regions) of the entire country. Following Carlino and Mills (1993), β-convergence requires that regions with initial incomes above average should grow slower than the rest of the country while regions with initial incomes below average should grow faster than the rest of the country. In terms of y_t, β-convergence requires that for regions where y_t is initially positive (negative), the growth rate of y_t should be negative (positive). Therefore, these requirements for β-convergence map into hypotheses regarding the parameters of the deterministic trend function of y_t.

Suppose that y_t is modeled as

$$y_t = \mu + \beta t + u_t \tag{1}$$

where u_t is a mean zero random process that is serially correlated. β represents the average growth of y_t over time and μ represents the initial level of y_t. According to β-convergence, if $\mu > 0$ then $\beta < 0$ and if $\mu < 0$ then $\beta > 0$. Though μ, the estimate of the intercept, is not precisely the same as y_0, the initial level of relative per-capita income, we have found that the differences between the two are very small for all eight U.S. regions. Therefore, evidence on β-convergence can be obtained from estimates of the trend function of y_t. Inference on estimates of μ and β is complicated by the fact that u_t is serially correlated and may be a unit root ($I(1)$) process. The approach taken by Carlino and Mills (1993) was to model u_t as an AR(2) process and rewrite y_t as an autoregressive process.

There are some pitfalls to writing y_t in the autoregressive form. First, the trend parameters in the autoregressive representation of y_t are nonlinear functions of μ, β and the serial correlation parameters. Therefore, obtaining information about μ and β requires untangling this nonlinear relationship. Second, the AR(2) model may not always provide an adequate approximation to the correlation structure of u_t for all regions, and thus lead to misspecification. Finally, when u_t is $I(0)$, information about β can be obtained from the estimate of the coefficient on the trend term in the autoregressive representation of y_t. But when u_t is $I(1)$, this estimate is not related to β (as the true coefficient becomes zero) and information about β must be obtained from the estimate of the coefficient on the intercept in the autoregressive representation of y_t. Therefore, the possibility of a unit root in u_t can cloud the interpretation of the point estimates of trend function parameters in the autoregressive representation of y_t.

We take a different approach which involves direct estimates of μ and β based on simple regressions. To test hypotheses about μ and β, we use a class of statistics recently proposed by Vogelsang (1998). The statistics are based on two simple regressions that are both estimated by OLS. The first regression, the y_t regression, is given by

$$y_t = \mu_1 DU_{1t} + \beta_1 DT_{1t} + \mu_2 DU_{2t} + \beta_2 DT_{2t} + u_t \tag{2}$$

where $DU_{1t} = 1$ if $t \leq T_b$ and 0 otherwise, $DU_{2t} = 1$ if $t > T_b$ and 0 otherwise, $DT_{1t} = t$ if $t \leq T_b$ and 0 otherwise and $DT_{2t} = t - T_b$ if $t > T_b$ and 0 otherwise. T_b is the date of a shift in the parameters of the trend function of y_t. T_b is considered either known, e.g. $T_b = 1946$, or unknown, in which case T_b is estimated from the data. The parameters μ_1 and μ_2 indicate whether relative per-capita income is above ($\mu_i > 0$) or below ($\mu_i < 0$) average at times 1 and T_b respectively. The parameters β_1 and β_2 are growth rates before and after the break.

The second regression, the z_t regression, is given by

$$z_t = \mu_1 DT_{1t} + \beta_1 SDT_{1t} + \mu_2 DT_{2t} + \beta_2 SDT_{2t} + S_t \tag{3}$$

where $z_t = \sum_{j=1}^{t} y_j$, $SDT_{it} = \sum_{j=1}^{t} DT_{ij}$, $i = 1, 2$ and $S_t = \sum_{j=1}^{t} u_j$. This regression is obtained by computing partial sums of y_t.

Testing for convergence amounts to testing whether the parameters μ_1, μ_2, β_1 and β_2 are different from zero and have signs consistent with convergence. Therefore, all that is needed are tests of the significance of the OLS estimates in the y_t and z_t regressions. Vogelsang (1997) provides statistics that can be used for this purpose. The statistics are simple modifications of standard t-statistics computed by OLS. Let t_y and t_z generically denote t-statistics for testing the null hypothesis that the individual parameters in the y_t and z_t regressions are zero. For the y_t regression the appropriate modified t-statistics are simply $T^{-1/2} t_y$, where T is the sample size. For the z_t regression the appropriate modified t-statistics are defined as $t - PS_t = T^{-1/2} t_z \exp(-bJ_T)$, where b is a constant and J_T is T^{-1} multiplied by the Wald statistic for testing $c_2 = c_3 = \cdots = c_9 = 0$ in the OLS regression

$$y_t = \mu_1 DU_{1t} + \beta_1 DT_{1t} + \mu_2 DU_{2t} + \beta_2 DT_{2t} + \sum_{i=2}^{9} c_i t^i + u_t \tag{4}$$

