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CONVERGENCE OF SECTORAL PRODUCTIVITY IN TURKISH PROVINCES: MARKOV CHAINS MODEL

TEMEL, Tugrul*
TANSEL, Aysit
GUNGOR, Nil Demet

Abstract
This study examines the role that sectors play in aggregate convergence of provincial labor productivity across the 67 provinces of Turkey during the 1975-1990 period. A Markov chain model is applied to characterize the long-run tendencies of productivity both at the aggregate and sectoral levels. In order to determine the likely sources of aggregate fluctuations, sectoral time-invariant distributions are compared with the aggregate distribution, and those sectors that exhibit similar distribution patterns as that of the aggregate distribution are characterized as dominant sectors. Evidence strongly suggests that the aggregate time-invariant distribution is determined mainly by the agricultural, industrial and transportation sectors. Specifically, the pattern of polarization of productivity levels in these three sectors is very similar to the pattern prevailing at the aggregate level. The results suggest that, in the long run, two convergence clubs are likely to emerge - one for the agricultural and another for the highly industrialized provinces. An exception is the service sector, which exhibits global convergence.
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* Tugrul Temel, Agricultural Economics and Rural Policy, Wageningen University and Research Center, Wageningen, Netherlands, e-mail: tugrul.temel@wur.nl; Aysit Tansel, Department of Economics, Middle East Technical University, 06531 Ankara, Turkey, e-mail: atansel@metu.edu.tr and Nil Demet Güngör, Department of Economics, Middle East Technical University, 06531 Ankara, Turkey, e-mail: ngungor@metu.edu.tr
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1. Introduction

A voluminous number of studies exist in the literature, testing the so-called convergence hypothesis that concerns how economy's average growth co-moves with the initial income level (Baumol, 1986; De Long, 1988; Barro, 1991; Barro and Sala-i-Martin, 1991, 1992; Mankiw, Romer and Weil, 1992; Temple, 1999). The assumption that the aggregate production function is concave plays a central role in this hypothesis. This assumption implies that capital and labor-poor economies are to grow sufficiently faster than those economies rich in these inputs, eventually balancing cross-economy differences in initial conditions. However, starting with Romer (1986) and Lucas (1988), the new growth theory has challenged the cross-country implications of this hypothesis, pointing to the failure of per capita income to equalize across rich and poor countries as evidence that poorer economies do not tend to catch up to richer ones. Non-convexities in production are viewed as the main reason for a non-diminishing relationship between the initial income level and subsequent income growth. Generally speaking, in the literature two methods have been widely used in testing this hypothesis. Parametric regression is applied to examine whether poor economies grow faster than rich ones so that the poor will catch up with the rich (Temel, 2000). This phenomenon is called β*-convergence*, and tested using the concepts of absolute and conditional convergence. Absolute convergence is said to occur if a negative correlation is present between initial income and ensuing income growth. Conditional convergence, on the other hand, is said to occur if convergence takes place with the control of additional variables, such as education, fertility, and health, while initial income varies inversely with income growth.[1] Closely related to the parametric regression is σ*-convergence* measured as the standard deviation of the logarithm of growth. This is often estimated to examine the dispersion of income growth over time. A second method often

[1] The reader is referred to Bernard and Durlauf (1996) for a discussion of β*–convergence.*

applied in the literature is that of nonparametric Markov chains (Quah, 1993a, 1993b, 1996a, 1996b; Temel, Aysit, and Albersen, 1999). This method requires information on transition dynamics of units under investigation, contained in cross-section and time-series data. Convergence is said to occur if long run forecasts of the movements approach zero as the forecast horizon grows.

In this study we adopt the Markov chains method to characterize long-run sectoral fluctuations in *labor productivity levels* across the 67 provinces of Turkey. We then contrast the sectoral fluctuations to long-run aggregate fluctuations in order to identify likely sectoral sources of the aggregate fluctuations. We opt for the application of the Markov method because it allows us to trace the movements within a distribution and to determine the time-invariant distributions at the both sectoral and the aggregate levels. Panel data, spanning the 1975-1990 period, is used in the calculations of the time-invariant distributions. Convergence is first examined at the aggregate level, and then sectoral analysis is carried out for the agriculture, industry, construction, wholesale trade, transportation, and services sectors.[2] The goal in individual sector analysis is to determine which sectors play a central role in aggregate convergence and to find whether trends in aggregate labor productivity are also reflected at the sectoral level.[3] The current study further examines whether the

[2] The six sectors are defined as agriculture (including hunting, forestry and fishing), industry (including mining, manufacturing, electricity, gas and water), construction, wholesale trade (including retail trade), transportation (including communication), and services (including financing, insurance, real estate, business services, community, social and personal services).

[3] Among the studies that examine sectoral convergence are Bernard and Jones (1996), Broadberry (1993), Dollar and Wolff (1988). These studies attempt to provide insights into the driving sectors. No consensus, however, has been reached regarding the determination of which sectors contribute the most to convergence. Bernard and Jones present evidence that manufacturing sectors in 14 OECD countries show no or little convergence in labor productivity or multifactor productivity convergence while services are found to drive aggregate convergence. Broadberry finds no evidence for convergence in labor productivity levels in the manufacturing sectors of Germany, U.K., and the USA; Dollar and Wolff,

polarization of provinces with respect to productivity yields convergence clusters; that is, groups of provinces each moving towards a different productivity level. Global convergence, on the other hand, occurs if all of the provinces move towards the same productivity level. Within-country analysis is desirable for policy-making and theoretical purposes. In the case of convergence, policy makers would have legitimate grounds for influencing growth-related variables. In addition, the underlying assumptions of the convergence hypothesis are most likely to be satisfied within a country since units under investigation in a country are subject to similar constraints regarding technological developments, government policies, and factor mobility. To the best of our knowledge, this study is the only one investigating convergence of sectoral labor productivity *within* Turkey, applying the Markov chains approach.

The main empirical finding of the study is that among the 67 provinces polarization emerges at the aggregate level. This is referred to as the 'twin peaks' phenomenon since groups of provinces form separate convergence clusters. The pattern of polarization indicates that, in the long run, two convergence clusters are likely to emerge - one for the agricultural and another for the highly industrial provinces. It might be that provinces with high productivity levels are employing more capital per worker than provinces with low productivity levels. This hypothesis, however, needs to be confirmed empirically. The shape of the time-invariant distribution for aggregate analysis is mainly affected by the agricultural, industrial, and transportation sectors. The aggregate and sectoral time-invariant distributions do not imply global convergence; and therefore, the labor productivity across the 67 provinces should not be expected to equalize in the long run.

Following the Introduction, Section 2 provides background information about the developments in the Turkish economy. Section

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on the other hand, find convergence of labor productivity levels in individual manufacturing industries over the 1963-82 period.

3 briefly describes Markov Chains model used in testing convergence of sectoral labor productivity in Turkish provinces. Data and the variables used in the empirical investigation are defined in Section 4. The empirical results are discussed in Section 5. Finally, Section 6 concludes the study.

