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Analysis of club convergence in the U.S. after the Great Recession

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Abstract

This paper examines club convergence using per capita real state domestic product and three technological variables, which are patents, research and development, and bachelor's degrees in science and engineering in the 50 states of the U.S. as it exits the Great Recession. This study finds the states that are in higher clubs with respect to per capita real state domestic product also ranks higher in the technological clubs, which is in keeping with clustering around different steady-state equilibria. In terms of policy implications, this paper also finds there to be a more direct nonrandom, statistically significant association between per capita real state domestic product and research and development, and bachelor's degrees in science and engineering and an indirect association with patents.

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1. Introduction

The discussion about convergence or divergence has become a renewed, growing interest to researchers and policymakers recently. The hypothesis of convergence, in practice, implies that per capita incomes for different countries are approaching each other, so this assumes that poorer countries are catching up with richer countries.

The neoclassical growth models argue that the rate of growth of relatively poorer economies is bigger than that of relatively richer ones, and they tend to converge toward a single long-run steady state (Solow 1956, and Swan 1956). Conversely, endogenous growth models state that there will be no convergence between poor and rich economies and these differences can also increase over time indefinitely (Durlauf 1996, Romer 1986, and Lucas 1988).

Modern growth theories have shown that the spread of per capita income in regions can show a trend for different steady-state equilibria if they differ in their initial conditions. This implies that the club convergence hypothesis enables multiple stable steady states (Durlauf and Johnson 1995). The club convergence hypothesis predicts that countries with similar structural characteristics and different initial income per capita can be a part of different clubs (Durlauf 1996). There are a number of factors explaining this hypothesis: capital market imperfections, imperfectly competitive market structures, or spillovers due to human and capital accumulation (Durlauf and Johnson 1995). Schumpeterian endogenous growth models provide an alternative explanation by placing technological change as the main factor for the emergence of convergence clubs (Castellacci 2008).

In order to investigate the performance of the 50 states as they exit The Great Recession, this paper uses per capita real State Domestic Product (SDP) and three technological variables, which are U.S. patents per capita, Research and Development (R&D) per capita, and the number of conferred Bachelor's degrees in Science and Engineering (S&E) per 1,000 individuals.

Phillips and Sul (2007 and 2009) advance the analysis of convergence by providing a methodology that is able to capture all three types of convergences, which are absolute convergence, conditional convergence, and club convergence as is utilized in this paper. The methodology deals with a test that is based on regression analysis, which this paper refers to as the PS *log t* test. This method adeptly handles heterogeneous data. Namely, it relies on a non-linear factor panel data modeling of economic transition dynamics that gathers both the time-varying idiosyncratic component and the single common growth component. The PS *log t* test does not require a pre-clustering of the economies, since this method is able to identify groups by unspecified factors that determine the formation of the convergence clubs.

The goal of this paper is two-fold with respect to the application of the methodology due to Phillips and Sul (2007). First, the type of convergence is determined using the per capita SDP and the three technological indicators; for the second goal, this paper examines whether or not the measures of technological development are related to the formation of convergence clubs for per capita SDP. Specifically, Fisher's Exact Test is used to test for independence between the variables in order to determine whether the technological clubs are conditional on club convergence for per capita SDP.

This study makes two new contributions to the empirical literature. First, it finds new evidence of convergence patterns of technological capabilities in the U.S. states as they exit The Great Recession, and second, it provides information about the relationships between the technological capacities of the states and the formation of convergence clubs in real SDP per capita.

The structure of the paper is as follows: Section 2 contains a brief description of the data; Section 3 contains the convergence of real SDP per capita for all 50 U.S. states; Section 4 presents the technological capabilities and patterns of convergence across 50 U.S. states; and Section 5 concludes.