The J_T statistic is a unit root statistic proposed by Park and Choi (1988) and Park (1990). J_T can be computed as $(RSS_Y - RSS_J)/RSS_J$, where RSS_Y is the residual sum of squares from regression (2), and RSS_J is the residual sum of squares from regression (4). Given a significance level for the test, b can be chosen so that the critical values of the $t - PS_T$ statistics are same when u_t is $I(0)$ and when u_t is $I(1)$. Therefore, the J_T modification results in t-tests from the z_t regression that are robust to $I(1)$ errors. If $b = 0$, in which case the J_T modification has no effect, the distribution of $t - PS_T$ is different when u_t is $I(0)$ compared to when u_t is $I(1)$. Use of $b = 0$ is appropriate if the errors are known to be $I(0)$ and we are certain the $I(0)$ asymptotic approximations are more accurate. The J_T modification is not needed in the y_t regression since the $T^{-1/2}t_y$ statistics have well-defined asymptotic distributions when u_t is $I(1)$. When u_t is $I(0)$, $T^{-1/2}t_y$ converges to zero. Therefore, $T^{-1/2}t_y$ is a conservative test when errors are $I(0)$. The $T^{-1/2}t_y$ statistics are designed to have power when u_t is $I(1)$ but remain robust when u_t is $I(0)$, while the $t - PS_T$ statistics are designed to have power when u_t is $I(0)$ but remain robust when u_t is $I(1)$. See Vogelsang (1997) for details.

Asymptotic distributions for the $T^{-1/2}t_y$ and $t - PS_T$ statistics are nonstandard (nonnormal) and depend on the break date used in the regressions. In particular, the critical values depend on whether the break date is assumed known or unknown. When the break date is assumed unknown, it must be estimated from the data. The method of estimation affects the asymptotic distributions. We use a straightforward method of estimating the break date. We estimate the y_t regression for break dates in the range $T_b^*, T_b^* + 1, \dots, T - T_b^*$ where $T_b^* = 0.1T$. Therefore, we do not consider break dates near the end points of the sample. This is called trimming. For each regression we compute T^{-1} multiplied by the Wald statistic for testing the joint hypothesis that $\mu_1 = \mu_2$ and $\beta_1 = \beta_2$ (this is the hypothesis that there is no break in the trend function of y_t). The estimated break date is the break date that results in the largest normalized Wald statistic.

The asymptotic distributions of the $T^{-1/2}t_y$ and $t - PS_T$ statistics for both known and unknown T_b follow directly from theorems in Vogelsang (1998). Critical values are tabulated by Vogelsang (1997), which we also report in Tables 1, 2 and 3.

A possible alternative testing approach is to jointly test that the signs of μ and β have opposite signs. Such a joint test could lead to higher power. However, this joint test is a nonstandard testing problem that has a complicated composite null hypothesis. Conceptually, we could extend the approach of Chernoff (1954); however, integrating the joint test into our framework would be a complicated and non-trivial extension of the econometric theory that is well beyond the scope of this paper. We leave this interesting methodological problem as a future research topic.

3. Empirical results

Annual BEA data on per-capita personal income from 1929–1990 for the eight U.S. regions, the same data as Carlino and Mills (1993), are used in this study. The regions are: New England, Mideast, Great Lakes, Plains, Southeast, Southwest, Rocky Mountains and Farwest. These eight series are plotted in Figures 1 and 2.

Recall Carlino and Mills's definition for convergence: both β-convergence and stochastic convergence are needed for actual convergence. Loewy and

Table 1. Empirical results using the z_t regression and $t - PS_T$ statistics without J_T correction. Regression: $z_t = \mu_1 DT_{1t} + \beta_1 SDT_{1t} + \mu_2 DT_{2t} + \beta_2 SDT_{2t} + S_t$