2. Developments in the Turkish economy

The development experience of Turkey shows two distinct periods: pre- and post-1980. Prior to 1980, Turkey's economic course was guided by 5-year development plans that led to fairly good growth rates (Buturak and Yeldan, 2003). Beginning in 1980, Turkey adopted a market-oriented development strategy in the aftermath of a severe balance of payments crisis in the late 1970s. A short-term stabilization package was adopted in order to bring Turkey out of crisis, which later turned into a full-fledged structural adjustment program backed by international organizations. Fiscal retrenchment and privatization were vital parts of the new policy prescription. This ideological shift toward a market-based export-oriented strategy necessitated a reduction of public intervention in economic activities. These developments also had important labor market implications and consequences. The 1983-1987 period of export-led growth is characterized by declining real wages. Wage suppression was used as a policy tool to keep labor costs down and encourage private investors. The re-distribution of resources from labor to capital in the post-1980 liberalization period brought about a change in the functional distribution of income in favor of capital, as witnessed by the decline in the share of wages in total non-agricultural income (Buturak and Yeldan, 2003). The average annual growth rate of labor productivity in the industrial sector was 6.2 percent for the period of 1970-1977. This figure declined substantially within the next two decades, to 3.0 percent for the 1980-1990 period and to 0.4 percent for the 1990-2000 period (Baş and Tansel, 2003). The post-1980 period is also marked by a widening of the rural-urban divide and deterioration in the personal distribution of income, both at the national and regional (provincial) levels, whereas prior to 1980 income distribution had shown an improvement.

Turkey ranks among the top twenty countries in terms of income inequality, with its Gini coefficient following Brazil's, Mexico's, Chili's and South Africa's (Sönmez, 2001). The latest comparable data on income inequality in Turkey are based on the 1987 and 1994 Household Labor Force Survey results (SIS, 1990 and 1996). The rise in the Gini coefficient[4] from 0.43 in 1987 to 0.49 in 1994 indicates that the income distribution has deteriorated over the 1987-1994 period. According to the 1994 survey results, İstanbul was the city of the most unequal income distribution among Turkey's cities. The Marmara region, where İstanbul is located, has a regional Gini coefficient of 0.56, while income distribution appears to be more equal in the less developed Eastern and Southeastern Anatolian regions, with Gini coefficients of 0.37 and 0.38 respectively (SIS, 1997). In general, income distribution is more unequal in urban areas than in rural; part of this is due to the fact that a huge internal migration took place toward industrial centers with limited employment opportunities. In fact, the liberalization period has seen unprecedented levels of unemployment. The latest figures after the 2001 crisis indicate that the overall unemployment rate has risen from 6.6 percent in 2000 to 11.4 percent in the last quarter of 2002.

There is evidence of further deterioration in income distribution after the February 2001 crisis, which brought about a 9.5 percent decline in GNP—the largest decline in the history of the Republic. Prior to the 2001 crisis, the Turkish economy experienced several other setbacks. In 1994, Turkey suffered its first economic crisis after a period of unregulated financial liberalization that began in 1989. In 1999, the economic crisis and the earthquakes in Marmara and Düzce led to a 6.4 percent contraction of the Turkish economy. These experiences have led not only to a decline in aggregate income but to a worsening in the income distribution between regions and across households. Regional disparities exist within Turkey at many levels, including output, income, educational attainment levels and in the sectoral shares of employment. A development gap persists between

[4] The Gini coefficient takes values between 0 and 1, where a value of 0 indicates a perfectly equal income distribution and a value of 1 indicates a perfectly unequal distribution of income.

the southeastern provinces and the western regions of the country, and private investors have been reluctant to invest in the less developed areas. A high level of income inequality and the massive rural-urban migration from the rich provinces to the poor provinces have become prominent features of the Turkish development experience. In 1975, one-fifth of the employed population was located in the relatively rich Marmara region, while the poorest regions, including Southeast Anatolia and Eastern Anatolia regions, together accounted for less than 20 per cent of the employed labor force. In 1990, the share of employed population increased for the Marmara region and declined for Southeast and Eastern Anatolia reflecting in part the dynamics outlined above. At the sectoral level, the share of employment in agriculture declined in all regions between 1975 and 1990, although the less developed regions continue to have a substantial proportion of labor employed in agriculture (Table 1).

Table 1.

	Agricultre		Industry		Construc-tion		Wholesale		Transport		Services	
Region	75	90	75	90	75	90	75	90	75	90	75	90
Marmara	46	29	18	24	4	7	8	13	4	5	18	21
Aegean	68	54	10	14	3	5	5	8	3	3	11	15
Mediterranean	72	57	8	10	3	5	4	8	3	3	9	15
Black Sea	80	71	7	8	2	3	3	5	2	2	6	11
Centre	64	52	8	11	3	5	5	7	3	4	15	21
Southeast	77	71	4	7	4	5	4	6	2	3	9	13
East	82	69	3	4	2	3	2	4	2	2	9	15

The Marmara region has the highest share (nearly a quarter) of industrial employment among Turkey's regions. The employment shares in the remaining sectors show increases for all regions, but this is more marked for the services sector. Table 2 presents the average annual growth rate in the employed population by sector for the 1975-1990 period. This table reveals that the growth in services sector employment for five regions (Aegean, Mediterranean, Black Sea, Southeast Anatolia and East Anatolia) has surpassed the growth rate of services employment for the Marmara region. The only exception is Central Anatolia. The average educational attainment level of the labor force has increased by about two years for all provinces and regions over the 1975-1990 period. There is no indication of a “catch-up” in education levels across regions: Marmara continues to have the highest educational attainment level, while Southeast Anatolia continues to be the region with the lowest level of educational attainment[5]. The 1990 level for Southeast Anatolia remains below the 1975 level for the Marmara region (Table 3).

Table 4 in the Annex gives the shares of the various sectors in total provincial Gross Provincial Product (GPP) for the richest and poorest provinces. In 1975, İstanbul, Ankara, İzmir, Adana, Bursa, Konya, Kocaeli, Zonguldak, Manisa and İçel were, in this order, the top ten richest provinces in terms of GPP in current prices. In 1990, these provinces, with the exception of Zonguldak, continued to be among the top ten. The poorest provinces in 1975 were Hakkari, Bingöl, Tunceli and Bitlis, in that order. Not surprisingly, the poorest provinces are also among the least industrialized in Turkey with less than 10 percent of GPP in industrial output and a very large share of GPP in agriculture. Many of the richest provinces (except for Konya and Manisa) in terms of GPPs are also those with the highest shares of industrial output.

In the 1990s, seven provinces (Adıyaman, Çorum, Denizli, Edirne, Gaziantep, Kahraman Maraş and Konya)—dubbed the Anatolian Tigers because of their impressive economic performance—emerged as local centers of industrial development (Filiztekin and Tunalı, 1999). This is not necessarily evident in the GPP data for the 1975-1990 period, except for Adıyaman. In 1975, Adıyaman was among the poorest provinces in Turkey. By 1990, however, Adıyaman had

[5] In terms of enrollment rates, there appears to be convergence at the primary and middle school levels but divergence at the high school level for the 1980-1994 period (see Tansel and Güngör, 2001).

moved up in rank from 61 to place 34th in total GPP share among Turkey's provinces, and showed a substantial increase in its industrial GPP share. The success of the Anatolian tigers is largely credited to the rise of small and medium sized enterprises (SMEs) with links to overseas markets. Recent evidence suggests, however, that the 2001 crisis has had a devastating effect on these provinces, with many businesses working below capacity or shutting down altogether. There is also indication of capital flight to the traditionally prosperous provinces and overseas (Kaya, 2002). This suggests that regional disparities are far from dissipating and is highly likely to persist in the future under the current economic and political environment.

