Changing regional inequalities in ageing across Europe

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Ilya Kashnitsky
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Chapter 1. Introduction: changing regional inequalities in ageing across Europe

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Europe is ageing unequally. Even though there are macro-level similarities in the demographic development of this part of the world, which has been the forerunner of Demographic Transition and is pioneering the unexplored area of post-transition population development (Lee, 2003), substantial regional differences exist. As fertility stabilizes at various below-replacement levels, mortality keeps declining, and migration increasingly redistributes population, countries and regions set out for different paths leading to different population structures (Wilson *et al.*, 2013). While the large anticipated increase in the proportion of elderly population is a well recognized challenge that affects all aspects of economic prosperity and financial stability of societies (Loichinger *et al.*, 2017), regional variation in population age structures is a less researched but possibly no less important issue.

Regional equality is an explicit goal of European Union regional policy. Most generally, it is understood as balanced quality of life across regions of Europe. This essential goal consumes up to one third of European Union's budget (European Commission, 2014). Economic performance of a region, measured as gross domestic product (GDP) per capita, is the key indicator. Hence, many studies on regional economic convergence aim to inform policy makers. The models used to measure regional economic convergence usually include some summary measures of population age structures as covariates (Ezcurra, 2007; Crespo Cuaresma *et al.*, 2014; Borsi and Metiu, 2015). Implicitly, these models assume positive association between convergence or divergence in population age structures and convergence or divergence in economies whenever the positive association between less aged population structure and economic performance holds. This assumption is quite questionable, especially in the context of regional population projections (Giannakouris, 2008, 2010; European Commission, 2014). The interplay between population ageing and economic convergence is far from being straightforward and uni-directional.

We argue that convergence in population age structures is in itself an important subject of study and possible policy targeting. Apart from purely economic reasons, there are numerous reasons why a balanced regional variation of population age structures could be desired. Uneven distribution of elderly population matters a lot for the provision of health care (Kinsella, 2001; Dijkstra *et al.*, 2013; Wister and Speechley, 2015). Disproportional ageing of some peripheral regions pose challenges for local housing planning (Bevan, 2009; Reher and Requena, 2017). Accelerating rural depopulation may cause an additional pressure on key infrastructure systems like energy supply (Liu *et al.*, 2017) or schools (Haartsen and Van Wissen, 2012; Barakat, 2014; Elshof *et al.*, 2014). There is some evidence of a clash of interests between generations in the publicly discussed decisions of education funding – elderly local societies are less willing to allocate public money to education (Schlaffer, 2018). Even the social institutions like democratic elections turn out to be quite vulnerable to differential ageing at the local level (Sabater *et al.*, 2017).

This thesis aims to look at the role of demographic change in the evolution of inequalities in population age structures across regions of Europe. It strives to increase our understanding of the demographic processes that shape regional population age structures, and how these processes are interrelated with regional economic development. The analysis is focused on changing relative differences over time, i.e. convergence or divergence.

Regional focus

The main focus of the present thesis is on regions. Quite often broad demographic conclusions on the prospects of population ageing are drawn from a country-level analysis (Wilson, 2001; Lutz *et al.*, 2008; Bloom *et al.*, 2015). Even though large differences exist between countries, a much bigger divide exists at the regional level, and the various effects of population ageing are much less researched in sub-national context (Andrews *et al.*, 2007; Rees *et al.*, 2012; Sabater *et al.*, 2017). For once, redistribution of population through internal migration plays a key role in the understanding of population dynamics (Rees *et al.*, 2013, 2017), and substantial differences distinguish centrally located and urbanized areas from the peripheral rural areas (Faggian *et al.*, 2017; Gutiérrez Posada *et al.*, 2018).

Throughout the thesis, with the exception of the **second chapter** where we have a more detailed picture for one particular point in time, we use a harmonized dataset on population age structures at the NUTS-2 level of administrative division in Europe – the one with most comparable and readily available statistical data. One of the objectives of NUTS was to provide a more or less comparable administrative division for all countries of Europe (European Commission, 2014). Nevertheless, in 2013, population figures for single NUTS 2 regions ranged from 28.5 thousands in Aland island (Finland) to almost 12 million in Ile-de-France (Paris and surroundings, France). We removed from consideration the non-European remote domains and territories of France, Portugal, and Spain; and we keep the United Kingdom in the analysis despite Brexit.

We divide Europe into three parts: eastern, southern, and western. Initially, we tried to use the official subdivision of European countries into northern, western, southern and eastern parts (EuroVoc, 2017). But the subset of northern regions turned out to be too small and heterogeneous. So to obtain more meaningful groups we merged Scandinavian regions with Western Europe and Baltic regions—with Eastern Europe.

Context and period overview

The study period in this thesis is spanning from the beginning of 2003 to end of 2012. Boundary changes (Eurostat, 2015) pose a considerable challenge in regional studies, and the revisions of the NUTS system together with the lower availability of regional level data defined our study period. Nevertheless, the study period happened to be uniquely interesting because it includes major shifts both in economies and population age structures. First, in 2004 happened the biggest enlargement of European Union that largely affected economic prospects of the newly admitted countries of Central and Eastern Europe and radically reshaped the intra-European migration landscape (Crespo Cuaresma *et al.*, 2008, 2015; Bosker, 2009; Okólski and Salt, 2014). Second, Europe was heavily stricken by the economic crisis of 2008-2009 (Crespo Cuaresma *et al.*, 2014; Percoco, 2016). Both events affected the process of economic convergence making the period very interesting to study (Ertur *et al.*, 2007; Dall'Erba *et al.*, 2008; Fingleton *et al.*, 2012; Doran and Jordan, 2013; Borsi and Metiu, 2015). The uneven impact of the economic crisis across Europe is of particular importance for convergence: the catching up East-European regions seem to recover rapidly while the falling behind South-European regions are the most stricken with the economic crisis (Salvati, 2016; Salvati and Carlucci, 2016). Finally, the second part of the study period was marked with the accelerated graying of relatively large baby-boom generation cohorts that started to leave the working age in 2010s changing the population age compositions faster than ever before (Lanzieri, 2011; Reher, 2015).

During the study period, the main difference in the share of the working-age population in Europe was between post-communist countries and the rest of Europe (Figure 1). The regions of Eastern Europe fully appreciated the benefits of demographic dividend only after the fall of the Eastern Bloc in 1990, when fertility dropped dramatically. In the rest of Europe, the demographic dividend started to wear off much earlier, in many countries, even before the start of the European Union's Regional Cohesion Program in 1990. The relative advantage of East-European regions in ageing was prominent within the study period, but it will almost disappear in the coming decades.

A steep decline in the share of the working-age population happened almost uniformly in Europe after 2010. The main reason for that is cohort turnover – the baby-boom generation, born after 1945, started to cross the age line of 65 accelerating ageing (Reher, 2015). Naturally, the "aftershock" of such a massive demographic perturbation of the past, as was the baby-boom in the Western world, is very perceptible (Van Bavel and Reher, 2013). The baby-boom was stronger in Northern and Western Europe, but the effect of baby-boomers' retirement on the share of the working-age population was partially leveled by changes in migration trends after the economic crisis of 2008; Northern and Western Europe experienced rise of in-migration at working ages, while less economically competitive regions of Eastern and Southern Europe experienced a drop of in-migration or even out-migration at working ages (Wilson *et al.*, 2013).

Measuring convergence

When one wants to answer a seemingly simple question – whether differences between regions increase or decrease over time – the result may vary depending on the choice of the estimation strategy. Since the rise of the convergence debate in economic literature (Baumol, 1986; Barro, 1991; Quah, 1993a) two main approaches stood out. The first was focused on finding associations between relative regional changes over time and the initial distribution (Barro and Sala-i-Martin, 1992); due to the main conclusions being drawn from the value of the regression coefficient, the method was named *beta-convergence* – a negative beta parameter (regression slope) means the regions with lower initial levels grow faster catching-up with the leaders. An alternative approach focuses on the development

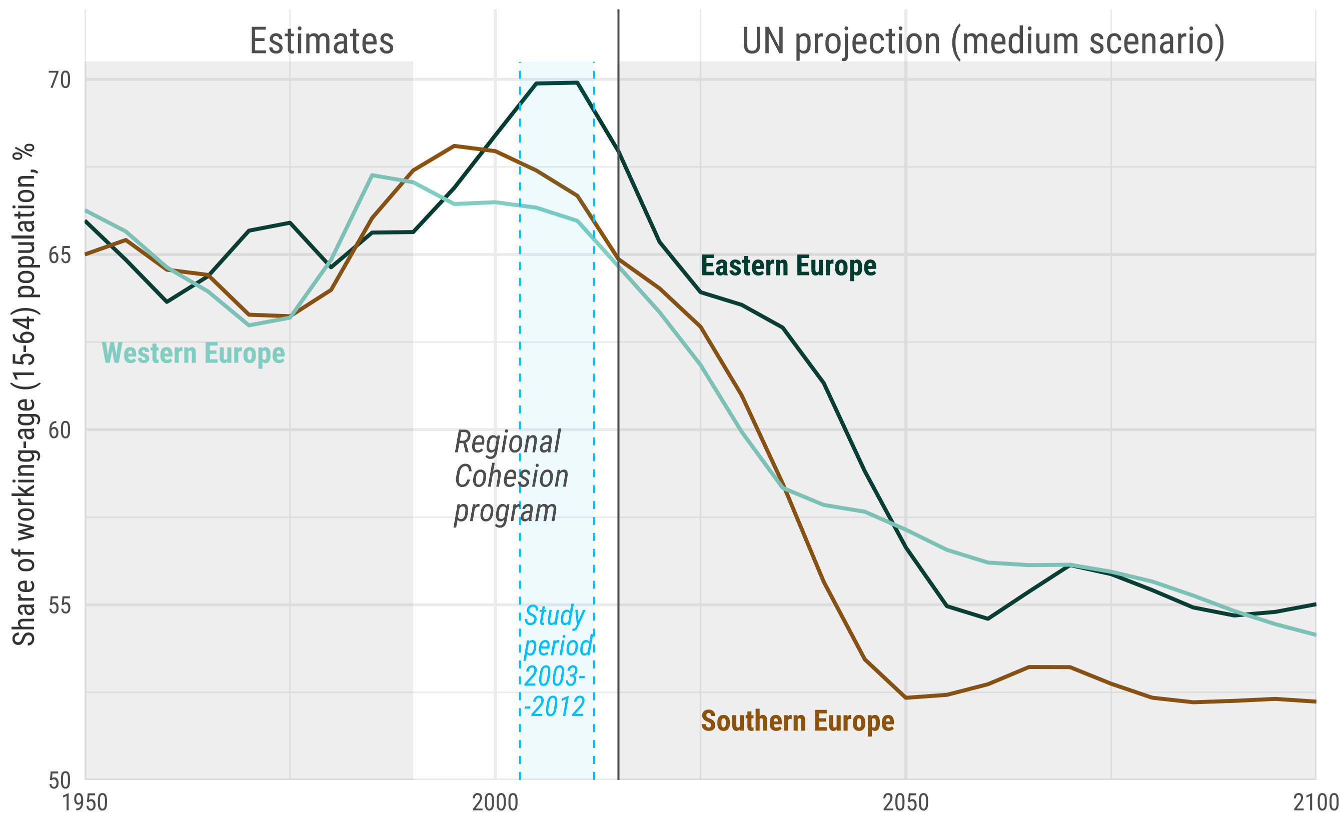

Fig. 1. Asynchronous demographic dividend in Europe: dynamics of the share of working age population in parts of Europe during the period 1975-2025. Source: UN Population Division, 2015. Note: within each part, data for countries are weighted by the number of NUTS-2 regions in countries for compatibility with the rest of the results at regional level.

of the overall variance over time; it got the name *sigma-convergence* after the Greek letter conventionally used to denote variance (Quah, 1993a).

At some point, the choice of a proper approach to quantify convergence caused quite a heated debate. When the seminal papers by Robert Barro and coauthors (1990, 1992; 1991) quickly gained popularity and started to determine the consensus scientific position on reducing income inequalities in many particular contexts, Danny Quah (1990, 1993b) pointed out that beta-convergence models are systematically flawed due to the regression to the mean, a statistical effect often referred to as Galton's fallacy (Galton, 1886). Independently, Milton Friedman (1992) noted the same fallacy and suggested a way to unify both statistical tests, an intuition which years later Edmund Cannon and Nigel Duck (2000) proved formally. Defending beta-convergence, Xavier Sala-i-Martin (1996a) considers ordinal ranking of teams in sport league tables. In this example, where variance is constant by definition and thus no sigma-convergence is possible, one can still be interested in the relative upward or downward movement of teams and can pose questions about time needed for a top-performing team to become average or for an underdog to turn great. These relative distribution perturbations are captured by beta-convergence. Sala-i-Martin concludes that beta-convergence analysis can and should enrich the results of sigma-convergence analysis, and it is not a valid idea to simply dismiss it due to the possibility of random fluctuations effect. Following him we apply both concepts to the study of changing regional differences in population age structures in Europe.

In fact it is formally shown that beta-convergence is a necessary but not a sufficient condition for sigma-convergence (Sala-i-Martin, 1996b). Due to random fluctuations, beta-convergence can occur even though sigma-convergence does not show a decrease in dispersion. First, if the proportion of working-age population in some regions is high or low at the start due to random fluctuations, one may expect that in subsequent periods these regions move closer to the average due to regression to the mean. This may result also in sigma-convergence. Second, if random fluctuations are large at the end of the period, dispersion across regions may be large (thus, no sigma-convergence) even though the regression slope coefficient is negative and significant indicating beta-convergence. Yet, demographic structures are quite stable, thus, random fluctuations are not likely to play a major role in our analysis.

Even though, sigma- and beta-convergence are formally interrelated (Friedman, 1992; Sala-i-Martin, 1996b; Cannon and Duck, 2000), each of the approaches reveals only a part of the convergence story. Sigma-convergence, like all other measures of inequality, shows if the overall dispersion decreases; beta-convergence identifies whether regions, on average, move towards the mean value. Combining both approaches, as we do in this thesis, helps to achieve deeper understanding (Sala-i-Martin, 1996a; Janssen *et al.*, 2016).

Yet both primary approaches – sigma-convergence and beta-convergence – rely on collapsing the whole distribution of elements to a single *summary point-estimate* – a measure of variance or the regression slope coefficient, correspondingly. In doing so the analysis looses all the rich information on the development of the *whole distribution*. This comes specifically important when dealing with the interplay of regional convergence in inter-related phenomena as we show in the **fourth chapter** exploring the interplay between convergence in economic development and convergence in population age structures and in the **fifth chapter** exploring the interplay between urbanization and convergence in population age structures in different parts of Europe. In both cases the complex inter-relation between the phenomena is completely masked in the conventional analysis based on summary measures and can only be understood by studying how the lower and upper tails of the distributions of groups of regions develop over time. With the distributional approach we manage to understand why convergence in population age structures does not necessarily imply convergence in economic performance and why the ongoing urbanization does not necessarily lead to divergence in population age structures. In the **sixth chapter** we go one step further and recognize that the distribution of regions consists of population age distributions that can also provide more information than just a point-estimate summary measure like the proportion of people at working ages. In this last paper we experiment with a new measure of convergence in population age structures based on the variance of regional distributions represented as ternary compositions. One important methodological goal on the thesis is to explore how going beyond the standard convergence techniques and use of basic summary measures can help us to uncover the otherwise hidden complex regularities.

Thesis outline

The present thesis consists of seven chapters: a common introduction, five interrelated studies, and common concluding remarks. You are reading the **first chapter**, which introduces the PhD project.

The **second chapter** uses an innovative data visualization technique of ternary color-coding to illustrate the variability of population ageing across Europe. Population age structures are represented as ternary compositions with proportions of kids, adults, and elderly people, and each ternary composition is mapped to a unique color produced by ternary color-coding. The resulting detailed map serves as a snapshot of the current state of population ageing at regional level in Europe. It depicts both large-scale and small-scale regional differences in population structures.

The **third chapter** explores the demographic sources of convergence/divergence in regional population age structures. The key measure in the paper is the Total Support Ratio, the ratio of people at working ages (15–64) to those outside the age range. We decompose changes in the Total Support Ratio in two steps. The change in population composition is decomposed into the separate effects of changes in the size of the non-working-age population and of the working-age population. The latter changes are further decomposed into the effects of cohort turnover, migration at working ages and mortality at working ages. The beta-convergence framework is used consistently to measure the partial demographic effects on convergence/divergence in the Total Support Ratio.

The **fourth chapter** addresses the most evident practical issue of studying convergence/divergence in population age structures – the interplay between regional dynamics in population age structures and economic development. The paper challenges the widespread assumption that convergence/divergence in population age structures always positively correlates with convergence/divergence in economic output. As we show, this is rarely true, and the reality is much more nuanced. The interplay between convergence/divergence in population age structures and convergence/divergence in regional economies depends on which particular groups of regions drive changes in the variance in the respective distributions.

The **fifth chapter** investigates the role of urban/rural differences in the convergence/divergence story. Since urbanization is a process operating at a low geographical level, and we consistently analyze NUTS-2 regions in this study, first we check if a process of urbanization happens at NUTS-2 level during our study period. Unlike classical beta and sigma approaches to convergence, in this study we focus not on one single summary statistic of convergence, but rather analyze the whole cumulative distribution of regions. Such an approach helps to identify which specific group of regions is responsible for the major changes.

The **sixth chapter** emphasizes the need to go beyond summary point estimates of population age structures in convergence analysis and presents a ternary compositions approach to convergence/divergence in regional population age structures. Standard convergence analysis deals with a distribution of point estimates across a number of analysis units. The presented distributional approach recognizes that each unit of analysis has its own distribution of the phenomenon we analyze, in our case – population age distribution. Such an approach helps to uncover the stories when changes in different parts of the units' distributions drive the overall variance in different directions. The ternary approach to convergence in population age structures highlights the different effects of relative changes in the proportions of kids, adults, and elderly people across the regions of Europe.

The final **seventh chapter** summarizes the main findings of the presented studies.

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Chapter 2. Regional population structures at a glance

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Population ageing is the major demographic challenge for humanity. Since population structures evolve rather slowly and predictably, the demographic, economic, environmental and social problems of ageing have been anticipated and discussed for many decades (Lee, 2011). Yet in the prime focus of these discussions has always been elderly population, with elderly people often defined as those older than a threshold—eg, 65 years or age at retirement—or with a certain number of estimated remaining years of life (Sanderson and Scherbov, 2010). Such a focus is quite reasonable and understandable, but not entirely correct. Ageing is not exclusively about the size of elderly population or its proportion in a population; ageing is a function of the whole age distribution of a population. Therefore, to understand ageing better, we need to focus on the evolution of the whole population age structure, not just the elderly part of it.

We offer a novel approach to visually investigate the diverse picture of population ageing in the present-day Europe. To map the whole population age structures rather than any single summary measure of ageing, we used ternary colour coding—a technique that maximizes the amount of information conveyed by colours. With this approach, each element of in a three-dimensional array of compositional data is represented with a unique colour. The use of colour mixtures to encode multiple data dimensions in a single attribute has been proposed by various authors. To our knowledge, ternary colour coding was first used in the context of map design by Olson (Olson, 1987). Later the approach has been used to map election results in a three-party system (Dorling, 1991), labor force composition by sector (Brewer, 1994), soil textures (Metternicht and Stott, 2003), composition of arctic sea-ice coverage (Denil, 2015), and cause-of-death compositions (Schöley and Willekens, 2017). We used colour coding to explore the differences in populations structures across Europe and provide the tools that we developed (Schöley and Kashnitsky, 2018) to streamline its use with R (R Core Team, 2017).

The diverse picture of colour-coded age structure of European regions (Figure 1) indicates varying stages of population ageing across Europe. The process of population ageing is not happening uniformly in all parts of Europe (Kashnitsky *et al.*, 2017) and regions differ quite a lot: eastern Europe is still undergoing demographic dividend, southern European regions are forming a cluster of lowest-low fertility, the baby boomers are ageing in western Europe, urban regions are attracting young professionals and forcing out young parents, and peripheral rural regions are losing their youths forever. Colour coding allows to map all regional population structures in Europe simultaneously. This map is not meant to easily inform the reader of the exact population structure in a specific region, rather, it provides a highly detailed snapshot of all the regional population structures, facilitating comparisons between them. One limitation of the approach is that the maps are not easily interpreted and usable by those who are colour blind; however, our generalised function that mixes colours (Schöley and Kashnitsky, 2018) makes it easy to change colours by rotating the colourspace, thus enabling those who are colour blind to use this setting more readily.

In the figure, we can clearly see large-scale and small-scale regional differences in population structures. At the macro level, the distinctions between Eastern, Western, and Southern Europe are evident. Eastern Turkey is the only example of a society that is still at the early stages of demographic transition. At the country level, the center-periphery contrasts are prominent. We can easily spot all capital regions and major urban areas that have a large working-age population, and their surrounding areas where families with kids tend to settle (ie, the suburbs of Paris). The population of the remote periphery ages at an accelerated pace because of out-migration of young individuals. Country borders are highly important because they often demarcate territories with different demographic histories (ie, Germany–Poland border). The map also reveals the signs of recent dramatic changes in population structures. For example, Spain received a tremendous inflow of international migrants in 2000s (Wilson *et al.*, 2013), eastern Germany experienced a draining effect of out-migration coupled with a drop in fertility levels in the last decades (Kemper, 2004), and Poland has had a massive labour out-migration because of European Union integration and more labour migrants moved from major Polish cities (Okólski and Salt, 2014). This map is a snapshot of European population at the regional level, and it tells numerous demographic stories.

Ternary colour coding is a useful and intuitive way of displaying three-component compositions at once. We strongly propose a wider use of the presented approach.

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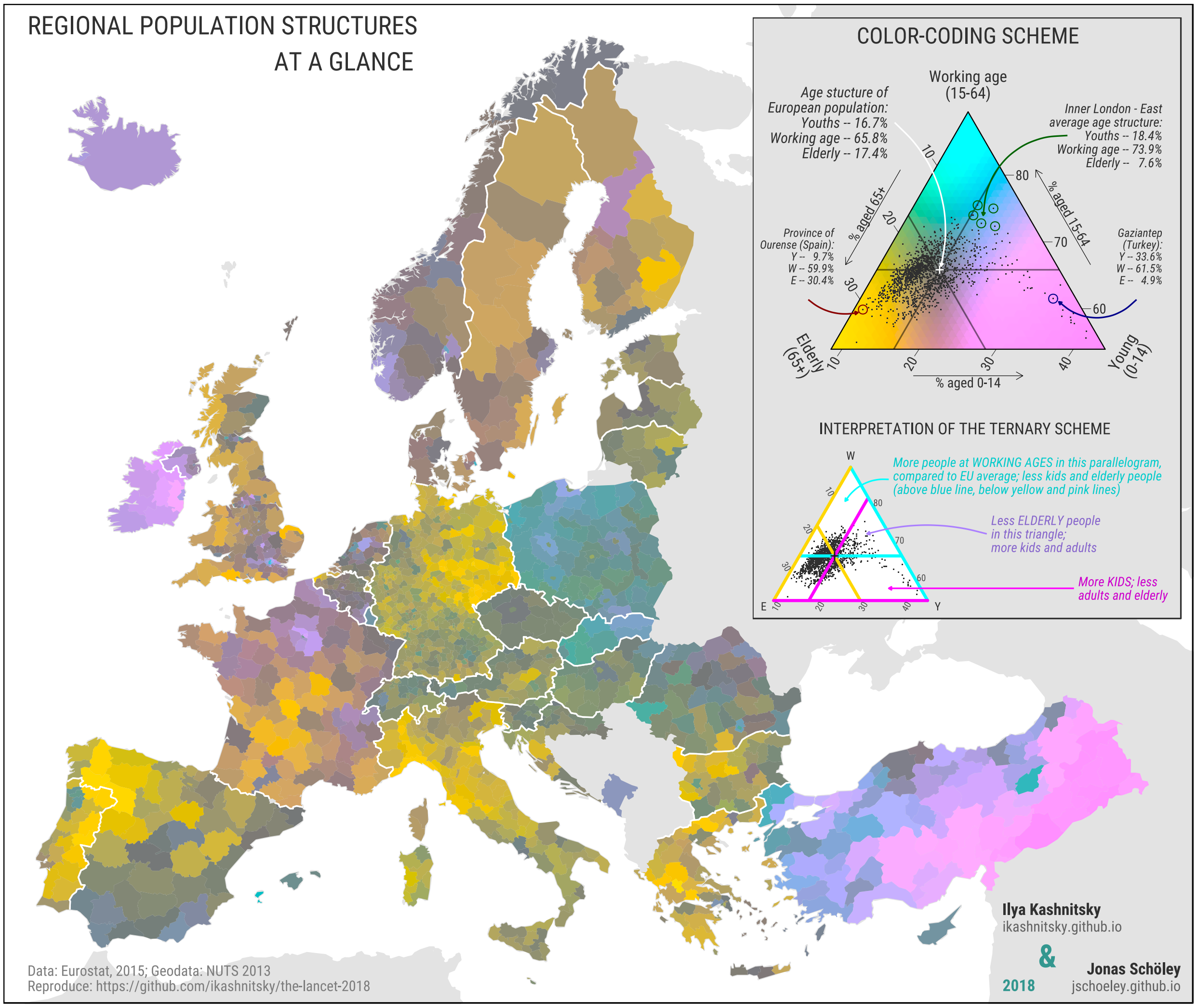

Fig. 1. Colour-coded map of population structures in European NUTS-3 regions in 2015. Each NUTS-3 region's population composition is uniquely colour coded. Colours show direction and magnitude of deviations from the center point, which represents the average age-composition of European population and has a dark grey colouring. Hue component of a colour encodes the direction of deviation: towards yellow – more elderly population (65+); cyan – more people at working ages (15-64); magenta – more kids (0-14). Chroma and lightness components signify the distance from the center ranging from desaturated and dark colours near the center to vivid and bright colours at the corners. The smaller schematic ternary plot at the bottom of the legend explains how to interpret the six different regions in the ternary colour key. We provide R code to fully reproduce this map.

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Chapter 3. Decomposition of regional convergence in population ageing across Europe

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1. Introduction

One of the long-lasting policy goals of European Union is to equalize as Population ageing is the most evident demographic challenge of European countries and regions. The unprecedented increase in the share of the elderly population raises concerns about the sustainability of social and economic developments (Feldstein, 2006; Bloom *et al.*, 2015). The sharp increase in the proportion of the elderly dependent population is expected to have a significant negative impact on pension systems (Gruber and Wise, 2008; Ediev, 2013; Hammer and Prskawetz, 2013), social and health care (Mahon and Millar, 2014), and public and personal transfers towards the elderly (Lee and Mason, 2010; Dukhovnov and Zagheni, 2015).

Differences in the past and current developments of demographic structures contribute to substantial spatial variation of ageing across European countries (Diaconu, 2015) and across regions (Gregory and Patuelli, 2015). Regional policies in European Union aim to reduce variation in all aspects that can influence differentiation in the quality of life, including demographic developments (Giannakouris, 2008; Commission, 2014). According to the European Commission's logic, convergence in ageing is desirable because it will contribute to the reduction in regional life quality disproportions.

In this paper we apply the widely used concept of beta-convergence to study how relative differences in ageing evolve (Baumol, 1986; Barro, 1991; Barro *et al.*, 1991). Beta-convergence utilizes linear regression approach to check the relationship between the growth and the initial distribution: if regions at the bottom of the initial distribution experience faster growth, then the variance of the distribution reduces by the end of the modeling period. To our knowledge, no other paper has explicitly analyzed population ageing using the convergence research framework. Lacking any prior empirical evidence on the matter, one can distinguish two contrasting hypotheses about the possible developments of the regional differences in population ageing. First, it seems reasonable to expect convergence in ageing at the end of the Demographic Transition in Europe: European countries move along the Demographic Transition path with varying timing and pace, and the differences should diminish by the end of the process when populations approach the post-transitional replacement regime. Alternatively, the process of urbanization is likely to contribute to a divergent pattern of ageing: urbanized regions tend to attract population at working ages, while rural regions are left with a higher proportion of people out of the labor market.

In this paper we examine the first hypothesis. For this purpose we analyze how regional differences in ageing have changed over the period 2003-2012. In addition we examine whether current trends in regional variation in ageing will continue. For this reason we examine Eurostat regional population projections for the upcoming three decades. In order to examine to what extent policy measures could be effective in promoting convergence in population ageing we assess the causes of changes in the working-age population: migration, mortality and cohort turnover. Cohort turnover is defined by the difference between the numbers of young people entering and older people leaving the working ages. To the extent that cohort turnover affects convergence in ageing, there is little room for policy options as the impact of cohort turnover can only be affected in the long run. To the extent that mortality affects convergence in ageing, one main question is whether convergence in mortality would lead to convergence in ageing. To the extent that migration affects convergence in ageing, policy makers may aim to affect the direction of migration flows between regions and countries.

We identify the role of demographic components that cause changes in the ratio of the working-age to the non-working-age population (total support ratio, TSR), thus influencing convergence in ageing. For that reason, we decompose the convergence in TSR into the effects of changes in the non-working-age population and changes in the working-age population. The latter is further decomposed into the effects of cohort turnover, migration at working ages, and mortality at working ages. Finally, we examine the time differences of convergence in TSR during the observed and projected parts of the study period. The temporal decomposition of convergence in ageing helps to identify the turning points in the recent development of regional differences in population structures and examine the possible future development.

2. Demographic transition and convergence in ageing

The demographic development after the baby boom is characterized by accelerating population ageing, as the relatively large cohorts of the baby boom come out of working ages, and below-replacement fertility does not provide equally large successive cohorts (Lee, 2003). Thus, it seems reasonable to expect convergence in ageing at the end of the Demographic Transition in Europe: European countries move along the Demographic Transition path with varying timing and pace, and the differences should diminish by the end of the process (Coleman, 2002). For example, as Dudley Kirk points out (Kirk, 1996::366), similarities in demographic transition made United Nations and World Bank base their population forecasts on the assumption of a standard transition. Though, different timing of the second demographic transition due to cultural and behavioral variability (Lesthaeghe, 2010) may affect the speed of convergence in ageing considerably. Thus one important question is whether the variability in population ageing does or does not lead to convergence in ageing at the regional level in Europe and whether future changes may be different from recent trends. We expect that cohort turnover, which reflects the existing disproportions in population structures, will lead to convergence in ageing, but it is less obvious what will be the effect of mortality and migration.

In this paper we use the methodological concept of beta-convergence to test if the variation in ageing across European regions has increased or decreased. This method was originally developed in the economic literature to study income inequalities (Baumol, 1986; Barro, 1991; Barro *et al.*, 1991). The method was rarely applied to demographic data before and, to our knowledge, was never used to analyze the development of regional differences in the population age composition. Previous demographic papers used convergence analysis techniques to study spatio-temporal regularities in mortality (Goesling and Firebaugh, 2004; Neumayer, 2004; Edwards and Tuljapurkar, 2005; Edwards, 2011; Tuljapurkar and Edwards, 2011; Richardson *et al.*, 2014; Janssen *et al.*, 2016) and migration (Barro and Sala-i-Martin, 2003; Ozgen *et al.*, 2010; Huber and Tondl, 2012; Kubis and Schneider, 2015).

With the use of convergence analysis we investigate whether regional differences in ageing increase or decrease over time in Europe. Beta-convergence occurs when regions which were less aged at the beginning of the study period experience stronger population ageing than the regions that were initially more aged. If there is beta- convergence, the model predicts that all regions would reach the steady-state level of population ageing in the future. If the condition is not satisfied, the modeling shows that the regions experience divergence, and there is no reason to expect a reduction in inequality.

