Innovation Dynamics in the EU: Convergence or Divergence?*

A Cross-Country Panel Data Analysis

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Summary: This paper investigates whether a convergence or divergence of national innovation capabilities of the 15 EU countries occurs in the course of time. An answer to this question permits immediate conclusions with regard to the success prospects of a convergence of per capita incomes and labor productivities within the EU. For the empirical analysis based on patents granted at the US-Patent and Trademark Office, the conventional tests for β- or σ-convergence as well as unit root tests for time series and panel data are used, which are both linked to different definitions of convergence. Taking all results together, evidence points to the fact that an absolute convergence of innovation capabilities is an exception. However, for a number of countries the results suggest either conditional convergence or convergence to an own growth path.

Zusammenfassung: Dieser Beitrag beschäftigt sich mit der Frage, ob es im Zeitablauf zu einer Angleichung (Konvergenz) oder Divergenz der nationalen Innovationsfähigkeiten der 15 EU-Staaten kommt. Die Beantwortung dieser Frage erlaubt auch unmittelbare Rückschlüsse bezüglich der Erfolgsaussichten einer Angleichung der Pro-Kopf-Einkommen und Arbeitsproduktivitäten innerhalb der EU. Zur empirischen Analyse auf der Basis der Patenterteilungen am US-Patentamt von 1963 bis 1998 werden sowohl die konventionellen Tests auf β- und σ-Konvergenz als auch Zeitreihen- und Panel-Einheitswurzeltests herangezogen, wobei beiden Gruppen von Testverfahren unterschiedliche Konvergenzdefinitionen zugrunde liegen. Zusammengefaßt zeigen die Ergebnisse, daß eine absolute Konvergenz der Innovationsfähigkeiten die Ausnahme ist, bei einer Reihe von Ländern kann jedoch auf eine bedingte Konvergenz oder eine Konvergenz zu einem eigenen Wachstumspfad geschlossen werden.

JEL classification: O30, O40, C21, C32, C33

Key words: Convergence, National Innovation Capabilities, Patents, Unit Root Tests, Cross Section Tests, Time Series and Panel Data Tests

Schlagwörter: Konvergenz, Nationale Innovationsfähigkeit, Patenterteilungen, Einheitswurzeltests, Querschnittstests, Zeitreihen- und Paneldatentests

1 Introduction

In spite of the dissimilarities in the theoretical foundation and the concrete design of the numerous approaches in neoclassical growth theory, evolutionary economics and a central branch of "new" growth theory, they show the common quintessence that technical progress and innovations are important driving forces of economic growth (Aghion/Howitt, 1998). Hence, the analysis of long-term development of the innovation dynamics respective of the innovation capabilities of countries can provide insights with regard to economic change generally and growth perspectives specifically. Of particular interest is the question whether there is a convergence or divergence of national innovation capabilities, i.e. whether technological gaps are persistent or whether they diminish or even close in the course of time.[1] If there is a converging development of national innovation capabilities, this might also push convergence of per capita incomes and labor productivities.

In this paper the question of a convergence or divergence of national innovation capabilities is investigated empirically for the 15 EU countries from 1963 to 1998 by means of conventional tests for β- and σ-convergence as well as unit root tests for time series and panel data. In the second section the term "national innovation capabilities" is defined and a measurement concept is provided. It is argued that patents granted at the US-Patent and Trademark Office are an adequate output indicator for the innovation capabilities of EU countries. In the third section two definitions of convergence are given and it is shown how they are linked to different test concepts (either cross-country tests for β- and σ-convergence or time series and panel data unit root tests). In the fourth section the different tests are applied. Finally, the fifth section concludes and the results are discussed with respect to the prospects for success of convergence of per capita incomes and labor productivities in the EU.

2 National Innovation Capabilities: Definition and Measurement Concept

For the empirical analysis the theoretical concept of national innovation capabilities has to be operationalized in such a manner that it can be depicted by one or several measurable indicator variables. According to Stern/Porter/Furman (2000), the national innovation capability of a country (as an economic as well as a political entity) can generally be defined as the potential to produce a stream of commercially-relevant innovations. There is actually a connection between the innovation capability and non-commercial scientific and technological progress, but the difference between these is that the latter does not necessarily include an economic application.[2] With regard to economic theory the innovation capability of a country is based fundamentally on three factors: its common innovation infrastructure, its technological and economic specialization and the quality of the linkages between its common infrastructure and those industries which are particularly important for the respective country.[3]

The factors constituting the common innovation infrastructure of a country are a central

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[1] A first approach to investigate the question whether the aggregated innovation activities of selected OECD countries are converging or diverging can be found in Patel/Pavitt (1994). Verspagen (1996) critizes their approach and Pavitt/Patel (1996) accept in their reply the methodological aspects of his objections.

[2] A detailed functional reference scheme of innovations is given in Grupp (1998).

[3] This differentiation is also undertaken by Stern/Porter/Furman (2000), in the course of which they mainly resort to the cluster-based approach of national competitive advantages of Porter (1990) to justify the second factor.

component of the R&D based models of the “new” growth theory as well as of the literature on the concept of national systems of innovations (e.g. Romer, 1990; Grossman/Helpman, 1991; Lundvall, 1992). The first group of models establishes a highly formalized connection between a few innovation inputs – in most cases only R&D employees or R&D expenditures as well as the stock of innovations – and an innovation output, which can be labelled as “idea production function”.[4] On the other hand, the literature on the concept of national systems of innovations more comprehensively describes – but often only descriptive and internationally comparative – all organizations and institutions that influence the innovation capability of a country, as well as the relations between them. Particularly, in contrast to the formal models of the “new” growth theory, this branch of theory stresses the role of governmental policies and specific institutional actors (Stern/Porter/Furman, 2000).

However, the sole analysis of the determinants of the innovation capability of a country on the highly aggregated level of the whole economy surely would not be sufficient. Depending on the industry considered, there are different relationships between innovation dynamics, competition and productivity growth. Furthermore, spill-overs between technologically neighboring industries, which form – in the terminology of Porter (1990) – an industrial cluster, may be important. The innovation capability of an individual cluster depends at the same time on the availability of specialized innovation inputs. Thus, the simple existence of a large number of well-educated scientists and engineers is not sufficient for a high R&D productivity in the form of commercially usable innovations, but the R&D personnel must also be specialized in those areas where a country has a lot of innovation possibilities due to its specialization pattern.

From this, the quality of the linkages between the common innovation infrastructure and the industries, in which a country is technologically and economically specialized, follows immediately as a third input factor, influencing the innovation capability of a country. This is as a rule a mutually-strengthening relationship. On the one hand, the innovation capability of an industry depends on the commonly available innovation infrastructure, and, on the other hand, a large innovation output on the sectoral level also strengthens the common innovation infrastructure.

This quite rough differentiation already shows that the input factors which influence the innovation capability of a country are diverse and complex, and that they can be captured only insufficiently by a single measurable indicator like R&D expenditures or R&D personnel.[5] Furthermore, both above-mentioned measures have some inherent shortcomings. On the one hand, small firms often do not undertake formal R&D, which is captured by the corresponding statistics, and as a result their technological activities aiming at innovations are measured only very incompletely (cf. e.g. Patel/Pavitt, 1994). On the other hand, such measures include different kinds of R&D (basic research, applied research and experimental development) in different areas (public and private research institutions as well as firms; civil and defence research), which have very different impacts on the innovation capability and after all on productivity (cf. Grupp, 1998; Jungmittag/Blind/Grupp, 1999).

However, even if the complex innovation inputs could be well approximated by indicator variables, they only constitute a potential for innovations that can be realized in different manners and to different extents. Hence, for measuring the innovation success or – to put it differently – the productivity of innovation inputs, a innovation output indicator is more suited. Such an indicator that captures commercially relevant innovations and ensures an international comparability are “international patents”.[6]

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[4] For the empirical estimation of such an “idea production function”, see Porter/Stern (2000).

[5] For a similar conclusion cf. Grupp (1998).