Region	Known Break Date, $T_b = 1946$				Unknown Break Date				
	$\tilde{\mu}_1$	$\tilde{\beta}_1$	$\tilde{\mu}_2$	$\tilde{\beta}_2$	$\tilde{\mu}_1$	$\tilde{\beta}_1$	$\tilde{\mu}_2$	$\tilde{\beta}_2$	$\hat{T}_b$
Northeast	0.342**	−1.205**	0.074**	0.045	0.318*	−0.781	0.076**	0.032	1943
	(4.619)	(−1.373)	(1.978)	(0.270)	(3.473)	(−0.616)	(2.342)	(0.238)	
Mideast	0.396**	−1.238**	0.148**	−0.144**	0.397**	−1.257**	0.146**	−0.143**	1947
	(11.320)	(−2.992)	(8.421)	(−1.851)	(12.251)	(−3.431)	(8.083)	(−1.745)	
Great Lakes	0.068**	0.204*	0.119**	−0.308**	0.174	−3.846	0.137**	−0.256**	1934
	(2.899)	(0.734)	(10.074)	(−5.889)	(0.883)	(−0.656)	(9.924)	(−5.427)	
Plains	−0.282**	1.053**	−0.073**	0.101*	−0.270**	0.864	−0.074**	0.096*	1944
	(−5.661)	(1.785)	(−2.922)	(0.912)	(−4.883)	(1.194)	(−3.333)	(1.025)	
Southeast	−0.676**	1.695**	−0.386**	0.684**	−0.674**	1.276*	−0.422**	0.692**	1941
	(−19.670)	(4.045)	(−21.673)	(8.685)	(−12.542)	(1.518)	(−28.725)	(11.938)	
Southwest	−0.502**	1.777**	−0.180**	0.284**	−0.473**	1.285	−0.190**	0.276**	1942
	(−6.992)	(2.092)	(−4.992)	(1.777)	(−4.843)	(0.897)	(−6.214)	(2.256)	
Rockies	−0.206**	1.151**	−0.036*	−0.109	−0.193**	0.940**	−0.062**	−0.019	1952
	(−3.767)	(1.780)	(−1.307)	(−0.897)	(−7.135)	(3.756)	(−2.540)	(−0.148)	
Farwest	0.256**	0.115	0.201**	−0.259**	0.244**	0.329	0.211**	−0.274**	1944
	(10.879)	(0.413)	(17.034)	(−4.950)	(9.487)	(0.978)	(20.455)	(−6.294)	
$I(0)$ 10% cv	±0.854	±0.683	±1.030	±0.908	±1.570	±1.330	±1.140	±0.936	
$I(0)$ 5% cv	±1.120	±0.883	±1.350	±1.200	±2.190	±1.760	±1.500	±1.270	

** and * denote significance at the 5% and 10% level using a one-tailed test. Values in parentheses are the $t - PS_T$ statistics using $b = 0$. The last two rows report the 10% and 5% asymptotic $I(0)$ critical values.

Table 2. Empirical results using the z_t regression and $t - PS_T$ statistics with J_T correction. Regression: $z_t = \mu_1 DT_{1t} + \beta_1 SDT_{1t} + \mu_2 DT_{2t} + \beta_2 SDT_{2t} + S_t$

