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REGIONAL COHESION:  
EVIDENCE AND THEORIES OF REGIONAL  
GROWTH AND CONVERGENCE

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**REGIONAL COHESION:  
Evidence and Theories of Regional Growth and Convergence**

**Abstract**

After arguing that the concepts of  $\beta$ -convergence and  $\sigma$ -convergence are independently interesting, this paper extends the empirical evidence on regional growth and convergence across the United States, Japan, and five European nations. We confirm that the estimated speeds of convergence are surprisingly similar across data sets: regions tend to converge at a speed of approximately two percent per year. We also show that the interregional distribution of income in all countries has shrunk over time. We then argue that, among the proposed potential explanations of this phenomenon, the one-sector neoclassical growth model and the hypothesis of technological diffusion seem to be the only one which survive scrutiny.

**Key Words:** Regional Economic Growth, Regional Cohesion, Convergence, Neoclassical Growth, Endogenous Growth, Capital Mobility, Technological Diffusion.

**JEL Classification:** O40, O41, O51, O52, O53.

During the last ten years, there has been a revival of interest in the forces that lead to economic convergence. This revival has been partly spurred by the renewed interest in the general topic of economic growth. A significant contribution to this revival has been the use of the convergence hypothesis as the main test to differentiate the two main current approaches to economic growth: the neoclassical model and the models of endogenous growth. Romer [1986] and Rebelo [1991] argued that the absence of convergence across economies throughout the world represented strong evidence against the neoclassical model and in favor of their theories of endogenous growth.

But there are reasons other than the testing of economic growth theories for the empirical study of economic convergence. We, as economists, are interested in knowing whether the distribution of income changes over time. For example, we are interested in whether, within a country, interregional differences in income levels tend to disappear or tend to increase over time. If they diminish, then we may be less worried about creating aid programs (such as the Regional and Cohesion Fund Policies carried out by the Government of the European Community) than if these differences tend to perpetuate themselves. We are also interested in knowing whether the regions that are relatively poor now are the same as the ones that were relatively poor one hundred years ago. If the answer is yes (that is, if poverty tends to persist over time), then we may want to enact public aid programs to allow the poor regions to escape this predicament. If the answer is no (that is, the economies that are relatively poor today are not likely to remain relatively poor in the future), then we may be no need to worry about the

country-wide distribution of income. As we will see in the next few sections, these questions are related to the empirical phenomenon which we call convergence.

In this paper, we will analyze and expand some of the results found in the recent empirical literature of regional convergence. We will argue that, in a variety of data sets, there is evidence of strong forces leading to regional convergence. Moreover, the estimated speeds of convergence are so surprisingly similar across data sets, that we can use a mnemonic rule: *economies converge at a speed of about two percent per year*. We will then analyze different ways to account for these results. The paper will conclude with a short review of the hypotheses which have been proposed to explain the convergence phenomenon. Explanations such as measurement error, government cohesion policies, migration, and perfect capital mobility will be ruled out. The neoclassical growth model (amended with partial capital mobility) and technological diffusion will be left as the likely explanations of the convergence phenomenon.

### (1) Concepts of Convergence

#### *$\beta$ -convergence versus $\sigma$ -convergence*

The first thing we shall do is define what is meant by convergence. In attempting to do this, we note that the literature has used many definitions (see for example Quah [1993a]). We will use two concepts:  $\sigma$ -convergence and  $\beta$ -convergence.

We will say that there is  $\beta$ -convergence in a cross-section of economies if we find a negative relation between the growth rate of income per capita

and the initial level of income.<sup>1</sup> In other words, we say that there is  $\beta$ -convergence if poor economies tend to grow faster than wealthy ones. This concept of convergence is often confused with an alternative definition of convergence, where that the dispersion of real per capita income across groups of economies tends to fall over time. This is what we call  $\sigma$ -convergence.

We will argue later that, although they are not identical, the two concepts of convergence are related. Some people have argued that the concept of  $\beta$ -convergence is irrelevant and the only thing of interest is whether the world distribution of income becomes more equitable over time. Quah [1993a] makes this point forcefully in the context of Galton's fallacy (see also Friedman [1992].)

We disagree with the Quah-Friedman assessment, because we believe that both concepts of convergence are interesting and should be analyzed empirically. Let us illustrate why  $\beta$ -convergence is interesting independently of  $\sigma$ -convergence, with two examples where  $\sigma$ -convergence is eliminated by construction. Consider the ordinal rankings of the NBA teams over time. The dispersion of rankings is constant by definition. Sports analysts and NBA owners are interested in questions such as "how quickly the great teams revert to mediocrity", "how long do dynasties last in basketball". For example, how long did it take for the great Boston Celtics of the 1950s and 1960s and the Los Angeles Lakers of the 1980s to become average teams?. How long will it take for the Chicago Bulls to go back to mediocrity now that the great Michael Jordan has retired.

The reverse is also interesting: How quickly do mediocre teams become

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<sup>1</sup>This phenomenon is sometimes called 'regression to the mean'.

great teams? For example, how long did it take to create the Celtics of the 1950s, the Lakers of the 1980s, or the Bulls of the 1990s? One could even be interested in the type of policies the NBA could introduce to transform bad teams into great teams in as little time as possible. For instance, we could ask whether the introduction of the draft accelerated the convergence process.

At the other end of the spectrum, we observe sports leagues like the Spanish soccer league where two teams, Barcelona and Real Madrid, win the overwhelming majority of the titles. We could ask what the mechanisms are that allow for this outcome (for instance, in Spain there is no draft and there are no salary caps; this enables the rich teams to buy the best players and, as a result they win more titles and become even richer). Once we identify these mechanisms, we can think about ways to increase the competitiveness of the other teams, and as a result, increase the aggregate interest in the league. We believe that all these questions are interesting. But note, that all of them refer to the concept of  $\beta$ -convergence, not  $\sigma$ -convergence. In fact, reducing the cross sectional variance in a sports league would probably not make any sense (consider how interesting a league would be if all teams tied for first place every single year!)

Similar examples can be constructed using economics. Consider, for example, two economies with identical degrees of income inequality. Suppose that, over a period of 50 years, these indexes of inequality remain constant (so neither economy exhibits  $\sigma$ -convergence across individuals.) The economic structures of the two countries, however, are very different. Country A is mainly agricultural. The scarce land is controlled by the small privileged class who bequeaths it to their children. Hence, the children of the rich

end up being rich and the children of the poor end up being poor. Economy B is centered around the industrial sector. A few skillful entrepreneurs, who had good ideas and were able to implement them, are the rich owners of the companies. The rest of the population works for them. Some of the workers' children have good ideas and entrepreneurial skills so that they start their own companies and become rich. Some of the children of the original owners are not as bright as their parents, so eventually they lose their parents' fortunes. After 50 years, the degree of income inequality remains constant but the wealth is held by different families. Economy B displays  $\beta$ -convergence in the sense that the growth rate of income was higher for the poor families than the rich ones. Economy A, on the other hand, does not display  $\beta$ -convergence because the growth rate of income for the rich was the same as that of the poor (so that their income differentials persisted over 50 years). Is our economy more like A or like B? If it is like B, how fast do the poor become rich and the rich poor? Can anything be done to transform economies like A into economies like B? All these interesting questions deal exclusively to the concept of  $\beta$ -convergence (note that  $\sigma$ -convergence has been eliminated by construction, and we can still find interesting economic questions to discuss).

These examples are NOT meant to suggest that  $\sigma$ -convergence is uninteresting. On the contrary, it is very important to know whether actual economies's incomes are becoming more similar or whether the differences between rich and poor families or individuals shrink over time. The examples illustrate that the two concepts examine interesting phenomena which are conceptually different:  $\sigma$ -convergence studies how the distribution of income evolves over time and  $\beta$ -convergence studies the mobility of income within the

same distribution. We believe, therefore, that both concepts should be studied and applied empirically and we will do so in this paper.

### *The Relation Between $\beta$ -Convergence and $\sigma$ -Convergence*

Although different, the two concepts of convergence are related. Suppose that  $\beta$ -convergence holds for a group of regions  $i$ , where  $i=1, \dots, N$ . In discrete time, corresponding perhaps to annual data, the real per capita income for economy  $i$  can be approximated by

$$(1) \quad \log(y_{it}) = a + (1-\beta) \cdot \log(y_{i,t-1}) + u_{it},$$

where  $a$  and  $\beta$  are constants, with  $0 < \beta < 1$ , and  $u_{it}$  is a disturbance term. The condition  $\beta > 0$  implies  $\beta$ -convergence because the annual growth rate  $\log(y_{it}/y_{i,t-1})$  is inversely related to the  $\log(y_{i,t-1})$ . A higher coefficient  $\beta$  corresponds to a greater tendency for convergence.<sup>2</sup> The disturbance term captures temporary shocks to the production function, the saving rate, and so on. We assume that  $u_{it}$  has mean zero, the same variance,  $\sigma_u^2$ , for all economies, and is independent over time and across economies.

In order to measure the cross-sectional dispersion of income, we take the sample variance of the log of income

$$(2) \quad \sigma_t^2 = (1/n) \sum_{i=1}^N [\log(y_{it}) - \mu_t]^2,$$

where  $\mu_t$  is the sample mean of  $\log(y_{it})$ . If  $N$  is large, then the sample variance is close to the population variance, and we can use (1) to derive the evolution of  $\sigma_t^2$  over time:

$$(3) \quad \sigma_t^2 \cong (1-\beta)^2 \cdot \sigma_{t-1}^2 + \sigma_u^2.$$

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<sup>2</sup>The condition  $\beta < 1$  rules out leapfrogging or overshooting, where poor economies are systematically predicted to get ahead of rich economies at future dates.



