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1 Introduction

There are a large number of studies and discussions which have been conducted in the field of convergence, but still, this topic remains a debated issue. In most of the studies, growth is used to determine convergence, but the issue remains with the variables that affect growth. The problem is that those growth determinates are mostly found insignificant or have the "wrong sign", which leads to contradicting results and conclusions.

Over the years, focusing on testing convergence, researchers have developed and used different concepts such as relative, beta (β) and sigma (σ) convergence.

In the 1990s, Barro & Sala-i-Martin (1991) proposed to use the growth equation, being derived from neoclassical growth model. The concept of convergence coming from this approach is known as β-convergence and it relates to the prediction that countries with relatively poorer economies should grow faster than the countries with relatively richer economies. Barro & Sala-i-Martin (1991) developed their convergence approach by introducing the concept of conditional and absolute β-convergence.

According to Friedman (1992), the β-convergence approach originally was introduced by Secrist (1933), who showed that at first the successful firms tend to do worse than the less successful firms, but they tend to improve later on.

However, Hotelling (1933) stated that the findings in (Secrist (1933)) are just some statistical illusion. Hotelling (1933) also pointed out that the true concept for convergence should be related to the variance of the distribution.

Furthermore, Friedman (1992) cited Hotelling (1933) who stated: *"The real test of a tendency to convergence would be in showing a consistent diminution of variance."* The concept, cited from Hotelling (1933) is called σ-convergence.

Different econometricians such as Quah (1996), Evans (1996) tried, under very restrictive conditions, to test the σ-convergence. A more formal test for σ-convergence is developed by Kong, Phillips & Sul (2018). Kong, Phillips & Sul (2018) proposed a simple trend regression to test σ-convergence.

Economic convergence is an important concept and also known as the key to European Union integration. Different policies were born to create a single market and help the less advantaged regions to catch up in the European Union.

This master's thesis aims to find evidence for economic convergence in the European Union countries, by using the data from EUROSTAT, World-Bank, IMF and running through the programming languages STATA and GAUSS. The econometric model proposed by Kong, Phillips & Sul (2018) will be used.

2 Literature Review

The literature on convergence is abundant, but considering the literature in the European context, the results are sometimes contradictory.

The literature to study convergence was mostly developed during the 1990s, in growth analyses on cross countries, where economists were more focused on studying the long-run behaviour of real GDP per capita across countries and the possibility of existence of convergence clubs in growth, where the countries can group according to their long-run real GDP per capita or their consumer behaviour.

Leading from this research, different concepts were created regarding convergence such as conditional and absolute β-convergence, which can be found in Barro (1991), Barro & Sala-i-Martin (1991), Barro & Sala-i-Martin (1992). The same concepts of convergence were also found in Evans (1996) and the whole overview of Barro & Sala-i-Martin's work on Durlauf & Quah (1999).

In particular, results focusing on convergence in European countries can be found in Barro & Sala-i-Martin (1995), who extend their studies by including the empirical evidence of regional convergence across Japan, the United States, and five European countries namely Germany, France, United Kingdom, Italy and Spain. Barro & Sala-i-Martin (1995) study both developed concepts of beta convergence and conclude that the rate of convergence is similar across countries at the regional levels.
Moreover, Barro & Sala-i-Martin (1995) also mention that the distribution of income has shrunk over time in all countries. Besides, in this particular paper, Barro & Sala-i-Martin (1995) also found evidence for both conditional and absolute β-convergence in those five European countries.

Although the literature focused on the methodology used by Barro & Sala-i-Martin is quite wide, there are a lot of studies questioning the adequacy of this β-convergence regression methodology mentioned by Barro & Sala-i-Martin (1991). An example would be Binder & Pesaran (1999),who show that in a case of stochastic technological progress, β-convergence can collapse, although beta convergence is used to study the path of growth in a given economy going toward its steady state.

Moreover, to support the above research concept, Durlauf et al. (2005) argue that in a cross-section framework, the negative sign of β-convergence on the initial income would simply imply that the economies can only converge toward their different steady states. On the other hand, using the definition Pesaran (2006) argues that β-convergence is referring to a convergence that happens within an economy.

Despite the research work on beta convergence, another important methodology to study convergence is σ-convergence. Sigma convergence means that if the cross-section variance of GDP per capita decreases overtime, then this particular group of economies converges. Friedman (1992) and later on Cannon & Duck (2000) proposed a regression, which specifically tests the sigma convergence.

As stated by Bliss (1999) and Bliss (2000), the evolving of the data distribution makes the test distribution under the null hypothesis harder to interpret. However, the rejection of the hypothesis of sigma convergence does not necessarily mean that convergence does not take place. This rejection occurs due to the dynamics transition of data.

There are different critiques regarding sigma convergence. According to Friedman (1992) and Quah (1993) sigma convergence does provide a necessary, but not a sufficient additive to explain the reduction in dispersion of real income per capita. Moreover, Friedman (1992) and Quah (1993) mentioned that if the countries that converge to equilibrium and also share the technologies and same internal structure, in the long run, the income dispersion should disappear due to all countries converging to the same real income per capita. On the contrary, if countries converge to their unique own equilibrium, then the dispersion of real income per capita will not reach zero.

Moreover, according to Miller & Upadhyah (2002), the dispersion movements, in the country-specific equilibrium, will lean on the initial distribution of real incomes per capita related to the long-run outcomes.

