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Regional Growth in Mexico: 1970-93

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Abstract

This paper finds convergence of real per capita GDP in Mexico's states and regions during the period of higher average national per capita growth (1970-85), and divergence during the lower-growth period (1985-93). These results hold across states and regions and within regions. The poorest states and regions grew more than twice as fast as the rest during the first period and experienced absolute and relative decline during the second period. The growth performance of a poor state in relation to the group of poor states was more erratic than the growth performance of a richer state in relation to its group.

JEL Classification Numbers:
C21, O49, O54

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Contents

Summary

This paper examines state and regional growth in Mexico during 1970-93 (omitting the oil-producing states of Campeche and Tabasco). Evidence of two kind of convergence of real per capita GDP (σ-convergence and β-convergence) is found during the period of higher average national per capita growth (1970-85), and divergence is found during the period of lower growth (1985-93). The results indicate that σ-convergence holds across states and regions, and within regions. As confirmation of the hypothesis of β-convergence, the poorest states and regions grew more than twice as fast as the rest during the period of higher growth, and experienced absolute and relative decline during the period of lower growth. The growth performance of a poor state in relation to that of the group of poor states was found to be more erratic over time than the growth performance of a richer state in relation to that of its group.

Convergence is reversed when economic growth halts, as indicated by the estimated annual speed of β-convergence of 2.4 percent for the period of positive average real per capita growth (1970-85) and -1.6 percent for the negative average growth period (1985-93). The link between convergence across states and national per capita growth also holds for regions.

The apparent presence of cross-state spillover effects in Mexico and the different behavior found across groups of states parallel findings in recent papers on states' GDP fluctuations in other countries. These papers show that there are asymmetries in the distribution of GDP by states and suggest that the initial impulse for fluctuations might be located in the highest-income states.

I. Introduction

The nature and empirical determinants of regional growth in Mexico have recently acquired great interest. In his September 1995, State of the Union address, President Zedillo announced his intention of transferring major federal policies to state governments. With these reforms, states will gain more autonomy in affecting variables critical to long term growth. Structural changes are likely to affect regional production and growth patterns. For instance, Hanson (1994) has found a migration of industries from central to northern states, which is attributed to the closer integration of Mexico with the United States.

This paper examines the evolution of growth and convergence of the real per capita gross domestic product (GDP) of the Mexican states during 1970-93. Concretely, the paper studies: (i) the hypothesis of σ-convergence that maintains that cross-state GDP dispersion declines over time in a growing economy, predicting that average GDP dispersion across states, as measured by the standard deviation of the logarithm of real per capita GDP, narrows over time, (ii) the behavior of the range between the highest per capita GDP state and the lowest, (iii) the absolute β-convergence (or catch up) hypothesis. It predicts that poor states would tend to grow faster per capita than rich ones, so that the poor states tend to catch up with the rich ones in terms of the level of per capita GDP, 1/ (iv) the dynamics of the distributions of states' per capita GDPs and the ranking of states within the distributions, and (v) the erraticism of states' growth.

Omitting the oil-producing states of Campeche and Tabasco, 2/ σ-convergence held during the period of positive average national per capita

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1/ The symbols σ and β stand for standard deviation and speed of convergence. The related concept of conditional β-convergence is defined as a situation in which states converge not to a common level of real per capita GDP but to levels conditioned on variables particular to each state, such as saving rates and population growth.

2/ They are excluded due to (i) their GDPs oscillate conspicuously, and their inclusion produces extreme values in the statistical analysis; (ii) oil revenues are federal rather than state property implying that, for those states, GDPs are greater than gross national product (GNP). Oil prices and output volumes directly affect the states' GDPs but not their GNPs.

growth (1970-85), while σ-divergence set in during the period of negative growth (1985-93). The standard deviation of real per capita GDP declined from 0.41 in 1970 to 0.32 in 1985--consistent with the σ-convergence hypothesis and a result also obtained by Caraza Herrasti (1993)--and increased to 0.40 in 1993. This convergence-divergence pattern is mirrored by the range between the richest and poorest states, which narrowed between 1970 and 1985 to widen thereafter. The ratio of real per capita GDP of the richest to the poorest states dropped from 5.5 in 1970 to 3.7 in 1985 to then increase to 5.4 in 1993 (contrasting with the United States, where that ratio decreased from 5.5 in 1900 to 2.2 in 1990). The similar behavior of these two measures of dispersion--standard deviation and range--suggests that a reduction (increase) in dispersion on average was associated with a narrowing (widening) of the distance between the poorest and the richest states.

We find evidence of absolute β-convergence across states for the period of positive per capita growth (1970-85) and of absolute β-divergence for the period of negative per capita growth (1985-93). The estimated speed of convergence is 2.4 percent per year for the positive growth period and -1.6 percent for the negative growth period, that is, convergence is reversed when economic growth halts.

The link between convergence across states and national per capita growth also holds for regions. When we group the states into the three traditional geographic regions--northern, central and southern--we find cross-regional convergence (Table 3) and intra-regional convergence (Table 4) for periods of higher national growth and divergence for periods of lower national growth. The observed convergence-divergence dichotomy might indicate the presence of spillover effects. That is, gains in the richer states trickle down to the poorer, while slowdowns in the former negatively affect the latter.

The inclusion of Campeche and Tabasco makes the range more erratic, increases the standard deviation, and alters the results. For example, the ratio between the highest and lowest GDP states increased from 5.5 in 1970 to 12.5 in 1985 and declined to 5.4 in 1993. The standard deviation increased from 0.40 in 1970 to 0.47 in 1985 and then went back to 0.42 in 1993. 1/

The apparent presence of cross-state spillover or trickle-down effects in Mexico and the different behavior found across groups of states relate to recent work on state fluctuations in the U.S. (Quah (1995)). Quah finds that asymmetries are important across different portions of the cross section distribution and suggests that the initial impulse for fluctuations locates in the highest-income states. The analysis of Mexican disaggregated

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1/ The sensitivity of the convergence results to the inclusion or exclusion of outliers has been reported by Ben-David (1994) and by Sherwood-Call (1996) for a sample of 113 market economies and for the states within the United States, respectively.

data is consistent with the story presented by Quah, and underscores the importance of looking at disaggregated data (Sala-i-Martin (1995)).

Harberger (1990) observed that industrial growth process in the United States is uneven. As he put it: "growth tends to be highly concentrated, to pop up in the most unlikely places, and then move on to other arenas." He used the analogy of the unequal growth of mushrooms contrasted with the even growth of dough with yeast. We have looked into this analogy for the Mexican states, rather than industries, and found that the seventeen states with the lowest real per capita GDP fit more closely to a mushroom-type growth process than the fifteen states with the highest real per capita GDP. This could be explained by the limited diversification of the poor states, which makes them more vulnerable to various types of shocks.

The rest of the paper is organized as follows. Section II examines national growth and Section III investigates the σ- and the absolute β-convergence hypotheses. Section IV looks at the dynamics of the distribution of states' GDPs. States' growth patterns are examined in Section V and Section VI contains concluding remarks. The paper has two appendices. Appendix I shows the political division, basic characteristics of each state, and state growth rates for various periods. Appendix II derives the convergence growth model.

II. National Growth

During 1970-93, Mexico's real per capita GDP grew at an average annual rate of 3.9 percent. A break in performance occurred in 1981 as shown in the growth-rate matrix in Table 1. 1/ The years on the horizontal and vertical axes refer to the initial and final years of a particular period. For example, the average annual growth rate for the period 1970-81, 6.9 percent, is shown in the intersection of the second column (which corresponds to 1970) and the twelfth row (which corresponds to 1981). Note that the average growth rate steadily decreases after 1981 as revealed by a downward look at the second column of the matrix. The growth rate for a given year is shown in the main diagonal of the matrix. Thus, the growth rate in 1983, -4.2, is found either as the last number on the 1983 row or as the intersection of the 1982-column and the 1983-row, indicating that the growth rate in 1983 represents the change of real GDP between 1982 and 1983.

To make the comparisons across time, and across states and regions, more homogeneous, it is convenient to focus on real per capita GDP. From 1970 to 1993, Mexico's real per capita GDP grew at 1.4 percent per year. The breakdown in Table 2 shows that the rapid per capita growth in 1970-80 was followed by a slowdown during 1980-85, a contraction in 1985-88 and a subsequent recovery.

1/ We use 1980 as the dividing year instead of 1981 because we do not have GDP data by states in 1981.

Table 1.

