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Capital Deepening and Manufacturing's Contribution to Regional Economic Convergence

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Abstract. Using data on the manufacturing sector for the 50 states during 1977-1996, we decompose labor productivity growth into changes due to enhanced efficiency, capital accumulation, and technological progress. We find some evidence that labor productivity is converging among the 50 states, although the variance of labor productivity increased during 1977-1996. Using a series of kernel distribution tests we find that capital accumulation and technological progress contributed to labor productivity growth during the period, but changes in state efficiency had no effect on productivity growth.

1. Introduction

While the relative position of the manufacturing sector in the economy has declined over the past three decades, its importance to regional economic growth and welfare is undeniable. The manufacturing sector still provides fifteen to twenty percent of total employment in many states and accounts for an even larger percentage of state output as measured by Gross State Product (GSP). A large, competitive manufacturing sector typically translates into a healthy region that is well-positioned in the race to attract additional jobs and industries.

Regional inequality continues to be a fact of life in the United States, but some studies give evidence that the inequality is shrinking. Much research revolves around the investigation of β-convergence or σ-convergence. The former, β-convergence, occurs when poorer regions (countries) grow faster than richer regions (countries) over time. The test for β-convergence typically involves regressing the growth rates of regions (countries) against the level of per capita income (or some other measure of regional welfare) in the initial period. A negative relation is indicative of β-convergence over time. With some exceptions, the evidence points to β-convergence occurring at the state level in the United States. In a widely-cited result, Barro and Sala-i-Martin (1991) indicate that the β-convergence rate for regions in the United States is approximately two percent per year.

The second type of convergence, σ-convergence, occurs when there is a reduction in the cross-region variance of the welfare measure; for example, income. While σ-convergence is a sufficient condition for β-convergence, it is not a necessary condition. It is possible for the measure of regional variance to remain constant over time, but yet there be substantial change in the relative rankings of the regions. The change in rankings can be evidence of β-convergence, but cannot be picked up by σ-convergence.

As Martin and Sunley (1998) note, the traditional neoclassical growth model, particularly as applied by Borts and Stein (1964) in a regional context, implies that regional convergence is a natural result of factor mobility. "Regional disparities are unlikely to be persistent, since such inequalities will set in motion self-correcting movements in prices, wages, capital, and labor, which will impart a strong tendency toward regional convergence," (Martin and Sunley, p. 201). An alternative view (see, for example, Myrdal (1957)), casts doubt on the ability of market forces to lead to regional convergence. "Economies of scale and agglomeration lead to the cumulative concentration of capital, labor, and output in certain regions at the expense of others…" (Martin and Sunley, p. 201). In this view, regional inequality is the natural state of nature, with no inherent tendency for regional incomes to converge.

The present study is an investigation into the contribution of the manufacturing sector to regional economic convergence. The focus is primarily upon labor productivity convergence during the period 1977-1996. In a mature economy, most of the gains in regional welfare are likely to occur as a result of improvements in productivity as opposed to increases in the employment of resources. Our investigation follows Kumar and Russell (2002) and centers on the relative contributions of technological change, technological catch-up and capital deepening to productivity change over the sample period.

We are particularly interested in knowing, first, if there is evidence of productivity convergence for the manufacturing sector among states during our sample period. Bernard and Jones (1996), for example, found no evidence of productivity convergence for the manufacturing sector of 14 OECD countries from 1970 to 1987. Second, by decomposing productivity growth into its constituent components: technological change, technological catch-up and capital deepening, we gain greater insight into the growth process for regions and, perhaps, discover where regional policy might be best brought to bear. For example, a policy to promote the attraction of capital (capital deepening) is likely to be much different from a policy to improve efficiency (technological catch-up).

The organization of this paper is as follows: the next section reviews the literature with respect to convergence. Two strands of the literature are briefly reviewed: (1) studies that address the question of regional economic convergence, and (2) studies that consider productivity convergence, particularly by sector. The third section of the paper presents the basic model that is based on the work of Kumar and Russell (2002). The fourth section presents our results, while the last section gives a summary of our results as well as some conclusions.

2. Background

The study of regional economic inequality and convergence has resulted in a wealth of research. Given economic data on prices, convergence in the classical sense would imply factor price equalization across regions or states. Smith (1975) incorporates input price data into a long-run growth model that predicts convergence of output per worker. In states which have low capital/labor ratios and thus low levels of labor productivity, the marginal return to capital is high relative to labor. Differences in factor returns across states cause capital and labor to migrate in opposite directions leading to a convergence in the capital/labor ratio and, in the absence of technological progress, convergence of output per worker. Smith finds evidence of convergence for US states during the period 1880 to 1960. Economic historians Mitchener and Lean (1999) use price-adjusted per capita personal income as their measure of regional economic welfare. For the long period, 1880-1980, they find considerable σ-convergence, as the standard deviation of state per capita income declines from 54.7 in 1880 to 12.2 in 1980. Most of the convergence is due to the gradual decline in the West's huge margin over the average level of per capita income that existed in the late nineteenth century. After 1940, the South plays an important role in convergence as its per capita income rises relative to the rest of the nation.

Among regional scientists, there is some disagreement as to the extent of regional economic convergence. As mentioned, Barro and Salai-i-Martin (1991) find that state per capita incomes are converging (β-convergence) at about two percent per year. They further find that regions in other countries experience similar rates of β-convergence. Barro and Salai-i-Martin also note that there are periods when the rate of convergence differs from its long run two percent rate; for example, a slower rate is observed in the 1970s and 1980s.

Carlino and Mills (1996) use time series analysis to check for σ-convergence among U.S. states and regions during the period 1929-90. They conclude that convergence among state per capita personal incomes had been largely achieved by 1946 and that the observed divergence of incomes in the 1970s and 1980s was a temporary phenomenon.

Tsionas (2000 and 2001), using a co-integration model, finds little evidence of either β-convergence or σ-convergence among U.S. regions over the period 1929-97 whether one uses per capita personal income or gross state product as the measure of regional economic welfare. He concludes that high factor mobility in the United States is not causing convergence in regional incomes or gross state product (Tsionas 2001).

The role of productivity growth in promoting economic convergence in the manufacturing sector has been addressed by several researchers. Bernard and Jones (1996) use an econometric model and measure productivity for six sectors in fourteen OECD countries over the period 1970-87. They find little evidence of convergence in productivity or its growth rate in the manufacturing sector, while other sectors, especially services, show strong evidence of convergence. Furthermore, they find that "…the degree of catch-up is less for TFP [total factor productivity] [than it is for labor productivity] suggesting that capital accumulation is playing a role in the convergence of labor productivity." (Bernard and Jones, 1996, p. 1218)

An earlier study by Dollar and Wolff (1994) looks at productivity convergence for selected manufacturing industries in fourteen OECD countries from 1963 to 1985. While the rate of convergence slows considerably in the second half of the period (1972-85), they find persistent convergence in total factor productivity (TFP), labor productivity and capital intensity during the sample period. They also find that the convergence of TFP is correlated with the convergence of capital-labor ratios, indicating that capital deepening is an important contributor to the convergence of productivity levels.

