ANALYSIS OF STOCHASTIC INCOME CONVERGENCE PROCESS IN 26 SUB-REGIONS OF TÜRKIYE USING FOURIER UNIT ROOT TESTS

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Abstract

The fundamental aim of the work is to investigate the per-capita income convergence in 26 sub-regions of the Turkish economy at NUTS-2 level for the period 2004-2022 using Fourier unit root analyses. Since the highest per-capita income level belongs to TR10 Istanbul sub-region, it is investigated whether the per-capita income of other sub-regions have converged to that of Istanbul sub-region. To accomplish the objective and facilitate policy implications, the linearity of the variables is first examined using the BDS Independence Test. In the second stage the validity of the convergence among sub-regions is investigated using Fourier-based KPSS, ADF and Sollis unit root tests. The findings of Fourier-based unit root tests point out that the per-capita incomes of the sub-regions located in the west, south-west and north-west of the country converge to those of Istanbul, whereas the per-capita incomes of the sub-regions in the central, south and south-east of the country diverge from those of Istanbul. In this respect, it is concluded that relatively wealthier sub-regions show a trend of converging towards Istanbul, while less affluent regions exhibit a tendency to diverge from it.

Keywords: Income convergence, Fourier unit root analysis, Turkish economy

JEL Classification: C22, D31, O47

TÜRKİYE'NİN 26 ALT BÖLGESİNDE STOKASTİK GELİR YAKINSAMASI SÜRECİNİN FOURIER BİRİM KÖK TESTLERİ İLE ANALİZİ

Öz

Bu çalışmanın temel amacı, Türkiye ekonomisinin NUTS-2 düzeyindeki 26 alt bölgesinde kişi başına gelir yakınsamasını 2004-2022 dönemi için Fourier birim kök analizleri kullanarak incelemektir. Bir başka deyişle, en yüksek kişi başına düşen gelir düzeyi TR10 İstanbul alt bölgesine ait olduğundan, diğer alt bölgelerin kişi başına gelir düzeylerinin İstanbul alt bölgesine yakınsayıp yakınsamadığı araştırılmıştır. Amaca ulaşmak ve politika çıkarımlarını kolaylaştırmak için ilk olarak değişkenlerin doğrusallığı BDS Bağımsızlık Testi kullanılarak incelenmiştir. İkinci aşamada, alt bölgeler arasındaki yakınsamanın geçerliliği Fourier tabanlı KPSS, ADF ve Sollis birim kök testleri kullanılarak araştırılmıştır. Fourier temelli birim kök testlerinin bulguları, ülkenin batısında, güneybatısında ve kuzeybatısında yer alan alt bölgelerin kişi başına gelirlerinin İstanbul'un kişi başına gelirine yakınsadığına; ülkenin orta, güney ve güneydoğusunda yer alan alt bölgelerin kişi başına gelirlerinin ise İstanbul'un kişi başına gelirinden ayrıştığına işaret etmektedir. Bu bağlamda, görece zengin alt bölgelerin İstanbul'a yakınsadığı, daha yoksul bölgelerin ise ıraksadığı sonucuna varılmaktadır.

Anahtar Kelimeler: Gelir yakınsaması, Fourier birim kök analizi, Türkiye ekonomisi

JEL Sınıflaması: C22, D31, O47

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1. Introduction

World economic history has witnessed significant developments in globalization processes. The wave of globalization, which initially emerged by integrating capital and financial markets in the 1870s, has maintained its momentum ever since. Since the second half of the twentieth century, this process has entered its third phase, characterized by increasing interdependence in goods, trade, finance, production, and information. The convergence process has emerged as the most significant concept accompanying this third wave of globalization and has been a frequent topic of discussion in economic literature, sparking intense debates.

The concept of convergence, as introduced by Solow (1956), describes the phenomenon in which underdeveloped or developing countries grow at a faster pace than developed countries, thereby reducing disparities in per capita income over time. This concept is predicated on a negative relationship between the initial level of per capita income and the subsequent income growth rate. The convergence hypothesis posits that productivity tends to increase more rapidly in underdeveloped or developing countries than in their developed counterparts, leading to a gradual narrowing of development and growth gaps between these groups of countries. According to this hypothesis, rapid increases in capital availability, investments in education, and the transfer of technologies and managerial practices from developed economies are key drivers of this process (Baumol and Blinder, 2010: 137). Neoclassical theory suggests that, due to the diminishing returns to capital, countries with lower capital-to-labor ratios and lower initial per capita income are expected to experience faster growth relative to wealthier nations. This principle implies that the marginal returns on capital are higher in poorer countries than in richer ones. Consequently, as Mbaku and Kimenyi (1997) argue, the convergence hypothesis implies that countries with initially high per capita incomes will exhibit slower economic growth relative to those with lower initial incomes. This notion rests on the assumption that poorer countries can adopt advanced technologies at lower costs, and that resource transfers generate greater income potential in these countries compared to their wealthier counterparts.

The convergence hypothesis is examined through three main analytical approaches: Beta (β) Convergence, Sigma (σ) Convergence, and Log Per Capita GDP Convergence. Beta convergence, characterized by the β coefficient, reflects the idea of stochastic convergence, if all countries have similar structural characteristics. According to Arbia and Piras (2015), the relationship between the average growth rate of per capita income and the initial per capita income level is described by equation (1):

$$\frac{y_{t,i}-y_{0,i}}{y_{0,i}} = \alpha + \beta y_{0,i} + \varepsilon_{t,i} \qquad (1)$$

In equation (1), $y_{t,i}$ denotes the per capita income level in country i at time t, while $y_{0,i}$ signifies the per capita income level at the initial year. The left-hand side of the equation, representing the dependent variable, indicates the income growth rate. Here, α represents the constant term, β is the convergence coefficient, and $\varepsilon_{t,i}$ is the error term. If the β coefficient is statistically significant and takes on a negative value, it indicates the presence of a convergence process. If it takes on a positive value, however, it suggests divergence. With the help of the regression model numbered (1), two other coefficients can be calculated: The first one is the speed of convergence and the second one is the half-life coefficient required to reach the steady-state equilibrium. The speed of convergence is calculated using the equation $s = -ln(1 + T\beta)/T$. The T value in this equation refers to the number of periods between t and $t-1$. Half-life is calculated using the equation $\tau = -ln\,(T)/ln(1 + \beta)$.

Sigma convergence refers to the process by which disparities in per capita income among different economies diminish over time. This concept is founded on the premise that, as time progresses, the income distributions of the economies being compared will increasingly resemble one another (Sala-i-Martin, 1996: 1020). The standard deviation (σ) of per capita income is commonly used to measure sigma convergence. A declining standard deviation indicates the presence of convergence, whereas an increasing or stable standard deviation suggests divergence (Valdes, 1999: 41). As noted by Gündem (2010), sigma convergence can be expressed using equation (2):

$$\sigma_t = \sqrt{I^{-1}\sum_{i=1}^{I}(S_{it} - \overline{S_t})^2} \qquad (2)$$

In equation (2), I signifies the country being analyzed, S_{it} indicates the income level of country I at time t, and $\overline{S_t}$ represents the average income level across all countries at time t.

Log per capita income convergence examines whether different countries exhibit a common deterministic or stochastic trend. The studies by Bernard and Durlauf (1995, 1996) and Evans and Karras (1996) highlight this type of convergence. Log per capita income convergence can be expressed by the equation numbered (3):

$$log(y_{it}) = \alpha + (1 - \beta)log(y_{i,t-1}) + u_{it} \qquad (3)$$

In equation (3), y_{it} is the average growth rate of per-capita income in country i, β is the convergence coefficient, $y_{i,t-1}$ is the initial period per-capita income in country i and u_{it} is the error term. When equation numbered (3) is rearranged, regression equation numbered (4) can be obtained:

$$log\left(\frac{y_{it}}{y_{i,t-1}}\right) = \alpha - \beta log(y_{i,t-1}) + u_{it} \quad (4)$$

This equation resembles the beta convergence equation, and depending on the sign of the beta coefficient, inferences can be made regarding the presence or absence of convergence (Young *et al*., 2008: 1086).