[6] Extensive discussions concerning the suitability of patents as innovation indicators can be found e.g. in

However, no patent can protect an invention worldwide, but a single invention can be applied for a patent in any number of countries. Such a patent protects an inventor either against potential imitators who would like to use the invention in that country or against imitators from other countries who would like to sell products using this invention in that country (Eaton/Kortum, 1996). Therefore the term "international patents" has to be narrowed down to refer to patents granted in a foreign country, and for achieving an international comparability, a foreign patent office in which all foreigners have approximately the same access conditions should be chosen. A comparison of patents at the respective domestic patent offices however would introduce a bias, because the individual patent offices are characterized by national peculiarities due to legal conditions and cultural differences, so that the leaning towards patenting could be very different. Furthermore, only patents granted to foreigners should be used to avoid biases in analyses on the basis of per capita or absolute numbers of patents at a certain national patent office, because there exists a home advantage at each national patent office resulting from the fact that an invention is usually first applied for a patent at the domestic patent office, and only for a limited number of these inventions a patent issuance is also sought in a foreign country. This restraint at applications abroad is based primarily on the very large expense of foreign procedures, so that only commercially especially interesting inventions are applied for a patent there (Schmoch, 1999).

As such a patent office the US Patent and Trademark Office (USPTO) was chosen, because, on the one hand, the patents granted there might show hardly any biases for the group of the EU countries, and, on the other hand, they permit – the European Patent office, whose data likewise contain only slight distortions through home advantages, was nevertheless first founded in 1977 and only provides reliable patent numbers since the beginning of the eighties – an analysis of the innovation dynamics over a longer time span from 1963 to 1998.[7] Beside that, there is a further reason to be said for the use of the data of the USPTO. From a economic point of view the US market, for which the patent protection is granted, is a particularly attractive and large market, which could be considered as a representative forum of international competition (Pavitt/Patel, 1988; Schmoch, 1999). Affiliated with the already mentioned filter function of the high costs of a foreign patent application, this circumstance guarantees that US patents are an indicator of the extent, to which a country develops worldwide new technologies and brings them to commercial application, or to put it differently, to what level it is able to produce inventions close to the technological frontier (Stern/Porter/Furman, 2000).

In spite of the above-mentioned advantages of patents as an indicator for the innovation output, it must also be noted, that its meaningfulness is subject to certain limits. On the one hand, only a part of patentable inventions will be applied for patents, because other property rights, e.g. trademarks, could be used for a legal protection of inventions, or because economic advantages could be preserved by a time lead, secrecy, good services or cost advantages. Firstly however, many of these possibilities of protection are not used alternatively but complementary to patent rights (Schmoch, 1999). Secondly, the patent indicator retains its meaningfulness, if it – as postulated – is highly correlated with the whole innovation output of a country and if the share of non-patented innovations is rather stable between countries and over time (Eaton/Kortum, 1996; Grupp, 1998; Eaton/Kortum, 1999; Porter/Stern, 2000).

Griliches (1990), Patel/Pavitt (1995), Grupp (1998), Grupp/Schmoch (1999) and Schmoch (1999).

[7] At most, there exists a certain indirect home bias for the United Kongdom and Ireland. Besides the patent registration fees, additional translation costs accrue, which do not occur in the case of these two countries (cf. Eaton /Kortum, 1999). Furthermore, the large stock of US foreign direct investment might cause a second indirect home bias for Ireland – e.g. compared to the European Patent Office – so that innovation dynamics in Ireland might be exaggerated a little bit since the beginning of the eighties.

On the other hand, the comparison of countries on a highly aggregated level is aggravated by the circumstance that industries with the same R&D intensity show different tendencies to patent, so that the total number of a country's patents also depends on its sectoral structure (Pavitt/ Patel, 1988; Schmoch, 1999; Porter/Stern, 2000; Stern/Porter/Furman, 2000). However, it can be assumed that the results of the convergence analysis are nearly unbiased if the technological specializations of the individual countries remain rather stable or even became more alike in the course of time.[8]

If the international comparability of patent data is largely given – as for the data of the USPTO in the case of the EU countries – and if the mentioned limitations are taken into consideration, it is certainly justified for the purposes of analysis pursued here to endorse the conclusion of Trajtenberg (1990): "patents are the only observable manifestation of inventive activity having a well-grounded claim for universality".

3 Approaches to Measure Convergence

Intuitively it is immediately obvious to speak of convergence if the distance between two (or more) economic time series diminishes in the course of time and finally becomes a constant in the case of a conditional convergence or zero in the case of an absolute convergence. Analytically, however, the two aspects of this intuitive understanding of convergence must be distinguished, because they have different implications for the measurement methods to be used and their meaningfulness.

The first part of this intuitive understanding considers convergence as a catching-up process. Assume $\log y_{it} > \log y_{jt}$, then this process can be written according to Bernard/Durlauf (1996) as

$$\mathrm{E}\left(\log y_{i,t+k} - \log y_{j,t+k} \mid \Im_t\right) < \log y_{it} - \log y_{jt}. \tag{1}$$

Thus an interesting economic variable y converges for two countries i and j between time t and $t+k$, if it can be expected on the basis of the information $\Im_t$ available at t (E is the expectation operator) that the distance between the logs of y diminishes in the considered time period. This implies that the backward country grows more rapidly than the country that shows a higher initial level of the interesting variable.

The second part, on the other hand, already implies the achievement of a steady state. Its formal definition requires that the long-term forecasts of the differences between the two countries converge towards a constant μ resp. towards zero, if the forecast horizon becomes infinitely, i.e.:

$$\begin{aligned} &\lim_{k\to\infty} \mathrm{E}\left(\log y_{i,t+k} - \log y_{j,t+k} \mid \Im_t\right) = \mu \text{ resp.} \\ &\lim_{k\to\infty} \mathrm{E}\left(\log y_{i,t+k} - \log y_{j,t+k} \mid \Im_t\right) = 0. \end{aligned} \tag{2}$$

In this case neither the initial levels of the interesting variable nor shocks occurring during that time have any impact on the steady state. (Bernard/Durlauf, 1995;1996). The definition can be extended immediately to the multivariate case of $n = 1, ..., N$ countries. Then applies:

$$\lim_{k\to\infty} \mathrm{E}\left(\log y_{1,t+k} - \log y_{n,t+k} \mid \Im_t\right) = \mu_n, \text{ for all } n \neq 1, \tag{3}$$

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[8] Empirical analyses, that permit this conclusion, can be found in Jungmittag/Grupp/ Hullmann (1998); Grupp/Jungmittag (1999) und Mancusi (2001).

with $\mu_n \neq 0$ in the case of a conditional convergence and $\mu_n = 0$ in the case of an absolute convergence.

In the case of the neoclassical growth model, both definitions capture aspects of its predictions. However, the second definition which orientates itself at the steady state of the economies is more restrictive than the first one, which is only a snapshot during the adjustment process. Or putting it differently: for a finite time horizon the first follows from the second definition (Bernard/Durlauf, 1996).

Evans (1996) and Evans/Karras (1996) propose a similar definition for the multivariate case, which, however, does not orientate itself at the ratios of the individual countries to a norm country but at the ratios of all countries to a common trend $\log A_t$. This modified second definition is:

$$\lim_{k\to\infty} \mathrm{E}\left(\log y_{n,t+k} - \log A_{t+k} \mid \Im_t\right) = \mu_n. \tag{4}$$

However, $\log A_t$ cannot be observed, so that it has to be substituted by an observable variable. Calculating for this purpose the mean for all countries yields

$$\lim_{k\to\infty} \mathrm{E}\left(\overline{\log y_{t+k}} - \log A_{t+k} \mid \Im_t\right) = \frac{1}{N}\sum_{n=1}^{N} \mu_n = 0, . \tag{5}$$

with $\overline{\log y_t} = \sum_{n=1}^{N} \log y_t / N$. Thus, equation (4) can be rewritten as

$$\lim_{k\to\infty} \mathrm{E}\left(\log y_{n,t+k} - \overline{\log y_{t+k}} \mid \Im_t\right) = \mu_n. \tag{6}$$

In the case of a theoretical analysis with an infinite time horizon the multivariate variant of the definition of Bernard/Durlauf coincides of course with the definition of Evans/Karras.[9] But in empirical analyses with limited samples the results might differ depending on the reference variable, e.g. the leading country or the mean (cf. Bernard/Jones, 1996).

