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Exploratory Spatial Data Analysis of σ-convergence in the U.S. Regional Income Distribution, 1969-1999

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미국의 지역별 소득분포의 시그마-수렴에 대한 탐색적 공간자료분석

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Abstract : This study is predicated on the recognition that regional analyses should take advantage of recent advances in spatial data analysis, especially ones utilizing spatial association measures, to investigate spatial dependence and spatial heterogeneity. Thus, the main objectives are to: (1) provide a critical review of empirical studies on the σ-convergence from a spatial perspective; (2) investigate spatio-temporal income dynamics across the U.S. labor market areas for the last 30 years (1969-1999) by utilizing various ESDA (exploratory spatial data analysis) techniques. The main findings are as follows. First, several spatial clusters throughout the years are detected, but rich clusters possess a higher level of internal homogeneity than poor clusters. It is also observed that the internal integrity within the clusters has substantially been eroded. Second, the thirty years does not reveal a significant spatial restructuring; whereas most areas in the tradition industrial cores are still enjoying a higher-than-average income level, most areas in the South suffer from the continuation of lower-than-average income. Third, the notion of σ-convergence is not empirically evidenced; rather, a general trend towards income divergence was detected since the late 1970s, particularly the mid-1990s. Two ascending trends in CV, each of which is oppositely associated with the Moran's *I* trend in the late 1980s and the late 1990s, suggest that different spatial processes were involved in those periods. That is, a contagious spatial process leading to spatial clustering was dominant in the former, while a sporadic spatial process inducing spatial dispersion somewhat prevailed in the latter.

Key Words : σ-convergence, ESDA (exploratory spatial data analysis), spatial association measures, spatial dependence, spatial heterogeneity.

요약 : 본 연구는 지역간 소득분포의 수렴/발산에 대한 경험적 연구 결과가 보여주고 있는 불일치성과 비일관성이 최근 발전을 거듭하고 있는 공간자료분석의 연구절차들을 도입함으로써 상당한 정도 해소될 수 있다는 인식에 기반하고 있다. 특히 '공간적 연관 통계치(spatial association measures)'를 이용한 다양한 탐색적 공간자료분석(ESDA; exploratory spatial data analysis) 기법들은 지역간 소득분포의 수렴/발산 연구에 새로운 지평을 열 수 있을 것이다. 이러한 측면에서, 본 연구는 두 가지 목적을 갖는데, 첫째는 시그마-수렴 테제와 그것에 근거한 경험적 연구결과에 대한 비판적 검토를 통해 공간적 효과(공간적 의존성과 공간적 이질성)에 대한 고려의 당위성을 논증하는 것이고, 둘째는 다양한 탐색적 공간자료분석 기법을 이용하여 미국 30년간의 지역별 소득자료에 적용하여 분석하는 것이다. 주요한 연구결과를 요약하면 다음과 같다. 첫째, 통계적 유의성을 갖는 소득의 집중지(clusters)가 확인되었다. 그러나 고소득 집중지의 내적 동질성이 저소득 집중지의 그것에 비해 훨씬 높은 것으로 드러났다. 또한 이러한 소득 집중지의 공간적 범위나 내적 견고성은 30년 동안 상당한 정도 훼손된 것이 확인되었다. 둘째, 지난 30 동안 현저한 공간적 재구조화는 발생하지 않았다. 즉, 고소득과 저소득의 공간적 구조는 크게 변화하지 않았다. 셋째, 뚜렷한 시그마-수렴은 지난 30년간에는 발생하지 않은 것으로 드러났다. 오히려 70년대 후반 이후 발산-수렴의 파동과 함께 점진적인 발산의 경향이 두드러진다. 특히 90년대 중반 이후 이러한 경향은 현저하다. 80년대와 90년대 후반기에는 모두 발산의 경향이 현저한데, 전자의 것은 공간적 집중과 관련되어 있고 후자의 것은 공간적 분산과 관련되어 있다. 이것은 두 시기의 지역적 발산이 상이한 공간적 과정과 연계되어 있음을 의미하는 것이다. 즉, 80년대 후반기에는 파급효과나 인접지역간의 연계를 바탕으로 성장의 공간적 범위가

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상대적으로 큰 접촉적 공간과정(contagious spatial processes)이 지배적이었다면, 90년대 후반기에는 역류효과나 계층적 성장을 바탕으로 성장의 공간적 범위가 국지적으로 드러나는 산발적 공간과정(sporadic spatial processes)이 지배적이었음을 함축하고 있다.

주요어 : 시그마-수렴, 탐색적 공간자료분석, 공간적 연관 통계치, 공간적 의존성, 공간적 이질성.

1. Introduction

A rich body of literature has recently been devoted to spatio-temporal dynamics in regional economic performance, even though the topic is not new at all. It seems that at least two factors are responsible for this trend. First, a profound wave of socio-economic restructuring, occurring especially in advanced societies, has directed researchers to its implications for regional economic fortunes. Second, the advent of the European Union not only as an international integration but also as an inter-regional integration has revived interest in the versatility of regional development (Arbia, 2001). In this context, the issue of spatio-temporal dynamics of income distribution or regional income convergence/divergence across regions has attracted enormous attention from a variety of academic fields in recent years.