The first formal of cross-country convergence definition is given by Bernard & Durlauf (1995) and Bernard & Durlauf (1996). According to Bernard & Durlauf (1995) and Bernard & Durlauf (1996) and their statistical definition, two countries can converge if their long term forecast is equal with each other. This means that those two countries converge, if and only if, the output gap between them is zero-mean stationary.

In this line, Pesaran (2006) stated that the definition of convergence given by Bernard and Durlauf requires that all economies should be identical. According to Pesaran (2006) definition, for two countries to converge, their output gap needs to be a stationary process. The output series are usually I(1) processes and the unit root test can be used to test for convergence.

As stated in the above statement, again Bernard & Durlauf (1996) mentioned that unit root tests are indeed applicable for convergence, only if countries are near their steady-state. On the contrary, if output tends to converge but these countries are not near their steady-state the unit root test will tend to reject the null hypothesis of convergence.

The methodology mentioned above by using the unit root test to check for convergence has led to a large number of drawbacks. The unit root test is not a correct and suitable methodology to study economic convergence.

To be more concrete, different pieces of literature study σ-convergence in economies and particularly we will be focused more on the literature based on the European Union countries.

For example, Boldrin & Canova (2001) study the sigma convergence by using the standard deviation of GDP per capita, unemployment rate and labour productivity. Boldrin & Canova (2001) use a sample composed of 185 regions of EU-15 countries.
Boldrin & Canova (2001) detect that the standard deviation of GDP per capita of the regions went from 0.27 in 1980 and decreased to 0.25 in 1996, by supporting the evidence of sigma convergence. On the other hand, the standard deviation for labour productivity oscillates over the whole sample widely, but at the end of the period 1996, it takes the same value that had in 1980.

Moreover, Boldrin & Canova (2001) consider the unemployment rate. Boldrin and Canova (2001) found that there was not a downward tendency meaning that those regions which had a high unemployment rate in 1980, still had a higher unemployment rate even in 1996.

Furthermore, Yin & Zestos (2003), studied the standard deviation of GDP per capita from 1960 up to 1995. Yin & Zestos (2003) were mainly focused on finding evidence for sigma convergence in different groups of EU regions. For the entire periods, Yin & Zestos (2003) identify for EU9, EU,12 and EU15 regions that the standard deviation had a downward trend and also concluded that there is evidence of the existence of sigma convergence even in the EU6 regions, but except from the period of 1980 up to 1996.

Paas & Schlitte (2006) study the EU-25 countries by dividing them into two groups composed of the countries of EU-15 and the other group composed of the ten new countries being part of EU in the period of 1995 up to 2002. For the countries of EU-25 Paas & Schlitte (2006) find a strong effect of sigma convergence and the coefficient of variation of income between regions decreased fast.
Similar, in the countries of EU-15 the coefficient of variation of income within regional shows a downward trend not as high as EU-25 countries.
On the other hand, the evidence for sigma convergence for the ten new member countries is not supported due to fluctuation of the coefficient of variation for all periods.

Furthermore, Paas & Schlitte (2006) study the sigma convergence within country for the EU-15 and EU-10 countries. Paas & Schlitte (2006) show

that for the EU-15 countries the variation of income per capita between regions was stable. By contrast, for the EU-10 countries the variation of income per capita between regions increases.

It comes in no surprise that the literature for sigma convergence has a variety of results for the sigma convergence for both EU-15 countries and even for EU-27 countries.
Mostly, literature is focused on the EU-15 countries and in those kinds of literature, there is evidence of the existence of sigma convergence between the period of the 1980 and the mid of 1990 where the reason why there is evidence for sigma convergence, was due to the poorest regions of the countries which were newly member of EU to catch up with the richer countries of EU.
However, this process of catching up stopped in the period of mid-1990s, and after that there was no evidence of a downward trend of sigma convergence.

On the other hand, the disparity of EU-27 regions continues to rapidly decrease since the late 1990s. There is evidence of sigma convergence in this period. The reason behind it was due to new countries that join the EU such and Eastern and Central Europe countries. The evidence shows that the poorer regions rapidly increase their growth rate compared to the richer regions of EU countries.

As Durlauf et al. (2005) mentioned, there is a need for a new econometric methodology to test the hypothesis of convergence. This new methodology will need to study the long-run convergence across different countries and also evaluate the overtime growth paths.

Different researchers who study convergence define club convergence as the tendency of real GDP per capita across countries to converge to multi steady state equilibria, one steady state equilibria for each basin of attraction. The basin of attraction are the initial conditions of those economies across countries. To detect the convergence club, a variety of statistical methods are used.

For example, Durlauf & Johnson (1995) use a data set of 121 countries. In favour of multiple regimes, they dismiss the linear model which studies the cross country economies behaviour. By using regression tree analysis, Durlauf & Johnson (1995) reject convergence in income per capital and find evidence of club convergence in multiple steady state.

Furthermore, Quah (1993), Quah (1996) and Quah (1997) proposes a distributional dynamic approach in order to study convergence. By viewing the evolution of the entire distribution over time, Quah examines the hypothesis of convergence club. He concludes that the income distribution has evolved

from unimodal called a "one peak" distribution toward the bimodal called a "twin peaks" distribution.

By using a threshold regression, Hansen (2000) was able to sort the countries into different regimes by providing enough evidence to support such the sort of multiple regimes.
Canova (2004), in terms of income per capita, proposes a new technique for grouping the converging countries. Canova's methodology implies that, for income per capita, countries exhibit multiple steady states. Canova finds that for European regions the steady state income distribution clusters around four (4) different poles, while on the other hand for the OECD countries the steady state income distribution clusters around two (2) different poles.