On the basis of these definitions the different procedures for measuring convergence can be evaluated with regard to their suitability and meaningfulness. Fundamentally, two groups of procedures can be distinguished. The first group mainly uses the cross-section characteristics of the data for a more or less large number of countries or regions. The second group focus on the time series characteristics of the data and tries to derive evidence for convergence from them. Hybrids of both procedures are the panel data procedures for measuring convergence.[10]

3.1 Cross-Section Tests of the Convergence Hypothesis

A large part of the vast number of empirical analyses concerning the convergence of economic developments, mainly – inspired by the theoretical dispute between neoclassical and "new" growth theory – of per capita incomes and labor productivities, uses internationally or regionally comparable cross-section datasets.[11] On their basis it should be ascertained whether a so called σ- or β-convergence of the interesting variables could be observed.

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[9] Cf. also the alternative formulation of the convergence definition of Evans (1996) and Evans/Karras (1996) in Evans (1998).

[10] In the following the focus is on such panel data procedures which can increase the efficiency of the time series procedures.

[11] Seminal contributions in this area are Baumol (1986), Dowrick/Nguyen (1989), Wolff (1991), Barro (1991) and Barro/Sala-i-Martin (1991).

Here, σ-convergence means the deduction of the dispersion of the interesting variable between the countries or regions considered. In most cases the variance respective the standard deviation or the coefficient of variation (i.e. the ratio of the standard deviation to the mean) are used as measures of dispersion. The coefficient of variation should be preferred if the mean of the interesting variable is growing in the course of time, because often the absolute dispersions grow with it, thereby impeding an intertemporal comparison on the basis of an absolute measure of dispersion. A formal test of the convergence hypothesis can be carried out by regressing the calculated measures of dispersion against a time trend (Lichtenberg, 1994).

This measurement approach is immediately tied to the first definition of convergence. But it is contrary to the second definition, because in that case the variances of the interesting variable as well as the differences between the countries would be in a stochastic world stationary with a constant mean if a convergence would be achieved (Evans, 1996). Moreover, it also can be called into question whether this measurement approach is suited to discriminate between a convergence according to the first definition and other developments of the distribution of the interesting variable. So, it is conceivable and for a larger group of countries at different stages of development also empirically demonstrable that the countries approach different steady states with an emaciation of the middle income group, i.e. convergence clubs of poor and rich countries are emerging in a process of a polarization.[12] However, a decreasing variance or coefficient of variance can be thoroughly consistent with such a development. Therefore, a reduction of a measure of dispersion can only be a first indication for a convergence as a catching-up process according to the first definition, before the data are subjected to further tests.

Much more popular than the tests for σ-convergence are the cross-section tests for β-convergence or mean reversion. Absolute β-convergence occurs if countries, which show initially a lower level of the interesting variable, grow faster than countries with a higher initial level. For this purpose the average growth rates $g_n = \left(\log y_{nT} - \log y_{n0}\right)/T$ of the interesting variable y are calculated for a fixed time period from 0 to T and the regression equation

$$g_n = \alpha + \beta \log y_{n0} + \varepsilon_n \tag{7}$$

is estimated by OLS. Then, it is concluded that the interesting variable converges for all N countries, if β is significantly smaller than zero. Analogously, the equation

$$g_n = \alpha + \beta \log y_{n0} + \boldsymbol{\gamma}'\mathbf{x}_n + \varepsilon_n \tag{8}$$

is used to measure conditional convergence. Here, $\mathbf{x}_n$ is a vector of control variables, assuming that they are responsible for the achievement of different steady states, and γ represents a vector of respective regression coefficients, which are significantly different from zero.

The obvious connection of this measurement approach to the first definition of convergence is also explicitly shown in Bernard/Durlauf (1996). Furthermore, they show that the estimated β is a weighted average of the ratios of the deviations of growth rates from their sample mean to the deviations of the initial levels from their sample mean. Thus, β-convergence holds if the weighted average of countries with above-average initial levels show below-average growth rates. The fact that the estimate or β is a weighted average means also that in the case of a negative β the differences between some pairs of countries – but not necessarily all pairs – have been reduced. Therefore, it can not be decided on the basis of this test whether all

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[12] For an extensive discussion of this phenomenon see Quah (1993; 1996; 1996a; 1996b; 1997; 1999). He proposes as an alternative not only the consideration of the second moments of the distribution of the interesting variable, but all the distribution dynamics.

countries converge, convergence clubs occur or whether some countries converge and others do not.

In the case that conditional β-convergence according to equation (8) is actually present but a test for absolute β-convergence is applied, the well-known problem of omitted variables occurs (cf. e.g. Harvey, 1990). If the initial level and the control variables are not orthogonal, it may be that the coefficient $\tilde{\beta}$, erroneously estimated under the assumption of absolute convergence, has a significantly negative sign while for the true $\beta \geq 0$ holds. Moreover, it cannot be assumed in practice that it is really possible to control for all influences which generate permanent differences between the interesting variables among countries. Thus, the problem of omitted variables might also be present if some control variables are included.

From the linkage of the concept of absolute β-convergence with the first definition of convergence follows therefore the testable hypothesis that the means of the stochastic processes which generate the growth rates must be different for countries with initially high and low levels of the interesting variable. However, β-convergence measured in this manner is contrary to the second definition of convergence, which implies that the means of the long-term growth rates are equal (Bernard/Durlauf, 1996; Evans, 1996; Evans/Karras, 1996; Evans, 1998).

Taking the arguments mentioned so far into account, Evans (1996) and Evans/ Karras (1996) show also for their definition of convergence (equation 4) that it is generally not consistent with the approach to measure β-convergence. According to them, the estimate of β from a cross-section regression permits only valid conclusions if, firstly, the interesting variable has the same first order autoregressive structure, if, secondly, all permanent cross-countries differences in the interesting variable are perfectly controlled for, and if, thirdly, shocks affecting this variable are contemporaneously uncorrelated. It would be, however, highly implausible to assume that these requirements are satisfied for real datasets. As the first two conditions have not to be fulfilled in the case of time series tests of the convergence hypothesis, they propose to use such procedures, as does Bernhard/Durlauf (1995; 1996) for their second definition of convergence.

However, before the time series procedures will be illustrated and discussed, two further inherent problems of the cross-section tests have to be mentioned. The first problem is of a more practical nature and concerns the often-used method of calculating the growth rates, the second is of a more fundamental nature and concerns the relationship between β- and σ-convergence.

The first problem consists of the utilization of all sample information available for the empirical analysis. Generally, the use of average growth rates is a waste of available time series information (Bohl, 1998). It is assumed implicitly that the individual countries follow completely stable growth paths not affected by shocks. Furthermore, for average growth rates it is not possible to distinguish between long-term trend growth and short-term growth fluctuations irrelevant for long-term growth analyses. Verspagen (1991) therefore proposes to estimate the long-term growth rates ϕ_n by means of the following trend function

$$\log y_{nt} = \delta_n + \phi_n t + \upsilon_n \tag{9}$$

and to use them afterwards in the cross-section regressions to test for β-convergence. However, only if $\log y_t$ is actually generated by a trend-stationary process, all time series information are utilized in this procedure.

The second problem concerns the compatibility of the tests for β- and σ-convergence. A negative β-coefficient does not always mean that the dispersion of the interesting variable reduces within the cross-sections of countries considered. It is true, that a negative β reduces the dispersion, but new shocks captured by the error term can increase it again (Barro/Sala-i-Martin, 1991). β-convergence is therefore only a necessary, but not a sufficient condition for σ-convergence. The degree of the latter also depends on the R^2 of the test equation, i.e. on the relative importance of random disturbances (Lichtenberg, 1994).