The primary objective of this research is to analyze per capita income convergence across 26 sub-regions of the Turkish economy at the NUTS 2 level for the period 2004–2022, utilizing Fourier unit root analyses. In particular, as the highest per capita income level is observed in the TR10 Istanbul sub-region, this study investigates whether the per capita income levels of other sub-regions have converged toward that of the Istanbul sub-region. The incorporation of NUTS 2 level data and the application of Fourier analyses—both of which are relatively novel in the econometric literature—distinguish this study from prior research. Specifically, most convergence studies focusing on the Turkish economy have been conducted at the national level, with few addressing sub-regional disparities. Additionally, existing studies in literature typically rely on linear unit root tests, time series, and panel data methods to assess the convergence process. By employing nonlinear unit root tests, this study makes a direct contribution to literature. The study is organized into five chapters: the second chapter reviews the literature on convergence in the Turkish economy, the third chapter describes the methodology and data used for empirical analysis, the fourth chapter presents the results of the analysis, and the fifth chapter provides a comprehensive evaluation of the findings.

2. Literature Review

In the field of economics, numerous studies have demonstrated that underdeveloped countries with low per capita incomes tend to grow more rapidly than developed countries with high per capita incomes, leading to a convergence process between these two groups. The convergence hypothesis, first introduced by Solow (1956), has garnered considerable attention and has become a central topic in analyses of the Turkish economy. Research examining the convergence process among Türkiye's provinces and sub-regions, as well as comparative studies between Turkey and other countries, has yielded noteworthy findings. These mixed results underscore the significance of the convergence issue and highlight the diverse policy implications that have emerged.

Some of the studies on the Turkish economy in the context of the convergence hypothesis have been conducted at the provincial level. The earliest province-based studies were conducted by Erk *et al*. (2000) and Doğruel and Doğruel (2003), who employed panel data analyses for 67 provinces and found that the absolute divergence process is dominant among them. Questioning the validity of these findings, Karaca (2004) considered the same 67 provinces but extended the study period to 1975–2000 and used panel data analyses. Utilizing both β and σ convergence criteria, Karaca (2004) confirmed the results of Erk *et al*. (2000) and Doğruel and Doğruel (2003), finding that income disparities among provinces increased during the period under review. Expanding both the period length and the number of provinces compared to previous studies, Karaalp and Erdal (2009) employed a panel GMM analysis for 73 provinces in Türkiye over the period 1993–2001. In contrast to earlier studies, their findings revealed the existence of an absolute convergence process among provinces. Other studies have focused on the nature of the convergence process among Türkiye’s provinces. For instance, Filiztekin (2018) analyzed the convergence process among provinces from 1975 to 1995 using panel data analyses and found that the convergence process exhibits a conditional structure. This study also observed that productivity levels and growth differ across sectors and provinces, with changes in sectoral employment making significant contributions to productivity growth and the convergence process. Another study examining the nature of convergence was conducted by Soyyiğit (2018), who tested the validity of the convergence process for 79 provinces over the period 2004–2014 using panel data analyses. This study also considered the effects of the 2009 crisis on convergence and generally found evidence of absolute convergence. Saygılı (2020), who analyzed convergence among 81 provinces in Türkiye over the period 2004–2018 using panel data analyses, concluded that conditional convergence occurred and found that investment incentives significantly contributed to convergence in high-income provinces and regions. Elmalı *et al*. (2021) conducted a similar study for the provinces of Türkiye for the period 1992–2017, employing spatial Durbin analysis, spatial lag models, and spatial error models using GDP per capita data estimated by night lights as well as traditional income data. Their results indicated the presence of absolute convergence between provinces. The only study analyzing convergence dynamics at the district level in Türkiye is by Yoloğlu (2021). Covering the period 1985–2004, this study explored whether there was any spatial interaction among districts. The findings revealed no sigma convergence at the district level, evidence of beta convergence between districts with low and medium development levels, and a tendency for developed districts to diverge from other districts.

Some of the convergence analyses of the Turkish economy have focused on sub-regions. Berber *et al*. (2000) employed cross-sectional analysis for seven regions in Türkiye over the period 1975–1997 and concluded that divergence tendencies are dominant among the regions. Ersungur and Polat (2006), in a similar study on a broader set of sub-regions, analyzed convergence among 12 NUTS-1 sub-regions using panel data analyses for the period 1987–2001. Their findings indicate a weak convergence trend. Notably, they argue that economic crises significantly influence the convergence process, with income disparities widening during periods of stability when there are no crises. Zeren and Yılancı (2011) examined the nature of convergence at the NUTS-2 level for the period 1991–2000 using panel data analysis. Their results provide evidence of both absolute and conditional convergence across regions, with absolute convergence present in 17 regions and conditional convergence in 25 regions. Focusing on the nature of convergence and the phenomenon of sectoral convergence, Abdioğlu and Uysal (2013) investigated the validity of general and sectoral convergence hypotheses for 26 NUTS-2 sub-regions between 2004 and 2008. Their findings, based on non-linear panel regression analyses, reveal absolute convergence in total gross value added across regions. Additionally, they found convergence within the agricultural, industrial, and service sectors. In a study by Sevinç and Akıncı (2017), the convergence or divergence among 26 sub-regions in Türkiye was examined using Geographically Weighted Regression analysis for the period 2004–2014. Their analyses of stochastic and conditional convergence indicate that divergence is the prevailing trend. Furthermore, they observed that poorer regions tend to converge with other poorer regions, while wealthier regions converge with other wealthier regions—underscoring the conclusion that divergence is the dominant pattern in the Turkish economy. Gündem (2017) analyzed income convergence among NUTS-2 regions for the periods 1987–2001 and 2004–2011. Classical regression analyses suggested that convergence occurred among regions; however, spatial econometric analyses indicated that convergence was either very slow or nonexistent. Güneş (2019) assessed the convergence process for 26 regions from 2004 to 2016, concluding that the absolute income convergence hypothesis was not supported, while conditional convergence was valid. Highlighting the role of sectoral dynamics, Güneş argued that agricultural employment and income hinder economic growth and interregional income convergence, while the services and industrial sectors have positive contributions. Kartal and Karşıyakalı (2023) presented a sectoral assessment of the convergence process, investigating the convergence of per capita income using the club convergence technique for NUTS-2 regions between 2004 and 2020. Their findings identified the presence of five convergence clubs among the regions. Additionally, they analyzed the average growth rates and sectoral contributions to growth within each club, concluding that convergence clubs are significantly shaped by the similarities in the sectoral structures of the regions.

Another group of studies on the convergence hypothesis focuses on income convergence between Türkiye and other countries or country groups. Atalay (2007) examines whether a convergence process exists between Türkiye and 12 new EU member states for the period 1993–2004 using panel data analysis. The findings reveal a tendency for both the new EU member states and Türkiye to converge toward the EU-15 countries. Akıncı and Yılmaz (2012) analyze the impact of Türkiye's membership in the Customs Union on the convergence process, investigating whether income convergence is valid between Türkiye and 17 Euro Area EU member states using a difference-in-differences approach for the period 1981–2010. The results indicate absolute divergence between Türkiye and Germany and Finland, whereas absolute convergence is observed between Türkiye and Greece, Ireland, the Netherlands, Spain, Austria, Cyprus, Slovenia, Estonia, Malta, Slovakia, and Luxembourg. Another study addressing income convergence between Türkiye and the EU is conducted by Öztürk (2013), who analyzes whether convergence occurred during the period 1950–2008 using time series analysis. The findings reveal that Türkiye did not converge with the EU in terms of per capita income. Studies in the literature also extend beyond convergence relations between Türkiye and the EU to include other countries and country groups. For instance, Bozkurt *et al*. (2014) and Yeşilyurt (2014) examine whether Türkiye tends to converge with high-income countries and OECD member countries, respectively, and conclude that the convergence process is dominant. In a similar study, Savacı and Karşıyakalı (2016) investigate the convergence of per capita income between Türkiye and EU member countries for the period 1960–2013 using time series methods. Their findings indicate the existence of β-convergence between Türkiye and Austria, Belgium, Denmark, Finland, France, Italy, Sweden, and Portugal since the 1990s, while divergence is observed between Türkiye and Greece and the United Kingdom. Akkoç and Şahin (2019) analyze multi-country conditional convergence using dynamic panel data techniques for 31 countries, including Türkiye, over the period 1999–2013. Their results support the presence of weak-form convergence and suggest that openness to foreign trade, investment, and improvements in total factor productivity positively influence economic growth and contribute to the convergence process. Conversely, Demirel (2021) investigates the convergence of Türkiye's income with that of the G7 countries using the RALS-LM technique, a new generation unit root test, and finds no evidence of convergence between Türkiye and the G7 group. Finally, Çetin and Ener (2023) assess whether the incomes of developing countries, including Türkiye, converge with that of the United States using panel data analyses for the period 2007–2020. Their findings reveal that only Azerbaijan and North Macedonia converge toward US per capita income, while 12 other countries exhibit divergence.