3. Data and methods

3.1. Data. This paper uses Eurostat data on population structure (Eurostat, 2015a) and mortality records by one-year age groups regions of EU28[1] for the period 2003-2012 (EuroStat, 2015). The data are aggregated at the NUTS-2 level, version of 2010 (Eurostat, 2015b). At the moment of data acquisition (March 2015), mortality records covered the period up to 2012. For the majority of regions, data on population structure are available since 2003. Hence, the availability of data limited the observed study period to 2003-2012. We also used Eurostat regional projections (Eurostat, 2015c) for three more decades, 2013-2042.

For some regions, data were partially missing. Due to the changes in administrative division at the NUTS-2 level, there were no data for all five regions of Denmark before 2007 (Kashnitsky, 2017) and two regions in the eastern part of German, Chemnitz (DED4) and Leipzig (DED5) before 2006. Furthermore, mortality data were missing for Ireland in 2012, and population structure data were missing for Slovenia in 2003-2004. We reconstructed the missings using the data from national statistical offices.

Exploratory data analysis showed inconsistency of population estimates for the regions of Romania. There was a Census in Romania in 2011 that registered a large, and previously underestimated, decrease in population size. Evidently, the outmigration from Romania was underreported. Yet, no rollback corrections were made, and Eurostat provides non-harmonized data for Romanian regions. Thus, we harmonized the population figures for Romanian regions.[2]

Finally, we excluded all non-European remote territories of France, Portugal, and Spain,[3] which are outliers both in geographical and statistical terms.

The data set used for the analyses contains data for 263 NUTS-2 for the observed (2003-2012) and projected (2013-2042) periods.

3.2. Measuring ageing. We measure population ageing as a decrease in the ratio of the working-age population to the non-working-age population. In line with Eurostat and UN definitions, we consider ages 15 and 65 as the margins of the working-age population. Thus, the measure of ageing that we use is the ratio of population aged 15-64 to the population below 15 years of age and above 65. We call this indicator the Total Support Ratio (TSR), which is in fact the inverse of the widely used Total Dependency Ratio (Division, 2002). There is some confusion around the use of the term Support Ratio in the literature. Quite often children are not included in the calculation of the Support Ratio (O'Neill *et al.*, 2001; Lutz *et al.*, 2003; Lutz, 2006). In that case, the indicator only shows the relative burden of the elderly population; UN Population Division (Division, 2002) calls this indicator Potential Support Ratio. In other papers, that deal not only with age structures of population but also with labor force participation and transfer accounts, by Support Ratio authors usually mean the ratio of effective labor to effective consumers (Cutler *et al.*, 1990; Lee and Mason, 2010; Prskawetz and Sambt, 2014). Another definition says that the Support Ratio is the size of the labor force as a share of the adult population (Börsch-Supan, 2003). We prefer to explicitly call the ratio of the working-age to the non-working-age population the Total Support Ratio, in line with the logic of the three versions of Dependency Ratio: Total, Youth, and Old-age.

[1] Currently (as of 2017), European Union consists of 28 countries, which are the following: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, The Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and UK.

[2] Using 2003 population structure as the reference and the mortality data, we estimate cohort-wise the anticipated population structure in 2012 with an assumption of no migration. The difference between the estimated and the observed population is explained by migration. While harmonizing the data, we kept the observed migration trends and distributed the excessive migration evenly across all the years of observation before 2012.

[3] The excluded NUTS-2 regions are the following: ES63, ES64, ES70, FR91, FR92, FR93, FR94, PT20, and PT30.

3.3. Decomposition of growth in the Total Support Ratio.

To explain which demographic factors cause changes in the TSR we apply a two-step decomposition. First, we examine to what extent changes in the TSR are due to changes in the size of the working-age population and to what extent to changes in the size of the non-working-age population. Second, we examine the demographic causes of changes in the working-age population.

At the *first step*, the overall change in the TSR is decomposed using the formula of Das Gupta (DasGupta, 1991):

$$
\begin{aligned}
TSR_2 - TSR_1 &= \frac{W_2}{NW_2} - \frac{W_1}{NW_1} \\
&= \left[\frac{1}{2}\cdot(W_2 + W_1)\cdot(\frac{1}{NW_2} - \frac{1}{NW_1})\right] \\
&+ \left[\frac{1}{2}\cdot(\frac{1}{NW_2} + \frac{1}{NW_1})\cdot(W_2 - W_1)\right]
\end{aligned} \tag{1}
$$

where W is working-age population; NW is non-working-age population; subscripts 1 and 2 denote the beginning and the end of the period, respectively. The two right hand side terms of equation 1 represent the effects of changes in non-working-age and working-age populations on the TSR, respectively. Note that changes in W affect both the first and second terms, but the effect on the first term is very small compared with that on the second term. The average change in the first term due to the changes in the working-age population over all 263 regions was only -0.7% with a standard deviation of 3.3%.

At the *second step*, the working-age term in the second term of the right hand side of equation 1 is decomposed further into changes due to the three components of the demographic balance at working ages: cohort turnover, migration, and mortality.

To estimate the components of change in working-age population we use the demographic balance formula:

$$
W_2 = W_1 + CT + M_W - D_W \tag{2}
$$

where CT is cohort turnover between periods 1 and 2, M_W is net migration at working ages, and D_W is the number of deaths at working ages. As the accuracy of migration records is always a problematic issue, following De Beer *et al.* (2012), we derive net migration at working ages indirectly from equation 2 for the observed period, 2003-2012. For the projected period, 2013-2042, the migration data are provided by Eurostat, so we derive the numbers of deaths using the demographic balance formula. Cohort turnover is calculated as the difference between people entering working ages, aged 14, and people leaving working ages, aged 64.

Replacing the $W_2 - W_1$ part of the working-age term in equation 1 using the demographic balance formula, equation 2, yields:

$$
\begin{aligned}
\frac{1}{2}\cdot(\frac{1}{NW_2} + \frac{1}{NW_1})\cdot(W_2 - W_1) &= \left[\frac{1}{2}\cdot(\frac{1}{NW_2} + \frac{1}{NW_1})\cdot CT\right] \\
&+ \left[\frac{1}{2}\cdot(\frac{1}{NW_2} + \frac{1}{NW_1})\cdot M_W\right] \\
&+ \left[\frac{1}{2}\cdot(\frac{1}{NW_2} + \frac{1}{NW_1})\cdot D_W\right]
\end{aligned} \tag{3}
$$

The three right hand side terms of equation 3 denote the effects of cohort turnover, migration at working ages, and mortality at working ages on TSR, respectively.

3.4. Beta-convergence approach to ageing.

To estimate beta-convergence we use the classical linear regression model specification, where change in a variable (in our case, total support ratio) over some period is regressed on the initial level. The specification looks as follows,

$$
TSR_2 - TSR_1 = \alpha + \beta TSR_1 + \varepsilon \tag{4}
$$

where TSR is total support ratio, α is the intercept of the regression line, β is the regression coefficient, ε is the error term. If the regression coefficient is negative, then beta-convergence is observed between years 1 and 2, meaning that the change in TSR is negatively correlated with the initial level of the TSR. Thus beta-convergence implies that a region with a relatively high TSR experiences less growth in the TSR than a region with a low TSR.

In convergence analysis, weights reflecting population sizes are often used (Theil, 1989; Goesling and Firebaugh, 2004; Milanovic, 2005; Dorius, 2008). Population-weighted convergence analysis shows whether inequality in the population becomes smaller; unit-weighted (in fact, non-weighted, as all units receive equal weights) convergence analysis tests whether the differences between units (countries/regions/districts) decrease. In this study, we are interested in the development of European regions as statistical units, thus, we choose the unit-weighted convergence analysis. Our choice is driven by the fact that European Cohesion policy is aimed at regions, irrespective of their population sizes.[4]

The specification of the regression model allows to perform a decomposition of convergence (the beta coefficient) into various separate effects. To understand how each of the demographic factors contributed to beta-convergence in ageing, we decompose the dependent variable, the change in TSR (see the previous sub-section), and run separate regressions for each partial change in TSR keeping the explanatory variable, the initial value of TSR, constant. A partial regression model shows the beta-convergence of regions taking into account only the change in

[4] One of the objectives of NUTS was to provide more or less comparable administrative division for all countries of Europe. Nevertheless, in 2013, population figures for single NUTS 2 regions ranged from 28.5 thousands in Aland island (Finland) to almost 12 million in Ile-de-France (Paris and surroundings, France).

TSR due to the component under consideration. As the components of change in TSR add up to total change, and all the partial models have the same regressor, beta-coefficients of the partial models add up to the total effect. That means, beta-coefficients from convergence models for the change in TSR due to the dynamics of non-working-age population (w) and working-age population (nw) add up to the beta-coefficient of the overall model (g); and beta-coefficients from the models for cohort turnover (ct), migration at working ages (mg), and mortality at working ages (mt) effects on TSR growth add up to beta-coefficient from the model for the working-age population dynamics' effect. For the ease of notation, we will refer to the partial model using the above symbols in brackets.

To use further the additive feature of the models, we ran a separate regression for each partial change in TSR in each year, dividing the study period into 4 decades – for each of the decades, the initial TSR distribution is used as an explanatory variable. The temporal decomposition gives insight into how the convergence process evolves throughout the study period. Summing up, in this paper, we use two dimensions of the decomposition of convergence in ageing: demographic factors of the change in the TSR, and time.

3.5. Software. The analysis and the necessary data preparation were conducted using R, a language and environment for statistical computing, version 3.3.2 (R Core Team, 2016). The crucial additional packages include: dplyr (Wickham and Francois, 2015), tidyr (Wickham, 2016a), ggplot2 (Wickham, 2016b), viridis (Garnier, 2016), rgdal (Bivand *et al.*, 2015). All the scripts are in the attachment for reproducibility.

4. Results

4.1. Descriptive results. The maps in figure 1 clearly reveal the story of a rapidly ageing Europe. The first and the last maps show Total Support Ratios of European NUTS-2 regions at the beginning and at the end of the whole study period, 2003 and 2043, 10 observed and 30 projected years; color scales are fixed for easier comparison. Virtually every single region experience a substantial decrease in the TSR over the study period; the average of all European regions decreased from 2.02 in 2003 to 1.96 in 2013 and is projected to further decrease to 1.37 by 2043, a 33% decrease over a period of 40 years (Figure 2).

The spatial variation of the TSR across Europe is distinct both in the beginning and in the end of the study period. The spatial pattern seems very similar despite the 40 years of pronounced changes. Regions in Eastern Europe were relatively high in the initial distribution, and they are expected to remain in the top by the end of the study period: the dots in figure 2, colored according to the macro regions of Europe,[5] show quite limited perturbation over time, and the lines showing the averages of subregions suggest the same. Even though the difference between East-European regions and the rest of Europe narrows, the distribution pattern changes only slightly.

The most prominent changes happen in the regions of Eastern Germany, a very special part of Europe in terms of demographic development (Klüsener and Goldstein, 2016). Those regions were "closing the opportunities window" of demographic dividend at the beginning of the study period (Van Der Gaag and De Beer, 2015). Thus, they experienced the biggest drop in the TSR during the first decade (Figure 1-B). With a usual decade-long time lag, East-European regions are starting to experience a similar drop in the second decade of our study period (Figure 1-C). Yet, unlike Eastern Europe, the regions of Eastern Germany continue to descent from the top of the TSR distribution to the bottom. Quite a big decrease in the TSR happens in Southern Europe, especially in Spain, where the migration-driven temporary increase in the TSR is gradually changing towards a projected long-run decrease, which is mainly driven by population structure dynamics together with low fertility. The changes in the TSR over the four decades of the study period suggest that the East-West gradient in Europe is likely to change to a North-South gradient in the coming future.

The development of subregions' average TSR over the study period (Figure 2) demonstrates the cyclic effect of demographic waves, which is most evident for Eastern Europe but also visible for other two subregions – Southern and Western Europe. These demographic waves have a major effect on TSR, and thus may considerably affect convergence in ageing. The most interesting effect is the rapid TSR decrease that starts in 2010, when the large generation of European baby-boomers started to cross the 65 years boundary (Van Bavel and Reher, 2013; Reher, 2015).

Some specific regions experience development that differs much from the other neighboring regions. For example, London, the biggest economic center in Europe, succeeds in constant attraction of relatively young population, which results in extremely high TSR (see the top path in Figure 2 and also Figure 10 in appendix). In contrast, regions of Eastern Germany experienced massive out-migration that, coupled with a strong shock of lowest-low fertility in the recent past, results in a dramatic drop of TSR (see the bottom paths in Figure 2 and Figure 1).

4.2. Decomposition of TSR growth. As described in the methodological part of the paper, the overall change in the TSR (g) can be decomposed into the effects of changes in the non-working-age population (nw) and the effects of changes in the working-age population (w). The latter can be further decomposed into the effects of cohort turnover (ct), migration at working ages (mg), and mortality at working ages (mt).

Figure 3 presents the two steps decomposition of change in the TSR during the whole study period (similar sets of maps for each of the decades can be found in the Appendix, Figures 6, 7, 8, and 9). Each of the partial effects reveals substantial variation across NUTS-2 regions, countries and EuroVoc subregions. Not only the overall dynamics of the TSR are highly uneven, but also the dynamics of each component.

The map of the overall change in the TSR (Figure 3-A) highlights the areas that faced the biggest absolute change. Eastern

[5] We divide Europe into three subregions: eastern, southern, and western. Initially, we tried to use the official subdivision of European countries into northern, western, southern and eastern parts (EuroVoc, 2017). But the subset of northern regions turned out to be too small and heterogeneous. So we merged Scandinavia with Western Europe and Baltic regions—with Eastern Europe.

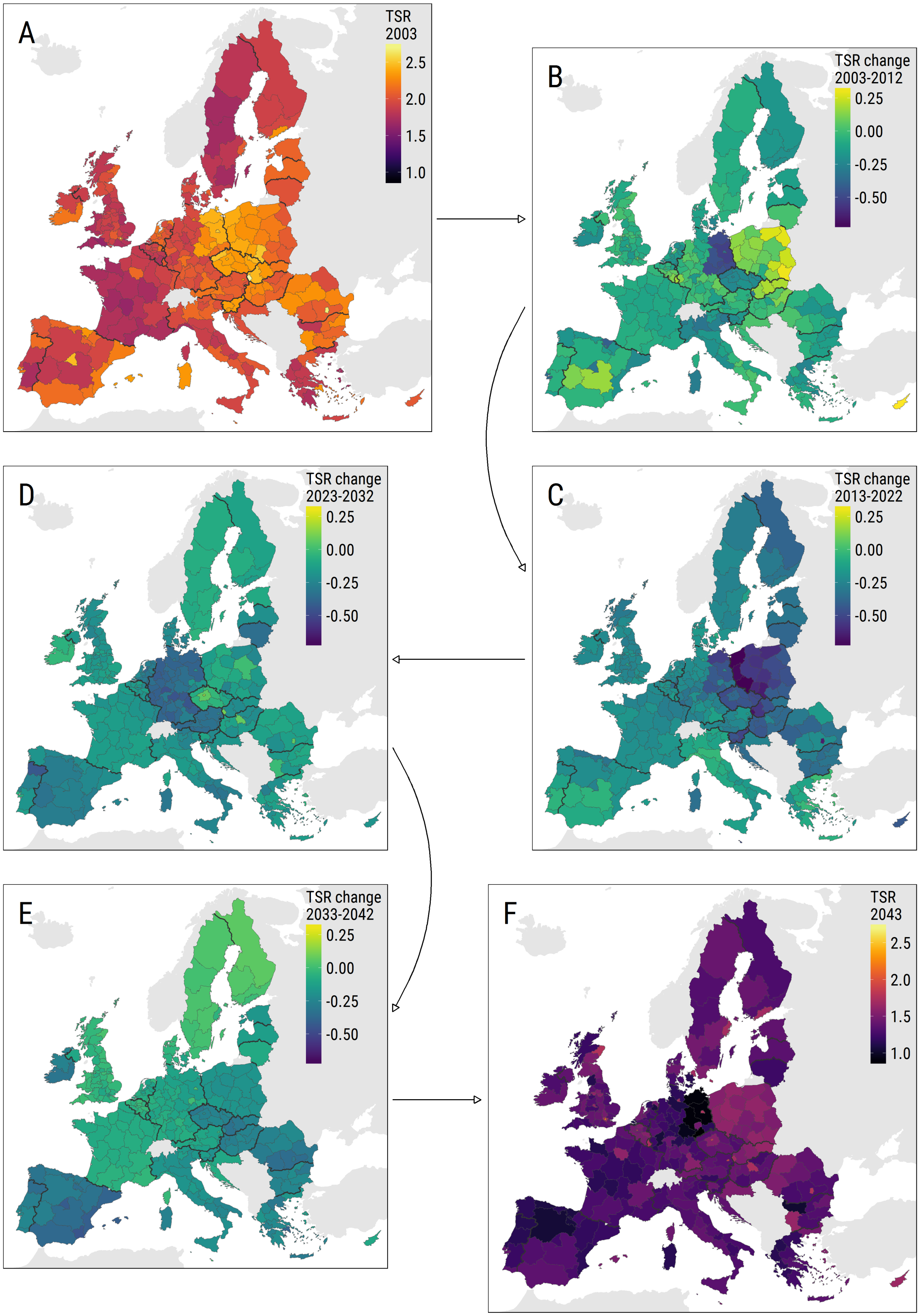

Fig. 1. Total Support Ratio dynamics in the 4 decades between 2003 and 2043. Notes: A – TSR in 2003; B – TSR growth during the observed period, 2003-2012; C, D, E – TSR growth in the 3 decades of the projected period, 2013-2022, 2023-2032, and 2033-2042, correspondingly; F – TSR in 2043. Color scales are fixed for better comparison: 1) in maps A and F; 2) in maps B, C, D, and E.

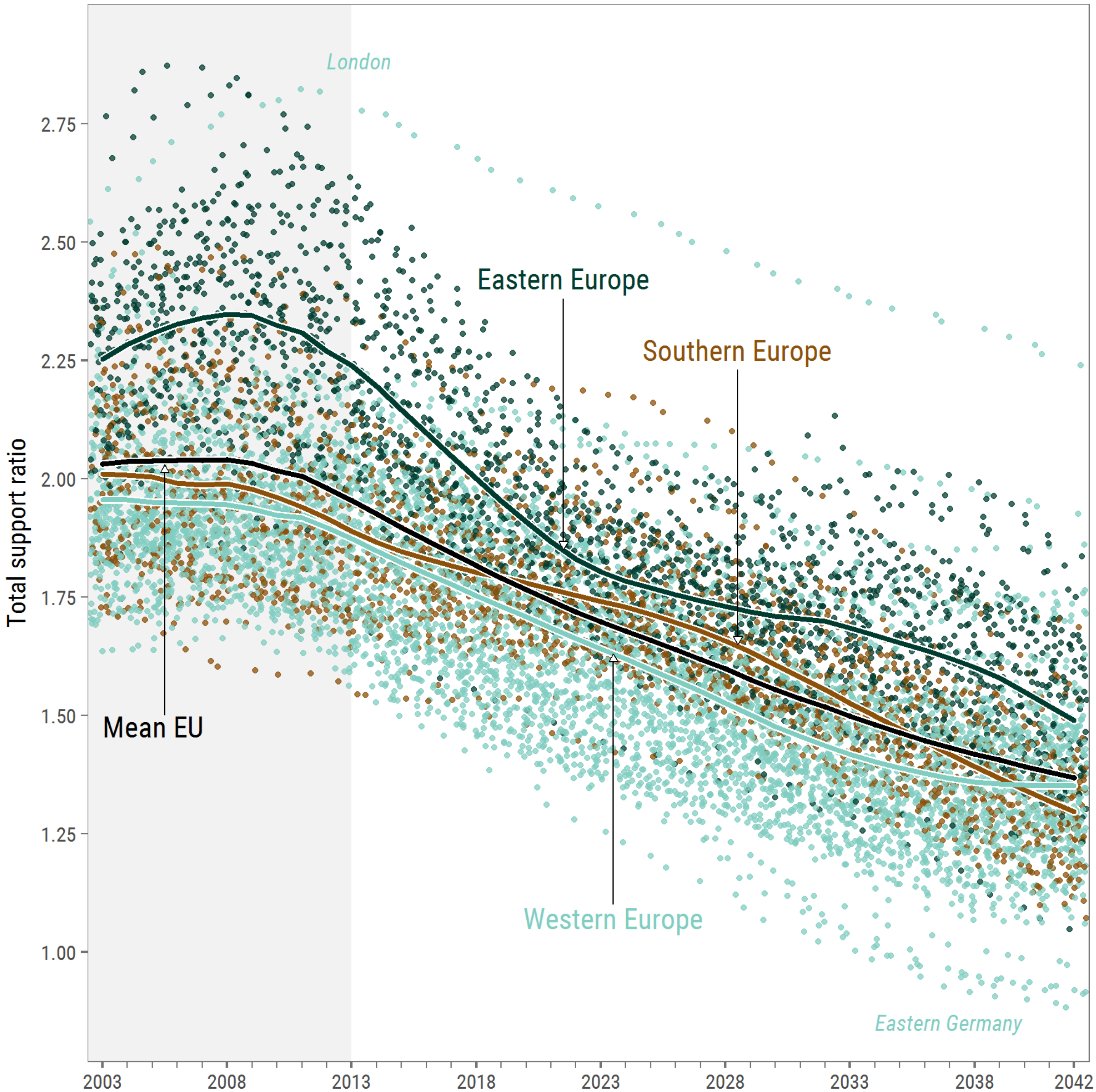

Fig. 2. Total Support Ratio dynamics in Europe during the period 2003-2042, NUTS-2 regions, four subregions' averages, and the European average. Notes: Each NUTS-2 region's TSR value in each year of the study period is represented with a point colored according to EuroVoc definition of European subregions. Lines represent group averages. The most prominent outliers (London – top; and 5 regions of Easrtern Germany, excl. Berlin, – bottom) are also labeled. Observed period marked with a light-grey background.

Germany experienced the most pronounced drop in the support ratio; with a considerable gap follow Czech Republic, Slovenia, Spain, Northern Italy, Hungary, and Bulgaria. The biggest increase happened in Belgium (particularly, in Wallonia, the Southern part) and Luxembourg, Sweden, United Kingdom, and Southern France.

The spatial variation in the TSR change due to the dynamics of non-working-age population (Figure 3-B) reveals two main findings. First, there is an evident North-South gradient, which can be explained by long-persisting European differences in fertility levels. Second, almost all major metropolitan regions are clearly visible because they experience a relatively sharp decline in the TSR due to the changes in the non-working-age population: Stockholm, Helsinki, Copenhagen, London, Amsterdam, Berlin, Prague, Budapest, Bucharest, Vienna, Paris, Rome, Madrid. Evidently, population replacement in the metropoli-

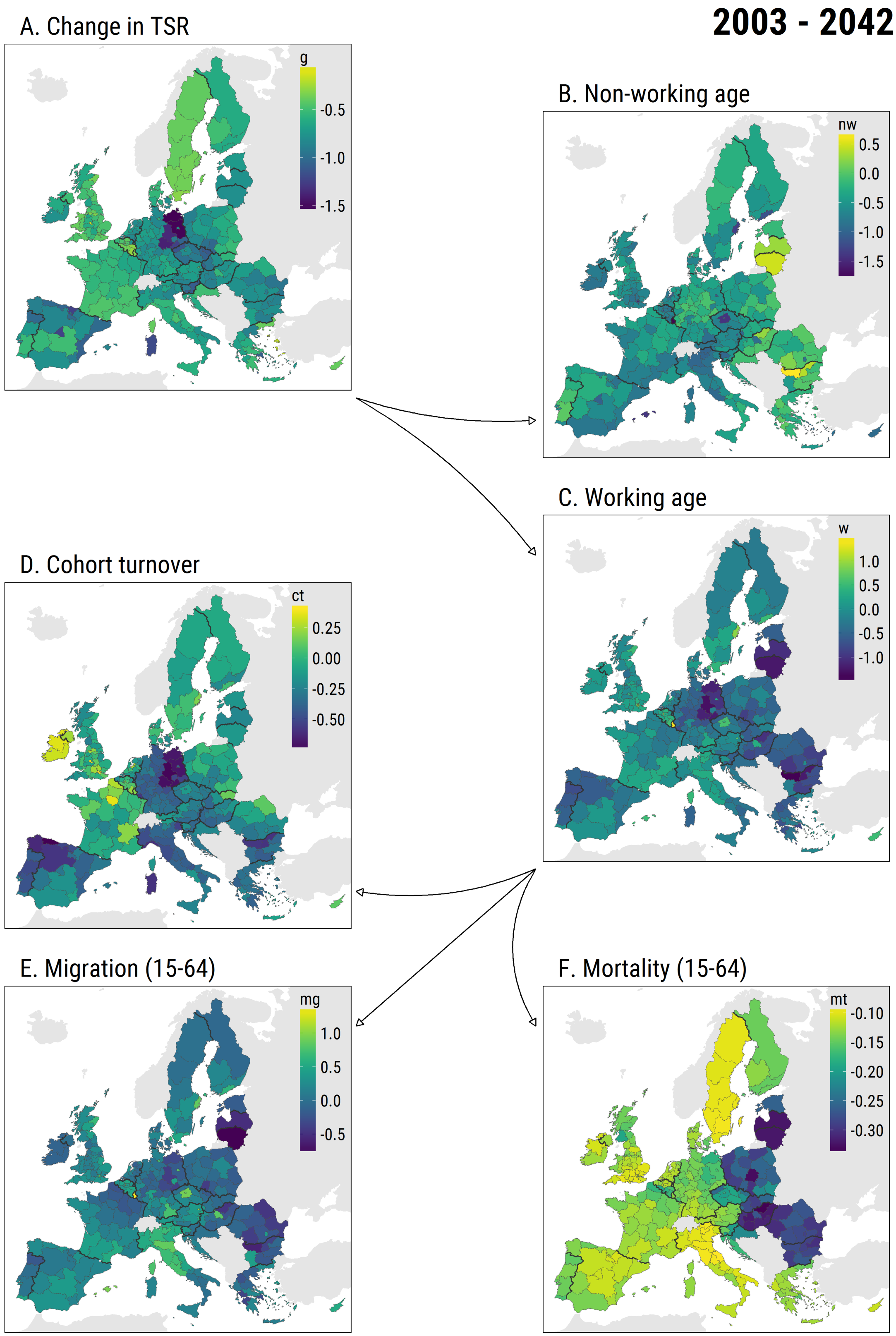

Fig. 3. Decomposition of change in TSR between 2003 and 2043. Notes: A – overall change; B – change due to dynamics in non-working-age population; C – change due to dynamics in working-age population; D – change due to cohort turnover; E – change due to migration at working ages; F – change due to mortality at working ages. Color scales are panel specific due to the big difference in variables' distributions.

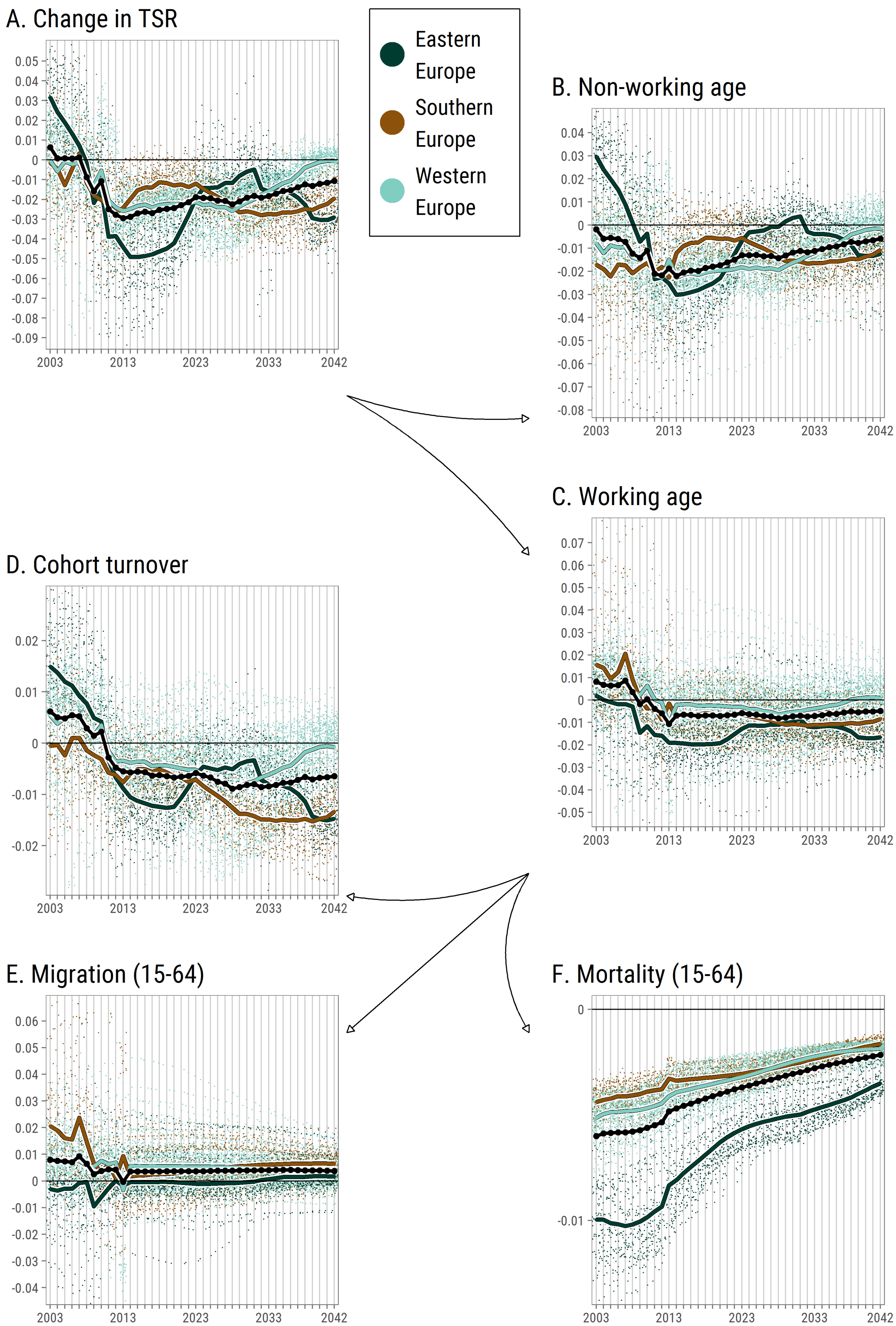

Fig. 4. Distributions of the decomposed components of change in TSR, all years between 2003 and 2043. Notes: Each NUTS-2 region is represented with a point colored according to EuroVoc definition of European subregion. Scales on y-axes are panel specific due to the big difference in variables' distributions.

tan areas is mainly driven by migration (Figure 3-E), rather than cohort turnover. The spatial variation of the TSR growth due to the changes in working-age population (Figure 3-C) clearly shows the attractiveness of the regions for the labor force.

The spatial pattern of changes in the TSR due to cohort turnover (Figure 3-D) is distinctively similar to what we know about fertility (Frejka & Sobotka, 2008) and child migration levels in Europe (Wilson *et al.*, 2013). Interestingly, lots of metropolitan areas have relatively higher increase or lower decrease in the TSR due to cohort turnover, which, probably, means that quite often people leave these areas before turning 65 (see, for example, the development of the population pyramid of London in the Appendix, Figure 10). The effect of migration at working ages on the TSR (Figure 3-E), apart from the mentioned above metropolitan areas regularity, shows some East-West gradient: emigration of working-age population from East-European regions, and especially from Baltic countries, is particularly high. But the most pronounced East-West gradient appears at the map of mortality at the working ages component of the change in the TSR (Figure 3-F). The prevalence of mortality at ages between 15 and 64 in the regions of Eastern Europe is striking. Even the optimistic convergence-based scenarios of Eurostat population projection do not promise that this divide would vanish in the coming three decades (Figure 3-F).