2. Data

The variables to test for convergence are per capita real SDP and three technological variables used for each of the 50 U.S. states. Per capita real SDP is chained-weighted in 2009 dollars and is extracted from the Bureau of Economic Analysis (BEA).[1]

The indicators of technological capabilities used in the study are as follows:

(a) U.S. patents divided by state population: The number of U.S. patents is gathered by state of origin, which is given by the residence of the first-named inventor, and the year of grant.[2]

(b) R&D as a percentage of real SDP: This shows the importance of R&D in the economy of a state. If it takes a high value, it means that a state has a high level of intensity regarding R&D activity or a major federal R&D facility, which could imply future growth in knowledge-based industries. The R&D indicator collects the R&D activities due to federal and state agencies, businesses, universities, and nonprofit organizations. It should be noted that the R&D-performing organizations can either fund themselves or receive external government funding.[3]

(c) S&E per 1,000 individuals: Bachelor's Degrees in Science and Engineering (S&E) conferred per 1,000 individuals between the ages of 18 to 24 represents the proportion of bachelor's-level training in S&E fields with respect to its college-age population, excluding students in the medical or technology fields. The number of awarded bachelor's degrees in S&E fields is provided by the National Center for Education Statistics and includes degrees from both public and private institutions. These values are reported by the state in which the degree-granting institution is located.[4]

The first two measures of technological innovation are used to measure innovative ability. They are proxies for what a country is able to produce in new technology and knowledge

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[1] It should be noted that Philips and Sul (2007) justify a data sample of 10 years with a minimum of 50 observations using Monte Carlo simulations. Data samples with similar date ranges have been considered by other papers such as Bartkowska and Riedl (2012), who examine club convergence in European regions, and Monfort, Cuestas, and Ordóñez (2013), who examine club convergence with respect to the gross domestic product per worker in the European Union.

[2] The source of the data is the Technology Assessment and Forecast (TAF) database maintained by the U.S. Patent and Trademark Office; please see https://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_utlh.htm for more details.

[3] The highest value of this indicator usually corresponds to New Mexico, because of the high concentration of R&D activities at two national laboratories in the state, as well as the relatively small gross domestic product of the state. The source of the data is the National Science Foundation (NSF); please see https://ncses.nsf.gov/indicators/states/indicator/rd-performance-to-state-gdp/table for more details.

[4] The source of the data is the National Science Foundation (NSF); please see https://ncses.nsf.gov/indicators/states/indicator/se-bachelors-degrees-per-1000-18-24-year-olds/table for more details.

(Archibugi and Coco 2004, and Castellacci 2011); the third and last technological variable is a proxy of a state's capacity to absorb and utilize external knowledge (Castellacci 2008).

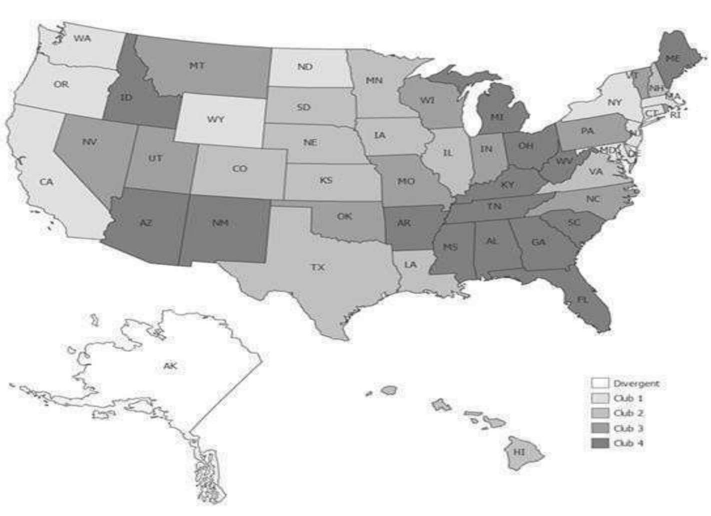
3. Convergence of per Capita real SDP across U.S. States from 1997 to 2010

The hypothesis of global convergence is strongly rejected at the 5% significance level as the PS *log t* test for per capita real SDP is tested across the 50 States from 1997 to 2010. The cluster mechanism procedure is able to identify four convergence clubs. The corresponding estimated *t*-statistic clearly is greater than -1.65 as is shown in Table 1. Table 1 presents the recursive algorithm results from the Phillips and Sul (2007) methodology, and it shows the convergence clubs obtained for real SDP per capita. Figure 1 illustrates the four-convergence club membership using the map of the U.S.