This is a first-order difference equation, which is stable if  $0 < \beta < 1$ . If there is no  $\beta$ -convergence so that  $\beta < 0$ , then the cross-sectional variance increases over time. That is, if there is no  $\beta$ -convergence, there cannot be  $\sigma$ -convergence (in other words,  $\beta$ -convergence is a necessary condition for  $\sigma$ -convergence). The steady-state value of  $\sigma_t^2$  is given by

$$(\sigma^2)^* = \sigma_u^2 / [1 - (1 - \beta)^2].$$

The steady-state dispersion falls with  $\beta$  but rises with the variance  $\sigma_u^2$  of the disturbance term. Note that the steady-state dispersion is positive even if  $\beta$  is positive as long as  $\sigma_u^2 > 0$ . We can solve the difference equation (3) to find an expression for  $\sigma_t^2$  over time:

$$(4) \quad \sigma_t^2 = (\sigma^2)^* + (1 - \beta)^2 \cdot [\sigma_{t-1}^2 - (\sigma^2)^*].$$

If  $\beta$ -convergence holds ( $\beta > 0$ ), then  $\sigma_t^2$  approaches its steady-state value  $(\sigma^2)^*$  monotonically. The key point, however, is that  $\sigma_t^2$  can increase or decrease towards the steady-state depending on whether the initial value of  $\sigma^2$  is above or below the steady-state. Note in particular that  $\sigma$  could be rising along the transition even if  $\beta > 0$ . In other words,  $\beta$ -convergence is not a sufficient condition for  $\sigma$ -convergence. Summarizing,  $\beta$ -convergence is a necessary but not a sufficient condition for  $\sigma$ -convergence.

In Section (3) we will analyze empirical evidence on  $\beta$ -convergence and  $\sigma$ -convergence separately. In a series of recent papers, Danny Quah has proposed new ways of jointly analyzing  $\sigma$  and  $\beta$  using Stochastic Kernels for the dynamics of the distribution of output or income per capita (see for example Quah [1993b]).

### *Conditional $\beta$ -Convergence*

Following Barro and Sala-i-Martin [1991, 1992a] and Mankiw, Romer and Weil [1992], we can also distinguish conditional from absolute convergence. We say that a set of economies displays conditional  $\beta$ -convergence if the partial correlation between growth and initial income is negative. In other words, if we run a cross-sectional regression of growth on initial income, holding constant a number of additional variables, and we find that the coefficient on initial income is negative, then we say that the economies in the data set display conditional  $\beta$ -convergence. If the coefficient of initial income is negative in a univariate regression, then we say that the data set displays absolute convergence.

In the regional data sets studied in this paper, we ignore the conditioning issue. There are two reasons for this. First, unlike the regressions involving cross-sections of countries, we find convergence in regional data sets, without the inclusion of conditioning variables. Second, and perhaps more importantly, a variety of studies have found that the estimates of  $\beta$  for regional data sets do not change substantially when the sets of variables that are usually held constant in cross-country studies are included in the analysis (see for example Barro [1991].)

### (2) Regional Data Sets

In a number of papers, Barro and Sala-i-Martin [1991, 1992a, 1992b, 1995] have analyzed the convergence properties of the regions within various countries. The results, extended to 1990, are reported in Table 1 and Figures 1 to 6. Table 1 provides evidence for  $\beta$ -convergence for the regions of the United States (48 contiguous states), Canada (10 provinces), Japan (47

prefectures), and Europe (73 nuts 2 regions). The dates for which data are available for the various countries differ somewhat. For the United States, we have annual personal income data computed by the U.S. Commerce Department beginning in 1929 (see Bureau of Economic Analysis [1986]). The concept of personal income used in these regional accounts corresponds to the concept used in the national accounts. Thus, if we add personal income for each of the states, we would get (at least theoretically) the U.S. aggregate figure for personal income<sup>3</sup>. We use the figures that exclude transfer payments. We expanded the data set with Easterlin's [1960a, 1960b] estimates of state personal income for 1880 (47 states and territories), 1900 (48 states and territories), and 1920 (48 states). These data also exclude transfer payments.

We do not have measures of price levels or price indexes for individual states. Therefore, we deflate the nominal values for each state by the national consumer price index. Given that we use the same price deflator for all states in a single year, the particular deflator that we use affects only the constant term in the empirical analysis. Population data are taken from the U.S. Bureau of the Census [1975] and Department of Commerce [1990].

The data on income across Japanese prefectures were collected by the Economic Planning Agency (EPA) of Japan and start in 1955. The prefectural income accounts are reported by the respective prefectures on the basis of the "1983 Standardized System of Prefectural Accounts" so the income for all prefectures is standardized. The data are collected annually (so there is no interpolation) by the EPA and published in the "Annual Report on Prefectural

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<sup>3</sup>Note, however, that we exclude Alaska, Hawaii and the District of Columbia from our analysis.

Accounts". The concepts of income used are adopted from the national income statistics so the aggregate of prefectural incomes of all 47 prefectures is theoretically identical to Japan's *national income*. As was the case for the United States, we use national price indexes to deflate each prefecture's income.

The data on population are prepared by the Statistics Bureau at the Management and Coordination Agency. The principal source of these data is the quinquennial Population Censuses taken by the Statistics Bureau. Data for intercensal years are computed by interpolation and use data on vital statistics and interprefectural migration. The estimates correspond to the stock of population as of October 1st each year.

We have GDP data for regions in seven European countries (Germany, United Kingdom, France, Italy, the Netherlands, Belgium, and Denmark), totaling 73 regions. Data for 1950, 1960, and 1970 are taken from Willem Molle. Data for 1966 (excluding France and Denmark), 1970 (excluding Denmark), 1974, 1980, and 1985 are from Eurostat. The nominal figures for GDP are expressed using current exchange rates in terms of a common currency unit. For the later years, the population data were collected by the Eurostat.

We have expanded the European data set to include the 17 regions (Comunidades Autonomas) of Spain. We had Spanish data on personal income and gross domestic product by province for the 50 provinces. The data were then aggregated up to the level of comunidades, using the latest definition (the regional distribution of provinces changed sometime during the 1970s). Starting in 1955, the data were collected (almost) biannually by the Banco de Bilbao and published in the "Spanish National Income and its Provincial Distribution" (*Renta Nacional Española y su Distribucion Provincial*).

Provincial population data are taken from the Spanish Statistical Abstract (Anuario Estadístico de España), published by the Instituto Nacional de Estadística.

This enormous data set was further expanded to include provincial personal income data for 10 Canadian provinces for the period 1961-1990. The data were provided to us by Coulombe and Lee [1993]. The main source of data for Canada is Cansim, which reports annual personal income, as well as population for the 10 provinces. The provincial personal income data are supposed to aggregate to the national total. Unlike the other countries, Canada collects price data by provinces. Hence, provincial rather than national prices were used in this case.

### (3) International Evidence on Regional Convergence.

We now use the regional data for the various countries to analyze regional convergence in incomes per capita. We can estimate the speed of convergence  $\beta$  by regressing the average growth rate of a set of regions between times  $t_0$  and  $t_0+T$  on the initial level of income. In order to estimate the speed of convergence precisely we estimate the nonlinear equation

$$(5) \quad (1/T)\log(y_{it_0+T}/y_{i,t_0}) = a - [(1-e^{-\beta T})/T] \cdot \log(y_{i,t_0}) + u_{it_0,t_0+T},$$

where  $u_{it_0,t_0+T}$  represents the average of the error terms,  $u_{it}$ , between times  $t_0$  and  $t_0+T$ .

Table 1 shows non-linear least-squares in the form (5) for 48 U.S. states for the period 1880 to 1990.<sup>4</sup> Each cell contains four numbers. The first

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<sup>4</sup>Equation (5) could be estimated using OLS as

is the estimate of  $\beta$ . Underneath in parenthesis, we report  $\beta$ 's standard error. To its right we report the adjusted  $R^2$  of the regression and below the  $R^2$ , the standard error of the regression (all equations have been estimated with constant terms, which are not reported in Table 1).

The first column reports the estimate of  $\beta$  for a single long sample (1880-1990). The point estimate is 0.0174 (s.e.=0.0026).<sup>5</sup> The large value of  $R^2$  can be also appreciated by looking at Figure 1, which is a scatter plot of the average growth rate of income per capita between 1880 and 1990 versus the log of income per capita in 1880.

The second column reports the breakdown of the overall period into sets of 10 year pieces (20 years for 1880 to 1900 and 1900 to 1920). We restrict the estimate of  $\beta$  over time, but we allow for time fixed effects. We also

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$$(1/T)\log(y_{it_{0+T}}/y_{i,t_0}) = a - (1-b_T) \cdot \log(y_{i,t_0}) + u_{it_0,t_0+T}.$$

The speed of convergence  $\beta$  could then be computed by using the equality  $(1-b_T) = [(1-e^{-\beta T})/T]$ . Note that OLS estimate  $(1-b_T)$  would be inversely related to  $T$  (the length of the period over which we compute the growth rate). The intuition is that, if there is convergence, then the growth rate should fall over time (because when the economy is richer, the growth rate is smaller). When we average long periods of time, we combine early periods with large growth rate with later periods with small growth rates. Hence, the growth rate predicted by the original (low) level of income is smaller the longer the time period of analysis. Note that as  $T$  goes to infinity the term  $1-b_T$  goes to zero, and as  $T$  goes to zero, the term  $1-b_T$  goes to  $\beta$ .

The reason for choosing to estimate equation (5) using non-linear least squares (NLS) rather than OLS is that the estimated speed of convergence  $\beta$  can be directly compared across samples with different length without having to use transformations. The NLS method is fine unless the autoregressive coefficient,  $b_T$ , is negative. We never found a sample period in any region of any country where the autoregressive coefficient was close to being negative. Hence, we conclude that the estimation of (5) using NLS is correct.

<sup>5</sup>This regression includes 47 states or territories. Data for the Oklahoma territory was unavailable for 1880.

hold constant the shares of income originated in agriculture and industry to proxy for sectoral shocks that affect growth in the short run. These variables prove not to affect the estimates of  $\beta$  over the long run. The restricted point estimate of  $\beta$  is 0.022 (s.e.=0.002).