Using similar data Koop (2001) investigates the sources of output growth for eleven OECD countries in six sectors (food, chemicals, paper, machinery, metals, and textiles) during 1970-1988. Output growth is decomposed into changes due to efficiency gains or losses, technical change, and changes in input usage. Koop finds that technical progress is important in explaining output growth in all sectors. Interestingly, technical progress seems to be greatest in those sectors that are most open to trade, a finding which suggests that trade is an important means of disseminating technical advances. Declines in input usage explain the stagnation of the textiles and metals sectors. Koop also finds little evidence supporting the convergence hypothesis. An exception is Japan, which had low initial levels of efficiency and subsequent fast efficiency growth. Finally, Koop finds that "inefficiency seems to be associated with slow growth phases of the business cycle. One explanation for this finding is that manufacturing industries are unwilling or unable to shed labor or capital during recessions." (Koop 2001, p.74)

Kumar and Russell (2002) use data envelopment analysis (DEA) to address the role of capital accumulation and the convergence of labor productivity. In their study of 57 countries, Kumar and Russell find that much of the subsequent change in output per worker from 1965 to 1990 was due to capital deepening as opposed to improvements in efficiency or technological change. From their research, "…it appears that the growth pattern [of productivity] may have been driven primarily by the pattern of capital accumulation." (Kumar and Russell, p. 538) With respect to the role of technological catch-up in convergence, they find that "…technological catch-up has done little, if anything, to lower income inequality across countries. Apparently, technology transfer has benefited relatively rich countries as much as relatively poor countries." (Kumar and Russell, p. 537)

In this study, we wish to determine if capital deepening is also a driving force in labor productivity growth at the state level in the U.S. As a secondary question, we are also interested in manufacturing's contribution to regional economic convergence. As noted, Bernard and Jones (1996) find that the manufacturing sector has shown little evidence of convergence for fourteen OECD countries; Dollar and Wolff, however, did find evidence of convergence in the manufacturing sector for OECD countries. We address the question of convergence in the manufacturing sector as it relates to states for the period 1977-1996. Barro and Salai-i-Martin (1995) argue that regions within a nation should exhibit a stronger tendency toward convergence as compared to countries. Given that regions within a nation are more likely to share technology, structural characteristics, institutions and preferences, the forces that promote convergence are likely to be higher than between nations.

3. Method

We follow the approach of Kumar and Russell (2002) and decompose an index of labor productivity change into the product of indices of efficiency change, capital accumulation, and technical change. In some caveats emphasized in the conclusion of their paper, Kumar and Russell suggest that because their comparison of labor productivity change across countries is highly aggregated, industry-specific studies might yield additional insights. We take Kumar and Russell's suggestion and estimate labor productivity change for the manufacturing sector for the fifty states from 1977-1996.

We assume that there are s=1,…,50 states, each producing manufacturing output, Y, using inputs of capital, K, and labor, L, in t = 1977-1996 periods. The production technology is represented as:

$$T^t = \{(K^t, L^t, Y^t) : (K^t, L^t) \text{ can produce } Y^t\}. \qquad (1)$$

Given the technology, T^t, the production function is

$$F(L^t, K^t) = \max\{Y^t : (K^t, L^t, Y^t) \in T^t\}. \qquad (2)$$

Assuming constant returns to scale one can write the production function as $y_s^t = F(1, k_s^t) = f(k_s^t)$, where $y = Y/L$ is labor productivity and $k = K/L$ is the capital-labor ratio. Some states may operate at less than 100% efficiency, so that actual labor productivity, y_s^t, is less than maximum potential labor productivity, which we denote $\overline{y}_s^t$. The output distance function is an alternative representation of the technology. Its value equals Farrell output technical efficiency, e_s^t, of each state in each period. The output distance function takes the form:

$$D_o(L_s^t, K_s^t, Y_s^t) = \min\{e_s^t : (\frac{Y_s^t}{e_s^t}, L_s^t, K_s^t) \in T^t \cdot \qquad (3)$$

We allow states to operate at less than maximum efficiency so that a state's labor productivity, y_s^t, is the product of maximum potential labor productivity, $\overline{y}_s^t$, and efficiency, e_s^t: $y_s^t = e_s^t \; x \; \overline{y}_s^t(k_s^t)$. An index of labor productivity growth between period t and t+1 is:

$$\frac{y_s^{t+1}}{y_s^t} = \frac{e_s^{t+1}}{e_s^t} \; x \; \frac{\overline{y}_s^{t+1}(k_s^{t+1})}{\overline{y}_s^t(k_s^t)} . \qquad (4)$$

The first term on the right hand side of (4) is an index of efficiency change caused by states moving closer or further from the frontier of the technology, T from period to period. The second term is the change in maximum potential labor productivity. Period to period changes in maximum potential labor productivity are caused by changes in the capital-labor ratio and by technical change. Let $\overline{y}_s^t(k_s^{t+1})$ represent maximum potential labor productivity in period t if state s had access to the period t+1 capital-labor ratio. Then, multiplying the right-hand side of (4) by $\frac{\overline{y}_s^t(k_s^{t+1})}{\overline{y}_s^t(k_s^{t+1})}$ yields

$$\frac{y_s^{t+1}}{y_s^t} = \frac{e_s^{t+1}}{e_s^t} \; x \; \frac{\overline{y}_s^{t+1}(k_s^{t+1})}{\overline{y}_s^t(k_s^{t+1})} \; x \; \frac{\overline{y}_s^t(k_s^{t+1})}{\overline{y}_s^t(k_s^t)} \qquad (5)$$