Region	Known Break Date, $T_b = 1946$				Unknown Break Date				
	$\tilde{\mu}_1$	$\tilde{\beta}_1$	$\tilde{\mu}_2$	$\tilde{\beta}_2$	$\tilde{\mu}_1$	$\tilde{\beta}_1$	$\tilde{\mu}_2$	$\tilde{\beta}_2$	$\hat{T}_b$
Northeast	0.342**	−1.205	0.074	0.045	0.318	−0.781	0.076	0.032	1943
	(4.314)	(−0.247)	(0.008)	(0.002)	(0.171)	(−0.000)	(0.000)	(0.000)	
	(3.724)	(−0.108)	(0.001)	(0.000)	(0.101)	(−0.000)	(0.000)	(0.000)	
Mideast	0.396**	−1.238**	0.148	−0.144	0.397**	−1.257	0.146	−0.143	1947
	(10.985)	(−1.407)	(0.737)	(−0.221)	(3.472)	(−0.141)	(0.101)	(−0.077)	
	(10.299)	(−0.980)	(0.330)	(−0.103)	(2.782)	(−0.037)	(0.021)	(−0.023)	
Great Lakes	0.068**	0.204	0.119**	−0.308*	0.174	−3.846	0.137*	−0.256*	1934
	(2.847)	(0.463)	(2.281)	(−1.613)	(0.503)	(−0.158)	(1.399)	(−1.345)	
	(2.737)	(0.371)	(1.397)	(−1.014)	(0.456)	(−0.087)	(0.700)	(−0.782)	
Plains	−0.282**	1.053**	−0.073*	0.101	−0.270**	0.864	−0.074	0.096	1944
	(−5.600)	(1.363)	(−1.222)	(0.427)	(−3.523)	(0.522)	(−1.071)	(0.456)	
	(−5.472)	(1.197)	(−0.917)	(0.325)	(−3.327)	(0.370)	(−0.717)	(0.333)	
Southeast	−0.676**	1.695	−0.386**	0.684**	−0.674**	1.276	−0.422**	0.692**	1941
	(−19.447)	(3.040)	(−8.612)	(3.885)	(−7.148)	(0.365)	(−4.064)	(2.967)	
	(−18.977)	(2.650)	(−6.351)	(2.911)	(−6.476)	(0.202)	(−2.037)	(1.725)	
Southwest	−0.502**	1.777*	−0.180	0.284	−0.473	1.285	−0.190	0.276	1942
	(−6.761)	(0.899)	(−0.327)	(0.165)	(−0.852)	(0.011)	(−0.015)	(0.031)	
	(−6.290)	(0.600)	(−0.133)	(0.070)	(−0.628)	(0.002)	(−0.002)	(0.006)	
Rockies	−0.206**	1.151**	−0.036	−0.109	−0.193**	0.940	−0.062	−0.019	1952
	(−3.716)	(1.267)	(−0.436)	(−0.345)	(−4.090)	(0.918)	(−0.367)	(−0.037)	
	(−3.609)	(1.076)	(−0.303)	(−0.244)	(−3.709)	(0.509)	(−0.185)	(−0.022)	
Farwest	0.256**	0.115	0.201**	−0.259**	0.244**	0.329	0.211**	−0.274**	1944
	(10.764)	(0.316)	(7.181)	(−2.331)	(7.170)	(0.481)	(7.723)	(−3.146)	
	(10.520)	(0.278)	(5.400)	(−1.779)	(6.826)	(0.358)	(5.475)	(−2.402)	
$I(0)/I(1)$ 10% cv	±0.854	±0.683	±1.030	±0.908	±1.570	±1.330	±1.140	±0.936	
$I(0)/I(1)$ 5% cv	±1.120	±0.883	±1.350	±1.200	±2.190	±1.760	±1.500	±1.270	

** and * denote significance at the 5% and 10% level using a one-tailed test. Values in parentheses are the $t - PS_T$ statistics with the first appropriate for a 10% test and the second appropriate for a 5% test. The last two rows report the 10% and 5% asymptotic critical values. The b's used to compute the statistics can be found in Vogelsang (1997).

Table 3. Empirical results using the y_t regression and $T^{-1/2}t_y$. Regression: $y_t = \mu_1 DU_{1t} + \beta_1 DT_{1t} + \mu_2 DU_{2t} + \beta_2 DT_{2t} + u_t$

Region	Known Break Date, $T_b = 1946$				Unknown Break Date				
	$\tilde{\mu}_1$	$\tilde{\beta}_1$	$\tilde{\mu}_2$	$\tilde{\beta}_2$	$\tilde{\mu}_1$	$\tilde{\beta}_1$	$\tilde{\mu}_2$	$\tilde{\beta}_2$	$\hat{T}_b$
Northeast	0.343**	−1.225*	0.060	0.140	0.318**	−0.805	0.064	0.116	1943
	(2.275)	(−0.880)	(0.641)	(0.385)	(2.022)	(−0.465)	(0.743)	(0.373)	
Mideast	0.394**	−1.220**	0.140**	−0.091	0.394**	−1.217*	0.137*	−0.083	1947
	(4.638)	(−1.555)	(2.646)	(−0.466)	(4.828)	(−1.702)	(2.582)	(−0.396)	
Great Lakes	0.072**	0.164	0.120**	−0.314*	0.128**	−1.856	0.130**	−0.246**	1934
	(0.924)	(0.228)	(2.455)	(−1.663)	(0.950)	(−0.538)	(3.326)	(−2.060)	
Plains	−0.274**	0.921*	−0.061	0.047	−0.262**	0.734	−0.065	0.056	1944
	(−2.172)	(0.791)	(−0.779)	(0.155)	(−2.000)	(0.541)	(−0.868)	(0.203)	
Southeast	−0.702**	1.780**	−0.383**	0.655**	−0.674**	1.273	−0.416**	0.656**	1941
	(−8.531)	(2.342)	(−7.464)	(3.296)	(−7.757)	(1.163)	(−9.712)	(4.399)	
Southwest	−0.492**	1.631**	−0.164*	0.206	−0.465**	1.144	−0.179	0.227	1942
	(−3.463)	(1.242)	(−1.850)	(0.600)	(−3.066)	(0.642)	(−2.276)	(0.811)	
Rockies	−0.191**	0.908*	−0.017	−0.184	−0.190**	0.909	−0.050	−0.097	1952
	(−1.589)	(0.818)	(−0.231)	(−0.636)	(−2.008)	(1.370)	(−0.676)	(−0.291)	
Farwest	0.262**	0.037	0.204**	−0.266*	0.247**	0.276	0.212**	−0.275**	1944
	(3.868)	(0.059)	(4.832)	(−1.629)	(4.160)	(0.449)	(6.247)	(−2.187)	
$I(0)$ 10% cv	±0.389	±0.676	±1.820	±1.560	±0.671	±1.470	±2.370	±1.480	
$I(0)$ 5% cv	±0.504	±0.887	±2.390	±2.040	±0.875	±2.000	±3.000	±2.010	