However, there has been no agreement at a theoretical level as to whether national economies have experienced a regional income convergence or divergence; some camps accentuate convergence over divergence, but others suggest an opposite. There has also been no agreement at an empirical level about whether the σ-convergence, the reduction of dispersions or variances in per capita income across regions, has really happened or not. Different empirical studies have reported different results. In the context of the U.S., for example, Evans and Karras (1996) and Sala-i-Martin (1996) find a consistent trend of convergence, while Quah (1996b) and Tsionas (2000, 2001a, 2001b) obtain evidences in the opposite direction. More importantly, almost all the empirical studies have been predicated on *aspatial* methods, even though regional income convergence is an essentially spatial theme. For example, a decrease in coefficient of variation, the most commonly used measure for σ-convergence, does not necessarily imply a spatial deconcentration or dispersion. This ignorance of spatial effects often prevents the empirical findings from providing more intuitive insights into spatio-temporal income dynamics.

I argue that regional analyses should take advantage of recent advances in spatial data analysis, especially ones utilizing spatial association measures, to investigate spatial dependence and spatial heterogeneity. Some recent works efficiently demonstrate the applicabilities of spatial data analyses to regional income convergence (Lopez-Bazo et al., 1999; Rey and Montouri, 1999; Rey, 2001; Le Gallo and Ertur, 2003; Mossi et al., 2003). In this regard, this paper aims to; (1) provide a critical review of empirical studies on σ-convergence from a spatial perspective; (2) investigate spatio-temporal income dynamics across the U.S. labor market areas for the last 30 years (1969-1999) by utilizing various ESDA (exploratory spatial data analysis) techniques.

2. A Critical Review on Regional Income Convergence

1) Theoretical Underpinnings: Three Different Stories

One might identify three academic camps involved in theoretical debates on regional income convergence/divergence. Firstly, the so-called 'new growth theory' based on a reformulation of neoclassical growth models (the inverted-U hypothesis by Kuznet, 1955; Solow, 1956; Williamson, 1965), 'endogenous growth theory' (according to Armstrong (1995a), Evans and Karras(1996), and de la Fuente (1997), Romer 1986; Lucas 1988; Romer 1990), and post-Keynesian traditions (according to Pons-Novell and Viladecans-Marsal

(1999), Verdoorn, 1949; Kardor, 1966, 1975) have stimulated empirical works on the growth convergence issue (among others, Barro and Sala-i-Martin, 1991, 1995; for a review, European Commission, 1997; Button and Pentecost, 1999). With some exceptions, this theory tends to underline a general trend towards equilibrium, which is evidenced by σ-convergence (a decrease of overall level of regional income inequality) and β-convergence (a negative relation between initial regional income levels and regional income growth rates).

Secondly, the California or Los Angeles School inspired by the French Regulation School postulates the nature of the transition from Fordism to post-Fordism and formulates conditions for 'New Industrial Spaces' (among others, Storper and Scott, 1986; Scott, 1988). Even though the main focus of the School is on 'successful regions', rather than an overall picture regarding spatial restructuring, some empirical works on regional disparities are based on the notions of the School (e.g., Dunford and Perrons, 1994; Rodriguez-Pose, 1999; Dunford and Smith, 2000). The post-Fordist spatial economic landscape implied by this line of theorization seems to be divergent rather than convergent. Some financial and producer service centers and local milieus accommodating flexible specialization dominate over old Fordist industrial regions and small- and medium-sized central places. In short, Fordism induces employment growth and income convergence, whereas post-Fordism is characterized by growth slowdown and income divergence (Dunford and Perrons 1994).

Thirdly, 'new economic geography' referring to works by economists (among others, Krugman, 1991, 1995; Fujita et al., 1999) has significantly contributed not only to the topic of regional income convergence but also to economic geography and regional sciences in general (for a review, see Martin 1999; Fingleton 2001). This camp provides a new insight into regional income dynamics. Reduction in transport and transaction costs associated with increased integration (by way of globalization or certain forms of economic supranationalism) fuels spatial agglomeration and localization externalities, leading to income divergence among regions in terms of the increased specialization (Martin, 1999; Martin and Tyler, 2000; Martin, 2001).

In general, the new growth theory accentuates convergence over divergence, while the Los Angeles School and new economic geography lean towards divergence over convergence. However, evidence is far from consistent. Empirics, even from the same camp, often report different stories.

2) Recovery of Spatiality in σ-convergence: Numerical Variance vs. Spatial Clustering

The σ-convergence refers to the reduction of dispersions or variances in per capita income across regions over time, usually measured by standard deviation or coefficient of variation of the regional income distribution (Barro and Sala-i-Martin, 1991; Rey, 2001). Sometimes, this type of convergence is called 'strong convergence', as apposed to 'week convergence' that refers to β-convergence (Nijkamp and Poot, 1998). This notion of convergence is deeply rooted in neo-classical growth theory (Kuznets, 1955; Williamson, 1965), and has been applied to numerous countries as summarized in Table 1. The results show a trend of long-term convergence in regional income distribution with some discrepancies. In the context of the US, five studies listed in Table 1 are based on state-level data and utilize measures of standard deviation or coefficient of variation. Barro and Sala-i-Martin (1991) report that the US regional income distribution has been characterized by a succession of a decrease, 1880-1920, an increase, 1920-1930, a decrease, 1930-the mid-1970s, and an increase, the mid-1970s-1988. Sala-i-Martin's later study (1996), with additional years, indicates a decrease in the early 1990s. Fan and Casetti (1994) document similar results, that is, a decrease, 1950-1980 and an increase, 1980-1989. Rey and Montouri (1999) also show the identical picture; a decrease up until 1980, an increase during the 1980s, and a decrease during the early 1990s. In UK, while most studies report a constant trend towards con-