Some studies on convergence analysis focus on the trickle-down process and highlight convergence patterns between rich and poor segments. Notably, Akıncı (2015, 2017) conducted significant research on this issue within the Turkish economy. Employing time series analysis to investigate convergence relationships between wealthy and poor regions in 12 Turkish sub-regions, the author finds that poorer regions tend to converge with other poor regions, and wealthier regions tend to converge with other wealthy regions, reflecting a prevailing divergence process between social classes. In contrast, Akıncı (2018), who utilizes unbalanced panel data for 65 countries, including Türkiye, finds that increases in the incomes of the wealthy are associated with corresponding increases in the incomes of the poor, and vice versa. However, the study also suggests that income transfers from the poor to the rich are more substantial than in the opposite direction, thereby challenging the validity of the trickle-down effect.

3. Data Set and Econometric Methodology

The primary objective of this study is to analyze per capita income convergence among 26 sub-regions of the Turkish economy at the NUTS-2 level over the period 2004–2022 using Fourier unit root analyses with annual data. In particular, the study aims to assess whether the per capita income levels of these sub-regions have converged toward the highest per capita income level in the TR10 Istanbul sub-region. To achieve this, the analysis utilizes per capita income figures for the sub-regions, expressed in U.S. dollar terms based on 2009 constant prices, and calculates the ratios of these figures to the per capita income of the Istanbul sub-region. This approach allows for an evaluation of whether the income levels of each sub-region are converging toward that of Istanbul. The choice of this period is primarily determined by data availability, as provided by the official Turkish Statistical Institute website.

When performing econometric analyses with time series data, structural breaks are likely to emerge within the dataset. As noted by Hepsağ (2022), these structural changes can influence the results of unit root tests. To address issues caused by sudden and drastic structural breaks, tests developed by Leybourne *et al*. (1998) and Harvey and Mills (2002) suggest that structural changes can occur in a gradual and smooth manner. Moreover, traditional unit root tests often struggle to reject the null hypothesis of non-stationarity. In contrast, newer unit root analyses, which account for smooth transitions and structural breaks, provide a better framework for detecting that variables may be stationary at the level.

To address these issues, Becker et al. (2006) developed a stationarity analysis by applying Fourier functions to the KPSS unit root test, referred to as the FKPSS test. This method can be demonstrated using regression Equation (5): (Becker et al., 2006: 383)

$$y_t = \alpha_0 + \sum_{k=1}^{n} a_k \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b_k \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t; \quad n < \frac{T}{2} \tag{5}$$

In regression equation numbered (5), *n* is the number of frequencies, *k* is the partial frequency, *T* is the number of observations of the analysis, *t* is the deterministic trend, π is the number of phi, *sin* and *cos* are the deterministic trigonometric terms in the regression, and ε is the white noise error term. Becker *et al*. (2006: 385-386) show the stationarity regression model pattern of the FKPSS with trend and intercept using equation numbered (6):

$$y_t = \alpha + \beta t + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + e_t \tag{6}$$

To solve regression Equation (6), KPSS analysis is applied to the error terms from the model with the optimal number k (the model that minimizes the sum of squared errors), and the null hypothesis of stationarity is tested against the alternative hypothesis of non-stationarity (Hepsağ, 2022: 134). The test statistic required for these hypotheses is calculated using Equation (7): (Becker et al., 2006: 386)

$$\tau_\tau(k) = \frac{1}{T^2} \frac{\sum_{t=1}^{T} \tilde{S}_t(k)^2}{\tilde{\sigma}^2} \tag{7}$$

$\tau_\tau(k)$ in equation numbered (7) reflects the test statistic to be obtained by using the model with intercept and trend. $\tilde{S}_t(k)^2$ in equation numbered (7) denotes the OLS residuals from solving model numbered (6) with the optimal *k* and $\tilde{\sigma}^2$ denotes the non-parametric long-run variance. If $\tau_\tau(k)$ test statistic is smaller than the critical values indicated by the optimum number of frequencies *k*, the null hypothesis of stationary cannot be rejected. On the contrary, if $\tau_\tau(k)$ test statistic is greater than the critical values indicated by the optimal number of frequencies *k*, the null hypothesis is rejected and the alternative hypothesis of non-stationarity is accepted.

Following the determination that the variable is stationary, the coefficients of the trigonometric terms (*sin* and *cos*) in the regression equation numbered (6), γ_1 and γ_2, should be examined to determine whether they are statistically significant. In this context, $F_\tau(\hat{k})$ test statistics are calculated for the trend and intercept case. In this case, the null hypothesis that the coefficients of the trigonometric terms are statistically insignificant $(\gamma_1 = \gamma_2 = 0)$ is tested against the alternative hypothesis that at least one of the coefficients of the trigonometric terms is statistically significant $(\gamma_1 \neq \gamma_2 \neq 0)$ (Hepsağ, 2022: 135). The test statistic used to calculate the $F_\tau(\hat{k})$ is determined by equation numbered (8):

$$F_\tau(\hat{k}) = \frac{(SSR_0 - SSR_1(k))/2}{SSR_1(k)/(T-q)} \tag{8}$$

In Equation (8), SSR_0 represents the sum of squared errors from the restricted model in regression equation (6), excluding the trigonometric terms, $SSR_1(k)$ is the sum of squared errors from the unconstrained model in equation (6), and *q* is the number of regressors in the unconstrained model (Becker et al., 2006: 391). If the calculated $F_\tau(\hat{k})$ test statistic exceeds the critical values provided by Becker et al. (2006), the null hypothesis is rejected, indicating that at least one coefficient of the trigonometric terms is statistically significant. This finding suggests that the series can be considered stationary according to Becker et al. (2006). On the other hand, if the calculated $F_\tau(\hat{k})$ test statistic is below the critical values, the null hypothesis cannot be rejected, meaning the coefficients of the trigonometric terms are statistically insignificant. In this case, the stationarity result cannot be confirmed using the FKPSS test proposed by Becker *et al*. (2006). Instead, as indicated by Hepsağ (2022: 135-136), the traditional KPSS stationarity analysis should be used.

Another nonlinear unit root test based on Fourier functions is the Fourier-ADF (FADF) test introduced by Christopoulos and Leon-Ledesma (2010). According to their methodology, which builds on the regression equation (6) proposed by Becker et al. (2006), a two-stage process should be followed to apply the FADF test. In the first stage, Christopoulos and Leon-Ledesma (2010) recommend solving the regression Equation (6) using the OLS method and identifying the kkk value for the model with the smallest residual sum of squares. They further assert that the residuals from the OLS estimation of the optimal model can be determined using equation (9): (Christopoulos and Leon-Ledesma, 2010: 1081)

$$\hat{e}_t = y_t - \hat{\alpha} - \hat{\beta}t - \hat{\gamma}_1 \sin\left(\frac{2\pi kt}{T}\right) - \hat{\gamma}_2 \cos\left(\frac{2\pi kt}{T}\right) \tag{9}$$

