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Demographic Metabolism at Work

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Abstract

In this paper, we transform the age-old wisdom that societies change through generational replacement into a formalized model that allows for quantitative forecasts of such societal changes for decades into the future. Using the term “Demographic Metabolism” which was introduced by Norman Ryder 50 years ago, we show how the blend of this concept with the methods of multi-dimensional population dynamics results in a sophisticated model with strong predictive power, particularly for such characteristics that once established tend to be sticky along cohort lines. We evaluate this model empirically and give a comprehensive summary of recent applications to the reconstruction and projection of educational attainment distributions by age and sex for all countries of the world that already resulted in major new assessments of the societal level returns to education. We revisit the past application of the model for forecasting the future spread of the prevalence of European identity in the EU and show that despite of the recent European crisis, the Demographic Metabolism continued to work as projected. Finally, we apply the model to the changing attitudes towards homosexuality in Japan, Spain and the USA and produce projections of the average tolerance levels in those countries up to 2040.

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1 Introduction

Exactly half a century ago, Norman Ryder published his influential paper on "The Cohort as a Concept in the Study of Social Change" (Ryder 1965). In this paper, which has become a standard reference on the origins of cohort analysis, among other topics he introduces the concept of "Demographic Metabolism" which he describes as the massive process of personnel replacement driven by births, lives and deaths of individuals (Ryder 1965, p.843). This concept is placed right at the intersection of individual level and aggregate level perspectives on change: While individuals succumb, societies become immortal, if reproduction is sufficient to offset mortality. Ryder combines this thought with the assumption that the individual's flexibility to change is restricted once certain characteristics or attitudes are established. Consequently, he viewed the continuous emergence of new participants in the social process and the withdrawal of their foregoers as the main force of social transformation.

Despite the fact that Ryder's 1965 article already provides most of the necessary conceptual elements of a formal theory of social change based on cohort replacement, such a transformation to a predictive theory has not happened until recently. In fact, the whole concept of demographic metabolism has not received much attention until a few years ago, when its combination with the powerful analytical tools of multi-dimensional (multi-state) demography – developed in the 1970s – facilitated its operationalization and the calculation of actual forecasts based on the demographic metabolism (Lutz 2013). In his article entitled "Demographic metabolism: A predictive theory of socioeconomic change", Lutz presents a consistent theoretical framework – including both intra-cohort transitions and inter-cohort changes, thus enlarging Ryder's original framework – and puts it to work in terms of actual numerical projections of the changing composition of populations that are sub-divided according to clearly defined, observable sources of

population heterogeneity. This approach has already been successfully applied to the reconstruction and projection of the changing composition of populations by age, sex and different levels of educational attainment for all countries in the world (Lutz & KC 2011; Lutz et al. 2014) and it has also been used for projecting the "soft" characteristic of European identity within EU member countries (Lutz et al. 2006). But the approach can be used for many other stable human characteristics. The main purpose of this article is to demonstrate the enormous potentials of the demographic metabolism approach for capturing and forecasting social change, half a century after it had been first introduced by Norman Ryder.

This paper will start with a brief introduction to the theory of demographic metabolism as prepared by the sociologist Karl Mannheim, conceptualized by Ryder and operationalized by Lutz. Next, we will present the formal model and its already established application to projecting populations by age, sex and level of education, before applying it to two different examples of "softer" human characteristics, namely (1) the spread of European identity within the European Union and (2) the question of the extent to which attitudes towards homosexuality in different countries of the world change from one cohort to the next. While in the first example we check an earlier assessment, that was based on pre-crisis Eurobarometer data from 1996 and 2004, against the actual data observed in 2013, thus providing an empirical validation of the predictive value of the model in stormy times that had not been foreseen a few years earlier, in the second example we will apply the demographic metabolism model to derive projections of the future prevalence of tolerance towards homosexuality in Japan, Spain and the US to 2040. The paper will conclude with a brief critical discussion and give an outlook to possible other fields of application of the presented approach.

2 Theoretical Background

The idea that societies change as new generations "take over" is already found in early writings on this topic by pre-Socratic philosophers and in Confucian philosophy, albeit in rather general and vague form. It is all the more surprising that such a plausible concept, which reflects everyday life experiences in most families, companies and institutions across all cultures and times, has so far inspired little systematic scientific effort to formally and comprehensively describe this important force of social change. This applies

both to the systematic analysis of historical evolutions and to taking inter-cohort change as the basis for forecasting.