Table 1. Empirical studies on σ-convergence

Spatial Units		Studies	Years	Indices*
Europe	EU regions	Barro and Sala-i-Martin (1991)	1950-1985	SD
		Armstrong (1995)	1975-1992	CV
		Dewhurst and Mutis-Gaitan (1995)	1981-1991	SD & CV
		Quah (1996a)	1980-1989	SD
		European Commission (1997)	1975-1993	SD & GC
		Button and Pentecost (1999)	1977-1990	CV
	EU countries	Dunford and Perron (1994)	1960-1989	SD
		de la Fuente (1997)	1870-1990	CV
		Dunford and Smith (2000)	1980-1996	CV
	UK regions	Sala-i-Martin (1996)	1950-1990	SD
		Chatterji and Dewhurst (1996)	1977-1991	SD & CV
		Dunford (1997)	1966-1992	CV
		Dickey (2001)	1970-1995	SD & CV
	France regions	Sala-i-Martin (1996)	1950-1990	SD
	Germany regions	Sala-i-Martin (1996)	1950-1990	SD
	Italy regions	Sala-i-Martin (1996)	1950-1990	SD
		Paci and Pigliaru (1999)	1951-1994	CV
	Spain regions	Mas et al. (1995)	1955-1991	SD
		Sala-i-Martin (1996)	1950-1990	SD
		Cuadrado-Roura et al. (1999)	1955-1995	SD
	Finland regions	Kangasharju (1998)	1970-1993	SD & CV
		Kangasharju (1999)	1970-1993	SD & CV
US	US states	Barro and Sala-i-Martin (1991)	1880-1988	SD
		Fan and Casetti (1994)	1950-1989	CV & ID
		Sala-i-Martin (1996)	1880-1990	SD
		Sum and Fogg (1999)	1939-1996	SD & CV
		Rey and Montouri (1999)	1929-1994	CV
Others	World countries	de la Fuente (1997)	1960-1985	SD
	OECD countries	de la Fuente (1997)	1960-1985	SD
	Brazil states	Mossi et al. (2003)	1939-1998	SD
	China regions	Zhao and Tong (2000)	1986-1994	SD & CV
	Ireland regions	O' Leary (2003)	1969-1996	SD
	Japan prefectures	Sala-i-Martin (1996)	1955-1990	SD

* SD: standard deviation; CV: coefficient of variation; ID: index of dissimilarity; GC: Gini coefficient

vergence, Chatterji and Dewhurst (1996) found that per capita GDP distribution across the UK regions has become more divergent.

Albeit the intuitive simplicity, σ-convergence has serious drawbacks. It does not provide insights into processes that may be driving the narrowing (or widening) of regional incomes. No information is provided regarding the relative movements of individual economies within the income distribution (Rey, 2001: 196). In other words, a diminishing standard deviation of incomes does not tell whether some poorer economies catch up with the richer economies faster than some others (Sala-i-Martin, 1996; Kangasharju, 1999; Tsionas, 2000). More serious problems that this approach bears, however, revolve around its lack of spatial perspectives.

First, studies based on σ-convergence should be enlightened by findings in the modifiable areal unit problem (MAUP). Such measures as standard deviation and coefficient of variation are strongly influenced by the level of spatial aggregation. In general, variance tends to decrease as the level of spatial aggregation escalates. In other words, a set of larger spatial unit is inclined to display a smaller variance due to a smoothing effect that outliers loose their peculiarities as spatial aggregation proceeds (Fotheringham and Wong, 1991; Wong, 1996). The magnitude and temporal trend of regional income convergence could vary depending on the spatial configuration of a study. Further, it may be unsustainable to compare the spatio-temporal trend among different countries each of which has a particular regionalization scheme (see Figure 6 in Sala-i-Martin (1996)).

Second, the numeric variance that σ-convergence is predicated on is immune to spatial clustering (Arbia, 2001). As illustrated by Lee (2001a), totally different spatial patterns can be generated from a numeric vector, and they cannot be differentiated by variance. What this implies is that σ-convergence does not measure *spatial* convergence that belies what is implied by '*regional* convergence'. It is necessary, thus, for researchers to look into the spatio-temporal trend of spatial dependence in income distribution if they are to obtain a substantive understanding of what has occurred in reality. In this sense, Wheeler (2001) reports from spatial correlogram analyses based on the US county level that spatial dependence in regional income growth is well pronounced and spatial autocorrelation drops off to zero over a distance of roughly 200 miles, with a strong stability within 40 miles. More important aspects of spatial dependence include the presence of inter-regional interaction, co-dependence, or spillover effects in regional income distributions (Quah, 1996a; Rey and Montouri, 1999; Rodriquez-Pose, 1999; Ying, 2000; Martin, 2001; Rey, 2001). Quah (1996a:954) correctly contends that 'physical location and geographical spillover matter more than do macro factors'. In this sense, a univariate spatial association measure or spatial autocorrelation index should be utilized to gauge spatial clustering not only for each year but also for growth rates between years. Surprisingly, only few papers recognize the importance of spatial dependence in regional income distributions and utilize univariate spatial association measures such as Moran's I and Geary's c (European Commission, 1997; Lopez-Bazo et al., 1999; Rey and Montouri, 1999; Rodriguez-Pose, 1999; Mossi et al., 2003).