In the second stage of the estimation process, the error residuals are assumed to follow a random walk process in the form $\hat{e}_t = \phi\hat{e}_{t-1} + v_t$ with $\phi = 1$. In the investigation of the unit root process, the ADF test is applied to the residual series and the $\Delta\hat{e}_t = \delta\hat{e}_{t-1} + \sum_{i=1}^{m}\Delta\hat{e}_{t-i} + v_t$ regression is considered. After estimating this regression using the OLS method, the null hypothesis of unit root $(\delta = 0)$ is tested against the alternative hypothesis of stationarity $(\delta < 0)$. The FADF test statistic is calculated using the $FADF = \frac{\hat{\delta}}{SE(\hat{\delta})}$ equation (Christopoulos and Leon-Ledesma, 2010: 1082). In this equation, $\hat{\delta}$ is the estimate of the δ parameter and $SE(\hat{\delta})$ is the standard error of this estimator. If the absolute value of the FADF test statistic is smaller than the critical values provided by Christopoulos and Leon-Ledesma (2010), the null hypothesis of a unit root cannot be rejected. Conversely, if the absolute value of the FADF test statistic exceeds the critical values from Christopoulos and Leon-Ledesma (2010), the null hypothesis of a unit root is rejected, indicating that the series is stationary. Once the series is found to be stationary, it is necessary to test whether the γ_1 and γ_2 parameters of the *sin* and *cos* trigonometric terms in equation (6) are statistically significant. During this testing process, the method proposed by Becker *et al*. (2006) is applied as described. If the coefficients of the trigonometric terms are found to be statistically insignificant, the unit root test result cannot be confirmed using the FADF test, and the conventional ADF unit root test should be employed instead.

Another nonlinear unit root test explored in this study is the Fourier-Sollis unit root test introduced by Ranjbar *et al*. (2018). This test is quite similar to the FADF unit root test proposed by Christopoulos and Leon-Ledesma (2010) and can be analyzed using regression Equations (5) and (6) (Ranjbar *et al*., 2018: 52-53). The Fourier-Sollis unit root test is estimated through a two-stage process. In the first stage, the number of frequencies (k), is determined using the OLS method, with the optimal k value selected based on the model with the smallest sum of squared residuals. In the second stage, the residuals from the first stage are assumed to follow an asymmetric ESTAR process, as proposed by Sollis (2009). The presence of a unit root cannot be tested directly with the asymmetric ESTAR model, which is considered as $\Delta\hat{\varepsilon}_t = 1-\exp\left(-\eta_1\left(\hat{\varepsilon}_{t-1}^2\right)\right)\left[1+\exp\left(-\eta_2\left(\hat{\varepsilon}_{t-1}\right)\right)\right]^{-1}\rho_1 + \left(1-\left[1+\exp\left(-\eta_2\left(\hat{\varepsilon}_{t-1}\right)\right)\right]^{-1}\rho_2\right)\hat{\varepsilon}_{t-1}+\omega_t$ in the Fourier-Sollis unit root test. In order to carry out the estimating process, a first-order Taylor expansion must be applied to the asymmetric ESTAR model. The Taylor expansion leads to the regression equation numbered (10) (Ranjbar *et al*., 2018: 54):

$$\Delta\hat{\varepsilon}_t = \psi_1\hat{\varepsilon}_{t-1}^3 + \psi_2\hat{\varepsilon}_{t-1}^4 + \sum_{i=1}^{m}\Delta\hat{\varepsilon}_{t-i} + \vartheta_t \qquad (10)$$

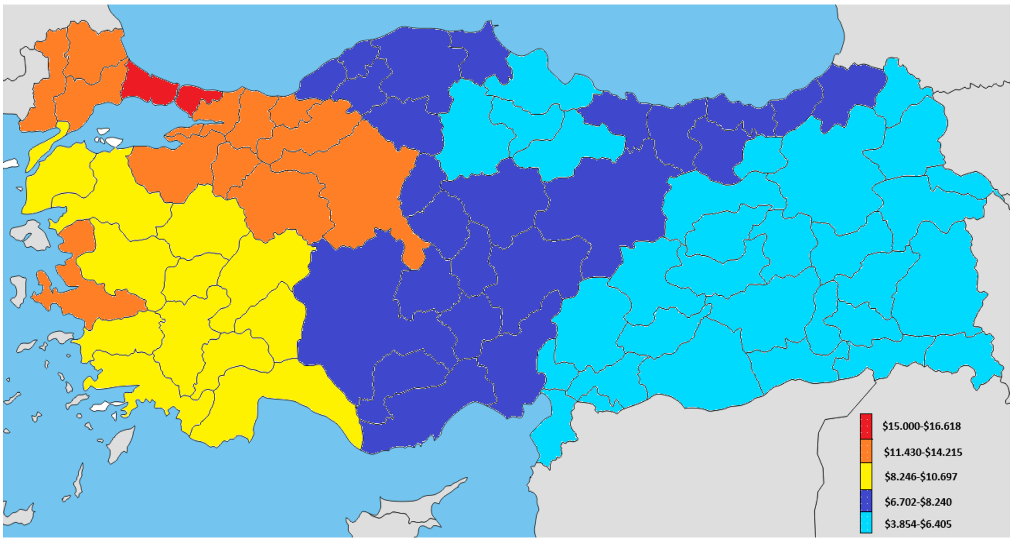
As a result of estimating the regression equation (10) using the OLS method, the null hypothesis expressing the existence of a unit root is formed as $\psi_1 = \psi_2 = 0$ and the alternative hypothesis expressing stationarity is formed as $\psi_1 \neq \psi_2 \neq 0$. The *F* test required to analyze the hypotheses is $F(k) = \frac{\left(SSR_R - SSR_{UR}(k)\right)/2}{SSR_{UR}(k)/T-q}$. If the calculated *F* statistic is greater than the critical values obtained by Ranjbar *et al*. (2018), the null hypothesis of unit root is rejected. On the contrary, if the calculated *F* test statistic is smaller than the critical values obtained by Ranjbar *et al*. (2018), the null hypothesis of unit root cannot be rejected.

Following the determination that the variables are stationary, it is necessary to determine whether the γ_1 and γ_2 parameters of the trigonometric terms in models numbered (5) and (6) are statistically significant. This analysis is performed by using equation (8) for both intercept and trend and intercept models. The critical values used for this test statistic represent the critical values obtained by Becker *et al*. (2006). If the coefficients of the trigonometric terms are statistically insignificant, it can be said that the unit root test result cannot be reported according to the Fourier-Sollis unit root test and the test that should be used is the Sollis (2009) unit root test (Hepsağ, 2022: 156-157).

4. Empirical Results

The main motivation of the paper is to investigate the convergence of per-capita income in 26 sub-regions of the Turkish economy at NUTS 2 level for the period 2004-2022 using Fourier unit root analyses. Since the highest per-capita income level belongs to TR10 Istanbul sub-region, it will be investigated whether the per-capita income levels of other sub-regions have converged to Istanbul sub-region. Before presenting the results of the analysis, the spatial distribution of average regional per-capita income levels in dollar terms is shown in Figure 1.

Figure 1: The Spatial Distribution of Average Regional Per-Capita Income Levels



Source: Authors' own calculations.

As illustrated in Figure 1, the TR10 Istanbul sub-region exhibits the highest average per capita income. Following Istanbul, the sub-regions with the next highest average per capita income levels are located in Western Anatolia and South-Western Anatolia. In contrast, the sub-regions with the lowest average per capita income levels are found in Central, Northern, Southern, and Eastern Anatolia. Figure 1 clearly demonstrates that, in terms of per capita income, Türkiye can be broadly divided into two regions—west and east—beginning with the TR51 Ankara sub-region. It is observed that the average per capita income levels in the regions to the east of Ankara are relatively low, while the regions to the west of Ankara exhibit higher average per capita income levels. This pronounced income disparity suggests that the country is effectively polarized, with the eastern regions remaining relatively impoverished and the western regions relatively affluent. Consequently, this study aims to examine whether the per capita income levels of the 25 sub-regions stochastically converge to that of the Istanbul sub-region.