Phillips & Sul (2003) argue that divergence in cross section is possibly a temporary phenomenon since in their way toward a common steady state, economies can exhibit transitional divergence. Phillips and Sul developed a new methodology to test for club convergence and they examine, for convergence in per capita output, totally three different samples.

The first sample is a US sample for which Phillips and Sul conclude that the transition path for every state in US sample appear to converge.
The second sample is an OECD sample, Phillips and Sul examine in terms of per capita output a divergence. Phillips and Sul argue that this divergence was until World War II. They find evidence that around 1950 this divergence changes and the transition path in OECD sample per capital output appear to converge.
Penn World Tables sample is the third sample where Phillips and Sul argue that although across the countries capital per output diverges, there is strong evidence that supports the presence of club convergence.

The most acquirable methodology to test for convergence is the one proposed by Phillips & Sul (2007). They proposed a new powerful methodology to test if those economies tend to converge in a more common steady state. This methodology allows for a deep variety of transitional paths and divergence. This methodology is called relative convergence, proposed to be used if the real data will support the Solow growth model. Clearly, the relative convergence was a powerful methodology.

In this research, Monfort (2008) tried to get a clear and a whole picture for the sigma convergence in the EU countries from the period of 1980 up to 2005. From 1980 up to 1996, there is strong evidence to support the existence of sigma convergence for the EU-15 countries and the coefficient of variation shows a decrease from 0.33 to 0.28. Sigma convergence is measured by a coefficient of variation.

Taking into consideration the other period from 1996 up to 2005, the coefficient of variation was stable with a value between 0.28 and 0.29. On the contrary, in the EU-27 regions, the disparity was rapidly reduced where the coefficient of variation felt from 0.43 in 1995 to the value of 0.35 in 2005.

Furthermore, in this line, Faucher (2014) finds a reversal trend of convergence in the EU during the financial crisis, which leads to a disparity of wealth within regions in the year of 2013 by returning to the observed level in the year of 2000.

On the other hand, in another recent research work Kong, Phillips & Sul (2018) developed a new different methodology called weak sigma convergence. This new methodology deals with problems where log real income per capita (yit) does not have a stochastic trend. Thus, if this occurs, then the relative convergence does not hold at all. This methodology was originally mentioned by Harold Hotelling (1933) and was further developed by Kong, Phillips & Sul (2018) which will be used in this master's thesis.

3 Methodology

3.1 Relative convergence

Phillips & Sul (2007) developed a new methodology called relative convergence. This model was focused on examining whether the real data supports the growth model of Solow. The growth rate of log real income per capita should converge to the level of steady-state if the progress of technology is homogenous. To be precise, in the long run, the time trend slope coefficient should be the same (identical).

Phillips and Sul proposed a non-linear time-varying model. This provides the basic need to model the transitional dynamics and to model even the behaviour in the long run.

The model allows a time-varying slope coefficient on the trend term. Phillips and Sul wrote $y_{i,t}$ of a country i as:

$$y_{it} = a_{it}\mu_t \quad (1)$$

where, μ_t is a component of a stochastic or non-stochastic trend and a_{it} is the time varying element, which captures the movements of a country i from a common path which is defined by μ_t

In line with the above framework, at some point in the future, all N economies will converge to a steady state if $\lim_{x\to\infty} a_{it+x} = a$ for all i = 1,2,3,....,N without taking into account whether countries are or are not near a steady state.

The main goal of Phillips and Sul is to test if the economic variable y_{it}, for all i = 1,2,3,....,N will tend to converge as $t \to\infty$ on one single steady state. To check the above goal, Phillips and Sul adopt Equation 1 for every economic variable in the whole sample.

μ_t, across economies, is assumed to be a common factor. By contrast, a_{it} are used to capture the transition dynamics. The peculiar components (a_{it}) are allowed to vary across economies and time. Convergence, as Phillips and Sul stated, is a dynamic process.

Considering that μ_t deals with the transition paths, the only way to test convergence is by examining the evolution of a_{it}. To sum up, Phillips and Sul only concentrate on a_{it}, while for μ_t, they do not assume any parametric form. So in other words, μ_t is factored out.

Because of over-parameterization, it is impossible to estimate directly the parameter a_{it}. Phillips and Sul assume a semi parametric form for the parameter a_{it}, which enables to construct a formal test for convergence. Specifically, Phillips and Sul eliminate the common factor μ_t. The elimination of the common factor μ_t was made through rescaling by the panel average:

$$h_{it} = \frac{y_{it}}{N^{-1}\sum_{i=1}^{N} y_{it}} = \frac{a_{it}}{N^{-1}\sum_{i=1}^{N} a_{it}} \quad (a)$$

$h_{i,t}$ is the relative measure, which with respect to panel average, catches the transition path.
Equation (b) is the semi-parametric form of a_{it} (time-varying coefficient), which is a necessary assumption to define a more formal econometric test for convergence.

$$a_{it} = a_i + \sigma_{it}\psi_{it} \quad (b)$$

where $a_{it} = \frac{a_i}{logtt^{\alpha}}$, $a_{it} > 0$, $t \geq 0$ and

ψ_{it} is weakly dependent over t, but it is iid(0,1) over i.