The first term on the right-hand side of (5), $\frac{e_s^{t+1}}{e_s^t}$, is the efficiency change from period t to period t+1. The second term, $\frac{\overline{y}_s^{t+1}(k_s^{t+1})}{\overline{y}_s^t(k_s^{t+1})}$, corresponds to technological change, which measures the vertical shift in the technology from period t to period t+1 given the capital labor ratio in period t+1. The last term on the right-hand side of (5) is an index of capital accumulation, $\frac{\overline{y}_s^t(k_s^{t+1})}{\overline{y}_s^t(k_s^t)}$, which indicates how much labor productivity in period t would increase if the state had access to the period t+1 capital-labor ratio but still faced the period t technology. Similarly, one could multiply the right-hand side of (4) by $\frac{\overline{y}_s^{t+1}(k_s^t)}{\overline{y}_s^{t+1}(k_s^t)}$ and get

$$\frac{y_s^{t+1}}{y_s^t} = \frac{e_s^{t+1}}{e_s^t} \; x \; \frac{\overline{y}_s^{t+1}(k_s^t)}{\overline{y}_s^t(k_s^t)} \; x \; \frac{\overline{y}_s^{t+1}(k_s^{t+1})}{\overline{y}_s^{t+1}(k_s^t)} \qquad (6)$$

which can also be broken into an index of efficiency change, technological change, and index of capital accumulation. In (6), the index of technical change measures the shift in the technology from period t to t+1 given the capital labor ratio in period t, and the index of capital accumulation is calculated for the period t+1 technology. Taking the geometric mean of (5) and (6) yields the tripartite decomposition of labor productivity of Kumar and Russell. In their formulation, the index of labor productivity is the product of efficiency change (EFF), technological change (TECH), and capital accumulation (KACCUM):

$$\frac{y_s^{t+1}}{y_s^t} = \frac{e_s^{t+1}}{e_s^t} [\frac{\overline{y}_s^{t+1}(k_s^{t+1})}{\overline{y}_s^t(k_s^{t+1})} \; x \; \frac{\overline{y}_s^{t+1}(k_s^t)}{\overline{y}_s^t(k_s^t)}]^{\frac{1}{2}} [\frac{\overline{y}_s^t(k_s^{t+1})}{\overline{y}_s^t(k_s^t)} \; x \; \frac{\overline{y}_s^{t+1}(k_s^{t+1})}{\overline{y}_s^{t+1}(k_s^t)}]^{\frac{1}{2}} \qquad (7)$$
$$=: EFF \; x \; TECH \; x \; KACCUM$$

We use linear programming (LP) to estimate the output distance function. The LP method assumes a piece-wise linear technology and we impose constant returns to scale so that productivity can be properly measured. The piece-wise technology takes the form:

$$T^t = \{(K^t, L^t, Y^t) : K^t \geq \sum_{s=1}^{S} z_s K_s^t, \; L^t \geq \sum_{s=1}^{S} z_s L_s^t, \; Y^t \leq \sum_{s=1}^{S} z_s Y_s^t, \; z_s \geq 0, \; s = 1, ..., 50\} \qquad (8)$$

Given the technology, T^t, the output distance function is estimated as:

$$D_o^t(K_s^t, L_s^t, Y_s^t) = \min\{e_s^t : K^t \geq \sum_{s=1}^{S} z_s K_s^t, \; L^t \geq \sum_{s=1}^{S} z_s L_s^t, \; \frac{Y_s^t}{e_s^t} \leq \sum_{s=1}^{S} z_s Y_s^t, \; z_s \geq 0, \; s = 1, ..., 50\} \qquad (9)$$

The LP problem (9) is solved for each of the fifty states for the years 1977-96. To decompose labor productivity into the effects of technological change and capital accumulation we also need to calculate $\overline{y}_s^t(k_s^{t+1})$ and $\overline{y}_s^{t+1}(k_s^t)$. These two mixed-period maximum potential labor productivity estimates are derived from two mixed-period output distance functions:

$$D_o^{t+1}(K_s^t, L_s^t, Y_s^t) = \min\{e_s : K^t \geq \sum_{s=1}^{S} z_s K_s^{t+1}, L^t \geq \sum_{s=1}^{S} z_s L_s^{t+1}, \frac{Y_s^t}{e_s} \leq \sum_{s=1}^{S} z_s Y_s^{t+1}, \; z_s \geq 0, s = 1, ..., 50\} \qquad (10)$$

and

$$D_o^t(K_s^{t+1}, L_s^{t+1}, Y_s^{t+1}) = \min\{e_s : K^{t+1} \geq \sum_{s=1}^{S} z_s K_s^t, \; L^{t+1} \geq \sum_{s=1}^{S} z_s L_s^t, \; \frac{Y_s^{t+1}}{e_s} \leq \sum_{s=1}^{S} z_s Y_s^t, \; z_s \geq 0, \; s = 1, ..., 50\} \qquad (11)$$

Problem (10) measures the distance from the observed (K, L, Y) combination in 1977-1995 to the frontier in 1978-1996, while problem (11) measures the distance from the observed (K,L,Y) combination in 1978-1996 to the frontier in years 1977-1995.

The piecewise line technology and the decomposition of labor productivity change is illustrated in Figure 1. We observe the labor productivity, y, and the capital-labor ratio, k, of three states in period t and t+1. In period t, the observations are represented by points A, B, and C, and in period t+1, the observations are represented by points A', B', and C'. The frontier technology in period t is represented by the lines 0A, AB, and the horizontal extension from B. The state represented by C produces inside (to the southeast) of T^t with $e_C^t = FC/FD$. In period t+1, the frontier technology is represented by 0A', A'B', and the horizontal extension from B'. The state represented by C in period t and by C' in period t+1 is still less than 100% efficient, but has higher labor productivity in period t+1. For the state at C', efficiency equals $e_{C'}^{t+1} = F'C'/F'D'$. Labor productivity change as derived in (7) is

$$y^{t+1}/y^t = \frac{F'C'/F'D'}{FC/FD} \, x \, [\frac{F'D'}{F'E} \, x \, \frac{FE'}{FD}]^{.5} \, x \, [\frac{F'D'}{FE'} \, x \, \frac{F'E}{FD}]^{.5} \qquad (12)$$

$$= EFF \quad x \quad TECH \quad x \quad KACCUM$$

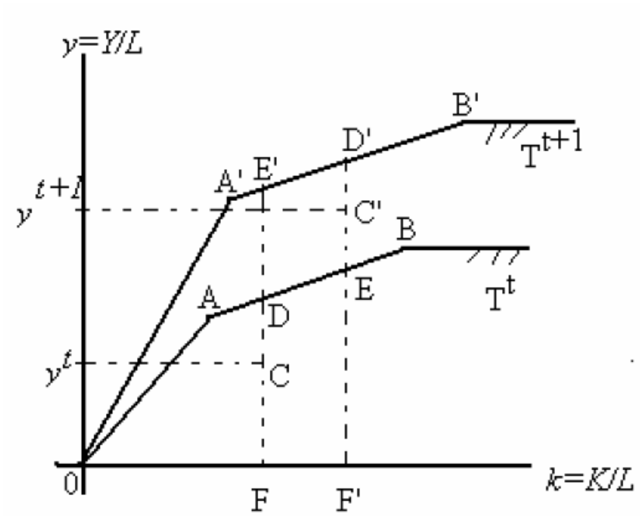

Figure 1. Labor productivity change

A disadvantage of using distance functions to analyze convergence is that economic information conveyed by input prices is ignored. However, an advantage of the use of distance functions is that the sources of labor productivity growth can be identified in the absence of input prices, or, when input price distortions exist due to differential marginal tax rates between regions, or when differences in regional amenities provide workers the incentive to tradeoff lower wages for more desirable living conditions. In these situations regional differences in factor prices might still exist even as labor productivity converges across those same regions.