Figure 2 shows the cross-sectional standard deviation for the log of per capita personal income net of transfers for 48 U.S. states from 1880 to 1992. We observe that the dispersion declined from 0.54 in 1880 to 0.33 in 1920, but then rose to 0.40 in 1930. This rise reflects the adverse shock to agriculture during the 1920s: the agricultural states were relatively poor in 1920 and suffered a further reduction in income due to the fall in agricultural prices. After the 1920s shock, dispersion fell to 0.35 in 1940, 0.24 in 1950, 0.21 in 1960, 0.17 in 1970, and a low point of 0.14 in 1976: The long-run decline stopped in the mid-1970s, after the oil shock, and  $\sigma_t$  rose to 0.15 in 1980 and 0.19 in 1988. The rise in income dispersion was reversed in the last two years of the 1980s and it kept falling through 1992. An interesting aspect of Figure 2 is that the behavior of the cross-sectional dispersion of personal income net of transfers is very similar to that gross of transfers. In particular, the dispersion of both measures of income fell after 1930, rose between 1977 and 1988 and fell between 1988 and 1992. This is true, even though the level of the dispersion is lower for income gross of transfers. Hence, it seems as if transfers help reduce cross-state dispersion of per capita income. However, interstate transfers are not responsible for the long run decline in income dispersion.

The second row of Table 1 reports similar estimates for 47 Japanese prefectures for the period 1955-1987. The first column corresponds to a single regression for the period 1955-1987. The estimated  $\beta$  coefficient is

0.019 (s.e.=0.004) with an adjusted  $R^2$  of 0.59. The standard error of the regression is 0.0027. The estimates reported in Table 1 use data starting in 1955 because income data by sector are not available before that date.

Income data, however, are available from 1930. If we use the 1930 data, the estimated speed of convergence would be 0.027 (s.e.=0.003). The good fit can also be appreciated in Figure 3. The evidently strong negative correlation between the growth rate 1930-1987 and the log of per capita income in 1930 confirms the existence of  $\beta$ -convergence across the Japanese prefectures.

To assess the extent to which there has been  $\sigma$ -convergence across prefectures in Japan, we calculate the unweighted cross-sectional standard deviation for the log of per capita income,  $\sigma_t$ , for the 47 prefectures from 1930 to 1990. Figure 4 shows that the dispersion of personal income increased from 0.47 in 1930 to 0.63 in 1940. One explanation of this phenomenon is the explosion of military spending during the period. The average growth rates for Districts 1 (Hokkaido-Tohoku) and 7 (Kyushu), which are mainly agricultural, were -2.4 percent and -1.7 percent per year respectively. On the other hand, the industrial regions of Tokyo, Osaka and Aichi grew at +3.7, +3.1, and +1.7 percent per year respectively.

The cross prefectural dispersion has decreased dramatically since 1940: it fell to 0.29 by 1950, to 0.25 in 1960, to 0.23 in 1970 and hit a minimum of 0.125 in 1978. It has increased slightly since then:  $\sigma_t$  rose to 0.13 in 1980, 0.14 in 1985 and 0.15 in 1987. Income dispersion has been relatively constant since then.

One popular explanation of the increase in dispersion for the 1980s is the take-off of the Tokyo region from the rest of Japan. Tokyo was relatively richer at the end of the 1970s (average per capita income in real



terms for Tokyo region was 2.000 billion yen and the average for the rest of Japan was 1.751 billion yen). Not only did they enjoy initial wealth, but they also experienced faster growth during the 1980s (2.95 percent a year versus 2.16 percent per year). This sequence of events could explain this apparent divergence. To check this point, Barro and Sala-i-Martin [1992b] calculated the cross sectional standard deviation of the log of per capita income for the seven Japanese Districts, and for the six Districts exclusive of Kanto-Koshin (which includes Tokyo). The exclusion of the Tokyo region shifts the cross sectional variance down for all periods, but it does not change the general behavior of  $\sigma_t$  over time. The increase in dispersion during the 1980s is larger if the Tokyo region is included, but it is still increasing if excluded. Thus, even though Tokyo contributed to the general increase in dispersion during the 1980s, its take off does not fully explain this divergence.

Rows 3 through 8 in Table 1 refer to  $\beta$ -convergence across European regions within eight countries (Germany, France, the United Kingdom, Italy, the Netherlands, Belgium, Denmark and Spain). The first row relates to the estimate of  $\beta$  for a sample of 40 years, 1950-1990, when we restrict the speeds of convergence to coincide across the 90 regions and over time. The estimate, however, allows for country fixed effects. The estimated speed of convergence is 0.015 (s.e.=0.002). The estimate of  $\beta$  when we allow each of the four decades to have a fixed time effect is 0.031 (s.e.=0.004).

Figure 5 shows the relation of the growth rate of per capita GDP (income per capita for Spain) for the 90 regions from 1950 to 1990 (1955 to 1987 for Spain.) The values shown are all measured relative to the means of the respective countries. The figure shows the type of negative relation that is

familiar from the U.S. states and Japanese prefectures. The correlation between the growth rate and the log of initial per capita GDP in Figure 5 is -0.72. Because the underlying numbers are expressed relative to own-country means, the relation in Figure 5 pertains to  $\beta$ -convergence within countries rather than between countries and corresponds to the estimates reported in column 1 of Table 3.

The estimates for the long sample for each of the five major countries (Germany, UK, France, Italy and Spain) are reported in the next five rows. The estimates range from 0.010 (s.e.=0.003) for Italy to 0.030 (s.e.=0.007) for the UK. The restricted panel estimates for the individual countries are reported in Column 2. Note that the individual point estimates are all close to 0.020 or two percent per year. They range from 0.0148 for France to 0.0292 for the United Kingdom. The estimates for Spain are 0.023 (s.e.=0.007) for the long sample and 0.019 (s.e.=0.004) for the restricted panel estimates with fixed time effects.

The final row reports the results for Canada as given by Coulombe and Lee [1993] for the period 1961 to 1991. The estimate of  $\beta$  for the 30 year sample is 0.024 (s.e.=0.008).

Figure 6 shows the behavior of  $\sigma_t$  for the regions within the largest five countries in the sample: Germany, the United Kingdom, Italy, France, and Spain. The countries are always ranked highest to lowest, as Italy, Spain, Germany, France, and the United Kingdom. The overall pattern shows declines in  $\sigma_t$  over time for each country, although little net change has occurred since 1970 for Germany and the United Kingdom. In particular, the rise in  $\sigma_t$  from 1974 to 1980 for the United Kingdom - the only oil producer in the European sample - likely reflects the effects of oil shocks. In 1990, the

values of  $\sigma_t$  are 0.27 for Italy, 0.22 for Spain (this value corresponds to 1987), 0.186 for Germany, 0.139 for France, and 0.122 for the United Kingdom.

The main lesson from this subsection is that there is convergence both in the  $\beta$  and  $\sigma$  sense across regions of the U.S., Japan, Europe, Spain, and Canada. The speeds of  $\beta$  convergence are extraordinarily similar across countries: about two percent per year.

#### (4) Alternative Explanations of these Results.

##### (i) *Econometric-Theory-Based Explanations*

##### *Measurement Error and Price Disparities.*

As is well known, the measurement error in the initial level of income leads to a negative bias in the least-squares estimation of the convergence coefficient. The regressions shown in Table 1, therefore, can exaggerate the estimated convergence coefficient  $\beta$ , if real income is measured with error.

Barro and Sala-i-Martin [1992a] argue that classical measurement error is an unlikely explanation of the observed phenomenon. They regress the growth rate of income on the lagged level of income and find that the estimated coefficients are very similar to the ones displayed in Table 1. If temporary measurement error was important, the finding would have been a much smaller convergence coefficient when the lagged income was used.

Aside from the usual problems of measurement of income, one reason to expect errors is that we divide all nominal variables in each year by a common price index. The finding of interregional convergence in levels of output could be explained by interregional convergence in price levels with no real convergence. Two of the data sets used here have regional prices available: Japan and Canada. Shioji [1992], estimates the speeds of

convergence for prefectures in Japan for the same subperiod reported in Table 1. The only difference between his estimates and ours is that he deflates prefectural income per capita by prefectural price levels. His estimated speeds of convergence, however, are virtually identical to the ones reported in Table 1. This suggests that mismeasurement of the price level is not responsible for the observed pattern of interregional convergence in Japan. Coulombe and Lee [1993] report convergence coefficients for Canadian provinces using provincial price deflators and they find similar speeds of convergence. Again, price convergence does not seem to be the explanation behind our Canadian convergence.

Finally, we should point out that measurement error can bias the regression coefficients to make it appear as if there was convergence when there is none. However, our analysis of  $\sigma$ -convergence is immune to the measurement error problem since measurement error cannot bias the measures of dispersion.<sup>6</sup> Since we tend to find that  $\sigma$ -convergence is associated with  $\beta$ -convergence in all samples, we find the measurement error argument unconvincing.

Thus, we are fairly confident that measurement error and interregional price dispersion cannot explain behind candidates to explain the convergence findings reported in Table 1 and Figures 1 to 6.

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<sup>6</sup>In order to argue that our findings about  $\sigma$ -convergence are also generated by measurement error, one would have to argue that the variance of the error falls over time.

*Danny Quah and the Unit Root Hypothesis in Short Samples.*

Quah [1994, this issue] suggests that the constant speed of convergence across data sets could be a manifestation of the well known small sample downward bias in unit root processes. Quah generates a number of Monte Carlo simulations of cross-sectionally independent random walks and runs cross-sectional regressions like the ones we run in Table 1. He shows that speeds of convergence of 2 percent per year can be estimated fairly consistently when the cross-sectional sample size is close to the sample size used in this paper (the length of time he needs to get speeds of 2 percent per year, however, are a bit larger than the ones we use in this paper).