Without appreciating the formal link between β- and σ-convergence, but based on their already cited more general statement, Barro/Sala-i-Martin (1991) conclude that both concepts are suitable for the investigation of different objects of research. If the subject of investigation is how fast and to which extent an interesting variable for an individual country is moving towards the average, then β-convergence is a suitable concept. However, if the distribution of the interesting variable over time should be determined, σ-convergence is the more suitable concept.

3.2 Time Series and Panel Data Tests for Convergence

For empirical tests of the uni- and multivariate variant of the convergence definition of Bernard/Durlauf (1995; 1996) – the equations (2) and (3) – as well as for the handleable version of the definition of Evans (1996) and Evans/Karras (1996) – equation (6) –, the use of time series procedures is immediately obvious because these definitions imply that the differences $\log y_{i,t+k} - \log y_{j,t+k}$ resp. $\log y_{n,t+k} - \overline{\log y_{t+k}}$ are generated by stationary processes. These stationary processes have zero means if convergence is absolute while their means are nonzero if convergence is conditional.

In order to check whether a time series is generated by a stationary, trend-stationary or non-stationary process, different unit root tests can be carried out.[13] Two candidates used in this analysis are the Augmented Dickey-Fuller- and the Phillips/Perron-test (Dickey/Fuller, 1979; Phillips/Perron, 1988). From an economic point of view there is some evidence that the differences in innovation capabilities are generated by an AR process of higher order. The catching-up process with regard to the innovation capabilities is partly the result of a diffusion process which lasts several years and the speed of acquiring and absorbing new knowledge, i.e. transforming it into innovations, depends on the already available stock of knowledge in the respective country. Therefore, it can be expected particularly for countries being far backward that the generation of innovation takes up longer time periods.[14]

Denoting for the sake of simplicity the differences of the log levels of the interesting variable for any pair of countries (definition of Bernard/Durlauf) or the difference of the log level of the interesting variable for any country and the mean of the log levels for all countries considered (definition of Evans/Karras) as $d_{nt}^{(ij)}$ or $d_{nt}^{(MW)}$, the ADF test equation in its most general form for an AR(p) process with an intercept and a deterministic trend t is:

$$\Delta d_{nt}^{(\cdot)} = \gamma_n + \delta_n t + \rho_n d_{n,t-1}^{(\cdot)} + \lambda_{ni} \sum_{i=1}^{p-1} \Delta d_{nt-i}^{(\cdot)} + v_{nt}. \tag{10}$$

The Phillips/Perron-test, on the other hand, is a semiparametric unit root test, because beside a parametric test equation which captures only an AR(1) process for the time series considered, i.e.

$$\Delta d_{nt}^{(\cdot)} = \gamma_n + \delta_n t + \rho_n d_{n,t-1}^{(\cdot)} + w_{nt}, \tag{11}$$

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[13] For an extensive discussion of the stationarity properties of time series cf. Jungmittag (1996), 244-250 as well as the literature cited there.

[14] Cf. Pascual (2000) for these arguments with regard to the analysis of differences in total factor productivity.

it uses a semiparametric approach to control for higher order serial correlation.

On the basis of the test results, the following conclusions with regard to the convergence of the interesting variable between two countries respective of one country towards the mean of the considered countries can be derived:

1. If the differences $d_{nt}^{(\cdot)}$ contain a unit root, i.e. $\rho_n = 0$, the interesting variable for two countries or for one country and the mean of all countries considered diverges over time.
2. If the differences are stationary, i.e. $\rho_n < 0$, firstly two cases can be distinguished which are compatible with the second convergence definition of Bernard/Durlauf (1995; 1996) and the convergence definition of Evans (1996) and Evans/Karras (1996), namely
    (a) $\gamma_n = 0$ and $\delta_n = 0$: in this case an absolute convergence occurs, or
    (b) $\gamma_n \neq 0$ and $\delta_n = 0$: this case indicates a conditional convergence, and the long-term difference of one country to another one resp. to the mean level is $-\gamma_n/\rho_n$.

    A number of empirical analyses are confined to these two cases and exclude the presence of a deterministic trend a priori.[15] However, this can lead to fallacies if the observed data is generated by a trend stationary process, i.e. additionally to $\rho_n < 0$ are

    (c) $\gamma_n \neq 0$ and $\delta_n \neq 0$: this case indicates according to the sign of trend coefficient a catching-up and possibly leapfrogging process or a falling-behind process.[16] Generally, this parameter constellation implies that the interesting variable in the country considered converges towards its own long-term growth rate which differs by $-\delta_n/\rho_n$ from the long-term growth rate of another country or of the mean. Thus, convergence according to the above-mentioned definitions cannot occur with a trend coefficient different from zero, but a positive trend can be compatible with the first definition of Bernard/Durlauf (1996) or the concept of β-convergence, which considers convergence as a catching-up process within a fixed time span.

Although the inclusion of a deterministic trend permits to throw a – temporary – bridge between the different definitions of convergence or the time series and cross-section tests, the fundamental differences between them have to be emphasized again. Actually, both concepts are based on different assumptions with regard to the statistical properties of the data (Bohl, 1998). In cross-section tests, it is assumed that the data are in transition towards a limiting distribution and convergence means that the initial differences diminish over a fixed time period. In time series tests, on the other hand, the assumption is tested whether the data are generated by time invariant processes near to their limiting distributions. Here convergence means that the initial conditions have no statistically significant effects on the expected values of the interesting values. Time series tests, however, have only poor power when applied to countries in transition, because they tend to accept the null hypothesis of no convergence by mistake. Therefore, the suitability of a measurement approach also depends upon whether the data are more characterized by transition or steady state dynamics (Bernard/Durlauf, 1996).

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[15] Cf. e.g. Aubyn (1999), Bernard/Durlauf (1995), Bernard/Jones (1996), Bohl (1998), Evans (1998), Evans/Karras (1996) and Pascual (2000).

[16] This case is also taken into account by Oxley/Greasley (1995; 1999), Camarero/Esteve/Tamarit (2000) and Lim/McAleer (2000). However, these authors interpret a trend-stationary process for the differences just as a catching-up process where the gap between two countries diminishes but does not close. Galli (1997) includes a deterministic trend in the test equation but its significance and meaningfulness is not considered.

However, the use of unit root tests for individual time series also raises a problem from the viewpoint of econometric theory. For the DF- and ADF-test as well as for the Phillips-Perron-test, it can be taken for given that they have only poor power in finite samples with regard to the alternative hypothesis $H_A : \rho_n < 0$ if ρ_n is close to zero, i.e. the probability of committing a type II error of an incorrect non-rejection of the null hypothesis is rather large. If the time series of interest are available for several cross-section units, the power of the unit root tests can be increased by applying them appropriately modified to these panel data. Some of the seminal contributions in this area are Breitung (1992), Breitung/Mayer (1994), Levin/Lin (1992; 1993) and Quah (1994). It is true, that these approaches modify the univariate DF- and ADF-tests in such a manner that they can be used for panel data, but they have two properties which are problematic in empirical applications. On the one hand, they assume – with the exception of Levin/Lin (1993) – identical dynamic structures for all cross-section units, so that one possible kind of heterogeneity of the time series is not taken into account. On the other hand, the second possible form of heterogeneity is also excluded because it is assumed that ρ is equal for all N cross-section units. Maddala (1999) and Maddala/Wu (1999) argue rightly that the null hypothesis normally makes sense, but that the alternative hypothesis is to strong to hold in hardly any empirical application. They take tests of the convergence hypothesis as an example where the null hypothesis that there is no convergence, and therefore $\rho = 0$, can be formulated, as is also done in this paper, but where the alternative hypothesis that all countries converge with the same rate makes hardly any sense.[17]

Taking up these arguments, two test procedures for panel data have recently been suggested, which are very flexible with regard to the dynamic specification for the individual cross-section units and avoid a rigid formulation of the alternative hypothesis (Im/Pesaran/Shin, 1997; Maddala/Wu, 1999).[18] Both test procedures are based on separate unit root tests for the individual time series and the common test statistics is derived from their results.