4. Data and Empirical Results

We estimate the index of labor productivity and its decomposition for the manufacturing sector using state aggregate data for the years 1977-1996. Real manufacturing output, Y, is produced using labor, L, and capital, K. Real manufacturing output, taken from the Bureau of Economic Analysis website (BEA), is a component of gross state product and is measured in millions of 2000 dollars. Labor is measured in thousands of hours and is composed of labor hours for production workers plus non-production workers. We assume that non-production workers work forty hours per week, fifty weeks per year. Data for labor are from the *Annual Survey of Manufactures*. The *Annual Survey* did not publish regional data for the years 1979-1981. However, national totals for manufacturing labor hours and workers were available for those years. We used employment data from the BEA for state manufacturing to generate estimates of labor hours in state manufacturing for those three years.

State manufacturing capital stock was estimated using the value added approach developed by Aaberg (1973). In this approach, value added in manufacturing minus total payroll is used as a measure of capital's contribution to production in the manufacturing sector. This is computed for each state and for the nation. A state's share of the national capital contribution is then used to allocate the national capital stock for a given year to that state. The national capital stock is taken from the Bureau of Economic Analysis website. For example, suppose in a given year, the national value added minus payroll is $1 trillion. If state A's corresponding value is $50 billion, then 5% ($50 billion/$1 trillion) of the national capital stock in that year is allocated to state A. This method is simple and allocates all of national capital to the 50 states (minus a small amount for the District of Columbia, which is not included in our sample). For 1977-1981, when value added data are not available for states, it was assumed that capital in the states grew at the same rate as the national capital stock in each year. Manufacturing data is measured in millions of 2000 dollars.

Descriptive statistics on each of these variables for the beginning and ending years of our sample, and for the pooled data, are outlined in Table 1. Average labor productivity increased from $28 per worker hour in 1977 to $38 per worker hour in 1996. The capital-labor ratio increased from $32 per worker hour in 1977 to $46 per worker hour in 1996. In 1977, Alaska had the highest labor productivity and Louisiana had the highest capital-labor ratio. Virginia had the lowest labor productivity in 1977 and New Mexico had the highest labor productivity in 1996. On average, the capital-labor ratio grew by 40% and labor productivity grew by 52% during 1977-1996.

Table 1. Descriptive Statistics

Variable	Mean	Std. Dev.	Min.	Max.
Pooled data 1977-1996:				
Y (1,000,000s of 2000 dollars)	23899	26364	418	143430
L (1,000 hrs.)	759207	816869	14100	4243000
K (1,000,000s of 2000 dollars)	28321	30682	391	172477
y=Y/L	0.032	0.007	0.016	0.115
k=K/L	0.039	0.012	0.013	0.177
1977:				
Y	21455	24988	620	95320
L	779808	863684	16700	3442000
K	23379	26463	988	110020
y=Y/L	0.028	0.005	0.016	0.041
k=K/L	0.032	0.009	0.013	0.063
1996:				
Y	28063	29392	1030	143430
L	759674	784860	19900	3912600
K	32386	33965	1072	172477
y=Y/L	0.038	0.010	0.028	0.092
k=K/L	0.046	0.021	0.025	0.177

Labor productivity of each state in 1977, and the contributions of efficiency change, technical change, and capital accumulation to labor productivity in 1996 are summarized in Table 2. A scatter plot of labor productivity ($y=Y/L$) and the capital-labor ($k=K/L$) ratio for each state in 1977 and 1996 is presented in Figure 2. The upward shift of the frontier from 1977 to 1996 indicates technical progress. However, Delaware's observed 1977 capital/labor ratio and labor productivity ratio was no longer feasible in 1996. In Figure 3, we plot the unit isoquant for 1977 and 1996. As can be seen, the shift in the isoquant indicates biased technical change in a capital using/labor saving direction, a result consistent with that found by Weber and Domazlicky (1999) for the state manufacturing sector during the period 1983-89. In 1977, Delaware and Alaska defined the frontier technology, but by 1996, Delaware, Connecticut, New Mexico, and Oregon produced on the frontier. New Mexico experienced the greatest growth in labor productivity during the period with labor productivity increasing from about $24 per worker hour in 1977 to $92 per worker hour in 1996.

We were concerned that the figures for New Mexico might be in error. However, after further research (see Waldman 2001), we found that the Intel Corporation went through a major expansion in New Mexico in the early 1990s that was completed by 1995. While twenty percent of New Mexico's manufacturing employment was in the electronic equipment sector, that same sector accounted for almost seventy-five percent of all manufacturing output. In addition, nominal output in the high tech manufacturing sector in New Mexico increased by 28-fold during the 1990s and by 66-fold in real terms. Thus, we are reasonably confident that the large measured change in labor productivity did occur in New Mexico, and was not due to a reporting or measurement error.

The geometric mean of labor productivity growth was 36% between 1977 and 1996. Efficiency change accounted for 5% of productivity growth, technical change contributed 13% to productivity growth, and

Table 2. State Estimates of Labor Productivity Change, 1977-1996

State	Y/L(1977)	EFF	TECH	KACCUM	Y/L(1996)
Far West					
AK	0.041	0.644	1.321	0.939	0.032
CA	0.028	0.995	1.188	1.119	0.037
HI	0.026	1.015	1.290	1.037	0.035
NV	0.030	0.886	1.244	1.000	0.033
OR	0.034	1.152	1.185	1.119	0.051
WA	0.032	0.815	1.235	1.031	0.033
Great Lakes					
IL	0.028	0.984	1.151	1.114	0.036
IN	0.029	1.006	1.183	1.103	0.038
MI	0.035	1.009	1.027	1.061	0.038
OH	0.031	0.980	1.171	1.133	0.040
WI	0.030	0.901	1.179	1.097	0.035
Mideast					
DE	0.037	1.000	0.746	1.721	0.048
MD	0.027	0.975	1.119	1.152	0.034
NJ	0.027	1.149	1.101	1.133	0.039
NY	0.029	1.061	1.120	1.171	0.040
PA	0.026	1.129	0.988	1.318	0.039
New England					
CT	0.025	1.533	0.875	1.117	0.037
ME	0.020	1.296	0.963	1.216	0.031
MA	0.024	1.091	1.060	1.199	0.034
NH	0.022	1.401	1.028	1.360	0.044
RI	0.021	1.527	0.814	1.075	0.028
VT	0.022	1.091	1.041	1.236	0.030
Plains					
IA	0.033	0.852	1.313	1.060	0.039
KS	0.027	0.842	1.236	1.038	0.029
MN	0.028	1.048	1.030	1.074	0.033
MO	0.029	1.015	1.195	1.132	0.039
NE	0.026	0.898	1.250	1.010	0.030
ND	0.027	0.890	1.277	0.993	0.030
SD	0.022	0.979	1.164	1.144	0.029
Rocky Mountain					
CO	0.028	0.991	1.141	1.190	0.037
ID	0.028	1.016	1.158	1.234	0.041
MT	0.033	0.815	1.248	0.994	0.033
UT	0.026	1.032	1.151	1.180	0.036
WY	0.037	1.042	1.363	0.982	0.052