Under the above specifics for a_{it} the convergence hypotheses for all i are:

$$H_o : a_i = a, \quad \alpha \geq 0$$

$$H_A : a_i \neq a, \quad \alpha < 0$$

The methodology developed by Phillips and Sul involves using the least squares regression to test for relative convergence. In the least-squares, the regression method uses an "log t" regressor in Equation 2.

$$log(\frac{H_1}{H_t}) - 2\log L(t) = \hat{a} + b\log t + \hat{u}_t \quad (2)$$

for $t = [rT], [rT]+1, ..., T$, $r > 0$, $L(t) = logt$ *and* $b = 2\hat{\alpha}$ where $\hat{\alpha}$ is a least squares estimate for α

And, $H_t = (N^{-1})\sum_{i=1}^{N}(h_{it} - 1)^2$ *(c)*

where h_{it} is defined in Equation (a)

Equation (a) and Equation (c) are the relative income of a country i. If the estimated $\hat{b}$ is significantly positive, then the above "log t" test provides sufficient evidence for relative convergence. The authors called it log t-test due to log t regressor on Equation 2.

Under the null hypothesis of convergence, the t-ratio of $\hat{b}$ converges to plus infinity. Under the alternative hypothesis of divergence, the t-ratio of $\hat{b}$ converges to minus infinity.
At 5% significance (one side test), the null hypothesis of convergence cannot be rejected if $t_{\hat{b}} \geq$ -1.65.
Phillips and Sul call it a one-sided t-test which is based on $t_{\hat{b}}$ and can be found in the Appendix (Formula I).

To test for relative convergence, the log t regression model Equation 2 will be in the programs STATA and GAUSS. Before running the regression it is important to check if the panel data in this thesis for all i and t support $y_{it} \geq 0$.
Another important detail is to check if the panel data used in this master's thesis has a strong trend behavior. As stated by Sul (2019), to check for a strong trend behavior, the trend regression (Equation (c)) should be run for each i and should also be check if $\hat{\beta}_i$ is significantly positive or negative for all i.

$y_{it} = \alpha_i + \beta_i t + \mu_{it}$ *(c)*

Sul also stated that if $\hat{\beta}_i$ for all i is significantly negative or positive then trend behavior is very strong. Trend behavior is relatively strong if most $\hat{\beta}_i$ are significantly positive, but the rest of $\hat{\beta}_i$ are not significantly negative. Moreover, trend behavior is not strong if some $\hat{\beta}_i$ are significantly positive, some of $\hat{\beta}_i$ are significantly negative and the rest of $\hat{\beta}_i$ are not significant at all, but are different from 0.

Sul (2019) states that if the trend behavior is very strong or relatively strong, it is recommended to use log t regression. On the other hand, if no strong trending behavior occurs then the log t regression is not recommended to run.

3.2 Sigma (σ)-convergence

According to Kong, Phillips & Sul (2018), the notion of sigma convergence is more applicable. Phillips & Sul (2007) state that the weak sigma convergence is more restrictive compared to the relative convergence when we are facing a distinct trend behaviour of common factors.

For example, when the common factor is composed of a component of a weak trend, then we can easily verify that weak sigma convergence holds while relative convergence does not hold at all.

The authors proposed the following notion for sigma convergence.

For the below trend regression, we will construct t-static of OLS estimate $\hat{\phi}$, which is based on Newey West HAC estimator where L = int($T^{\frac{1}{3}}$)).

$$K_{nt}^{y} = \hat{a} + \phi \mathrm{t} + \hat{\mu}_t \quad (3)$$

Where the variable K_{nt}^{y} will be the cross sectional variance of $y_{i,t}$.

The above is called the one-sided t-test, which is based on $t_{\hat{b}}$ and can be found in the Appendix. So, based on the t-ratio, we can easily check if $y_{i,t}$ is weakly sigma convergent, or if it fluctuates or if it is diverging. At 5% critical value (one side test, 1.65) we have the following bounds.

$t_{\hat{\phi}} < -1.65$

Evidence for weak sigma (σ)-convergence

$-1.65 < t_{\hat{\phi}} < 1.65$

Evidence for fluctuation

$t_{\hat{\phi}} > 1.65$

Evidence for sigma (σ)-divergence

However, when $y_{i,t}$ includes a non-stochastic or a stochastic trend, then the time-varying component $y_{i,t}$ is dependent mainly on the time-varying nature of the stochastic trend. To be more precise, lets take F_t as a common factor estimator. After that, we run the below regression for each i with the estimates of F_t.

$y_{it} = a_i + \lambda_i F_t + \hat{\mu}_{it} \quad (4)$

The above equation is used when we face more than one common factor. If it appears to have a single common factor, then instead of F_t the cross-sectional average of the sample can be used.

However, according to Phillips and Sul, it is important to include the fixed

effects in z_{it} in the regression model.

$z_{it} = y_{it}$ - $\hat{\lambda}_i F_t = a_i + y_{it}^0 + (\lambda_i F_t$ - $\hat{\lambda}_i F_t)$ *(5)*

At the end, the trend regression (Equation 5) will be run with z_{it}.

To test for weak sigma convergence, this thesis will run the regression model (3) by using the variable K_{nt}, which is the cross-sectional variance of $y_{i,t}$. Then we will run again the regression by including the fixed effects in z_{it}. Both models will be run using the STATA and GAUSS language programs.

The hypotheses for weak sigma convergence are :

H_0 : there is no weak σ-convergence
H_A : there is weak σ-convergence

If the t ratios are less than - 1.65, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_A) is preferred. When the alternative hypothesis is preferred, we conclude that we find enough evidence to support weak σ-convergence.

If the t ratios are greater or equal - 1.65, the null hypothesis (H_0) is preferred and the alternative hypothesis (H_A) is not supported. When the null hypothesis is preferred, we conclude that we did not find enough evidence to support weak σ-convergence.