Mexico: Average Annual Rate of Growth of Real GDP

(In percentage)

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1970	6.5																				
1971	5.1	3.8																			
1972	6.1	6.0	8.2																		
1973	6.6	6.6	8.0	7.9																	
1974	6.4	6.4	7.3	6.8	5.8																
1975	6.3	6.3	6.9	6.5	5.8	5.7															
1976	6.0	6.0	6.4	5.9	5.3	5.1	4.4														
1977	5.7	5.6	5.9	5.4	4.8	4.5	3.9	3.4													
1978	6.1	6.0	6.3	6.0	5.6	5.6	5.6	6.1	9.0												
1979	6.4	6.4	6.7	6.5	6.3	6.4	6.6	7.3	9.3	9.7											
1980	6.7	6.7	7.0	6.9	6.7	6.9	7.1	7.8	9.3	9.5	9.2										
1981	6.8	6.9	7.2	7.1	7.0	7.1	7.4	8.0	9.2	9.2	9.0	8.8									
1982	6.2	6.2	6.5	6.3	6.1	6.1	6.2	6.5	7.1	6.7	5.7	4.0	-0.6								
1983	5.5	5.4	5.5	5.3	5.0	4.9	4.8	4.9	5.2	4.4	3.1	1.2	-2.4	-4.2							
1984	5.3	5.3	5.4	5.1	4.9	4.8	4.7	4.7	4.9	4.3	3.2	1.8	-0.5	-0.4	3.6						
1985	5.2	5.1	5.2	4.9	4.7	4.6	4.5	4.5	4.6	4.0	3.1	1.9	0.3	0.6	3.1	2.6					
1986	4.6	4.5	4.6	4.3	4.0	3.9	3.7	3.6	3.7	3.0	2.1	1.0	-0.5	-0.5	0.8	-0.6	-3.8				
1987	4.5	4.3	4.4	4.1	3.9	3.7	3.6	3.5	3.5	2.9	2.1	1.1	-0.1	-0.0	1.0	0.2	-1.0	1.9			
1988	4.3	4.2	4.2	3.9	3.7	3.5	3.4	3.3	3.3	2.7	2.0	1.1	0.1	0.2	1.1	0.5	-0.2	1.6	1.2		
1989	4.2	4.1	4.1	3.9	3.7	3.5	3.4	3.3	3.3	2.8	2.1	1.4	0.5	0.6	1.5	1.0	0.6	2.1	2.3	3.3	
1990	4.3	4.1	4.2	3.9	3.7	3.6	3.4	3.4	3.4	2.9	2.3	1.7	0.9	1.1	1.9	1.6	1.4	2.7	3.0	3.9	4.4
1991	4.2	4.1	4.1	3.9	3.7	3.6	3.5	3.4	3.4	3.0	2.4	1.8	1.2	1.4	2.1	1.9	1.8	2.9	3.2	3.8	4.0
1992	4.2	4.1	4.1	3.9	3.7	3.5	3.4	3.4	3.4	3.0	2.5	1.9	1.3	1.5	2.2	2.0	1.9	2.9	3.1	3.6	3.6
1993	4.0	3.9	3.9	3.7	3.5	3.4	3.3	3.2	3.2	2.8	2.3	1.8	1.3	1.4	2.0	1.8	1.7	2.6	2.7	2.9	2.9

Source: INEGI (1994, 1996a)

Table 2. Mexico: Rates of Growth of Real Per Capita GDP

(Average annual percent change)

1970-93			
1.44			
1970-85		1985-93	
2.41		-0.37	
1970-80	1980-85	1985-88	1988-93
3.14	0.96	-2.20	0.74

Source: Own calculations based on INEGI (1972, 1986, 1992, 1996a, 1996b).

Table 3. Mexico: Growth Rates of Real Per Capita GDP by Region and by States' GDP Group

(Average annual percent change)

	1970-80	1980-85	1985-88	1988-93
National	3.14	0.96	-2.20	0.74
Regional				
Northern states	2.36	1.68	-0.54	-0.17
Central states	2.70	0.17	-1.24	1.40
Southern states	8.10	3.41	-9.67	-0.18
States' GDP Group				
Highest fifteen states	2.23	1.32	1.53	1.05
Lowest seventeen states	4.47	0.56	-3.22	-0.02
Of which: six lowest	4.96	0.86	-3.04	-0.27

Source: Own calculations based on INEGI (1972, 1986, 1992, 1996a, 1996b).

The post-1980 lower growth was due to the 1982-83 and the 1986 recessions, and the mild recovery thereafter. Although the former recession was deeper and longer, it was preceded by a boom and followed by a vigorous recovery. This resulted in low but positive average per capita growth rate during 1980-85. The 1986 recession differed from the previous one in that the recovery thereafter was milder, thus resulting in a contraction during 1985-88, and in positive albeit mild growth in 1988-93.

The variety of shocks, structural reforms and the diverse growth experiences that took place during 1970-93 affected the regions differently. The Southern region, comprised mostly of lower real per capita GDP states expanded vigorously, thus catching up with other regions, during the period of positive national growth, including the slowdown of the first half of the 1980s (Table 3). A turnabout took place when the southern region switched from an average real per capita growth of over 6 percent during the 1970s and early 1980s to -9.7 percent during 1985-88, followed by stagnation in 1988-93. The negative growth performance of 1985-93 was associated with a setback in convergence for the poorer states and regions.

III. Growth Across States

This section examines σ-convergence, range convergence and divergence, and absolute β-convergence. The hypothesis of σ-convergence predicts that states' cross-sectional real per capita GDP dispersion declines over time. The hypothesis of absolute β-convergence predicts that poor states would tend to grow faster per capita than rich ones, so that the poor states tend to catch up with the rich ones in terms of the level of per capita GDP.

1. Cross-state and intra-regional σ-convergence and divergence

GDP dispersion across states is measured by the standard deviation of the natural logarithm of the states' real per capita GDP. Table 4 shows the standard deviation across all states as well as within regions.

In the period 1970-85, there is σ-convergence across all states as the standard deviation declined from 0.41 to 0.32. These standard deviations are statistically different at a 10 percent significance level. In the period 1985-93, there is σ-divergence, however, as the standard deviation increased to 0.40 in 1993, about the same level it had in 1970. Note that σ-convergence coincides with the period of higher rates of growth for the nation, while divergence takes place in periods of lower growth rates. This supports the notion that a slowdown in the national rate of growth widens GDP dispersion within the country.

The pattern of cross-state σ-convergence until 1985 followed by divergence also holds at the intra-regional level. GDP dispersion within either the northern or the central region narrowed steadily from 1970 to

Table 4. Mexico: Cross-State and Intra-Regional σ-convergence 1/

(Standard deviation of log of real per capita GDP, percent)

	1970	1975	1980	1985	1988	1993
National						
Cross-state	0.41	0.39	0.36	0.32	0.35	0.40
Intra-regional						
Northern	0.38	0.38	0.36	0.28	0.29	0.30
Central	0.37	0.34	0.33	0.31	0.33	0.41
Southern	0.40	0.48	0.43	0.32	0.42	0.58

Source: Own calculations based on INEGI (1972, 1986, 1992, 1996a, 1996b).

1/ Excludes Campeche and Tabasco.

Table 5. Mexico: Regression Analysis of Convergence 1/

	1970-93	1970-85	1970-80	1980-85	1985-93
$\hat{\alpha}$	0.038	0.100	0.094	0.139	-0.070
	(2.51)	(6.90)	(4.20)	(3.41)	(1.52)
$\hat{\beta}$	0.007	0.024	0.019	0.034	-0.016
	(1.36)	(4.26)	(2.56)	(2.77)	(1.59)
$\hat{T}_{half}$	98	29	37	21	43 2/
Adjusted R^2	0.10	0.50	0.24	0.26	0.12
F (1,28)	2.10	26.51	7.39	8.40	2.73
T (Years)	23	15	10	5	8
Obs. (States)	30	30	30	30	30

1/ Coefficients $\hat{\alpha}$ and $\hat{\beta}$ are nonlinear least squares regression estimates of equation 2, where the dependent variable is the ith state's average growth rate; t-values are in parentheses. The coefficient $\hat{\beta}$ is the estimated speed of convergence and $\hat{T}_{half} = \ln(2)/\hat{\beta}$ is the half-life. The regressions exclude Campeche and Tabasco.

2/ Corresponds to the concept of $\hat{T}_{double}$; that is, the number of years that it would take to double to current gap.

1985, and widened subsequently. GDP dispersion within the southern region, however, was quite erratic and widened markedly from 1970 to 1993.

2. Range-convergence and divergence

The range of a distribution measures dispersion by the distance between the highest and the smallest values of the distribution. Excluding the oil-producing states of Tabasco and Campeche, the ratio between the real per capital GDPs of the richest and poorest states, gradually shrunk from 5.5 in 1970 to 4.9 in 1975, 4.8 in 1980 and 3.7 in 1985. A reversal took place thereafter, as the ratio rose to 4.3 in 1988 and 5.4 in 1993.

Like the standard deviation, the range also shows convergence in the period of faster growth and divergence during slower growth. This suggests that a reduction (increase) in the average dispersion was associated with a narrowing (widening) of the distance between the poorest and the richest states.

For the sake of comparison, Barro and Sala-i-Martin (1995) found that in 1890, the real per capita income of the richest U.S. state (Montana) was 5.5 fold that of the poorest state (South Carolina); while in 1990, the richest state (Connecticut) was 2.2 times richer than the poorest (Mississippi). The authors also report that, in 1926, the richest Canadian province (British Columbia) was 2.2 times richer than the poorest (Prince Edward Island); while in 1992, the richest province (Ontario) was 1.4 times richer than the poorest (Newfoundland).

The dispersion observed among Mexican states also holds among the traditional geographic regions. In 1970 the real per capita GDP of the northern region was roughly equal to that of the central region. There was, however, a striking difference between the northern and central regions vis-à-vis the south. Real per capita GDP of the southern region was half of that in either of the other two regions.

Finally, the inclusion of Tabasco and Campeche alters previous results on range-convergence and σ-convergence. In 1985, the ratio of the real per capita GDP of the richest state (Campeche) to that of the poorest state (Oaxaca) was 12.5, compared with 5.5 in 1970. This indicates a widening of the richest-poorest gap during 1970-85. The richest-poorest ratio subsequently declined to 5.4 in 1993. The standard deviation increases from 0.40 in 1970 to 0.47 in 1985, and then declines to 0.42 in 1993. Sherwood-Call (1996) and Ben-David (1994) also find their results to be sensitive to the inclusion or exclusion of particular U.S. states and countries, respectively.