Table 1. Convergence Clubs for per capita SDP

	States	*t*-Statistic	$\widehat{\beta}$	Average real SDP per capita (2010)
Club 1	Connecticut, Wyoming, Delaware, New York, Massachusetts, New Jersey, Maryland, Washington, North Dakota, California, Oregon	1.3462	0.1860	57,228
Club 2	Virginia, Illinois, Nebraska, Hawaii, Colorado, Louisiana, Iowa, South Dakota, Minnesota, New Hampshire, Texas, Kansas	3.5438	0.5445	48,403
Club 3	Pennsylvania, Rhode Island, Nevada, Wisconsin, North Carolina, Indiana, Missouri, Vermont, Utah, Oklahoma, Montana	0.0959	0.0297	42,678
Club 4	Ohio, Georgia, New Mexico, Tennessee, Michigan, Florida, Maine, Arizona, Kentucky, Alabama, West Virginia, South Carolina, Arkansas, Idaho, Mississippi	-0.2384	-0.0514	37,535

Figure 1. Convergence Clubs for per capita SDP



4. Technological Capabilities and Patterns of Convergence across the United States

The existence of clustering, polarization, and in turn convergence clubs, is strongly explained by the innovation capacity. Schumpeterian growth models also have the ability to incorporate foreign advanced technologies (Castellacci 2008). Indeed, the process of diffusion is expensive, and the states below the technological frontier need to have social and institutional capabilities that are successful in imitating advanced technology (Castellacci 2007).

These inductive forces, represented by an innovation system, are the technological abilities of a state related to the efforts across all scientific and technical fields, including the educational system, the skills and capabilities of the labor force, and the development of science in universities, and public research centers (Urraca-Ruiz 2013). States with a lower technological level, when compared to more advanced states, can increase their undeveloped position. Their growth rates could improve through the diffusion of international technology only by imitation (Fagerberg 1987, and Castellacci 2007).

4.1. Technological Capabilities across the States and Identification of Technological Clubs

As is known from the endogenous growth perspective, one of the basic explanatory factors that determines the persistent difference in economic performance is the gap in innovation capacity among economies (Rodríguez-Pose and Crescenzi 2008).

The technological capabilities for the four income clubs at the beginning and end of the analyzed period, 1997 and 2010 respectively, are displayed in Table 2. It also shows the technology-gap between Club 1 and Club 2, as well as between Club 2 and Club 3 and Club 3 and Club 4.

Table 2. Technological Capabilities across the 50 States of the U.S.

	Club 1		Club 2		Club 3		Club 4	
TECHNOLOGICAL CAPABILITIES	1997	2010	1997	2010	1997	2010	1997	2010
Patents per capita	294.04	464.27	185.99	271.03	212.57	304.32	153.07	202.05
R&D as a percentage of SDP	2.84	3.31	1.43	1.82	1.77	2.01	1.84	2.02
Bachelor's S&T enrollment	34.7	32.4	30.8	28.7	30.9	29.1	27.4	25.4
TECHNOLOGY GAP			Club 1 *vs*. Club 2		Club 2 *vs*. Club 3		Club 3 *vs*. Club 4	
			1997	2010	1997	2010	1997	2010
Patents per capita			1.58	1.71	0.87	0.89	1.39	1.51
R&D as a percentage of SDP			1.98	1.82	0.81	0.91	0.96	0.99
Bachelor's S&E enrollment			1.13	1.13	0.99	0.99	1.13	1.14

The results imply the existence of technological differences between the richest group and the first middle-income group, and also between the second middle-income one and the groups of poorer states, but not between the middle-income groups. The main technology gap, between clubs, has been the corresponding between the richest states and the highest middle-income ones, especially regarding R&D expenditure and patents per capita.

Since one of the goals is to estimate the patterns of convergence in technological capabilities across U.S. states, the PS *log t* test is applied to the number of patents proportional to the state's population, R&D as a percentage of real SDP and S&E per 1,000 individuals.