3.3 β-convergence

β-convergence is related to the prediction that poor economies should grow faster than rich economies. The method measuring the beta convergence is developed from the neoclassical growth model of Ramsey (1928), Solow (1956) and Koopmans (1965). This method was later made known by the research papers of Barro & Sala-i-Martin (1991) and Barro & Sala-i-Martin (1992). Moreover, in the neoclassical growth model, the beta coefficient captures the rate at which country i real GDP per capita can reach a steady-state rate of growth.

Barro & Sala-i-Martin developed the concept of β-convergence into conditional β-convergence and absolute β-convergence. Beta convergence for the unconditional and even for conditional requires a negative relation between the cross-sectional GDP per capita, or the income per capita and growth.

Derived from the neoclassical growth model Equation 6 estimates the beta coefficient to find evidence for the absolute beta convergence.

$$\frac{1}{T} \cdot log(\frac{y_{iT}}{y_{i0}}) = \alpha - [\frac{1-e^{-\beta T}}{T}] \cdot log(y_{i0}) + U_{i0,T} \quad (6),$$

where:

y_{iT} = real GDP per capita for country i in year t

y_{i0} = initial period of real GDP per capita for country i

T = length of the time interval, in years

$U_{i0,T}$ = error term

log = natural logarithm

In Equation 6 the dependent variable is the average rate of growth of a country i in an interval of T years.

The model in Equation 7 will help us to find evidence for the conditional beta convergence.

$$\frac{1}{T} \cdot log(\frac{y_{iT}}{y_{i0}}) = \alpha - [\frac{1-e^{-\beta T}}{T}] \cdot log(y_{i0}) + \Theta X_{iT} + U_{i0,T} \quad (7),$$

where

X_{iT} is a set of exogenous variables that can influence the Real GDP per capita.

To find the results about absolute and conditional β-convergence based on Barro & Sala-i-Martin (1992) the Nonlinear Least Squares (NLS) method is used by the STATA program. In Barro & Sala-i-Martin, real GDP per capita is a dependent variable and other variables are explanatory variables.

4 Data

The data used in this master's thesis are taken from 28 European countries, namely Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the United Kingdom.

The dataset consists of yearly data of 28 European countries for a period from 1995 up to 2018. This panel data consists of seven variables for 28 EU countries.
Those variables are Real GDP per capita, Total Investment, Government Expenditure, Unemployment rate, Trade-openness, and Inflation rate.

The data used in this master's thesis are taken from EUROSTAT, World-Bank and IMF.

5 Empirical Results

5.1 β-convergence

	Absolute convergence	Conditional convergence
Alpha	3.142***	3.805***
Beta	0.724***	0.676***
Total investment		-0.0113***
Government Expenditure		-0.00129
Unemployment Rate		-0.019***
Trade-openness		0.00230***
Inflation Rate		-0.00219***
R^2	0.715	0.762
$^* p < 0.05,\ **p < 0.01,\ ***p < 0.001$		

Table 1: Regression results for β-Convergence

Table 1 shows the results of Absolute and Conditional β-Convergence regression. To conclude if there is any evidence of beta convergence, we need to check the coefficient of beta, which is the coefficient of initial real GDP per capita. On the other hand, to conclude the existence of convergence, the coefficient of beta must be negative. If it is positive, then it indicates that we are facing divergence.

Considering the results above, we do not conclude that we have evidence for Absolute β-Convergence or Conditional β-Convergence. So there is no β-Convergence by using the Barro & Sala-i-Martin method. With regards to the proposed method, it is stated that if the beta coefficient is positive, then it indicates that we are facing divergence. Thus, results in the above table indicate that we are facing divergence in the dataset of EU-28.

5.2 Statistical pitfalls of β-Convergence

Beta convergence was used to explain the conditions for poor countries to catch up with the rich countries.

According to Phillips & Sul, the methodology of β-Convergence should not be used because of statistical pitfalls that this methodology suffers.

To explain the statistical pitfalls, Phillips and Sul (2019) consider Model A and Model B, which are data-generating process.

Model A $\quad y_{it} = a_i + b_i t + y_{it}^o$

Model B $\quad y_{it} = a_i + (b_i + c_i t^{-\alpha})t + y_{it}^o \quad$ for $\alpha > 0$,

where t= 0,1,... , T.

When t = 0 and under the assumption that $y_{i0}^o = 0$, the initial income in Model A and Model B become a_i. For the moment, the random part, y_{it}^o, is ignored.

According to Phillips and Sul, beta convergence has been tested as above:

β-convergence $\quad Cov(y_{i0}, \frac{y_{iT}-y_{i0}}{T}) < 0$

where $\frac{(y_{iT}-y_{i0})}{T}$ estimates the long-run growth rate of y_{it} and is called long-run average. Phillips and Sul argue that if we take the limit of $\frac{(y_{iT}-y_{i0})}{T}$, long-run average becomes the growth rate in the steady state in both Model A and Model B. The negative covariance between the long-run growth rate and initial income exists if

Model A $\quad Cov(a_i, b_i) < 0$

Model B $\quad Cov(a_i, b_i) < 0 \quad$ or $\quad Cov(a_i, c_i) < 0$

As t $\to \infty$, the negative covariance between a_i and b_i in both Model A and Model B implies permanent divergence of y_{it}

b_i in the Model A is heterogeneous technology. According to Phillips and Sul, the negative correlation between technology growth rate and initial income leads initially to a temporal convergence, but in the long-run leads to a permanent divergence.