3. Absolute β-convergence and divergence across states

The absolute β-convergence hypothesis asserts that poor states or regions tend to grow faster per capita than rich ones--without conditioning on any other characteristic of states or regions. The underlying assumption of this hypothesis is that all states tend to converge to a common steady-

The neoclassical growth model produces an equation relating the average growth rate with the logarithms of the steady state and the initial real per capita GDP, and various parameters (see Appendix II):

$$\frac{1}{t}\ln\frac{y_t}{y(0)} = \frac{1}{t}(1-e^{-\beta t})\ln y^* - \frac{1}{t}(1-e^{-\beta t})\ln y(0), \tag{1}$$

where ln denotes natural logarithm; y_t, $y(0)$ and y^* are real per capita GDPs at the current year t, at the initial year 0, and at the steady state, respectively. The left hand-side expression, $(1/t)\ln(y_t/y(0))$, is the average growth rate. 1/ The parameter β measures the speed of convergence, that is, the rate at which the difference between $\ln y^*$ and $\ln y_t$ is reduced. 2/

Equation (1) can be estimated by a cross-section regression of the average growth rate on the beginning-of-period real per capita GDP:

$$\frac{1}{T}\ln\frac{y_{iT}}{y_i(0)} = \alpha + \frac{1}{T}(1-e^{-\beta T})\ \ln y_i(0) + e_i, \tag{2}$$

where y_i is the logarithm of real per capita GDP of the ith state, T and 0 correspond to the final and initial years in the data set used to compute the growth rate, T-0 = T represents the period length, and e_i represents the average of the error terms between dates 0 and T.

Equation 2 is estimated using Nonlinear Least Squares (NLSQ) regression applied to data for 30 states (Campeche and Tabasco are excluded). The matrix of real per capita GDP by state was constructed as follows. The nominal GDPs by state for the years of 1970, 1975, 1980, 1985, 1988 and 1993 were converted into real GDP using the national GDP deflator (there are no price indices by state). The real per capita GDP by state was obtained using the population by state from the census data for the years 1970, 1980, 1990 and 1995, and interpolation.

Cross-section regression results, and estimates of the speed of convergence and of the half-life are reported in Table 5. For the whole period under study, 1970-93, the estimated β parameter is positive (0.7 percent) but statistically insignificant, indicating weak absolute β-convergence. For the sub-period 1970-85, the estimated parameter $\hat{\beta}$ is positive (2.4 percent) and statistically significant. These results indicate the presence of absolute β-convergence meaning that states with

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1/ In continuous time, real per capita GDP at time t is given by $y_t = y(0)e^{gt}$, which implies a constant growth rate of $g = (1/t)\ln(y_t/y(0))$. In the empirical application, we calculated the average growth rate in discrete time using $y_t = y(0)(1+g)^t$, which implies $g = [y_t/y(0)]^{1/t} - 1$.

2/ Defining $D_t = \ln y^* - \ln y_t$ and $D(0) = \ln y^* - \ln y(0)$, equation 1 can be expressed as $D_t = e^{-\beta t}D(0)$, which underscores that D_t decreases over time at a rate of 100β percent per year.

lower initial GDP tended to grow faster than those with higher initial GDP, thus narrowing the distance between the rich and poor states. This pattern can be visualized in Charts 1 and 2, which show a negative relationship between the logarithm of the states' real per capita GDP at the beginning of period and their average growth rates.

For the period 1985-93, the estimated coefficient $\hat{\beta}$ is negative and marginally statistically significant. In this subperiod there was absolute β-divergence meaning that the gap between rich and poor states tended to widen. In those years, divergence coincided with a negative per capita average national growth rate and erratic states' growth behavior. Chart 3 shows a positive relationship between the initial real per capita GDP and states' growth rates for the period of negative national growth.

The estimated β is the annual rate at which the gap between the logarithms of the steady state and current real per capita GDPs is reduced. We can use this estimate to compute the number of years, T_{half}, that it would take to reduce by half the gap between the logarithms of the initial and the steady state GDPs. This parameter, also called half-life, can be calculated with the following formula $T_{half} = \ln(2)/\beta = 0.69/\beta$ (see Appendix II).

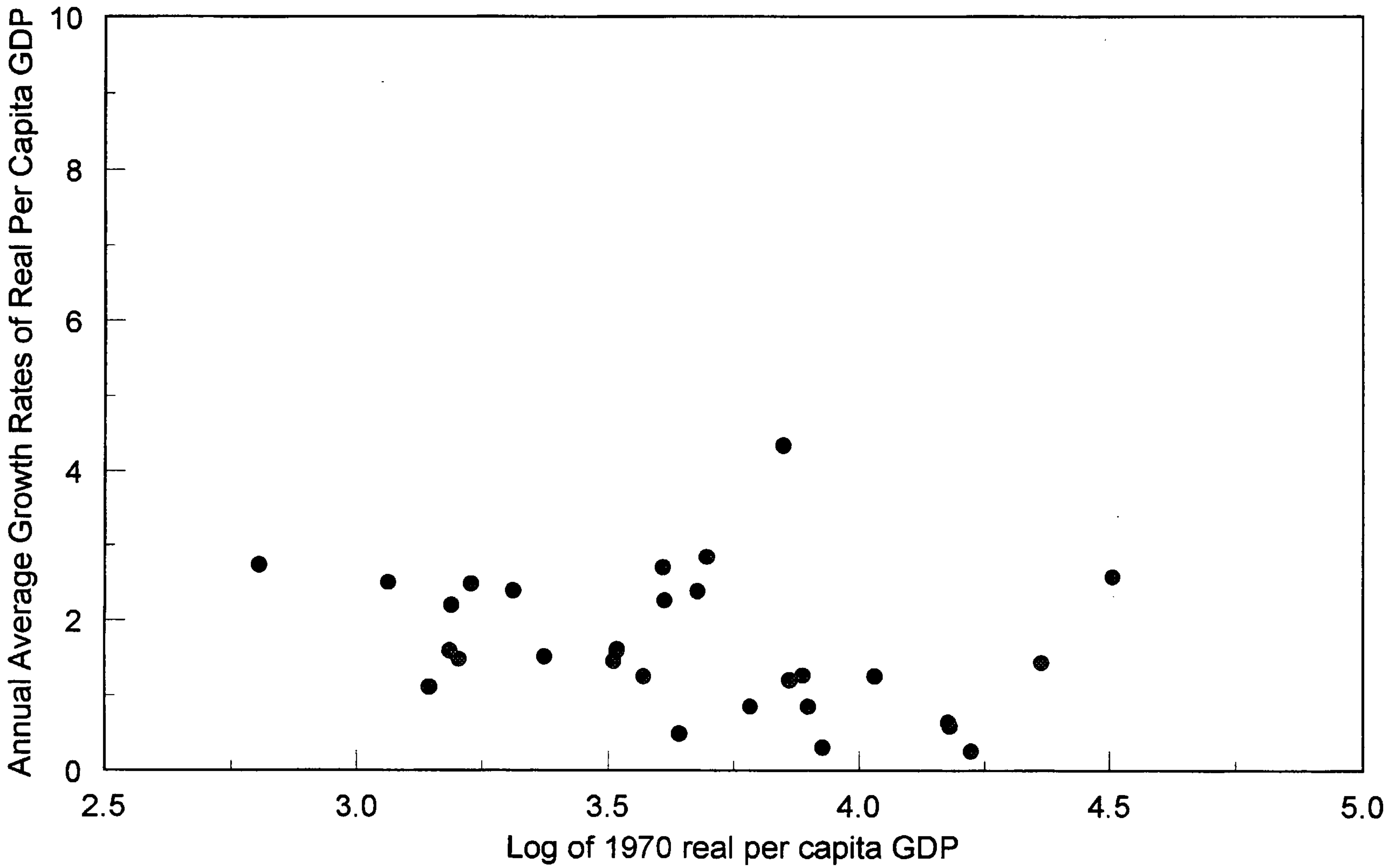
We obtain a half-life of 98 years for the period 1970-93; however, for the period of positive growth (1970-85) the estimated half-life was 29 years. 1/ When the estimated speed of convergence is negative, as in the period 1985-93, the gap between the rich and the poor states is widened. If divergence were maintained at the estimated rate, it would take 43 years to double the original gap.

The estimated speed of convergence of 0.7 percent for the whole period 1970-93 is less than the 2 percent found by Caraza Herrasti during 1970-90 for Mexico, and by other authors for other countries and regions (Barro and Sala-i-Martin (1995), Shioji (1995) and Mao and Rivera-Batiz (1995)). However, the higher-growth period of 1970-85 yields a speed of convergence coefficient of 2.4 percent per year, which is in line with the findings of the above mentioned authors. During 1985-93 convergence breaks down as the speed of convergence coefficient becomes -1.6 percent per year, indicating divergence. Sherwood-Call (1996) and Button and Pentecost (1995) also report divergence during the eighties for the United States and OECD countries, respectively.

The results suggest that the process of convergence in Mexico hinged on the economic growth performance. Convergence held for periods of positive growth and divergence set in when the economy contracted. Thus, the speed of convergence was not a constant, differing across periods with dissimilar national growth patterns.