Quah's conclusion is that the constant estimates of 2 percent per year could just be a statistical illusion since a collection of random walks estimated in a cross section could deliver such an outcome. However, he also says that this is unlikely. His reasoning is that the standard errors associated with his estimates are very large. In fact, a zero speed of convergence (the true speed) can almost never be rejected in his Monte Carlo simulations. This is never the case in the estimates of Table 1.

One big problem with Quah's analysis is that his collection of independent random walks predicts that the cross-sectional dispersion of income should be increasing over time. We showed in Figures 2, 4, and 6 that this is not the case for virtually any of the countries in our samples. In other words, if the incomes in the real world have been generated by independent random walks like the ones proposed by Quah, then where did Figures 2, 4 and 6 come from?<sup>7</sup>

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<sup>7</sup>This terminology was first introduced by Sala-i-Martin [1990].

(ii) *National Government Policies.*

An intriguing possible explanation for the convergence results is that the government of the country whose regions are being studied purposefully redistributes income across regions in such a way that convergence appears to occur at a speed of about two percent per year.

Although not fully studied in all data sets, we can access this possibility as follows. First, in the United States (where the data are available) the pattern of convergence, both in the  $\beta$  and the  $\sigma$  sense, seems to be exactly the same for income net of transfers and income gross of transfers. Furthermore, the pattern of convergence seems to exist in income per capita as well as Gross Domestic Product. The data for European regions is GDP. This measure of output refers to production before transfers. Taken together, this evidence suggests an empirically minor role of *public transfers*.

But the government could induce convergence by spending, hiring and investing in the relatively poor regions financed by taxes from the relatively rich regions. If this were true, however, convergence should vanish from our regional data sets once such measures of public spending are held constant. Sala-i-Martin [1990] adds measures of federal spending, investment and employment in a cross-state growth regression for the United States and finds little change in the convergence coefficients. In fact, in the United States, there seems to be no relation between the level of income of a region and the amount of spending or employment by the Federal government in that region.

Finally, we can argue that the effect of the government in the process of convergence is minor by observing that the speeds of convergence are

surprisingly similar across data sets. Since the degree to which national governments use regional cohesion policies is very different, the fact that the speeds of convergence are very similar across countries suggests that public policy plays a very small role in the overall process of regional convergence.

*(iii) Growth Models: Neoclassical versus Endogenous Growth.*

The standard neoclassical growth model is now the conventional way of explaining convergence results found in the previous subsection. Consider the constant saving rate version of the model due to Solow [1956] and Swan [1956]. Let  $s$  be the constant saving rate, where  $0 < s < 1$ . In a closed economy, savings are equal to gross investment, and gross investment, in turn, is equal to the net increase in the capital stock plus depreciation. Written in per capita terms, the increase in the capital stock is given by

$$(6) \quad \dot{k} = s \cdot Af(k) - (\delta + n)k,$$

where  $k$  is the capital stock per person,  $Af(k)$  is the production function in per capita terms,  $\delta$  is the depreciation rate and  $n$  is the exogenous rate of population growth. The parameter  $A$  reflects the level of technology, where technology is considered in a macroeconomic sense that includes aggregate distortions such as taxation, imperfect property rights, and other things of this nature. We assume for the moment that  $A$ ,  $\delta$ , and  $n$  are exogenous constants. Equation (6) is the fundamental differential equation of the Solow-Swan model which, given  $k_0$ , describes the dynamic behavior of capital at all future times. If we divide both sides of (6) by  $k$ , we get an

expression for the growth rate of the capital stock,  $k$ :

$$(7) \quad \gamma_k = s \cdot Af(k)/k - (\delta+n).$$

Given  $k_0$ , the behavior of the economy can be analyzed using Figure 7. The figure displays two functions: a horizontal line at  $\delta+n$  which we will call the depreciation curve and a downward-sloping line,  $s \cdot Af(k)/k$ , which we will call the savings curve. Equation (7) indicates that the growth rate is the difference between the two. The neoclassical assumption of diminishing returns to capital ensures that the savings curve is downward sloping. The Inada conditions (which are also standard assumptions in the neoclassical model) ensure that the savings curve is vertical at  $k=0$  and it approaches the horizontal axis as  $k$  tends to infinity. Since the savings curve takes all values between zero and infinity, we are sure that it crosses the depreciation line at least once (that is, an intersection exists). Since it is always downward sloping, we are sure that it crosses it only once (that is, the intersection is unique). Thus, the crossing point is called the steady-state capital stock.

The important point for the purpose of our discussion is that the saving curve is downward sloping. If we think that all economies within one of our data sets (say all the states of the U.S.) have a similar technology in the sense of having similar parameters  $A$  and  $\delta$ , as well as similar saving rates,  $s$ , and rates of population growth,  $n$ , then they will all converge to a single steady state. Figure 7 shows that, in this case, the growth rate corresponding to the poor economy (whose capital stock is called  $k_{\text{poor}}$ ) is larger than the growth rate of the rich one ( $k_{\text{rich}}$ ). Hence, if the only difference across economies is the initial capital stock, the neoclassical model predicts convergence in the sense that poor regions will grow faster



than rich ones.<sup>8</sup>

The intuition behind the convergence implication of the neoclassical model is that, because of diminishing returns to capital, each addition to the capital stock generates enormous additions to output when the capital stock is small. The opposite is true when the capital stock is large.

*The One-Sector Model of Endogenous Growth.*

The convergence prediction of the neoclassical model conflicts with the prediction of the one-sector models of endogenous growth. Consider, for example, the simplest of such models, the AK model. The linear AK technology violates two key neoclassical assumptions: diminishing returns to capital and the Inada conditions. If we substitute the neoclassical technology  $Af(k)$  by the linear technology  $Ak$ , then the growth equation (7) becomes

$$(8) \quad \gamma_k = s \cdot A - (\delta + n).$$

The dynamic behavior of this model is depicted in Figure 8. The depreciation curve is still a horizontal line at  $\delta + n$ . The savings curve is no longer downward sloping but, rather, it is a horizontal line at  $s \cdot A$ . Figure 8 is drawn under the assumption that  $sA > \delta + n$ , which implies a positive and constant distance between the saving and depreciation line and, as a result, a positive and constant growth rate.

Consider now two economies which differ only in the initial capital stocks ( $k_{\text{rich}}$  and  $k_{\text{poor}}$  in Figure 8). The model predicts that the growth

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<sup>8</sup>If there are regional differences in saving rates, technologies or rates of population growth, then the model predicts conditional convergence in that the steady-state of each economy needs to be held constant empirically (see Barro and Sala-i-Martin (1991, 1992a) and Mankiw, Romer and Weil (1992).) See also the discussion in Section One.

rate of the two economies is the same so they will not converge.<sup>9</sup>

The fact that the neoclassical model predicts convergence and the AK model does not, explains why the convergence hypothesis has received so much attention in the last few years: it is one simple way to test the two models.<sup>10</sup>

*Open Economy Considerations: Interregional Credit Markets.*

One the main critiques of the neoclassical interpretation of the convergence phenomenon is that the economies in the sample are not obviously closed in that they all have access to the same capital market. The neoclassical model with perfect capital mobility, however, predicts instantaneous convergence to the steady state, which is in clear contradiction with the estimated speed of 2 percent per year.

The problem with this line of reasoning is that the setup with perfect

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<sup>9</sup>If we allow for cross-regional differences in  $A$ ,  $s$ ,  $\delta$  or  $n$ , then the growth rates will not be the same across economies. However, there will not be a systematic negative relation between growth and the initial level of income unless the  $A$  or  $s$  ( $\delta$  or  $n$ ) are systematically higher (lower) for poor regions. There is no a priori reason why this would be the case. Hence, the model still does not predict convergence.

<sup>10</sup>Strictly speaking, the convergence hypothesis is not a test of endogenous growth, but instead, a test of the absence of diminishing returns. A CES technology with high elasticity of substitution, for example, may generate positive steady-state rates of growth and convergence. The reason is that the key to endogenous growth is the violation of the Inada condition, while the key to convergence is the existence of diminishing returns to capital. The CES production mentioned above displays diminishing returns to capital (so it predicts convergence), but violates the Inada conditions so it generates endogenous growth. See also the production functions proposed by Kurz [1968] and Jones and Manuelli [1990].

Furthermore, Mulligan and Sala-i-Martin [1993] show that two-sector models of endogenous growth like those of Uzawa [1965] and Lucas [1988] predict convergence regressions like the ones we estimate in this paper. To test the neoclassical model from these models, a good measure of human capital is needed. Although there have been attempts to compute measures of human capital, a satisfactory estimate is not yet available.

capital mobility is just as unrealistic as the setup with no capital mobility at all: even though the economies under consideration have access to national and international capital markets, it does not follow that they can borrow unlimited amounts of resources. In particular, in order to borrow they need collateral and maybe not all the capital stock in the economy can be used as such (for example, in the absence of slave markets, it may be hard to use human capital as collateral.) Barro, Mankiw and Sala-i-Martin [1995] propose a model of partial capital mobility where only a fraction of the capital stock can be used as collateral. Their main conclusion is that the speed of convergence predicted for a closed economy (with no capital mobility), is very similar to the speed predicted by an open economy model where the share of mobile capital that can be used as collateral is about one half. For all practical purposes, therefore, the assumption of a closed economy does not yield terribly misleading results, as long as one is ready to believe that mobility exists but is not quite perfect. Thus, the neoclassical model with partial capital mobility is consistent with the empirical evidence on convergence.

Barro, Mankiw and Sala-i-Martin [1995] also show that the one sector model of endogenous growth cannot predict convergence whether there is perfect, partial, or no capital mobility at all.

*(iv) Can an Extended AK Model Explain Convergence?*

The neoclassical model is clearly a good candidate to account for the convergence results. We can now ask whether we can amend the AK model so that it too predicts convergence.