The growth rate of technology progress in Model B is time varying as $b_i + c_i t^{-\alpha}$

The temporal convergence holds, even if there is no correlation between

a_i and b_i, as long as $Cov(a_i, c_i) < 0$.

Phillips and Sul argue that only when $b_i = b$ and $Cov(a_i, c_i) < 0$, for all i, do the initially poor countries grow faster than initially rich countries. But as t increases the growth rate of the poor countries decreases over time and eventually the growth rate of the poor countries reaches the steady-state level b. The growth rates of rich countries would be around the steady-state level if initially rich countries have $c_i = 0$.

Phillips and Sul argue that Model B is just an example of what growth economists actually want to capture. According to them, the growth economists want to catch the initially rapid catching up and then just slowing down the growth rate at a certain point.

Finally, Phillips and Sul state that β-convergence is just a necessary condition for convergence but it is not a sufficient condition for convergence. Phillips and Sul also conclude that β-convergence does not support at all the Solow growth model, but the Solow growth model can lead to the condition of β-convergence.

According to Phillips and Sul it is always more useful to firstly test the weak σ-convergence. If for example the panel data has a stochastic or non-stochastic trend then weak σ-convergence usually statistically implies relative convergence. Furthermore, theoretically the reverse implication is not true, but almost in all cases, if the relative convergence is rejected, then usually weak σ-convergence is also rejected.

(Kong, Phillips & Sul 2019) explain that the disagreement between weak σ-convergence and relative convergence can easily be seen if the panel data does not have any stochastic or non-stochastic trend. The relative convergence in this particular case is not well defined. On the other hand, it is more meaningful to test the weak σ-convergence. In addition, if weak σ-convergence is rejected, then it is reasonable to investigate relative convergence.

5.3 Weak σ-convergence test

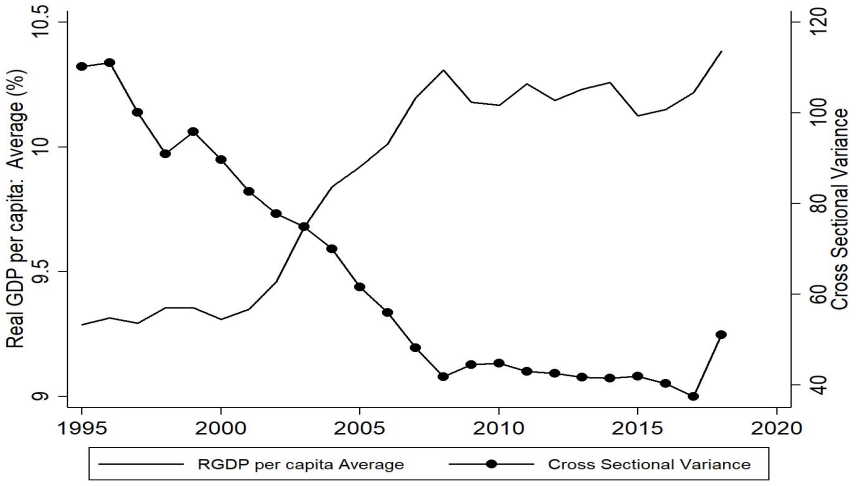

Figure 1: Cross sectional means and variances of Real GDP per capita

Figure 1 shows the plot of the average of Real GDP per capita and the sample variance for 28 European countries in a period from 1995 to 2018. Considering the figure, cross-sectional variance is decreasing with some fluctuations in this period.

Furthermore, for the weak sigma convergence test, we will run two different variances. The first is $K_{n,t}$, which consists of the cross-sectional variance of $y_{i,t}$. The second one is called $K^z_{n,t}$, which includes the fixed effect of $z_{i,t}$.

Table 2 shows the results of weak sigma convergence using the first variance $K^y_{n,t}$.

	$\hat{\phi}$ (2)	$t_{\hat{\phi}}$ (2)	$\hat{\phi}$ (3)	$t_{\hat{\phi}}$ (3)
Real GDP per capita	-0.031	-8.447	-0.031	-7.733
Total investment	0.0003	1.154	0.0003	1.173
Government Expenditure	-0.00004	-0.109	-0.00004	-0.100
Unemployment Rate	-0.004	-1.39	-0.004	-1.334
Trade-openness	0.0015	2.101	0.0015	1.925
Inflation Rate	-0.008	-3.105	-0.008	-2.941

Table 2: Weak (σ)-convergence regression results

Table 2 provides the trend regression results for $K^y_{n,t}$ including the coefficients of $\hat{\phi}$ for all variables in lag 2 and lag 3 and the results of $t_{\hat{\phi}}$ for respective lags (lag 2 and lag 3). The lag(2) and lag(3) are chosen based on the Newey and West's HAC estimator (1987). Accordingly, the selection rule is defined as int($T^{\frac{1}{3}}$). In this data set, T is 24. So based on the HAC estimator, we have $24^{\frac{1}{3}}$, which is approximately 2.89 and it is logical to choose lag(2) and lag(3).

It can be easily verified that $\hat{\phi}$ is not dependent at all on the choice of lags. As we can see $\hat{\phi}$ remains the same for lag(2) and lag(3). By contrast, the t-ratio ($t_{\hat{\phi}}$) is dependent on the choice of lags. For sigma convergence, we need to check t-ratio results in table 2 for both lags and compare to the critical value -1.65. Then conclude whether we can accept or reject the null hypothesis (H_0: there is no weak σ-convergence).