The test suggested by Im/Pesaran/Shin (1997) (in the following IPS-test) is based on averaging the t-statistics of the ADF-tests for the individual time series, so that it is also labelled as t-bar test.[19] In its most general form, based on N test equations

$$\Delta y_{nt} = \gamma_n + \delta_n t + \rho_n y_{n,t-1} + \lambda_{ni} \sum_{i=1}^{p-1} \Delta y_{nt-i} + v_{nt},$$
$$\text{for all } n = 1, 2, ..., N, \qquad (12)$$

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[17] Bernard/Jones (1995) use the approach of Levin/Lee (1992) with some modifications for the convergence analysis of the total factor productivities in different industries of the OECD countries. Evans/Karras (1996) and Evans (1998) apply a modified version of the approach of Levin/Lee (1993) to test for convergence of per capita incomes between the US states as well as between a group of 54 countries while Bohl (1998) applies their original approach to test for per capita income convergence between the eleven West German Bundesländer. Gaulier/Hurlin/Jean-Pierre (1999) again modify the approach of Evans/Karras (1996) and suggest a nested test procedure to characterize different processes of convergence. They apply their approach to three groups of countries (EU, OECD and 86 countries worldwide).

[18] Some other unit root tests for panel data are proposed in the theoretical and applied econometric literature, however, they maintain in most cases the above-mentioned rigid choice of hypothesis and assumptions (cf. O'Connell, 1998; Hadri, 2000; Harris/Tzavalis, 1999 and Taylor/Sarno, 1998). Pascual (2000) applies the multivariate approach of Taylor/Sarno (1998) to test for convergence of total factor productivities in different industries of 13 OECD countries. In a second step, he applies the approach of Breuer/NcNown/Wallace (1999) to determine the number of converging countries.

[19] Im/Pesaran/Shin (1997) also suggest an analogous constructed LM-bar test.

the null hypothesis that all N time series of the cross-section contain a unit root, i.e.

$$H_0 : \rho_n = 0 \text{ for all } n, \tag{13}$$

is tested against the alternative hypothesis

$$H_A : \rho_n < 0,\ n = 1, 2, ..., N_1,\ \rho_n = 0,\ n = N_1 + 1, N_1 + 2, ..., N. \tag{14}$$

Thus, ρ can be different for the individual time series and it is allowed under the alternative hypothesis that some of the time series contain a unit root. Under the assumption that N and T are sufficiently large, the consistency of the test is warranted if the share of stationary time series is greater than zero under the alternative hypothesis, namely, if $\lim_{N\to\infty} (N_1/N) = c_1$, $0 < c_1 \leq 1$.

The test statistic is

$$\Psi_{\bar{t}} = \frac{\sqrt{N}\left\{\bar{t}_{NT} - \frac{1}{N}\sum_{n=1}^{N} E\left[t_{nT}\left(p_i - 1, \mathbf{0}\right) \mid \rho_n = 0\right]\right\}}{\sqrt{\frac{1}{N}\sum_{n=1}^{N} Var\left[t_{nT}\left(p_i - 1, \mathbf{0}\right) \mid \rho_n = 0\right]}}, \tag{15}$$

where $\bar{t}_{NT}$ is the mean of the ADF-test statistics $t_{nT}\left(p_i - 1, \boldsymbol{\lambda}_n\right)$ of the individual time series. The means $E\left[t_{nT}\left(p_i - 1, \mathbf{0}\right) \mid \rho_n = 0\right]$ and the variances $Var\left[t_{nT}\left(p_i - 1, \mathbf{0}\right) \mid \rho_n = 0\right]$ of the individual t statistics under the null hypothesis have been computed for different values of $p_i - 1$ and T via stochastic simulations. They are displayed in table 2 of the appendix in Im/Pesaran/Shin (1997). Under the null hypothesis, the test statistics is asymptotically standard normal distributed. Its consistency is warranted if $N \to \infty$ and $T \to \infty$ diverge controlled, so that $N/T \to k$, where k is a finite positive constant.

However, as for most other unit root tests for panel data, it is necessary for ensuring consistency that the disturbances of the individual test equations are contemporaneously uncorrelated. This will not always be given in practice, because the cross-section units may be affected by common shocks. If these shocks can be captured by common time-specific effects of the form

$$v_{nt} = \theta_t + \varepsilon_{nt}, \tag{16}$$

it is obvious to remove these effects by subtracting the cross-section means from the individual time series, i.e. to use $\tilde{y}_{nt} = y_{nt} - \frac{1}{N}\sum_{n=1}^{N} y_{nt}$ for testing (cf. Im/Pesaran/Shin, 1997). In addition to the fact that this de-meaning warrants asymptotically the independence of the individual processes for the disturbances of the test equations, it has the advantage of ensuring the compatibility with the convergence definition of Evans/Karras (1996).[20] Moreover, since their definition coincides with the second convergence definition of Bernard/Durlauf (1996) when the time horizon becomes very long, the alternative subtraction of the time series values of the initially leading country might have in the case of a convergence asymptotically the same effect.[21]

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[20] If the time effects are time series specific or if they vary across subgroups, they could be, if θ_t is a known function – e.g. $\theta_t = t$ – incorporated immediately in the ADF-test equation (Im/Pesaran/Shin, 1997).

[21] An application of the IPS-test in the context of a convergence analysis for 102 countries can be found in Lee/Pesaran/Smith (1997).

Maddala/Wu (1999) suggest an alternative unit root test for panel data based on quasi-averaging (in the following MW-test). However, the significance levels of the unit root tests for the individual time series are combined here directly. Resorting to Fisher (1932), the fact is used that the significance levels w_n of continuous test statistics are independent, identically-distributed random variables, and their transformation $-2 \log w_n$ obeys a χ^2-distribution with two degrees of freedom. Applying the additivity property of the χ^2-distribution yields the test statistic for N cross-section units

$$W = -2 \sum_{n=1}^{N} \ln w_n, \tag{17}$$

which is χ^2 distributed with $2N$ degrees of freedom. Due to this simple combination of significance levels, the MW-test is highly flexible, and, in contrast to the IPS-test, it can be based on any unit root test at all.

In like manner for the IPS-test, the validity of the MW-test requires that the disturbances of the test equations for the individual time series are not contemporaneously correlated. Therefore, the same de-meaning procedure as for the IPS-test suggests itself here.

Unit root tests for panel data based widely on asymptotic properties naturally raise questions concerning their properties and power in finite samples. Here, only extensive simulation studies can provide answers. Im/Pesaran/Shin (1997) as well as Maddala/Wu (1999) find that their respective tests perform better than the test of Levin/Lin (1993). However, such a comparison is not really permissible and hardly meaningful because the test of Levin and Lin is based on another alternative hypothesis than the IPS- and MW-test (cf. also Maddala, 1999). Furthermore, Maddala/Wu (1999) conclude that their test performs slightly better than the IPS-test. According to their simulation results, it is true that the power of the IPS-test is slightly higher if there is no contemporaneous correlation of the disturbances of the individual test equations, but if such a correlation is present, this problem is less serious in the case of the MW-test. This applies particularly when T and N are only moderately large. Choi (2001) concludes the following on the basis of his simulation studies:

1. The empirical size of the IPS- and the MW-test is close to the nominal significance level of 5 % for small N. The MW-test shows slight size biases for $N = 100$, while the IPS-test shows also no bias when N is large relative to T.

2. The MW-test performs better than the IPS-test with regard to the size adjusted power.

3. The power of both tests decreases when a linear trend is included in the test equations.

Finally, it has to be emphasized that unit root tests based on averaging have to be interpreted carefully when the result for one time series dominates the whole test. Maddala (1999) takes a MW-test for ten cross-section units as an example, where $w_n = 0,5$ for nine units and $w_n = 0,000001$ for one unit. In such a case, the χ^2-value will be very large and the null hypothesis that all time series are nonstationary must be clearly rejected. This result does not contradict the alternative hypothesis that some of the considered time series are stationary, but summarizing conclusions for all ten time series cannot be drawn from it. Thus, unit root tests for panel data are hardly meaningful if there are some outliers. In this case, the relevant information comes from the individual time series.