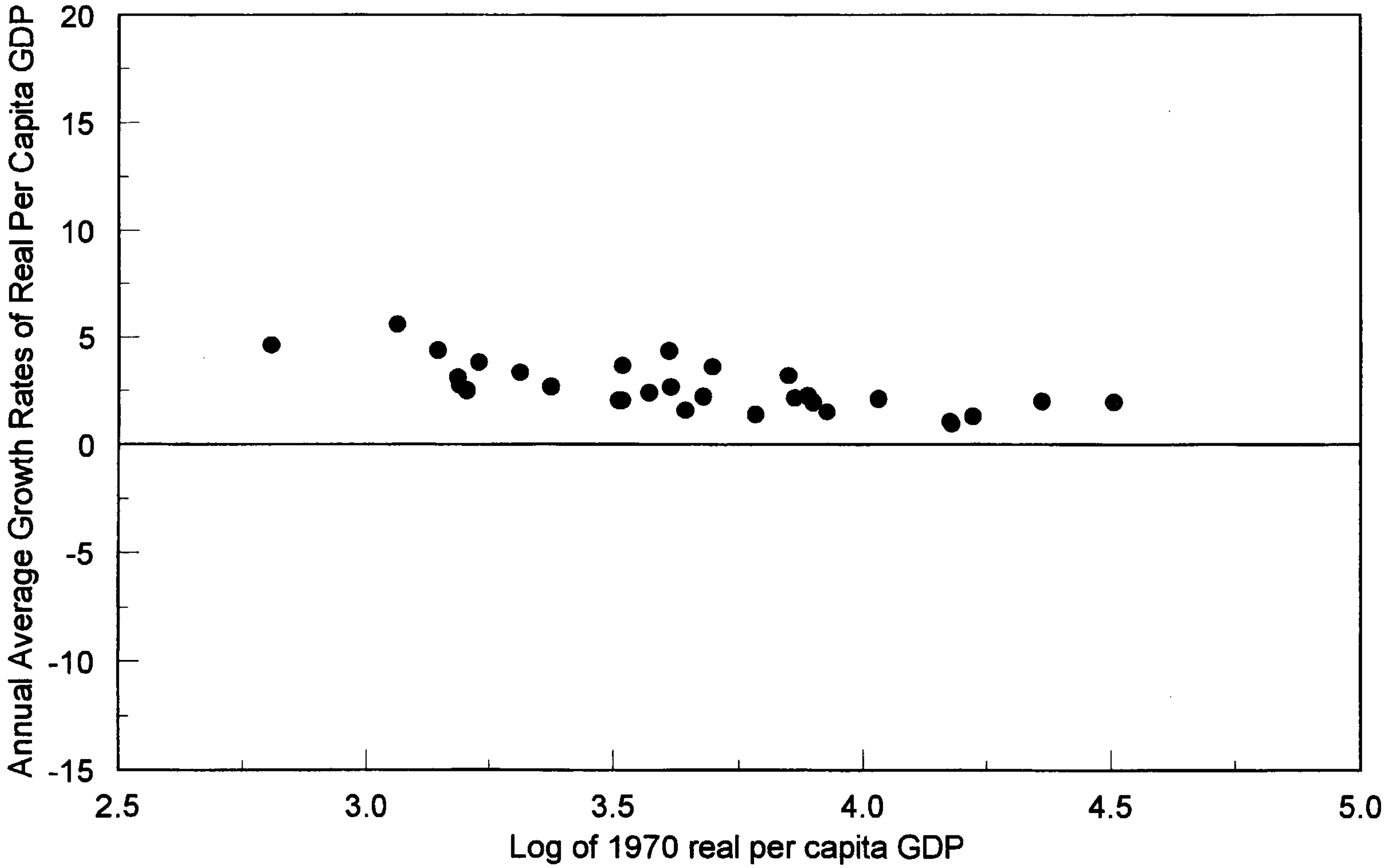
1/ Notice that this figure does not represent the number of years needed to close half of the gap between GDPs, but rather between the logarithms of GDPs. The number of years needed to close half the GDP gap, is greater than that needed to close half the logarithmic GDP gaps.

Chart 1
MEXICO
Convergence Across Mexican States, 1970-1993



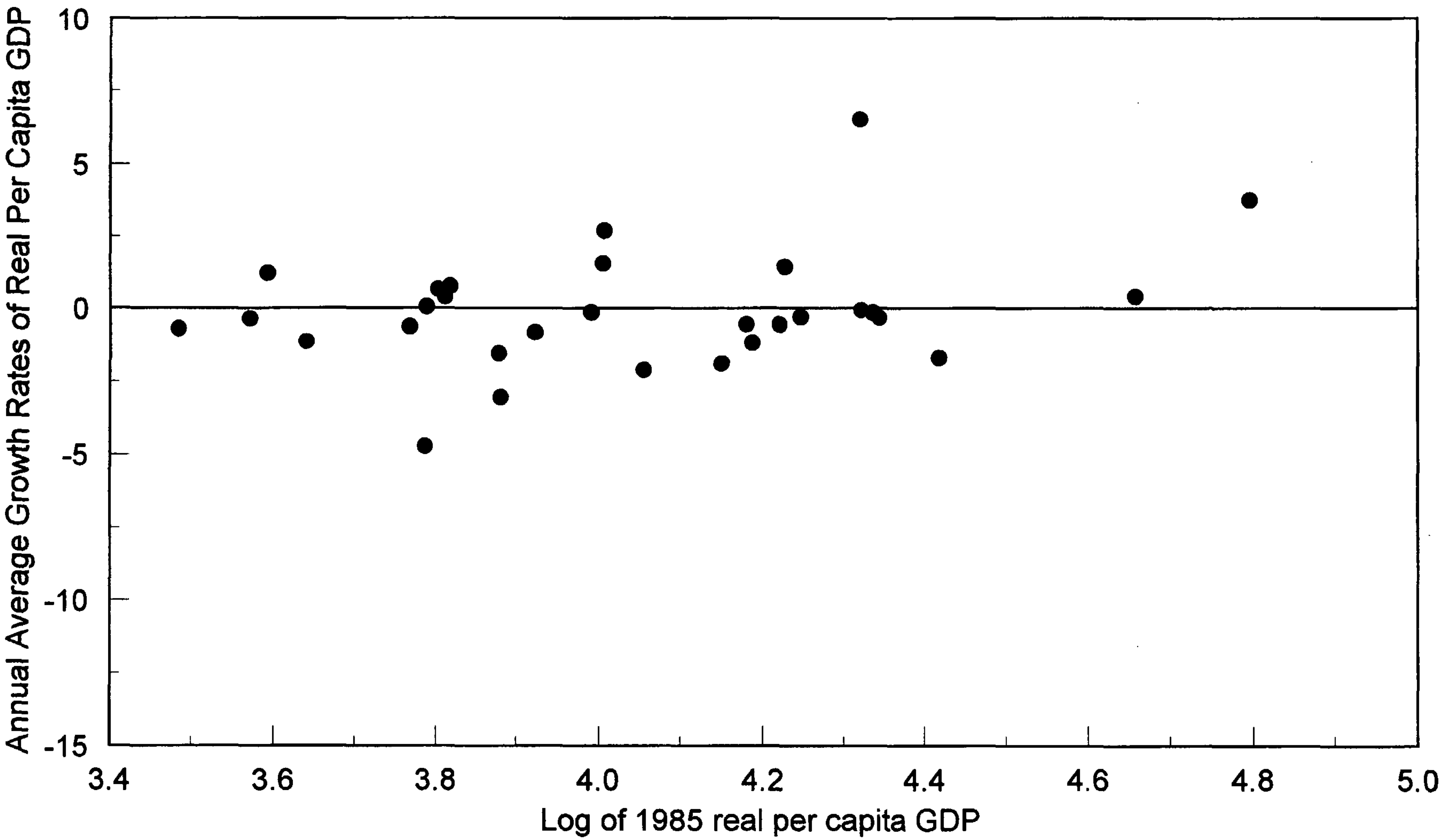
Note: It excludes two observations corresponding to the state of Tabasco whose coordinates are (3.53,1.74) and Campeche with (3.67,6.13)

Chart 2
MEXICO
Convergence Across Mexican States, 1970-1985



Note: It excludes two observations corresponding to the state of Tabasco whose coordinates are (3.53,7.86) and Campeche with (3.67,16.86)

Chart 3
MEXICO
Divergence Across Mexican States, 1985-1993



Note: It excludes two observations corresponding to the state of Tabasco whose coordinates are (4.66,-8.81) and Campeche with (3.67,6.13)

4. From cross-regional convergence to divergence

The pattern of regional convergence mirrors that of the states. There was cross-regional absolute β-convergence between the poorer southern and the richer northern-central regions for the period of positive average national rate of growth (1970-85) as shown in Table 3. However, there was regional β-divergence in 1985-93, which was more noticeable in the subperiod of 1985-88. This might indicate trickle down effects from the northern-central states to the southern states.

IV. Dynamics of Distribution and State Rankings

The dynamics of the cross-state distributions of the logarithm of real per capita GDP is shown in Chart 4. In 1970, the initial year of our study, the distribution was quite symmetric and close to normal, with 47 percent of the states included on the three first bars at the left of the histogram, and the rest on the last three bars. After 1970, the distribution became progressively more asymmetric until 1985 when 94 percent of the states were concentrated on the first three bars. Subsequently, there was a return toward symmetry as can be visually ascertained from Chart 4. In 1988 and 1993, the three first bars of the distribution included 88 and 81 percent of the states, respectively.