We start by looking at Figure 8, which says that, if  $A$ ,  $s$ ,  $\delta$  and  $n$  are

constant, then the growth rate is independent of the capital stock. We can think of the neoclassical model as a way to relax the assumption that the average product of capital (which in Figure 8 is given by A) is a constant: diminishing returns to capital make the average product of capital a decreasing function of  $k$ . The savings curve becomes downward sloping so the savings and depreciation curves become closer as  $k$  increases (as depicted in Figure 7), and this is what makes the model predict convergence.

Along similar lines, we could generate convergence in the AK model if we could argue that the saving rate  $s$  was a decreasing function of  $k$  (so that the savings curve in Figure 8 is downward sloping) or if the rate of population growth,  $n$ , or the depreciation rate,  $\delta$ , were increasing functions of  $k$  (so that the depreciation curve is upward sloping.) We analyze these possibilities in this section.

#### *Endogeneizing the Saving Rate.*

We can see in Figure 8 that if we can generate a saving rate decreasing in  $k$ , we will obtain an endogenous growth model that predicts convergence. The setups in the literature on endogenous growth always allow representative agents to choose their consumption and saving behavior optimally. In other words, the saving rate is allowed to move freely with  $k$ . The general prediction, however, is that if the technology is linear in capital, then the saving rate does not fall with  $k$  but, rather, it is optimally set to a constant. This is true, for example, for all positive intertemporal elasticities of substitution (as long as this elasticity is kept constant). To get the saving rate to fall along the transition, we would need to have the rate of return falling sharply. The problem is that the rate of return

in an AK economy is constant.

The AK model may predict convergence in a setup with heterogeneous agents whose discount rates increase with the level of wealth (Uzawa [1968]): if poor people are more patient than rich people (that is, if their discount rate is lower), then they prefer steeper consumption profiles. In other words, they tend to consume relatively less and save relatively more than rich people. It follows that the income growth rates for the poor are higher (that is, there will be  $\beta$ -convergence across families or regions.)

Notice that for this argument to work, we need to assume that rich people are more impatient, an assumption which has been often criticized and dismissed as implausible (one would think that rich people can afford to be more patient). One clever way of explaining the positive relationship between discount rates and wealth is provided by Mulligan [1993]. His main point is that in order to be altruistic towards people, one has to spend time with them to develop the required attachment. Parents with high wages find it more expensive to spend time with their children so they end up being less altruistic towards them. It follows that they discount the future more (because the future is the time when their children, rather than themselves, will consume).

#### *Endogeneizing Depreciation*

Another specification of the AK model that would result in convergence is to have the depreciation curve be an increasing function of  $k$ . One way to do this would be to argue that the depreciation rate is an increasing function of  $k$ . Surprisingly, the depreciation rate remains an unexplored area of research so theories that relate the physical rate of depreciation to the

capital stock are unavailable.

### *Endogeneizing Population Growth*

Another way to get an upward sloping depreciation curve is to have the rate of population growth be an increasing function of  $k$ . In general, the stock of population grows for three reasons: increases in fertility, reductions in mortality, and migration. The relation between mortality and growth remains an unexplored research area. There has been a recent interest in the relation between fertility and growth (see for instance Becker and Barro [1988] and Barro and Becker [1989].) However, it is easy to see that endogenous fertility rates cannot be the explanation behind the existence of convergence within the AK model: in order to explain convergence, fertility (and population growth) should rise with the stock of capital. Empirically, however, the exact opposite is true: rich countries have lower fertility rates. This leaves migration as the only potential explanation of the potential positive relation between the rate of population growth and the stock of capital.

Like the mobility of physical capital, mobility of persons could potentially be the explanation behind the findings on interregional convergence. Both capital and labor move to those economies which deliver the highest return for their services. This implies that capital moves from rich regions to poor regions whereas labor moves from poor economies to rich economies. If the capital stock is positively related to wages, it follows that the rate of population growth will be positively related to the capital stock (see Dolado, Goria, and Ichino [1993].) Unfortunately, in the AK model the wage rate is not positively related to the capital stock so that the

relation between the rate of population growth and the capital stock disappears. Hence, the AK model does not predict convergence, even when we allow for migration (See Barro and Sala-i-Martin [1995, Chapter 9].)

At the empirical level, Barro and Sala-i-Martin [1991, 1992b, 1995] show that the sensitivity of migration to initial income is small and about 0.0025 for the United States, Japan and Europe (Germany, France, U.K., Italy, and Spain). In other words, a ten percent income differential triggers a migration rate that changes the rate of population growth by 0.25 percent. Taking this into account, they show that the convergence coefficients are virtually unchanged once one allows for interregional migration to occur. Hence, from an empirical point of view, migration does not seem to be the answer either.

*(v) Technological Diffusion*

Another way to generate convergence is to allow for the level of technology of the poor economies to catch up with that of the rich. In 1962, Nelson and Phelps postulated that the rate of technological progress for a country was a function of the distance between its level of technology and the level of technology of the world leader. In other words,

$$(9) \quad \dot{A}_i/A_i = \lambda \cdot (A_{\text{leader}} - A_i),$$

where  $A_i$  is the level of technology of region  $i$ , and  $A_{\text{leader}}$  is the level of technology of the world leader. If we embed this assumption in an otherwise AK model, we can easily generate convergence in the levels of per capita income (capital may not converge but the parameter  $A$  does).

We can incorporate this idea in the modern models of endogenous growth and R&D explored by Romer [1990] and Grossman and Helpman [1991]. These

models assume that technological progress takes the form of new types of capital goods, and generates endogenous growth because there are no diminishing returns to the number of goods. The new goods are introduced by firms who purposefully perform research and development to invent the goods in exchange for a permanent patent that allows them to collect monopoly profits on the sales of such goods. They show that, other things being equal, the growth rate is a negative function of the cost of inventing new products (the cost of R&D).

One can amend these models to allow for technological diffusion (see Barro and Sala-i-Martin, 1995, Chapter 8). For example, we can think of lagging countries as being able to imitate the products invented in the leading nations. The process of imitation would be similar to the process of R&D in that a fraction of resources would have to be spent to learn how to imitate the product. The growth rate for these imitating countries would be a function of the imitation costs. To the extent that imitation costs are lower than innovation costs, the lagging countries would tend to grow faster so the economies would converge.

The question is what happens when the poor imitating countries (which grow faster than the rich, innovating countries) completely catch up so that there are no more goods to be imitated (one can argue that this situation applies to Japan today.) Presumably, they will have to become innovators themselves and they will have to pay the higher cost of innovation, which will reduce their growth rate.

We could also think that the cost of imitation is a negative function of the goods that remain to be imitated (the cost of imitation converging to the innovation cost as the number of goods that remain to be copied goes to



zero). The idea is that there are some goods that are easy to copy and others that are not. If countries can choose from a large pool of goods, they will start copying the ones that are easy and cheaper to imitate. As they exhaust the easy goods, they will have to switch towards goods that are harder to copy. The growth rate of productivity would fall as the productivity differential (reflected in the pool of goods that remain to be copied) disappears. Note that this model would provide a micro-foundation to the Nelson and Phelps conjecture about the form of technological convergence.

#### (5) Conclusions

This paper reviewed and extended the empirical evidence on regional convergence. We argued that both  $\sigma$  and  $\beta$ -convergence seem to occur in a variety of data sets. The speeds at which the regions of different countries converge over different time periods are surprisingly similar: about two percent per year. This estimate is very robust and always strongly significant. If we think of its economic meaning, however, we note that a speed of two percent per year is quite slow. It implies, for example, that 50 percent of the distance between an economy's initial level of income and its steady state disappears in about 35 years, and that 75 percent of this difference vanishes only after 70 years. Put another way, one fourth of the original income differences are predicted to remain after a long period of 70 years.

A variety of explanations that could account for these findings were explored. Some of them were rejected: we argued that statistical artifacts such as measurement error and small sample bias in integrated processes were

unlikely explanations. Regional price dispersion and national public policies that attempted to induce convergence were not likely to be the underlying forces behind the observed patterns of convergence either. We also argued that the one-sector models of endogenous growth could not explain these findings, even if we amended them to include capital mobility, endogenous fertility, or migration. Endogeneizing the saving rate was a potential solution in a world of heterogeneous agents, but only if rich individuals were less patient than poor ones (an assumption that is often seen as implausible.)

Among the still plausible explanations, the neoclassical model without or with partial capital mobility is the most popular one. The slow speeds of convergence estimated in the different data sets, however, suggest that the parameterizations of the neoclassical model normally used by economists are inconsistent with the evidence because they tend to generate much higher predictions for the speed of convergence. For example, the neoclassical model with a capital share of 0.3 tends to predict speeds of convergence of about 6 or 7 percent per year. In order to make the model consistent with the magnitudes estimated, the capital share needs to be close to 0.7 or 0.8 (see Barro and Sala-i-Martin [1992a].) This can be achieved by thinking of capital in a broad sense that includes human capital elements.

Another set of theories consistent with the evidence on regional economic convergence are models of endogenous growth with technological diffusion. According to these theories, the slow speed of two percent per year suggests that technology does not instantaneously flow across countries. The theoretical reason for such a low speed of technical adaptation may be the existence of imitation and implementation costs. These costs may be

negatively related to the amount of technology which remains to be imitated.

The evidence discussed in this paper cannot distinguish the neoclassical hypothesis diminishing returns to capital from the hypothesis of positive (but slow) rates of technological diffusion. Further research is therefore needed in order to find out which one of the two hypothesis is more likely to dominate the process of regional economic cohesion.