Third, σ-convergence is global in nature such that it focuses only on an average aspect, or trend, ignoring the possible spatial heterogeneity often pronounced in the spatial organization of income (Rey and Montouri, 1999; Ying, 2000). This point also applies to global spatial association measures. For each year, hot and cold spots can be identified. A series of spatial distributions of income over years could reveal a trajectory of spatial restructuring over time. In this sense, local univariate spatial association measures should be utilized as attempted (Lopez-Bazo et al., 1999; Rey and Montouri, 1999; Ying, 2000; Rey, 2001; Le Gallo and Ertur, 2003). Moreover, bivariate local statistics should be involved to conduct a comparison between different temporal snapshots and thus to detect bivariate hot and cold spots. This procedure is expected to provide an efficient analytical tool for investigating where and the extent to which spatial restructuring has occurred over time.

Fourth, a well-designed spatial unit, other than arbitrary ones such as states and census regions, is needed. A viable spatial unit could be a regional labor market area where a vast majority of people live and work, and an intra-regional functional integration is distinctive to a certain degree. Use of regional labor market areas is expected to reveal the versatile nature of regional income disparities more efficiently and thoroughly.

3. Spatio-temporal Income Dynamics across the US Labor Market Areas, 1969-1999: σ-convergence

1) Research Design

Data sources for regional income are dictated by spatial aggregation level to a large extent. In general, larger spatial units, such as census regions and states, provide more affluent data sources. Since those spatial units are often arbitrary regions rather than functional regions, their use prevents researchers from obtaining a 'ground-level' reality. The county as a spatial unit is not a good choice, either, simply because a substantive proportion of labor force commutes across county boundaries. Thus, a regionalization scheme aggregating counties into functional regions should be involved.

In this study, main spatial units are 391 labor market areas (LMAs) for the conterminous U.S. (Killian and Tolbert, 1993; Tolbert and Sizer, 1996). Their definition is first based on a commuting flow matrix among counties, and a hierarchical cluster analysis aggregates 3,141 counties into 741 commuting zones (CZs). The CZs are then aggregated into 394 LMAs in terms of a minimum population requirement (100,000) and inter-CZ commuting flows (Tolbert and Sizer, 1996). Three LMAs in Alaska and Hawaii are excluded for this study. Per capita personal income data are used for this empirical study. The data sets have been collected and maintained by the Bureau of Economic Analysis, and are available via REIS (Regional Economic Information System) at the county level from 1969 to 1999.

An effective use of ESDA (exploratory spatial data analysis) techniques utilizing local spatial association measures is crucial for this application part. Local Moran's I_i and local Geary's c_i (Anselin, 1995), and Local Lee's S_i and L_i (Lee, 2001a, 2001b, 2004a, 2004b, 2004c) play a main role in developing and implementing the significance mapping techniques (see Anselin (1995, 1996, 2000) for the techniques associated with Moran's statistic; see Lee (2001b) those with Geary's statistic and Lee's S_i; see Lee (2004b) those with Lee's L_i). Each technique is utilized to reveal a particular aspect of spatio-temporal income dynamics in the US. The entire thirty years are divided into three sub-periods, 1969-1979, 1979-1989, and 1989-1999, and four years, 1969, 1979, 1989, and 1999, are utilized as benchmarks to provide particular snapshots, allowing for tracking a spatio-temporal evolution.

This empirical study is divided into three parts.

First, spatial distributions of per capita income across LMAs are explored and significant spatial clusters are detected for the four different years. Quartile maps allow for an effective comparison among the four different spatial patterns. Local-S significance and Geary significance maps identify significant spatial clusters for each year and a comparison of different years is expected to reveal temporal heterogeneity in spatial dependence of regional income distributions.

Second, temporal trends in regional income distribution over time are examined. Bivariate ESDA techniques such as local-L scatterplot and significance maps reveals spatial heterogeneity in temporal change during 1969-1999 across LMAs.

Third, σ-convergence is examined in conjunction with spatial clustering. The relationship between coefficients of variation and Moran's *I*s is investigated for LMAs, and an attempt is undertaken to provide a feasible explanation of the relationship. Distributions of spatial outliers detected by Moran significance maps are expected to provide a new insight into the relationship between numerical variance and spatial clustering.