** and * denote significance at the 5% and 10% level using a one-tailed test. Values in parentheses are the $T^{-1/2}t_y$ statistics. The last two rows report the 10% and 5% asymptotic critical values.

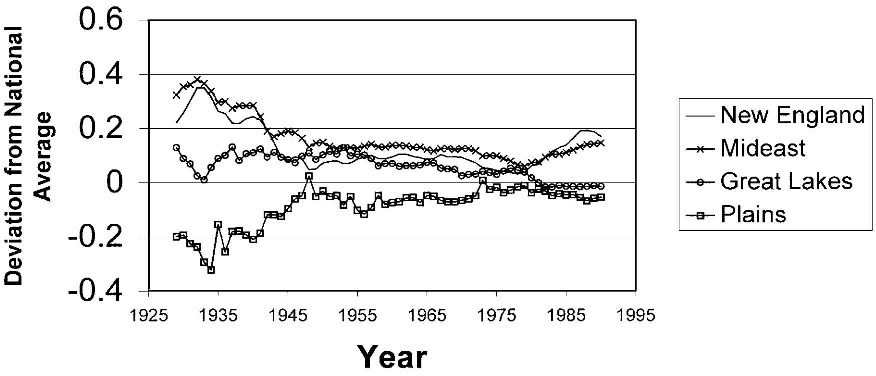

Fig. 1. Relative Personal Income

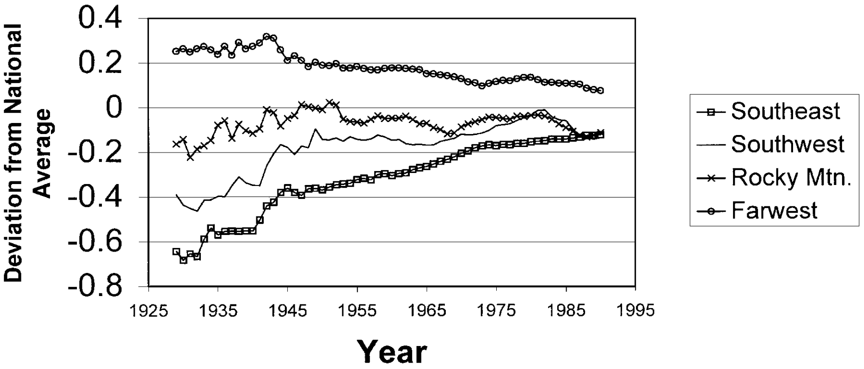

Fig. 2. Relative Personal Income

Papell (1996) have adequately demonstrated that stochastic convergence holds for seven of the U.S. regions, with the exception being the Rocky Mountains. If we can establish β-convergence for any of the seven regions that satisfy stochastic convergence, then we have established convergence.

It turns out there is evidence to suggest that stochastic convergence holds for the Rocky Mountains as well, using new unit root tests proposed by Perron and Rodriguez (1998). See the appendix for more details. Thus, we can conclude that stochastic convergence holds for the Rocky Mountains as well as the other series.

In the regressions discussed in the previous section, the key to this question lies in the point estimates of the intercepts and slopes. Testing for convergence amounts to testing whether the parameters μ_i and β_i, $i = 1, 2$, are different from zero and negatively related. This negative relation is vital to the analysis, because convergence indicates initially rich regions (with a positive intercept) grow at a slower rate than poorer regions (shown by a negative trend point estimate).

We estimate both known and unknown trend break date models. The former is in the spirit of Carlino and Mills. The latter completely avoids the potential data-mining criticism arising from the choice of break date. This is achieved by letting the data choose the break date (The interested reader should consult Perron (1989) and the papers in the July 1992 issue of the *Journal of Business and Economic Statistics* for a detailed discussion of the choice of break date). It will become clear that using an endogenous trend break date model weakens the case for regional β-convergence in that there are fewer statistically significant point estimates.