3. Markov Chains model

The Markov chain model, employed in various contexts by Stokey, Lucas and Prescott (1989), and Quah (1993, 1996) among others, is applied to trace movements within a distribution. In our context, this model is used to obtain information on four characteristics of the dynamically evolving distribution of provincial labor productivity levels: external shapes, intra-distribution dynamics, long-run behavior, and the speed of convergence.

Let $\mathbf{F}_t$ denote the distribution of the odds between individual provincial productivity level and Turkey's average labor productivity, and assume that this distribution evolves as

$$\mathbf{F}_{t+1} = \mathbf{P}' \mathbf{F}_t$$

where $\mathbf{P}$ is the $(n*n)$ transition probabilities matrix. The above first-order equation describes the evolution of $\mathbf{F}_t$ by mapping $\mathbf{F}_t$ into $\mathbf{F}_{t+1}$. An element p_{ij} of $\mathbf{P}$ represents the probability that a province in class i in period t will be in class j in period $t+1$. Using the minimum variance criterion of Cochran (1966), the distribution $\mathbf{F_t}$ is somewhat arbitrarily partitioned into n intervals. According to this criterion, within-class or interval variance is minimized on the basis of labor productivity levels. There are two important assumptions involving this first-order equation.[6] First, we assume that it is a first-order process. Specifically, the probability that a province will be in a particular class in period *t+1* depends only on the province's class in period *t* and not on its class in the previous periods. In our context, this assumption is reasonable because we only have three periods to analyze. Second, we assume that the transition probability matrix is stationary. Then, the *s*-step ahead distribution is given by,

$$\mathbf{F}_{t+s} = (\mathbf{P}')^{s}\, \mathbf{F}_{t}.$$

The time-invariant distribution of provincial productivity could be found when $s \to \infty$. The stationarity implies that the probability that a province in class *i* in period *t* will be in class *j* in period *t+1* is constant over time. A maximum likelihood estimate of this probability is given by,

$$p_{ij} = 1/(T-1) \sum_{t=1}^{T-1} (N_{ij}^{t} / N_{i}^{t})$$

where N_{ij}^{t} is the number of provinces moving from class *i* to *j* in period *t*; N_{i}^{t} is the total number of provinces in class *i* during period *t*; and T is the number of time periods. In Annex A1 we include a section on the existence and uniqueness of a time-invariant distribution.

4. Variables and data

The variable of interest $\mathbf{F}_t$ is the odds ratio of provincial labor productivity to sectoral average productivity. To discretize the variable $\mathbf{F}_t$, required by the Markov analysis, we adopt an empirical procedure. We first calculate the variable $\mathbf{F}_t$ for the initial year t=1975 and then sort it in ascending order. Next, we divide $\mathbf{F}_{1975}$ into intervals in such a way that each interval has minimum variance (Cochran, 1966). The jump points in the sorted $\mathbf{F}_{1975}$ are considered cut-off points for intervals, suggesting the intervals C_1 = [0, 0.60], C_2 = [0.61, 0.79], C_3 = [0.80, 0.99], C_4 = [1.0, 1.19], C_5 = [1.20, 1.39], C_6 = [1.40, ∞] for the aggregate level and for the agricultural,

[6] Testing procedures for these assumptions are discussed in detail in the Appendix.

industrial, wholesale trade, transportation and service sectors. For the construction sector, the intervals become C_1 = [0, 0.40], C_2 = [0.41, 0.80], C_3 = [0.81, 1.20], C_4 = [1.21, 1.60], C_5 = [1.61, 2.00], C_6 = [2.01, ∞]. The sectoral gross provincial products for the 67 provinces of Turkey are taken from Özötün (1980 and 1988) for the years 1975 and 1985 and from the State Institute of Statistics (SIS) (1995) for the year 1990. The two series are comparable except for the inclusion of new sectors in the more recent SIS series. The data on the worker population are obtained from SIS (1990). These are used to compute the aggregate as well as the sectoral labor productivity levels. Until 1989, Turkey had a total of 67 provinces; in 1990 this number became 73. To make the census years comparable, the 1990 figures for the new provinces were added to their former provinces. The data set contains a total of 268 (67*4) observations on 67 provinces for the four 5-year intervals over the 1975-1990 period. Aggregate labor productivity is defined as the ratio of total provincial income to the provincial labor force. Likewise, sectoral labor productivity is calculated as the ratio of sectoral provincial income to the sectoral provincial labor force.

5. Empirical results

The Markov chain provides insights into the four characteristics of the dynamically evolving distributions of provincial labor productivity levels. The average of $\mathbf{P}_t$ over the time periods (1975-1980, 1980-1985, and 1985-1990) is used as an estimate of **P**. This estimation is made for both aggregate and sectoral labor productivity levels. The distribution $\mathbf{F}_t$ contains the gaps between individual provincial labor productivities and Turkey's average. $\mathbf{F}_t$ is computed and sorted for each of the years, 1975, 1980, 1985, and 1990. This process is repeated at the aggregate and sectoral levels.

Aggregate Productivity. The elements of **P** in the tables should be interpreted as follows. The third row in Table 5, for example, indicates that, out of 268 provinces, 55 of them fall into class 3. Of those 2 percent moved from Class 3 to 1; 29 percent from Class 3 to 2; 14 percent from Class 3 to 4; 7 percent from Class 3 to 5; 2

percent from Class 3 to 6; and 47 percent remained in Class 3. Furthermore, those provinces in classes 1 and 6 show high persistence since they tend to stay in the same class with probabilities of 0.89 and 0.87, respectively. The provinces in the middle classes show low tendency to remain in the same class while provinces in classes 2, 3, and 4 have a tendency to switch to a lower class; provinces in Class 5 have a tendency to move one class up to Class 6. The two-period-ahead transition probabilities matrix represented by Tables 5 through 11 is used to predict the behavior of aggregate and sectoral productivity levels for the year 2000. The prediction for the aggregate productivity level in Table 5 indicates high persistence in classes 1 and 6, and low persistence among the middle classes. Thus, our *ex post* observations for 1990 are expected to hold in 2000 with a stronger tendency of the middle classes to vanish. Assuming the economic structure over 1975-1990 remains the same in the future, we expect to observe an increasing disparity in provincial productivity levels.

Table 5 presents the implied ergodic distribution[7] of aggregate provincial productivity levels, which is the unique solution to the system of equations in Theorem 1. Everything else constant, time-invariant probabilities indicate that, in the long run, the probability of a province to stay in classes 1 and 2 is 47 percent (i.e., $\pi_1 + \pi_2 = 0.35 + 0.12$) while it is 22 percent for Class 6 (i.e., $\pi_6 = 0.22$). Polarization of provinces implied by the time-invariant probability shows that some of the provinces tend to become poor, while some tend to become rich. These two groups of provinces form convergence clusters in the sense that the low productivity provinces which are placed in classes 1 and 2 (6) in 1975 tend to remain in these classes in the long run[8]. Furthermore, note that twice as large a probability mass is concentrated in classes 1 and 2 as compared to Class 6.