When the PS *log t* test is applied to patents per capita across U.S. states, the hypothesis of overall convergence is rejected at the 5% significance level. The clustering mechanism is then applied, and 11 convergence clubs and four divergent states are found. Then, the Phillips and Sul's (2009) merging test procedure is applied, and seven convergence clubs are identified. Table 3 reports the convergence clubs result for patents per capita.

Table 3. Convergence Clubs for Patents per Capita

	States	*t*-Statistic	$\widehat{\beta}$
Club 1	Vermont, Washington, Massachusetts, California, Idaho, Minnesota, Oregon, New Hampshire, Connecticut, New Jersey, Colorado, Utah	-0.0575	-0.2582
Club 2	Delaware, Michigan, New York	-0.3149	-0.4715
Club 3	Wisconsin, Arizona, Texas, North Carolina, Rhode Island, Kansas, Illinois, Ohio, Pennsylvania, Iowa	-0.0090	-0.0643
Club 4	New Mexico, Nevada, Virginia, Georgia, North Dakota, Florida, Missouri, Maine	-0.5486	-1.4647
Club 5	Tennessee, Wyoming, Oklahoma, Kentucky, Nebraska	-0.3718	-1.2525
Club 6	South Carolina, Montana, Alabama, Hawaii, South Dakota	0.0040	0.0083
Club 7	Louisiana, West Virginia, Mississippi	0.0854	0.5053
Divergent	Maryland, Indiana, Arkansas, Alaska		

R&D as a percentage of SDP is the second variable tested for convergence in innovation, and Phillips and Sul's (2009) hypothesis of overall convergence is rejected at the 5% significance level. Eight convergence clubs are discovered with three states diverging, which are Oklahoma, Louisiana, and Wyoming. After the merging test procedure is performed, six convergence clubs appear (Phillips and Sul 2009). Table 4 shows the convergence club results for R&D as a percentage of real SDP.

Table 4. Convergence Clubs for R&D as a Percentage of SDP

	States	*t*-Statistic	$\widehat{\beta}$
Club 1	New Mexico, Maryland, Massachusetts, Washington, Connecticut	-0.1274	-0.3267
Club 2	California, Delaware, Michigan, New Jersey, Missouri, Virginia	-0.0084	-0.0203
Club 3	New Hampshire, Idaho, Rhode Island, Oregon, Minnesota, Utah, Colorado, Illinois, Indiana, Arizona, Pennsylvania, Alabama, Wisconsin, North Carolina, Ohio, Iowa	0.1526	0.5140
Club 4	Vermont, Tennessee, Texas, Kansas, South Carolina, New York, Georgia, North Dakota, Florida, South Dakota, Montana, Hawaii, Nebraska	-0.3043	-1.0682
Club 5	Maine, Kentucky, Mississippi, West Virginia, Nevada	0.1422	0.2008
Club 6	Alaska, Arkansas	0.7521	0.6224
Divergent	Oklahoma, Louisiana, Wyoming		

The last technological variable regards Bachelor's Degrees in Science and Engineering Conferred per 1,000 individuals, which is a proxy for the ability to absorb, and hopefully utilize, external knowledge in U.S. states. The PS *log t* test is applied to the S&E data where seven clubs are initially found. After the merging procedure, five convergence clubs are found with there being four divergent states, which are New Mexico, Pennsylvania, Idaho, and Illinois (Phillips and Sul 2009). Table 5 presents the results for the S&E degrees convergence clubs.