The empirical results are presented in Tables 1 through 4. Tables 1, 2 and 3 report the raw point estimates along with t-statistics and critical values for assessing significance. In each of these tables results are given for both known and unknown break dates. The last column in these tables reports the estimated break date. It is interesting to note that in six of eight regions the estimates of T_b fall within World War II and are relatively close to 1946. Table 4 conveniently summarizes the results of Tables 1, 2 and 3 with respect to convergence.

Table 1 reports results using the z_t regression and the $t - PS_T$ test used to assess statistical significance of the point estimates. The $t - PS_T$ statistics are given in parentheses below each point estimate and asymptotic critical values are given in the bottom two rows. In this table, the J_T correction was not applied when computing the $t - PS_T$ statistics ($b = 0$ was used). The results of Loewy and Papell (1996) indicate that most of the series have stationary errors. Therefore, the J_T correction may not be needed if the persistence of the errors is such that the $I(0)$ asymptotic approximation is accurate for $t - PS_T$. But, results based on Table 1 must be viewed with caution as even clearly stationary errors with realistic persistence (for example, AR(1) errors with autoregressive parameters of 0.8) could spuriously inflate the $t - PS_T$ statistics in the sample size with which we are dealing.

Unlike Table 1, the results in Tables 2 and 3 are robust to highly persistent errors and are, while more conservative, more reliable. Evidence of convergence or divergence based on Table 2 or 3 can be viewed as strong and robust. Table 2 contains the same point estimates as in Table 1, but the J_t correction is used. Because of this, the $t - PS_T$ statistics are smaller in magnitude compared to Table 1. We report $t - PS_T$ statistics for 10% and 5% tests in parentheses below each point estimate. Table 3 reports results using the y_t regression and provides the $T^{-1/2}t_y$ statistic below each point estimate. An important result appearing in Tables 1, 2 and 3 is that estimates of μ_1 are statistically different from zero for all eight regions. This says that initial percapita GDP of the regions were not the same in 1929. Therefore, the question as to whether income convergence has occurred is relevant for all U.S. regions, i.e. the regions were not in equilibrium in 1929.

Table 4 summarizes the results of Tables 1, 2 and 3. A C denotes point estimates consistent with β-convergence (That is, $\mu > 0$ and $\beta < 0$, or $\mu < 0$ and $\beta > 0$) that are both statistically significant at least at the 10% level. A c denotes point estimates consistent with β-convergence but with only one coefficient statistically significant at least at the 10% level. The D and d denote point estimates consistent with divergence, where D signifies both coefficients are statistically significant and d signifies one coefficient is statistically significant. An E denotes point estimates that are small in magnitude and not statistically different from zero. Such point estimates suggest β-convergence has already occurred.

For all eight regions, there is considerable evidence for all the series that

Table 4. Summary of empirical results

Region	$t-PS_T$: $I(0)$ Errors Assumed				$t-PS_T$: Robust to $I(1)$ Errors				$T^{-1/2}t_y$: Robust to $I(1)$ Errors			
	$T_b = 1946$		T_b Unknown		$T_b = 1946$		T_b Unknown		$T_b = 1946$		T_b Unknown	
	Pre-break	Post-break	Pre-break	Post-break	Pre-break	Post-break	Pre-break	Post-break	Pre-break	Post-break	Pre-break	Post-break
Northeast	*C*	*d*	*c*	*d*	*C*	*E*		*E*	*C*	*E*	*c*	*E*
Mideast	*C*	*C*	*C*	*C*	*C*		*c*		*C*	*c*	*C*	*c*
Great Lakes	*D*	*C*		*C*	*D*	*C*		*C*	*d*	*C*	*c*	*C*
Plains	*C*	*C*	*c*	*C*	*C*	*c*	*c*	*E*	*C*	*E*	*c*	*E*
Southeast	*C*	*C*	*C*	*C*	*C*	*C*	*c*	*C*	*C*	*C*	*c*	*C*
Southwest	*C*	*C*	*c*	*C*	*C*				*C*	*c*	*c*	
Rockies*	*C*	*d*	*C*	*d*	*C*	*E*	*c*	*E*	*C*		*c*	*E*
Farwest	*d*	*C*	*d*	*C*	*D*	*C*	*d*	*C*	*d*	*C*	*d*	*C*

* The Rockies is the only region Loewy and Papell (1996) found to be inconsistent with stochastic convergence.
C denotes point estimates consistent with β-convergence that are statistically significant at least at the 10% level.
c denotes point estimates consistent with β-convergence with only one estimate statistically significant at least at the 10% level.
D denotes point estimates consistent with divergence that are statistically significant at least at the 10% level.
d denotes point estimates consistent with divergence with only one estimate statistically significant at least at the 10% level.
E denotes point estimates very small in magnitude and statistically insignificant which suggests that β-convergence has occurred (Equilibrium growth).