Taking this objection into account, the following test strategy is applied for the part of the convergence analysis based on time series and panel data. At first, ADF- as well as

Phillips-Perron-tests are carried out for each of the 15 EU countries. In this process, particular attention is turned to the question of whether the individual test equations contain a significant constant and trend, because this is crucial for the type of convergence. Afterwards, in a first step, all ADF-tests were summarized into a IPS-test and all ADF- as well as Phillips-Perron-tests into MW-tests respectively. In a second step, IPS- and MW-tests are carried out again for the subgroups of test equations without a (or with an insignificant) constant (if stationary: absolute time series convergence), with a constant (if stationary: conditional time series convergence) and with a constant and a time trend (if stationary: convergence as catching-up and leapfrogging process or falling-behind process, i.e. convergence to an own long-term growth rate). All these tests are carried out with regard to the mean $\overline{\log y_t}$ and the initially leading country.

4 Empirical Results

Based on the different definitions of convergence, it is analyzed econometrically in the following whether a convergence or divergence can be observed for the US patents granted to the 15 EU countries in the period from 1963 to 1998. In this process, the whole range of test procedures presented and discussed in the previous section is applied. Thus, their comparability is warranted and the possibly different results could be weighed up.

4.1 Tests for β- and σ-Convergence

As a starting point of the analysis, the standard deviations and coefficients of variation of the US patents per one million inhabitants granted to the EU countries were calculated for each year. The trend of the standard deviations clearly increase (figure 1). This result is in accordance with the finding of Patel/Pavitt (1994) that the standard deviations of per capita US patents granted to 16 OECD countries (twelve EU countries without Greece, Luxemburg and Austria as well as Japan, Canada, Norway and Switzerland) increase from 35.05 in the period 1963 – 1968 to 53.58 in the period 1986 – 1990. If it is assumed that both datasets are comparable, the EU countries seem to be more homogeneous than their group of countries, because the EU standard deviations were considerably smaller during the whole observation period. Moreover, similar to the 16 OECD countries considered by Patel/Pavitt (1994), the standard deviations of the EU countries also do not follow a uniform trend. They increase rather strongly in the period from 1963 to 1974 before they reach a first plateau. After the then following decline they level off at a second, slightly higher plateau from the mid eighties until the beginning of the nineties. For the rest of the nineties, a decrease of the absolute dispersions can first be observed, before they increase again at the end of the observation period.

As already mentioned in the previous section, however, an intertemporal comparison of absolute measures of dispersion is hardly meaningful, if the mean of the considered variable increases over time. As this is the case for the US patents granted to the EU countries, a relative measure of dispersion like the coefficient of variation is more suitable to test for σ-convergence.[22] Figure 1 shows that the coefficient of variation decreases during the whole sample period from 1963 to 1998 without larger fluctuations. At same time the R^2 of 0.908 confirms the high significance of the negative trend. This finding provides evidence that there is a long-term growing similarity between the innovation capabilities within the EU, at

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[22] This objection to the proceeding of Patel/Pavitt (1994) can also be found in Verspagen (1996).

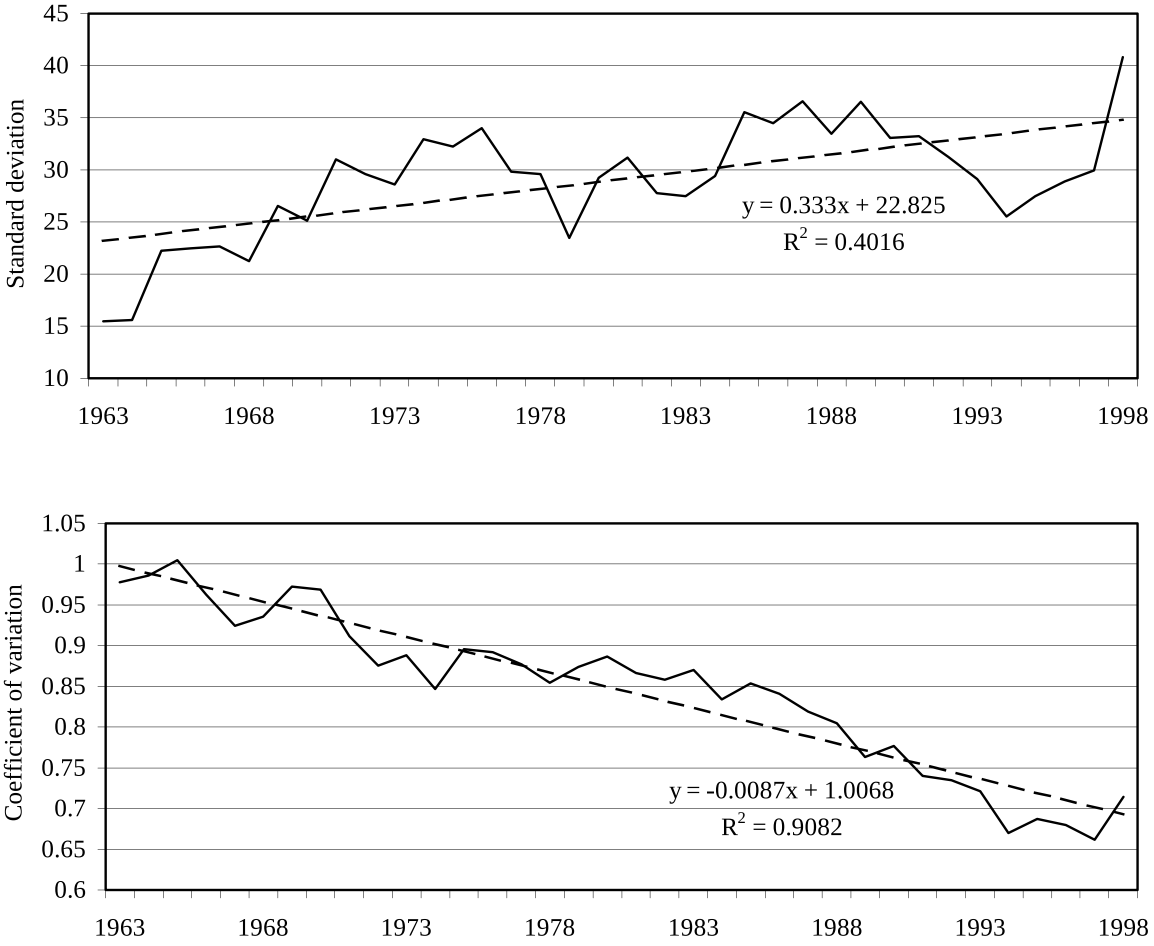
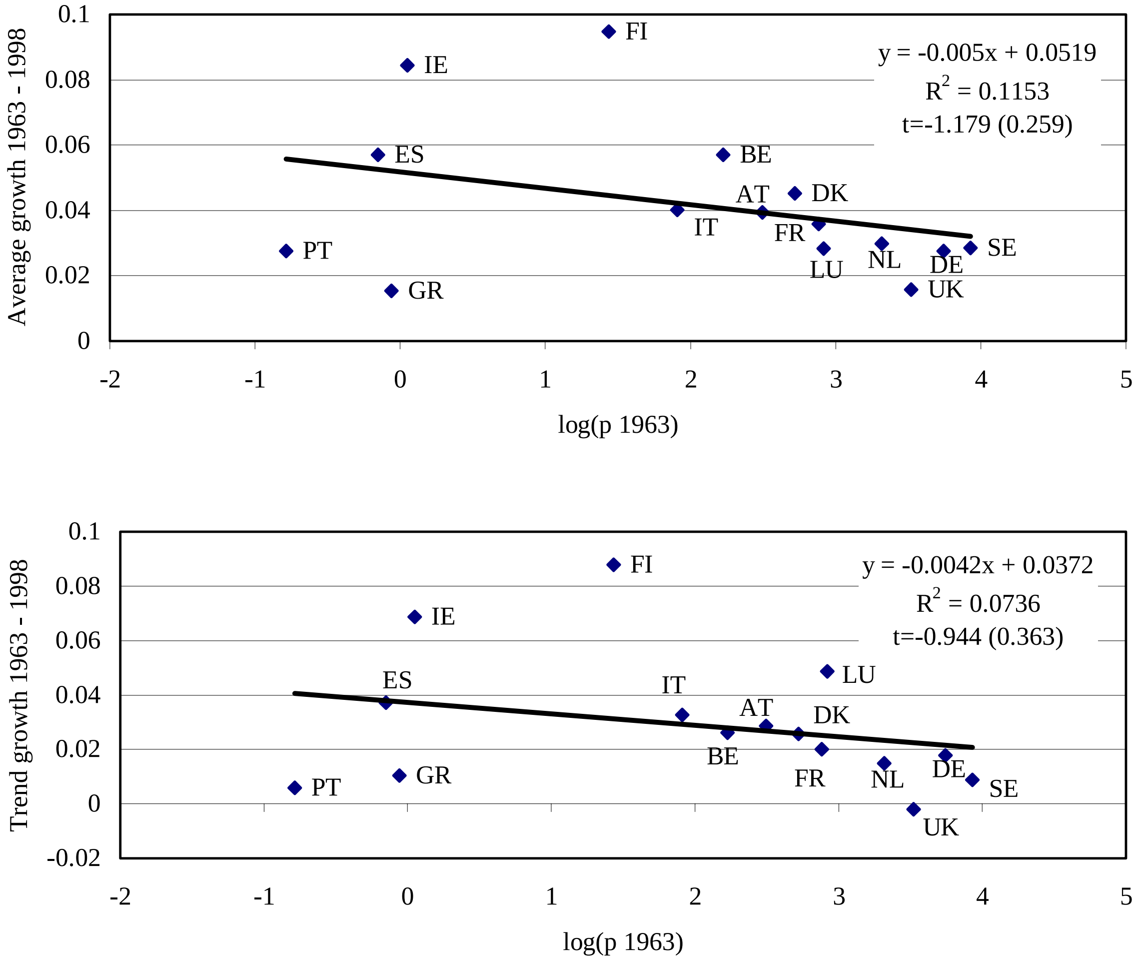