Since the convergence process of regional per-capita income level is analyzed within the scope of nonlinear unit root analysis in this study, it is important to first determine the linearity properties of the variables. In this context, the BDS Independence Test, which is introduced to the econometrics literature by Broock *et al*. (1996) and allows the determination of the linearity properties of the data set, is used. The BDS Independence Test, which examines whether the data sets exhibit independent similar distribution properties, is applied to the error terms of standard estimation models and focuses on estimating the dependence structure of the error residuals and the negligible non-linear part of the forecasts. This technique, which transforms the time series data into an *m*-dimensional vector for the calculation of test statistics and therefore determines the *m* numbers, forms the sequence vector of $\chi_{N-m}^{m} = \left(\chi_{N-m}, \chi_{N-m+1}, \chi_{N-m+2}, \ldots, \chi_{N}\right)$. Based on this sequence vector, the BDS test statistic is calculated using equation numbered (11) (Sezgin-Alp and Kırkbeşoğlu, 2015: 253-254):

$$BDS_{\varepsilon,m} = \frac{\sqrt{N\left[C_{\varepsilon,m} - \left(C_{\varepsilon,m}\right)^{m}\right]}}{\sqrt{V_{\varepsilon,m}}} \sim N\left(0,1\right) \tag{11}$$

The obtained test statistic is interpreted by considering the null hypothesis that the series are independent and identically distributed. Therefore, the alternative hypothesis emphasizes the validity of the dependence relationship with a non-linear pattern (Fischer and Koller, 2001: 5). Therefore, Table 1 shows the BDS Independence Test results for regional per-capita income level.

Table 1: The Results of BDS Independence Test

Optimum Dimension (m)	Epsilon Value (ε) 0.5 BDS Stat.	0.5 Prob.	m	0.7 BDS Stat.	0.7 Prob.	m	0.9 BDS Stat.	0.9 Prob.
TR21 (Tekirdağ-Edirne-Kırklareli) – TR10 (İstanbul)								
4	-0.028**	0.016	4	-0.222***	0.000	6	-0.241***	0.000
TR22 (Balıkesir-Çanakkale) – TR10 (İstanbul)								
3	0.031**	0.020	4	-0.030	0.390	5	-0.041*	0.085
TR31 (İzmir) – TR10 (İstanbul)								
3	-0.088***	0.000	3	-0.127***	0.001	6	-0.142***	0.007
TR32 (Aydın-Denizli-Muğla) – TR10 (İstanbul)								
6	0.091***	0.000	2	0.115***	0.000	2	0.039***	0.000
TR33 (Manisa-Afyon-Kütahya-Uşak) – TR10 (İstanbul)								
6	0.044***	0.000	2	0.121***	0.000	2	0.054***	0.000
TR41 (Bursa-Eskişehir-Bilecik) – TR10 (İstanbul)								
2	0.066***	0.000	2	0.059***	0.000	2	-0.013**	0.011
TR42 (Kocaeli-Sakarya-Düzce-Bolu-Yalova) – TR10 (İstanbul)								
3	-0.048***	0.000	5	-0.123***	0.000	6	-0.166***	0.000
TR51 (Ankara) – TR10 (İstanbul)								
2	0.014	0.187	5	0.083***	0.001	6	-0.202***	0.000
TR52 (Konya-Karaman) – TR10 (İstanbul)								
2	0.171***	0.000	2	0.156***	0.000	5	-0.060**	0.011
TR61 (Antalya-Isparta-Burdur) – TR10 (İstanbul)								
6	0.009	0.500	2	0.069***	0.000	4	-0.243***	0.000
TR62 (Adana-Mersin) – TR10 (İstanbul)								
4	-0.073***	0.005	6	-0.346***	0.000	6	-0.153*	0.070
TR63 (Hatay-Kahramanmaraş-Osmaniye) – TR10 (İstanbul)								
3	-0.014	0.507	4	-0.097**	0.014	5	-0.123***	0.000
TR71 (Kırıkkale-Aksaray-Niğde-Nevşehir-Kırşehir) – TR10 (İstanbul)								
2	0.137***	0.000	2	0.032**	0.017	2	-0.019***	0.000
TR72 (Kayseri-Sivas-Yozgat) – TR10 (İstanbul)								
6	0.010**	0.013	4	0.014	0.546	4	-0.048**	0.019
TR81 (Zonguldak-Karabük-Bartın) – TR10 (İstanbul)								
2	0.105***	0.000	2	0.087***	0.000	3	0.008	0.442
TR82 (Kastamonu-Çankırı-Sinop) – TR10 (İstanbul)								
6	-0.039**	0.011	6	-0.113***	0.007	6	-0.114***	0.001
TR83 (Samsun-Tokat-Çorum-Amasya) – TR10 (İstanbul)								
5	-0.016**	0.011	3	0.004	0.798	3	-0.027**	0.020
TR90 (Trabzon-Ordu-Giresun-Rize-Artvin-Gümüşhane) – TR10 (İstanbul)								
3	-0.072***	0.008	3	-0.105***	0.004	3	-0.103***	0.001
TRA1 (Erzurum-Erzincan-Bayburt) – TR10 (İstanbul)								
2	0.125***	0.000	2	0.138***	0.000	2	0.008	0.122
TRA2 (Ağrı-Kars-Iğdır-Ardahan) – TR10 (İstanbul)								
6	0.076***	0.000	2	0.100***	0.000	2	0.025***	0.000

Table 1: The Results of BDS Independence Test (Continue)

Optimum Dimension (m)	Epsilon Value (ε) 0.5 BDS Stat.	Prob.	m	0.7 BDS Stat.	Prob.	m	0.9 BDS Stat.	Prob.
TRB1 (Malatya-Elazığ-Bingöl-Tunceli) – TR10 (İstanbul)								
2	0.047***	0.001	4	0.029	0.401	4	-0.052**	0.029
TRB2 (Van-Muş-Bitlis-Hakkari) – TR10 (İstanbul)								
6	0.021**	0.036	2	0.098***	0.000	5	-0.002	0.918
TRC1 (Gaziantep-Adıyaman-Kilis) – TR10 (İstanbul)								
5	0.068***	0.000	6	-0.217***	0.000	3	-0.004	0.759
TRC2 (Şanlıurfa-Diyarbakır) – TR10 (İstanbul)								
6	-0.044***	0.000	6	-0.178***	0.000	6	-0.329***	0.000
TRC3 (Mardin-Batman-Şırnak-Siirt) – TR10 (İstanbul)								
6	0.145***	0.000	2	0.134***	0.000	5	-0.095***	0.000

Note: ***, ** and * indicate that the coefficients are statistically significant at the 1%, 5% and 10% significance level, respectively. The optimum number of dimensions was calculated over a maximum number of 6 dimensions. **Source:** Authors' own calculations.

The results of the BDS independence test, presented in Table 1, indicate that the data sets for each sub-region do not exhibit independent linear distributions but rather display non-linear dependence relationships. This suggests that regional per capita income levels follow a non-linear pattern. Given this non-linear dynamic, it is appropriate to employ non-linear unit root tests to assess whether per capita income levels exhibit smooth transition behavior. Traditional linear unit root tests may not adequately reject the null hypothesis of non-stationarity, whereas new-generation non-linear unit root tests, which account for smooth transitions and structural breaks, provide a more robust evaluation. These tests can help determine whether the variables are stationary at their levels. Accordingly, Tables 2, 3, and 4 report the results of the FKPSS, FADF, and Fourier-Sollis unit root tests, respectively.