2) Regional Income Distribution and Identification of Spatial Clusters

Figure 1 shows spatial patterns of per capita personal income across LMAs for the four benchmark years, 1969, 1979, 1989, and 1999. For a comparison, a quartile classification scheme is applied to each map. One finding is that the spatial distribution of per capita income has not significantly changed over the 30 years. The persistent spatial structure involves higher income lev-

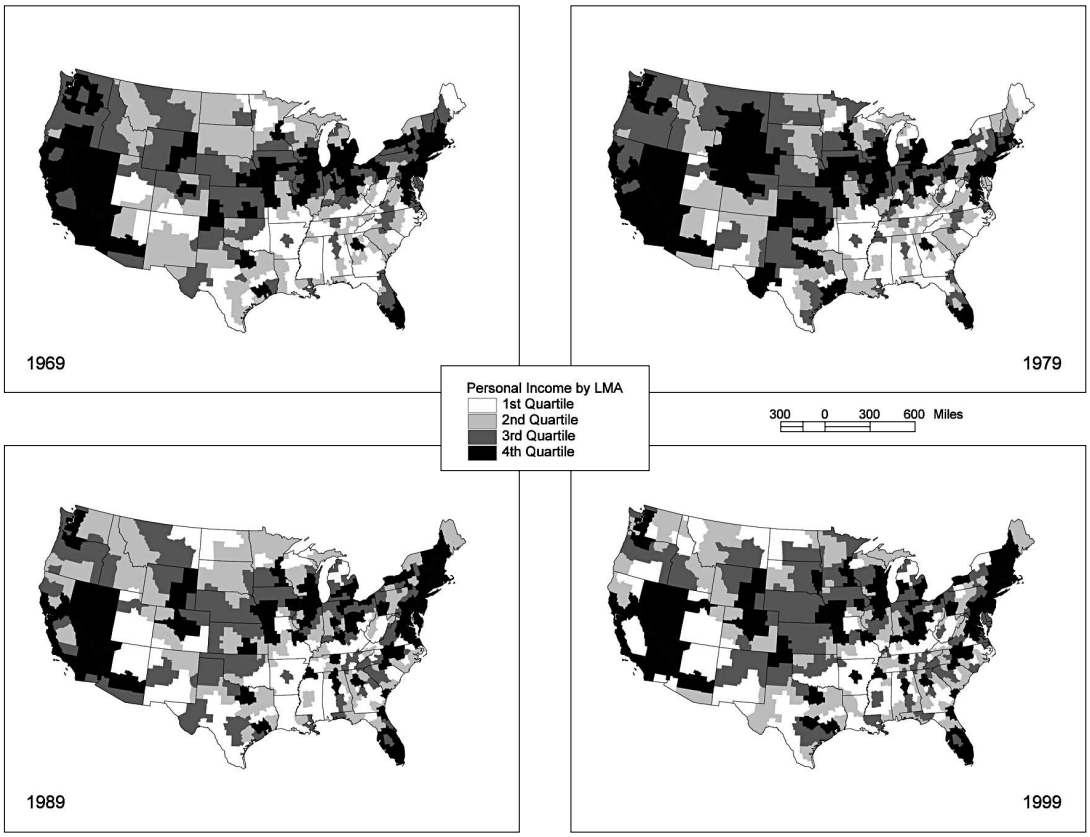

Figure 1. Spatial distributions of per capita personal income across the US LMAs

els in the Megalopolis, the Midwest, and western coastal regions, southern Florida, and lower income levels in areas from the northwest Mountain region to southern Texas, most areas of the South, the northwestern part of the Midwest, and the Ohio River Valley (ORV) region (Brown et al., 1996, 1999; Brown, 1999; Brown et al., 2004). Table 2 lists the top and bottom ten LMAs in terms of per capita income for the four years. Spatio-temporal continuation becomes more obvious from the list. Five out of top 10 LMAs in 1969 occupy the top five spots in 1999, and 7 out of bottom 10 LMAs in 1969 have not lost their seats in the 1999 bottom 10 list. The top 10 list for 1999 shows that three LMAs centered on Boston, Denver, and Minneapolis emerge for the first time which have been regarded as cities successfully adjusting to new economic conditions in the post-Fordist era.

In spite of the continuation of the dominant spatial morphemics, several spatial shifts are also detected. First, the traditional industrial cores in the Midwest have been spatially disintegrated. Especially areas centered on Detroit have lost much of its internal integrity. Second, some areas in the South, particularly the Pediment, have experienced relatively higher income growth. Those areas include Winston-Salem, Charlotte, and Raleigh in North Carolina, Birmingham in Alabama, and Austin in Texas.

This finding well corresponds to Brown's thesis of 'continuity amidst restructuring' (Brown, 1999; Brown et al., 2004). He contends (Brown et al., 2004) that "while many types of change occurred through the Fordist/Post-Fordist transition, they are not necessarily

Table 2. Top and bottom 10 LMAs in per capita personal income, 1969, 1979, 1989, and 1999

Years	Top 10	Bottom 10
1969	San Francisco, CA	Not distinguishable city, KY
	New York, NY	Brownsville, TX
	Bridgeport, CT	Laredo, TX
	Chicago, IL	Greenville, MS
	Newark, NJ	Not distinguishable city, KY
	San Jose, CA	Clarksdale, MS
	Wilmington, DE	Richmond, KY
	Los Angeles, CA	McComb, MS
	Detroit, MI	Somerset, KY
	Reno, NV	Tuscaloosa, AL
1979	San Francisco, CA	Laredo, TX
	Casper, WY	Brownsville, TX
	San Jose, CA	Somerset, KY
	Reno, NV	Gallup, NM
	Chicago, IL	McComb, MS
	Houston, TX	Richmond, KY
	Newark, NJ	Hinesville, GA
	Los Angeles, CA	Clarksdale, MS
	Bridgeport, CT	Roanoke Rapids, NC
	New York, NY	Not distinguishable city, MO
1989	West Palm Beach, FL	Laredo, TX
	Bridgeport, CT	Brownsville, TX
	San Francisco, CA	Gallup, NM
	Newark, NJ	Not distinguishable city, KY
	New York, NY	McComb, MS
	Baltimore, MD	Greenville, MS
	Boston, MA	Richmond, KY
	San Jose, CA	Somerset, KY
	Brick Township, NJ	West Memphis, AR
	Sarasota, FL	Provo, UT
1999	San Jose, CA	Brownsville, TX
	San Francisco, CA	Gallup, NM
	Bridgeport, CT	Laredo, TX
	New York, NY	Not distinguishable city, KY
	Newark, NJ	Somerset, KY
	West Palm Beach, FL	Greenville, MS
	Boston, MA	El Paso, TX
	Denver, CO	Not distinguishable city, KY
	Baltimore, MD	McComb, MS
	Minneapolis, MN	Yuma, AZ