Table 1

Countries	Long-Run Single Regression		Panel Estimates	
	$\beta$ (s.e.)	$R^2$ (s.e. Reg.)	$\beta$ (s.e.)	
United States 48 States (1880-1990)	0.017 (0.002)	0.89 [.0015]	0.022 (0.002)	...
Japan 47 Prefectures (1955-1990)	0.019 (0.004)	0.59 [.0027]	0.031 (0.004)	...
Europe Total 90 regions (1950-1990)	0.015 (0.002)	--- ---	0.018 (0.003)	...
Germany (11 regions)	0.014 (0.005)	0.55 [0.0027]	0.016 (0.006)	...
UK (11 regions)	0.030 (0.007)	0.61 [0.0021]	0.029 (0.009)	...
France (21 regions)	0.016 (0.004)	0.55 [0.0022]	0.015 (0.003)	...
Italy (20 regions)	0.010 (0.003)	0.46 [0.0031]	0.016 (0.003)	...
Spain (17 regions) (1955-87)	0.023 (0.007)	0.63 [0.004]	0.019 (0.005)	...
Canada 10 Provinces (1961-91)	0.024 (0.008)	0.29 [0.0025]	--- ---	

Notes to Table 1: The regressions use non linear squares to estimate equations of the form:

$$(1/T)\ln(y_{it}/y_{i,t-T}) = a - [\ln(y_{i,t-T})](1 - e^{-\beta T})(1/T) + \text{"other variables"},$$

where  $y_{i,t-T}$  is the per capita income in region  $i$  at the beginning of the interval divided by the overall CPI.  $T$  is the length of the interval; "other

variables" are regional dummies and sectoral variables that hold constant temporary shocks that may affect the performance of a region in a manner that is correlated with the initial level of income (recall that when the error term is correlated with the explanatory variable, then the OLS estimate of  $\beta$  is biased).

Each column contains four numbers. The first one is the estimate of  $\beta$ . Underneath it, in parentheses, its standard error. To its right, the adjusted  $R^2$  of the regression and below the  $R^2$ , the standard error of the equation. Thus, constant, regional dummies and/or structural variables are not reported in the Table.

The coefficients for Europe Total include one dummy for each of the eight countries.

Column 1 reports the panel estimates when all the subperiods are assumed to have the same coefficient  $\beta$ . This estimation allows for time effects. For most countries, the restriction of  $\beta$  being constant over the subperiods cannot be rejected (see Barro and Sala-i-Martin [1995].)

Column 2 reports the value of  $\beta$  estimated from a single cross section using the longest available data. For example, for the United States, the coefficient  $\beta$  estimated by regressing the average growth rate between 1880 and 1990 is  $\beta=0.022$  (s.e.=0.0002).

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Figure 1: Convergence of Personal Income across U.S. States. 1880 Personal Income and Income Growth from 1880 to 1990

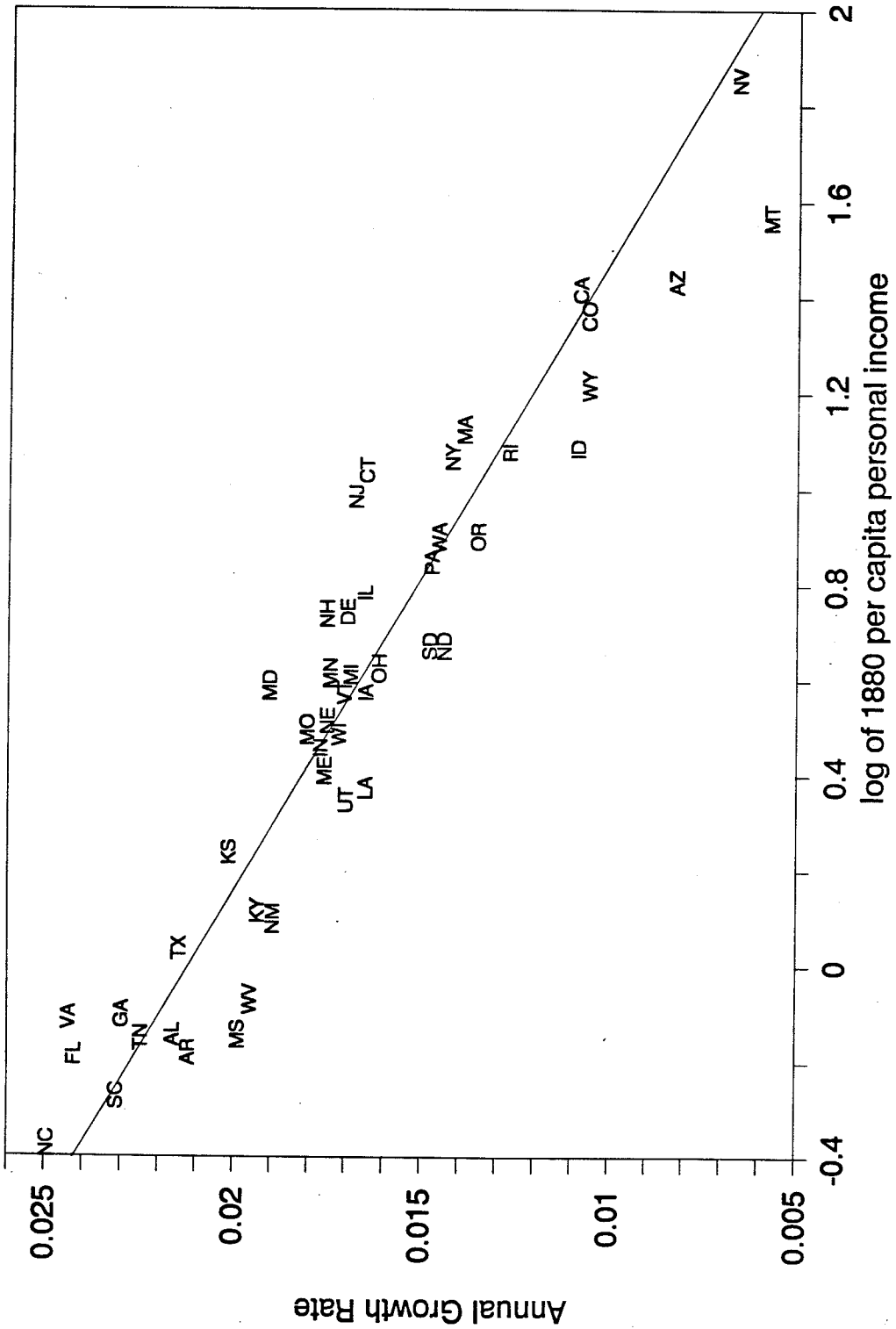


Figure 2:  
Dispersion of Personal Income across U.S. States, 1880-1992

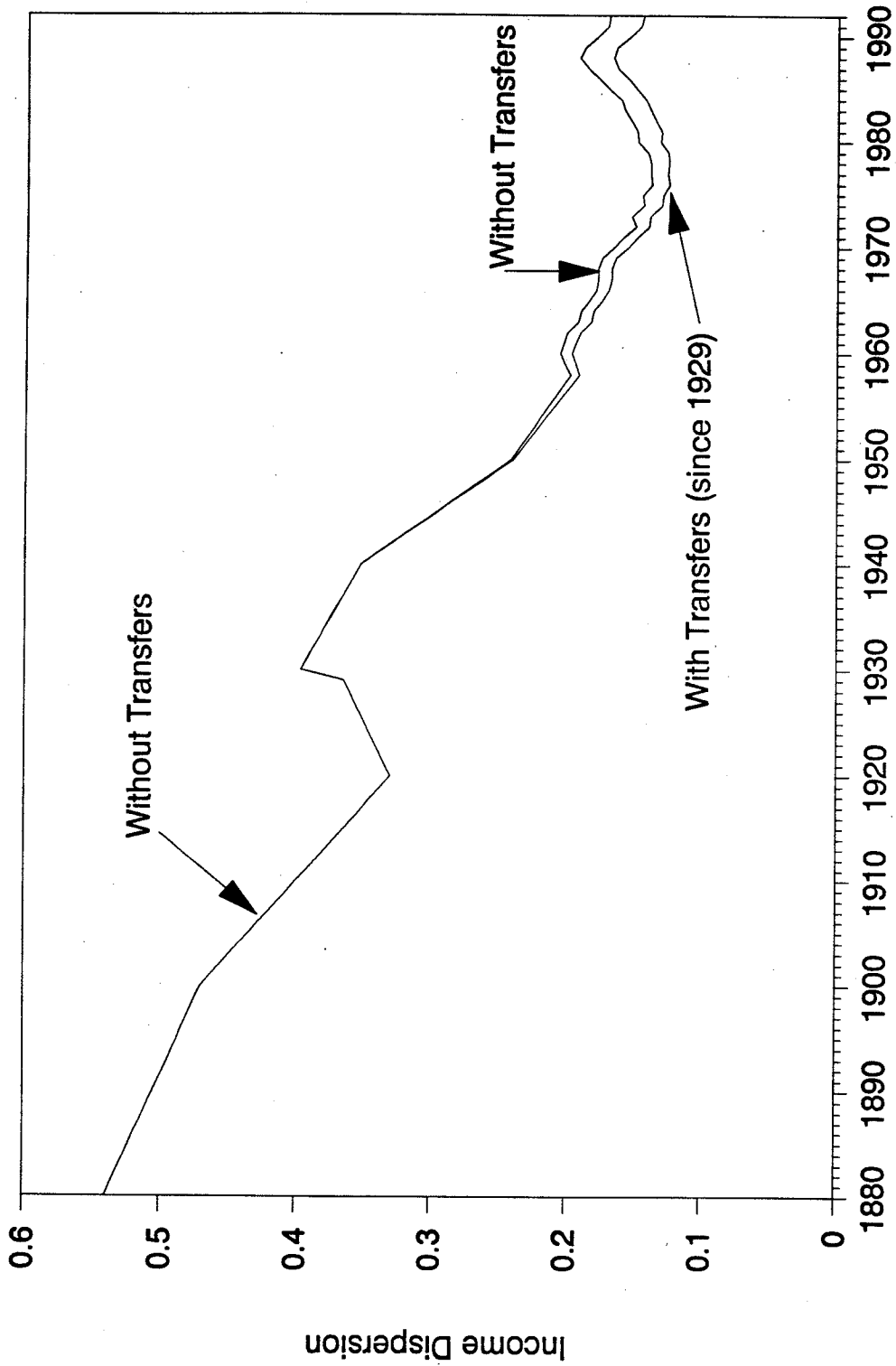


Figure 3:  
 Convergence of Personal Income Across Japanese Prefectures  
 1930 Income and Income Growth 1930-1990