Figure 1: Test for σ-convergence of the US patents per one million inhabitants

least as far as they can be captured by international patents. However, this calculation of the σ-convergence provides no information whether all EU countries are participating in this convergence of innovation capabilities. Namely, if the convergence is caused by a catching-up process of those countries which have initially only relative few US patents per one million inhabitants, then they should have higher growth rates of patents granted in the subsequent years. Therefore, it will be interesting to compare this result with the results of the tests for β-convergence and of the time series and panel data tests.

In the next step of the analysis, the usual tests for absolute β-Convergence were applied to the US patents granted to the EU countries. As the patents enter these calculations in logs and as for some countries and years there were no patents, the original data had to be transformed in a suitable manner. Analogously to the proceeding of Eaton/Kortum (1996), one was added to the number of patents of each country and for each year, before they were divided by the population and logs were taken. The growth rates which should be explained by the logs of the initial levels of per capita patents granted in 1963 are, on the one hand, the average growth rates and, on the other hand, the trend growth rates from 1963 to 1998.

Figure 2 shows that the estimates of the β-coefficients have negative signs, but the null hypothesis $\beta = 0$ cannot be rejected at the usual levels of significance. Therefore, it has to



Note: White's heteroskedasticity consistent estimators of the covariance matrix are used to compute t-values. Significance levels in parentheses.

Figure 2: Tests for β-convergence of the US patents per one million inhabitants

be concluded that there is no β-convergence of innovation capabilities for all 15 EU countries. However, since the three South European countries Greece, Portugal and Spain show hardly any or no growth dynamics of patents granted, the convergence equations were estimated again without these countries. If the average growth rates are used as the variable to be explained, the result is (heteroskedasticity consistent t-values in parentheses):

$$\begin{array}{rcccl} \hat{g}_n = & \underset{(7.717)}{0.093} & - & \underset{(-5.127)}{0.019} & \log p_0, \ R^2 = 0.743. \end{array}$$

Analogously the estimation for the trend growth rates yields:

$$\begin{array}{rcccl} \widehat{\phi}_n = & \underset{(5.608)}{0.080} & - & \underset{(-4.248)}{0.019} & \log p_0, \ R^2 = 0.645. \end{array}$$

In both cases, the β-coefficient is quite significantly smaller than zero. If the problem of omitted variables is left aside for a moment, evidence points to an absolute β-convergence of the innovation capabilities of the remaining EU countries.[23] However, the convergence speed of 1.9 % per year is only rather slow and astonishingly equals the conditional convergence rate of 2 % which is ascertained in different cross-section studies of per capita incomes (e.g. Barro/Sala-i-Martin, 1992 and Sala-i-Martin, 1996).

4.2 Time Series and Panel Data Tests for Convergence

The time series tests were carried out for the sample period from 1967 to 1998, while the earlier observations were used for differencing and potential lags to capture higher order serial correlation in the time series. The additionally applied panel data tests complete the analysis and can compensate for the shortcomings of the time series tests in some cases. However, the results of the time series tests are often so unambiguous that the panel data tests can only confirm them.

The results of these tests are displayed in table 1. The first group comprises those countries with test equations containing in the case of the Phillips-Perron-test neither a constant nor a trend and in the case of the ADF-test an insignificant constant and no trend. Actually, it would be preferable also to carry out the ADF-tests without a constant, but the simulated means and variances of the IPS test statistics are only tabulated in Im/Pesaran/Shin (1997) for cases with a constant. Belgium and Germany belong to this first group and the time series as well as the panel data tests show that the null hypothesis of a unit root cannot be rejected at the usual levels of significance.

The MW- and the IPS-test overwhelmingly show for the second group for countries with test equations containing a significant constant that there is – at least for some of them – a conditional convergence of innovation capabilities (case 2: no unit root, i.e. $\rho_n < 0$, and the constant $\gamma_n \neq 0$). Furthermore, the results of the unit root tests for the individual time series are so unambiguous that such a conditional convergence can be assumed for Austria, Denmark, Italy and Portugal, while Luxemburg and Spain do not converge against the mean.

The third group comprises those countries with test equations containing a significant constant as well as a significant trend. These countries grow in the long term with another rate than the mean. With regard to the innovation capabilities they either catch up or fall back. In the long term they converge towards their own growth paths. Again, the results of the panel data tests which show that at least some countries converge towards their own growth paths, could be narrowed down by the largely unambiguous results of the time series tests. Finland, France and Greece converge towards their own growth paths. There is not such a convergence in the case of Sweden and the United Kingdom. The results for Ireland and the Netherlands are ambiguous. Here, it is true, that the Phillips-Perron-statistics suggest convergence towards unique growth paths for the countries in question, but the ADF-tests with a larger number of lags clearly do not permit the rejection of the null hypothesis of no convergence. As it can be assumed that the nonparametric correction of the Phillips-Perron-test captures the existing autocorrelation structure only very incompletely in these cases, the results of the ADF-tests with lags of one or three years should be considered as more reliable. Furthermore, the MW- and IPS-tests for all 15 EU countries show, as expected from the individual results, that the US patents of some EU countries do not contain a unit root.

Alternatively, it was also tested for the US patents whether the individual EU countries converge towards Sweden, the initially leading country in 1963 (table 2). If those countries

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[23] A differentiation between absolute and conditional convergence can be carried out in the next step of the analysis by means of the time series and panel data tests, because there the intercepts will capture the country-specific differences.