LMAs are named after largest cities within them

manifest in terms of spatial variation over time... all regions declined early in this transition and, apparently, more or less to the same degree... yet, most of the formerly dominant regions rebounded, albeit with a different economic structure (e.g., service or high-technology industries rather than Fordist-type traditional industry)". Even though theoretical underpinnings seeking to explain 'spatial fixity' over 'spatial plasticity' in economic performance have been proposed, empirical studies that might evidence the theoretical notions are very few. Among others, Melachroinos and Spence (1999) show how 'sunk costs' function as a change-inhibiting factor in regional economic performance across Greece prefectures from 1984 to 1993.

To identify spatial clusters for each pattern, I utilize the local-S significance map technique (Lee, 2001b). Since local S_i is relatively liberated from the tyranny of reference areas, it works better than local Moran's I_i in identifying spatial clusters. Per capita personal income is first transformed by natural logarithm, and a one-tailed test at the 95% confidence level based on the conditional randomization (See Lee, 2004c). Figure 2 clearly shows the spatio-temporal dynamics in regional income distribution. Two crucial observations are made. First, the most dramatic spatial change had occurred during the 1980s. Second, the internal integrity of spatial clusters has been substantially eroded over 30 years.

The 1969 map displays five distinctive spatial clusters: the Megalopolis, the Midwest industrial belt, the Pacific as richer regimes, and the ORV region and the South as poorer regimes. In 1999, the spatial regimes are still observed, but their internal integrity has signifi-

Figure 2. Local-S significance maps: spatial clusters in per capita personal income across the US LMAs

Figure 3. Geary significance maps: local homogeneity in per capita personal income across the US LMAs

cantly been eroded: the Midwest industrial belt has been largely disintegrated; the Pacific has shrunken to the San Jose-San Francisco area and the Seattle area; the poor parts of the South are now confined to the Lower Mississippi; spatial clustering is only found around Chicago area within the Midwest industrial belt. In contrast, the Megalopolis and the southern Florida have maintained regional homogeneity as higher income areas. Areas in Colorado centered on Denver, Colorado Springs, and Fort Collins have emerged as a new hot spot during the 1990s.

The 1979 map in Figure 2 shows that northwestern mountain areas centered on Casper and Laramie in Wyoming appeared as significant higher income clusters. It also displays that the poor South had expanded to east and the Megalopolis had shrunken during 1970s. The trend, however, substantively reversed during the 1980s: the northwestern high income centers disappeared; the Megalopolis had expanded; the poor South had been confined to the Lower Mississippi. The most notable change in during the 1990s seen from the 1999 map in Figure 2 is the shrinking California.

Figure 3 examines a different aspect of spatial dependence in regional income distribution. As discussed (Lee, 2001b), local Geary's c_i is better at assessing local homogeneity in comparison with local Lee's S_i and Moran's I_i that are better at detecting spatial clusters. Simply, local Geary's c_i captures local variance. Spatial clusters do not necessarily mean that there is little variance within them; a high level of internal heterogeneity within a spatial cluster identified by local S_i or I_i is often observed. Geary significance maps in Figure 3 reveal

that there are substantive internal variance within the Pacific region in 1969 and 1979 detected as spatial clusters in Figure 2, and suggest that rich clusters in 1989 and 1999 possess a higher level of internal homogeneity than poor clusters. While the 1999 maps in Figure 2 and in Figure 3 are almost identical for the high income clusters, they are significantly different for the poor clusters.

3) Spatial Co-patterning and Bivariate Spatial Clusters in Regional Income Change

A correlation analysis utilizing Pearson's *r* and Lee's *L* (Lee, 2001a) shows that there is an extremely high relationship between 1969 and 1999 regional income distributions (respectively 0.810 and 0.416), so that regional income disparity in the US over last 30 years is characterized by continuity rather than change.