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[7] The concepts of “time-invariant”, “ergodic”, and “limiting probabilities” have the same meaning. Ergodicity also implies path-independence; that is, initial productivity levels do not matter.

[8] In the 1975 classification, the following provinces were in class 6: Adana, Eskisehir, Bursa, Ankara, Içel, Izmir, Zonguldak, Kocaeli, and Istanbul. In

Sectoral Productivity. We examined the agricultural and industrial sectors together due to similarities of their ergodic distributions. Their transition probabilities are reported in Tables 6 and 7 respectively. Figures 2 and 3 show graphs of their ergodic distributions. The dominant characteristics of the kernels are as follows. The likelihood of the provinces in classes 1 and 6 to remain in the same classes is over 60 percent. This moderate persistence to stay in the same class implies two peaks at the two tails of the distribution with thinning middle classes. The two-year-ahead transition probabilities further display a similar persistence across the same classes in both sectors. Tables 6 and 7 give the implied ergodic distributions for the agricultural and industrial sectors, respectively. As expected, these distributions are quite similar and also seem to be the driving forces behind the aggregate distribution. Polarization of provinces implied by the time-invariant probabilities shows that some provinces tend to have very low while some tend to have very high agricultural and industrial labor productivities. These two groups form convergence clubs in the same manner as the aggregate productivity levels discussed in the previous section. Interestingly, more than three and a half times as large a probability mass is concentrated in classes 1 and 2 as compared to Class 6. Table 8, which gives the transition probabilities matrix for the construction sector, shows a different picture. The second class indicates the highest persistence with 54 percent probability, while the rest of the classes reveal very weak persistence. The two-period-ahead kernel for the year 2000 further shows a similar structure. The ergodic distribution is skewed to the right with an upward pointing tip at the right tail of the distribution (Figure 4). Such a distribution implies convergence to a productivity level lower than Turkey's average although there is some evidence of a small cluster around the upper

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1990, Tekirdag, Bilecik, Kirklareli were added to this list while Zonguldak exited class 6. Similarly, the following provinces were in classes 1 and 2 in 1975: Bingöl, Agrı, Hakkari, Adiyaman, Ordu, Gümüshane, Kars, Sinop, Van, Bitlis, Yozgat, Erzurum, Tokat, Çankiri, Tunceli, Kastamonu, Mardin, Mus, Giresun, and Erzincan. In 1990, Afyon, Sivas, Trabzon, Nigde, Isparta, and Sanliurfa were added to this list while Adiyaman exited to class 4 and Çorum to class 3.

tail. When compared to Class 6, the probability mass is five times higher in classes 1 and 2. Table 9 reports the transition probabilities for the wholesale and retail trade sectors. In this table, Class 1 has the highest persistence with 71 percent probability, while the persistence is low for the rest of the classes. The ergodic distribution is rather flat with no indication of convergence or polarization (Figure 5). Labor productivities across the provinces seems to be distributed uniformly over the 6 classes considered. Table 10 reports the transition probabilities for the transportation sector. The persistence in Class 1 is quite strong with 80 percent probability. A similar tendency is observed in the two-period-ahead kernel. Although the ergodic distribution has three groupings, the probability mass is mainly concentrated in the middle classes, 3 and 4 (Figure 6). There are three convergence clusters in this sector that divide the provinces into low, middle and high productivity provinces. This feature of the ergodic distribution is quite distinct compared to the distributions of other sectors. Table 11 gives the transition probabilities for the service sector. The first three classes show high persistence with 50 percent or higher probabilities. The two-period-ahead transition matrix indicates a tendency to move towards the middle classes. This tendency becomes stronger over time as the limiting distribution indicates (Figure 7). The bell-shaped ergodic distribution of the service sector implies global convergence to Turkey's average. Table 12 gives the speed of convergence[9] and mobility indices. The second largest eigenvalue of **P** measures the speed of convergence (Quah 1996a). For the imaginary eigenvalues, their 'modules' were used for comparison. The highest speed is observed in the aggregate ergodic distribution. The high speed in agriculture and industry seems to be behind this result. We also computed two measures of mobility: μ_1 and μ_3 (Quah 1996a). The lower is μ_1, the more persistence there is in the kernel ***P***.

[9] The "speed of convergence" here gives the rate of convergence to the ergodic distribution. This concept is different from the one used in the convergence studies applying regression analysis. The calculation of "passing time" in our context (non-parametric estimation) corresponds to the speed of convergence in the parametric approach. See Quah (1996b) for passing time.

Accordingly, the aggregate transition matrix shows the highest persistence followed by the services, agriculture, and transportation sectors. The index μ_3 is an asymptotic mobility index that takes on high values when ***P*** is highly persistent. This implies low mobility for small values of μ_3. Accordingly, the aggregate has the lowest mobility followed by agriculture, transportation, and the service sectors. A comparison of the ergodic distributions of the agricultural, industrial, and transportation sectors with the aggregate ergodic distribution implies that these three sectors significantly determine the shape of the limiting probability distribution for the aggregate productivity level (Figure 8). These sectors make up about 50 percent of total labor productivity in 1975 and 60 percent in 1990. Both the percentage of the labor force in agriculture and the agricultural share of GDP have been declining over time. In 1993, although about half of the labor force is occupied with agriculture, agriculture generates about one-sixth of the GDP. Thus, the productivity is rather low in agriculture unlike the other sectors[10]. In fact, productivity in agriculture is about five to ten times smaller than in other sectors.

6. Concluding remarks

This study applied a non-parametric Markov chain model to characterize the long run fluctuations in the aggregate and sectoral productivity levels across the 67 provinces of Turkey over the period 1975-1990. This model was then used to project the two-year-ahead transition probabilities into the year 2000 and to determine the time-invariant distributions at the aggregate and sectoral levels. The asymptotic speed of convergence to the time-invariant distribution

[10] Seventy-nine percent of the total labour force in 1960 was employed in agriculture. This figure decreased to 53 percent in 1990 while for the industrial sector the same figure increased from 11 in 1960 to 18 in 1990; and it increased from 10 in 1960 to 29 in 1990 in the service sector (World Bank, 1984, 1996). The share of agriculture in GDP was 30 percent in 1970 and declined to 15 percent in 1993, while industry's share in GDP increased from 27 to 30 percent. The service sector's share in the same period increased from 43 to 55 percent (World Bank, 1993).

was also calculated. The time-invariant distribution implies a polarization at the aggregate level, suggesting low productivity in some provinces, high in others. At the sectoral level, the implied time-invariant distributions are similar for agriculture and industry, suggesting the presence of two convergence clusters: One is the cluster of low-productivity, another is the cluster of high-productivity provinces. These tendencies are more pronounced than those at the aggregate level. The time-invariant distribution for the construction sector is skewed to the right with an upward tendency at the right tail, suggesting convergence to a productivity level lower than Turkey's average. The distribution for wholesale and retail trade is rather flat with no indication of convergence or polarization.