Figure 4 illustrates the importance of demographic waves in the development of population structures. This is particularly evident for East-European regions. The downfall of fertility in the 1990s produced a very small generation giving a short-term alleviating effect (demographic dividend), but resulting in a big negative impact of cohort turnover on the TSR 15 years later and a smaller alleviating echo effect about 30 years later. The timing of the effect of migration on the change in the TSR is only visible in the observed part of the study period. The pre- and post- 2008 economic crisis migration shocks are very pronounced (note also that the y-axis scale range is relatively big for the migration component). In the projected part of the study period, according to the converging baseline assumption, migration intensities are extrapolated with reducing variance, which result in a very smooth development of an almost fixed distribution. With such a projection, migration at working ages can hardly have any effect on convergence in ageing (see the next sub-section).

4.3. Beta-convergence analysis.

The results of the beta-convergence modeling for all regions of Europe are shown in Figure 5; panels A and B show the components of the first and the second steps of the decomposition of changes in the TSR, respectively. Each point in the plot represents an estimate of the beta-coefficient from the corresponding partial model. Panels C and D show the same model estimates but in a cumulative way, revealing the overall convergence process throughout the study period.

The dynamics of beta-coefficients from g models indicate that there was divergence (positive beta-coefficients) in 2003 and 2004, and then convergence (negative beta-coefficients) for the rest of the observed period with local peaks in 2009 and 2013. The rapid convergence continues till the beginning of the 2020s. From two previous results sub-sections we know that this period is characterized by the anticipated rapid decrease in the TSR in East-European regions. Then, there is hardly any convergence in the 2020s and early 2030s while East-European regions experience an alleviating echo effect of a relatively smaller generation born to the very small generation of parents born in the 1990s (see, for example, populations pyramids for Romania in the Appendix, 11). Finally, fast convergence starts again in the middle of the 2030s when the smaller "echo generation" enters working-ages. In short, most of the regional convergence in ageing in Europe seems to be driven by the dynamics of the TSR in the regions of Eastern Europe.

Thus the overall convergence trend is mainly set by changes in the size of the non-working-age population in the first half of the study period; changes in the size of the working-age population contribute much less to the overall convergence. Though, in the second half of the study period, convergence is mainly driven by the working-age population. In the end, the cumulative contributions of both components are almost equal.

The contribution of ct is very similar to the effect of nw: it contributes to divergence slightly in the beginning of the period and then follow closely the population structure dynamics in Eastern Europe. The impact of mg is quite insignificant throughout the study period due to the mentioned above features of Eurostat regional population projection. The influence of mt is the most stable, which can be explained by the very slow pace of changes in mortality rates and the huge initial differences between Eastern Europe and the rest. It contributes to convergence because both the initial TSR and mortality rates at working ages are higher in East-European regions. By the end of the study period, the cumulative effect of the moderate but stable year-by-year contributions accounts for about 40% of the convergence in w.

5. Conclusion and discussion

In this paper we investigate how regional differences in population ageing across Europe developed over the last decade and how they are likely to evolve in the coming three decades. The results show that there was convergence in ageing during the biggest part of the period 2003-2012 and it is anticipated during the first and the third decades of the projected period (2013-2022 and 2033-2042). Note that the occurrence of convergence in the future depends on the accuracy of the Eurostat projections. These projections depend on assumptions about future changes in cohort turnover, mortality and migration. While assumptions about cohort turnover and mortality generally are reliable, the validity of assumptions about future migration is rather uncertain.

The speed of convergence depends mainly on the development of the Total Support Ratio in East-European regions in relation to the rest of Europe. Convergence is, by definition, a temporary process. The convergence in ageing among European NUTS-2 regions throughout the 40 years long study period can be explained by the fact that the initial variation in ageing was at a local peak because of the East-European regions that experienced the ending phase of the window of demographic opportu-

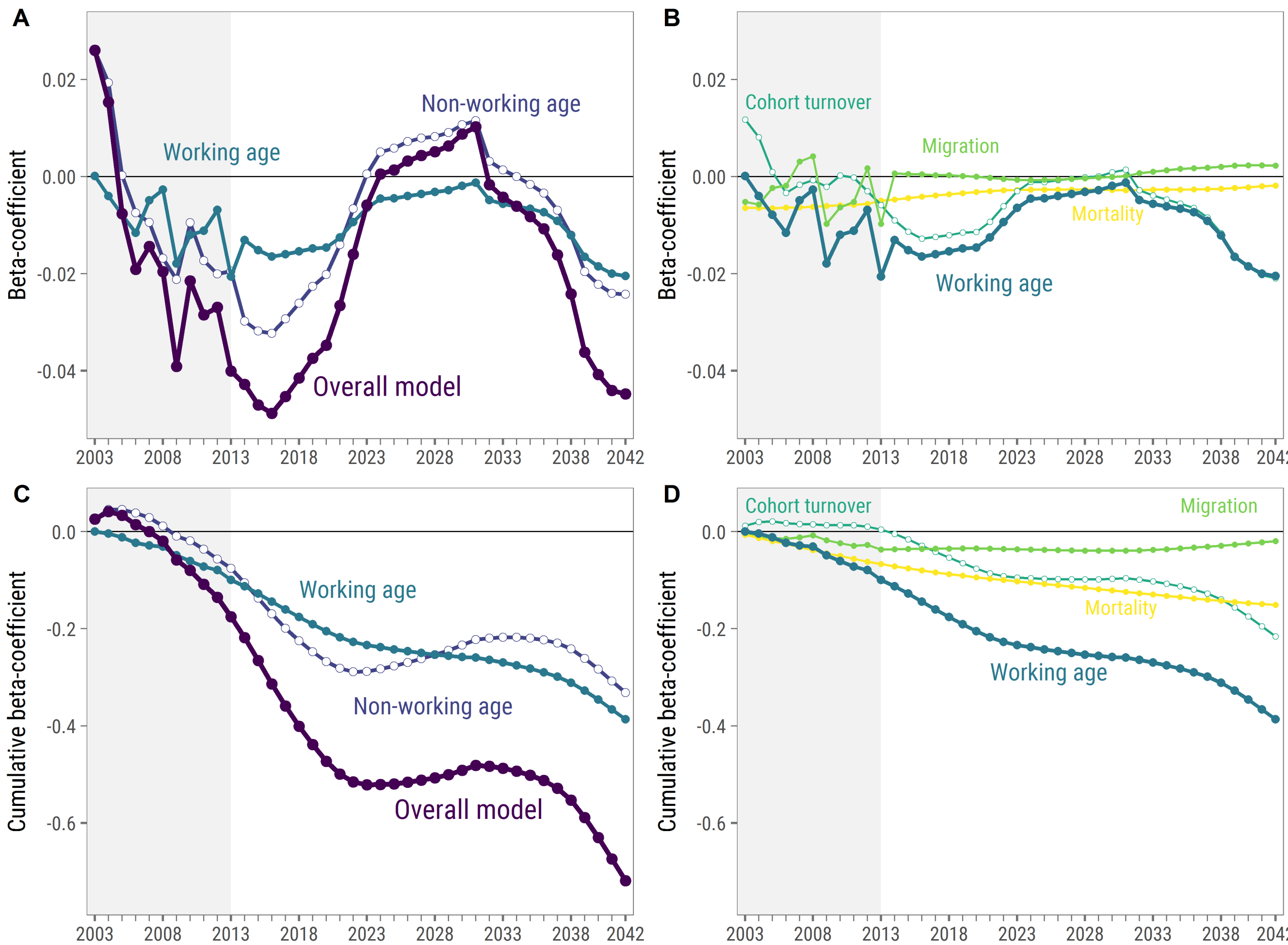

Fig. 5. Bi-dimensional decomposition of beta-convergence estimates by (1) component of change in TSR and (2) time. Notes: Each point represents beta-coefficient from the corresponding partial model. The left panels show the first step of TSR growth decomposition; the right panels shows the second step. Panels A and B show beta-convergence estimates for each year separately; panels C and D show the cumulative effect. Observed period marked with a light-grey background.

nities.

Population structures affect convergence in ageing through cohort turnover and changes in the size of the non-working-age population. Growth of the non-working-age population is responsible for approximately half of the overall convergence in the study period. Of the second half, which is attributed to the effect of growth in the working-age population, cohort turnover is responsible for about 60% of the effect.

Mortality at working ages has the most stable impact on convergence in ageing. It accounts for about 40% of the convergence effect through changes in the size of the working-age population. Interesting in itself, this finding limits the scope for policy options: if policy makers aim at convergence in mortality this may be in conflict with aiming at convergence in population ageing. Even though convergence in ageing may be desirable, the persisting higher mortality in East-European regions is, by no means, a policy option. Yet, this component is likely to contribute significantly to convergence in ageing in the coming decades because improvements in mortality rates go very slowly (Vallin and Meslé, 2004).

Quite surprisingly, migration at working ages assumptions in the Eurostat projections has an almost no effect on convergence in ageing in the long run. This can be explained by the assumption that there will be convergence in every demographic indicator, which are baseline assumptions of the EUROPOP2013 regional population projections. Interestingly, the contribution of migration at working ages is crucial in explaining the biggest fluctuation of the effect of change in working-age population during the observed period. The most notable is the change of the trend in 2009, which is likely to be caused by sharpened out-migration from East-European regions after the outbreak of the economic crisis; and the preceding local peak of 2004-2005 was, most likely, linked to the increased migration intensities after the biggest EU enlargement. The relative importance of migration during the observed period and the lack of effect in the projected period indicate that convergence in migration flows, as projected by the basic Eurostat scenario, may not be the most realistic outcome.

The relatively big impact of cohort turnover leaves room for policy options, since the size of the impact depends on the age boundaries of 15 and 65 years. If policies aimed at raising the retirement age will be effective, the upper age boundary of 65 should be raised. This will have a positive impact on the level of the TSR. Note that crossing the age margin of 65 may have different implications for different parts of Europe due to varying participation rates after 65 (Sanderson and Scherbov, 2007, 2010, 2015). Similarly, with the persistent growth of educational attainment, the lower border of working ages may be raised (Harper, 2014). This will have a negative impact on the level of the TSR. In this paper we focused on the pure demographic effects that alter population structures, but the societal meaning of age is not constant. Thus, the use of more nuanced definitions of dependent populations (Spijker and MacInnes, 2013) and labour support (Prskawetz and Sambt, 2014) are welcome in the further research on regional convergence in population ageing in Europe.

One important question is whether convergence in population ageing contributes to economic convergence. Although, researchers mainly find proofs of the negative effects of accelerating ageing on the economy and on social structures, some demographers call for a calmer evaluation of the consequences of ageing (Vaupel and Loichinger, 2006; Van Dalen and Henkens, 2011; Lloyd-Sherlock *et al.*, 2012). Moreover, some economists even doubt the negative influence of population ageing on economic development, at least in the beginning of the period of accelerated ageing (Gómez and De Cos, 2008). But even if we rely on a negative link between ageing and economic development, the interplay between convergence in ageing and economic cohesion is not stable over time and space: it depends on the change in productivity and labor force participation (Kashnitsky *et al.*, 2020).

The mentioned limitations ask for further research on convergence in ageing. In this paper, we analyzed for the first time the evolution of population structures using beta-convergence modeling and attempted to understand how demographic components of population growth contribute to the convergence process. Our results together with theoretical aspirations and prior research in the field (De Beer *et al.*, 2012) indicate that examining urban/rural differences will be very useful for the analysis of convergence in ageing.

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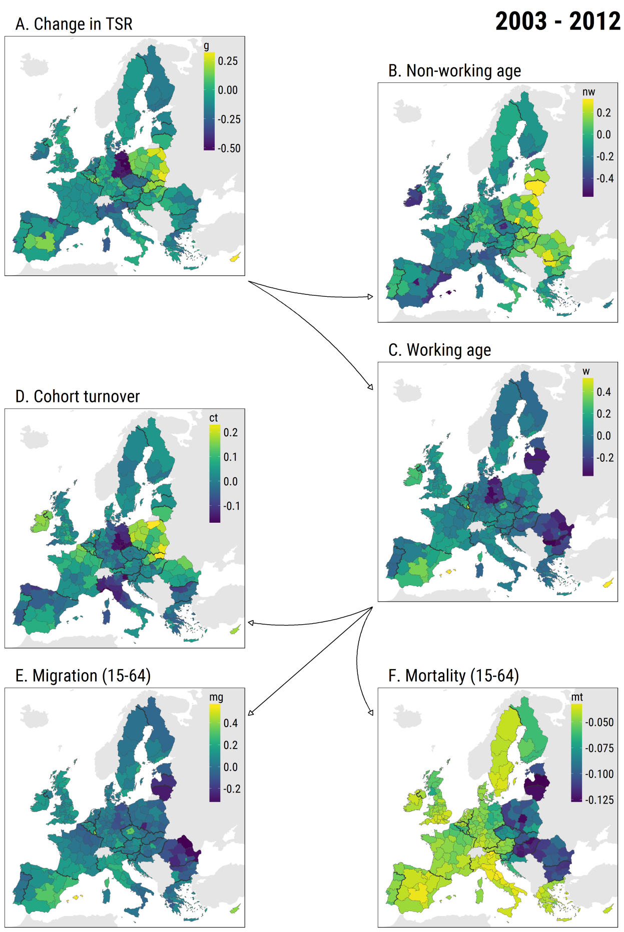

Fig. 6. Decomposition of change in TSR between 2003 and 2013. Notes: A – overall change; B – change due to dynamics in non-working-age population; C – change due to dynamics in working-age population; D – change due to cohort turnover; E – change due to migration at working ages; F – change due to mortality at working ages. Color scales are panel specific due to the big difference in variables' distributions.

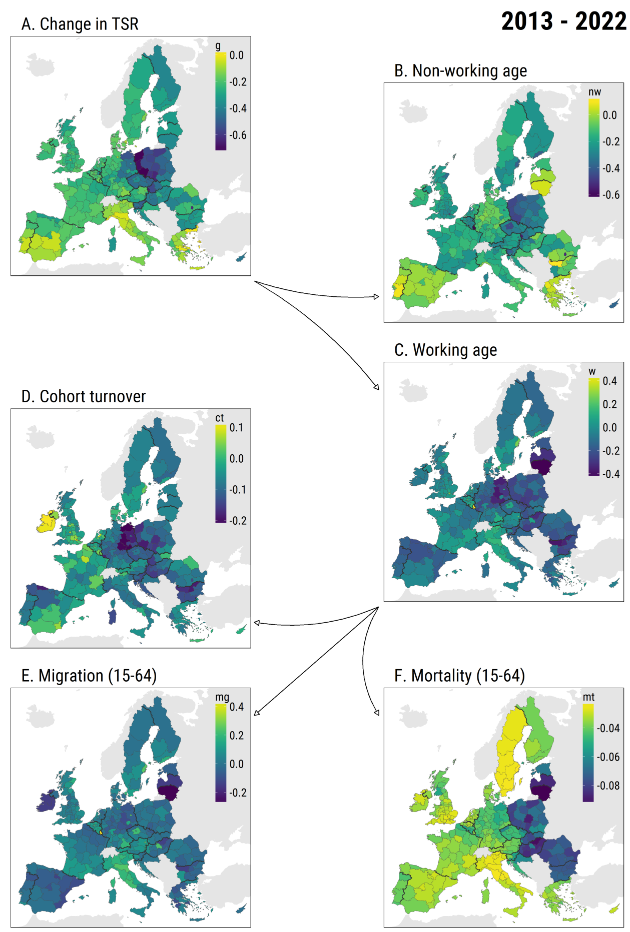

Fig. 7. Decomposition of change in TSR between 2013 and 2023. Notes: A – overall change; B – change due to dynamics in non-working-age population; C – change due to dynamics in working-age population; D – change due to cohort turnover; E – change due to migration at working ages; F – change due to mortality at working ages. Color scales are panel specific due to the big difference in variables' distributions.

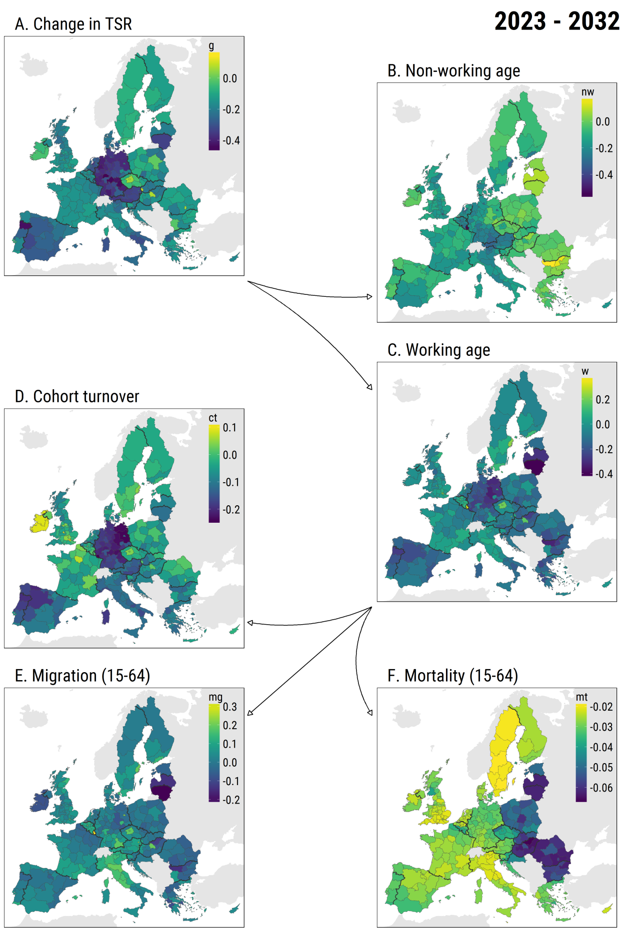

Fig. 8. Decomposition of change in TSR between 2023 and 2033. Notes: A – overall change; B – change due to dynamics in non-working-age population; C – change due to dynamics in working-age population; D – change due to cohort turnover; E – change due to migration at working ages; F – change due to mortality at working ages. Color scales are panel specific due to the big difference in variables' distributions.

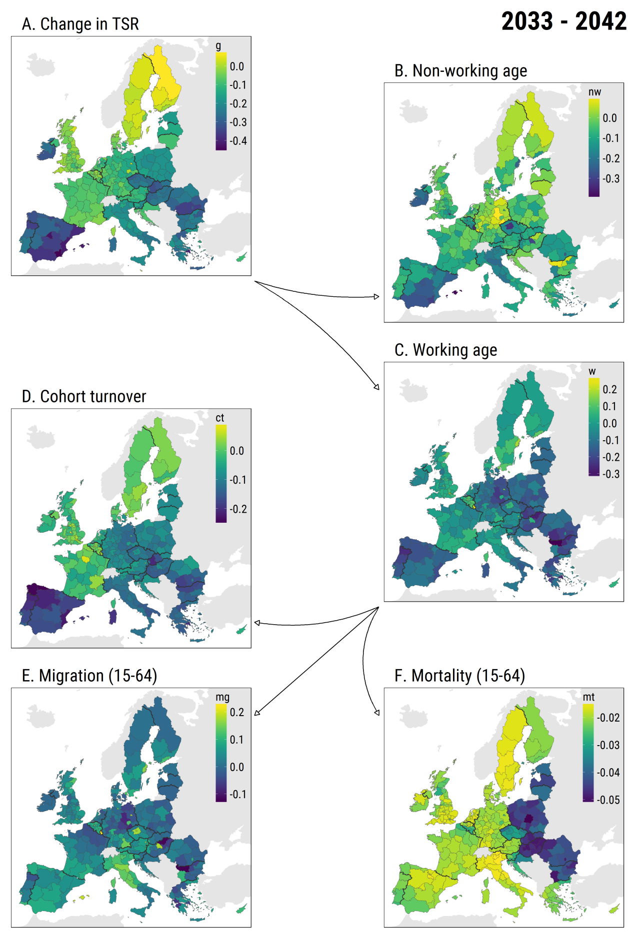

Fig. 9. Decomposition of change in TSR between 2033 and 2043. Notes: A – overall change; B – change due to dynamics in non-working-age population; C – change due to dynamics in working-age population; D – change due to cohort turnover; E – change due to migration at working ages; F – change due to mortality at working ages. Color scales are panel specific due to the big difference in variables' distributions.

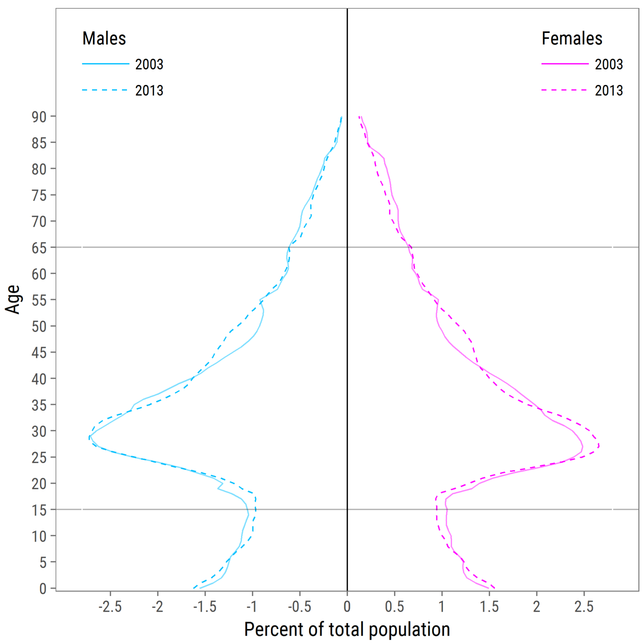

Fig. 10. Population pyramids of London in 2003, 2013.' distributions.

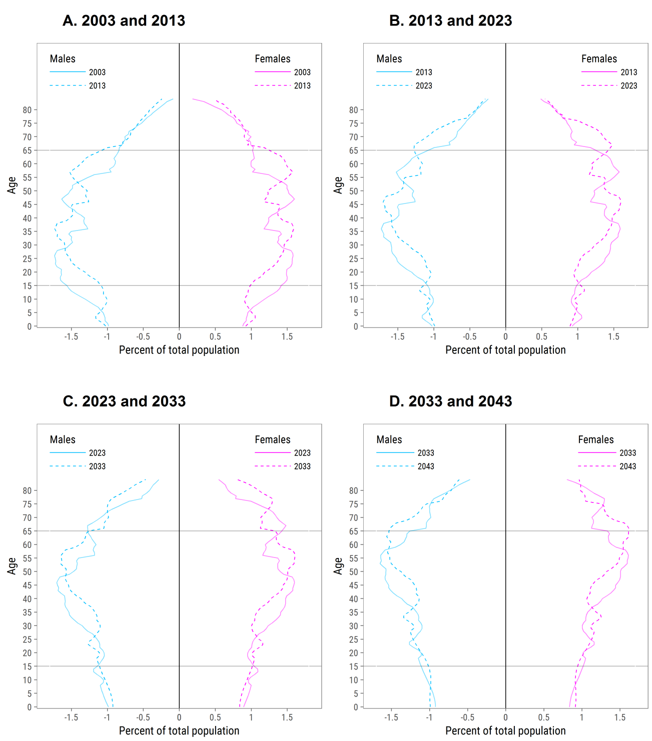

Fig. 11. Population pyramids of Eastern Europe in 2003, 2013, 2023, 2033, 2043.

Country	# of NUTS-2 reg.	Total population Country	Mean pop. of region	Country	Mean pop. of region	TSR	Average TSR growth due to g	nw	w	mt	mg	ct	TSR
		2003	2003	2013	2013	2003	2003-2012						2013
Eastern Europe													
BG	6	7.8	1.3	7.3	1.2	2.14	-0.126	0.090	-0.216	-0.109	-0.061	-0.046	2.02
CZ	8	10.2	1.3	10.5	1.3	2.40	-0.235	-0.241	0.006	-0.084	0.099	-0.009	2.16
EE	1	1.4	1.4	1.3	1.3	2.10	-0.135	-0.005	-0.130	-0.104	-0.064	0.038	1.97
HU	7	10.1	1.4	9.9	1.4	2.17	-0.002	0.077	-0.079	-0.117	0.009	0.029	2.17
LT	1	3.4	3.4	3.0	3.0	2.02	0.020	0.309	-0.289	-0.125	-0.278	0.114	2.04
LV	1	2.3	2.3	2.0	2.0	2.13	-0.124	0.187	-0.310	-0.129	-0.214	0.032	2.01
PL	16	38.2	2.4	38.1	2.4	2.26	0.151	0.130	0.021	-0.098	-0.040	0.159	2.44
RO	8	21.8	2.7	20.0	2.5	2.24	-0.075	0.120	-0.194	-0.105	-0.168	0.078	2.17
SK	4	5.4	1.3	5.4	1.4	2.44	0.069	0.023	0.046	-0.097	0.007	0.137	2.51
Southern Europe													
CY	1	0.7	0.7	0.9	0.9	2.05	0.327	-0.214	0.541	-0.039	0.404	0.176	2.38
EL	13	11.0	0.8	11.1	0.9	1.91	-0.116	-0.106	-0.010	-0.041	0.037	-0.005	1.79
ES	19	39.9	2.5	44.5	2.8	2.13	-0.123	-0.304	0.180	-0.042	0.226	-0.004	2.00
HR	2	4.3	2.2	4.3	2.1	2.01	0.005	0.008	-0.003	-0.071	0.054	0.014	2.01
IT	21	57.1	2.7	59.7	2.8	1.98	-0.144	-0.165	0.021	-0.037	0.115	-0.056	1.84
MT	1	0.4	0.4	0.4	0.4	2.17	-0.016	-0.143	0.128	-0.046	0.099	0.074	2.15
PT	7	10.0	2.0	10.0	2.0	1.98	-0.130	-0.110	-0.019	-0.052	0.048	-0.015	1.85
SI	2	2.0	1.0	2.1	1.0	2.36	-0.195	-0.211	0.016	-0.068	0.073	0.011	2.17
Western Europe													
AT	9	8.1	0.9	8.5	0.9	2.12	-0.051	-0.115	0.064	-0.048	0.086	0.026	2.07
BE	11	10.4	0.9	11.2	1.0	1.90	0.000	-0.151	0.151	-0.051	0.137	0.065	1.90
DE	38	82.5	2.2	82.0	2.2	2.07	-0.116	-0.054	-0.062	-0.051	0.029	-0.041	1.95
DK	5	5.4	1.1	5.6	1.1	1.95	-0.143	-0.158	0.015	-0.049	0.045	0.020	1.81
FI	5	5.2	1.0	5.4	1.1	1.99	-0.161	-0.202	0.041	-0.055	0.074	0.022	1.83
FR	26	60.1	2.7	63.7	2.9	1.81	-0.088	-0.150	0.062	-0.049	0.044	0.066	1.73
IE	2	4.0	2.0	4.6	2.3	2.05	-0.165	-0.427	0.262	-0.040	0.140	0.162	1.89
LU	1	0.4	0.4	0.5	0.5	2.04	0.187	-0.258	0.445	-0.048	0.390	0.102	2.23
NL	12	16.2	1.3	16.8	1.4	2.07	-0.152	-0.174	0.022	-0.045	0.017	0.050	1.92
SE	8	8.9	1.1	9.6	1.2	1.81	-0.070	-0.132	0.062	-0.038	0.080	0.020	1.74
UK	37	59.5	1.6	63.9	1.7	1.88	-0.043	-0.154	0.111	-0.046	0.107	0.050	1.84

Table 1. Summary statistics for the observed period by countries.

Chapter 4. Economic convergence in ageing Europe

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1. Introduction

One of the long-lasting policy goals of European Union is to equalize as much as possible quality of life across member countries and their regions. In practice, this aim manifests itself in the attempts to reduce regional disparities in economic development through the Regional Cohesion Program. Since the beginning of the EU Cohesion Policy in the late 1980s, the program has allocated increasingly large funding, and the results of the implemented measures are claimed to be quite successful (Cappelen *et al.*, 2003; Leonardi, 2006; Pellegrini *et al.*, 2013). Particularly, the "success story" could be heard in the context of Eastern-European regions catching up with the advantageous regions of the older EU states (Bosker, 2009). Multiple studies have found evidence of decreasing income disparities over time in Europe, both before and after the EU enlargement (Neven and Gouymte, 1995; Fingleton, 1999; Ezcurra *et al.*, 2005; Ezcurra and Rapún, 2007; Monfort, 2008; Maza *et al.*, 2012; Borsi and Metiu, 2015). However, a notable part of the reduction in regional disparities that is attributed to the Cohesion Policy, may have been explained by different dynamics in regional population structures that most studies on economic cohesion tend to overlook (Crespo Cuaresma *et al.*, 2014a).

The major point of regional policies in the European Union is to reduce disproportions in all aspects that can influence differentiation in the quality of life, including demographic developments (Giannakouris, 2008; European Commission, 2014). The logic behind these policies implies that convergence in population age structures is desirable because it will contribute to the reduction in regional economic and life quality disproportions. Yet, as we show in this paper, this assumption does not necessarily hold in real life. Changes in population structures, that affect economic prospects, are not happening uniformly across countries and regions of Europe (Wilson *et al.*, 2013; Reher, 2015). Reducing, lasting or increasing disparities in potential labour supply may accelerate or hinder economic convergence depending on whether these disparities favor the more economically developed regions or the lesser developed ones. Thus, the interplay between convergence or divergence in population ageing and convergence or divergence in economic development is not straightforward and, to our knowledge, has never been addressed in the literature. The goal of this paper is to shed light on this association.

The paper is organized as follows. Section 2 summarizes theoretical considerations about the relationship between demographic and economic convergence and introduces the conceptual framework, discussing the possible interconnection between convergence in ageing and economic convergence. Section 3 presents the analytical strategy. Section 4 describes the features of the data and provides background information about the setting of the study. Section 5 first overviews the observed dynamics of variance in both population structures and economic output. Then using the chosen counterfactual approach it establishes the contribution of convergence in ageing to convergence in economies. Finally, the third subsection provides an explanation of the observed relationships. The discussion of the results, some limitation and prospects for future research are included in section 6.

2. Theoretical considerations and the proposed framework

Various theoretical and empirical studies have shown that population ageing – i.e. changes in the population age structure that result in a shrinking relative size of the working age population – has a negative effect on economic growth (Bloom and Williamson, 1998; Prskawetz *et al.*, 2007; Bloom *et al.*, 2010; Crespo Cuaresma *et al.*, 2014b; Van Der Gaag and De Beer, 2015). A decline in the size of the working age population has a downward effect on GDP per capita, whereas an increase in the number of elderly citizens has an upward effect on costs of pensions and care (Kluge, 2013; Van Nimwegen, 2013; Kluge *et al.*, 2019). Other things equal, a decrease in the share of the working age population slows down the economic growth of a region (Teixeira *et al.*, 2017). Thus, population ageing appears to be one of the main determinants of long-term economic prospects, that can possibly affect economic convergence (Kelley and Schmidt, 1995; Croix *et al.*, 2009; Bloom *et al.*, 2010; Lee and Mason, 2010). Unlike many previous studies, we prefer to define population ageing as the process altering the whole age distribution of the population instead of focusing exclusively on the elderly part of the population (Kashnitsky and Schöley, 2018). With such an approach, and in the context of modern Europe, which is the most advanced region in terms of demographic transition, the share of working age population is the most suitable basic summary indicator of population ageing (Lee, 2003).