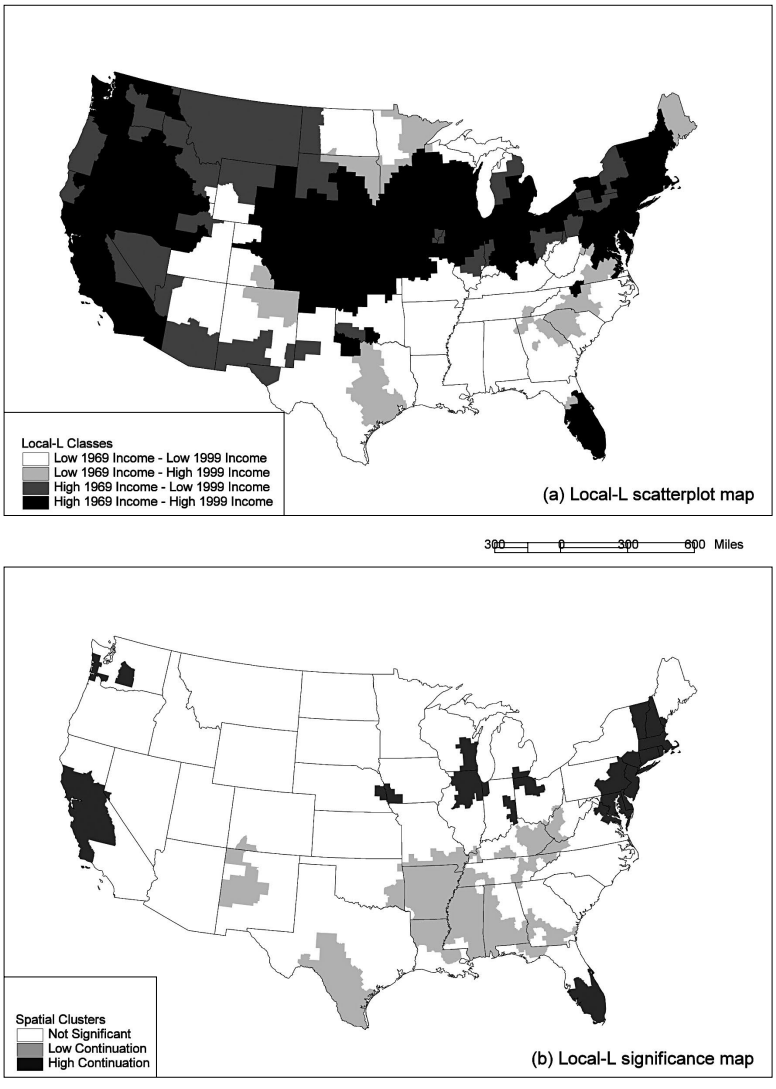

Figure 4. Local-L scatterplot map and significance map of per capita personal income across the US LMAs, 1969-1999

However, it should not be assumed that each local area equally follows the global trend. Bivariate ESDA techniques using local Lee's L_i such as local-L scatterplot map and local-L significance map (for a detailed description about the techniques, see Lee, 2001b, 2004b) are expected to reveal spatial heterogeneity in income trajectory over the last 30 years that each local has experienced.

Figure 4(a) allows one to detect a distinctive pattern. First, the traditional core areas are characterized by the continuation of a higher income level with LMAs experiencing the high-low transition. Second, the Pacific counterpart shows a similar pattern, that is, most areas still enjoy higher-than-average income levels and some occasional LMAs suffer from economic downturns. Third, areas from the Intermountain through the South to the southern Atlantic coast remain poor except for southern Florida. Within those areas, most of the low-high swing areas reside. They include areas in the Pediment, the Dallas-Houston corridor in Texas, and northern New Mexico centered on Santa Fe. Figure 4(b) selects areas with a statistical significance from Figure 4(a). Bivariate spatial hotspots or spatio-temporal hotspots include the Megalopolis, the central California, Chicago areas, and spatio-temporal coldspots include the lower Mississippi, the ORV region, the southern Texas, and northwestern New Mexico, part of the Four Corners.

4) σ-convergence and Spatial Dependence of Income Distribution

Figure 5 displays the temporal trend of income dispersion measured by the coefficient of variation (CV) and Moran's *I*. It is striking to observe that the graph of CV in the figure does not acknowledge any evident trend of income convergence during 1969-1999. Perhaps, the last 30 years is too short to display a distinctive trend of convergence/divergence. A graph from Rey and Montouri (1999) shows a constant decrease of CV from 1930 and 1975 followed by a relatively flat line. However, some interesting patterns are detected. First, albeit a cyclical fluctuation, a general trend is a convergence until the mid-1970s and then a divergence. Especially during the late 1990s, the trend

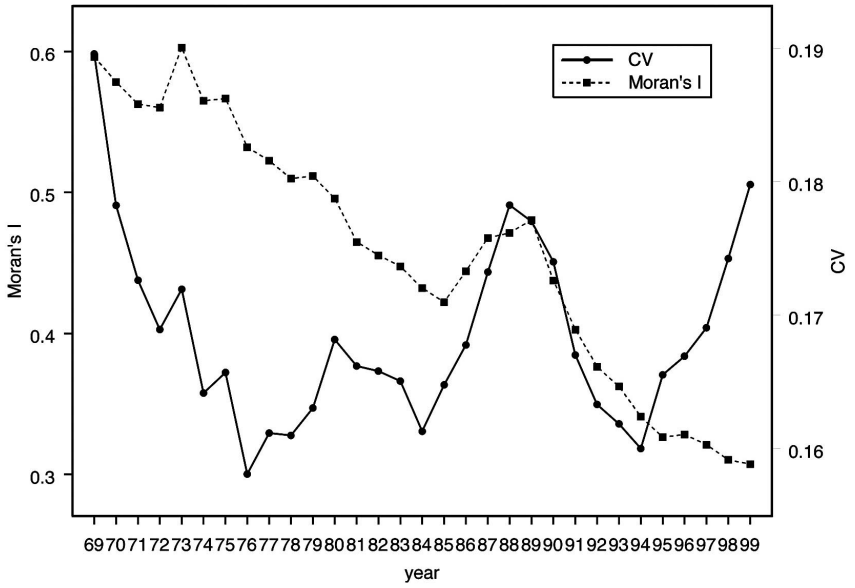

Figure 5. Coefficients of variation and Moran's Is of per capita personal income across the US LMAs, 1969-1999

of divergence is remarkable.