Table 2: The Results of FKPSS Stationarity Analysis

Variable	Model with Intercept					Model with Trend and Intercept					Result
	Partial Frequency (k)	$\tau_\mu(k)$	Critical Value	$F_\mu(\hat{k})$	Critical Value	Partial Frequency (k)	$\tau_\tau(k)$	Critical Value	$F_\tau(\hat{k})$	Critical Value	
TR21-TR10	1	0.369	1%: 0.269	8.146***	1%: 6.730	1	0.246	1%: 0.071	19.475***	1%: 6.873	Divergence
TR22-TR10	2	0.236***	1%: 0.667	10.317***	1%: 6.730	2	0.142***	1%: 0.202	13.712***	1%: 6.873	Convergence
TR31-TR10	2	0.172***	1%: 0.667	4.822*	10%: 4.133	2	0.197***	1%: 0.202	11.238***	1%: 6.873	Convergence
TR32-TR10	1	0.317	1%: 0.269	8.235***	1%: 6.730	2	0.230	1%: 0.202	3.120	10%: 4.162	Divergence
TR33-TR10	2	0.294***	1%: 0.667	6.375**	5%: 4.929	2	0.149***	1%: 0.202	6.769**	5%: 4.972	Convergence
TR41-TR10	1	0.281	1%: 0.269	17.412***	1%: 6.730	1	0.150	1%: 0.071	3.151	10%: 4.162	Divergence
TR42-TR10	4	0.204***	1%: 0.722	4.229*	10%: 4.133	2	0.130***	1%: 0.202	4.185*	10%: 4.162	Convergence
TR51-TR10	1	0.202***	1%: 0.269	17.310***	1%: 6.730	1	0.069***	1%: 0.071	6.304***	5%: 4.972	Convergence
TR52-TR10	1	0.384	1%: 0.269	11.957***	1%: 6.730	1	0.294	1%: 0.071	4.157	10%: 4.162	Divergence
TR61-TR10	1	0.329	1%: 0.269	12.285***	1%: 6.730	5	0.137***	1%: 0.217	3.896	10%: 4.162	Divergence
TR62-TR10	1	0.317	1%: 0.269	8.235***	1%: 6.730	1	0.215	1%: 0.071	17.832***	1%: 6.873	Divergence
TR63-TR10	2	0.296***	1%: 0.667	4.102	10%: 4.133	1	0.161	1%: 0.071	3.408	10%: 4.162	Divergence
TR71-TR10	2	0.275***	1%: 0.667	3.781	10%: 4.133	1	0.188	1%: 0.071	3.120	10%: 4.162	Divergence
TR72-TR10	1	0.317	1%: 0.269	8.235***	1%: 6.730	1	0.260	1%: 0.071	4.909*	10%: 4.162	Divergence
TR81-TR10	1	0.380	1%: 0.269	4.573*	10%: 4.133	5	0.136***	1%: 0.217	3.563	10%: 4.162	Divergence
TR82-TR10	2	0.237***	1%: 0.667	3.473	10%: 4.133	2	0.136***	1%: 0.202	6.238**	5%: 4.972	Convergence
TR83-TR10	1	0.258***	1%: 0.269	10.679***	1%: 6.730	1	0.230	1%: 0.071	9.677***	1%: 6.873	Convergence
TR90-TR10	1	0.347	1%: 0.269	6.793***	1%: 6.730	1	0.267	1%: 0.071	6.759**	5%: 4.972	Divergence
TRA1-TR10	1	0.374	1%: 0.269	9.813***	1%: 6.730	1	0.295	1%: 0.071	9.046***	1%: 6.873	Divergence
TRA2-TR10	1	0.374	1%: 0.269	6.040**	5%: 4.929	1	0.256	1%: 0.071	2.672	10%: 4.162	Divergence
TRB1-TR10	1	0.369	1%: 0.269	4.438*	10%: 4.133	1	0.291	1%: 0.071	2.436	10%: 4.162	Divergence
TRB2-TR10	1	0.371	1%: 0.269	6.521**	5%: 4.929	1	0.267	1%: 0.071	4.241*	10%: 4.162	Divergence
TRC1-TR10	1	0.382	1%: 0.269	11.394***	1%: 6.730	2	0.126***	1%: 0.202	8.453***	1%: 6.873	Convergence
TRC2-TR10	1	0.364	1%: 0.269	6.186**	5%: 4.929	2	0.129***	1%: 0.202	3.559	10%: 4.162	Divergence
TRC3-TR10	2	0.284***	1%: 0.667	6.299**	5%: 4.929	2	0.131***	1%: 0.202	10.158***	1%: 6.873	Convergence

Note: *** in the $\tau_\mu(k)$ and $\tau_\tau(k)$ test indicates that the variable is stationary at 1% significance level and the *, ** and *** in the $F_\mu(\hat{k})$ and $F_\tau(\hat{k})$ tests indicate that at least one of the coefficients of the trigonometric terms is statistically significant at 10%, 5% and 1% significance levels, respectively. Critical values are obtained from Table 1 in Becker *et al.* (2006).

Table 3: The Results of FADF Unit Root Analysis

Variable	Model with Intercept					Model with Trend and Intercept					Result
	Partial Frequency (*k*)	$F_{ADF}(\mu)$	Critical Value	$F_{\mu}(\hat{k})$	Critical Value	Partial Frequency (*k*)	$F_{ADF}(\tau)$	Critical Value	$F_{\tau}(\hat{k})$	Critical Value	
TR21-TR10	1	-2.556	10%: -3.52	8.146***	1%: 6.730	1	-3.665	10%: -4.15	19.478***	1%: 6.873	Divergence
TR22-TR10	2	-3.522**	5%: -3.28	10.317***	1%: 6.730	2	-4.786**	5%: -4.16	13.712***	1%: 6.873	Convergence
TR31-TR10	2	-1.238	10%: -2.91	4.822*	10%: 4.13	1	-4.298*	10%: -4.15	11.238***	1%: 6.873	Convergence
TR32-TR10	1	-3.654*	10%: -3.52	8.235***	1%: 6.730	2	-3.537	10%: -3.79	3.120	10%: 4.16	Convergence
TR33-TR10	2	-2.844	10%: -2.91	6.375**	5%: 4.929	2	-6.196***	1%: -4.83	6.769**	5%: 4.972	Convergence
TR41-TR10	1	-2.917	10%: -3.52	17.412***	1%: 6.730	1	-4.030	10%: -4.15	3.151	10%: 4.16	Divergence
TR42-TR10	4	-2.902*	10%: -2.59	4.229*	10%: 4.13	1	-6.254***	1%: -5.11	8.175***	1%: 6.873	Convergence
TR51-TR10	1	-3.754*	10%: -3.52	17.310***	1%: 6.730	1	-3.757	10%: -4.15	6.304**	5%: 4.972	Convergence
TR52-TR10	1	-2.153	10%: -3.52	11.957***	1%: 6.730	1	-3.688	10%: -4.15	4.157	10%: 4.16	Divergence
TR61-TR10	1	-3.757*	10%: -3.52	12.285***	1%: 6.730	5	-3.091	10%: -3.28	3.896	10%: 4.16	Convergence
TR62-TR10	2	-1.092	10%: -2.91	4.862*	10%: 4.13	1	-3.174	10%: -4.15	17.832***	1%: 6.873	Divergence
TR63-TR10	2	-1.576	10%: -2.91	4.342*	10%: 4.13	1	-3.699	10%: -4.15	3.408	10%: 4.16	Divergence
TR71-TR10	2	-2.329	10%: -2.91	3.781	10%: 4.13	1	-3.623	10%: -4.15	3.120	10%: 4.16	Divergence
TR72-TR10	1	-3.278	10%: -3.52	4.041	10%: 4.13	1	-4.086	10%: -4.15	4.909*	10%: 4.16	Divergence
TR81-TR10	1	-2.062	10%: -3.52	4.573*	10%: 4.13	5	-2.776	10%: -3.28	3.563	10%: 4.16	Divergence
TR82-TR10	2	-2.600	10%: -2.91	3.473	10%: 4.13	2	-3.460	10%: -3.79	6.238**	5%: 4.972	Divergence
TR83-TR10	1	-3.679*	10%: -3.52	10.679***	1%: 6.730	1	-3.701	10%: -4.15	9.677***	1%: 6.873	Convergence
TR90-TR10	1	-2.862	10%: -3.52	6.793***	1%: 6.730	1	-4.076	10%: -4.15	6.759**	5%: 4.972	Divergence
TRA1-TR10	1	-2.702	10%: -3.52	9.813***	1%: 6.730	1	-3.606	10%: -4.15	9.046***	1%: 6.873	Divergence
TRA2-TR10	1	-2.594	10%: -3.52	6.040**	5%: 4.929	1	-3.576	10%: -4.15	2.672	10%: 4.16	Divergence
TRB1-TR10	1	-2.985	10%: -3.52	4.438*	10%: 4.13	1	-3.022	10%: -4.15	2.436	10%: 4.16	Divergence
TRB2-TR10	1	-2.351	10%: -3.52	6.521	5%: 4.929	1	-3.171	10%: -4.15	4.241*	10%: 4.16	Divergence
TRC1-TR10	1	-0.896	10%: -3.52	11.394***	1%: 6.730	2	-2.403	10%: -3.79	8.453***	1%: 6.873	Divergence
TRC2-TR10	1	-3.711*	10%: -3.52	6.186**	5%: 4.929	2	-3.385	10%: -3.79	3.559	10%: 4.16	Convergence
TRC3-TR10	2	-1.936	10%: -2.91	6.299**	5%: 4.929	2	-3.633	10%: -3.79	10.158***	1%: 6.873	Divergence