Table 2 (Continued). State Estimates of Labor Productivity Change, 1977-1996

State	Y/L(1977)	EFF	TECH	KACCUM	Y/L(1996)
Southeast					
AL	0.023	1.156	0.923	1.205	0.030
AR	0.023	1.021	1.106	1.156	0.030
FL	0.024	1.075	1.054	1.154	0.035
GA	0.037	1.123	1.123	1.172	0.046
KY	0.038	0.866	1.341	1.083	0.052
LA	0.021	0.916	1.446	1.029	0.029
MS	0.023	1.088	1.118	1.112	0.034
NC	0.020	1.093	1.028	1.315	0.033
SC	0.023	1.285	0.979	1.337	0.031
TN	0.023	1.044	1.107	1.130	0.030
VA	0.016	1.728	0.928	1.568	0.039
WV	0.032	0.968	1.305	1.104	0.044
Southwest					
AZ	0.028	1.093	1.200	1.178	0.043
NM	0.024	1.606	1.499	1.595	0.092
OK	0.026	1.176	1.147	1.195	0.041
TX	0.031	0.919	1.325	1.040	0.040

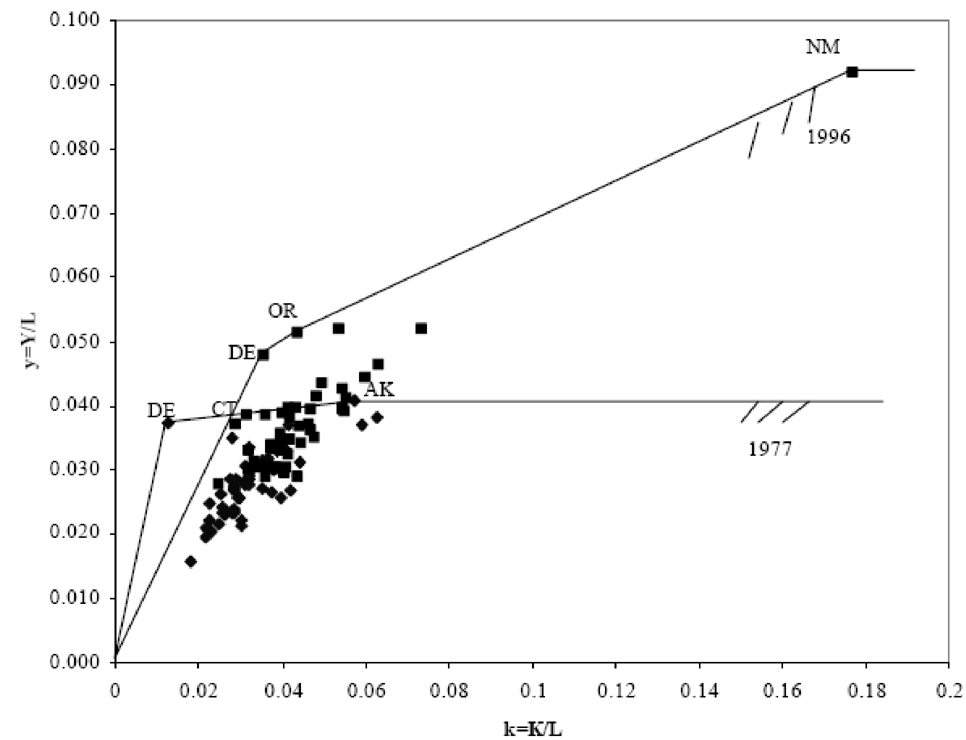

Figure 2. Labor productivity in 1977 and 1996

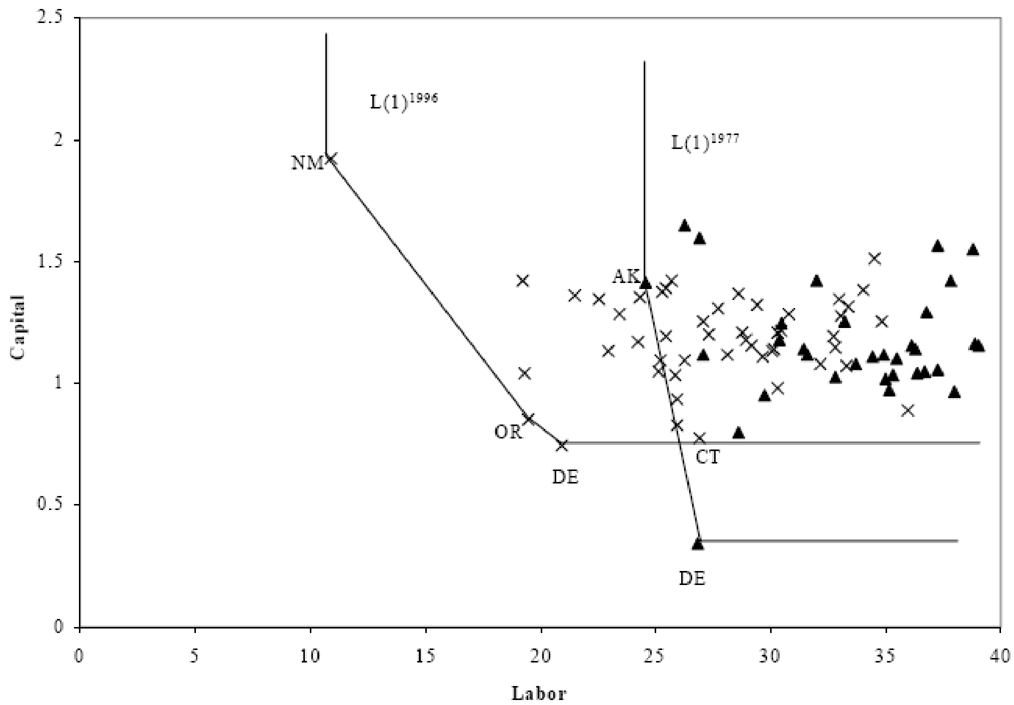

Figure 3. The unit isoquant in 1977 and 1996

capital accumulation contributed 15% to productivity growth. (1.36=1.05x1.13x1.15). Nineteen states became less efficient (EFFCH<1), eight states experienced technical regress (TECH<1, and only four states (AK, MT, ND, and WY) experienced declines in productivity due to declines in the capital/labor ratio (KACCUM<1). Each of the nineteen states that experienced declines in efficiency also experienced growth due to technical progress. This result is consistent with the idea that as technical progress occurs, some states fail to adopt the best technology, and become more inefficient over time. Although TECH and KACCUM are negatively correlated (rho=-0.46), there is a significant positive correlation (rho=0.81) between the capital-labor ratio in 1977 and subsequent technical progress.