The transportation sector shows three convergence clusters: low, middle, and high productivity provinces. Finally, we observe a bell-shaped distribution for the service sector, implying global convergence to the sectoral average productivity. That is, in the service sector low productivity provinces are more likely to catch up with high productivity provinces, which is also an observation made by Bernard and Jones (1996). Global convergence in the service sector can be, in part, attributed to the nature of activities engaged in this sector where production almost solely depends on skilled labor, the most mobile factor. From these observations we may conclude that agriculture, industry, and transportation sectors are the driving forces behind aggregate fluctuations in labor productivity. The aggregate and sectoral time-invariant distributions point to several institutional and technological constraints at work. First of all, in spite of the substantial labor mobility across provinces, there are large differences in the accumulated human capital of the labor force across provinces. We can surmise that highly skilled labor is required, particularly in industry, services, and parts of the construction sectors, while the transportation, wholesale and retail trade sectors may be attracting somewhat unskilled labor. Labor productivity also depends on the amount of capital available in the relevant sector. But it is well known that in spite of generous incentives, capital is reluctant to move to the eastern part of Turkey, and labor escapes from there.

There are also institutional impediments that slow down the diffusion of new technology and hence factor mobility. In addition, the lack of proper infrastructure and its unequal distribution biases technological dispersion. The rate of technological dispersion may differ across sectors, which might be one of the reasons for observing different patterns in the time-invariant distributions for the different sectors. Among the other reasons for polarization of provinces with respect to labor productivity levels, one might include the differences in factor intensities across the sectors (Dollar and Wolff, 1988). It is interesting that the time-invariant distribution for the aggregate analysis overstates the two peaks compared to other sectors. This result might be due to data aggregation. Thus, the results should be interpreted with special care when aggregate data are used. There is ample scope for future studies. Efforts should focus on the extension of the single variable Markov chain model, which was applied by the current study, to develop a multivariable Markov chain method. Such extension would allow us to identify the factors behind convergence of cross-province labor productivity and to analyze the role of government policies in influencing the direction of factor-intensity. This role, provided that it is significant, would open up new avenues for studying the direction of technological change and economic growth.

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Annex

A1. **Existence and uniqueness of a time-invariant distribution:** If the elements p_{ij}^{n} of the stationary transition matrices converge to some value as $n \to \infty$, then we conclude that there exists a time-invariant probability that the process will be in class *j* after a large number of transitions, and this distribution is independent of the initial class. Below, we provide definitions referred to in the derivation of a time-invariant distribution, and state the theorem, adopted from Ross (1985, p.132-187), which guarantees the existence and uniqueness of it (see Debreu and Herstein (1953) for the properties of ***P***, and Feller (1950) for further details about Markov chains).

Definition 1. Class *j* is said to be *accessible* from class *i* if $p_{ij}^{n} > 0$ for some $n \geq 0$.
Definition 2. Two classes *i* and *j* that are accessible to each other are said to *communicate*.
Definition 3. For any class *i* we let f_i denote the probability that, starting in class *i*, the process will ever reenter class *i*. Class *i* is said to be *recurrent* if $f_i = 1$, and *transient* if $f_i < 1$. Class *i* is recurrent if $\sum_{n=1}^{\infty} p_{ij}^{n} = \infty$ and transient if $\sum_{n=1}^{\infty} p_{ij}^{n} < \infty$.
Definition 4. A Markov chain is said to be *irreducible* if there is only one grouping of classes (that is, if all classes communicate with each other).
Theorem. For an irreducible ergodic Markov chain $\lim_{n\to\infty} p_{ij}^{n}$ exists and is independent of *i*. Furthermore, letting $\pi_j = \lim_{n\to\infty} p_{ij}^{n}$, $j \geq 0$, then π_j is the unique non-negative solution of $\pi_j = \Sigma^{\infty}_{i=0} \pi_i p_{ij}$, $j \geq 0$ and $\Sigma^{\infty}_{j=0} \pi_j = 1$.

Intuitively speaking, this theorem says that if a Markov chain process is described by a constant transition matrix ***P***, and if the process is allowed to work for a long period of time, then a time-invariant distribution will eventually be reached. Namely, after a long period of time, the proportions in the various categories would be approximately constant and would not depend upon the proportions in these categories at an initial time period. Since *N* provinces are investigated at every period we might expect that $(N*\square_i)$ provinces would be in class *i* after a very long period of time. This does not mean that we should expect $(N*\square_i)$ provinces to "settle down" in class *i*, but rather that, after a long period of time, $(N*\square_i)$ provinces can be expected to be in class *i*, and in another analysis after some more time, the same number $(N*\square_i)$ of provinces, which are most probably not all the same ones, can also be expected to be in class *i*. Although simple Markov chains might provide useful representations of dynamic processes, they have several shortcomings. First, and perhaps most important, they do not explain why countries experience changes in their per capita income over time. They simply describe the probabilities associated with transitions from one state to another. Stratification of the sample by levels of a variable may yield some explanatory power, but the procedure is cumbersome when more than one or two additional variables are introduced into the analysis. The Markov chain approach is further limited by its general inability to deal with measurement error. With the exception of certain models, simple Markov chain models assume that all observed changes are the true changes. But, when the variables of interest are survey responses, observed changes will almost certainly contain some unreliability. A third shortcoming is that time-invariant probabilities depend on an *a priori* grouping or stratification of the observations. The ideal grouping of the observations is one that minimizes within-group and maximizes between-group heterogeneity of transition rates. The problem, of course, is to find the variables that yield the best grouping.

Table 2. Average annual % increase in employed population 1975-1990, sectors by regions

Region	Total	Agri-culture	Industry	Cons-truction	Wholesale	Trans-portation	Services
Marmara	2.8	-0.2	5.0	6.3	6.0	3.7	3.7
Aegean	2.1	0.6	4.3	5.2	5.3	2.9	4.5
Mediterranean	2.8	1.4	4.2	7.4	7.6	4.0	6.3
Black Sea	1.2	0.4	2.2	4.0	5.0	2.2	4.9
Central	1.5	0.1	3.4	5.0	4.2	2.6	3.5
Southeast	2.0	1.5	5.0	2.4	5.0	3.4	4.8
Eastern	1.2	0.0	3.5	4.6	4.8	2.8	4.5

Source: Calculated from SIS Censuses, 1975-1990.