The progressive greater asymmetry of the distributions from 1970 to 1985 is consistent with the findings of convergence in that period. The changing asymmetry between 1970 and 1980 is a consequence of the faster growth of the seventeen states with lowest real per capita GDP (4.5 percent, see Table 3) compared with the growth of the fifteen states with the highest real per capita GDP (2.2 percent). The increase in asymmetry from 1980 to 1985 reflects the faster growth of the six states with lowest GDP relative to the lowest seventeen states. The return to symmetry observed thereafter is a consequence of divergence as the seventeen bottom states contracted at the same time that the fifteen top states grew.

A recent line of research (Ben-David (1994) and Quah (1996)) suggests that cross-country growth might take place through the formation of convergence clubs in the sense that countries can be divided into subgroups which converge to different steady-state income levels. This type of process will generate a multimodal distribution, where each mode represents a "club". Ben-David (1994) finds two convergence clubs -wealthiest and poorest countries- and nonconvergence for intermediate income countries in a sample of 113 market economies during 1960-85.

The Mexican states' GDP distributions from 1970 to 1988 do not exhibit bimodality. However, this does not preclude the possibility of the appearance of convergence clubs in the future. The 1993 distribution shows an incipient concentration at the upper extreme of the distribution. It is too early to tell whether this is a tendency toward a bimodal distribution, or a temporary feature due to the multiple shocks that occurred in eighties and nineties.

A ranking of states ordered by their real per capital GDP is reported in Table 6. The table reveals that (i) very few states cross ranks between

Table 6. Mexico: State Rankings
(Based on real per capita GDP)

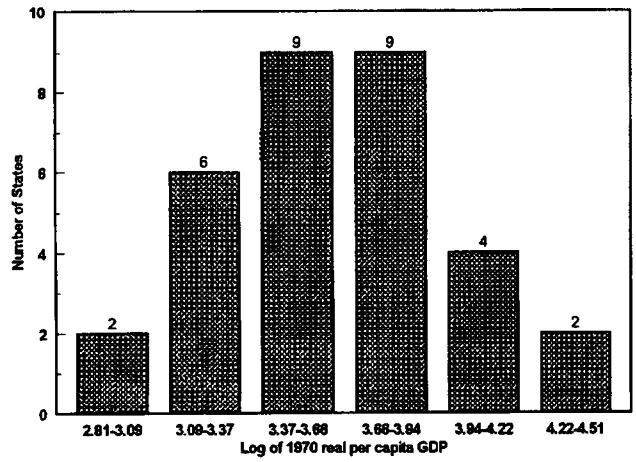
		1970	1975	1980	1985	1988	1993
Fifteen highest GDP states							
DISTRITO FEDERAL	C	1	1	2	2	2	1
NUEVO LEON	N	2	2	3	4	3	4
BAJA CALIFORNIA	N	3	3	4	5	5	9
BAJA CALIFORNIA SUR	N	4	4	5	8	7	8
SONORA	N	5	7	8	7	8	6
COAHUILA	N	6	6	7	6	6	7
MEXICO	C	7	8	11	15	15	16
TAMAULIPAS	N	8	12	9	13	14	15
JALISCO	C	9	10	10	12	11	12
CHIHUAHUA	N	10	11	12	14	9	13
QUINTANA ROO	S	11	5	6	9	4	3
SINALOA	N	12	14	19	19	18	17
COLIMA	C	13	13	13	11	13	5
MORELOS	C	14	17	17	17	16	11
CAMPECHE	S	15	18	18	1	1	2
Seventeen lowest GDP states							
VERACRUZ	C	16	20	20	22	21	25
AGUASCALIENTES	C	17	19	16	18	17	14
QUERETARO	C	18	15	15	10	10	10
NAYARIT	N	19	21	23	20	23	21
TABASCO	S	20	9	1	3	12	18
DURANGO	N	21	23	21	16	19	19
YUCATAN	S	22	16	22	23	24	20
GUANAJUATO	C	23	22	26	24	25	23
PUEBLA	C	24	24	25	28	28	26
SAN LUIS POTOSI	N	25	27	27	25	20	22
HIDALGO	C	26	28	24	26	22	24
MICHOACAN	C	27	25	28	31	30	30
GUERRERO	S	28	29	30	30	29	27
ZACATECAS	N	29	31	31	29	26	29
CHIAPAS	S	30	30	14	27	31	32
TLAXCALA	C	31	26	29	21	27	28
OAXACA	S	32	32	32	32	32	31

Source: Own calculations based on INEGI (1972, 1986, 1992, 1996a, 1996b).

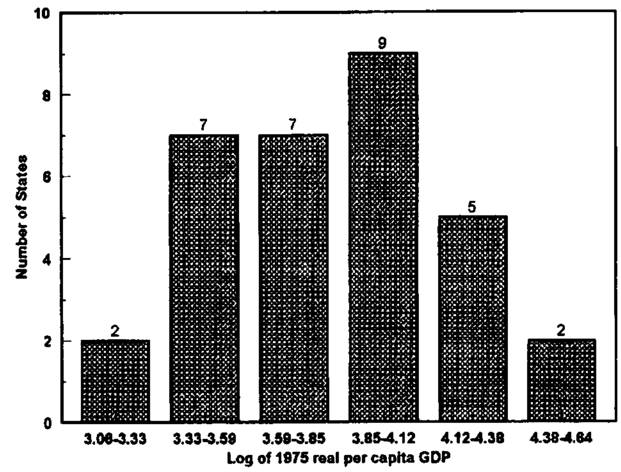
Note: N, C and S stand for Northern, Central and Southern states.

Chart 4
MEXICO: Cross-State Distribution Dynamics

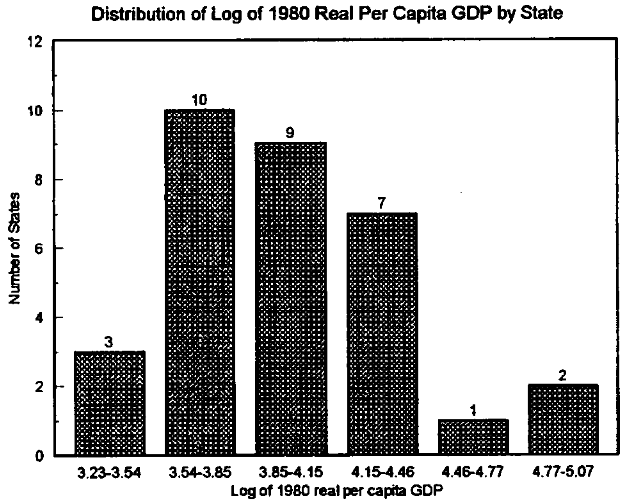
Distribution of Log of 1970 Real Per Capita GDP by State



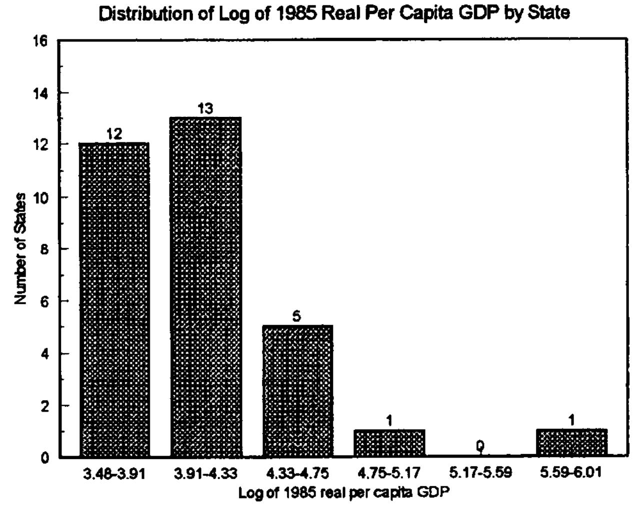
Distribution of Log of 1975 Real Per Capita GDP by State



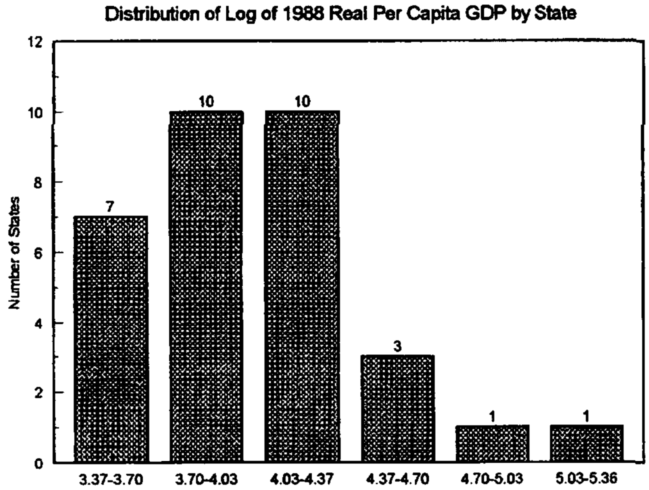
Distribution of Log of 1980 Real Per Capita GDP by State



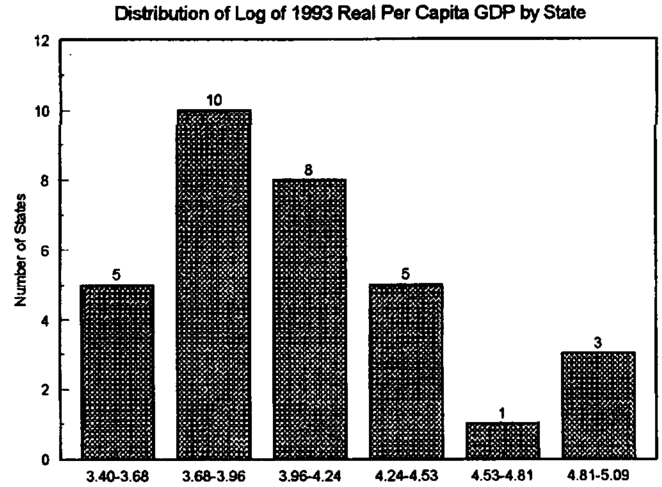
Distribution of Log of 1985 Real Per Capita GDP by State



Distribution of Log of 1988 Real Per Capita GDP by State



Distribution of Log of 1993 Real Per Capita GDP by State



the upper and lower groups during the whole period (Mexico and Sinaloa move to the lower group, while Aguascalientes and Querétaro move upwardly) and, (ii) the six poorest states in 1970 were the same in 1993.