The Real GDP per capita t-ratio ($t_{\hat{\phi}}$) for lag(2) and lag(3) are -8.447 and -7.733 respectively. Since the t-ratio of Real GDP per capita are smaller than the critical value -1.65, the null hypothesis is not supported . Thus, the alternative hypothesis is supported. Real GDP per capita is weakly sigma converging. Furthermore, the t-ratio for Real GDP per capita with three lags weakens slightly compare to the t-ratio with two lags. The important part, however, is that t-ratio with three lags are less than -1.65.

Same as Real GDP per capita, the t-ratio of Inflation Rate is smaller than the critical value -1.65. Then, the null hypothesis is rejected and the alternative hypothesis is supported. Eventually, Inflation Rate is weakly sigma converging. Moreover, the t-ratio for Inflation Rate with three lags weakens slightly compared to the t-ratio with two lags. However, the important part is that t-ratio with three lags is less than -1.65.

In Table 2 we can see that t-ratios of Total investment, Government Expenditure, Unemployment Rate and Trade-openness are not smaller than the critical value -1.65. Then the null hypothesis of no weak σ-convergence is accepted. Therefore, Total investment, Government Expenditure, Unemployment Rate and Trade-openness are not weakly sigma converging. Thus, four variables do not converge at all.

Table 3 provides the results of weak sigma convergence with $z_{i,t}$ using the second variance $K^z_{n,t}$.

	$\hat{\phi}$ (2)	$t_{\hat{\phi}}$ (2)	$\hat{\phi}$ (3)	$t_{\hat{\phi}}$ (3)
Real GDP per capita	-0.002	-0.803	-0.002	-0.775
Total investment	-0.0001	-0.574	-0.0001	-0.571
Government Expenditure	0.0002	0.561	0.0002	0.525
Unemployment Rate	-0.0042	-2.098	-0.0042	-1.964
Trade-openness	0.0001	0.158	0.0001	0.148
Inflation Rate	-0.0004	-0.521	-0.0004	-0.500

Table 3: Weak (σ)-convergence regression results with $z_{i,t}$

In analogy with Table 2, for sigma convergence we need to check t-ratio results in table 3. Comparing both lag variants to the critical value -1.65 permits to conclude whether we can accept or reject the null hypothesis of weak σ-convergence.

The Real GDP per capita t-ratios ($t_{\hat{\phi}}$) for lag(2) and lag(3) are -0.803 and -0.775 respectively. Since the t-ratios of Real GDP per capita are not smaller than the critical value -1.65, the null hypothesis is supported. Real GDP per capita is not weakly sigma converging.

Same as Real GDP per capita, the t-ratios of Total investment, Government Expenditure, Trade-openness, and Inflation Rate are not smaller than the critical value -1.65. Then the null hypothesis is supported. Therefore, Total investment, Government Expenditure, Trade-openness, and Inflation Rate are not weakly sigma converging. As noted in Table 2, again the t-ratios with three lags weaken slightly compared to the t-ratio with two lags.

In Table 3 we can see that t-ratio of Unemployment Rate is smaller than the critical value -1.65. Thus the alternative hypothesis is supported. Unemployment Rate is weakly sigma converging.

By using the second variance with $z_{i,t}$, we found different conclusion compared to the first variance in Table 2. The difference between the results of first and second variance is that the evidence becomes weakened. This

occurs because the fixed effect $z_{i,t}$ includes the additional term of $\lambda_i F_t$ - $\hat{\lambda}_i F_t$.

5.4 Relative convergence test

	$\hat{b}$	$t_{\hat{b}}$
Real GDP per capita	0.004	0.038
Total investment	-1.34	-2.261
Government Expenditure	-0.945	-1.556
Unemployment Rate	-0.693	-2.356
Trade-openness	-0.637	-4.823
Inflation Rate	-0.686	-5.249

Table 4: Relative Convergence regression results

Real GDP per capita and Government Expenditure support the null hypothesis of full convergence. The log(t) value of Real GDP per capita and Government Expenditure are not smaller than the critical value -1.65, meaning that the null hypothesis is accepted. From the null hypothesis it can be concluded that Real GDP per capita and Government Expenditure support relative convergence.

As for other variables, all of them do not support relative convergence. $t_{\hat{b}}$ are negative (see: Table 4) and are smaller than the critical value -1.65, the null hypothesis is rejected. This means that Total investment, Unemployment Rate, Trade-openness, and Inflation Rate do not support the null hypothesis of relative convergence.

6 Conclusion

To conclude, this research examines the economic convergence of European Union countries from 1995 to 2018. Weak σ-convergence and relative convergence are developed by Phillips and Sul to find evidence for economic convergence.

The empirical results provide evidence on weak σ-convergence and on relative convergence. As outlined above, it is always more useful to test firstly weak σ-convergence. Weak σ-convergence is more applicable and does also have some restrictions compared to relative convergence. To provide evidence for convergence, the t-ratio results from the regression have been compared to the critical value of -1.65.

Furthermore, to test for weak σ-convergence, two variances were computed and the t-ratios of all variables for lag(2) and lag(3) were compared to the critical value. After comparing, the t-ratios of the first variance for Real GDP per capita and Inflation Rate are less than -1.65, leading to the rejection of the null hypothesis.
In other words, Real GDP per capita and Inflation Rate are weakly sigma converging. The other variables Government Expenditure, Unemployment Rate, Total investment, and Trade-openness are not weakly sigma converging.