β-convergence has or is occurring. For the Mideast, Plains, Southeast and Southwest regions there is strong evidence of β-convergence before WWII and some evidence of β-convergence after WWII. Statistical significance is stronger when the break date is assumed known to be 1946. Results are weaker when the break date is assumed unknown. But, this reflects greater uncertainty in the model with respect to the break date and power is lower. For the Great Lakes and Farwest there is evidence of β-convergence before WWII (pre-break), but post-WWII (post-break) there is strong evidence, regardless of the econometric model, of β-convergence. For the Northeast, there is strong evidence of β-convergence before WWII (pre-break) if $T_b = 1946$ is used. There is weaker evidence if T_b is assumed unknown. After WWII (post-break) the point estimates are close to zero and not statistically significant, suggesting the Northeast has attained a level of per-capita GDP, and GDP growth, similar to that of the United States. The Northeast indeed suggests strongly that convergence has occurred. Finally, for the Rocky Mountain region there is evidence that supports β-convergence before 1946 (pre-break). After 1946 (post-break), the point estimates are small and not statistically significant, suggesting β-convergence had completed, as in the Northeast. A general pattern in all of the results is that point estimates are much smaller after 1946 (post-break) than before 1946 (pre-break), suggesting that the bulk of convergence occurred before 1946. This conclusion was also suggested by the results of Carlino and Mills (1993).

At the suggestion of one of the referees, we checked the sensitivity of our results with regard to starting and ending dates. We used a starting date of 1934, and found that the empirical results were largely unaffected with the exception of the Great Lakes. This is not surprising, if we examine Figure 1, we see a large outlier during the early 1930s for this region, which is clearly skewing the results. With 1934 as the starting date, the estimated break date changes to 1956, and the point estimate on β_1 becomes positive, small in magnitude and statistically insignificant. We also estimated the models using an ending date of 1979 (dropping the post 1980 data). Our results did not substantially change.

It is interesting to point out that for some regions (see the plots for New England, Mideast and Southwest), there appears to be some evidence of divergence after 1980. A detailed statistical analysis of the post 1980 period is not feasible given the small number of observations. Also, given that the series exhibit high variability, it would be hard to determine whether actual divergence is occurring, or whether a temporary shock (away from convergence) to these regions occurred. Although we cannot make a strong statement about which option is more likely, it seems more plausible that the latter occurred. We base this conjecture on the facts that the late 1970s and 1980s were characterized by shifts in relative income and productivity in many regions of the United States due to the oil price shocks, sharp recession, and subsequent economic recovery that was led by New England, the Mideast and California.

Overall, our results combined with Loewy and Papell (1996) indicate that there is considerable evidence that real per-capita income levels and growth of the U.S. regions have been converging since 1929, which much of the convergence (in terms of magnitude) occurring before WWII but continuing throughout the 20th century. In the few cases where there is evidence of divergence, it only occurred before 1946, and had switched to β-convergence in the post-war period.

Finally, if we take the conservative view and only focus on the robust results of Tables 2 and 3 and treat the break date as unknown, there is still weak evidence of β-convergence for most of the regions pre-break date, and stronger evidence than reported by Carlino and Mills (1993) for β-convergence in the post-break date period.

4. Conclusion

In this paper, we re-examined the question of regional income convergence for the United States using more general and robust econometric methods than previous authors. We reported empirical evidence on β-convergence for regions of the United States using test statistics proposed by Vogelsang (1997). There is considerable evidence to suggest that β-convergence has or is occurring for all eight regions by 1990 and that many of the results are robust to the form of serial correlation in the errors, as well as the persistence of the errors. Evidence in favor of β-convergence is stronger if the break date is assumed known to be 1946 compared to assuming an unknown break date. Ironically, the evidence on stochastic convergence, as shown by Loewy and Papell (1996), is stronger if the break date is assumed unknown. Together, our results, along with Loewy and Papell's, suggest there is substantial evidence that income convergence has or is occurring in United States regions even if robust conservative econometric methods are used. This finding is consistent with Solow's neoclassical growth model, since population growth rates, depreciation rates and technological growth rates are all presumably similar across the regions as well.