Convergence in population ageing, i.e. convergence of the share of the working age population, does not necessarily lead to economic convergence (Goldstein and Kluge, 2016). Convergence in ageing may even contribute to economic divergence. This depends on differences in the levels of the share of the working-age population between economically advantageous and lagging-behind regions. For example, if the share of the working age population is relatively low in poor regions, convergence in ageing helps to reach economic convergence because the advantage of the rich regions due to population age composition declines (Salvati, 2016). In contrast, if the share of the working age population is relatively high in poor regions with low productivity, convergence in ageing may slow down economic convergence, as it eliminates one of the poor regions' resources for faster economic development, i.e. the favourable age composition of the population. Divergence in ageing, in that latter case, contributes to a faster economic convergence (Crespo Cuaresma *et al.*, 2016). Thus, for better understanding the mechanisms of regional cohesion, we need to distinguish four types of regions: rich regions with low and high shares of the working age population and poor regions with low and high shares of the working age population. This paper introduces a new method to visualize the relationship between changes in the share of the working age population and in GDP per capita in the four types of regions. To our knowledge, only a couple of recent studies explicitly focused on the investigation of changes in relative dynamics of population ageing with the use of convergence analysis (Kashnitsky *et al.*, 2017; Sabater *et al.*, 2017; Gutiérrez Posada *et al.*, 2018); and none examined the interplay between convergence in ageing and economic convergence.

To illustrate the possible interrelationship between convergence in ageing and economic convergence, let us consider four hypothetical regions such that they represent the four types of combination of GDP per capita and the share of the working age population levels, above and below the median values: rich-high, rich-low, poor-high, and poor-low (see the black dots in Figure 1). Then consider the joint change in the variance of the two variables when the share of working age population is changed only in one of the regions. Assuming constant labour productivity, changes in the share of the working age population would result in proportionate changes in GDP per capita (i.e. changes in region's position in Figure 1 follow the diagonal lines). In such a setting, there can be four principal cases of interaction between convergence in ageing and economic convergence (Figure 1).

First, if there is a decrease in the rich region with a high share of the working age population, there is an overall decrease in the variance of both the demographic and economic variables; hence, convergence in ageing contributes to economic convergence. Second, if the same region experiences an increase in the share of the working age population and in GDP per capita, that results in divergence both in ageing and economy. These two cases represent the positive correlation between convergence in ageing and economic convergence. Third, when the rich with a low share of the working age population experiences a decrease in that share, that results in divergence in ageing contributing to economic convergence. Alternatively, in the fourth case, when the rich region with the small working age population experiences an increase, convergence in ageing contributes to economic divergence. The latter two cases represent a negative correlation between convergence in ageing and economic convergence. Of course, there are four complementary cases, when the changes occur in the poorer regions (pink arrows in Figure 1), but these four cases only mirror the four discussed cases.

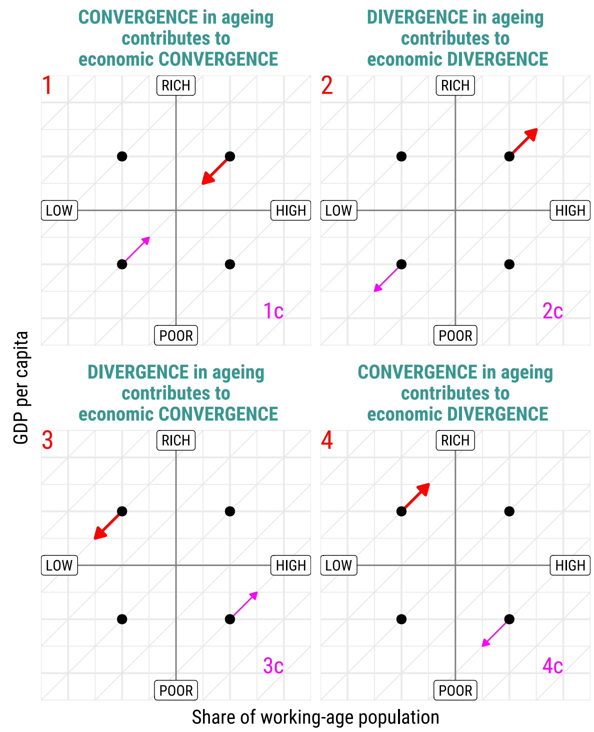

Fig. 1. Possible interplay between convergence in ageing and economic convergence. Note: black dots represent the 4 regions. The arrows show the change that happens in one of the regions: red arrows represent changes in rich regions, pink arrows represent the 4 complementary cases, when changes occur in the poor regions. A change in one point affects variance on both variables.

With this theoretical framework we can see that the standard hypothesis of a positive association between convergence in economies and convergence in ageing only holds when the strongest changes happen to rich regions with a high share of the working age population or poor regions with a low share. Alternatively, when the overall variance is mostly driven by changes in poor regions with a high share or rich regions with a low share, one would expect to find a negative association between convergence in economies and convergence in ageing.

3. Analytical strategy

Aiming to investigate the association between convergence or divergence in economies and population structures, we use the sigma convergence approach (Monfort, 2008), i.e. we conceptualize regional convergence as a decrease in the variance across regions. To measure convergence, we use Theil's T index of inequality (Theil, 1967, 1979) as the measure of variance. This analysis shows the baseline convergence in economies and population structures separately.

To analyze the impact of convergence in ageing on economic convergence, we decompose economic growth into productivity and demographic components using the following formula:

$$\frac{Y_{t_0+T}/P_{t_0+T}}{Y_{t_0}/P_{t_0}} = \frac{Y_{t_0+T}/W_{t_0+T}}{Y_{t_0}/W_{t_0}} \cdot \frac{W_{t_0+T}/P_{t_0+T}}{W_{t_0}/P_{t_0}}$$

where t_0 is the starting year, T is the length of the period, Y is gross domestic product, P is the population size, W is the size of the working-age population. In the right-hand side of equation 1, the two elements represent productivity and the change in the population structure respectively. Note that in this paper we define productivity by the ratio between GDP and the size of the working age population. This implies that productivity not only depends on labour productivity (the ratio of GDP and the work force) but on labour force participation (the ratio of the work force and the working age population) as well. Thus, the decomposition we use is a slightly simplified version of the one proposed by Bloom and Williamson (1998). We aim primarily to assess the impact of the size of the working age population rather than disentangling the effects of labour productivity and participation. Other researchers used more elaborated versions of the formula (Hsu, 2017), but they studied the effects of components of economic convergence rather than convergence in any of the components.

In order to check how convergence in ageing affects economic convergence, we conduct a counterfactual analysis. Using the decomposition of economic growth, we estimate counterfactual economic growth rates based on the assumption of no change in population structures and the actual development in the productivity component using a slightly modified version of equation 1:

$$Y_{t_0+T}/P_{t_0+T} = Y_{t_0}/P_{t_0} \cdot \frac{Y_{t_0+T}/W_{t_0+T}}{Y_{t_0}/W_{t_0}} \cdot \frac{W_{t_0+T}/P_{t_0+T}}{W_{t_0}/P_{t_0}}$$

in which the GDP per capita in year t_o is multiplied by the growth in productivity $\frac{Y_{t_0+T}/W_{t_0+T}}{Y_{t_0}/W_{t_0}}$ and the change in the share of the working age population $\frac{W_{t_0+T}/P_{t_0+T}}{W_{t_0}/P_{t_0}}$. Then, we compare convergence for the observed and counterfactual economic growth rates. The difference is interpreted as the effect of convergence in ageing on economic convergence.

This approach is based on the assumption of constant productivity, i.e. we assume a linear positive relationship between changes in the share of the working age population and changes in GDP per capita. Note that we define productivity by the ratio of GDP and the size of the working age population. Regional differences in the change of productivity can affect the relationship between convergence in ageing and economic convergence.

The analysis and the necessary data preparation were conducted using R, a language and environment for statistical computing, version 3.4.0 (R Core Team, 2017). The following additional packages were essential for the analysis and data visualization: tidyverse (Wickham, 2017), rgdal (Bivand *et al.*, 2015), cowplot (Wilke, 2016), RColorBrewer (Neuwirth, 2014).

4. Data and background dynamics

This paper uses Eurostat data on population age structure (Eurostat, 2015a) and mortality records (EuroStat, 2015) by one-year age groups for the period 2003-2012. The data are aggregated at the NUTS-2 level, version of 2010 (Eurostat, 2015b). At the moment of data acquisition (March 2015), mortality records covered the period up to 2012. For the majority of countries, data on population structure are available since 2003. Hence, data were available for the period 2003-2012. Necessary data harmonization steps were performed (Kashnitsky *et al.*, 2017).

GDP estimates at regional level were taken from the Cambridge Regional Database (Cambridge Econometrics, 2015). Several notes have to be made concerning the use of these data. First, GDP is a measure that relates to the year for which it is calculated; population estimates, in contrast, are given at the beginning of each year. Since we have quite a limited study period, and do not want to shorten it further by calculating mid-year population, we assumed that GDP estimates refer to the end of the year. We did a sensitivity analysis, which showed that the assumption does not affect the results strongly. Second, the Cambridge Regional Database uses the 2006 version of NUTS, and the population data from Eurostat uses the 2010 version of NUTS. The required transformations were performed to match the data from both data sets. Finally, as the economic database does not include Croatia in the 2015 version of the database, we also removed it from the analysis. The data set used for the analyses contains data for 261 NUTS-2 regions of EU27 for the period 2003-2012.

The study period analyzed in this paper, from 2003 to 2012, is a rather unique one. Two major events, that directly affect the relationship between demographic structures and economic performance of the regions, happened within this period. First, in 2004 the European Union experienced the biggest ever enlargement in its history. This major reshaping European political landscape notably affected intra-European migration flows (Crespo Cuaresma *et al.*, 2008, 2015; Bosker, 2009). Second, Europe was heavily stricken by the economic crisis of 2008-2009 (Crespo Cuaresma *et al.*, 2014a; Percoco, 2016). Both events affected the process of economic convergence making the period very interesting to study (Ertur *et al.*, 2007; Dall'Erba *et al.*, 2008; Fingleton *et al.*, 2012; Doran and Jordan, 2013; Borsi and Metiu, 2015). The uneven impact of the economic crisis across Europe is of particular importance for convergence: the catching up East-European regions seems to recover rapidly while the falling behind South-European regions are the most stricken with the economic crisis (Salvati, 2016; Salvati and Carlucci, 2016) (Figure 2). We divide Europe into three parts: Eastern, Southern, and Western. Initially, we tried to use the official subdivision of European countries into Northern, Western, Southern and Eastern parts (EuroVoc, 2017). But the subset of Northern regions turned out to be too small and heterogeneous. So, we merged Scandinavia with Western Europe, and the Baltic regions with Eastern Europe.

Not only the features of regional economic development make the study period interesting for analysis, the demographic settings are also unusual. During the study period, the main dif-

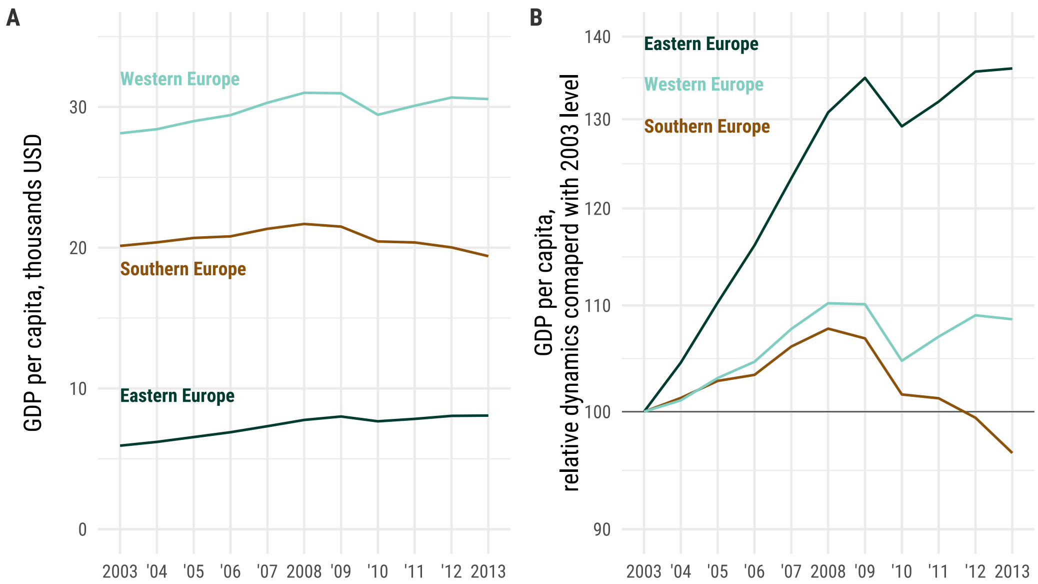

Fig. 2. GDP per capita dynamics by parts of Europe: A – absolute values; B – relative dynamics.

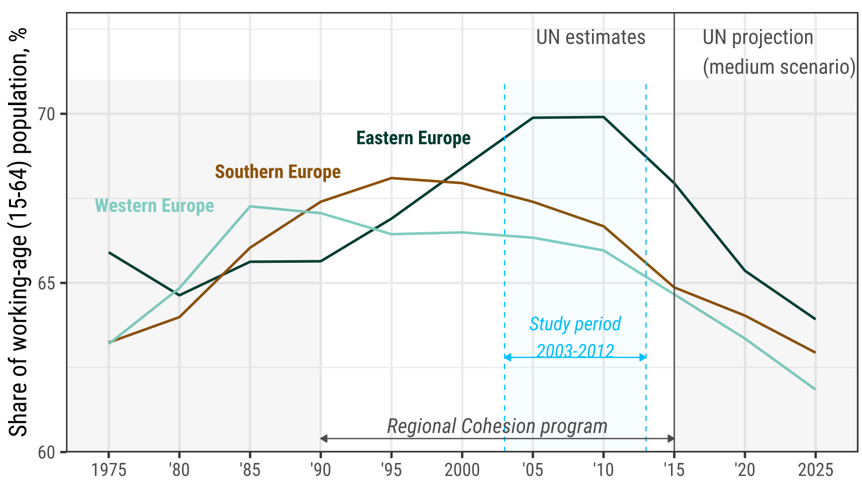

Fig. 3. Asynchronous demographic dividend in Europe: dynamics of the share of working age population in parts of Europe during the period 1975-2025. Note: within each part, data for countries are weighted by the number of NUTS-2 regions in countries for compatibility with other results in the paper.

ference in the share of the working-age population in Europe lied between post-communist countries and the rest of Europe (Figure 3). In 2003, the sharp contrast was still clearly visible even within the reunited Germany (Figure 4-A).

Post-communist countries were relatively late with the onset of the Demographic Transition (Lee, 2003) and, especially, the Second Demographic Transition (Lesthaeghe, 2010). Only after the collapse of communism did they experience the sharp fertility decline that contributed largely to the boost of their economies. The other countries of Europe that did not have a communist past started to experience accelerating ageing and recuperating fertility even before the study period (Reher, 2011; Wilson *et al.*, 2013). It is clear, that the regions of Eastern Europe fully appreciated the benefits of demographic dividend only after the fall of the Eastern Bloc in 1990, when fertility dropped dramatically. In the rest of Europe, the demographic dividend started to wear off much earlier, in many countries, even before the start of the Cohesion Program (Van Der Gaag and De Beer, 2015). The relative advantage of East-European regions in ageing was prominent within the study period, but it will reduce substantially in the coming years (Kashnitsky *et al.*, 2017).

A steep decline in the share of the working age population happened uniformly in Europe after 2010. The main reason for that is cohort turnover. The baby-boom generation, born after 1945, started to cross the age line of 65 accelerating ageing (Lanzieri, 2011). Naturally, the “aftershock” of such a massive demographic perturbation of the past, as was the baby-boom in the Western world, is very perceptible (Van Bavel and Reher, 2013;

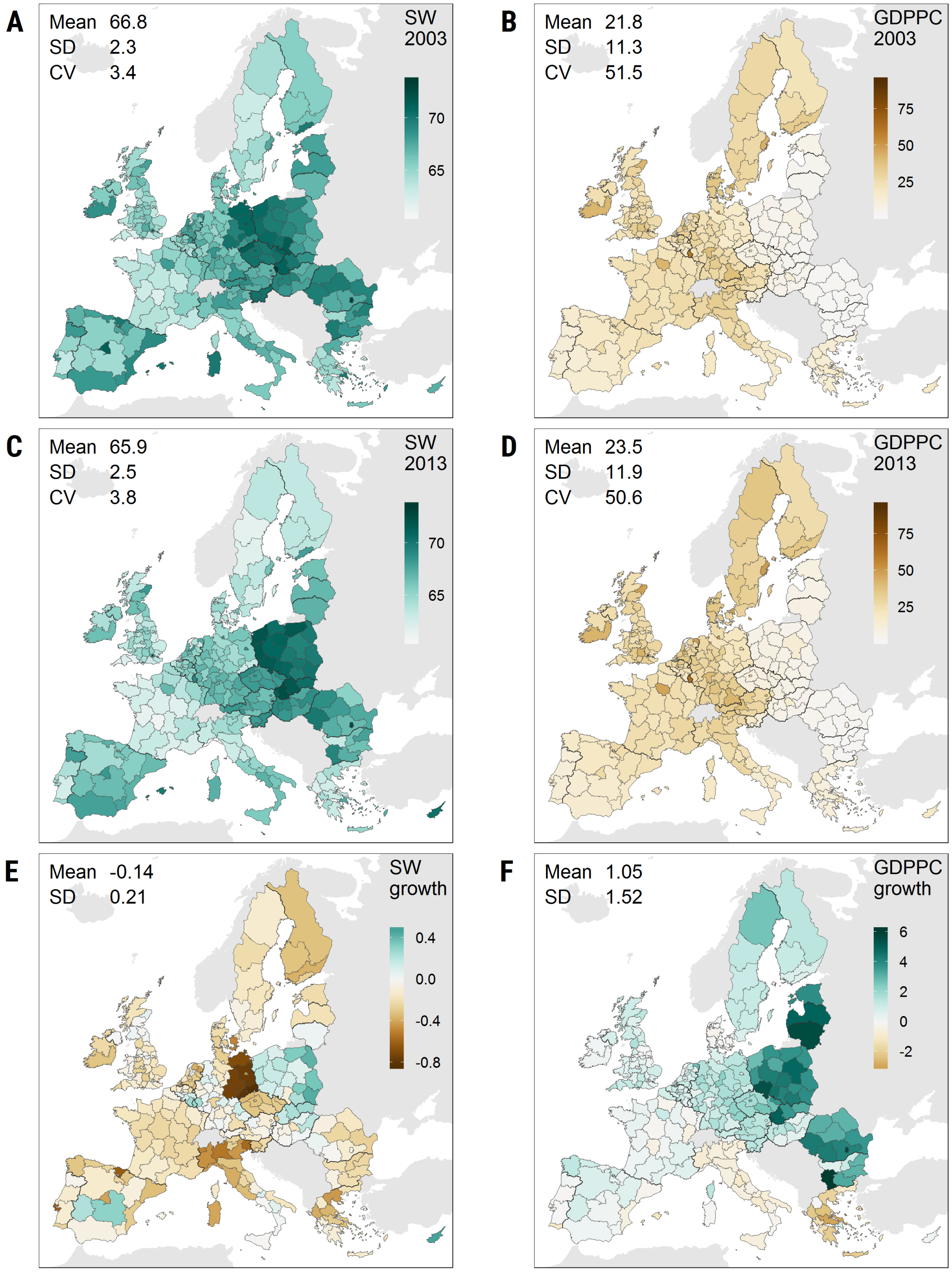

Fig. 4. Descriptive maps: A – share of working age population in 2003, percent; B – GDP per capita in 2003, thousands USD; C – share of working age population in 2013, percent; D – GDP per capita in 2013, thousands USD; E – share of working age population annualized growth rate in 2003-2012, percent; F – GDP per capita annualized growth rate in 2003-2012, percent.

Wilson *et al.*, 2013).

The effect of baby-boomers' retirement on the share of the working-age population was especially strong in Northern and Western Europe (Van Bavel, 2010; Groenewold and De Beer, 2014; Reher, 2015). Interestingly, it was partially leveled by reversals of migration flows after the economic crisis of 2008 (Wilson *et al.*, 2013; Crespo Cuaresma *et al.*, 2015). Northern and Western Europe experienced a rise of in-migration at working ages, while less economically competitive regions of Eastern and Southern Europe experienced a drop of in-migration or even net out-migration at working ages. To some extent, migration compensated the effect of cohort turnover on the regional disparities in population age structures (Kashnitsky *et al.*, 2017).

5. Results

5.1. The components: economic convergence and divergence in population ageing.

During the period 2003–2012, economic convergence occurred in Europe; sigma-convergence analysis indicates that income inequality reduced during the study period, though, only before the onset of the economic crisis. Simultaneously, inequality in the share of the working age population has risen throughout the study period indicating divergence (Figure 5). Though, the pooled trends for Europe mask substantial differences between the three parts of Europe: within each of them the development of the variance in both GDP per capita and the share of working age population has varied substantially.

Eastern Europe has seen a slight overall decrease in income inequality. In Southern Europe, there was economic convergence in the first part of the period, but after the outbreak of the economic crisis, it has changed to a rapid divergence. Western Europe has experienced the smallest changes in variance. The direction of changes in Western Europe has been opposite to those of Sothern Europe: divergence in the first part of the period and convergence in the second part of the study period. The relative changes in Theil's index of inequality suggests that in the three parts of Europe different groups of regions were most struck by the 2009-2008 economic crisis.

As with the difference in income variance dynamics, changes in the variance of the share of working age population has been notably different in the three parts of Europe. Eastern Europe has experienced divergence throughout the study period. Southern Europe saw divergence before the economic crisis and convergence after. Western Europe, on the other hand, has experienced fast convergence in the first part of the period, and divergence in the second.

Notably, with the exception of a constant divergence in ageing in Eastern Europe, the changes in variance reverse during the study period, resulting in almost no change by the end of the period. This again highlight the uniqueness of the study period that contained economic crisis, graying of baby boomers, and ending of demographic dividend in Eastern Europe.

5.2. Interplay: the relationship between convergence in ageing and economic convergence.

As described in the methodological section, we conduct a counterfactual analysis to assess the effect of convergence or divergence in ageing on convergence or divergence in economies. Assuming no change in population age structures, we first estimate to what extent economies would converge if there were no demographic effect on economic growth, i.e. the only source of economic growth was the growth in productivity (including labour force participation). Then, we compare the no-population-change results with the actual observed evidence for convergence or divergence, and thus assess the effect that convergence in ageing has on convergence in regional economies. Because of the huge differences in the dynamics of the variance between the parts of Europe, we conduct the analysis separately for the parts and the two sub-periods (Table 1).

Consider Southern Europe (middle columns in both panels of the table). In the first part of the period (2003-2007), regions of Southern Europe experienced divergence in population ageing, Theil's index of inequality in the share of the working age population increased by 24%. At the same time economic convergence happened, i.e. Theil's index of inequality in GDP per capita decreased. Even without change in population structures, the decrease would have been about 10%. When we account for changes in the share of the working age population, the convergence turns out to be even stronger; the decrease in Theil's index becomes about 14%. Thus, divergence in ageing resulted in faster economic convergence, revealing a negative correlation between them. In the second sub-period (2008-2012), convergence in ageing contributed to a slowdown of the baseline economic divergence in Southern Europe, hence, revealing a positive correlation between convergence in ageing and economic convergence.

The results of the counterfactual analysis reveal quite a diverse picture. Convergence in population ageing can contribute to economic convergence (Southern Europe in 2008-2012) and divergence in ageing can have a diverging effect on the economy (Western Europe in 2008-2012). But convergence in ageing can also result in economic divergence (Western Europe in 2003-2007), while demographic divergence can have a converging effect on the economy (Eastern Europe in both periods and Southern Europe in 2003-2007).

To understand the relationship between demographic and economic convergence or divergence, we examine differences between ageing in rich and poor regions. Figure 1 showed that the direction of the effect of population ageing on the economy differs depending on whether the main change in ageing occurs in rich or poor regions. If the major changes in population structures occur in those regions that are relatively rich and have a high share of the working age population or in regions that are relatively poor and have a low share of the working age population, the relationship is expected to be positive, irrespective of whether there is convergence or divergence in ageing (cases 1 and 2 in Figure 1). In contrast, when the major changes in population structures occur in the group of regions that are poor but have a higher share of the working age population or regions that are rich with a low share of the working age population the relationship is likely to be negative (cases 3 and 4 in Figure 1).

5.3. The clue: who's driving the relationship.

In order to identify the regions showing the major demographic changes Figure 6 shows the changes in the distributions of regions according to the share of the working age population for rich and poor regions. For each of the three parts of Europe and for each period, we distinguish poor and rich regions by dividing the regions in two groups according to the initial GDP per capita (below and above the median values). Then we plotted the initial and final distributions of the share of the working age population. Note that we did the grouping separately for both sub-periods, so that some regions may have appeared, for example, in the poorer group in the first sub-period and in the richer group in the second sub-period, and vice versa. Figure 7 shows how regions were classified in four groups: poor and rich regions with low and high shares of the working age population. For ex-

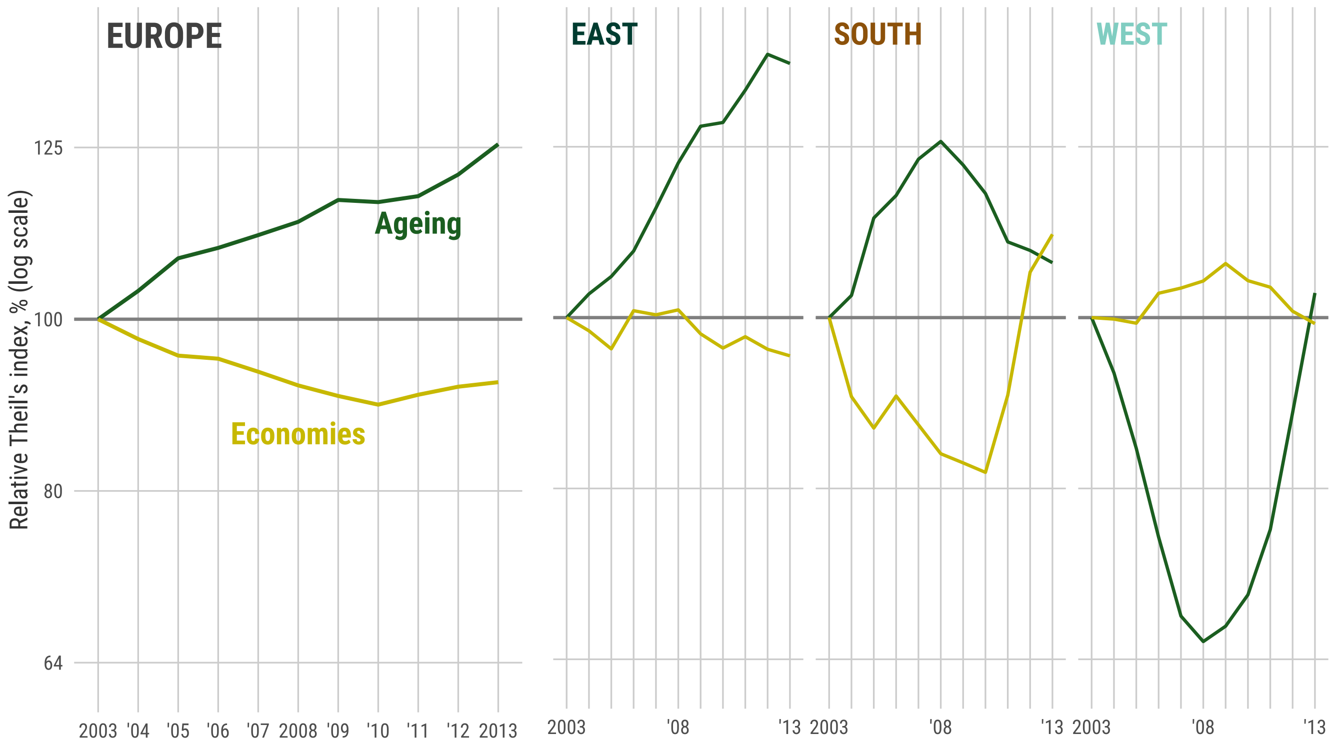

Fig. 5. Sigma-convergence analysis of regional variation in GDP per capita and the share of the working age population – the relative dynamics of Theil's index of inequality, 2003 is taken for 100 percent; log scale.

	2003-2007			2008-2012		
	EAST	SOUTH	WEST	EAST	SOUTH	WEST
Relative change in Theil's index of inequality in AGEING	122.2	123.8	65.1	115.2	86.5	160.7
Convergence or divergence in AGEING	divergence	divergence	convergence	divergence	convergence	divergence
Relative change in Theil's index of inequality in ECONOMIES -- CONDITIONAL	102.4	89.4	103.0	97.1	135.7	92.0
Relative change in Theil's index of inequality in ECONOMIES -- REAL	101.0	83.7	104.9	94.2	133.2	94.6
Effect of population structure on con/divergence in ECONOMIES	convergent	convergent	divergent	convergent	convergent	divergent
Association between convergence in AGEING and convergence in ECONOMIES	**–**	**–**	**–**	**–**	**+**	**+**

Table 1. Relationship between con/divergence in ageing and economic con/divergence

ample, in the first sub-period, Cyprus was in the rich group of regions of Southern Europe with a low share of the working age population; in the second sub-period, it stayed relatively rich but moved to the upper half of the share of working age population distribution (see Figure 7).

A change in the slope of the cumulative density for a group of regions between the beginning and the end of the period (lines of the same colors) in Figure 6 shows whether there was convergence or divergence in ageing: a steeper slope at the end of the period implies convergence, a flatter slope means divergence.

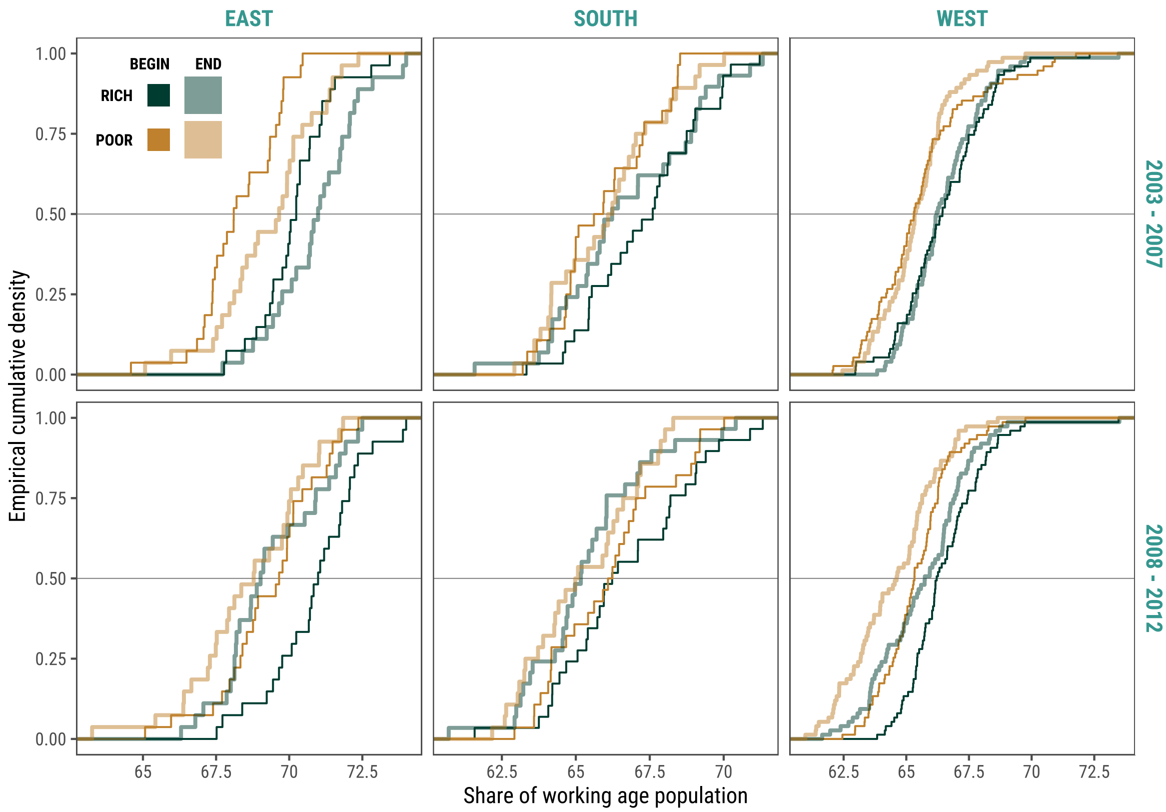

Fig. 6. Empirical cumulative densities of the share of working age population distributions, divided in halves by GDP per capita. Note: solid lines represent distributions at the beginning of the period, half-transparent lines – the end the period.