Geometric mean estimates of the labor productivity growth and its components for the years 1977-1996 are presented in Table 3. Except for the years, 1979-80, 1981-82, and 1989-90, the average state experienced annual productivity growth. Efficiency declined in eight out of the nineteen years and the effects of capital accumulation on productivity were negative in only three of the nineteen years.

Given that our estimation procedure is nonparametric and that the distributions of labor productivity, efficiency, technological change, and capital accumulation are likely to be non-normal, we use kernel-based methods to test whether the distributions changed from 1977 to 1996. To test various hypotheses we use the T-statistic of Li (1996) to test for the difference between two density functions, *f(x)* and *g(x)* for a random variable x. The kernel density estimate is given as:

$$\hat{f}(x) = \frac{1}{nh}\sum_{j=1}^{J} k\left(\frac{x_j - x}{h}\right) \qquad (10)$$

where h is the window width and n is the sample size. (Pagan and Ullah 1999).

The kernel distribution of labor productivity in 1977 and 1996 is presented in Figure 4. As seen in the figure, the distribution of labor productivity in both years appears to be non-normal and shifts to the right. We follow Li (1996) and test whether the distributions of labor productivity in 1977 and 1996 are different from each other. An accepted measure of the closeness between two functions, *f(x)* and *g(x)* is the integrated squared difference, $I(f,g) = \int_x (f(x) - g(x))^2 dx$. This function has the property that I(*f,g*)≥0 and holds with equality if and only if *f(x)*=*g(x)*. Li (1996) has shown that a T-statistic can be used to test for the difference between the two density functions, where

$$T = \frac{n\sqrt{h}\, I}{\hat{\sigma}} \sim N(0,1)'$$

I is estimated as

$$I = \frac{1}{n^2 h}\sum_{i=1}^{N}\sum_{j=1, j\neq i}^{N}[k(\frac{x_i - x_j}{h}) + k(\frac{y_i - y_j}{h}) - k(\frac{x_i - y_j}{h}) - k(\frac{y_i - x_j}{h})] \quad (11)$$

and the variance is estimated as

$$\hat{\sigma}^2 = \frac{1}{n^2 h\sqrt{\pi}}\sum_{i=1}^{N}\sum_{j=1}^{N}[k(\frac{x_i - x_j}{h}) + k(\frac{y_i - y_j}{h}) + 2k(\frac{x_i - y_j}{h})]. \quad (12)$$

The functions *k(.)* are kernel functions that are bounded and satisfy $\int_{-\infty}^{\infty} k(u)du = 1$ for $u = \frac{x_j - x}{h}$ and where $h \to 0$ as $n \to \infty$. We use a standard normal kernel to estimate each density function. We apply the bootstrap of Pagan and Ullah (1999) 500 times in estimating the T-statistic.

Table 3. Annual Estimates of the Components of Productivity Change

Years	EFF	KACCUM	TECH	$(Y/L)^{t+1}/(Y/L)^t$
1977-78	0.969	1.006	1.048	1.023
1978-79	0.982	1.005	1.019	1.006
1979-80	1.030	1.018	0.926	0.971
1980-81	1.015	1.004	0.998	1.017
1981-82	1.053	1.003	0.938	0.989
1982-83	0.946	1.003	1.102	1.045
1983-84	1.022	0.997	1.032	1.052
1984-85	1.019	1.003	1.000	1.022
1985-86	0.993	0.995	1.031	1.019
1986-87	0.969	1.005	1.031	1.004
1987-88	0.991	0.997	1.065	1.052
1988-89	1.030	1.011	0.978	1.020
1989-90	1.001	1.002	0.975	0.977
1990-91	0.984	1.007	1.029	1.019
1991-92	1.020	1.001	0.984	1.004
1992-93	0.936	1.003	1.083	1.017
1993-94	1.057	1.006	0.979	1.041
1994-95	1.002	1.016	1.011	1.028
1995-96	1.038	1.010	0.964	1.011

We present the results of various tests concerning the distribution of labor productivity in 1977 and 1996 and the component changes of labor productivity during the period 1977-1996 in Table 4. To begin, we test and find strong evidence that the distribution of labor productivity in 1977 is different from the distribution of labor productivity in 1996.

Following Kumar and Russell (2002) we present a series of counterfactual tests to determine the significance of efficiency change, technical change, and capital accumulation to labor productivity change. The index of labor productivity change given in (7) can be rewritten as:

$$y^{1996} = EFF \ x \ TECH \ x \ KACCUM \ x \ y^{1977} \quad (13)$$

Given the frontier technology in 1996, we first test whether $f(y^{1996})=g(y^{1977}xEFF)$. That is, in the absence of capital deepening or technical change, did efficiency change cause the distribution of labor productivity in 1996 to be different from that found in 1977? We also test whether, in the absence of efficiency change or capital deepening, the distribution of labor productivity in 1996 is different from the counterfactual level in 1977. This test is specified as $f(y^{1996})=g(y^{1977}\text{xTECH})$. Furthermore, in the absence of efficiency change and technical change is the distribution of labor productivity in 1996 different from the counterfactual level in 1977 allowing for the effects of capital deepening? This test is specified as $f(y^{1996})=g(y^{1977}xKACCUM)$. For each of these tests, we reject the null hypothesis that the distributions are equal. These results indicate that the change in the distribution of labor productivity