Appendix

In this appendix, we show there is evidence to suggest that stochastic convergence holds for the Rocky Mountains using new unit root tests proposed by Perron and Rodriguez (1998). These tests are extensions of the Zivot and Andrews tests (1992) tests based on the GLS detrending method proposed by Elliot, Rothenberg, and Stock (1996). Let $\bar{c} = -23$ and define $\bar{\alpha} = 1 + \bar{c}/T$. Let $\tilde{y}_t$ denote the residuals from a regression of y_t^* on $1^*, t^*, DU_{2t}^*$ and DT_{2t}^*, where

$$y_1^* = y_1, \quad y_t^* = y_t - \bar{\alpha} y_{t-1}$$

$$1^* = (1, 1 - \bar{\alpha}, 1 - \bar{\alpha}, \ldots, 1 - \bar{\alpha}), \quad t^* = t - \bar{\alpha}(t-1)$$

$$DU_{2,1}^* = 0, \quad DU_{2t}^* = DU_{2t} - \bar{\alpha} DU_{2t-1}$$

$$DT_{2,1}^* = 0, \quad DT_{2t}^* = DT_{2t} - \bar{\alpha} DT_{2t-1}.$$

Consider the regression

$$\Delta \tilde{y}_t = \pi \tilde{y}_{t-1} + \sum_{j=1}^{k} c_j \Delta \tilde{y}_{t-j} + e_t. \tag{A1}$$

Regression (A1) is estimated for all possible break dates, with the trend break chosen to minimize $t_{\hat{\pi}}$, where $t_{\hat{\pi}}$ is the standard t-statistic for testing $\pi = 0$. For each value of T_b, k is chosen by the data dependent method suggested by Perron and Vogelsang (1992) and used by Loewy and Papell (1996). For the Rocky Mountain series $k = 0$ and the estimated break date is 1951, with $\min(t_{\hat{\pi}}) = -4.058$ (these values of k and T_b are the same as those obtained by Loewy and Papell (1996)). The 5% asymptotic critical value as reported by Perron and Rodriguez (1998) is -3.96, indicating that a unit root can be rejected. Thus, we can conclude stochastic convergence holds for the Rocky Mountains as well as the other series.

References

Barro R, Sala-i-Martin X (1992) Convergence. Journal of Political Economy 100:223–251

Baumol W (1986) Productivity growth, convergence and welfare: What the long-run data show. American Economic Review 76:1072–1085

Brown SJ, Coulson NE, Engle RF (1990) Non-cointegration and econometric evaluation of models of regional shift and share. NBER Working Paper 3291

Carlino GA, Mills LO (1993) Are US regional incomes converging? Journal of Monetary Economics 32:335–346

Chernoff H (1954) On the distribution of the likelihood ratio. Annals of Mathematical Statistics 54:573–578

Dowrick S, Quiggin J (1997) The measures of GDP and convergence. American Economic Review 87:41–64

Easterlin RA (1960) Interregional differences in per-capita income, population and total income, 1840–1950. In: Conference on Research in Income and Wealth, Trends in the American Economy in the Nineteenth Century. New York, National Bureau of Economic Research 73–140

Elliot G, Rothenberg T, Stock JH (1996) Efficient tests for an autoregressive unit root. Econometrica 64:813–836

Loewy MB, Papell DH (1995) Are US regional incomes converging? Some Further Evidence. Journal of Monetary Economics 38:587–598

Mankiw NG, Romer D, Weil DN (1992) A contribution to the empirics of economic growth. Quarterly Journal of Economics 107:407–437

Parente S, Prescott EC (1993) Changes in the wealth of nations. Quarterly Review (Federal Reserve Bank of Minnesota): 3–16

Park JY (1990) Testing for unit roots and cointegration by variable addition. In: Fomby B, Rhodes F (ed.) Advances in Econometrics: Cointegration, Spurious Regressions and Unit Roots. Jai Press, London, pp. 107–134

Park JY, Choi B (1988) A new approach to testing for a unit root. CAE Working Paper 88-23 (Cornell University, Ithaca NY)

Perron P (1989) The great crash, the oil price shock, and the unit root hypothesis. Econometrica 57:1361–1401

Perron P, Rodriguez G (1998) GLS detrending, efficient unit root tests and structural change. Mimeo, Boston University Department of Economics

Quah D (1993) Galton's fallacy and tests of the convergence hypothesis. Scandinavian Journal of Economics 93:427–443

Solow RM (1956) A contribution to the theory of economic growth. Quarterly Journal of Economics 70:65–94

Vogelsang TJ (1997) Testing for a shift in trend when serial correlation is of unknown form. CAE Working Paper 97-11 (Cornell University, Ithaca NY)

Vogelsang TJ (1998) Trend function hypothesis testing in the presence of serial correlation. Econometrica 66:123–148

Zivot E, Andrews DWK (1992) Further evidence on the great crash, the oil price shock and the unit root hypothesis. Journal of Business and Economic Statistics 10:251–270