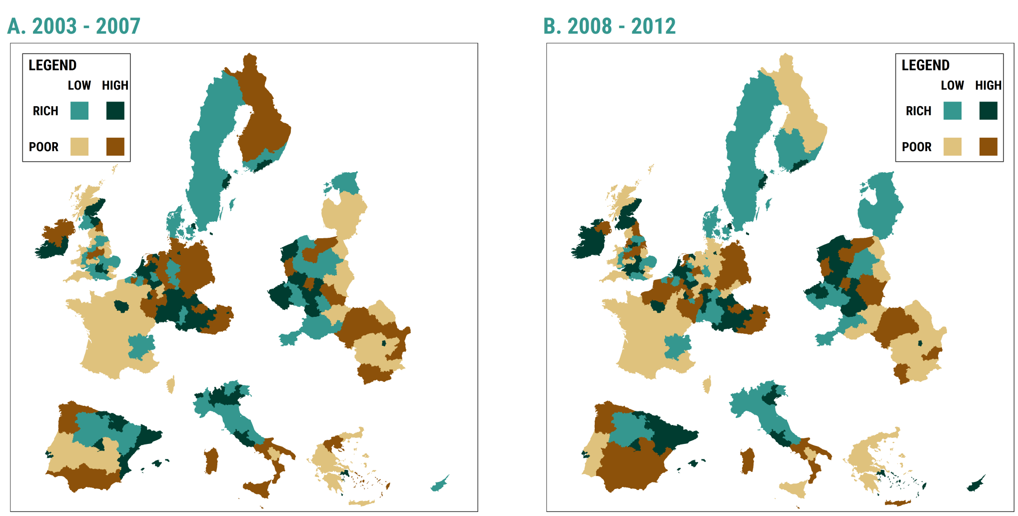

Fig. 7. Classification of European regions in 4 groups according to the level of GDP per capita and the share of working age population at the beginning of sub-periods: poor-low, poor-high, rich-low, and rich-high. Note: regions were classified separately for each sub-period (x2) and each part of Europe (x3).

Figure 6 shows which part of the distribution contributed most to the observed change. Most importantly, the change in the distance between the cumulative density lines for the poor and rich regions (different colors) indicates the effect of convergence or divergence in ageing on economic convergence or divergence: decreasing distance means a convergent effect; increasing distance means a divergent effect. And we can identify which group of regions and which part of its distribution contributed most to the narrowing or the widening of the distance between poor and rich regions. This explains the direction of the relationship between demographic and economic convergence or divergence.

To illustrate the interpretation of Figure 6, consider Southern Europe (the middle panels). The share of the working age population in rich regions is higher than in poor regions. Since the distance between the cumulative density lines for poor and rich regions decreased in the first sub-period (2003-2007), demographic change had a convergent effect on the economy (see also the corresponding column in Table 1). The main cause of the narrowing of the lines for poor and rich regions was the change in the lower part of the rich regions' distribution – these are mainly non-metropolitan regions of Northern Italy and Northern Spain (Figure 7). Such a case corresponds with the third case from the conceptual framework (bottom-left panel in Figure 1, pink arrow); this case explains the situation when divergence in ageing contributes to economic convergence – and that is precisely what happened in Southern Europe in the first sub-period. In the second sub-period (2008-2012), the distance between the cumulative density lines for poor and rich regions again narrowed. But this time the change was mainly driven by the developments in the upper part of the rich regions' distribution – now the group consisted mostly of the metropolitan regions of Southern Europe (Figure 7). That corresponds to the first case from the conceptual framework (top-left panel in Figure 1), when convergence in ageing contributes to economic convergence, thus revealing a positive association between them.

In Eastern Europe, the main changes occurred in the upper part of the poor regions' distribution during the first sub-period and in the lower part of the rich regions' distribution during the second sub-period – third case from the hypothetical framework and its inverse. In Western Europe, the main changes first happened in the upper part of the poor regions' distribution – fourth case (bottom-right panel in Figure 1); then, in the second sub-period, changes in the lower part of the poor regions' distribution were driving the increase in the distance between density lines – the inverse of second case (top-right panel in Figure 1).

Thus, population convergence does not have to lead to economic convergence and demographic divergence does not necessarily imply economic divergence. On the contrary: in many cases the relationship is inverse.

6. Conclusion and discussion

The evidence of economic convergence in Europe corresponds with earlier findings (Fingleton, 1999; Eckey and Türck, 2007; Borsi and Metiu, 2015). Separate analysis for the parts of Europe showed that large differences between parts of Europe are the main driver of convergence in GDP per capita, which correspond with the results of Crespo Cuaresma et al. (2014a). In contrast, differences in the dynamics of the share of the working age population contribute to divergence in ageing in Europe, but we see some convergent regional dynamics within parts of Europe.

We employed counterfactual analysis to estimate to what extent relative changes in population structures affect economic convergence. We used the decomposition of GDP per capita growth rates into the productivity (which includes also labour force participation) and demographic components. Then we analyzed the changes in the GDP per capita variance assuming no change in the demographic component. The difference between the zero population change scenario and the real development of regional economies shows the effect of convergence in ageing on economic convergence. We found that the direction of the relationship varies over time and in different subgroups of regions. It depends on the characteristics of the regions that experience the biggest changes in population structures, whether those regions are relatively poor or rich, and have relatively low or high shares of the working age population. If the main changes occur in the rich regions with a high share of the working age population or in poor regions with a low share of the working age population, the relationship is positive. Otherwise, when rich regions with a low share or poor regions with a high share experience the biggest changes in population structures, the relationship between convergence in ageing and economic convergence is negative.

The empirical evidence for the three parts of Europe in two periods showed that all four possible cases occurred. This result has a strong policy implication. With the main goal of the European Union's Regional Program to reduce regional disparities in the quality of life, it is important to understand that not every indicator should converge in order to facilitate economic cohesion. As shown in this paper, lasting or even increasing regional differences in population age structures often contribute to faster economic convergence. Policy measures that affect regional population age structures in order to promote economic convergence should address the right group of regions depending on the type of relationship between convergence in ageing and convergence in economies.

Our study is the first to focus on the interrelation between convergence in population structures and convergence in economic development. Further research may focus on disentangling the effects of labour force participation and labour productivity. While labour force participation usually decreases with age (Lee and Reher, 2011; Bloom *et al.*, 2015), and thus ageing of the working age population has a negative impact on total labour force participation, the effect on productivity is more complex. Some researchers find evidence in support of the human capital theory, showing a positive effect of labor force ageing on GDP through the growth in productivity (Lindh and Malmberg, 1999, 2009; Croix and Monfort, 2000; Futagami and Nakajima, 2001; Gómez and De Cos, 2008; Rauhut, 2012). Other researchers show a negative effect (Bloom and Williamson, 1998; Bloom *et al.*, 2010; Crespo Cuaresma *et al.*, 2016; Teixeira *et al.*, 2017).

The framework for analyzing the effect of convergence in ageing on economic convergence, proposed in this paper, addresses a new question in the field of demographic economics. This question is gaining importance in the light of the rapidly declining share of the working age population, while future convergence in ageing among European regions is likely to occur. With the rapidly declining share of the working age population, the only source of economic growth is increased productivity including an increase in labour force participation. The demographic burden that follows the prosperous years of demographic dividend will have an increasing downwards effect on GDP per capita in the coming decades (Van Der Gaag and De Beer, 2015). In such a setting, the relative regional differences in the dynamics of population structures may have a bigger effect on regional cohesion. Even though the direct effect of the population age structure on economic development is rather small, the role of convergence in ageing on economic convergence appears to be quite significant and in many cases is as important as the effect of relative changes in productivity and labour force participation.

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Chapter 5. Unequally ageing regions of Europe: Exploring the role of urbanization

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1. Introduction

Human populations experience the demographic transition at varying times and speeds (Lee, 2003; Reher, 2004). While booming population growth and persisting high levels of fertility are still the major issues in the least developed countries (Bloom, 2011), governments in developed countries are most worried about the rapid ageing of their populations (Lutz *et al.*, 2008; Bloom *et al.*, 2015) and the societal and economic challenges this poses for future generations (Lloyd-Sherlock, 2000; Skirbekk, 2008; Christensen *et al.*, 2009). As the demographic dividend—the most profitable period of demographic modernization, when the burden on the working-age population is the smallest—is left behind in most developed countries (Van Der Gaag and De Beer, 2015), the way to deal with population ageing is becoming the central topic of demographic debate (Van Nimwegen, 2013).

Even though all European countries are experiencing population ageing, there are relative differences in the speed of the process across countries and regions (De Beer *et al.*, 2012; Rees *et al.*, 2012; Kashnitsky *et al.*, 2017). In the context of a rapidly ageing population (Giannakouris, 2008), migration becomes an increasingly important component of population change (Findlay and Wahba, 2013); Coleman (2006) has gone as far as proposing the concept of the third demographic transition, in which migration plays the key role in population replacement. While more public attention is fixed on international migration (Van Wissen, 2001; Czaika and Haas, 2014), internal migration is crucial in determining subnational population structures (Rees *et al.*, 2013, 2017). And the key distinction in the relative speed of population ageing at subnational level is between urban and rural areas, which is in turn largely driven by migration, mostly internal (De Beer *et al.*, 2012). Ageing and urbanization are seen as the two main demographic transitions of developed populations (Beard and Petitot, 2010).

This paper examines differences in population ageing across NUTS-2 regions, which are the result of an attempt to unify geographical levels and facilitate cross-country comparisons (Eurostat, 2015a). Most existing research on urban–rural differences focuses on the more granular level of NUTS-3 regions or even the more local level (Sabater *et al.*, 2017; Gutiérrez Posada *et al.*, 2018). However, at the NUTS-2 level many more internationally comparable statistics are available. Moreover, the NUTS-2 level is the most important geographic level in terms of data-informed policy decisions (De Beer *et al.*, 2012, 2014; Capello and Lenzi, 2013; European Commission, 2014). Therefore this paper examines urban–rural differences across the 261 NUTS-2 regions in the European Union (EU-27) over the period 2003–13, for which a harmonized data set is available (De Beer *et al.*, 2014; Kashnitsky *et al.*, 2017). All the regions included in the analysis are shown in the reference map, Figure A1 in Appendix 1. The analysed countries do not include Croatia, which is a current state of the EU but joined only in 2013. However, the United Kingdom, which exited the EU in 2020, is included. Here and throughout the paper, the references to groups of regions, such as Eastern Europe, mean a subset from the analysed EU-27 countries.

Once we have established the concept of urbanization at NUTS-2 level, we explore whether urban–rural differences are contributing towards convergence or divergence in population ageing. The process of urbanization is likely to contribute to a divergent pattern of ageing: urbanized regions tend to attract people of working ages, while rural regions are left with a higher proportion of people out of the labour market (Smailes *et al.*, 2014). On the other hand, there is extensive evidence of an urban health and longevity advantage (Beard and Petitot, 2010; Kibele, 2014; Chen *et al.*, 2017; Naito *et al.*, 2017). This urban health bonus, coupled with lower fertility in the most urbanized areas (Kulu *et al.*, 2009; Vobecká and Piguet, 2011; Van Nimwegen, 2013), is likely to contribute to faster ageing in urban areas, offsetting the direct effect of urbanization (Zeng and Vaupel, 1989). Even though there are multiple studies that document increasing disproportions in local population structures (Chen *et al.*, 2017; Faggian *et al.*, 2017; Sabater *et al.*, 2017; Gutiérrez Posada *et al.*, 2018), it is rather unclear whether a similar pattern can be found at the NUTS-2 level.

There are large demographic differences between Eastern, Southern, and Western Europe that might also manifest themselves in the process of urbanization. For example, Shucksmith *et al.* (2009) found that the urban–rural difference in quality of life is much smaller in Western Europe compared with Eastern Europe. Similarly, Crespo Cuaresma *et al.* (2014) uncovered a large heterogeneity between Eastern European regions. Even though on average they are catching up, the gap between the biggest urban regions and the periphery is widening within countries. Multiple studies have revealed a widening gap between the deprived peripheral regions and the better-off urban areas in the countries of Southern Europe after the financial crisis of 2008–09 (Salvati, 2016; Salvati and Carlucci, 2017). Thus, our paper examines the differential effect of the urban–rural divide on convergence or divergence in ageing in Western, Southern, and Eastern Europe.

2. Is there urbanization at the NUTS-2 regional level?

The official Eurostat urban–rural classification exists only at the NUTS-3 level (Eurostat, 2017); such a classification requires quite a granular delimitation of urban areas, which is only possible at low enough levels of spatial disaggregation. However, most statistics comparable at the pan-European level are aggregated at the NUTS-2 level, which is the prime level of regional analysis within the EU. Also, the regional Cohesion Policy programmes operate at the NUTS-2 level (Leonardi, 2006). NUTS-2 regions are rather large: on average, a NUTS-2 region has an area of 19,700 km2 and a population of 1.87 million, comparable to a small country such as Slovenia (European Commission, 2014; Kashnitsky and Mkrtchyan, 2014). Almost every NUTS-2 region includes both urban and rural populations, which makes it difficult to classify the regions into binary urban or rural groupings. The challenging classification task was solved within the NEUJOBS project. To proxy urban–rural differences, NUTS-2 regions were classified into three categories: Predominantly rural, Intermediate, and Predominantly urban. This classification was designed in such a way as to keep the population figures of the three categories as close as possible to that of the official Eurostat NUTS-3 level classification (De Beer *et al.*, 2012, 2014). In this paper we use a simplified version of the NEUJOBS classification (Figure 1A).

On average, European regions aged a bit over the study period, 2003–13 (Figures 1B, 1C): the mean proportion of population that was of working age (15–64) decreased by almost one percentage point, from 66.8 to 65.9 per cent. Note that in the rest of the paper we use the term 'share of working-age population' to mean the total population aged 15–64 as a proportion of the whole population. At the same time, inequality in regional population age structures increased—the standard deviation of the share of working-age population rose from 2.26 to 2.51 per cent, and the coefficient of variance rose accordingly, from 0.034 to 0.038. This large-scale glance suggests that together with the dominant process of population ageing, there was divergence in population age structures, at least as measured by these two variance-based metrics. The question we want to tackle is whether this divergence could be explained to some extent by differential population age structure developments in urban and rural regions. Yet, first we need to figure out if urbanization is still happening in Europe.

There is evidence of both urbanization and counter-urbanization occurring in modern Europe at the local level (Kabisch and Haase, 2011). If anything, regional paths of economic (Ballas *et al.*, 2017) and demographic (Wolff and Wiechmann, 2017; Gurrutxaga, 2020) development are becoming rather more heterogeneous; Danko and Hanink (2018) found similar results for the counties of the United States (US). The reasonable question arises: are European regions still experiencing urbanization when we look at urban–rural differences at the NUTS-

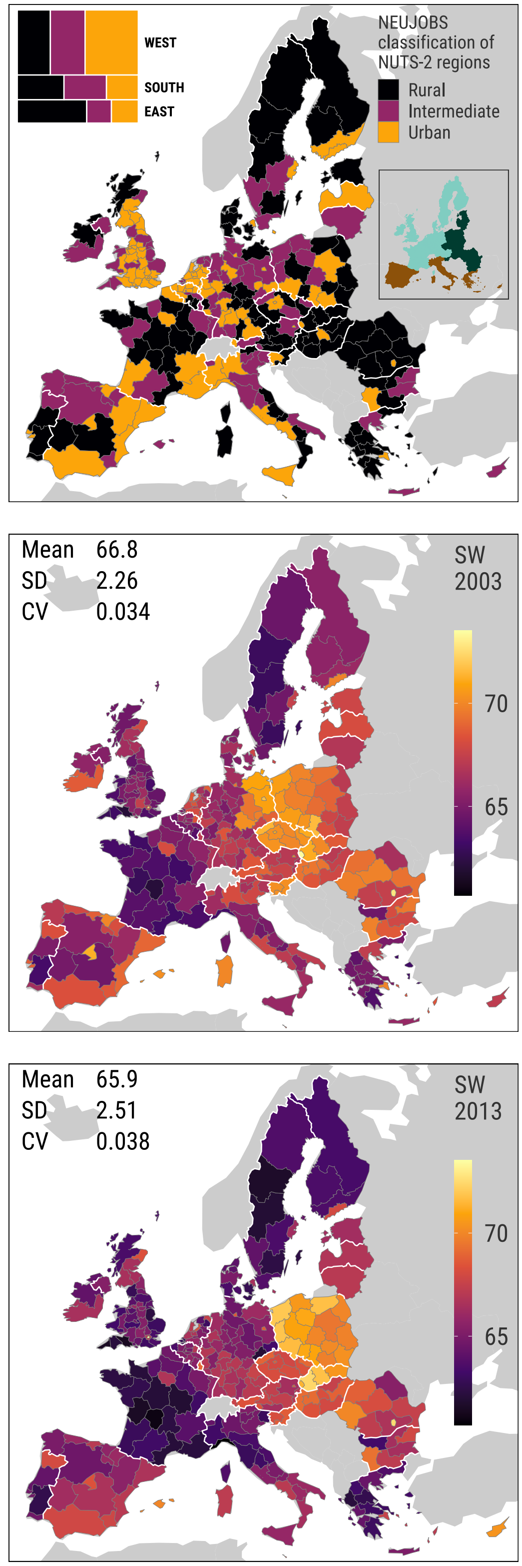

Fig. 1. Reference maps of the EU-27 NUTS-2 regions: A – NEUJOBS urban-rural classification, inset map shows the division of European countries into Western, Southern, and Eastern parts, mosaic plot in the top left corner gives the relative frequencies of the regions across the three parts of Europe and Urban/Intermediate/Rural classification; B, C – percentage of working-age population in 2003 and 2013. Note: See Appendix 1 for the reference map with all the regions labelled. SD refers to the standard deviation and CV to the coefficient of variance.

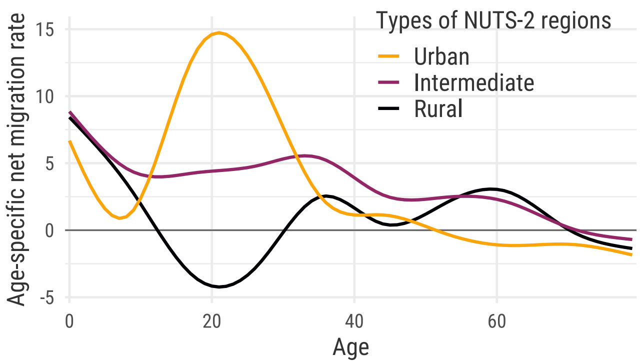

Fig. 2. Age-specific total net migration rates by urban-rural types of NUTS-2 regions, pooled single year data for the period 2003-2012. Note: The lines are smoothed using a generalized additive model. Source: Own calculations based on demographic balance; migration change includes both internal and international migration.

2 level? To address this question, we calculate total net age-specific migration rates for all NUTS-2 regions using the demographic balance approach (Kashnitsky *et al.*, 2017). With such an approach, we capture age-specific change in population size due to total migration, not distinguishing between regional (internal) migration and international migration flows (within or outside the EU). Then these rates are smoothed separately for each of the three NEUJOBS categories of regions: Predominantly rural, Intermediate, and Predominantly urban (Figure 2).

The age pattern looks exactly as we would expect to see in the presence of ongoing urbanization. The process of urbanization implies that people migrate from less urbanized territories to urban agglomerations. Migration always has a characteristic age profile, with higher intensities at young adult ages (Pittenger, 1974; Rogers *et al.*, 2002). This is precisely what we see in Figure 2—it clearly shows that Predominantly urban regions receive much more in-migration at young adult ages compared with Intermediate and Predominantly rural regions. Rural regions lose population at young adult ages; these young people are most likely to migrate to more urbanized areas, which are able to offer them better educational and employment opportunities. In contrast young families with children and older adults tend to move from Predominantly urban to Predominantly rural and Intermediate regions. Note that the three lines do not balance off at zero net migration, which means that on top of migration between the regions, Europe sees quite a substantial inflow of international migration. To sum up, if we have successfully defined urbanization at the NUTS-2 aggregation level, then there was ongoing urbanization over the period 2003–12.

To account for the possible differences between Eastern, Southern, and Western Europe, we also carry out similar smoothing separately for each of the three parts of Europe (Figure 3). Following the logic of our previous research (Kashnitsky *et al.*, 2020), we divide European NUTS-2 regions not into four parts—as is done by Eurostat's official (EuroVoc, 2017) classification—but into three parts: Eastern, Southern, and Western. We choose not to distinguish Northern Europe as a separate part because of its relatively small size (just 22 NUTS-2 regions) and considerable inner heterogeneity: the Nordic regions are merged with Western Europe, and the Baltic regions are classified as Eastern Europe (with which they have much more in common in terms of the analysed variables). See the small inset map in Figure 1A showing the division of the NUTS-2 regions across the three parts of Europe.

All three parts of Europe experienced faster population growth through migration in the at adult ages in the Predominantly urban regions than in the Intermediate or Predominantly rural regions, which means that urbanization was occurring at the NUTS-2 level. However, there are some differences between the three parts of Europe in the way they have urbanized. Regions of Southern Europe experienced the highest net migration rates within the study period: even the Predominantly rural regions saw population growth through migration, though much more moderate than that of the Predominantly urban and Intermediate regions. This was due to relatively high international migration. Another feature of Southern European regions is that Intermediate regions are closer to Predominantly urban regions in terms of the age-specific migration profile (based on this we simplify the classification to just Predominantly urban (or Urban) and Predominantly rural (or Rural) in subsequent analyses; see 'Data' subsection). The main difference between Eastern and Western Europe is in the later life migration out of the urban areas, suburbanization and counter-urbanization, that is evident for the latter—by a net migratory surplus in rural regions at the mature adult ages—and non-existent for the former.

One question is whether the net migration age profiles change over time. In Appendix 2, Figure 8, we check these profiles for the first (2003–07) and the second (2008–12) halves of the study period. In contrast with the analysis for the US (Cooke, 2011, 2013), we see no major reduction in net age-specific migration rates over time, except in Southern Europe where the reason is likely the economic crisis of 2008–09, coupled with the extremely high in-migration rate just before it.

In summary, despite some notable differences, all the three parts of Europe clearly experienced urbanization at NUTS-2 level during the study period, with urbanization being defined as relative population change due to migration. That brings us back to the question of whether urbanization has contributed to convergence or divergence in population structures.

3. Methods and data

3.1. Methods. In this paper we focus on the share of the population that is of working age as a summary measure of the population age structure. The working-age population is defined conventionally as the proportion of people aged 15–64 in the total population. The reason for choosing this indicator is that it is expected to have a positive relationship with the economic growth potential of regions (Van Der Gaag and De Beer, 2015).

To compare urban–rural differences in the share of working-age population, we calculate empirical cumulative densities and plot the distributions of corresponding groups of regions arranged in ascending order. This distributional approach to convergence analysis has several advantages. First, it allows us to distinguish different causes of convergence. For instance, conver-

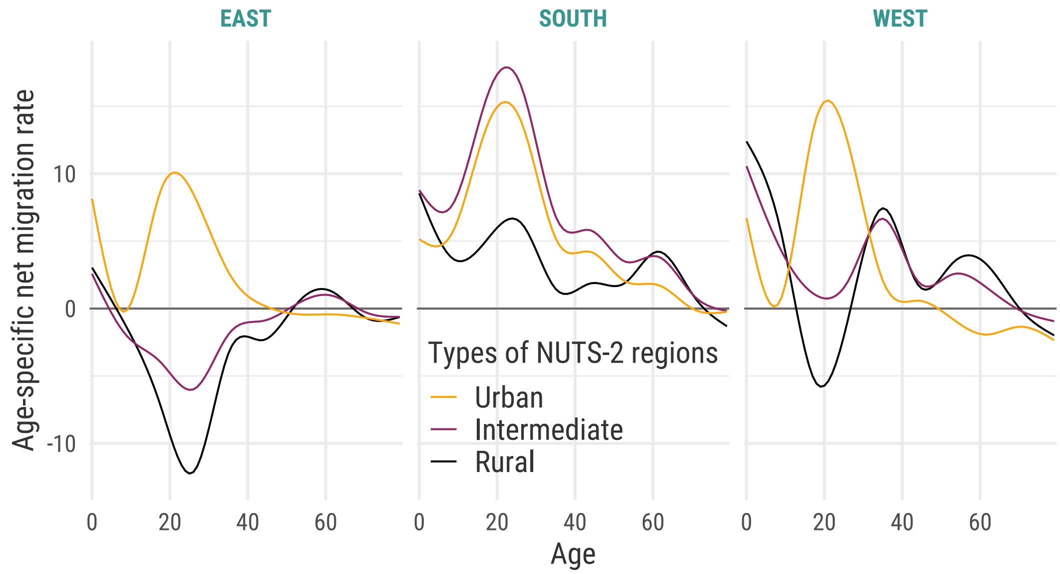

Fig. 3. Age-specific total net migration rates by urban-rural types of NUTS-2 regions and parts of Europe, pulled single year data for the period 2003-12. Note: The lines are smoothed using a generalized additive model. Source: Own calculations based on demographic balance; migration change includes both internal and international migration.

gence can be due to smaller differences across clusters of regions or smaller differences within clusters of regions, and cumulative distributions show both at the same time. Changes in the distance between separate distributions show whether there is convergence or divergence between clusters. This can be seen clearly from changes in the difference in the median values. Changes in the slope of the distributions show whether there is convergence or divergence within a group of regions: the steeper the slope, the smaller the variation of values in the distribution. Hence, an increase in the slope indicates convergence within the group of regions. Second, the approach helps to distinguish the effects of changes that occur in the upper and lower parts of the distribution. This is important since there is a conceptual distinction between convergence occurring due to catching-up of lagging regions or a faster decrease in the upper part of the distribution. Finally, when the profiles of the cumulative density distributions for two groups of regions become more similar over time, this can also indicate a specific type of distributional convergence not otherwise captured by summary measures.

Empirical cumulative densities provide a powerful visualization framework for picturing convergence. However, in order to assess the magnitude of changes, we also need to calculate metrics based on the distributions. For this purpose we use a logistic-type model in which we allow the slope parameter to vary between the lower and upper parts of the distribution, that is, above and below the median value:

$$f(x) = \delta(x \geq m)\frac{e^{a(x-m)}}{1+e^{a(x-m)}} + \delta(x < m)\frac{e^{b(x-m)}}{1+e^{b(x-m)}}$$

where $f(x)$ is the cumulative density function, x is the share of the working-age population, m is the median value, $\delta(x)$ is the indicator function; a, b, and m are the parameters to be estimated by non-linear least squares.

Greater estimated values of the a and b parameters indicate that the cumulative density curve is steeper. Hence, an increase in these parameter values over time means convergence, while a decrease means divergence. Furthermore, if a increases there is convergence above the median; if b increases there is convergence below the median. A change in the median value (parameter m) implies a shift of the whole distribution. If, for example, a and b do not change and m increases, that means that the whole distribution is shifted uniformly toward higher values of x, but neither convergence nor divergence due to the change in the cluster distributions is observed; at the same time, between-cluster convergence/divergence is defined by the relative movement of the cluster medians.

3.2. Data. We analyse population age structures of the 261 NUTS-2 regions of the EU-27 using a harmonized data set for the years 2003–12 (Kashnitsky et al. 2017). The overseas territories of France, Spain, and Portugal are excluded from the data set. The data come from Eurostat (2015b). We use the 2010 definition of NUTS regions (Eurostat, 2015a) and a modified version of the EuroVoc (2017) official classification of parts of Europe, in which we split Northern European regions between Western Europe (Nordic countries) and Eastern Europe (Baltic countries). The NEUJOBS urban–rural classification of NUTS-2 regions is used (De Beer *et al.*, 2012, 2014). We simplify it by eliminating the Intermediate category: based on the profile of age-specific net migration rates (Figure 3), Intermediate regions are classified in Southern Europe as Predominantly urban, and in Eastern and Western Europe as Predominantly rural.

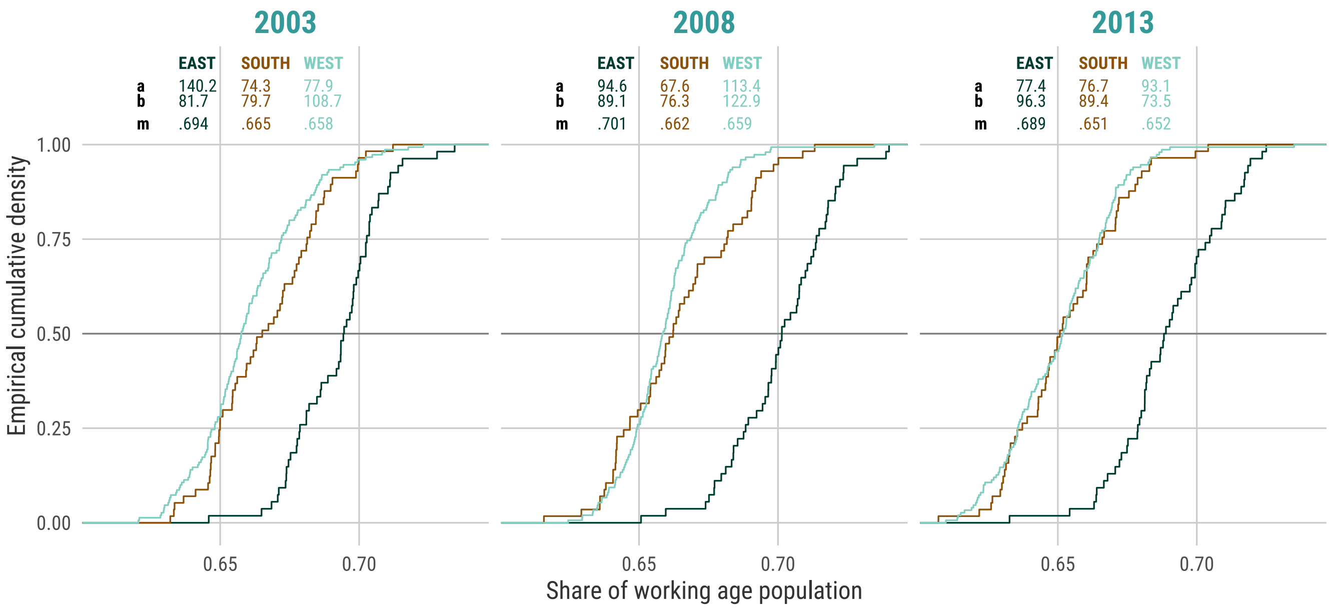

Fig. 4. Empirical cumulative densities of the share of working-age population for NUTS-2 regions in the three parts of Europe, 2003, 2008, and 2013. Note: The annotated tables represent the parameters of the cumulative densities estimated by non-linear least squares – a and b are the parameters of the logistic curve above and below the median, correspondingly, and m is the median value of the share of working-age population.