Table 3:Mean years of schooling completed by labor force, regions by census years

Region	1975	1980	1985	1990	Change 1975-1990
Marmara	4.57	5.32	5.82	6.29	1.72
Aegean	3.71	4.42	4.99	5.41	1.70
Mediterranean	3.50	4.22	4.83	5.30	1.80
Black Sea	2.86	3.56	4.25	4.66	1.80
Central Anatolia	3.87	4.65	5.23	5.75	1.88
Southeast Anatolia	2.03	2.63	3.25	3.73	1.70
Eastern Anatolia	2.50	3.04	3.70	4.15	1.65

Table 4:Sectoral Gross Provincial Product Shares for the Richest & Poorest Provinces

	Agri-culture		Industry		Cons-truction		Whole-sale		Trans-portation		Services	
Richest	75	90	75	90	75	90	75	90	75	90	75	90
İstanbul	**1.3**	**1.4**	33	32	**4.2**	**4.7**	26	27	10	12	16	18
Ankara	14	**6.1**	17	19	**6.1**	11	14	22	8.5	16	33	19
İzmir	15	10	33	31	**3.7**	**5.5**	15	20	6.5	14	19	15
Adana	30	19	20	27	10	**4.7**	12	19	6.5	12	17	16
Bursa	25	19	29	35	**2.0**	**7.4**	12	14	8.3	9.2	17	9.4
Konya	46	30	10	19	**5.7**	**7.3**	10	15	8.7	13	15	11
Kocaeli	5.6	3.3	61	58	**2.5**	**4.4**	6.2	10	4.0	5.9	**9.5**	7.1
Zonguldak	11	14	52	43	**0.9**	**4.2**	6.0	10	7.2	12	13	11
Manisa	44	34	11	27	6.8	4.3	12	15	7.0	6.7	16	9.4
İçel	29	20	31	30	5.9	5.2	9.0	17	5.5	8.9	14	11
Poorest												
Hakkari	62	24	2.2	1.2	11	5.0	2.1	3.7	3.4	6.4	17	55
Bingöl	55	39	5.4	6.5	8.3	5.3	3.5	4.9	5.2	6.5	19	35
Tunceli	60	46	2.3	1.8	5.5	2.1	3.1	5.0	3.8	6.0	23	38
Bitlis	44	36	6.	7.	6.6	3.5	5.	7.	12	15	20	28

			9	0			6	0				
Ağrı	59	42	3.4	4.5	4.8	2.6	3.0	9.6	6.8	9.1	19	29
Gümüşhane	51	32	4.5	3.5	4.2	3.9	4.7	9.2	12	25	20	15
Adıyaman	57	42	6.6	30	2.9	4.9	4.2	6.4	5.4	3.6	18	9.1
Bilecik	47	21	9.3	48	1.9	4.1	6.3	4.3	9.3	9.4	23	8.1
Muş	69	55	1.7	4.9	5.6	2.7	2.8	3.4	4.7	5.6	14	25
Sinop	42	35	6.5	10	4.1	7.4	6.6	12	9.0	16	27	17

Source: Tansel and Güngör (1997b). Richest and poorest in 1975.

Table 5. Transition Probability Matrix (**P**): Aggregate

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.89	0.08	0.02	0.02	0	0	63
2	0.31	0.46	0.19	0.04	0	0	45
3	0.02	0.29	0.47	0.14	0.07	0.02	55
4	0	0	0.23	0.54	0.17	0.06	51
5	0	0	0.11	0.31	0.19	0.39	15
6	0	0	0.03	0.06	0.04	0.87	39
Ergodic Distrib.	0.35	0.12	0.13	0.13	0.05	0.22	
Eigenvalue (λ)	0.18	0.51	1	0.73	0.92	0.07	
	Two-Period-Ahead Transition Probabilities Matrix (P^2)						
	1	2	3	4	5	6	
1	0.82	0.11	0.04	0.03	0	0	
2	0.43	0.28	0.19	0.07	0.02	0.01	
3	0.12	0.27	0.32	0.17	0.06	0.06	
4	0	0.07	0.25	0.38	0.14	0.16	
5	0	0.03	0.16	0.26	0.11	0.44	

6	0	0.01	0.06	0.1	0.05	0.78	

Table 6. Transition Probability Matrix (**P**): Agriculture

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.67	0.31	0.02	0	0	0	38
2	0.37	0.42	0.16	0.02	0	0.03	53
3	0.04	0.24	0.42	0.21	0.07	0.02	54
4	0.03	0.12	0.21	0.40	0.15	0.09	43
5	0	0	0.11	0.26	0.32	0.31	39
6	0	0	0	0.04	0.31	0.65	41
Ergodic Distrib.	0.28	0.22	0.13	0.11	0.11	0.15	
Eigenvalue (λ)	1	0.88	0.58	0.26	0.06	0.10	
	Two-Period-Ahead Transition Probabilities Matrix (P^2)						
	1	2	3	4	5	6	
1	0.56	0.34	0.08	0.01	0	0.01	
2	0.41	0.34	0.15	0.05	0.02	0.03	
3	0.14	0.24	0.27	0.19	0.09	0.07	
4	0.08	0.16	0.21	0.25	0.15	0.15	
5	0.01	0.06	0.14	0.22	0.24	0.33	
6	0	0	0.04	0.13	0.31	0.52	

Table 7. Transition Probabilities Matrix (**P**): Industry

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.63	0.22	0.08	0.02	0.03	0.02	74
2	0.37	0.37	0.16	0.05	0.02	0.03	71
3	0.21	0.25	0.35	0.06	0.06	0.07	36

4	0	0.13	0.20	0.31	0.18	0.18	26
5	0.14	0.14	0.14	0.19	0.08	0.31	20
6	0	0.06	0.03	0.07	0.23	0.61	41
Ergodic Distrib.	0.33	0.22	0.14	0.07	0.08	0.16	
Eigenvalue (λ)	1	0.72	-0.08	0.36	0.22	0.13	
	Two-Period-Ahead Transition Probabilities Matrix (P^2): Industry						
	1	2	3	4	5	6	
1	0.49	0.25	0.13	0.04	0.04	0.05	
2	0.41	0.27	0.16	0.06	0.04	0.06	
3	0.31	0.25	0.19	0.08	0.06	0.11	
4	0.12	0.18	0.18	0.16	0.13	0.23	
5	0.18	0.17	0.14	0.12	0.13	0.26	
6	0.06	0.11	0.09	0.12	0.17	0.45	

Table 8. Transition Probabilities Matrix (**P**): Construction

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.23	0.58	0.15	0.04	0	0	29
2	0.11	0.54	0.23	0.05	0.05	0.02	100
3	0.07	0.33	0.29	0.20	0.02	0.09	74
4	0.04	0.11	0.39	0.12	0	0.34	31
5	0.07	0.20	0.15	0.42	0.08	0.08	12
6	0.08	0.13	0.36	0.11	0.06	0.26	22
Ergodic Distrib.	0.10	0.39	0.27	0.11	0.03	0.10	
Eigenvalue (λ)	1.00	0.42	-0.0432+ 0.1179i	-0.0432- 0.1179i	0.11	0.08	
	Two-Period-Ahead Transition Probabilities Matrix (P^2): Construction						
	1	2	3	4	5	6	
1	0.13	0.50	0.23	0.07	0.03	0.04	
2	0.11	0.44	0.24	0.11	0.04	0.06	

3	0.09	0.35	0.29	0.12	0.03	0.12
4	0.08	0.27	0.31	0.14	0.03	0.17
5	0.08	0.27	0.31	0.14	0.01	0.19
6	0.09	0.30	0.29	0.15	0.03	0.14