Table 1: Unit root tests for the patents granted at the USPTO with regard to the mean of the 15 EU countries

Country	PP-statistic	Sig. level	ADF-statistic	Sig. level	Lags
Group 1: No resp. insignificant constant, no trend					
BE	0.104	0.809	-1.617	0.462	0
DE	-1.306	0.170	-0.697	0.834	0
Panel data tests for group 1					
MW-test	4.198	0.380	1.906	0.753	
IPS-test			0.587	0.722	
Group 2: Constant, no trend					
AT	-3.351	0.021	-3.379	0.019	0
DK	-3.624	0.011	-3.581	0.012	0
ES	-1.812	0.368	-1.789	0.379	0
IT	-3.006	0.045	-3.002	0.045	0
LU	-2.081	0.253	-2.150	0.228	0
PT	-4.521	0.001	-4.530	0.001	0
Panel data tests for group 2					
MW-test	41.444	0.000	41.543	0.000	
IPS-test			-4.262	0.000	
Group 3: Constant and trend					
FI	-4.086	0.016	-4.156	0.013	0
FR	-3.812	0.029	-3.899	0.024	0
GR	-6.303	0.000	-6.337	0.000	0
IE	-4.226	0.011	-2.104	0.524	1
NL	-3.986	0.020	-3.199	0.103	3
SE	-2.403	0.371	-2.302	0.421	0
UK	-2.832	0.197	-2.885	0.180	0
Panel data tests for group 3					
MW-test	57.073	0.000	46.892	0.000	
IPS-test			-4.367	0.000	
Panel data tests for all 15 EU countries					
MW-test	102.715	0.000	90.341	0.000	
IPS-test			-5.441	0.000	

that are potential candidates for an absolute convergence are firstly considered, i.e. whose test equations contain no or an insignificant constant and no trend, the null hypothesis of no convergence cannot be rejected on the basis of the MW- as well as the IPS-test. This result is also supported by the time series tests for France, Italy and Luxemburg. The case of Germany is a bit different. For the Phillips-Perron-test, the alternative hypothesis of an absolute convergence cannot be rejected, at least at a significance level of 9 %. The rejection of the alternative hypothesis that at least one of the four countries converges towards Sweden by the MW-test might be caused by the high probability of rejection for France. Here, the already-cited reminder of Maddala (1999) applies to be prudent in the interpretation of panel data tests which are based on averaging and where single outliers could carry a lot of weight. The risk of a misinterpretation is particularly high in the case of a small number of cross-section units and therefore the individual time series should receive particular attention. It

Table 2: Unit root tests for the patents granted at the USPTO with regard to the leading country in 1963 Sweden

Country	PP-statistic	Sig. level	ADF-statistic	Sig. level	Lags
Group 1: No resp. insignificant constant, no trend					
DE	-1.671	0.089	-1.335	0.601	0
FR	-0.446	0.514	-1.402	0.569	0
IT	-1.010	0.274	-1.326	0.605	0
LU	-1.226	0.197	-2.089	0.285	0
Panel data tests for group 1					
MW-test	12.005	0.151	5.658	0.685	
IPS-test			-0.027	0.489	
Group 2: Constant, no trend					
AT	-2.235	0.198	-2.311	0.175	0
GR	-5.678	0.000	-5.612	0.000	0
NL	-1.888	0.333	-1.739	0.403	0
PT	-4.623	0.001	-4.645	0.001	0
UK	-2.056	0.263	-2.029	0.274	0
Panel data tests for group 2					
MW-test	42.313	0.000	41.849	0.000	
IPS-test			-4.383	0.000	
Group 3: Constant and trend					
BE	-1.833	0.665	-1.826	0.669	0
DK	-3.489	0.058	-3.476	0.059	0
ES	-2.006	0.576	-1.942	0.610	0
FI	-2.984	0.152	-3.091	0.125	0
IE	-2.816	0.202	-2.790	0.211	0
Panel data tests for group 3					
MW-test	14.589	0.148	14.710	0.143	
IPS-test			-1.219	0.111	
Panel data tests for 14 EU countries (with regard to Sweden)					
MW-test	68.907	0.000	62.217	0.000	
IPS-test			-3.392	0.000	

is true, that the ADF-test also rejects the null hypothesis for Germany, but the low level of significance is due to fact that the test equation contains an insignificant constant which in this case unjustifiable forces up the critical value. Furthermore, since both test equations contain no lags, it has to be assumed that the in this case more favorable PP-statistic captures remainders of serial correlation and also heteroskedasticity. It can therefore be concluded that an absolute convergence of innovation capabilities between Germany and Sweden takes place.

The results for the other two groups are very obvious. In the second group, a conditional convergence towards Sweden can be assumed only for Greece and Portugal. However, the level differences compared with Sweden will remain very large. Additionally, Denmark converges in the third group to its own growth path. These results of no convergence towards Sweden or of a convergence to an own growth path, which differs from those of Sweden, are for the most part in accordance with the former results with regard to the mean, because Sweden does not converge towards the mean.

5 Summary and Conclusions

In this paper the question of a convergence or divergence of national innovation capabilities is empirically investigated for the 15 EU countries from 1963 to 1998 by means of the available range of different measurement approaches, which are partly based on different concepts of convergence, so that an immediate comparability is not always given.

The alternative measurement of σ-convergence by means of an absolute measure of dispersion, the standard deviation, and a relative measure of dispersion, the coefficient of variation, yields contradictory results. The standard deviation shows an increase in dispersion, i.e. a divergence of innovation activities, while the coefficient of variation shows a decline of relative dispersion. Since the literature comes to realize in the meantime that a relative measure of dispersion is more suitable for an intertemporal comparison of growing variables, evidence points to a σ-convergence of the US patents per one million inhabitants granted to EU countries.

The simple cross-section regressions for all 15 EU countries show that there is no β-convergence between all EU countries, or to put it differently, the number of patents granted to initially backward countries do not grow faster on average than the number of patents granted to the initially already rather innovative countries. However, evidence changes when the three South European countries Greece, Portugal and Spain are excluded from the sample. Then β-convergence can be inferred, but the resulting convergence speed of 2 % is very low.

However, if it is taken into consideration that the β-coefficients estimated in cross-section regressions are weighted averages which permit no conclusions with regard to the question between which countries the differences diminish, and if instead the hypothesis resulting from the first definition of convergence, namely that the means of the stochastic processes determining the growth rates must be different for initially backward and leading countries, is used immediately, a more differentiated picture emerges. In such a comparison, the growth rates of Greece, the Netherlands and Portugal do not differ significantly from the long-term trend growth rate of Sweden, the leading country in 1963.[24] Thus, these countries do not catch up. The result for Germany lies at the limit, however, based on a one-sided hypothesis, its growth rate is at a significance level of 3 % larger than the growth rate of Sweden. On the other hand, the long-term growth rate of the United Kingdom is significantly smaller than those of the initially leading country, so that it falls back.

The small growth differences towards Sweden, the leading country in 1963, are surely no problem in the case of Germany and the Netherlands, because both countries are already very innovative in the considered time period, and are almost moving on the same per capita level like Sweden. However, Greece and Portugal are not able to leave their low levels, and the initially relatively strong position of the United Kingdom erodes through falling-back processes.

The results of the time series and panel data tests show first of all that there are converging developments within the EU. This hypothesis cannot be rejected by the panel data tests for all 15 EU countries. However, a closer inspection of the test results shows that the convergence behavior of the individual EU countries differs considerably. An absolute convergence of innovation capabilities is a rare exception within the EU, only for Germany a absolute convergence towards the initially leading country Sweden can be observed. If convergence occurs, it is in most cases a conditional convergence to a level different from the mean (Austria, Denmark, Italy, Portugal) or from the level of the initially leading country (Greece and Portugal), or a

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[24] Wald-tests were used to check the equality of trend growth rates. The detailed results are available on request from the author.

convergence towards unique growth paths (Finland, France and Greece or Denmark).

Such a conditional convergence of the innovation capabilities might be a main obstacle to achieve an absolute convergence of per capita incomes or labor productivities within the EU, and no convergence or also conditional convergence of innovation activities might hinder conditional economic convergence. Taking all results together, evidence points to the fact that the differences in innovation capabilities are an essential cause for the differences in per capita incomes and labor productivities as well as for the growth differences within the EU.

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