Figure 5 provides another insight into regional income convergence when the CV trend is compared to that of Moran's *I*. A complete correspondence between them indicates that income convergence/divergence is directly associated with spatial dispersion/clustering. Obviously, a contagious process of income distribution is more likely to result in spatial clustering than a sporadic process. First, spatial autocorrelation measured by Moran's *I* gradually decreases during the 30 years, which means that spatial clustering is less pronounced in recent years and can be evidenced from Figure 1 and Figure 2. Second, two peaks in income divergence in terms of CV, one in 1989 and the other in 1999, seem to be oppositely related to spatial clustering. The 1989 divergence exactly corresponds to spatial clustering in Moran's *I*, while the 1999 divergence is oppositely associated with Moran's *I*. It can be concluded that income growth or decline may have happened within particular spatial regimes during the late 1980s. Thus, the trend towards income divergence may have been driven by 'contagious spatial processes'. In contrast, another trend of the income divergence in the late 1990s may have been dictated by 'sporadic spatial processes' such that income growth or decline occurred at particular classes of regions that may be represented by population size.

This argument may be advocated by Figure 6 where spatial outliers, defined as areas significantly different from their neighbors, are displayed. Throughout the years, significant spatial outliers of high-low association (high values surrounded by low values) are found in

Figure 6. Moran significance maps: detection of spatial outliers in per capita personal income across the US LMAs, 1969-1999

the South. When 1979 map is compared to 1989 map in Figure 6, one may notice that the number of spatial outliers decreased, indicating spillover effects during the 1980s. Especially, disappearance of spatial outliers in the Pediment during the 1980s, e.g. Charlotte, Atlanta, and Birmingham, are clearly associated with spillover effects (see 1979 and 1989 maps in Figure 1). In contrast, the 1999 map in Figure 6 shows that more areas have become significant spatial outliers during the 1990s. This implies that income growth/decline had been more selective in a spatial sense. For example, Charlotte and Birmingham in the Pediment resurrect as spatial outliers, and areas, including Columbus in Ohio, Traverse City in Michigan, Raleigh in South Carolina, San Antonio in Texas, and Phoenix in Arizona are newly identified as spatial outliers of high-low association. Re-orientation of economy towards selective large cities or economic aggravation in already-lagged areas, for example, may explain the trend. Apparently, this type of spatial process tends to reduce the level of spatial clustering, depending on the given spatial scale, LMAs.

4. Conclusions

In this paper, I analyzed the US annual regional income data from 1969 to 1999 in order to examine the regional income convergence hypothesis by utilizing various ESDA techniques. A series of local-S significance maps evidenced the presence of spatial dependence in regional income distribution resulting in distinctive spatial clusters, and showed a spatial disintegration within traditional industrial cores in the U.S. over time. Geary significance maps reported that local homogeneity was more obvious within hot spots (significantly high income areas) than within cold spots (significantly low income areas).

Extremely high Pearson's r and Lee's L between 1969 and 1999 income distributions indicate the dominance of continuity over change during the 30 years. A local-L scatterplot map between 1969 and 1999 regional income distributions revealed a significance level of heterogeneity across the US areas. While most areas in the tradition industrial cores including the Midwest industrial belt and the Megalopolis and areas in the Pacific are still enjoying a higher-than-average income level, most areas in the South suffer from the continuation of lower-than-average income.

The notion of σ-convergence was not empirically evidenced. Rather, a general trend towards income divergence was detected since the late 1970s, more obviously since the mid-1990s. It was observed that temporal trends in coefficients of variation and Moran's Is did not necessarily correspond to each other. Especially, two peaks of income divergence in terms of coefficients of variation, one in the late 1980s and the other in the late 1990s, seem to have been associated with different spatial processes. Contagious spatial processes leading to spatial clustering were dominant in the former, while sporadic spatial processes inducing spatial dispersion somewhat prevailed in the latter. This was supported by Moran significance maps identifying spatial outliers.

As mentioned in the introduction part, this paper is focused on one aspect of regional income convergence, σ-convergence. Thus, a subsequent work should be undertaken to investigate the other aspect, β-convergence which points to the catch-up hypothesis that poorer regional economies grow faster than richer regional economies (Barro, 1991; Barro and Sala-i-Martin, 1991). This is important because β-convergence is a necessary condition for σ-convergence and a substantial change in the ranking of regions in economic performance could happen without being captured by σ-convergence (Barro and Sala-i-Marin, 1991; Sala-i-Martin, 1996; Nijkamp and Poot, 1998; Kangasharju, 1999; Tsionas, 2000). However, it is more important to recognize that β-convergence may be more problematic than σ-convergence in the sense that it obviously ignores such spatial effects as spatial dependence and spatial heterogeneity. A full-fledged spatial analysis on

β-convergence will provide much more insights into the topic of regional income convergence/divergence.

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