On the other hand, the t-ratio of the second variance for Unemployment Rate is smaller than the critical value -1.65. Then, the alternative hypothesis is accepted. Thus, Unemployment Rate is weakly sigma converging. Other variables such as Real GDP per capita, Total investment, Government Expenditure, Trade-openness, and Inflation Rate are not weakly sigma converging.

Moreover, the relative convergence test was also computed in this master's thesis. The log(t) regression model is used to test relative convergence. Log(t) values of all variables were compared with the critical value -1.65. Subsequently, Real GDP per capita and Government Expenses accept the null hypothesis, by confirming that those particular variable support relative convergence.
On the other hand, other variables such as Unemployment Rate, Inflation Rate, Total investment and Trade-openness do not support at all the null hypothesis of relative convergence.

To sum up, taking into consideration the empirical results on weak σ-convergence and relative convergence from 1995 to 2018, we conclude that there is evidence of sigma convergence on the European Union. However, convergence will remain a very debatable topic.

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7 Appendix

7.1 Relative convergence

c $t_{\hat{b}} = \frac{\hat{b}}{\sqrt{\hat{\Omega}_u^2 / \sum_{t=r}^{T} (logt - (T-r)^{-1} \sum_{t=r}^{T} logt)^2}}$ *(I)*

$r = int(T/3)$ and $\hat{\Omega}_u^2$ is long run variance of $\hat{\mu}_t$

7.2 Weak σ-convergence

$$t_{\hat{b}} = \frac{\hat{\phi}}{\sqrt{\hat{\Omega}_u^2 / \sum_{t=1}^{T} (t - T^{-1} \sum_{t=1}^{T} t)^2}} \quad \textit{(II)}$$

$\hat{\Omega}_u^2 = \frac{1}{T} \sum_{t=1}^{T} \hat{\mu}_t^2 + 2 \frac{1}{T} \sum_{\ell=1}^{L} \vartheta_{\ell L} \sum_{t=1}^{T-\ell} \hat{\mu}_t \hat{\mu}_{t+\ell}$

and $\hat{\mu}_t = K_{nt}^y - \hat{a} - \hat{\phi}_t$

$\vartheta_{\ell L}$ = Bartlett lag kernel weight

7.3 Hypothesis

7.3.1 Relative convergence

H_0 : there is relative convergence
H_A : there is no relative convergence

7.3.2 Weak σ-convergence

H_0 : there is no weak σ-convergence
H_A : there is weak σ-convergence

7.4 Abstract

Convergence is a very debatable topic in all growth literature. In different kinds of literature, the authors try to find evidence about the existence of economic convergence. This master's thesis tries to find evidence for economic convergence across the European Union countries from 1995 up to 2018. Moreover, the concepts of sigma-convergence and beta-convergence are discussed. To find evidence of economic convergence, the methodology proposed by Phillips & Sul is used.

In addition, the well known and debatable method from the 90s, proposed by Barro & Sala-i-Martin about the beta-convergence is briefly explained. While discussing the method of Barro & Sala-i-Martin, the reasons are explained why according to Phillips & Sul, this proposed method is not recommended to be used.

This master's thesis is organized into the following sections. The first section consists of an introduction, where the idea of convergence is explained in more detail and why according to Phillips & Sul, beta (β) convergence is a necessary condition for convergence, but not a sufficient one. The second section consists of the literature review. The third section includes the methodology of relative convergence, sigma (σ) convergence and β-convergence. The fourth part briefly explains the data used. Next, the fifth section is based on empirical results, which analyses the estimated results of the regression models for β, relative and σ- convergence. Finally, the last section summarizes based on the results obtained from the regression models.

7.5 Zusammenfassung

Konvergenz ist in der gesamten Wachstumsliteratur ein sehr umstrittenes Thema. In verschiedenen Arten von Literatur versuchen die Autoren, Beweise für die Existenz wirtschaftlicher Konvergenz zu finden. In dieser Masterarbeit wird versucht, Belege für die wirtschaftliche Konvergenz in den Ländern der Europäischen Union von 1995 bis 2018 zu finden. Darüber hinaus werden die Konzepte der Sigma-Konvergenz und der Beta-Konvergenz diskutiert. Um Anzeichen für eine wirtschaftliche Konvergenz zu finden, wird die von Phillips & Sul vorgeschlagene Methodik verwendet.

Darüber hinaus wird die bekannte und umstrittene Methode aus den 90er Jahren, die von Barro & Sala-i-Martin zur Beta-Konvergenz vorgeschlagen wurde, kurz erläutert. Bei der Erörterung der Methode von Barro & Sala-i-Martin werden die Gründe erläutert, warum nach Ansicht von Phillips & Sul die Verwendung dieser vorgeschlagenen Methode nicht empfohlen wird.

Diese Masterarbeit gliedert sich in folgende Abschnitte. Der erste Abschnitt besteht aus einer Einführung, in der die Idee der Konvergenz näher erläutert wird und warum nach Phillips & Sul die Beta (β)-Konvergenz eine notwendige, aber keine ausreichende Konvergenzbedingung ist. Der zweite Abschnitt besteht aus der Literaturübersicht. Der dritte Abschnitt enthält die Methodik der relativen Konvergenz, σ-Konvergenz und β-Konvergenz. Im vierten Teil werden die verwendeten Daten kurz erläutert. Als nächstes basiert der fünfte Abschnitt auf empirischen Ergebnissen, die die geschätzten Ergebnisse der Regressionsmodelle für β, Relativ und σ-Konvergenz analysieren. Schließlich fasst der letzte Abschnitt die Ergebnisse der Regressionsmodelle zusammen.