In more recent history, the strain of thought that comes closest to the idea of viewing social change as being driven by the succession of generations, is to be found in the writings of art historians in the late 19th and early 20th centuries who explain the sequence of different historical epochs as being a consequence of the replacement of older generations of artists through new ones with new views of the world, new priorities and new styles of producing art (Dilthey 1900). The first social scientist to offer a comprehensive synthesis of this view of history was Karl Mannheim. In his essay on "The Problem of Generations" (first published in German in 1928 and translated to English in 1952), Mannheim describes two opposing views on generations: The first one is referred to as the "biological" or "positivist" perspective, as it deals with aspects of generations that are measurable, such as the average periods of time taken for the older generation to be replaced by the new one in public life (Mannheim 1928, p.278). This perspective can safely be interpreted as demographic. The other approach, which he calls "romantic-historical", is clearly associated with the writings of the German historian Dilthey and is non-quantitative in scope. There the central notion is "entelechy" or the expression of the "inner aim" of a generation which is synonymous with its "inborn way of experiencing life and the world" (Mannheim 1928, p.283). Mannheim seemed to be more in favor of the first view, but in applying it, he focused only at the past, trying to understand the forces shaping history, rather than looking into the future.

Examining the forces behind inter-generational changes and the conditions under which a new group of people growing up becomes sufficiently different from the previous one in order to be called a new generation, Mannheim defined a generation as being determined by its "social location" (German: soziale Lagerung), which is being shared by all members of a generation. In fact, he compares it to the way in which one is a member of a specific social class, but viewed over time rather than cross-sectionally. In this view, generation and class have in common that both "endow the individuals sharing in them with a common location in the social and historical process, and thereby limit them to a specific range of potential experience, predisposing them for a certain characteristic mode of thought and experience, and a characteristic type of historically relevant action" (Mannheim 1928, p.291). This is where the more formal cohort approach of contemporary

demography, under which inner values (entelechy) may be a consequence but never a defining criterion for membership in a generation, is very different from Mannheim's approach, which is still to a certain degree trying to capture the qualitative inner spirit of a generation.

More than a generation after Mannheim, the Canadian-American demographer Norman Ryder took up the topic from a more demographic perspective. His essay on "The Cohort as a Concept in the Study of Social Change" was published in 1965, but he mentions in a footnote that an earlier version of the paper was already presented in 1959. Some of these thoughts are also included in his 1980 book "The Cohort Approach" (Ryder 1980). Ryder starts from the central, but (then and now) rarely used notion of "demographic metabolism", which he defines as the "massive process of personnel replacement" driven by the births, lives and deaths of individuals (Ryder 1965, p.843). While he saw the flexibility for individuals to change over their life time as limited, the appearance of new individuals in the social process provides an opportunity for social transformation: "the continual emergence of new participants in the social process and the continual withdrawal of their predecessors compensate the society for limited individual flexibility" (Ryder 1965, p.844). Based on the assumed inflexibility of individuals over their lifetimes, Ryder arrives at the strong statement that "The society whose members were immortal would resemble a stagnant pond" (Ryder 1965, p.844). An important additional thought of his was, that the "metabolism may make change likely, or at least possible, but it does not guarantee that the change is beneficial." (Ryder 1965, p.844). Hence, this is not necessary an approach to describe social progress but more neutrally social change that may go in any direction.

Ryder defined a cohort in what has since become the standard textbook definition: "A cohort may be defined as the aggregate of individuals (within some population definition) who experienced the same event within the same interval" (Ryder 1965, p.845). In most applications, birth is taken as the defining event, but it could also be marriage or any other clearly identifiable life cycle event that determine an individual's cohort membership. One decisive step in which Lutz (2013) went beyond Ryder was to relax the assumption of strong cohort determinism. This step was inspired by developments within the field of demography, particularly multi-dimensional cohort component analysis (e.g. Rogers 1975; Keyfitz 1985), which provided the tools necessary

to study changes that happen over the life course. Hence, the possibility of lifelong learning and changes within birth cohorts can in itself present a force of socioeconomic change, such that immortality would no longer necessarily result in Ryder's "stagnant pond".