Note: *, ** and *** in the $F_{ADF}(\mu)$ and $F_{ADF}(\tau)$ test indicates that the variable is stationary at 10%, 5% and 1% significance levels and the *, ** and *** in the $F_{\mu}(\hat{k})$ and $F_{\tau}(\hat{k})$ tests indicate that at least one of the coefficients of the trigonometric terms is statistically significant at 10%, 5% and 1% significance levels, respectively. Critical values of $F_{ADF}(\mu)$ are obtained from Table 1 in Christopoulos and Leon-Ledesma (2010) and critical values of $F_{\mu}(\hat{k})$ and $F_{\tau}(\hat{k})$ are obtained from Table 1 in in Becker *et al.* (2006). Since the critical values required for the model with trend and intercept are not available in Christopoulos and Leon-Ledesma (2010), critical values of $F_{ADF}(\tau)$ are obtained from Table 1 in Hepsağ (2021).

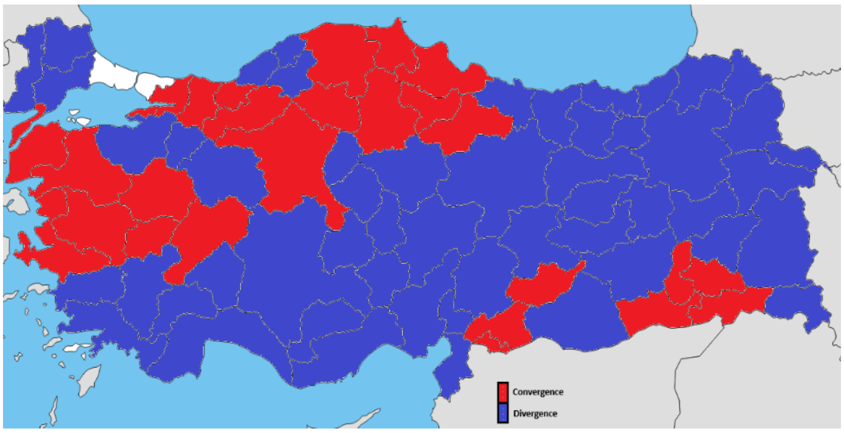
Source: Authors' own calculations.

Table 4: The Results of Fourier-Sollis Unit Root Analysis

Variable	Model with Intercept					Model with Trend and Intercept					Result
	Partial Frequency (k)	$F_{F-Sollis}$	Critical Value	$F_{\mu}(\hat{k})$	Critical Value	Partial Frequency (k)	$F_{F-Sollis}$	Critical Value	$F_{\tau}(\hat{k})$	Critical Value	
TR21-TR10	1	3.869	10%: 6.233	8.146***	1%: 6.730	1	6.344	10%: 7.991	19.475***	1%: 6.873	Divergence
TR22-TR10	2	1.178	10%: 5.066	10.317***	1%: 6.730	2	1.969	10%: 6.959	13.712***	1%: 6.873	Divergence
TR31-TR10	2	1.150	10%: 5.066	4.822*	10%: 4.133	1	8.378*	10%: 7.991	11.238***	1%: 6.873	Convergence
TR32-TR10	1	2.819	10%: 6.233	8.235***	1%: 6.730	2	3.377	10%: 6.959	3.120	10%: 4.162	Divergence
TR33-TR10	2	1.221	10%: 5.066	6.375**	5%: 4.929	2	7.109*	10%: 6.959	6.769**	5%: 4.972	Convergence
TR41-TR10	1	3.682	10%: 6.233	17.412***	1%: 6.730	1	5.091	10%: 7.991	3.151	10%: 4.162	Divergence
TR42-TR10	4	0.592	10%: 4.457	4.229*	10%: 4.133	1	8.811*	10%: 7.991	4.185*	10%: 4.162	Convergence
TR51-TR10	1	7.056*	10%: 6.233	17.310***	1%: 6.730	1	6.484	10%: 7.991	6.304***	5%: 4.972	Convergence
TR52-TR10	1	0.918	10%: 6.233	11.957***	1%: 6.730	1	7.323	10%: 7.991	4.157	10%: 4.162	Divergence
TR61-TR10	1	23.076***	1%: 9.771	12.285***	1%: 6.730	5	2.991	10%: 5.859	3.896	10%: 4.162	Convergence
TR62-TR10	2	0.406	10%: 5.066	8.235***	1%: 6.730	1	6.524	10%: 7.991	17.832***	1%: 6.873	Divergence
TR63-TR10	2	1.102	10%: 5.066	4.102	10%: 4.133	1	2.803	10%: 7.991	3.408	10%: 4.162	Divergence
TR71-TR10	2	0.729	10%: 5.066	3.781	10%: 4.133	1	1.925	10%: 7.991	3.120	10%: 4.162	Divergence
TR72-TR10	1	2.354	10%: 6.233	8.235***	1%: 6.730	1	4.672	10%: 7.991	4.909*	10%: 4.162	Divergence
TR81-TR10	1	3.649	10%: 6.233	4.573*	10%: 4.133	5	3.245	10%: 5.859	3.563	10%: 4.162	Divergence
TR82-TR10	2	1.815	10%: 5.066	3.473	10%: 4.133	2	6.424	10%: 6.959	6.238**	5%: 4.972	Divergence
TR83-TR10	1	8.865**	5%: 7.348	10.679***	1%: 6.730	1	9.610**	5%: 9.218	9.677***	1%: 6.873	Convergence
TR90-TR10	1	9.620**	5%: 7.348	6.793***	1%: 6.730	1	9.088*	10%: 7.991	6.759**	5%: 4.972	Convergence
TRA1-TR10	1	7.211*	10%: 6.233	9.813***	1%: 6.730	1	9.690**	5%: 9.218	9.046***	1%: 6.873	Convergence
TRA2-TR10	1	4.052	10%: 6.233	6.040**	5%: 4.929	1	5.924	10%: 7.991	2.672	10%: 4.162	Divergence
TRB1-TR10	1	5.848	10%: 6.233	4.438*	10%: 4.133	1	10.297**	5%: 9.218	2.436	10%: 4.162	Convergence
TRB2-TR10	1	8.315**	5%: 7.348	6.521**	5%: 4.929	1	11.038**	5%: 9.218	4.241*	10%: 4.162	Convergence
TRC1-TR10	1	1.690	10%: 6.233	11.394***	1%: 6.730	2	1.114	10%: 6.959	8.453***	1%: 6.873	Divergence
TRC2-TR10	1	2.509	10%: 6.233	6.186**	5%: 4.929	2	0.504	10%: 6.959	3.559	10%: 4.162	Divergence
TRC3-TR10	2	1.902	10%: 5.066	6.299**	5%: 4.929	2	1.133	10%: 6.959	10.158***	1%: 6.873	Divergence

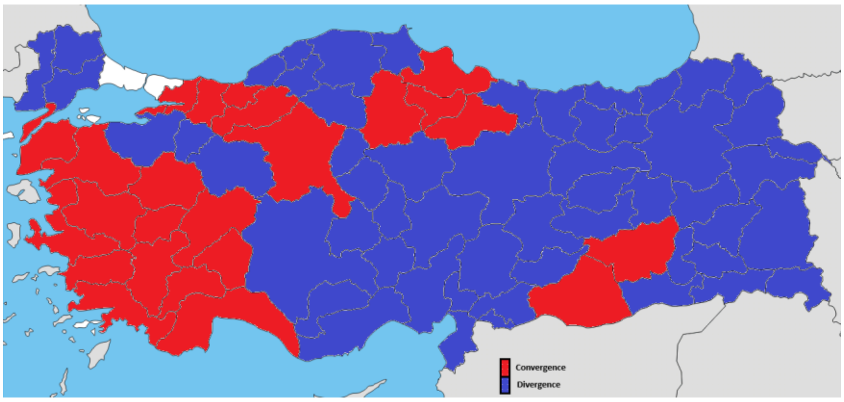
Note: *, ** and *** in the $F_{F-Sollis}$ test indicates that the variable is stationary at 10%, 5% and 1% significance level respectively and the *, ** and *** in the $F_{\mu}(\hat{k})$ and $F_{\tau}(\hat{k})$ tests indicate that at least one of the coefficients of the trigonometric terms is statistically significant at 10%, 5% and 1% significance levels, respectively. Critical values of $F_{F-Sollis}$ are obtained from Table 1 in Ranjbar *et al.* (2018) and critical values of $F_{\mu}(\hat{k})$ and $F_{\tau}(\hat{k})$ are obtained from Table 1 in Becker *et al.* (2006).
Source: Authors' own calculations.