In 1970, the six richest states were Distrito Federal, Nuevo León, Baja California, Baja California Sur, Sonora, and Coahuila in that order; while the six poorest states were Oaxaca, Tlaxcala, Chiapas, Zacatecas, Guerrero and Michoacán. The real per capita GDP of the richest state (Distrito Federal) was 5.5 fold that of the poorest state (Oaxaca). Five out of the six richest states were in the northern region (the richest, Distrito Federal, is in the central region).

In 1993, the six richest states were Distrito Federal, Campeche, Quintana Roo, Nuevo León, Colima and Sonora in that order; while the six poorest states were the same as in 1970. The real per capita GDP of the richest state (Distrito Federal) was 5.4 fold that of the poorest state (Oaxaca). The six richest states were equally divided among the northern, central and southern regions.

V. Do States Grow Smoothly?

Large, well-diversified industrial economies tend to growth smoother than less-diversified developing economies. For example, in the United States, growth rates fluctuate between 0 and 3 percent, while in Mexico, they exhibit large swings from one year to the other (Table 1). This large variability in the national growth rate is accentuated at the state level, even when averaged over five year periods.

The upswings and downswings in the Mexican states' growth performance resemble Harberger's (1990) observation that industries exhibit uneven and highly unpredictable growth. He likened the uneven growth across industries within the United States with the randomness of the reproduction of mushrooms, as contrasted with the even expansion of dough as a consequence of the yeast. We have looked into this analogy for the states, rather than industries, and found that the seventeen states with lowest real per capita GDP fit more closely to a mushroom-type growth process than the top GDP states.

After some empirical testing we found convenient to classify states into two sub-groups: the fifteen highest and the seventeen lowest states according to their real per capita GDP. This classification is robust with respect to time as there are only a few states crossing ranks during the period 1970-93 (see Table 6). The even or uneven growth performance of a particular state is evaluated by the behavior of the deviation of the growth rate of that particular state from the average growth rate of the reference group.

The behavior of the deviations of the growth rate of a particular state from the growth rate of the reference group can be gauged by their magnitude and by their change in sign from period to period. The average magnitude of the deviation serves as a measure of dispersion of growth performance within the group. The change in the deviation sign can be used to measure randomness, in the sense of the extent to which a state maintains a consistently superior or inferior growth performance with respect of that of the reference group.

Even and erratic state growth patterns can be visualized in Chart 5. The horizontal and vertical axes measure state real GDP per capita and the growth rate, respectively. The clusters in each panel represent states' GDPs and growth rates in periods t and t+1, and the dividing line represents the group average growth rate, which remains the same in both periods. The diagram at the top shows a case in which the deviations of a particular state do not change their sign and are relatively small. The diagram at the middle shows a case in which performance remains inferior but the magnitude of the deviations are larger with respect to the top panel. The diagram at the bottom shows a case in which a particular state changes from below average to above average performance.

We calculated the deviation of each state growth rate from the median growth rate for its GDP group. The matrix of these deviations, presented in Table 7, shows two traits. First, the mushroom-type pattern is more evident in the lowest GDP states as evidenced by the fact that 61 percent of the deviations exceed one percentage point, compared with 47 percent for the highest GDP states. The percentage of deviations exceeding two percentage points are 36 and 20 percent for the highest and lowest GDP states, respectively. Second, states' growth performance in relation to their reference group is unpredictable as evidenced by the change in sign in the deviations in about 56 percent of the cases for both groups.

The greater growth rate dispersion in poorer states raises the question of how the economic structure and policy in those states differ from that in richer states. We conjecture that the limited diversification of the poorer states makes their growth rate more responsive to economic and political shocks. This limited diversification within a state makes applicable the analogy of growth across industries within a nation to growth across states within a nation (see Appendix I).

VI. Conclusions

We find convergence in Mexico has been associated with growth, the estimated speed of convergence was 2.4 percent per year during 1970-85, the emergence of divergence after 1985, and the sensitivity of results to the inclusion or exclusion of inordinate states. These results are in line with the findings reported in the recent convergence literature. 1/ For

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1/ Barro and Sala-i-Martin (1991), Blanchard and Quah (1992), and Carlino and Mills (1993) found regional convergence in the United States, and Barro and Sala-i-Martin (1991) find evidence of convergence among European regions. Other studies have confirmed tendencies for regional convergence in rapidly growing economies such as Japan after World War II (Barro and Sala-i-Martin (1992) and Shioji (1995)), and post-1978 China (Mao and Rivera-Batiz (1995), Chen and Fleisher (1995), and Jian, Sachs and Warner (1996)). Canova and Marcet (1995) report regional convergence among OECD regions, but to different steady state levels.

Chart 5
Patterns of Growth Fluctuations Relative to the Group Average

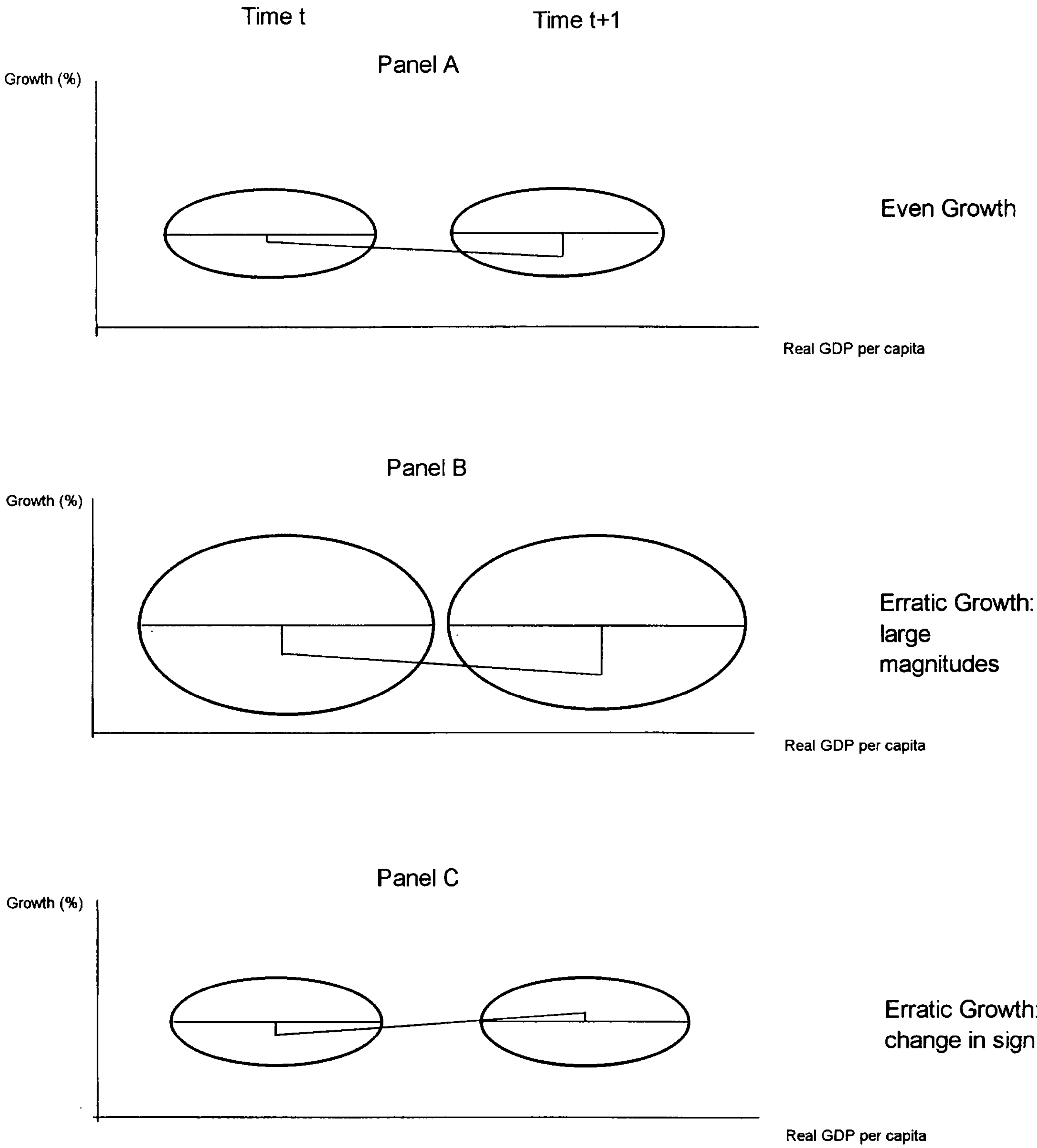

Table 7. Mexico: Deviations of States Growth Rates from the Median of Their GDP Group