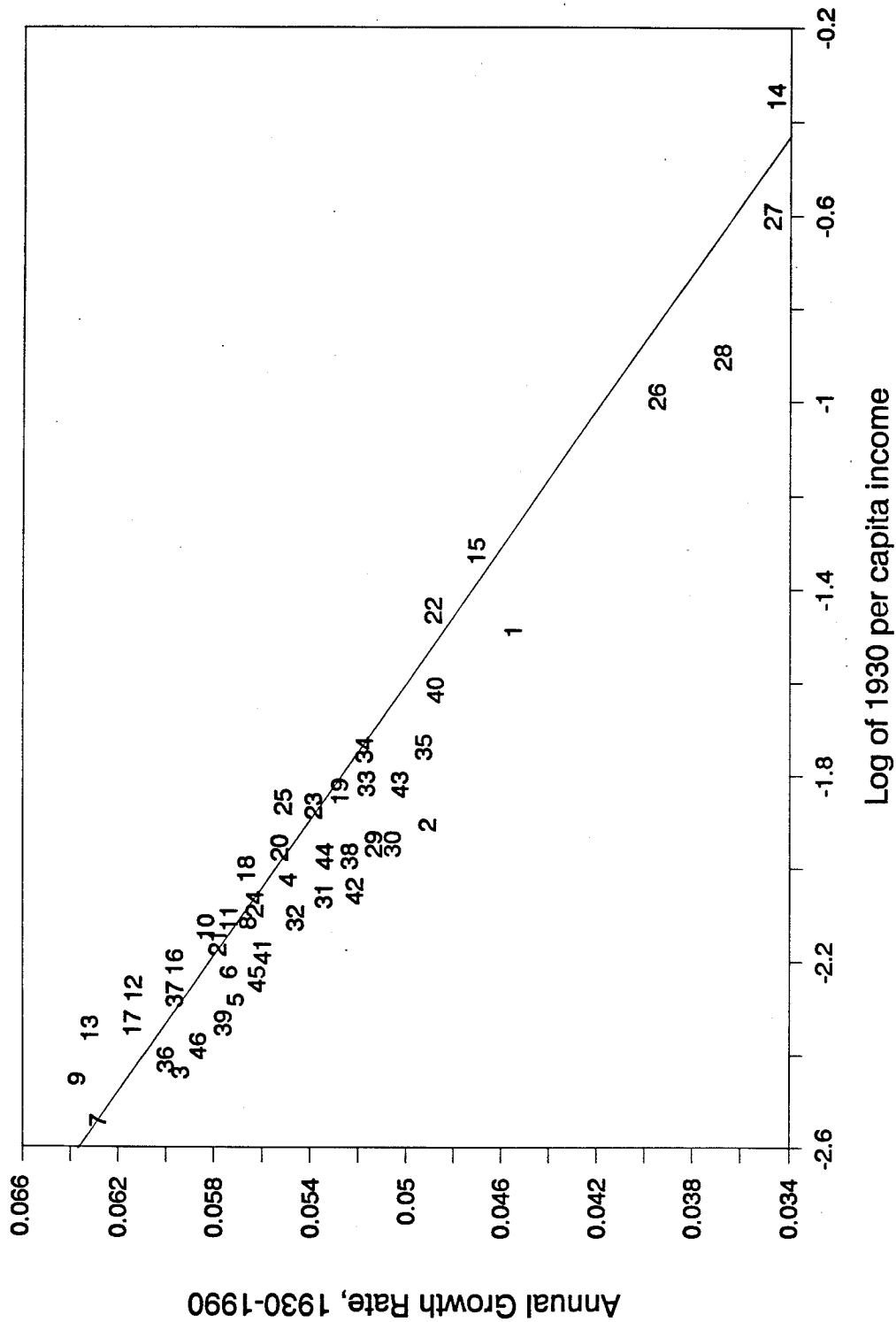


Figure 4:  
Dispersion of Personal Income Across Japanese Prefectures  
1930-1990

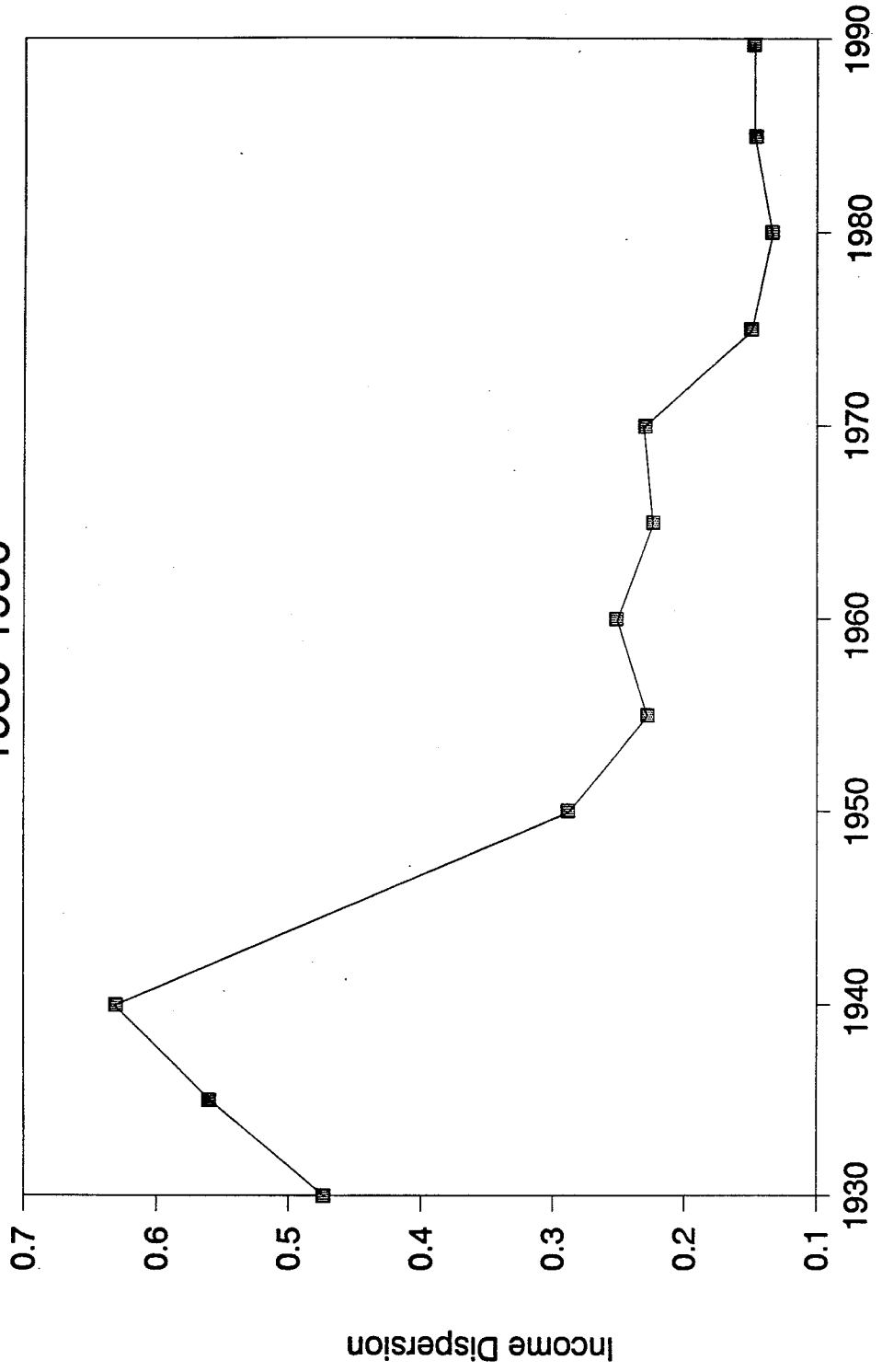


Figure 5: Growth Rate from 1950 to 1990 versus 1950 per capita GDP for 90 Regions in Europe