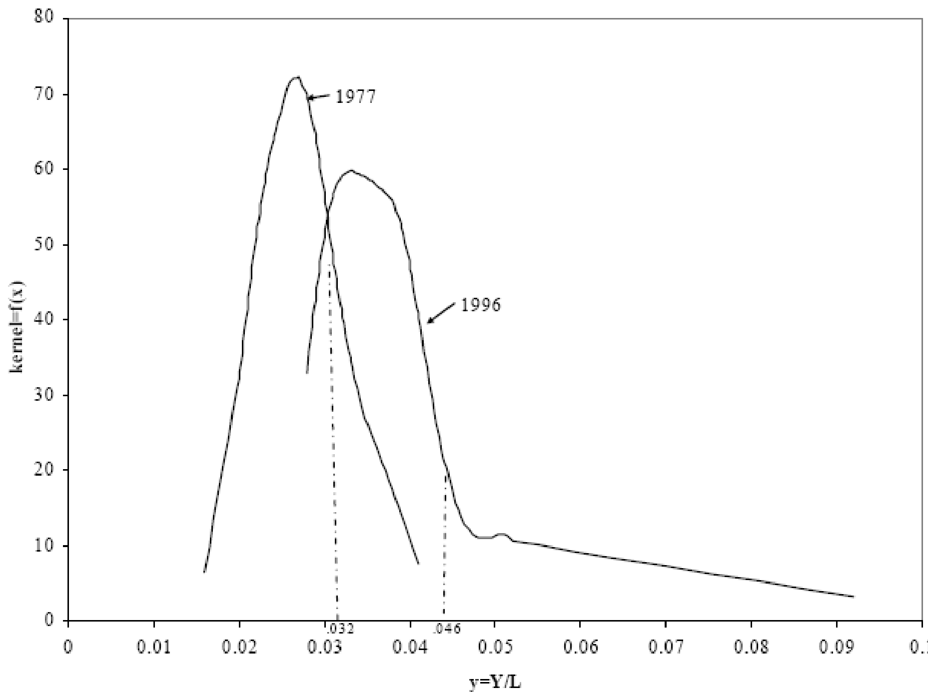

Figure 4. Kernel distribution of labor productivity in 1977 and 1996

from 1977 to 1986 cannot be explained solely by the effect of efficiency change, or solely by technical change, or solely by capital accumulation.

Table 4. Kernel Distribution Tests

Test of:	T
$f(Y/L^{1996})=g(Y/L^{1977})$	11.88
$f(Y/L^{1996})= g(Y/L^{1977}$xEFF)	12.33
$f(Y/L^{1996})= g(Y/L^{1977}$xTECH)	3.93
$f(Y/L^{1996})= g(Y/L^{1977}$xKACCUM)	4.69
$f(Y/L^{1996})= g(Y/L^{1977}$xEFFxTECH)	3.99
$f(Y/L^{1996})= g(Y/L^{1977}$xEFFxKACCUM)	2.78
$f(Y/L^{1996})= g(Y/L^{1977}$xTECHxKACCUM)	0.81

Can the change in labor productivity from 1977 to 1996 be explained by the product of efficiency change and technical change, or by the product of efficiency change and capital accumulation, or by the product of technical change and capital accumulation? These test results are presented in the last three lines in Table 4. We reject the null hypothesis that labor productivity growth can be explained solely by the effects of efficiency change and technical change. We also reject the hypothesis that productivity growth can be explained solely by the product of efficiency change and capital accumulation. However, we cannot reject the hypothesis that labor productivity growth is explained solely by the product of technical change and capital accumulation. This result indicates that changes in efficiency had no significant impact on the change in the distributions of labor productivity in 1977 and 1996. Taken together, the test results reported in Table 4 indicate that labor productivity increased in the manufacturing sector from 1977-1996 and that technical change and capital accumulation made a significant contribution to the change, while changes in state efficiency had no significant impact on labor productivity growth.

Is labor productivity converging? In Figure 5 we graph the level of labor productivity in 1977 and the value of the labor productivity index, y^{1996}/y^{1977}. The negative correlation of -0.41 between y^{1977} and y^{1996}/y^{1977} provides some evidence that labor productivity in the manufacturing sector is experiencing β convergence. In Figures 6-8, we graph labor productivity in 1977 against the indices of efficiency change, technical change and capital accumulation. Similar to Kumar and Russell, the relation between technical change and initial labor productivity is positive. Also similar to Kumar and Russell, we find that capital accumulation contributes to β-convergence. However, contrary to their results, we find a negative relation between efficiency change and labor productivity in 1977. This indicates that technological catch-up through greater efficiency has a role in promoting β-convergence within the U.S. This result is not too surprising, since communication barriers are lower within a country as compared to between countries, which should facilitate transmission of technological breakthroughs between regions.