A second step made by Lutz to transcend Ryder's original conception of the demographic metabolism was to develop it further into a demographic theory of social change with predictive power. Projecting observable differentials in relevant dimensions of social heterogeneity along cohort lines and over time, using said tools of multi-dimensional cohort component analysis we can make quantifiable predictions of how the future will be different. To what degree cohort effects dominate over age and period effects depends on the specific characteristic studied. In some cases (e.g. highest educational attainment after a certain age) the characteristic is sticky by definition and does not change for most people after a certain age, in other cases (such as the examples to be used later in the text of European identity or attitudes toward homosexuality) this is a matter of empirical analysis for the past and corresponding assumptions for the future.

For a formal description of the theory, as well as a detailed discussion of its main propositions, refer to Lutz (2013). For our present purposes it suffices to summarize that it views people – individual humans – as the primary building blocks and agents of any society. Hence, to describe changes at the aggregate societal level it has to focus on the changing distribution of these individuals and the specific characteristics that they carry. Secondly, for any population at any given point in time members can be sub-divided into disjoint groups (states) according to clearly specified and measurable individual characteristics (in addition to age and sex). Possible applications of the theory of demographic metabolism require splitting up the population according to the particular characteristics of interest and subsequently to sub-divide the members of each category by age and sex. Thirdly, at any point in time members of a sub-population (state) defined by certain characteristics can move to another state (associated with different characteristics), and these individual transitions can be mathematically described by a set of age- and sex-specific transition rates. Finally, for any given population consisting of sub-groups that are significantly different from each other with respect to relevant characteristics, a change over time in the relative size of these sub-groups will result in a

change in the overall distribution of these characteristics in the population, and hence in social change.

The choice of a characteristic that is worth studying with respect to its changing distribution within a society is context-specific and therefore the definition of the relevant sub-groups depends on the research questions asked. In this paper, we will discuss and present two such characteristics: European identity, i.e. whether a person says to have a European identity in addition to a national one, and the tolerance a person expresses towards homosexuality. We chose these applications of the demographic metabolism not only to showcase the versatility of the approach, but also because in the case of the identity topic, we can make use of earlier model-based projections that can be evaluated based on data that has become available in the meantime. The second topic is particularly suitable because attitudes towards homosexuality have shifted so dramatically over recent decades and projections of the likely future trend are not yet available.

3 The Multi-Dimensional Cohort-Component Model and its Application to Human Capital Projections

Many demographic methods are based on the concept of the life table and deal with the transitions of people from one state to another over a certain time interval. In its most fundamental form, a life table distinguishes only between two states, being alive and being dead (single decrement life table), and is constructed on the basis of age-specific mortality rates which are used to derive probabilities of surviving to certain ages, as well as expected remaining years of life at any given age. Since age-specific mortality rates differ substantially by sex, there is a long tradition to calculate life tables separately for men and women.

Aside from this standard differentiation by age and sex, however, conventional demography still considers populations as largely homogeneous —for example, it is typically assumed that for all men aged 50–54 the risk of death is equal, despite large differentials related to clearly identifiable risk factors, such as smoking, obesity, or level of educational attainment (Caselli et al. 2014). In the multi-state case, this restriction is relaxed and mortality rates can be different for sub-groups depending on further distinguishing characteristics. This corresponds to the generalization of the simple life table to multiple-decrement and increment-decrement life tables (e.g. Schoen & Nelson

1974). In essence, such tables describe movements of people that can go back and forth between more than two states and where transition rates differ depending on the current state.