Table 9. Transition Probabilities Matrix (**P**): Wholesale and Retail Trade

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.71	0.13	0.12	0	0	0.04	51
2	0.33	0.27	0.19	0.10	0.07	0.04	35
3	0.04	0.17	0.43	0.18	0.07	0.11	55
4	0.06	0.12	0.14	0.35	0.11	0.22	44
5	0	0.08	0.19	0.13	0.45	0.15	34
6	0	0.08	0.09	0.20	0.38	0.25	49
Ergodic Distrib.	0.22	0.14	0.20	0.15	0.16	0.13	
Eigenvalue (λ)	1.00	0.71	0.28+ 0.0637i	0.28- 0.0637i	0.12	0.06	
	Two-Period-Ahead Transition Probabilities Matrix (P^2): Wholesale and Retail Trade						
	1	2	3	4	5	6	
1	0.54	0.15	0.17	0.04	0.03	0.06	
2	0.34	0.17	0.20	0.11	0.09	0.09	
3	0.12	0.16	0.26	0.19	0.14	0.13	
4	0.11	0.13	0.18	0.22	0.19	0.17	
5	0.04	0.12	0.21	0.18	0.29	0.16	

6	0.04	0.11	0.17	0.20	0.30	0.17

Table 10. Transition Probabilities Matrix (**P**): Transportation

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.80	0.10	0.07	0.03	0	0	50
2	0.31	0.26	0.25	0.08	0.08	0.02	32
3	0.10	0.09	0.45	0.21	0.08	0.07	58
4	0.04	0.02	0.09	0.46	0.07	0.32	54
5	0	0.04	0.21	0.17	0.38	0.20	30
6	0	0.00	0.14	0.21	0.29	0.36	44
Ergodic Distrib.	0.24	0.07	0.19	0.20	0.13	0.17	
Eigenvalue (λ)	1.00	0.81	0.32+0.076i	0.32-0.076i	0.15	0.09	
	Two-Period-Ahead Transition Probabilities Matrix (P^2): Transportation						
	1	2	3	4	5	6	
1	0.68	0.11	0.11	0.06	0.02	0.02	
2	0.36	0.13	0.22	0.14	0.09	0.08	
3	0.16	0.08	0.27	0.23	0.11	0.15	
4	0.06	0.03	0.15	0.31	0.16	0.29	
5	0.04	0.05	0.22	0.23	0.23	0.22	
6	0.02	0.03	0.19	0.25	0.24	0.27	

Table 11. Transition Probabilities Matrix (**P**): Services

	Classes						
Classes	1	2	3	4	5	6	N=268
1	0.63	0.22	0.05	0.05	0.05	0	18
2	0.14	0.59	0.15	0.06	0.06	0	45
3	0.03	0.12	0.50	0.31	0.04	0	64
4	0.03	0.02	0.28	0.45	0.14	0.08	79
5	0	0.03	0.03	0.39	0.43	0.12	45
6	0	0	0.05	0.25	0.32	0.38	17
Ergodic	0.10	0.15	0.23	0.30	0.15	0.07	

Distrib.							
Eigenvalue (λ)	1.00	0.74	0.52	0.11	0.42	0.19	

	Two-Period Ahead Transition Probabilities Matrix (P^2): Services					
	1	2	3	4	5	6
1	0.43	0.28	0.10	0.10	0.07	0.07
2	0.17	0.40	0.18	0.14	0.09	0.01
3	0.06	0.15	0.36	0.32	0.09	0.03
4	0.05	0.06	0.28	0.36	0.16	0.09
5	0.02	0.04	0.15	0.38	0.28	0.14
6	0.01	0.02	0.12	0.35	0.29	0.21

Table 12. Speed of Convergence and Mobility Indices

	λ -	Mobility Indices	
Sector	Speed	$\mu_1(P)$ = (n-	$\mu_3(P)$ = 1 -
Aggregate	0.92	0.52	0.08
Agriculture	0.88	0.63	0,12
Industry	0.72	0.73	0,28
Construction	0.42	0.90	0,58
Wholesale/Retail Trade	0.71	0.71	0,29
Transportation	0.81	0.66	0,19
Services	0.74	0.61	0,26

Note: λ is the second largest eigenvalue of the P matrix; the mobility indices are from Quah (1996a).

Fig 2. Ergodic distribution for agriculture

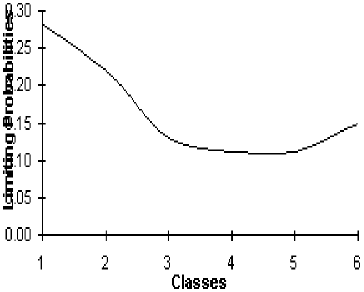


Fig 3. Ergodic distribution for industry

Fig 4. Ergodic distribution for construction

Fig 5. Ergodic distribution for wholesale

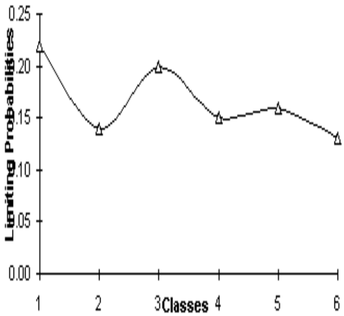


Fig 6. Ergodic distribution of transportation

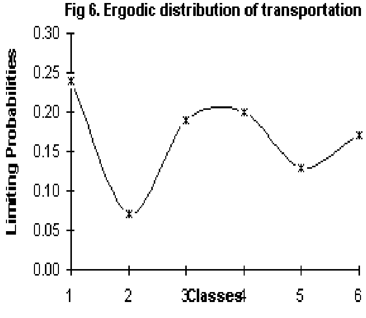


Fig 7. Ergodic distribution for services

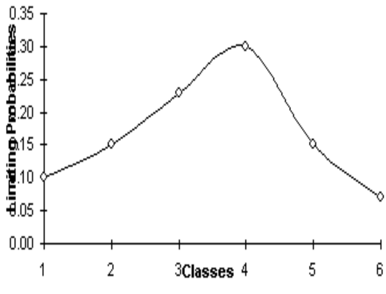
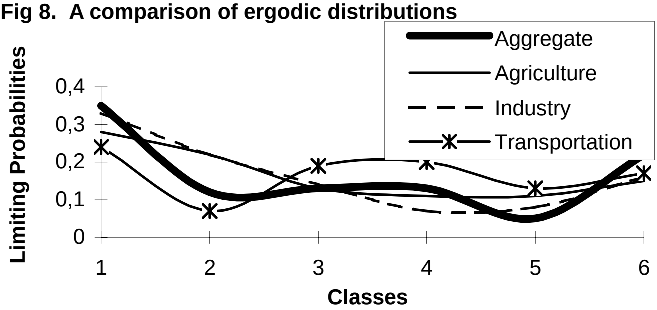