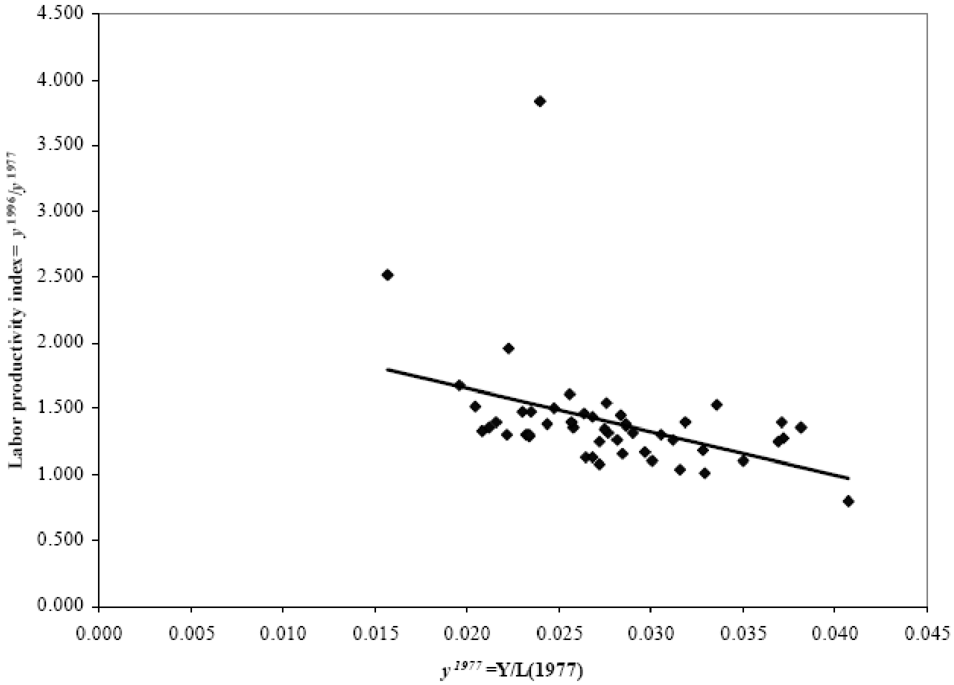

Figure 5. Evidence of labor productivity convergence

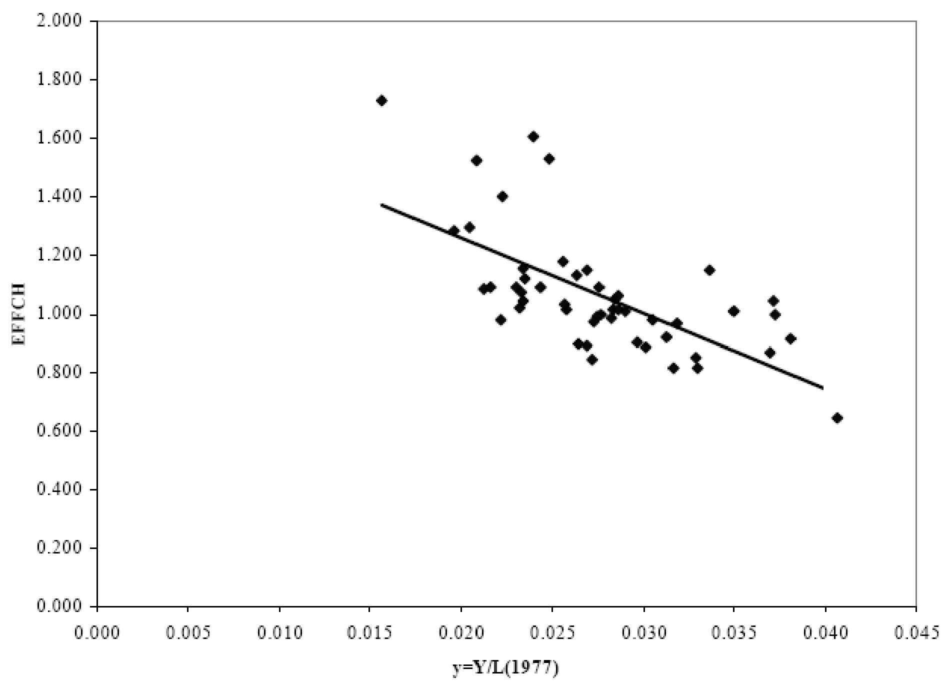

Figure 6. Efficiency change and labor productivity in 1977

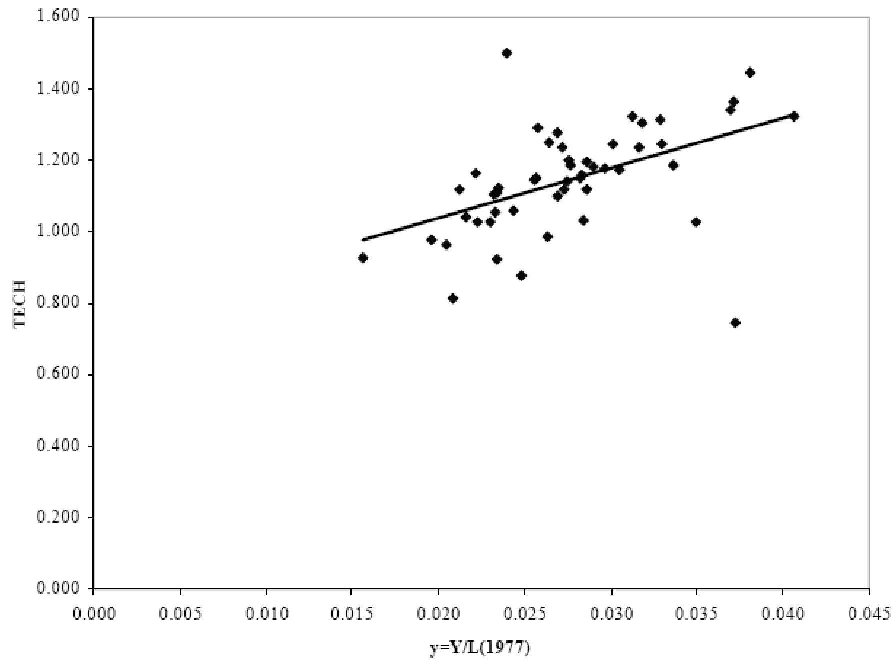

Figure 7. Technical change and labor productivity in 1977

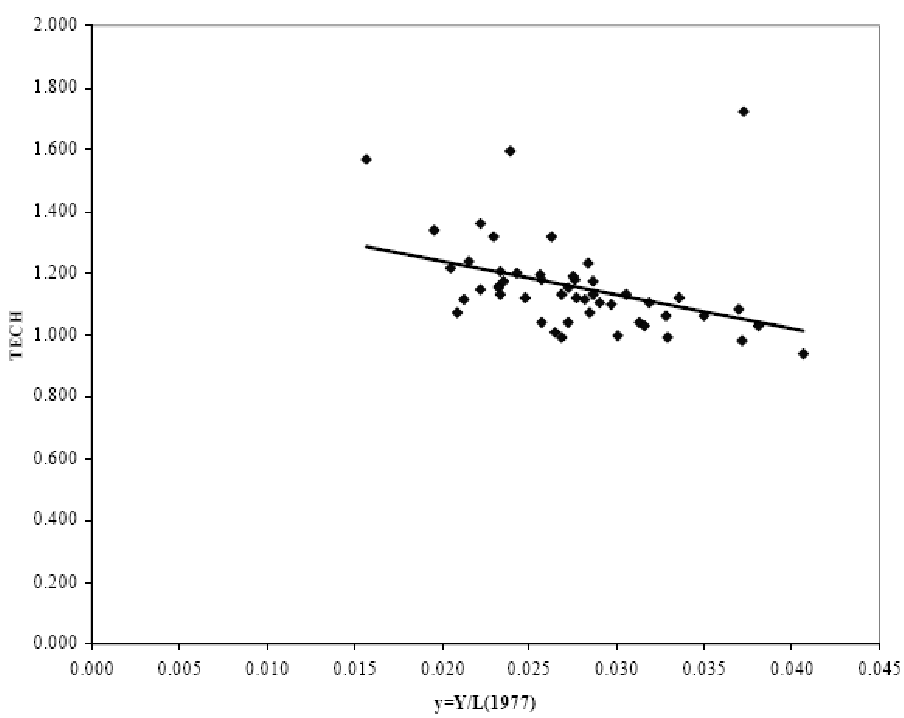

Figure 8. Capital accumulation and labor productivity in 1977

Returning to Figure 4, the kernel distribution of labor productivity in 1996 is more spread out than the kernel distribution of labor productivity in 1977 which suggests that σ-convergence has not occurred. This result is similar to Bernard and Jones, who found no evidence of σ-convergence in the manufacturing sector for fourteen OECD countries in the period 1970-87.

5. Summary

Despite its declining relative position in the U.S. economy, manufacturing continues to be a major source of jobs and income at the national and regional levels. In this paper we investigate the role of the manufacturing sector in promoting regional convergence, especially as it relates to labor productivity. We find that capital deepening and efficiency change have contributed to β-convergence in labor productivity, although the effects of efficiency change are small and potentially insignificant. However, technical change has tended to cause a divergence in labor productivity within U.S. regions. While β-convergence occurred during 1977-96, there is no evidence of σ-convergence during the same time period.

The policy implications of the results of this paper are several. Given that capital deepening plays an important role in the convergence of labor productivity, low productivity regions can improve their position by attracting capital; not a surprising result. National policies such as special tax credits to encourage the location of capital in disadvantaged regions would help to promote convergence of labor productivity. Since technological catch-up as measured by efficiency change has contributed to the convergence of labor productivity, national policies to facilitate the interregional transmission of new ideas and techniques would also be appropriate.

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