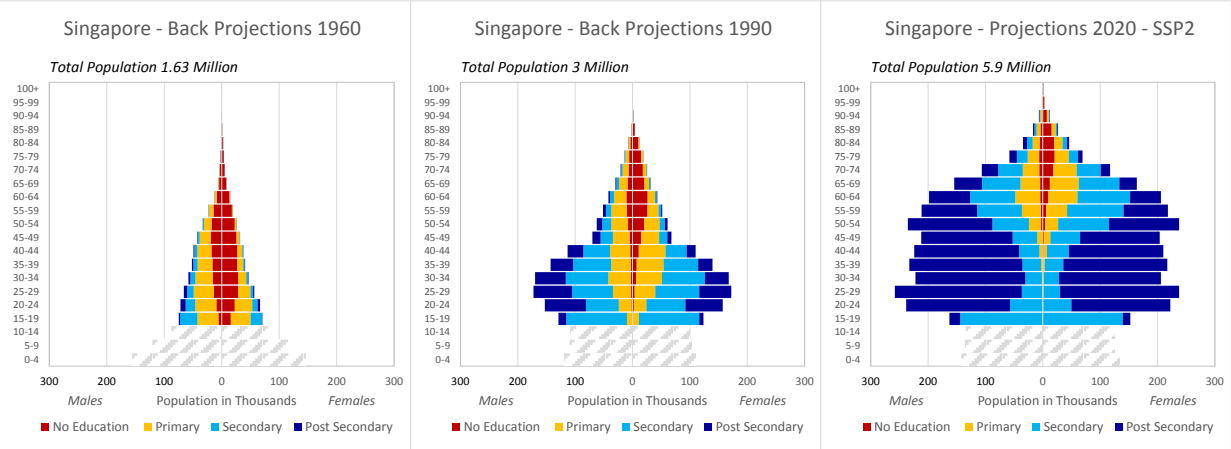
These methodological advances made in the 1970s also led to the development of the multi-state population projection model – the model used for the empirical application of demographic metabolism-based forecasts – that can simultaneously project the populations of different categories (states, regions) with different fertility, mortality, and migration patterns, as well as movements between the categories. Initially focused on regionally defined states, applications were soon expanded further to analyze marital status transitions (Schoen & Nelson 1974), labor force participation and working life tables (Willekens 1978), health and morbidity status (Manton 1988), and cross-classifying marital status and number of children (Lutz 1989).

The multi-state model is most powerful for projecting the future distributions of characteristics that are sticky, i.e. rather enduring over the individual life cycle beyond young age. One such characteristic, which is normally acquired at younger ages and then maintained throughout life, is the highest level of educational attainment. Hence, the application to highest educational attain is exemplary for the application of the Demographic Metabolism model and shall for this reason be briefly summarized here. To our knowledge, the application of the multi-state projection model to education was first used in a study of population–development–environment interactions on the island of Mauritius (Lutz 1994) and has since been successfully elaborated for educational attainment scenarios of all countries in the world (Lutz et al. 2007; Lutz & KC 2011; Lutz et al. 2014).

When we look at the distribution of educational attainment by age in countries where education has increased rapidly in the past, this stickiness of educational attainment over the life cycle becomes particularly noticeable. Figure 1 shows the education and age pyramids for Singapore as reconstructed and projected applying the multi-dimensional cohort-component model (Lutz & KC 2011). In this figure, the age groups of the conventional age pyramid are sub-divided through color shading: red corresponds to “never been to school”, yellow “some primary education”, green “completed junior secondary education”, and blue “completed first level post-secondary or higher”. The phenomenal expansion in educational attainment of the Singaporean population over the

past 60 years are clearly visible in comparing the graphs for 1960, 1990 and 2020. This may well reflect (together with South Korea) the fastest and most remarkable expansion in formal education in human history. While in 1960 the majority of the female population above age 20 had never attended school, 30 years on the population below age 40 already approached universal secondary education, although the cohorts above age 50 remained still very poorly educated.

Figure 1. Age and education pyramids for Singapore in 1960, 1990, and 2020 with colors indicating different educational attainment categories (Source: Lutz et al. 2014)



These different proportions could be directly experienced by a visitor to Singapore around 1990 who found a divided society: The shiny streets and shopping malls where populated by well-educated, young people dressed in Western clothes who spoke perfect English and embraced the latest technology more than Europeans at the time. But turning around the corner to the backside of the building, he found himself in a poor developing country with elderly people, speaking only Chinese, living in a parallel world. It was a society divided into two classes. But unlike the self-reproducing classes, which are commonly studied in sociology (e.g. Blau & Duncan 1967; Erikson & Goldthorpe 2002), these were classes defined by age-cohort membership: The older ones, who were of school age when Singapore was still a very poor country without much of a school system, and the younger ones, who already could benefit from the very rapid expansion of the school system since the late 1950s. And unlike the self-reproducing class structure of a society, that can continue to exist in spite of general increases in educational attainment between cohorts, these cohort-based classes were scheduled to disappear with the passage

of time, as the less educated cohorts continue to move up the age pyramid until they pass away and the younger better educated take their place: demographic metabolism at work.

But the demographic metabolism does not only help decomposing and analyzing past changes. It is a particularly powerful and operational concept for forecasting future changes of the population composition along cohort lines. If we know, for instance, how many 25-year old women have completed secondary education today, this is a very good basis for projecting how many 65-year old women with at least secondary education there will be alive 40 years into the future. One only has to adjust for the possibilities of education-specific mortality risks and migration. The predictive power of this model thus derives directly from the fact that human lives today tend to last more than 70 years and hence the future composition of the population is partly predetermined for decades into the future by the current composition.