(In percentage points)

	1970-75	1975-80	1980-85	1985-88	1988-93
Fifteen states with highest real per capita GDP					
Median growth rate	2.72	1.55	1.05	-0.4	-0.28
DEVIATIONS					
DISTRITO FEDERAL	0.10	1.67	-1.19	1.47	5.64
NUEVO LEON	-0.38	1.14	-0.10	--	1.15
BAJA CALIFORNIA	-0.82	0.22	-0.79	-0.74	-1.74
BAJA CALIFORNIA SUR	--	--	-2.45	1.38	-0.40
SONORA	-2.12	-0.96	0.95	0.48	--
COAHUILA	1.13	-0.13	--	0.65	-0.38
MEXICO	0.33	-0.60	-0.55	-1.56	-1.55
TAMAULIPAS	-0.21	1.70	-0.96	-1.89	-0.21
JALISCO	0.50	0.79	0.12	-1.20	0.37
CHIHUAHUA	0.65	-0.14	0.62	1.52	-1.24
QUINTANA ROO	6.71	-0.86	-1.35	3.95	8.59
SINALOA	--	-2.38	1.27	-1.25	1.04
COLIMA	3.61	-0.38	2.32	-2.11	4.17
MORELOS	-0.11	0.08	1.36	0.21	4.73
CAMPECHE	-0.27	0.16	52.11	-19.09	-5.90
Seventeen states with lowest real per capita GDP					
Median growth rate	4.09	2.59	1.76	-1.79	0.24
DEVIATIONS					
VERACRUZ	-2.68	-0.19	-0.82	0.04	-1.65
AGUASCALIENTES	-0.48	--	--	0.59	2.99
QUERETARO	1.68	-0.33	3.25	-0.39	0.60
NAYARIT	-1.65	-0.14	0.48	-2.58	1.12
TABASCO	7.19	19.82	-9.65	-13.36	-5.02
DURANGO	-1.40	1.06	2.86	-3.58	-0.36
YUCATAN	2.96	-3.33	-1.82	0.58	1.74
GUANAJUATO	-1.02	-1.37	0.04	--	1.46
PUEBLA	-0.72	1.16	-0.88	-2.19	1.21
SAN LUIS POTOSI	-1.59	1.07	2.07	3.17	--
HIDALGO	--	3.66	-0.63	2.99	-0.87
MICHOACAN	0.81	-0.14	-1.61	2.18	-1.05
GUERRERO	0.48	-0.40	-0.29	2.05	1.55
ZACATECAS	-2.46	0.13	3.15	3.59	-3.09
CHIAPAS	0.14	11.66	-6.30	-8.12	-1.72
TLAXCALA	3.73	-0.18	4.89	-5.18	-0.89
OAXACA	1.20	0.86	3.38	-1.94	0.93

Source: Own calculations based on INEGI (1972, 1986, 1992, 1996a, 1996b).

example, a 2 percent speed of convergence is reported by Caraza Herrasti (1993) for Mexico during 1970-90, and by Barro and Sala-i-Martin (1995) and others for various countries. Sherwood-Call (1996) reports divergence in the eighties within the United States, while Button and Pentecost (1995) reject the convergence hypothesis for OECD countries in the same period. Also, Sherwood-Call (1996) and Ben-David (1994) find their results to be sensitive to the inclusion or exclusion of particular U.S. states and countries.

The observation of convergence during positive average national growth and divergence during negative growth is not consistent with the notion of a constant speed of convergence and an unchanging pattern of absolute β-convergence. It is consistent, however, either with conditional β-convergence or with the existence of idiosyncratic regional shocks. Further research is necessary to identify the role played by conditioning variables such as human capital, and the nature of the shocks affecting states and regions.

Greater data availability in the future will allow the testing of statistical models that correct for the statistical biases arising when regions converge to different steady states (Canova and Marcet (1995)), there are convergence clubs (Ben-David (1994), Quah (1996)), and there are inconsistent estimates due to correlated individual effects and endogenous explanatory variables (Caselli, Esquivel and Lefort (1995)).

The analysis revealed substantial variability in the state and regional growth patterns. This can be induced by and, at the same time, can effect national macroeconomic variables. Future research could be directed to spell out (i) the impact of macroeconomic policies on regional growth, (ii) the effect of changes in regional growth on macroeconomic variables such as fiscal revenues and expenditures, imports and exports, and country risk premia, and (iii) the development of early warning indicators based on changes in regional growth patterns.

APPENDIX I

Mexico: Political Division

Mexico: Characteristics of the Mexican States in 1990

	Index of GDP in 1993	Population ('000)	Education 1/	Occupation as Percent of Economically Active Population: Agriculture	Occupation as Percent of Economically Active Population: Manufacturing	Number of Persons Employed in Maquilas 2/	Number of Total Ejidatarios 3/	Oil and Natural Gas Production as Percent of Total National 4/
Northern States								
1. Baja California	2.5	1,661	15.7	9.2	22.7	84,043	6,648	--
2. Baja California Sur	0.5	318	12.2	16.5	8.5	--	566	--
3. Coahuila	2.8	1,972	11.7	11.2	24.8	21,224	35,948	0.1
4. Chihuahua	2.9	2,442	10.7	15.6	25.6	124,386	5,097	--
5. Durango	1.2	1,349	9.3	26.9	16.4	--	2,841	--
6. Nayarit	0.7	825	11.3	37.0	9.8	--	5,687	--
7. Nuevo León	6.5	3,099	15.3	5.6	29.0	--	--	--
8. San Luis Potosí	1.8	2,003	9.9	30.5	16.9	--	--	0.7
9. Sinaloa	2.2	2,204	9.6	10.4	--	30,204	--	--
10. Sonora	2.6	1,824	13.4	19.7	15.7	29,441	16,775	--
11. Tamaulipas	2.6	2,250	11.3	14.5	18.3	76,817	11,020	1.1
12. Zacatecas	0.8	1,276	7.8	37.3	8.5	--	4,780	--
Central States								
1. Aguascalientes	0.9	720	10.4	13.7	24.2	--	1,523	--
2. Colima	0.6	429	11.1	23.2	9.8	--	1,008	--
3. Distrito Federal	24.1	8,236	14.4	0.6	20.7	--	--	--
4. Guanajuato	3.5	3,983	8.9	21.1	24.2	--	15,202	--
5. Hidalgo	1.6	1,888	10.2	35.6	15.0	--	22,146	--
6. Jalisco	6.6	5,303	10.9	14.5	23.5	--	14,040	--
7. México	10.5	9,816	14.5	8.2	27.5	--	18,538	--
8. Michoacán	2.3	3,548	8.5	32.7	14.8	--	47,796	--
9. Morelos	1.6	1,195	14.4	19.2	15.7	--	13,628	--
10. Puebla	3.2	4,126	9.4	35.6	17.4	--	6,409	--
11. Querétaro	1.4	1,051	10.4	16.0	24.6	--	2,657	--
12. Tlaxcala	0.6	761	13.3	27.2	24.6	--	2,539	--
13. Veracruz	4.9	6,228	8.7	37.7	11.2	--	3,508	4.4
Southern States								
1. Campeche	1.6	535	8.3	32.6	9.1	--	990	67.3
2. Chiapas	1.8	3,210	6.0	56.8	5.8	--	665	--
3. Guerrero	2.0	2,621	9.2	34.7	8.9	--	1,676	--
4. Oaxaca	1.7	3,020	7.0	55.6	9.8	--	1,067	--
5. Quintana Roo	1.3	493	12.2	19.0	6.2	--	--	--
6. Tabasco	1.5	1,502	9.6	34.0	8.2	--	4,599	26.5
7. Yucatán	1.3	1,363	8.9	26.2	15.2	--	4,729	--
Total (National)	100.0	81,250	11.1	100.0	100.0	429,725	282,286	100.0

Sources: Population and Education: INEGI, Censo de Población y Vivienda 1990; Agriculture and manufacturing: INEGI, Censo de Población y Vivienda 1990, Table 32; Maquila: Pick and Butler (1994), pp. 380-381; Ejidos: Anuario Estadistico Banamex, 1974-1975, Table 10.4; Oil: Pick and Butler (1994), p. 234.

1/ Population of age 12 plus with secondary education to total population age 12 plus.
2/ Data for 1989. State data comprises the leading municipios only.
3/ Data for number of owners in 1974-75. Data for Guanajuato incorporates part of Michoacan.
4/ Data for 1988.