Table 5. Convergence Clubs for Bachelor's Degrees in Science and Engineering

	States	*t*-Statistic	$\widehat{\beta}$
Club 1	Vermont, Wyoming, California, Maryland	0.2394	0.1744
Club 2	Alaska, New Jersey, Washington, Virginia, Colorado, Connecticut, Hawaii, Montana, Maine, South Dakota, Massachusetts, Oregon	0.8029	0.2572
Club 3	Utah, North Carolina, Iowa, New Hampshire, Michigan, Wisconsin, Rhode Island, Nevada	0.8641	0.1831
Club 4	New York, Delaware, Texas, Florida, Louisiana, Nebraska, South Carolina, Georgia, Minnesota, Ohio, Indiana, West Virginia, Alabama, Oklahoma, Mississippi, Tennessee, Kansas	-1.5521	-0.3207
Club 5	North Dakota, Kentucky, Missouri, Arkansas, Arizona	-1.5706	-0.4676
Divergent	New Mexico, Pennsylvania, Idaho, Illinois		

4.2. Are Real SDP Clubs Related to Technological Clubs Identification?

In order to determine if there is a nonrandom statistical association between the 3 technological variables and per capita real SDP, Fisher's Exact Test is used with the results being found in Table 7.[5]

Table 7. Fisher's Exact Test Results*

Dependent Variable	*Independent Variable*	*p-value*
SDP Clubs	Patents Clubs	0.1790000
SDP Clubs	R&D Clubs	0.0007900
SDP Clubs	S&E Clubs	0.0426000
Patents Clubs	R&D Clubs	0.0000029

* When p-value ≥ 0.05 the null hypothesis of independence is accepted at the 5% of significance level; otherwise, the independence is rejected.

Hence, regarding per capita real SDP and the three technological variables, there is a direct nonrandom relationship between R&D as a percentage of real SDP and S&E per 1,000 individuals. In addition, there is an indirect relationship between per capita real SDP and patents as a percentage of real SDP since patents as a percentage of real SDP has a direct nonrandom relationship with R&D as a percentage of real SDP.

[5] For more information about Fisher's Exact Test, please refer to Weisstein, Eric W. "Fisher's Exact Test." From *MathWorld*--A Wolfram Web Resource. https://mathworld.wolfram.com/FishersExactTest.html.

5. Conclusions

The degree of economic convergence with a two-steps procedure to empirically test for the conditional convergence hypothesis in the U.S. from 1997 to 2010 is analyzed using the still novel methodology developed by Phillips and Sul (2007).

First, the PS *log t* test is applied in order to endogenously identify club convergence, and then this methodology is applied to test for convergence patterns in technological capabilities in the U.S. through the use of three indicators related to technology. Second, the existence of a relationship between the clubs is found in real per capita SDP and the technological characteristics of the states.

Regarding the per capita SDP from 1997 to 2010, the U.S. does not display absolute convergence, but it displays club convergence using the PS log *t* test. The test shows the existence of four clubs with different speeds of convergence. Upon exiting the Great Recession, the U.S. has four convergence clubs in per capita real SDP, which differs from the findings of two convergence clubs in Barrios, Tierney, Nazarov, and Kim (2020), whose data sample is from 1997 to 2017.

This paper also finds there to be convergence clubs using three technological variables, which are patents as a percentage of real SDP, R&D as a percentage of real SDP, and S&E per 1,000 individuals. There are seven convergence clubs in patents as a percentage of real SDP, six convergence clubs in R&D as a percentage of real SDP, and five convergence clubs in S&E per 1,000 individuals.

To be in either Clubs 1 or 2 using per capita real SDP, the states generally tend to be in the clubs that are above unity in the transition path curves with respect to the 3 technological variables. The reverse seems to be the case for Clubs 3 and 4 using per capita real SDP.

In addition, the use of Fisher's Exact Test indicates a nonrandom and statistically significant relation between per capita real SDP and R&D as a percentage of real SDP, and S&E per 1,000 individuals. It should also be noted that patents as a percentage of real SDP and R&D as a percentage of real SDP share a nonrandom, statistically significant association while patents as a percentage of real SDP and per capita real SDP do not share a statistically significant association according to Fisher's Exact Test at the 5% significance level. Therefore, patents can possibly affect per capita real SDP through R&D as a percentage of real SDP, indirectly.

From the policy point of view, the findings of this paper recommend that if a state wants to move to a higher convergence club using per capita real SDP, it needs to improve with respect to R&D and S&E, which have some important policy implications.