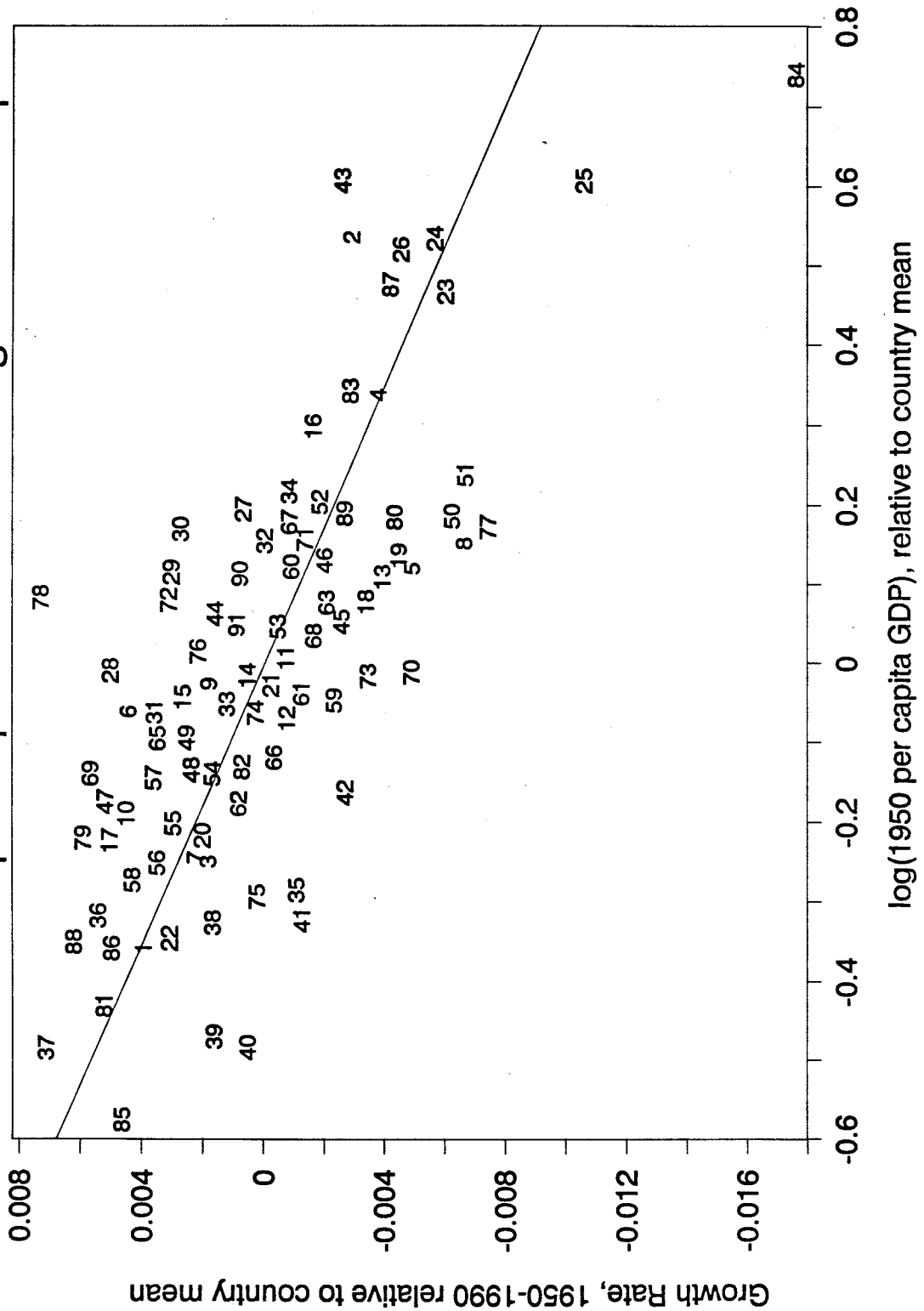


FIGURE 6: DISPERSION,  $\sigma_t$ , OF GDP PER CAPITA  
WITHIN FIVE EUROPEAN COUNTRIES

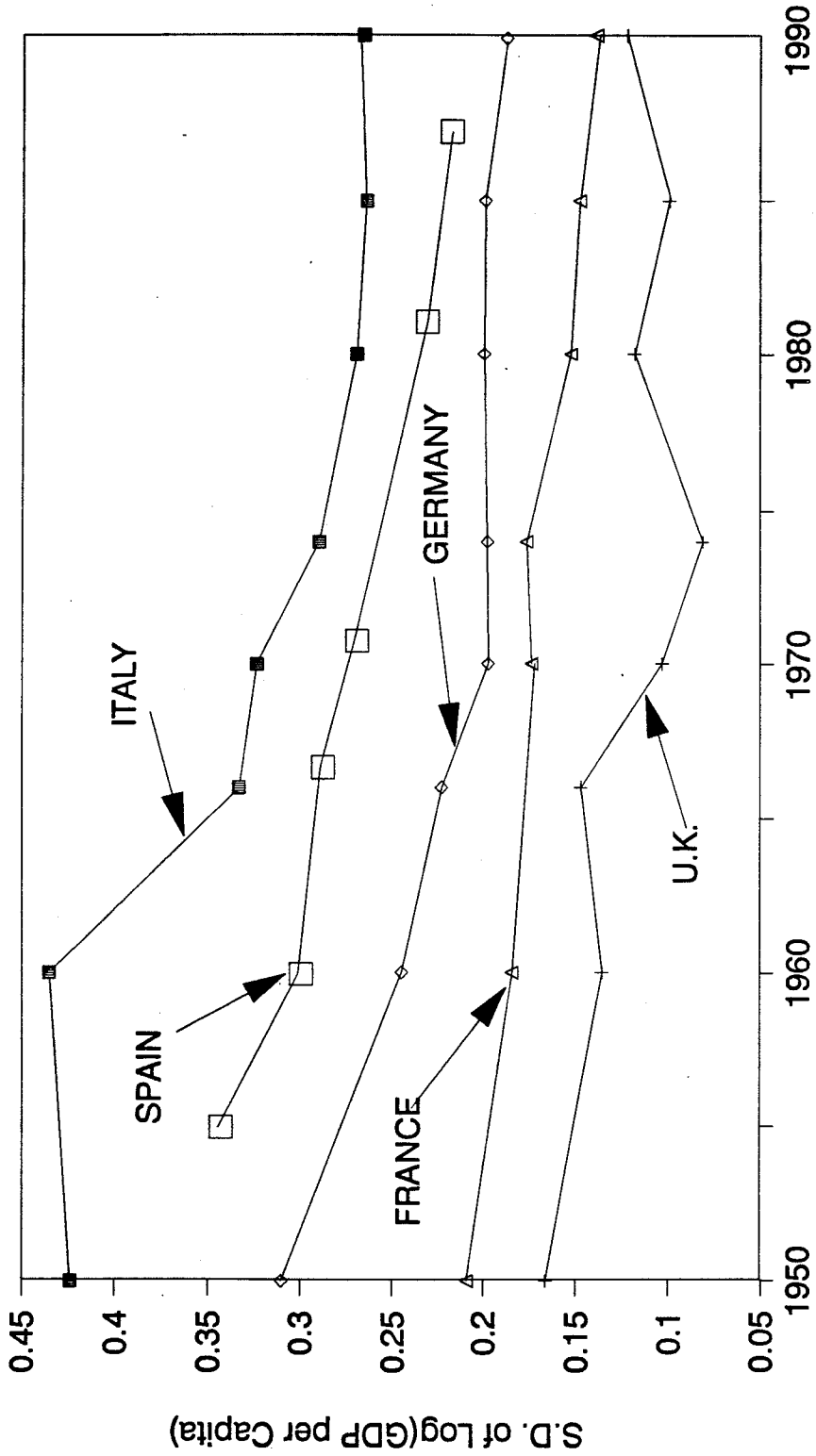


Figure 7: The Neoclassical Model of Solow and Swan

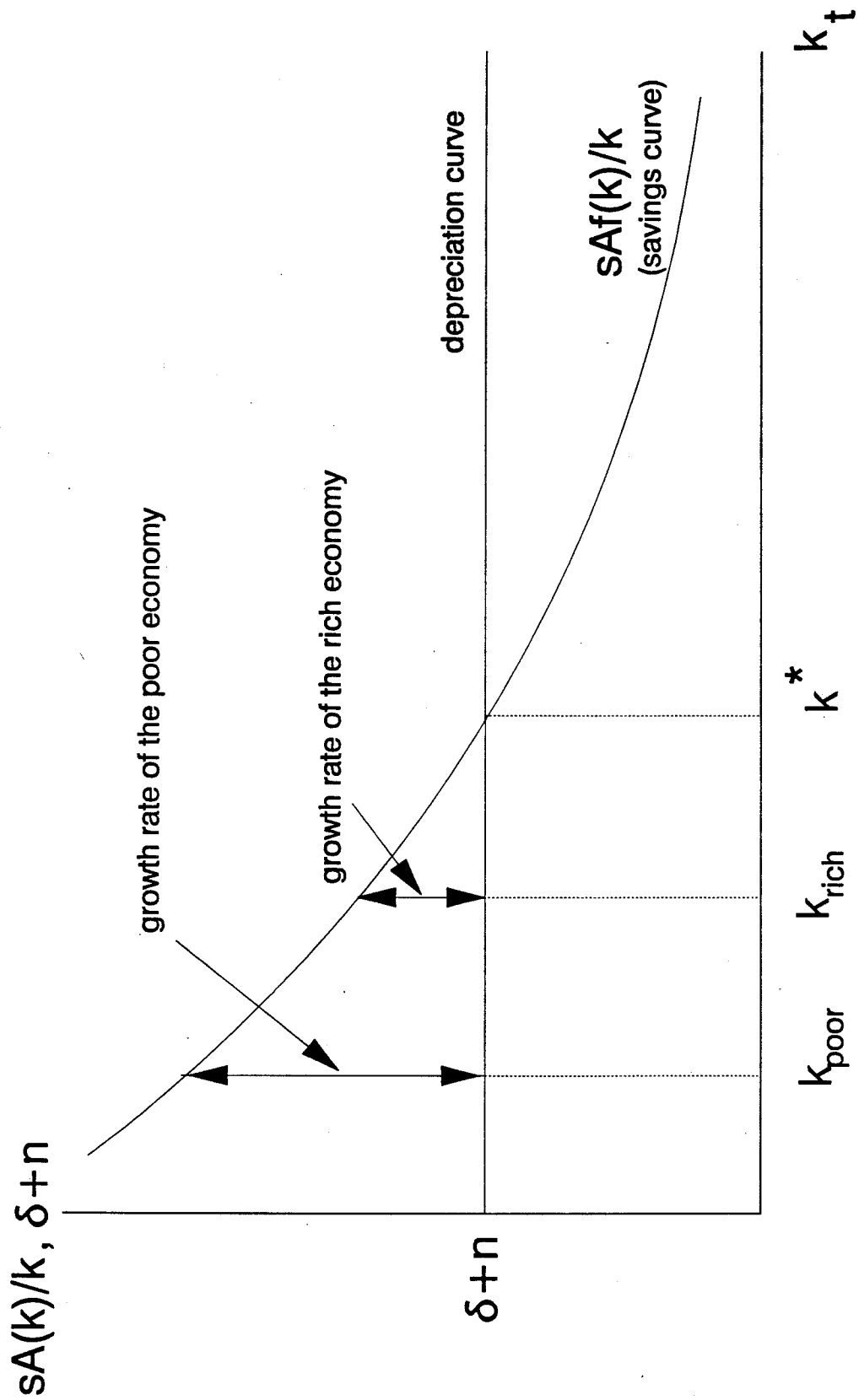


Figure 8: The One Sector Model of Endogenous Growth