Mexico: Average Annual Growth Rates of Real Per Capita GDP by States and by Regions
(In percent)

	1970-93	1970-85	1985-93	1970-80	1980-85	1985-88	1988-93
NORTHERN STATES	1.28	2.13	-0.31	2.36	1.68	-0.54	-0.17
1 BAJA CALIFORNIA	0.26	1.31	-1.69	1.84	0.26	-1.14	-2.02
2 BAJA CALIFORNIA SUR	0.59	0.94	-0.06	2.13	-1.40	0.98	-0.68
3 COAHUILA	1.25	2.10	-0.32	2.62	1.05	0.25	-0.66
4 CHIHUAHUA	1.20	2.14	-0.54	2.38	1.67	1.12	-1.52
5 DURANGO	1.61	3.65	-2.12	3.17	4.62	-5.37	-0.12
6 NAYARIT	1.25	2.38	-0.82	2.44	2.25	-4.37	1.36
7 NUEVO LEON	1.43	1.99	0.40	2.51	0.95	-0.40	0.87
8 SAN LUIS POTOSI	2.40	3.33	0.67	3.08	3.83	1.38	0.24
9 SINALOA	0.85	1.39	-0.15	0.93	2.32	-1.65	0.76
10 SONORA	0.64	1.06	-0.15	0.59	2.00	0.08	-0.28
11 TAMAULIPAS	0.85	1.94	-1.17	2.88	0.09	-2.29	-0.49
12 ZACATECAS	1.59	3.08	-1.13	2.17	4.91	1.80	-2.85
CENTRAL STATES	1.34	1.85	0.40	2.70	0.17	-1.24	1.40
1 AGUASCALIENTES	2.26	2.65	1.54	3.09	1.76	-1.20	3.23
2 COLIMA	2.84	3.60	1.44	3.71	3.37	-2.51	3.89
3 DISTRITO FEDERAL	2.57	1.95	3.73	3.02	-0.14	1.07	5.36
4 GUANAJUATO	1.45	2.03	0.38	2.14	1.80	-1.79	1.70
5 HIDALGO	2.48	3.80	0.05	5.17	1.13	1.20	-0.63
6 JALISCO	1.26	2.24	-0.55	2.78	1.17	-1.60	0.09
7 MEXICO	0.31	1.50	-1.88	2.00	0.50	-1.96	-1.83
8 MICHOACAN	1.48	2.48	-0.36	3.67	0.15	0.39	-0.81
9 MORELOS	2.38	2.21	2.68	2.12	2.41	-0.19	4.45
10 PUEBLA	1.51	2.66	-0.62	3.56	0.88	-3.98	1.45
11 QUERETARO	2.70	4.34	-0.30	4.00	5.01	-2.18	0.84
12 TLAXCALA	2.50	5.60	-3.07	5.08	6.65	-6.97	-0.65
13 VERACRUZ	0.49	1.58	-1.54	1.90	0.94	-1.75	-1.41
SOUTHERN STATES	2.77	6.52	-3.91	8.10	3.41	-9.67	-0.29
1 CAMPECHE	6.13	16.86	-11.41	2.08	53.16	-19.49	-6.18
2 CHIAPAS	1.11	4.37	-4.73	9.13	-4.54	-9.91	-1.48
3 GUERRERO	2.20	2.73	1.21	3.37	1.47	0.26	1.79
4 OAXACA	2.74	4.62	-0.70	4.37	5.14	-3.74	1.17
5 QUINTANA ROO	4.33	3.18	6.50	4.97	-0.30	3.55	8.31
6 TABASCO	1.74	7.86	-8.81	16.71	-7.89	-15.15	-4.78
7 YUCATAN	1.59	2.03	0.77	3.08	-0.06	-1.21	1.98
REGIONAL STATISTICS							
NORTHERN STATES							
Maximum Value	2.40	3.65	0.67	3.17	4.91	1.80	1.36
Minimum Value	0.26	0.94	-2.12	0.59	-1.40	-5.37	-2.85
Range Value	2.14	2.71	2.79	2.57	6.31	7.17	4.21
Average per states	1.16	2.11	-0.59	2.23	1.88	-0.80	-0.45
Standard Deviation (SD)	0.57	0.88	0.83	0.79	1.88	2.28	1.23
CENTRAL STATES							
Maximum Value	2.84	5.60	3.73	5.17	6.65	1.20	5.36
Minimum Value	0.31	1.50	-3.07	1.90	-0.14	-6.97	-1.83
Range Value	2.54	4.11	6.80	3.26	6.79	8.18	7.20
Average per states	1.86	2.82	0.12	3.25	1.97	-1.65	1.21
Standard Deviation (SD)	0.84	1.20	1.87	1.09	1.98	2.18	2.38
SOUTHERN STATES							
Maximum Value	6.13	16.86	6.50	16.71	53.16	3.55	8.31
Minimum Value	1.11	2.03	-11.41	2.08	-7.89	-19.49	-6.18
Range Value	5.02	14.83	17.91	14.64	61.05	23.04	14.49
Average per states	2.83	5.95	-2.45	6.24	6.71	-6.53	0.12
Standard Deviation (SD)	1.79	5.17	6.23	5.14	20.90	8.54	4.84
REGIONAL COMPARISONS							
Northern states	1.28	2.13	-0.31	2.36	1.68	-0.54	-0.17
Central states	1.34	1.85	0.40	2.70	0.17	-1.24	1.40
Southern states	2.77	6.52	-3.91	8.10	3.41	-9.67	-0.29
Maximum Value	2.77	6.52	0.40	8.10	3.41	-0.54	1.40
Minimum Value	1.28	1.85	-3.91	2.36	0.17	-9.67	-0.29
Range Value	1.49	4.67	4.32	5.74	3.24	9.13	1.69
Average per region	1.80	3.50	-1.28	4.39	1.76	-3.82	0.31
Standard Deviation (SD)	0.84	2.62	2.31	3.22	1.62	5.08	0.94

Convergence model, the Convergence Speed, β, and the Half-life, T_{half}.

Consider a production function expressed in terms of effective units of labor:

$$y_t = k_t^{\alpha},$$

where $y_t = Y_t/(A_tL_t)$ and $k_t = K_t/(A_tL_t)$ represent real GDP (y) and capital (k) both per unit of effective labor (AL), and α<1. $A_t = A_0e^{gt}$ represents the labor-augmenting technological progress, and $L_t = L_0e^{nt}$ is the labor force.

The economy resource constraint implies that real GDP per effective labor equals real consumption per effective labor plus change in capital per effective labor plus the change in capital required to keep the capital-effective labor ratio constant:

$$y = (1-s)y + \dot{k} + k(g+n+\delta).$$

where s is the constant savings rate, g is the rate of change of the labor-augmenting technological progress, n is the rate of increase of the labor force and δ is the rate of capital depreciation.

The resource constraint and the production function imply $\dot{k} = sk^{\alpha} - k(g+n+\delta)$, which can alternatively be expressed as $\dot{k}/k = sk^{\alpha-1} - (g+n+\delta)$. Imposing $\dot{k} = 0$, yields the steady state value of the capital-effective labor ratio: $k^* = [s/(n+g+\delta)]^{1/(1-\alpha)}$.

Expanding $\dot{k}/k$ in a Taylor's series around the steady-state value, k^*, obtains a differential equation for the behavior of k around its steady state:

$$\dot{k}^*/k^* = sk^{*(\alpha-1)} - (g+n+\delta) + s(\alpha-1)k^{*\alpha-2}(k - k^*) + \dots.$$

Given that $sk^{*\alpha-1} - (g+n+\delta) = 0$, the above differential equation can be approximated by:

$$\dot{k}^*/k^* \sim s(\alpha-1)k^{*\alpha-1}(k - k^*)/k^* = s(\alpha-1)[(g+n+\delta)/s](k - k^*)/k^*.$$

Defining $\beta \equiv -(\alpha-1)(g+n+\delta) > 0$, obtains:

$$\dot{k}^*/k^* \sim -\beta(k - k^*)/k^*.$$

Note that, given that $\beta > 0$, the stock of capital per effective labor grows whenever its current level, k, is below its steady-state level, k^*.

A differential equation for real GDP per unit of effective labor can be derived from the production function:

$$\dot{y}/y = \alpha\dot{k}^*/k^* \sim -\alpha\beta(k - k^*)/k^*$$

$$\sim -\alpha\beta(\ln k_t - \ln k^*) = -\alpha\beta[(\ln y_t)/\alpha - (\ln y^*)/\alpha]$$

$$= -\beta(\ln y_t - \ln y^*).$$

Note that, given that $\beta > 0$, real GDP per effective labor grows whenever its current level is below its steady-state level.

The general solution to the above differential equation is $\ln y_t = \ln y^* + \Omega e^{-\beta t}$, where Ω is the constant of integration. Solving for the constant of integration at $t = 0$, obtains $\Omega = \ln y(0) - \ln y^*$. Plugging the constant of integration into the general solution obtains equation 1 in the text:

$$\ln y_t - \ln y(0) = (1 - e^{-\beta t}) \ln y^* - (1 - e^{-\beta t}) \ln y(0).$$

Making $t = T$, dividing both sides by T, and defining $\alpha \equiv ((1 - e^{-\beta T})/T) \ln y^*$, gives equation 2 in the text.

The half-life, T_{half}, is the time that it takes to reach the midpoint between the logarithms of initial and steady state incomes, $\ln y(0)$ and $\ln y^*$. The previous equation can alternatively be expressed as:

$$\ln y_t = (1 - e^{-\beta t}) \ln y^* + e^{-\beta t} \ln y(0).$$

The midpoint between $\ln y^*$ and $\ln y(0)$ is given by $\ln y(T_{half}) = (1/2) \ln y^* + (1/2) \ln y(0)$. This means that $(1 - \exp(-\beta T_{half})) = 1/2$ and $\exp(-\beta T_{half}) = 1/2$. Both equations imply: $\exp(-\beta T_{half}) = 1/2$. Taking the natural logarithm in the last equality obtains the half-life: $-\beta T_{half} = \ln(1/2)$, or $T_{half} = \ln(2)/\beta = 0.69/\beta$.

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