4. Results

4.1. Convergence or divergence in population structures?. To address the main question of the paper—whether urbanization is contributing to divergence (our main hypothesis) or convergence in population age structures—we first want to figure out what the baseline dynamics of the relative regional differences in population structures within the study period were.

A glance at the empirical cumulative densities of the share of working-age population in the three parts of Europe (Figure 4) tells the story of the ending phase of the demographic dividend in Eastern Europe (Van Der Gaag and De Beer, 2015; Kashnitsky *et al.*, 2020) The median values for this group of regions were much higher throughout the study period than those for Southern or Western Europe. In the first half of the period, 2003–08, Eastern Europe showed distinct diverging development from the rest of Europe—its distribution line moved further apart from the two other lines, and m increased from 0.694 to 0.701, while it decreased slightly in Southern Europe and stagnated in Western Europe. In this period Eastern Europe was still benefiting from the main phase of demographic dividend. However, in the second half, 2008–13, the gap between Eastern and the rest of Europe started to decrease, indicating the end of the demographic dividend and the start of rapid downward convergence: m decreased by 0.012 in Eastern Europe, 0.011 in Southern Europe, and only 0.007 in Western Europe. The differences between Southern and Western Europe, which were driven entirely by the regions in the upper part of the distributions, virtually disappeared—the South caught up with the West, the forerunner of demographic transition. This may reflect the fact that there were only a handful of regions in Southern Europe that managed to keep a relatively high share of working-age population. Population ageing was especially fast in the upper part of the distribution of Eastern European regions, most likely caused by the rapid outflow of working-age migrants from the urbanized areas of Eastern Europe to Western Europe (Okólski and Salt, 2014).

The overall differences between Eastern, Southern, and Western Europe increased a bit in the first half of the study period due to the divergent development of Eastern Europe, but then decreased a lot by the end of the study period. In fact, the differences in the cumulative density distributions between Southern and Western Europe disappeared completely. On analysing the slopes of the empirical cumulative densities, we notice that they became much more similar towards the end of the study period; in every part of Europe the distribution of regions became alike. However, the distributions themselves became less steep, meaning that the overall variance in the share of working-age population increased, indicating divergence within the three parts of Europe. In other words, regions in every part of Europe became more heterogeneous by the end of the study period. This effect is most clearly visible in Western Europe, which was characterized by a squeezed lower tail of the distribution in 2003. By 2013 the lower half of the distribution had become much shallower and wider, which reflects the fact that there are some regions in Western Europe that are ageing at an accelerated pace. Most likely, these are the regions of rural periphery (Kashnitsky and Schöley, 2018). This raises the question of whether the divergence in population age structures can be attributed to the effects of urbanization.

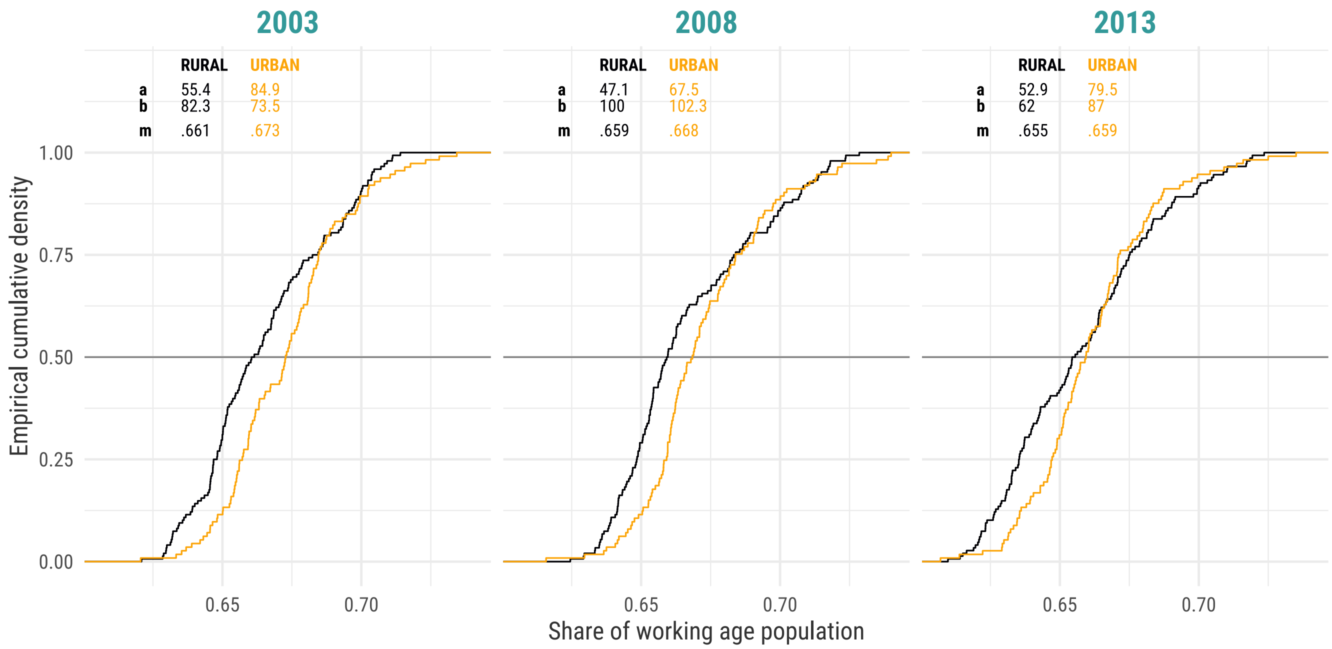

Fig. 5. Empirical cumulative densities of the share of working-age population for NUTS-2 regions in the two urban–rural categories, Europe, 2003, 2008, and 2013.

4.2. The contribution of urbanization. Figure 5 compares the empirical cumulative densities of Predominantly rural and Predominantly urban regions in Europe as a whole at the beginning, middle, and end of the study period. At first glance, they look surprisingly alike, and there seems to be very little change between the lines over time. This is an artefact driven by the systematic differences in the timing of demographic transition between the three parts of Europe (Kashnitsky *et al.*, 2020). As in the case of the analysis of convergence in ageing for all European NUTS-2 regions in (Figure 4), the differences between Eastern, Southern, and Western Europe are masking the differences that exist between the urbanized and less urbanized regions.

When similar empirical cumulative densities are calculated for each part of Europe separately, the picture becomes much more informative (Figure 6). The dynamics of the distributions suggest that in every part of Europe, differences between urban and rural regions have decreased over time—the cumulative distribution lines for urban and rural regions come closer to each other over time in every part of Europe. This means that the process of urbanization—which, as we saw in Figures 2 and 3, was occurring in Europe at NUTS-2 level over the study period—contributed to convergence of regions in population structures rather than the expected divergence.

In Eastern European regions, the distributions of urban and rural regions have become very similar, indicating convergence. Also, the urban–rural difference in the median values reduced strongly in the second part of the study period, from 0.012 to 0.006. At the same time, within the urban and rural groups of regions, variation increased in the regions with relatively high shares of population of working age—the slopes above the median became less steep: the value of the a parameter for rural regions declined from 173.5 to 81.8 between 2003 and 2013, and for urban regions from 130.8 to 94.1.

In Southern Europe, urban regions aged fastest, reducing the gap with rural regions: the values of m for urban regions decreased from 0.677 to 0.657 over the ten-year period. As a result, the urban–rural difference in m decreased from 0.027 to 0.014. The Southern regions saw the biggest increase in variation within urban and rural groups of regions, which may reflect the uneven effect of the 2008–09 economic crisis that hit this part of Europe hardest. The a parameter for rural regions declined from 152.0 to 90.2, and for urban regions from 139.2 to 84.4; the b parameter for rural regions decreased from 207.8 to 103.5, and for urban regions from 85.1 to 79.7.

Western regions saw a rapid convergence in the first part of the period, and then divergence in the second part. The a parameter for rural regions increased from 89.7 to 125.6 in the first subperiod and declined to 65.0 during the second subperiod; for urban regions there was an increase from 72.6 to 106.4 followed by a decrease to 100.4. The b parameter for rural regions increased from 108 to 138.2 followed by a decrease to 94.0, and for urban regions an increase from 116.4 to 164.6 was followed by a decrease to 110.3. The difference in the medians did not change in the first subperiod, but increased in the second subperiod, even though both urban and rural regions saw greying of the first baby boomers; the urban–rural difference in m increased from 0.008 in 2003 to 0.013 in 2013. This reflects the uneven effect of the ageing of the baby boom generation across Western regions—it hit rural regions more than urban regions and hit the lower half of

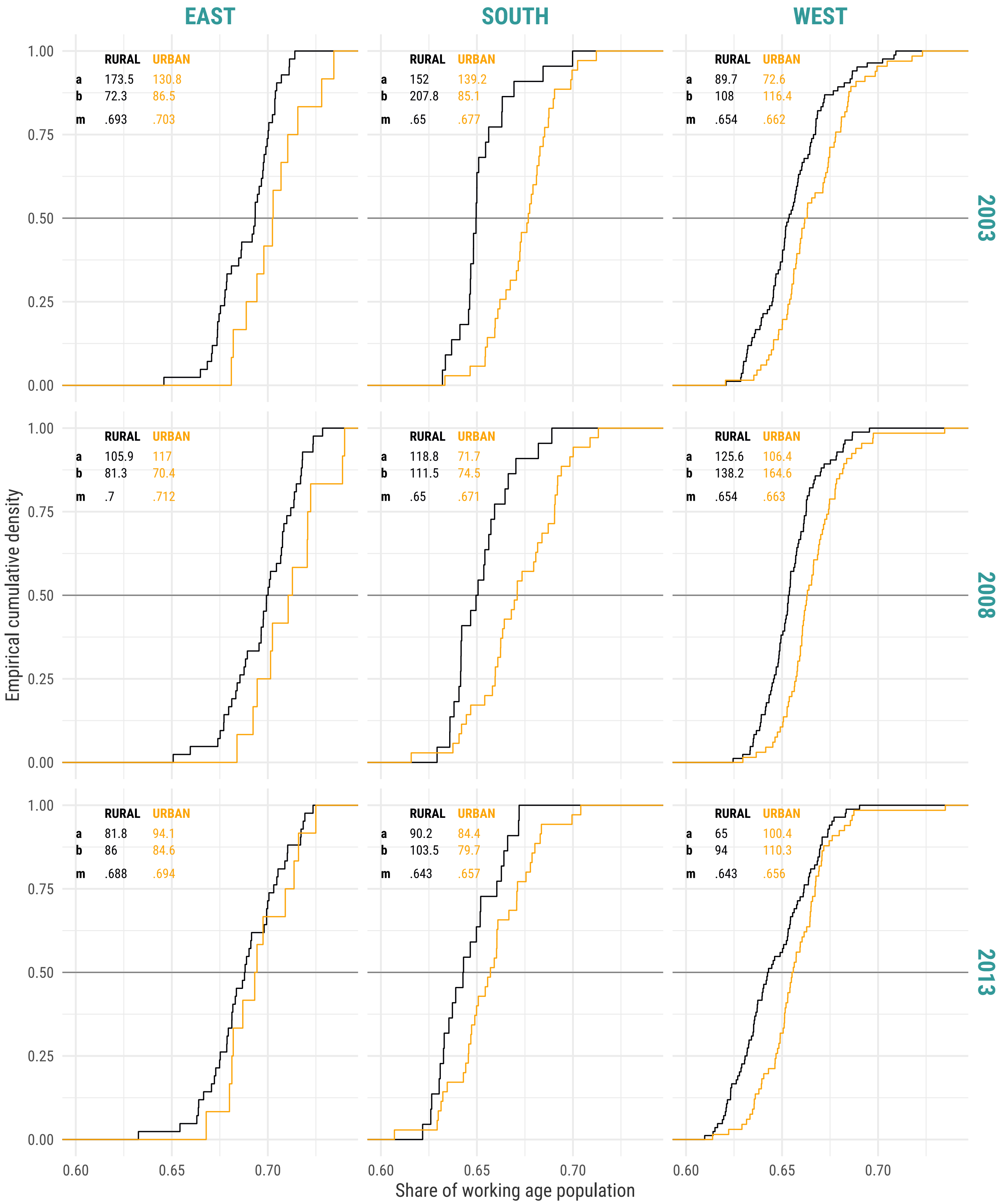

Fig. 6. Empirical cumulative densities of the share of working-age population for the NUTS-2 regions in three parts of Europe and the two urban-rural categories of regions, , 2003, 2008, and 2013.

the distribution of urban regions more than the upper half. In fact, only the second part of the study period in Western regions shows us a picture close to the one that we expected, in which faster ageing in rural regions increases the gap in population age structures between urban and rural regions and increases the heterogeneity within both groups of regions.

The distributions for South and West, that in the first analysis (Figure 4) became almost identical towards the end of the study period, no longer look so similar once we distinguish between urban and rural regions (Figure 6). In Southern regions the main urban–rural differences occur in the upper half of the distribution, indicating that there are a certain number of urban regions that have been more successful in preserving a younger population structure. In contrast, in Western regions the upper half of the rural distribution does not differ a lot from that of the urban regions. This may be the result of less contrast in the urban–rural continuum in the densely populated parts of Western Europe, meaning that prosperous rural regions do not age much faster than urban regions.

The overall contribution of urban–rural differences to regional differences in population ageing is clearly visible in the changes of the median values. In both Eastern and Southern Europe this difference reduced significantly during the study period, indicating convergence across urban and rural regions in population ageing, in contrast to the overall divergence of population age structures. Western Europe saw a slight increase in the difference between the medians, which was to some extent compensated by the reduced difference in the upper half of the distribution. In general, we see a decrease in the estimated values of the a and b parameters, which means that within urban and rural groups of regions there was divergence in population age structures. In all three parts of Europe, the fastest divergence occurred in the upper half of the distributions. This means that, in the context of a rapidly ageing Europe, there are some regions that have been more successful in keeping a relatively high proportion of their population at working ages.

5. Discussion

Our results show that overall NUTS-2 regions in Europe have become less similar in population age structures over time, though the differences between the three parts of Europe—Eastern, Southern, and Western—have diminished. Similarly, yet contrary to our expectations, continuing urbanization does not appear to have led to divergence in population age structures, that is, increasing disparities between urban and rural regions. Instead, both categories of regions have become more heterogeneous. Towards the end of the study period, we observe that regions in the upper part of the rural distribution, those with the highest share of working-age population, have become less different from the corresponding upper part of the urban distribution. This development is less prominent in the lower part of the distributions—rural regions with the lowest shares of working-age population form particularly disadvantaged clusters. This suggests that the urban–rural classification is becoming less informative. This finding is in line with other published papers (Kabisch and Haase, 2011; Pagliacci, 2017; Wolff and Wiechmann, 2017; Danko and Hanink, 2018).

One limitation of our study is the rather crude conventional approach to the definition of ageing based on the fixed age boundaries of the working-age population. With increasingly flexible later-life working arrangements, the cut-off of 65 years of age is progressively becoming less descriptive of a population's real productivity (Vaupel and Loichinger, 2006; Lee *et al.*, 2014). Ideally, we would want to use estimates for population consumption and production age curves at regional level, similar to the National Transfer Accounts estimated for countries (Kupiszewski, 2013; Vargha *et al.*, 2017; Kluge *et al.*, 2019). Unfortunately, these estimates are not yet available at the regional level, which is the focus of this study on urban–rural differences.

One possible refinement of the presented results could include a more nuanced approach to the definition of age boundaries for the older-age population (Sanderson and Scherbov, 2010; Spijker and MacInnes, 2013; Kjærgaard and Canudas-Romo, 2017; Loichinger *et al.*, 2017). The arbitrary conventional working-age lower boundary of 15 years is also changing its meaning with the persistent growth in educational uptake among older teenagers (Kc *et al.*, 2010; Harper, 2014) and the prolonging of transitions to adulthood (Billari and Liefbroer, 2010; Bongaarts *et al.*, 2017). Thus, conventional age cut-offs are becoming less and less valuable in defining the transition to the working-age category. This is especially important given the tremendous diversification of lifestyles and generally much increased variability in pathways to adulthood (Buchmann and Kriesi, 2011; Damaske and Frech, 2016). In fact, the more variable the age of becoming 'adult', the less informative any fixed cut-off point becomes. To address this limitation of our study, we check how sensitive the regional differences in the share of working-age population are to shifting the lower age boundary from the conventional 15 years to 20 years, and the upper boundary from 65 to 70 years (see Appendix 3). The sensitivity check suggests that our results are robust to the definition of the working-age population—shifting the definition of working-age population may slightly offset the timing of the demographic transition but not reverse the relative regional differences.

Another possible way to develop the present study would be to focus on other relevant dimensions of regional inequality that may contribute to convergence or divergence in population age structures and may interact with other urban–rural differences, for example in the ethnic (Franklin, 2014), socio-economic (Tselios, 2014) and educational (Striessnig and Lutz, 2013; Goujon *et al.*, 2016) structures of the population.

The evident difficulty of research on urban–rural differences in population structures lies in the urban–rural classification itself. In this paper we rely on the classification developed in the NEUJOBS project (De Beer *et al.*, 2012, 2014). Apart from the aggregation difficulties that are discussed, and solved by this approach, there are challenges posed by the constantly evolving urban–rural continuum. For instance, many regions of Europe still experience urban sprawl (Morollón *et al.*, 2016, 2017; Salvati and Carlucci, 2016). There have been multiple attempts to develop a more nuanced approach to urban–rural classification (Champion, 2009; Pagliacci, 2017). Some studies have shown that movements of urban–rural boundaries can have quite some effect on urban–rural differences in demographic development (Chen *et al.*, 2017). The increasing difficulty of the urban–rural boundary delimitation even motivated Caffyn and Dahlström (2005) to call for a new interdependence approach in urban–rural research, as opposed to the conventional approach that is focused on differences.

6. Conclusions

Our paper examines whether urbanization has contributed to divergence in population ageing between urban and rural NUTS-2 regions. We first show that at the NUTS-2 level the age profiles of net migration indicate that there has been ongoing urbanization. Young adults tend to move from rural to urban regions. However, our results show that this has not resulted in an increase in the difference in population age structures between urban and rural regions. The effect of net migration has been rather small, outweighed by the overall divergence in the regional distributions of the shares of working-age population. We find support for previous studies that have shown urban areas becoming more and more heterogeneous (Kabisch and Haase, 2011; Wolff and Wiechmann, 2017). It is important to distinguish urban regions that tend to form successful clusters, in terms of preserving favourable population age structures, from less prosperous ones (Sabater *et al.*, 2017). This distinction was especially evident in Southern Europe after the 2008–09 economic recession (Salvati, 2016; Salvati and Carlucci, 2017). Regional population age structures are becoming more unequal both in urban and rural groups of regions, and the binary urban–rural classification is becoming less and less useful in distinguishing macro patterns in regional population age structure dynamics.

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8. Appendix 1

Figure 7 provides a reference to help the reader navigate across the vast number of NUTS-2 regions in Europe. Please find the complete list of regions at Eurostat website, the page devoted to history of NUTS (Eurostat, 2015a). The NUTS version used in in this paper is 2010. Eurostat also provides a detailed explanation of the urban-rural typology at NUTS-3 level (Eurostat, 2017).

9. Appendix 2

Figure 8 is a sensitivity check for the possible leveling off of urbanization driving migration. As we see, only in Southern Europe the intensity of positive migration reduced slightly in the second part of the study period. Though, this effect is likely driven by the economic crisis of 2008-2009 and might be rather a temporary shock than a more permanent change.

10. Appendix 3

The working-age population defined using the conventional age boundaries of ages 15 and 65 is gradually becoming a less and less valuable proxy for the economically active part of the population. Thus, in Figure A3 we carry out a sensitivity check comparing three more definitions of working-age population against the conventional definition. We test all four combinations of the lower age boundary (15 or 20) and the upper age boundary (65 or 70). Since the resulting working-age groups differ in the number of single ages they contain—45, 50, or 55 years—we perform z-standardization of the four differently defined proportions of the population that is of working age. We plot the z-standardized distributions of the share of working-age population with the alternative age boundaries for the three parts of Europe and the years 2003, 2008, and 2013. The distributions do not change substantially with a change in the age definition, which suggests that there should be no major difference in the results of the current study were we to choose an alternative definition of the working-age population. Due to the present waves in population age structures, shifting the definition of the working-age population may slightly offset the timing of the demographic transition but not reverse the relative regional differences.

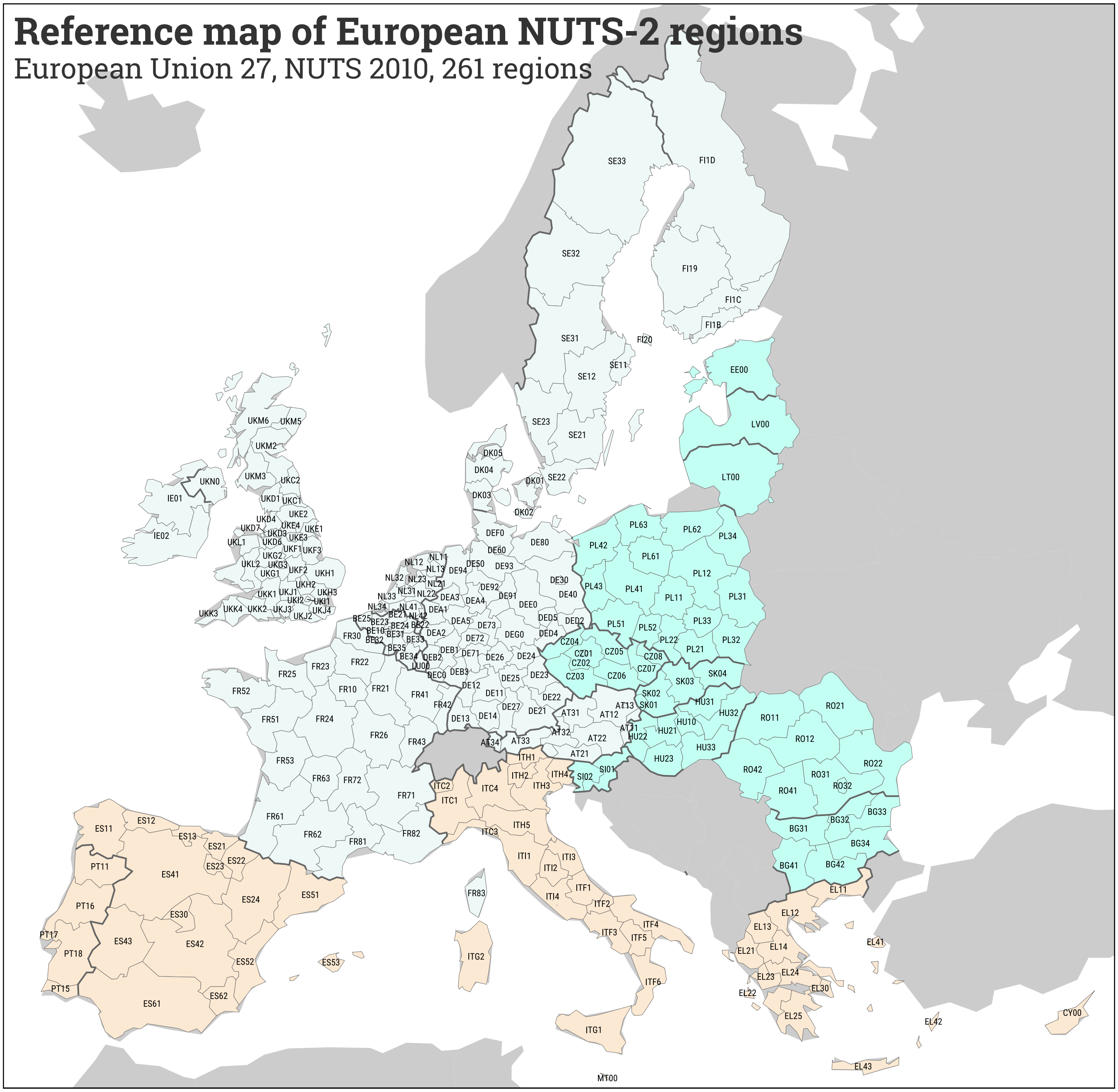

Fig. 7. Reference map of the EU-27 NUTS-2 regions.

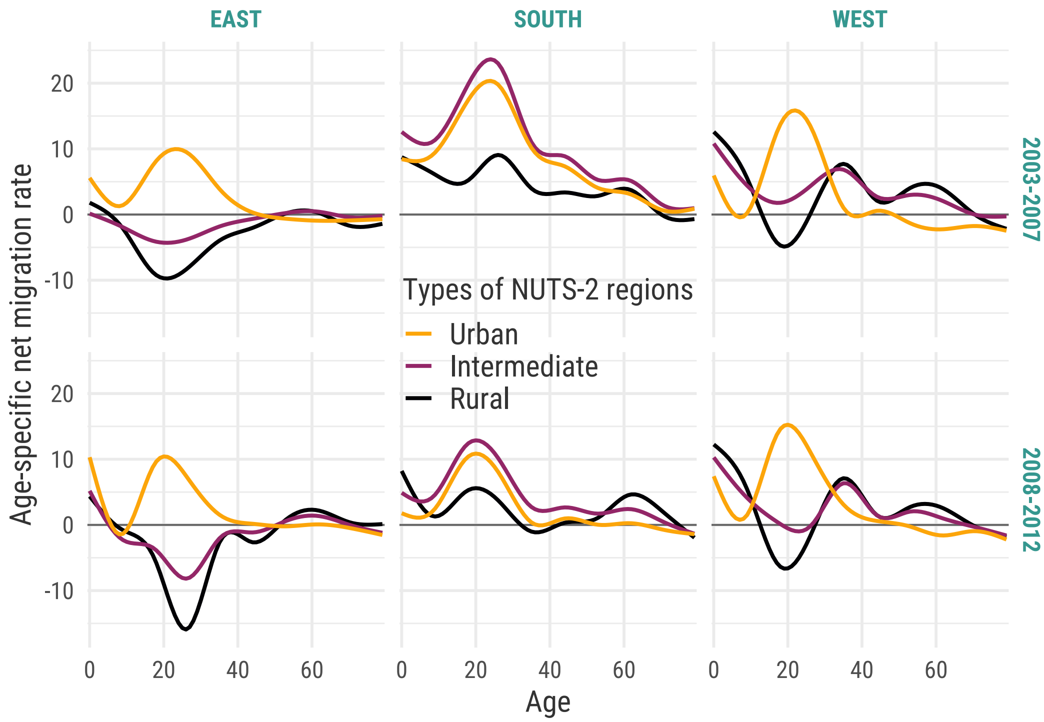

Fig. 8. Age-specific total net migration rates by urban-rural types of NUTS-2 regions: pooled single year data for two subperiods, 2003-07 and 2008-12, of the main study period, 2003-2012. Note: the lines are smoothed using a generalized additive model. Source: own calculations based on demographic balance; migration change includes both internal and international migration.

Fig. 9. Box plots for the z-standardized shares share of working-age population calculated using the conventional lower and upper age boundaries of 15 and 65 years (green colour or light grey in print) and three alternative definitions–age boundaries of 15–70, 20–65, and 20–70 years (dark grey): NUTS-2 regions in three parts of Europe, 2003, 2008, and 2013

Chapter 6. A new approach to convergence in population age structures

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1. Introduction

Demography is a discipline of transitions. Even the main "in-house" theory is called Demographic Transition (Notestein, 1945; Kirk, 1996). The discipline also studies the epidemiological transition (Omran, 2005), fertility transition (Cleland and Wilson, 1987; Mason, 1997), mobility transition (Zelinsky, 1971), urbanization (Davis, 1955), educational transition (Lutz *et al.*, 2007; Kc *et al.*, 2010), second demographic transition (Van De Kaa, 1987; Lesthaeghe, 2010) and even the third one (Coleman, 2006). The most characteristic feature of transitions is that they never happen uniformly across populations partly because the preliminary conditions and innovations never spread equally (Rogers, 1976; Vallin and Meslé, 2005).

Transitions move the average value of the key indicator from one level to another. As populations move along the transition route at varying times and pace (Reher, 2015), the difference between them first increases then decreases. At the level of populations, transitions often follow a logistic curve. Imagine, you observe a fleet of cars moving from one traffic light to the other: first, when they accelerate, the distance between them increases, later on, as they break and squeeze closer to the next traffic light, the distance decreases. In a similar manner, we expect to see divergence in the quantified measure at the beginning of any transition and convergence in this measure at the end of a transition. In fact, convergence is usually assumed as the result of a transition, and the measurable concept of convergence is routinely used to define the end a transition (Coleman, 2002).

The relative differences in demographic developments are imprinted in population age structures (Reher, 2015). Comparative analysis of population age structures can be used to back-track the demographic processes that had shaped them and thus reveal the demographic histories of the populations (Wilson *et al.*, 2013; Rodríguez-Vignoli and Rowe, 2018). We follow this approach and analyze regional differences in population age structures to let them tell the story of unequal uptake of the ageing transition in different parts of Europe and across the persisting urban/rural divide.

In this paper we propose to analyze regional age distributions as ternary compositions, with population divided in three broad age groups: youths (0–14), working age (15–64), and elderly (65+). Traditional summary measures of population age structures, which are calculated as the ratios of these age groups, can easily and meaningfully be visualized in ternary plots. As an example, Figure 1 demonstrates Total Support Ratio (a) and Old Age Dependency Ratio (b) in simulated populations. A fixed value of the summary measure (2 for TSR and 1/4 for OADR) corresponds to an isoline in the ternary plot. This is an illustration that several different populations can have exactly the same traditional summary measures with different population age compositions. Thus, focusing only on the summary measures can hide the major structural dynamics in the regional populations.

Exactly the same is true for analyzing differences between the regional populations over time. In this paper we analyze variance between regional age structures, represented as ternary composition, in the restricted three-dimensional barycentric coordinate space. Ternary compositions approach shows the contribution of the three broad age groups into convergence in population age structures. This is a new approach to measure convergence in compositional data, which can be used in any application when data is representable as compositions.

2. Background and hypotheses

Contemporary Europe consists of populations that have already finished the Demographic Transition or are undergoing through the final stages of it (Lee, 2003), when population ageing becomes the main demographic challenge (Reher, 2011). Still there persists a major difference between three main parts of Europe: East, South, and West. While the Southern and Western regions were ageing rapidly throughout the study period, Eastern Europe only started to experience a decline in the proportion of working-age population togetehr with a rapid increase in the proportion of elderly after 2008; this marks the lagging behind of Eastern Europe along the Demographic Transition path (Figure 2).