Patents seem to have an indirect statistical association to per capita real SDP through R&D, so this relationship can be an argument to increase public spending either in tax incentives or in direct aid to promote patents investment, which can move a state to a higher convergence club in per capita real SDP.

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Appendix

Table A. Convergence Clubs for per Capita Real SDP & the Technological Variables

States	Convergence Clubs			
	Real SDP Per Capita	Patents Per Capita	R&D as % of Real SDP	S&E per 1,000 People
Alaska	0	0	6	2
Maryland	1	0	1	1
Connecticut	1	1	1	2
Massachusetts	1	1	1	2
Washington	1	1	1	2
California	1	1	2	1
New Jersey	1	1	2	2
Oregon	1	1	3	2
Delaware	1	2	2	4
New York	1	2	4	4
North Dakota	1	4	4	5
Wyoming	1	5	0	1
Colorado	2	1	3	2
New Hampshire	2	1	3	3
Minnesota	2	1	3	4
Illinois	2	3	3	0
Iowa	2	3	3	3
Kansas	2	3	4	4
Texas	2	3	4	4
Virginia	2	4	2	2
Nebraska	2	5	4	4
Hawaii	2	6	4	2
South Dakota	2	6	4	2
Louisiana	2	7	0	4
Indiana	3	0	3	4
Utah	3	1	3	3
Vermont	3	1	4	1
Pennsylvania	3	3	3	0
North Carolina	3	3	3	3
Rhode Island	3	3	3	3
Wisconsin	3	3	3	3
Missouri	3	4	2	5
Nevada	3	4	5	3
Oklahoma	3	5	0	4
Montana	3	6	4	2
Arkansas	4	0	6	5
Idaho	4	1	3	0

Michigan	4	2	2	3
Ohio	4	3	3	4
Arizona	4	3	3	5
New Mexico	4	4	1	0
Florida	4	4	4	4
Georgia	4	4	4	4
Maine	4	4	5	2
Tennessee	4	5	4	4
Kentucky	4	5	5	5
Alabama	4	6	3	4
South Carolina	4	6	4	4
Mississippi	4	7	5	4
West Virginia	4	7	5	4

Table B: Convergence Clubs for per Capita Real SDP & the Technological Variables (In Alphabetical Order by State)

States	Convergence Clubs			
	Real SDP per Capita	Patents per Capita	R&D as % of Real SDP	S&E per 1,000 People
Alabama	4	6	3	4
Alaska	0	0	6	2
Arizona	4	3	3	5
Arkansas	4	0	6	5
California	1	1	2	1
Colorado	2	1	3	2
Connecticut	1	1	1	2
Delaware	1	2	2	4
Florida	4	4	4	4
Georgia	4	4	4	4
Hawaii	2	6	4	2
Idaho	4	1	3	0
Illinois	2	3	3	0
Indiana	3	0	3	4
Iowa	2	3	3	3
Kansas	2	3	4	4
Kentucky	4	5	5	5
Louisiana	2	7	0	4
Maine	4	4	5	2
Maryland	1	0	1	1
Massachusetts	1	1	1	2
Michigan	4	2	2	3
Minnesota	2	1	3	4
Mississippi	4	7	5	4
Missouri	3	4	2	5
Montana	3	6	4	2
Nebraska	2	5	4	4
Nevada	3	4	5	3
New Hampshire	2	1	3	3
New Jersey	1	1	2	2
New Mexico	4	4	1	0
New York	1	2	4	4
North Carolina	3	3	3	3
North Dakota	1	4	4	5
Ohio	4	3	3	4
Oklahoma	3	5	0	4
Oregon	1	1	3	2
Pennsylvania	3	3	3	0

Rhode Island	3	3	3	3
South Carolina	4	6	4	4
South Dakota	2	6	4	2
Tennessee	4	5	4	4
Texas	2	3	4	4
Utah	3	1	3	3
Vermont	3	1	4	1
Virginia	2	4	2	2
Washington	1	1	1	2
West Virginia	4	7	5	4
Wisconsin	3	3	3	3
Wyoming	1	5	0	1