Fig 8. A comparison of ergodic distributions



Appendix: In this Appendix we first explain how to test for the two assumptions of a Markov chain: time-stationarity of the transition probability matrices and the first-order Markov property (see Anderson and Goodman (1957) for a detailed discussion of the test procedures applied in the present paper). Then a theoretical framework is provided for the existence of a time-invariant distribution to which the process converges. For illustrative purposes, the following contingency table will be referred to throughout the Appendix:

$$A_t = \begin{array}{cccc} \text{Classes} & 1(t) & 2(t) & \text{Total} \\ 1(t-1) & n_{11}^t & n_{12}^t & n_{1.}^t \\ 2(t-1) & n_{21}^t & n_{22}^t & n_{2.}^t \\ \text{Total} & n_{.1}^t & n_{.2}^t & n^t \end{array}$$

where *t=0,1,2,3* and *i=j=1,2*. Using A_1, A_2, and A_3, and the definitions given in the text we construct a table with (*T*m*) (or 3 by 2) dimensions:

$$Z_i = \begin{array}{ccc} t/j & j=1 & j=2 \\ t=1 & \hat{p}_{i1}^1 & \hat{p}_{i2}^1 \\ t=2 & \hat{p}_{i1}^2 & \hat{p}_{i2}^2 \\ T=3 & \hat{p}_{i1}^3 & \hat{p}_{i2}^3 \end{array}$$

Assumption 1. The transition probabilities are constant over time. Here the null hypothesis is $H_0 : p_{ij}^t = \hat{p}_{ij}$ for all *t*, and an alternative to this assumption is that the transition probability depends on *t*, $H_1 : p_{ij}^t = \hat{p}_{ij}^t$ where $\hat{p}_{ij}^t = \left(\dfrac{n_{ij}^t}{n_i^{t-1}} \right)$ is the estimate of the transition probability for time *t*. Under these hypotheses, the likelihood ratio is of the form, $\lambda = \prod_t \prod_{i,j} \left[\dfrac{\hat{p}_{ij}}{\hat{p}_{ij}^t} \right]^{n_{ij}^t}$, where $\prod_{t=1}^{T} \prod_{i,j} \hat{p}_{ij}^{n_{ij}^t}$ hold under H_0 and $\prod_{t=1}^{T} \prod_{i,j} (\hat{p}_{ij}^t)^{n_{ij}^t}$ holds under H_1. And $-2\log\lambda$ is distributed as $\chi^2_{(T-1)[m(m-1)]}$ when H_0 is true. It should be noted that the likelihood ratio resembles likelihood ratios obtained for standard tests of homogeneity in contingency table A_t. The null hypothesis states that the random variables represented by the *T* rows in Z_i have the same distribution. In order to test it, we calculate $\chi_i^2 = \sum_{i,j} n_i^{t-1} (\hat{p}_{ij}^t - \hat{p}_{ij})^2 / \hat{p}_{ij}$. If H_0 is true, χ_i^2 has the limiting distribution with (*m-1*)(*T-1*) degrees of freedom, and the set of χ_i^2's is asymptotically independent, and the sum $\chi^2 = \sum_{i=1}^{2} \chi_i^2 = \sum_i \sum_{t,j} n_i^{t-1} (\hat{p}_{ij}^t - \hat{p}_{ij})^2 / \hat{p}_{ij}$ has the usual limiting distribution with (*T-1*)[*m(m-1)*] degrees of freedom. Another way of testing the same hypothesis is to calculate $\lambda_i = \prod_{t,j} \left[\dfrac{\hat{p}_{ij}}{\hat{p}_{ij}^t} \right]^{n_{ij}^t}$ for *i=1,2* by using *Z*. The asymptotic distribution of $-2\log\lambda_i$ is χ_i^2 with (*m-1*)(*T-1*) degrees of freedom. The test criterion based on λ can then be written as $\sum_{i=1}^{m} -2\log\lambda_i = -2\log\lambda$.

Assumption 2. The Markov chain is of a given order.

Intuitively speaking, this assumption states that the location of a province at time (*t+1*) is independent of its location at time *t*. A Markov chain is second-order if a province is in class *i* at time (*t-2*), in *j* at time (*t-1*), and in *k* at time *t*. Let p_{ijk}^t denote the probability that a province follows a second-order chain. Time stationarity then implies $p_{ijk}^t = p_{ijk}$ for all *t=2,...,T*. A first-order stationary chain is a special case of second-order chain, one for which p_{ijk}^{t} does not depend on *i*. Now let n_{ijk}^{t} be the number of provinces in class *i* at *(t-2)*, in class *j* at *(t-1)*, and in class *k* at *t*. Let $n_{ij}^{t-1} = \sum_{k} n_{ijk}^{t}$ and $n_{ijk} = \sum_{t=2}^{T} n_{ijk}^{t}$. The maximum likelihood estimate of p_{ijk} for stationary chains is $\hat{p}_{ijk} = \left(\frac{n_{ijk}}{\sum_{l=1}^{m} n_{ijl}} \right) = \left(\frac{\sum_{t=2}^{T} n_{ijk}^{t}}{\sum_{t=2}^{T} n_{ij}^{t-1}} \right)$. The null hypothesis in this case is H$_0$: $p_{1jk} = p_{2jk} = \ldots = p_{mjk} = p_{jk}$ for *j, k = 1,...,m*. The likelihood ratio test criterion is

$$\lambda = \prod_{i,j,k=1}^{m} \left[\frac{\hat{p}_{jk}}{\hat{p}_{ijk}} \right]^{n_{ijk}} \text{ where } \hat{p}_{jk} = \left(\frac{\sum_{i=1}^{m} n_{ijk}}{\sum_{i=1}^{m} \sum_{l=1}^{m} n_{ijl}} \right) = \left(\frac{\sum_{t=2}^{T} n_{jk}^{t}}{\sum_{t=1}^{T-1} n_{j}^{t}} \right)$$

is the maximum likelihood estimate of p_{jk}. Under the null hypothesis, $-2\log\lambda$ has an asymptotic-$\chi^2_{m(m-1)^2}$ distribution where $\chi_j^2 = \sum_{i,k} n_{ij}^{*} (\hat{p}_{ijk} - \hat{p}_{jk})^2 / \hat{p}_{jk}$ and $n_{ij}^{*} = \sum_{k} n_{ijk} = \sum_{k} \sum_{t=2}^{T} n_{ijk}^{t} = \sum_{t=2}^{T} n_{ij}^{t-1} = \sum_{t=1}^{T-1} n_{ij}^{t}$ with *(m-1)*^{2} degrees of freedom.

The corresponding test using the likelihood ratio is $\lambda_j = \prod_{i,k=1}^{m} \left[\frac{\hat{p}_{jk}}{\hat{p}_{ijk}} \right]^{n_{ijk}}$. The asymptotic distribution of $-2\log\lambda_j$ is chi-square with *(m-1)*^{2} degrees of freedom. To test the joint hypothesis H$_0$: $p_{ijk} = p_{jk}$ for all *i,j,k=1,2,...,m*, we calculate $\chi^2 = \sum_{j=1}^{m} \chi_j^2 = \sum_{j,i,k} n_{ij}^{*} (\hat{p}_{ijk} - \hat{p}_{jk})^2 / \hat{p}_{jk}$ which has the usual limiting distribution with $m(m-1)^2$. Similarly, the joint test criterion is $\sum_{j=1}^{m} -2\log\lambda_j = -2\log\lambda = 2\sum_{i,j,k} n_{ijk}[\log\hat{p}_{ijk} - \log\hat{p}_{jk}]$.