As European populations age at an increasing pace, we expect relative differences in the proportion of elderly people between regions to increase, since the uptake of accelerated ageing is not happening uniformly and is shaped by previous demographic histories. In other words, we observe European regional populations stepping into the new ageing transition. In line with the theoretical knowledge and empirical evidence of how transitions unfold (Coleman, 2002; Vallin and Meslé, 2004), we expect relative differences in the proportion of elderly people to explain most of the regional variation in population age structures. In contrast, the proportion of the young population is likely to reduce differences in population age structure across regions as they become closer to the more uniform post-transitional lev-

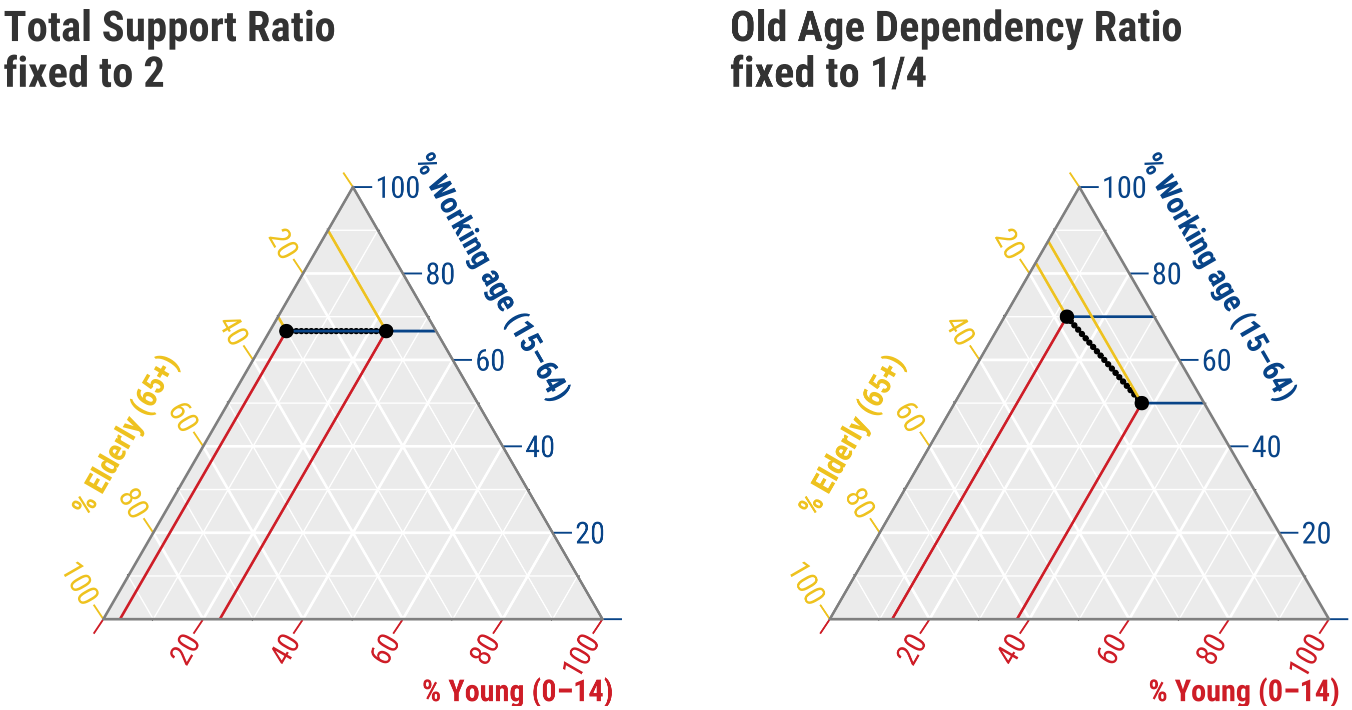


Fig. 1. Examples of classical ageing indicators for generated populations represented in barycentric coordinate space: A – Total Support Ratio, people at working ages (15–64) divided by people outside working ages, fixed to 2 with the proportion of elderly varying between 10 and 30 percent; B – Old Age Dependancy Ratio, elderly people (65+) divided by people at working ages (15–64), fixed to 1/4 with the proportion of people at working ages varying between 50 and 70 percent.

els of fertility (Watkins, 1990; Coleman, 1993; Basten *et al.*, 2011). Hence, our hypotheses are: different age groups pull the overall variance in opposite directions: changes in elderly population contribute to divergence in population age structures, changes in the young population, in contrast, promote convergence (H1); how strongly the differential effect of the age groups on convergence/divergence is pronounced depends on the population's progress along the Demographic Transition (H2). As the logic outcome of the second hypothesis we expect to find substantial differences in the convergence/divergence process across the three parts of Europe – Eastern, Southern, and Western – that have remarkable gaps in the timing of structural changes in population age composition (Figure 2).

Urban/rural differences often play an important role in the demographic processes that shape population age structures (Davis, 1955; Crespo Cuaresma *et al.*, 2014). Differences in living conditions affect mortality and fertility (Shucksmith *et al.*, 2009), and migration reshapes population age structures directly (Franklin, 2014; Faggian *et al.*, 2017). Some studies find the theoretically anticipated growing urban/rural divide in ageing (Smailes *et al.*, 2014; Van Der Gaag and De Beer, 2015; Sabater *et al.*, 2017); while others uncover more complicated regularities that signify that both urban and rural categories of regions become more heterogeneous (Kabisch and Haase, 2011; Danko and Hanink, 2018), though differently across Europe (Crespo Cuaresma *et al.*, 2014; Kashnitsky *et al.*, 2020a). We include the urban/rural dimension in the analysis to see how it interacts with the changing differences between parts of Europe. We expect urban/rural differences to contribute to divergence in population age structures between the regions (H3) and anticipate that this difference in the group means may be masked by increasing heterogeneity within the groups of urban and rural regions (H4).

The studies that investigate relative differences in population age structures are often based on summary measures of age distributions of populations: support ratio (O'Neill *et al.*, 2001; Lutz *et al.*, 2003; Prskawetz and Sambt, 2014), proportion of elderly (Lutz *et al.*, 2008; Spijker and MacInnes, 2013), median age (Lutz *et al.*, 2008), proportion of working-age population (Bloom and Williamson, 1998; Van Der Gaag and De Beer, 2015; Kashnitsky *et al.*, 2020b). We argue that, even though population ageing is one of the main demographic issues today, to understand regional convergence/divergence in population age structures one needs to consider ageing as the process that happens in the whole age distribution. Ageing is not exclusively about the size of elderly population or its proportion in a population, it is a function of the whole age distribution of a population. Moving from the convergence analysis of point estimate summary measures of demographic structures to the analysis of distributions can help uncover the differences in the parts of Europe that have unequal paths through the Demographic Transition imprinted in their current population age structures.

The advantage of the distributional approach holds when we want to analyze relative differences in regional population structures and their evolution over time, i.e. convergence in population age structures. The distributional approach not only gives an answer to the question whether relative differences increase

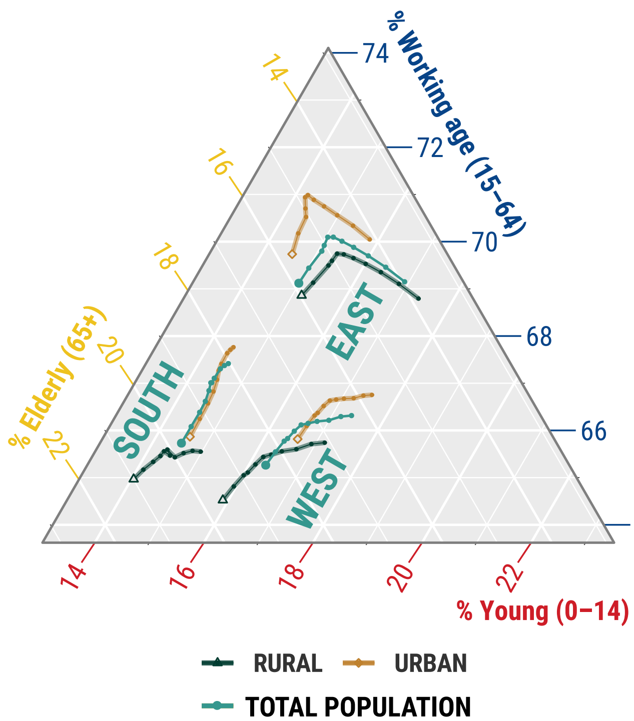


Fig. 2. Population age structures of Eastern, Southern, and Western Europe, year-by-year evolution over 2003–2013; additional lines show subpopulations living in urban and rural NUTS-2 regions; last data points, 2013, are identified by markers.

or diminish over time but also can indicate the input of changes in different parts of the age distributions. Here it is important to note that the distributional approach in convergence literature usually refers to the distribution of regions (Islam, 2003), and in this paper we go deeper by exploring the underlying distributions of population age structures within regions instead of focusing on just a single summary measure.

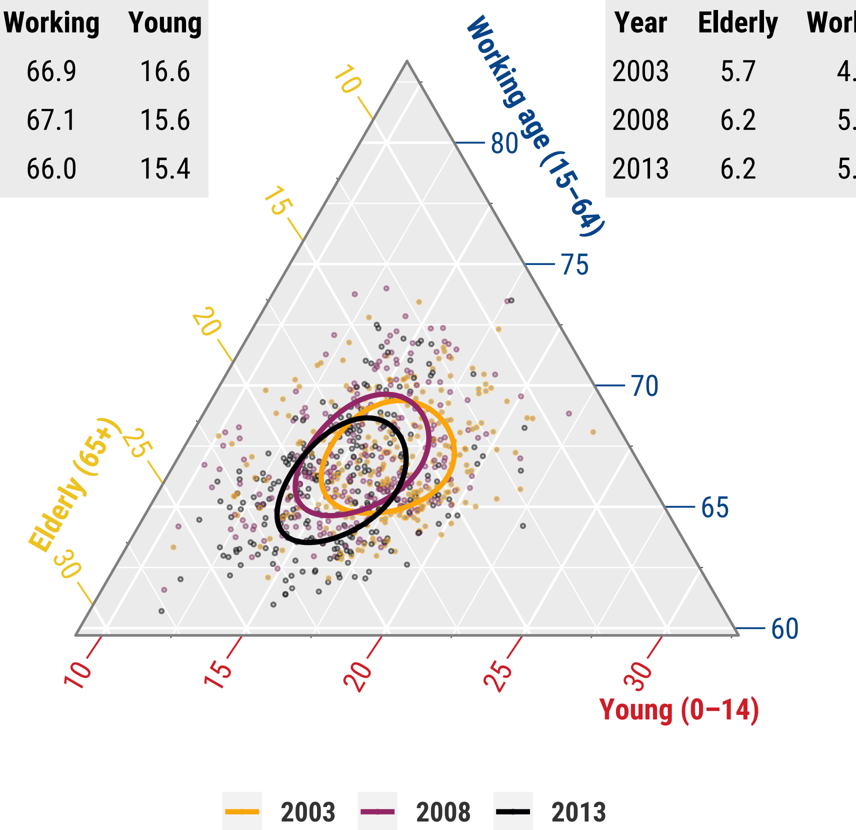
3. Methods

3.1. Ternary diagrams. The geometry of three-dimensional data space restricted by summation to unity was first developed by the famous mathematician August Ferdinand Möbius (1827) who named this coordinate system as barycentric. Ternary plots have a fascinating non-linear history of re-inventions and adoption in applied academic research (Howarth, 1996). Following the pioneering works in physics and chemistry, visualizations of ternary compositions were widely accepted in petrology (Mead, 1915; Iddings, 1920; Holmes, 1921),soil classification (Davis and Bennett, 1927; Soil Survey Staff, 1951), water analysis (Piper, 1944), and gas flammability monitoring (Zabetakis, 1965). Apparently, the first to use them in population studies was Italian geneticist Bruno De Finetti (1926) who visualized proportions of genotypes in the population studying local dialects. In demography, these plots were first used by Soviet statistician Olimpiy Kvitkin (1932) in the paper describing the results of USSR 1926 census. But probably the first wide public attention was drawn to ternary plots only when they were used to map the results of elections in the British three-dimensional political landscape (Berrington, 1965).

3.2. Ternary colorcoding. The next big step in visualizing ternary compositions happened with the idea that they can be mapped to unique colors, when each element in a three-dimensional array of compositional data is represented as one of the three primary colors, red, green, and blue. The mixed colors are next used in geographic maps, maximizing the amount of information conveyed by colors. The use of color mixtures to encode multiple data dimensions in a single attribute has been proposed by various authors. To our knowledge, ternary colorcoding was first used in the context of map design by Olson (1987). Later the approach has been used to map election results in a three-party system (Dorling, 1991), labor force composition by sector (Brewer, 1994), soil textures (Metternicht and Stott, 2003), composition of arctic sea-ice coverage (Denil, 2015), and cause-of-death compositions (Schöley and Willekens, 2017). Here we employ colorcoding to explore the differences in populations structures across Europe (Kashnitsky and Schöley, 2018) and provide the tools that we developed (Schöley and Kashnitsky, 2018) to streamline its use with R (R Core Team, 2017).

3.3. Ternary confidence ellipses. To visualize variance in ternary compositions we plot confidence ellipses, which represent confidence intervals in the barycentric coordinates. With one dimension, we can calculate confidence interval (CI) of the mean assuming normal distribution of the means drawn from the population, e.g. 95% CI. That means, if we generate our data again and again 95% of the calculated means will fall within the 95% CI. this concept can easily be used for higher dimensional cases. With two dimensions, as a result we get a confidence ellipse. With three dimensions, the range of possible mean values fall in a confidence ellipsoid (distorted sphere). This ellipsoid can be projected on a plane in barycentric coordinates when our three dimensional data is represented with compositions, in which case we have an ellipse drawn in the ternary triangle. The mean ellipses are calculated with the R package {compositions} (Boogaart *et al.*, 2018). In principle, the approach is scalable to higher dimensionality than ternary, but ternary compositions can be meaningfully visualized, which yields immediate insight (Kashnitsky and Aburto, 2019).

A confidence ellipse is defined by three things only: 1) center, which is the mean composition of the data cloud; 2) sample size; 3) variance. Since sample size is held constant when we compare the same number of regions over time, the shape of the ellipse is only defined by the tri-dimensional variance. This is where we can interpret an ellipse as a visualization of sigma convergence of ternary compositions. Sigma convergence is named after the Greek letter that usually denotes variance; the term is applied to distigiush the family of variance based convergence measures (Quah, 1996; Sala-i-Martin, 1996; Janssen *et al.*, 2016). One way to express parameters of the ellipse numerically is to show its ranges along the three axes, i.e. the length of the ellipse projected to each of the axes.



Average compositions

Year	Elderly	Working	Young
2003	16.5	66.9	16.6
2008	17.3	67.1	15.6
2013	18.6	66.0	15.4

Ranges of ellipses

Year	Elderly	Working	Young
2003	5.7	4.6	4.8
2008	6.2	5.0	4.4
2013	6.2	5.1	4.1

Fig. 3. Ternary variance of European NUTS-2 regions in population age structures in 2003, 2008, and 2013.

4. Data

We analyze population age structures of the 261 NUTS-2 regions of EU-27 using a harmonized dataset for the years 2003–2012 (Kashnitsky *et al.*, 2017). The overseas territories of France, Spain and Portugal are excluded from the dataset. The data comes from Eurostat (2015a). We use the 2010 definition of NUTS regions (Eurostat, 2015b) and a modified version of EuroVoc (2017) official classification of parts of Europe, in which we split Northern European regions between Western (Nordic countries) and Eastern (Baltic countries) Europe. We use the NEUJOBS urban/rural classification of NUTS-2 regions (De Beer *et al.*, 2012, 2014), and simplify it by eliminating the intermediate category: based on the profile of age-specific net migration rates, in Southern Europe intermediate regions were classified as urban, and in Eastern and Western Europe – as rural (Kashnitsky *et al.*, 2020a). As a sensitivity analysis – to see if the results do not change much at a finer geographical level – we look at the population age structures at NUTS-3 level for three selected countries – Romania, Italy, and Netherlands, one from each part of Europe; at this geographic level we use the Eurostat urban/rural classification directly.

5. Results

During the study period, European regions experienced divergence in population age structures (Kashnitsky *et al.*, 2017). In the first approximation, divergence was caused by the lagging demographic development of Eastern Europe during the first half of the period and later on by the increasing differences in population age structures between regions in each part of Europe. Although indicating the major pattern, this broad picture does not tell us how population dynamics in different age groups contributed to this overall divergence. Using the outlined ternary compositions analysis, we can derive this information (Figure 3).

Looking at the tri-dimensional ternary ellipses, we can see that the average age composition of European regions was ageing over the period (see also the left inset table), at first mostly due to the decrease of the proportion of kids, but in the second half of the period also due to the decrease in the share of working age population. We can also notice that the ellipses stretched along the axis of elderly proportion and narrowed along the axis of the proportion of kids. This means that the overall divergence was driven by increasing variance in the share of elderly population and, to some extent, the share of working age population. In con-

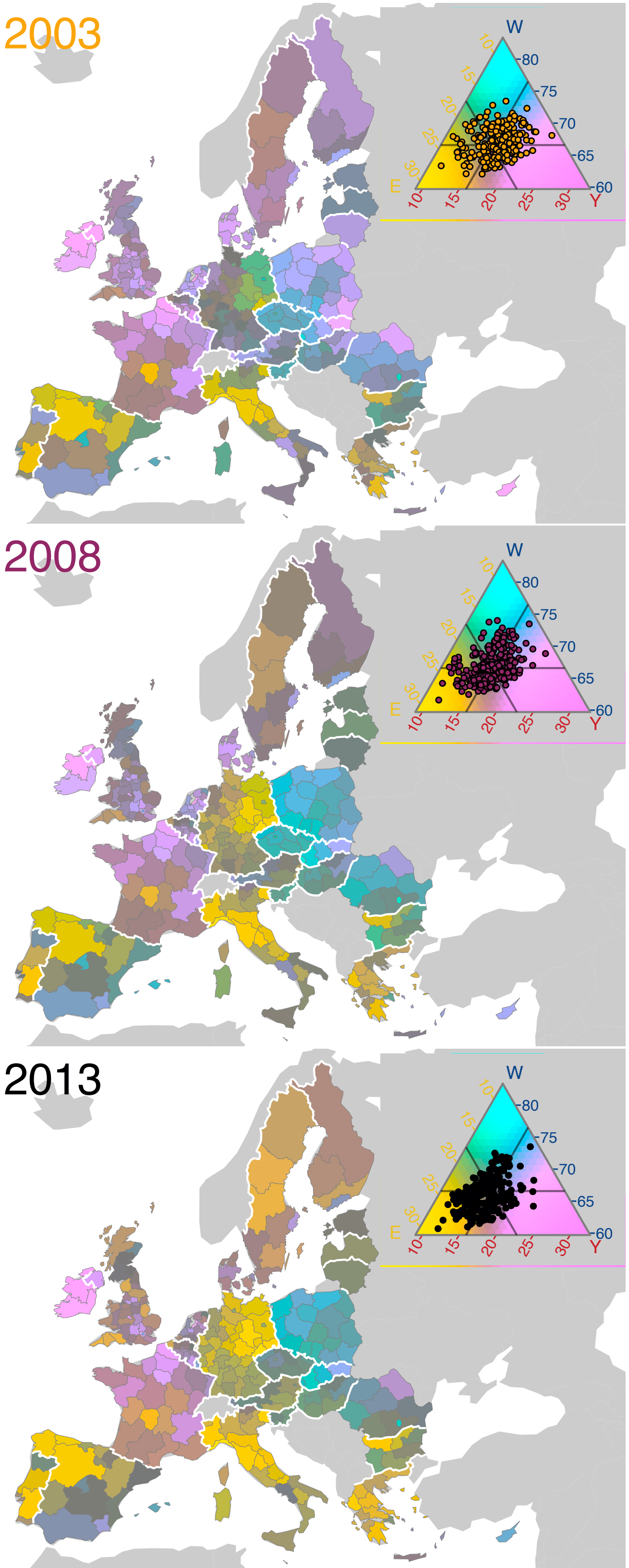


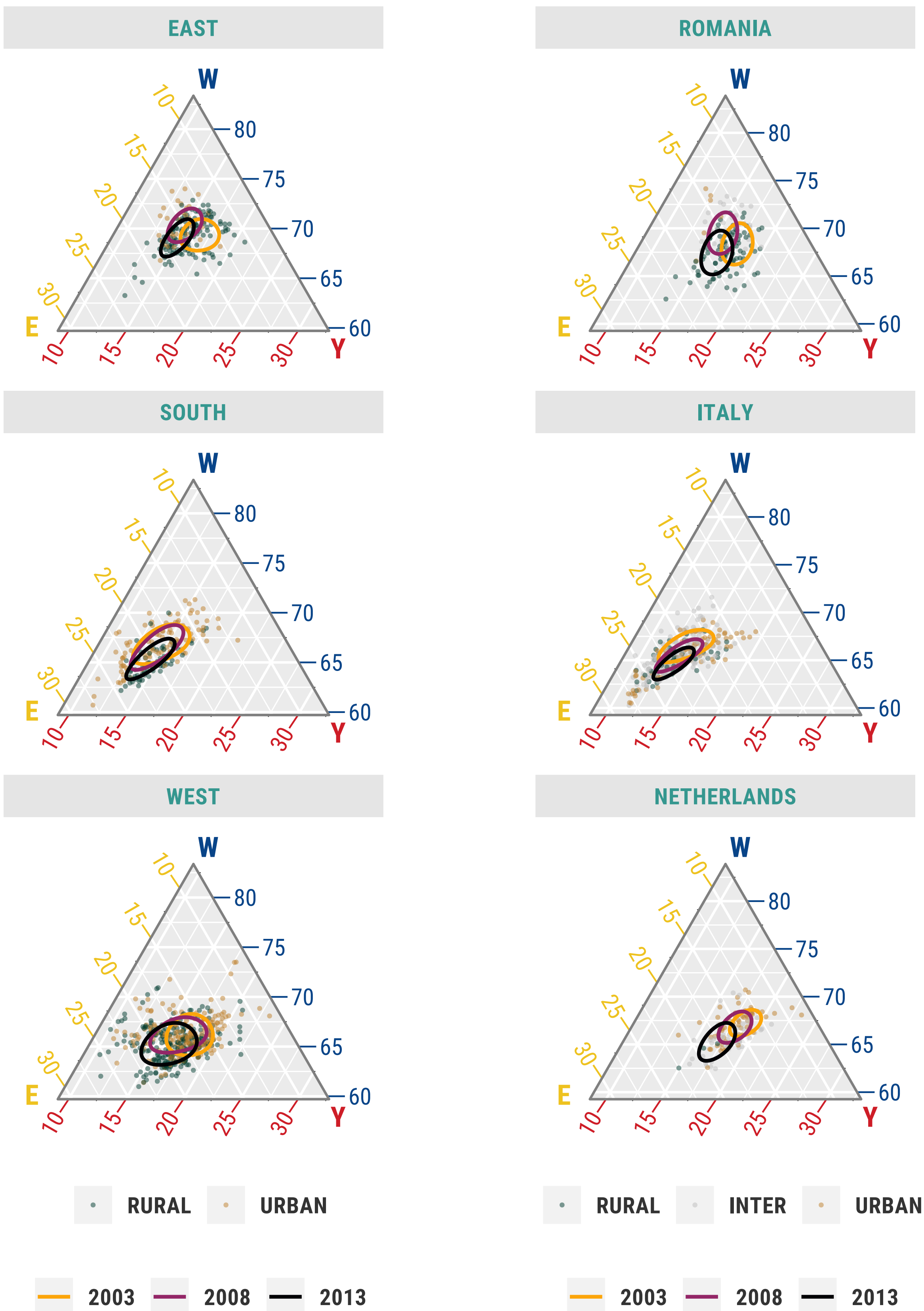
Fig. 4. Colorcoded maps of population age structures of European NUTS-2 regions in 2003, 2008, and 2013.

trast, the changing shares of kids reduced differences between regions, thus contributing to convergence in population age structures (see the right inset table). For example, in 2003 the mean share of elderly people fell between 13.6% and 19.3%, with 95% confidence. This gives the range of 5.7 percentage points. Over the 10 observed years we saw divergence in population structures, and by 2013 this range rose to 6.3 percentage points. Similar changes happened to the variance in working-age component. At the same time, population structures of NUTS-2 regions became more similar with regard to the share of kids, i.e. the youth component contributed to convergence, and the range of values in the proportion of kids decreased from 4.8 to 4.1 percentage points.

The overall ageing of European population is represented by color-coded maps (Figure 4), in which the population structures are represented as ternary compositions encoded by single colors. Over the study period we can register an increase in the frequency and intensity of yellowish colors, which signifies an increase in the share of elderly population in many regions. The most pronounced transition can be found in Germany, especially in its Eastern part. Apart from the ageing story, the three maps depict the story of late demographic dividend in Eastern Europe (Van Der Gaag and De Beer, 2015; Kashnitsky *et al.*, 2020a) – while regions in Western and Southern Europe age throughout the study period, Eastern Europe first experiences the ending phase of the Demographic Transition. The timing of demographic transition is crucial for understanding the major trends in regional variations of population age structure (Kashnitsky *et al.*, 2017). The other distinction clearly visible in the maps is the difference between urbanized capital and other central regions and the more peripheral rural ones, which seems to diminish over time. We next use this visual insight from the maps and zoom in to analyze separately the three parts of Europe distinguishing between urban and rural groups of regions.

Splitting up the ternary picture by part of Europe shows very different developments in each of them (Figure 5-A). The peak of demographic dividend in Eastern Europe happened at the middle of the study period, 2008. This uncharacteristic for the rest of European regions uniform increase in the share of working age population drove the average European age composition upwards (Figure 3). Regions of Southern Europe saw accelerated ageing quite uniformly resulting in convergence, see the shrinking confidence ellipses. In contrast, regions of Western Europe saw increase in the variability of population age compositions, meaning that some regions aged faster than the others causing overall divergence. Conducting the same analysis for three selected countries – Romania, Italy, and Netherlands, one from each part of Europe – at NUTS-3 level, we can see that the overall picture stays consistent (Figure 5-B). Scaling down to a lower level of spatial aggregation does not change the picture which means that the differences in demographic convergence trends between the three parts of Europe result from the differences in demographic processes that operate at the macro level – the differences in the demographic histories.

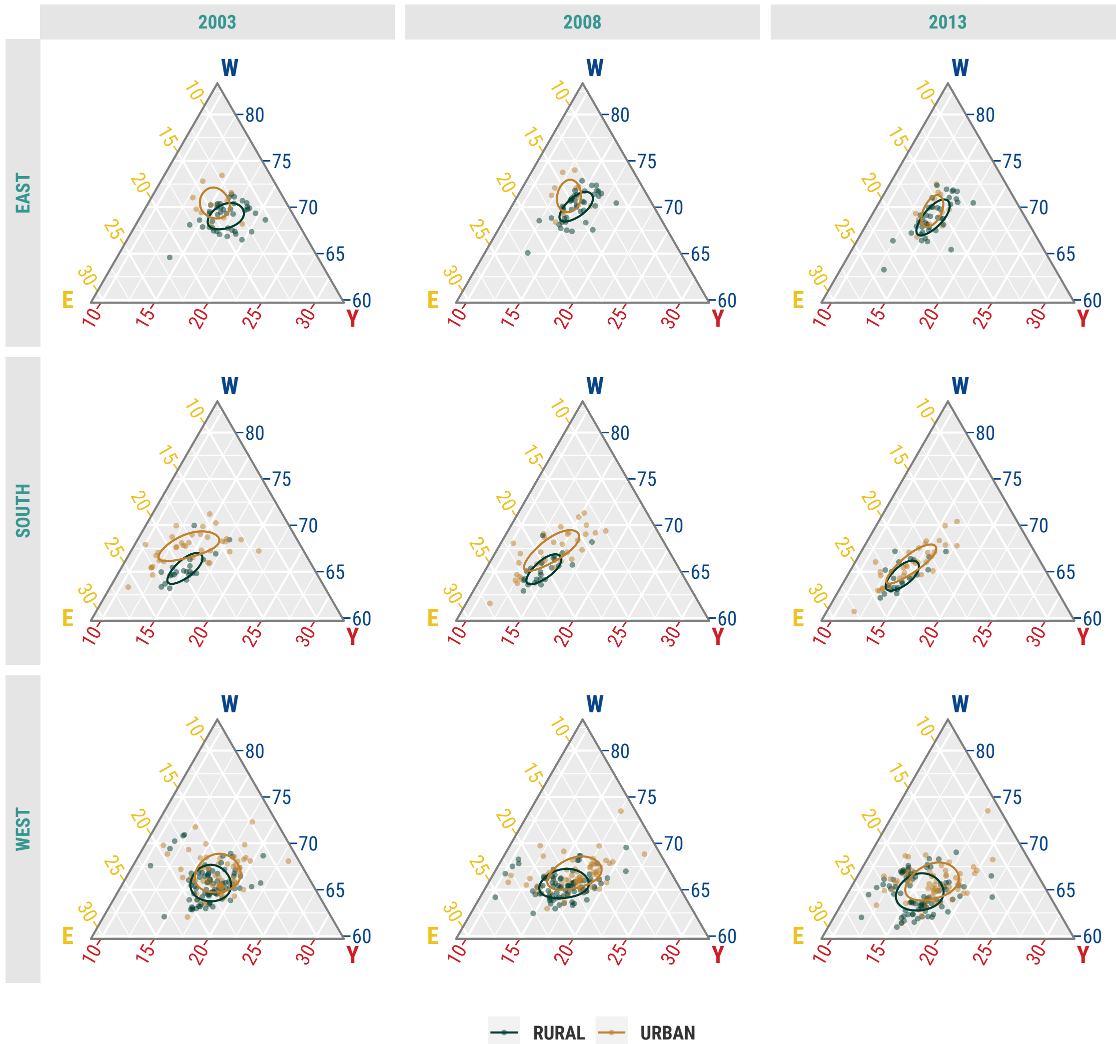
These differences across the parts of Europe may be to some extent explained by unequal development of more urbanized



(a) NUTS-2 regions in the three parts of Europe: East, South, and West

(b) NUTS-3 regions in the three countries: Romania, Italy, and Netherlands.

Fig. 5. Population age structures in 2003, 2008, and 2013



		2003			2008			2013		
		Elderly	Working	Young	Elderly	Working	Young	Elderly	Working	Young
EAST	RURAL	4.1	2.8	3.2	4.3	3.2	2.5	4.7	3.9	2.2
	URBAN	3.1	3.3	3.4	3	3.5	2.7	3.2	3.4	1.9
SOUTH	RURAL	4.6	3.3	2.4	4.5	3.2	2.4	4.4	3.2	2.4
	URBAN	6.7	3.2	5	7	4.4	3.8	6.5	4.2	3.1
WEST	RURAL	4.3	3.9	4.3	5.1	3.2	4.7	5.1	4	4.7
	URBAN	4.9	4.2	4.6	5.9	3.6	4.8	6	4.1	4.8

Fig. 6. Ternary variance of European NUTS-2 regions in population age structures in 2003, 2008, and 2013 by part of Europe and urban/rural status: top panels – mean ellipses; bottom panels – ranges of the ellipses.

and less urbanized regions (Figure 6). In Eastern Europe, only rural regions experienced divergence in the proportion of elderly and working-age population. Both urban and rural regions experienced sharp convergence in the reducing proportion of the youths. In Southern Europe, there was not much change in the variance of population compositions in rural regions, while urban regions saw considerable convergence in the proportion of young and some divergence in the share of working age population. The difference between average compositions of urban and rural groups of regions reduced. In Western Europe, the variance in the proportion of elderly increased considerable in the first half of the period; the variance in the share of working age population decreased in the middle of the period.

The differences between urban and rural regions diminished in Eastern and Southern Europe, and this development became a major driver of overall convergence in population age structures. In Western Europe the urban/rural gap stayed more or less the same while demographic development in each of the groups contributed to the overall divergence in population age structures.