Figure 2: Convergence and Divergence Results according to FKPSS Analysis



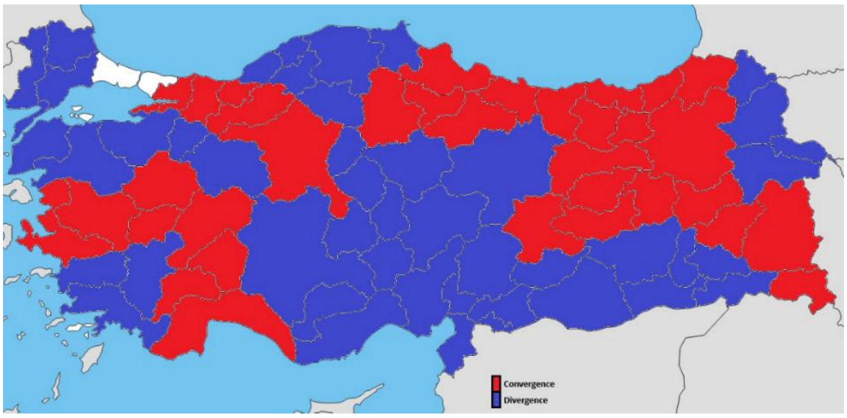
Source: Authors' own calculations.

Figure 3: Convergence and Divergence Results according to FADF Analysis



Source: Authors' own calculations.

Figure 4: Convergence and Divergence Results according to Fourier-Sollis Analysis



Source: Authors' own calculations.

The results from the FKPSS and FADF analyses, presented in Tables 2 and 3, indicate that the per capita income levels in the western, southwestern, and northwestern sub-regions of Türkiye are converging towards those of the Istanbul sub-region. Specifically, if the TR51 Ankara sub-region is considered a dividing line between the eastern and western parts of the country, it can be inferred that sub-regions to the west of Ankara are converging with Istanbul's income levels, while sub-regions to the east are diverging. This pattern suggests that wealthier sub-regions located in the west of Ankara are approaching Istanbul's income levels, while poorer sub-regions in the east are lagging further behind. Theoretically, convergence should occur more rapidly in poorer regions compared to richer ones. However, the analysis reveals a contrasting trend: richer regions are becoming wealthier, while poorer regions are becoming relatively poorer. This finding highlights an unbalanced growth process in Türkiye, suggesting that the development gap between the western and eastern regions is likely to widen over time.

As with the previous two tests, the Fourier-Sollis unit root analysis presented in Table 4 demonstrates that the per capita income levels of sub-regions in the western, southwestern, and northwestern parts of the country are converging toward those of the Istanbul sub-region. However, unlike the other two tests, the Fourier-Sollis analysis also indicates that the per capita income levels in the northeastern and eastern sub-regions are converging toward Istanbul's levels. Considering that the northeastern and eastern regions have the lowest per capita incomes, this finding supports the theoretical proposition that poorer regions will converge with richer ones. Nevertheless, this result does not alter the broader observation that rich regions tend to converge with other rich regions in the Turkish economy. In this context, while it can be argued that wealthier regions are becoming wealthier, it can also be emphasized that the relative poverty levels of poorer regions may be diminishing. Consequently, it is expected that the income disparities between eastern and western regions will gradually decrease over time, fostering a more balanced development process. Furthermore, consistent with the FKPSS and FADF findings, the Fourier-Sollis analysis reveals that the per capita income levels of the central, southern, and southeastern sub-regions differ significantly from those of Istanbul. Therefore, the development gap between these sub-regions, where divergence processes have emerged, and the Istanbul sub-region is expected to widen. Overall, the predominance of divergence over convergence highlights the emergence of an unbalanced development process in Türkiye, suggesting that regional development disparities will continue to increase.

5. Conclusion and Policy Recommendations

The primary objective of this research is to analyze per capita income convergence across 26 sub-regions of the Turkish economy at the NUTS 2 level for the period 2004–2022, utilizing Fourier unit root analyses. In particular, as the highest per capita income level is observed in the TR10 Istanbul sub-region, this study investigates whether the per capita income levels of other sub-regions have converged toward that of the Istanbul sub-region.

To address this issue, the linearity of the regional per capita income data was evaluated using the BDS Independence Test, which revealed the presence of non-linear dependence in the data. This finding suggests that Fourier-based unit root tests are well-suited for analyzing the unit root process of regional per capita income levels within a smooth transition framework. Accordingly, the FKPSS, FADF, and Fourier-Sollis unit root tests were employed to assess the stationarity of the variables, thereby evaluating the convergence or divergence dynamics across regions. The results from these analyses indicate that per capita income levels in the western, southwestern, and northwestern sub-regions of Türkiye are converging with those of the Istanbul sub-region. Conversely, per capita income levels in the central, southern, and southeastern sub-regions are diverging from those of Istanbul. Notably, while the FKPSS and FADF tests show divergence in the eastern, northeastern, and southeastern regions, the Fourier-Sollis test suggests convergence in the eastern and northeastern regions. Overall, these findings imply that per capita income levels in the central, southern, and southeastern regions are diverging from Istanbul's income level, indicating a widening development gap in these areas. This points to a dominant divergence process rather than convergence in Türkiye, highlighting an increasingly unbalanced development trajectory in which wealthier regions grow richer while poorer regions continue to lag behind. These findings are consistent with previous studies by Erk et al. (2000), Berber et al. (2000), Doğruel and Doğruel (2003), Karaca (2004), Akıncı (2015), Sevinç and Akıncı (2017), Akıncı (2018), and Güneş (2019).

The growing income disparities between provinces and regions in Türkiye, particularly since the 1960s, have contributed to what can be described as the "West-East" problem. In response, various economic policies have been implemented since the late 1960s to reduce income inequalities, yet the redistribution of income to the detriment of the eastern regions has not been adequately addressed. The globalization process, which has gained prominence since the 1980s alongside the rise of the neo-liberal economic paradigm, has significantly fueled internal migration from eastern to western regions. As a natural consequence, uneven urbanization, security challenges, the weakening of labor's bargaining power against capital, precarious and informal employment, subcontracting practices, and the limited capacity of industry to absorb labor have all contributed to the phenomenon of the "rich getting richer and the poor getting poorer." This process has intensified the East-West divide, reinforced the center-periphery dynamic within the country, and resulted in a concentration of central regions in the western part of Türkiye, while the periphery is predominantly located in the east. This trajectory undermines balanced development and exacerbates the widening development gap between western and eastern regions. From this perspective, there is an urgent need for effective macroeconomic policies aimed at stimulating regional development and reducing regional income disparities. Regional development programs must be carefully designed to leverage local resources and geographical characteristics, with the active support of the central administration. Targeting regional disparities requires prioritizing underdeveloped areas based on comprehensive analysis, ensuring efficient allocation of resources, and implementing policies focused on improving human development. Moreover, enhancing investment in less developed regions can play a critical role in narrowing the income gap between regions. Finally, identifying economic policies that can bolster the weak regional dynamics of the eastern regions, as well as leveraging international resources for regional development, are expected to mitigate income disparities.

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