6. Discussion

The results support our hypotheses H1 and H2, that use the concept of Demographic Transition explaining the differential effect of population age groups on convergence or divergence in population age structures and the remarkable differences between the parts of Europe, which followed the transition with varying timing. Changes in the regional variation of the proportion of younger population contributed to convergence in population age structures while the diverging developments were mainly driven by changes in the proportion of the elderly population.

We expected to see that with continuing urbanization in Europe urban/rural differences would increase contribution to the overall divergence in the population age structures. This expectation, hypothesis H3, proved wrong – we don't observe a consistent widening of the difference between urban and rural groups of the regions in any of the three part of Europe. This would have been surprising if not for the supported H4, that offers an explanation to documenting the increasing variability of population age structures withing urban and rural groups of regions. All in all, it seems that the binary distinction between urban and rural regions is becoming less and less useful in distinguishing differential developments of the population age structure dynamics. This finding goes in line with other published papers (Kabisch and Haase, 2011; Pagliacci, 2017; Danko and Hanink, 2018).

One limitation of ternary approach is the number of categories, strictly limited to three. In principle, higher dimension computations are possible (Boogaart *et al.*, 2018), but there are no meaningful ways to represent the results uniquely and comprehensibly. Even the ternary plots require some effort to understand from the reader who sees them for the first time. Yet, we believe, with wider acceptance of ternary diagrams, they have chances of becoming a more regular and standard data visualization tool.

One major advantage of working with ternary compositions is the possibility to color-code them in a unique and intuitive way to display three-component compositions at once (see the maps in Figure 4). We strongly propose a wider use of the presented approach. In this short paper we presented an example of its use that tells the rich story of regional convergence in population age structures in Europe.

7. Concluding remarks

In this paper we explore a novel approach to investigate and visualize the diverse picture of population ageing in the present-day Europe. The use of ternary age structure compositions allows to uncover different effects of population change in three age groups (kids 0–14, working age 15–64, and elderly 65+) on convergence in population age structures. These differences correspond with our knowledge of the demographic histories of European populations. For example, the convergent effect of changes in the share of youths is something we expect to observe with the fall of fertility at the end of Demographic Transition. In contrast, diverse regional paths of the accelerating phase of population ageing contribute to growing differences in the share of elderly population and result in divergence in population age structures. These distinctions are masked completely if we choose to focus conventionally on simple summary measures of population age structures.

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Chapter 7. Conclusions: changing regional inequalities in ageing across Europe

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The multidimensional investigation

The aim of this thesis is to examine relative differences in population age structures between European regions, whether they converge or diverge, how demographic change affects inequalities in regional age structures, and to what extent these differences interplay with economic convergence. We started off with direct application of the classic convergence analysis methodologies from economic literature to population age structures data and proceeded with developing more nuanced approaches that consider distributions of interest rather than just summary statistics and point estimates. The order of chapters aims to structure the various perspectives from which we can approach the research of unequal and unequally developing regional population age structures in Europe.

This thesis unravels the complex picture of differential population ageing of European regions. The specific chapters address various dimensions of complexity: the **second chapter** gives a one moment glance at the finest available comparative geographic level; the **third chapter** analyses the underlying demographic forces that drive changes in the Total Support Ratio, the summary measure of regional population age structures; the **fourth chapter** links unequal demographic developments to unequal economic growth; the **fifth chapter** adds the urban/rural dimension to the analysis of population age structures at the same time moving to the analysis of the whole distributions of regions rather than going on with the point estimate measures of convergence; the **sixth chapter** recognizes regional populations as ternary compositions and thus helps to understand which age groups drive convergence or divergence in regional population age structures.

Main results

In the **second chapter** we provided a detailed snapshot-like overview of the current state population age structures at the finest available comparable geographic level in Europe – NUTS-3. The map, in which every region is colored according to the three-part population age composition using ternary color-coding, shows remarkable differences that exist until now between the parts of Europe and countries. This evident visual effect manifests the importance of distinct demographic histories in different societies and hints on the apparently large possible effect that directed policies may bring over long enough periods of time. Another pronounced distinction in the map is the urban/rural divide that is clearly visible in most of the European countries. This result draws attention to the necessity of subnational analysis and the deep structural differences that exist between central and peripheral areas. The coherent representation of the three part age compositions using single colors represents the advantage of the distributional approach (even such a rough one) over the conventional use of point estimate summary measures.

Having this new and more complex understanding of how variations in population age structures may affect economic convergence, we proceed in the **third chapter** to a detailed analysis of demographic factors that change regional population age compositions and affect convergence or divergence in them. To our knowledge, no explicit quantification of the changes in regional population ageing differentiation existed. We investigate how regional differences in population ageing developed over the recent decade and how they are likely to evolve in the coming three decades, and we examine how demographic components of population growth contribute to the process. In this chapter, we use the beta-convergence approach to test whether regions are moving towards a common level of population ageing. The change in population composition, measured with Total Support Ratios, is decomposed into the separate effects of changes in the size of the non-working-age population and of the working-age population. The latter changes are further decomposed into the effects of cohort turnover, migration at working ages and mortality at working ages. European NUTS-2 regions experienced notable convergence in population ageing during the period 2003-2012 and are expected to experience further convergence in the coming three decades. The observed beta-convergence in ageing mainly depends on changes in the population structure of East-European regions. Cohort turnover plays the major role in promoting convergence. Differences in mortality at working ages, though quite moderate themselves, have a significant cumulative effect. The projections show that when it is assumed that net migration flows at working ages are converging across European regions, this will not contribute to convergence of population ageing. Here, just like in the earlier case with the interplay between regional convergence or divergence in ageing and economic performance, we see that converging components do not automatically imply convergence of the composite measure.

The **fourth chapter** addresses the most evident rationale for studying relative differences in population age structures – how do they affect convergence or divergence in economic development. Countless previous studies recognized population age composition as an important factor of economic growth that may be responsible to a certain extent for the observed inequalities in the growth trajectories and changing relative differences in income levels. None of the previous studies, to the best of our knowledge, focused on how convergence or divergence in regional population age structures, i.e. changing relative differences in population age structures, may affect convergence or divergence in regional economic performance. Being primarily interested in the dynamics of population age structures, in this paper we studied the possible interplay between regional convergence or divergence in ageing and economic performance. Our results, obtained with the use of a simplified conceptual framework, suggest that this association in reality can go any direction depending on the relative changes in the distributions of regions. A positive association happens only when the biggest changes happen to regions that are both rich and have a bigger proportion of people at working ages in the population structure, or alternatively when the biggest changes happen to the group of regions that are both poor and more aged. If anything, the negative association was observed more frequently.

The focus of the **fifth chapter** is on the urban/rural divide in regional population age structures. We first check whether the concept of ongoing urbanization is applicable and meaningful at NUTS-2 geographical level, at which we have reliable and harmonized over a decade population compositions data. Most NUTS-2 regions contain both urban and rural population, but we still can judge whether characteristic for urbanization age-specific migration pattern are manifested in the population relocation between more and less urbanized NUTS-2 regions. Since young adults tend to move from rural to urban regions whereas older adults move from urban to rural regions, one may expect that differences in population ageing across urban and rural regions have increased. We examine whether differences in population ageing across urban and rural NUTS-2 regions of the EU-27 over the period 2003-2013 have diverged. In this chapter we offered a new methodological approach stepping away from classical beta and sigma approaches to convergence. We focus not on any single summary statistic of convergence, but rather analyze the shape of the whole cumulative distribution of regions using parametric logistic curve modeling above and below the median of the distribution of regional shares of working age population. Such an approach helps to identify which specific group of regions is responsible for the major changes (which links back to the framework discussed in the **fourth chapter**). Our results suggest that, despite the expectations, there was no divergence in age structures between urban and rural regions, rather divergence happened within each of the groups of regions.

Finally, in the **sixth chapter** we try out an innovative approach to study convergence or divergence in ternary compositions of population age structures rather than in point estimates. Compared to the methodological approach in the **fifth chapter**, this is a different way of going beyond point estimates analysis. In the **fifth chapter** we analyzed distributions of regional summary measures of population age structures (share of working age population) instead of just producing a point estimate measure of convergence, as is conventionally done within the classical frameworks of beta and sigma approaches to convergence. Here we make a step forward in recognizing the underlying ternary compositions of regional population age structures instead of melting them down to a single summary measure. This approach allows us to reflect the differential input of changes in the three main age groups–i.e. kids aged 0–14, adults aged 15–64, and elderly aged above 65–into the overall convergence or divergence in regional population age structures. We also recognize the important distinctions between the three parts of Europe and the urban and rural groups of regions within them. The results show that the observed divergence in population age structures is mostly driven by the unequal onset of accelerated ageing, i.e. an increase in the proportion of elderly. In contrast, the dynamics of the proportion of kids reduces the overall variance in population age structures, which is something we can reasonably anticipate at the end of the demographic (and especially fertility) transition in Europe. Similar to the results in the **fifth chapter**, we see that both urban and rural regions become more heterogeneous while average population age compositions of both groups of regions move closer to each other.

Binding the complex picture together

There are three main findings and ideas that cut across all the individual studies in the present thesis: one theoretical, one methodological, and one empirical.

Converging components do not imply overall convergence. Quite often – we see it in published economic studies that use population composition as one of the variables and even in the scenarios of demographic projections – when correlation between two variables is observed, a positive interplay between their dynamically changing variances is assumed. As we show in the conceptualized model of convergence interplay in the **fourth chapter** and also find in the **third** and **fifth chapters**, this easy and intuitive assumption may be quite misleading. Neither positive association between the share of working age population and economic output guaranties concordance in convergence/divergence, nor a converging assumption on future migration necessarily brings convergence in population age structures, nor even continuing urbanization can drive the relative difference in population age structures between the urban and rural groups of regions in the anticipated direction. As we figured out, it matters a lot which part of the respective distributions of regions on the studied interplaying variables is driving the main change. Not recognizing the complexity of convergence may lead to intuition driven falsely simplified policies. The need to analyze changes in the distributions of regions brings us to the common methodological issue.

Use distributions rather than summary measures. This is the crucial finding of our research – the understanding how important the distributional approach is to convergence analysis. Only looking at the full distributions of the groups of regions we may uncover the complex ways in which these group differences affect the overall convergence or divergence. Also, the summary measures can mask the substantial differences between the population due to their different population structures – e.g. the demographic pressure on the working age population may be composed of the various mixtures of the proportions of the youths and the elderly. Focusing only on the summary measures can hide the major structural dynamics in the regional populations.

Demographic histories do matter a lot. Demographic structures are rather stable and slowly and predictably evolving systems. The large differences in population age structures between countries and parts of Europe, which appeared as a result of differences in the demographic histories and various timing of the Demographic Transition, still manifest themself in the present-day Europe and drive the largest shifts in relative population compositions. Thus, most noticeable differences exist between the large groups of Eastern, Southern and Western regions, and the biggest changes are attributable to the dynamics of East-European regions.

Methodological contribution

The research project that resulted in the present dissertation started with an idea to tackle regional inequities in population age structures with the formal methods of convergence analysis developed in the economic literature. Since, to the best of our knowledge, this had not been done before, we started with the direct application of the classical approaches to convergence analysis – the regression based *beta-convergence* analysis in the **third chapter** and the variance based *sigma-convergence* analysis in the **fourth chapter**.

Only in the **third chapter** we used the *beta-convergence* approach. We chose it for the goal of the first exploration utilizing the possibility to formally decompose the changes in the Total Support Ratio in the flexible regression analysis setting. The decomposition that we had proposed allowed to identify the separate effects of demographic processes on the changing disparities in the regional population age structures. Yet, already from the first takes of analyzing relative differences in regional population age structures, we faced the necessity to consider the differential developments in the lower and upper parts of the regions' distribution to uncover the complex developments of unequal regional population ageing in the context of the ending Demographic Transition.

Starting from the **fourth chapter** we focused on the convergence analysis of the variance, following the classical idea of *sigma-convergence*. In this chapter we developed the conceptual framework of the interplay between convergence in two inter-related phenomena, which highlighted the need to recognize differential developments in the lower and higher parts of the corresponding regional distributions. The direction of the effect of population ageing on the economy differs depending on whether the main change in ageing occurs in rich or poor regions. If the major changes in population structures occur in those regions that are relatively rich and have a high share of the working age population or in regions that are relatively poor and have a low share of the working age population, the relationship is expected to be positive, irrespective of whether there is convergence or divergence in ageing. In contrast, when the major changes in population structures occur in the group of regions that are poor but have a higher share of the working age population or regions that are rich with a low share of the working age population the relationship is likely to be negative. Without a closer focus on the lower and upper parts of the regions' distributions of the both phenomena, the interplay of changing differences between them, convergence or divergence, cannot be explored and explained.

Similarly, in the **fifth chapter** we explore how ongoing urbanization affects convergence or divergence in population age structures. Modeling the empirical cumulative distributions of regions' shares of working age population separately above and below the median values allows us to compare the parameters of the logistic curves for urban and rural groups of regions, thus uncovering the role that urbanization plays in the evolution of unequal ageing across the regions of Europe.

Finally, in the **sixth chapter** we explore another dimension in the data going beyond a single summary measure of population age structures and recognizing the separate input of the three main age-groups into the changing differences between the regional population age structures. This chapter builds upon the the exploratory analysis presented in the **second chapter** and offers a way to measure and compare variances of the groups of regions represented as ternary compositions. Effectively, this approach goes beyond the single-dimensional distribution of the regions recognizes that each region has its own age distribution of the population. This approach helps to uncover the multi-directional effects on convergence or divergence in population age structures that separate age groups cast. These differently directed effects cancel out when we conventionally analyze the summary measures of population age structures and thus remain masked unless we adapt the more nuanced analytical approaches.

Limitations and prospects for future research

As we focused on applying convergence analysis to population age structures and apparently examined a new question in the demographic literature, we started off with using the conventional approach to age categorization – using age boundaries of 15 and 65 years as cut-off values of working-age population. Using more nuanced approaches to defining younger and elderly populations can be a very beneficial direction of future research.

Mortality rates keep decreasing across the full range of ages in most of the developed countries and there seems to be no organic end to these improvements (Oeppen and Vaupel, 2002; Vaupel, 2010). Not only do we see an increase in average lifespans, but also remarkably reducing inequalities in the length of life due to the rectangularization of the survival curve (Aburto *et al.*, 2019; Janssen and De Beer, 2019). Age 65 becomes less and less relevant in describing the beginning of the elderly part of life (Vaupel and Loichinger, 2006; Lee *et al.*, 2014). Hence, different approaches were put forward to account for the changing meaning of chronological age and elderly population as the transition to lower mortality regimes unfolds (Spijker and MacInnes, 2013; Kjærgaard and Canudas-Romo, 2017; Loichinger *et al.*, 2017).

Among others, probably, the most noticeable change of viewpoint is brought by the idea of prospective ageing (Ryder, 1975) and the family of indicators that grew out of it (Sanderson and Scherbov, 2007, 2010, 2015). Focusing on the remaining life expectancy can largely improve our understanding of the consequences of population ageing and may even revert our impression of the happening transition (Kjærgaard and Canudas-Romo, 2017; Balachandran *et al.*, 2019; Ediev *et al.*, 2019). In the context of regional economic convergence of European regions, the prospective ageing approach has shown advantageous both in explaining the current growth dynamics and producing long-run forecasts (Crespo Cuaresma *et al.*, 2014). Recently the very first paper was published (Sidlo *et al.*, 2019), in which the prospective aging framework was employed to study directly the regional differences in population age structures at the level of NUTS-2 regions – taking population survival information into consideration does change the overall picture of unequal population ageing in Europe. It turns out that the most aged regions are also the ones with the biggest improvements in longevity. Another application to regional data has also recently came out for Russia (Gietel-Basten *et al.*, 2019). Yet, placing the research question of regional convergence in population age structures into the prospective ageing frameworks is still an open call.

The other arbitrary conventional age boundary of 15 years, delimiting working age population is also changing its meaning with the persistent growth of educational attainment (Kc *et al.*, 2010; Harper, 2014) and prolonging transitions to adulthood (Liefbroer and Corijn, 1999; Billari, 2004; Billari and Liefbroer, 2010; Bongaarts *et al.*, 2017). Thus, conventional age cut-offs become less and less valuable in defining the transition to working age category. This is especially important with a tremendous diversification of lifestyles and generally much increased variability in the pathways to adulthood (Buchmann and Kriesi, 2011; Damaske and Frech, 2016). In fact, the more variable is the age of becoming adulthood, the less informative any fixed cut-off point becomes.

One fruitful perspective to deal with the complex definition of working age population employs the use of the actual information on labour market participation to have much more nuanced definitions of dependent populations and labour support (Spijker and MacInnes, 2013; Prskawetz and Sambt, 2014). Leading the pioneering research ideas of Ronald Lee and Andrew Mason (Lee and Mason, 2010; Lee *et al.*, 2014), the global project of National Transfer Accounts was launched to fill the gap in our knowledge of the age patterns of production and consumption around the world. Although, the very data demanding nature of NTA estimations does not yet allow to apply these ideas directly to the research at the sub-national level.

The regional focus of the research poses traditional difficulties and limitations. One cause of ambiguity and field for innovative approaches in future studies lies in the classification for the regions into urban and rural. The continuing urbanization and the spatial increase of the urban areas known as urban sprawl call to rethinking the approaches to urban/rural classification (Champion, 2009; Pagliacci, 2017). The areal changes of urban-rural boundaries cast quite some effect on the urban-rural differences in demographic development (Chen *et al.*, 2017). The increasing difficulty of the urban-rural boundary delimitation even motivated Caffyn and Dahlström (2005) to call for a new interdependence approach in urban-rural research as opposed to the conventional approach that is focused on differences.

Another traditional issue that might also challenge some of the results presented in this thesis is known in the domain of regional studies as modifiable area unit problem, which documents the possible effect of the geographical scale and aggregation of data on the studied spatial phenomena (Dapena *et al.*, 2016; Stillwell *et al.*, 2018). Limited with the consistent and comparable data availability, we did only one and rather rudimentary attempt to conduct the analysis at NUTS-3 level in the **sixth chapter**, which nevertheless showed the robustness of obtained results. With the wider availability of more granular regional data, it will be possible to study convergence in population age structures at lower geographical level.

Contribution and policy implications

In this project we investigate the unequal development of population age structures across the regions of Europe as they come into the phase of accelerated population ageing. We apply convergence analytical techniques and develop our own ones in order to study the interplay of changing relative differences in population age compositions and economic development, the effects of demographic processes shaping the population age structures and the effect of the migration driven distinction between urban and rural areas. To our knowledge, these are the first comparative studies to address the questions at the sub-national level in Europe. Our study period, 2003–2012, even though it is limited to a large extent by data availability, is a uniquely interesting one that contains several crucial economic, political and demographic events as the background for the unfolding of the major aging transition.

Our results emphasize that policy measures that affect regional population age structures in order to promote economic convergence should address the right group of regions depending on the type of relationship between convergence in ageing and convergence in economies. Even though the direct effect of the population age structure on economic development is rather small, the role of convergence in ageing on economic convergence appears to be quite significant and in many cases is as important as the effect of relative changes in productivity and labour force participation. The real trade-off challenge for regional policies comes when the association between the two convergence processes is negative.

While there is economic rationale for convergence in population age structures, regional policy needs to take into account population age composition not only as a factor of economic development, but also for the own virtue of a balanced regional composition of population. In the increasingly aged societies large disproportions in age composition of regions are expected to cause problems for the main societal institutions including education, local labour markets, and elderly care. European Union regional policy should *not* be based on economic indicators alone – balanced regional population age structures promote equality and contribute to sustainable development.

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Nederlandse samenvatting

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In dit proefschrift wordt de rol van demografische verandering in de ontwikkeling van verschillen in leeftijdsopbouw van de bevolking in Europese regio's onderzocht. Het doel van het onderzoek is om een beter begrip te krijgen van de rol van demografische processen die de leeftijdsstructuur van de bevolking in de regio's bepalen, en hoe deze processen verband houden met de regionaal-economische ontwikkeling. De focus is daarbij op de veranderingen van de verschillen tussen regio's in de tijd, dat wil zeggen convergentie of divergentie.

In het eerste hoofdstuk wordt de context geschetst voor het belang van de nadruk op convergentie en divergentie in bevolkingsopbouw, en dan niet alleen voor demografen, die natuurlijk altijd al een gezonde belangstelling hebben voor bevolkingsdynamiek. Dit hoofdstuk geeft een overzicht van de onderzoeksthema's die in het proefschrift aan de orde komen. De datacontext van deze studie wordt ook geïntroduceerd: een decennium aan regionale bevolkingsgegevens van de Europese Unie. De onderzoeksperiode, van 2003 tot en met 2012 is buitengewoon interessant, omdat er zich in deze periode enkele grote verschuivingen in politiek, economie en demografie hebben voorgedaan in Europa. Ten eerste vond in 2004 de grootste uitbreiding tot nu toe van de Europese Unie plaats, met grote gevolgen voor de nieuw toegetreden landen van Midden- en Oost-Europa, en met grote gevolgen voor het intra-Europese migratielandschap. Ten tweede werd Europa zwaar en ongelijkmatig getroffen door de economische crisis van 2008-2009, die alle domeinen van het leven van mensen trof, en met duidelijke gevolgen voor hun demografisch gedrag. Beide gebeurtenissen hadden grote invloed op het proces van economische convergentie. De Europese eenwording heeft expliciet tot doel dat regio's convergeren, terwijl de ongelijke impact van de economische crisis in Europa tot meer divergentie heeft geleid. Veel Oost- Europese landen lijken zich sneller hersteld te hebben van de crisis, in vergelijking tot Zuid-Europese regio's die zwaarder zijn getroffen. Ten slotte werd het tweede deel van de onderzoeksperiode gekenmerkt door de versnelde vergrijzing van relatief grote babyboomgeneratiecohorten die vanaf 2010 met pensioen zijn gegaan, waardoor de leeftijdssamenstelling van de bevolking sneller dan ooit tevoren veranderde.

In het tweede hoofdstuk wordt een gedetailleerd snapshot-achtig overzicht van de huidige leeftijdsstructuren van de bevolking gepresenteerd op het best beschikbare vergelijkbare geografische niveau in Europa - NUTS-3. De kaart, waarop elke regio is ingekleurd volgens de driedelige leeftijdssamenstelling van de bevolking met behulp van ternaire kleurcodering, laat opmerkelijke verschillen zien die tot nu toe bestaan tussen de delen van Europa en landen. Dit duidelijke visuele effect toont de invloed van de demografische geschiedenis aan op de huidige leeftijdsstructuren van Europese regio's, en op het potentiële belang van bevolkingsbeleid op lange termijn ontwikkelingen. Een ander duidelijk onderscheid op de kaart is dat tussen stad en platteland. Dit resultaat onderschrijft de meerwaarde van subnationale analyse en de grote structurele verschillen die bestaan tussen centrale en perifere gebieden. De coherente weergave van de drie leeftijdscategorieën met behulp van enkele kleuren toont ook de meerwaarde aan van het gebruik van een verdeling (zelfs een simpele zoals hier gebruikt) ten opzichte van samenvattende puntschattingen.

Met dit nieuwe en meer complexe begrip van hoe variaties in leeftijdsstructuren van de regionale bevolking de economische convergentie kunnen beïnvloeden, wordt in het derde hoofdstuk een gedetailleerde analyse gegeven van demografische factoren die de regionale leeftijdsverdeling beïnvloeden die tot convergentie of divergentie van die regionale leeftijdsstructuren kunnen leiden. Voor zover wij weten, bestond er tot op heden in de literatuur nog geen expliciete kwantificering van de veranderingen in de regionale differentiatie van de vergrijzing van de bevolking. We onderzoeken hoe regionale verschillen in de vergrijzing van de bevolking zich in de afgelopen tien jaar hebben ontwikkeld en hoe ze de komende drie decennia waarschijnlijk zullen evolueren, en we onderzoeken hoe demografische componenten van bevolkingsgroei bijdragen aan het proces. In dit hoofdstuk gebruiken we de methode van de bètaconvergentie om te testen of regio's op weg zijn naar een gemeenschappelijk niveau van vergrijzing.

De verandering in bevolkingssamenstelling, gemeten met Total Support Ratios, wordt opgesplitst in de afzonderlijke effecten van veranderingen in de omvang van de niet- werkende bevolking en die van de beroepsbevolking. Deze laatste veranderingen worden verder uitgesplitst in de effecten van cohortverloop, sterfte en migratie op de omvang van de bevolking in de werkzame leeftijdscategorie. In de Europese NUTS-2-regio's is in de periode 2003-2012 een opmerkelijke convergentie in de vergrijzing van de bevolking opgetreden en dit zal naar verwachting in de komende drie decennia gecontinueerd worden. De waargenomen bèta-convergentie bij de veroudering hangt voornamelijk af van veranderingen in de bevolkingsstructuur van Oost-Europese regio's. Cohortverloop (de invloed van de inen uitstroom van cohorten van verschillende omvang op de grootte van de leeftijdsgroep) speelt de belangrijkste rol bij het bevorderen van convergentie. De verschillen in sterfte in de werkzame leeftijdscategorie, hoewel op zichzelf beperkt van omvang, hebben een significant cumulatief effect. De projecties laten zien dat wanneer wordt aangenomen dat de netto migratiestromen in de werkende leeftijdscategorie tussen de Europese regio's convergeren, dit niet zal bijdragen aan de convergentie van de vergrijzing. Hier zien we, net als in het eerdere geval met het samenspel tussen regionale convergentie of divergentie in vergrijzing en economische prestaties, dat convergerende componenten niet automatisch convergentie van de samengestelde maat impliceren.

Het vierde hoofdstuk behandelt de meest voor de hand liggende vraag die aan de basis ligt van het bestuderen van relatieve verschillen in leeftijdsstructuren van de bevolking: hoe beïnvloedt regionale convergentie c.q. divergentie van leeftijdsverdelingen de convergentie of divergentie in economische ontwikkeling. Talloze eerdere studies erkenden de leeftijdssamenstelling van de bevolking als een belangrijke factor voor economische groei die tot op zekere hoogte verantwoordelijk kan zijn voor de waargenomen ongelijkheden in de groeitrajecten en veranderende relatieve verschillen in inkomensniveaus. Geen van de eerdere studies, voor zover wij weten, was gericht op hoe convergentie of divergentie in regionale leeftijdsstructuren van de bevolking, d.w.z. veranderende relatieve verschillen, de convergentie of divergentie in regionale economische prestaties kunnen beïnvloeden. Omdat onze interesse primair lag bij de dynamiek in leeftijdsstructuren van de bevolking, hebben we in dit artikel de mogelijke wisselwerking tussen regionale convergentie of divergentie in vergrijzing en economische prestaties bestudeerd. Onze resultaten, verkregen met behulp van een vereenvoudigd conceptueel raamwerk, suggereren dat deze associatie in werkelijkheid elke richting kan gaan, afhankelijk van de relatieve veranderingen in de distributies van regio's. Een positieve associatie vindt alleen plaats als de grootste veranderingen plaatsvinden in regio's die zowel rijk zijn als een groter aandeel mensen op werkende leeftijd in de bevolkingsstructuur hebben, of als de grootste veranderingen plaatsvinden in de groep regio's die zowel arm als ouder zijn. De negatieve associatie tussen demografische en economische convergentie werd in ieder geval vaker waargenomen dan de positieve associatie.

De focus van het vijfde hoofdstuk ligt op de kloof tussen stad en platteland in de leeftijdsstructuren van de regionale bevolking. We gaan eerst na of het concept van voortdurende verstedelijking toepasbaar en zinvol is op NUTS-2 geografisch niveau, waarop we betrouwbare en geharmoniseerde bevolkingsgegevens over een periode van een decennium hebben. De meeste NUTS-2-regio's hebben zowel stedelijke als plattelandsbevolking, maar we kunnen zeker beoordelen of een leeftijdsspecifiek migratiepatroon dat karakteristiek is voor verstedelijkte regio's tot uiting komt in de verplaatsing van de bevolking in en uit die regio's. Aangezien jongvolwassenen de neiging hebben om van landelijke naar stedelijke regio's te verhuizen, terwijl oudere volwassenen van stedelijke naar landelijke regio's verhuizen, mag men verwachten dat de verschillen in vergrijzing tussen stedelijke en landelijke regio's zijn toegenomen. We onderzoeken of de verschillen in vergrijzing van de bevolking tussen stedelijke en landelijke NUTS-2-regio's van de EU-27 in de periode 2003-2013 uiteenlopen. In dit hoofdstuk hebben we een nieuwe methodologische benadering gepresenteerd die niet is gebaseerd op de eerder gebruikte bèta- en sigma-benaderingen naar convergentie. We richten ons niet op een enkele samenvattende statistiek van convergentie, maar analyseren eerder de vorm van de gehele cumulatieve verdeling van het aandeel van de regionale bevolking in de werkzame leeftijdscategorie met behulp van piecewise (nl afzonderlijk voor de deelcurves boven en onder de mediaan) parametrische modellering van logistische curves. Deze benadering leidt tot het identificeren van de specifieke groep regio's die verantwoordelijk is voor de belangrijkste veranderingen (in het verlengde van de resultaten in hoofdstuk vier). Onze resultaten suggereren dat, in tegenstelling tot wat verwacht werd, er geen divergentie in leeftijdssamenstelling optrad tussen stedelijke en landelijke regio's, maar eerder divergentie binnen elk van de groepen regio's.

In het zesde hoofdstuk proberen we een innovatieve benadering uit om convergentie of divergentie in ternaire samenstellingen van leeftijdsstructuren van de bevolking te bestuderen in plaats van in puntschattingen. In vergelijking met de methodologische benadering in het vijfde hoofdstuk is dit een andere manier om verder te gaan dan analyse van puntschattingen. In het vijfde hoofdstuk hebben we al verdelingen geanalyseerd, maar die waren gebaseerd op één samenvattende regionale maat, nl. het aandeel van de bevolking in de werkzame leeftijdscategorie. Hier gaan we nog een stap verder, door in plaats van een puntschatter per regio te kijken naar de ternaire verdeling in drie leeftijdscategorieën. Deze benadering stelt ons in staat om de afzonderlijke invloed van elk van de drie gebruikte leeftijdscategorieën - d.w.z. kinderen van 0-14 jaar, volwassenen van 15-64 jaar en ouderen ouder dan 65 jaar - op convergentie of divergentie vast te stellen. We erkennen ook het belangrijke onderscheid tussen de drie delen van Europa en de stedelijke en landelijke groepen regio's daarbinnen. De resultaten laten zien dat de waargenomen divergentie in de leeftijdsstructuren van de bevolking voornamelijk wordt veroorzaakt door het ongelijke begin van versnelde veroudering, d.w.z. een toename van het aandeel ouderen. Daarentegen vermindert de dynamiek van het aandeel kinderen de algehele variantie in de leeftijdsstructuren van de bevolking, iets wat we redelijkerwijs kunnen verwachten aan het einde van de demografische (en vooral vruchtbaarheids-)transitie in Europa. Vergelijkbaar met de resultaten in het vijfde hoofdstuk zien we dat zowel stedelijke als landelijke regio's heterogener worden, terwijl de gemiddelde leeftijdssamenstelling van beide groepen regio's dichter bij elkaar komt te liggen.

Ten slotte bindt het zevende hoofdstuk de afzonderlijke hoofdlijnen van het onderzoek bij elkaar om het complexe beeld van de Europese regionale bevolkingsdynamiek te ontrafelen. In dit laatste hoofdstuk worden ook de beperkingen van het project besproken en de mogelijke wegen om het onderzochte onderwerp verder te verdiepen.