The further one goes out into the future, the lower is the proportion that is already predetermined by the current age and education distribution and the broader becomes the range of uncertainty, which is driven by uncertain future fertility, mortality, migration and education transitions leading to an increasing importance of scenario assumptions. While multi-dimensional population projections by level of education have become state of the art and even form the "human core" of a new set of global change scenarios (the so-called SSPs or Shared Socioeconomic Pathways) that are widely agreed upon among the world's leading climate change modelling teams (Lutz & KC 2011; KC & Lutz 2014; O'Neill et al. 2014), this approach is rarely explicitly characterized as being based on the demographic metabolism, although the basic concept behind such projections clearly is the above described model of social change through cohort replacement.

But the characteristics one might be interested in do not always have to be sticky as in the case of highest level of educational attainment. The remaining part of the paper will deal with applying this demographic model to forecasting the distributions of two "softer" characteristics for which persistence along cohort lines first needs to be assessed empirically.

4 The Demographic Metabolism of European Identity

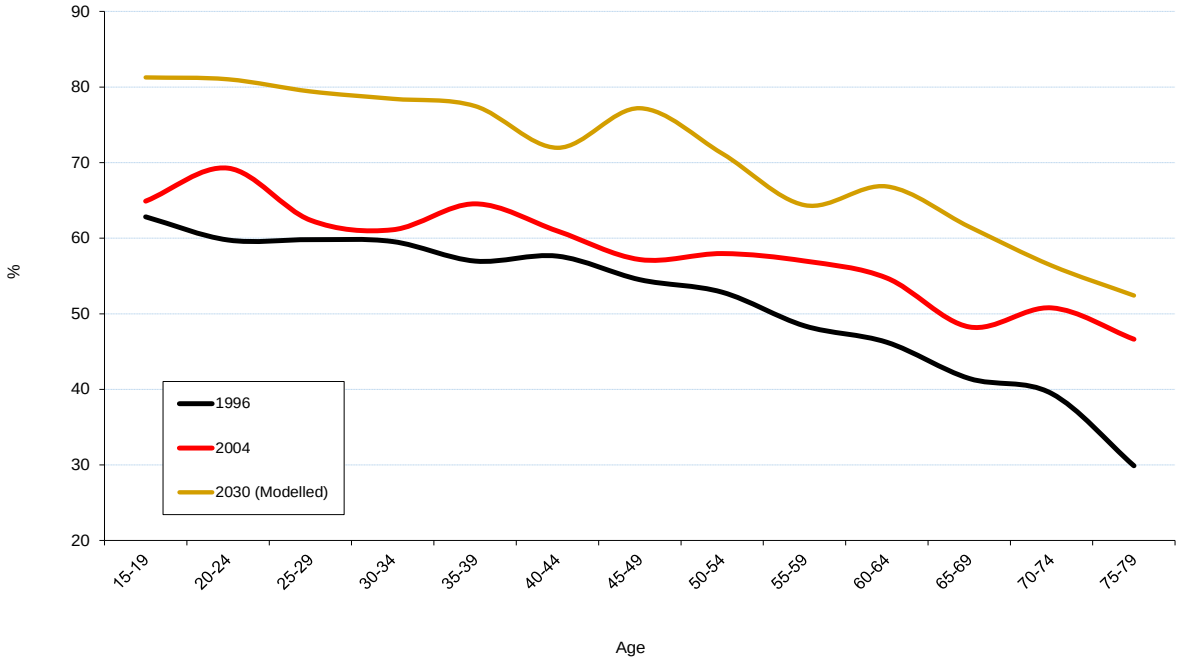
Highest level of educational attainment is usually considered to be a "hard" variable, such as age, that can even be validated through official certificates. But there are other human characteristics that are "soft" in the sense that they can only be assessed through the expressed personal opinion of people in a survey and that can, at least in principle, easily change over time. In this section we will show that the model of demographic metabolism can also be applied to such softer subjective and possibly more volatile characteristics.

First, we will focus on the changing pattern of European identity (as opposed to strictly national identities) as it has been assessed by the Eurobarometer surveys over many years. Some political commentators and observers of the recent economic crisis and its associated effects on the Euro, as well as the future of the European Union more generally speak of an apparent revival of nationalism in many EU member countries (Rachman 2014; Wodak & Boukala 2015) and the distinct possibility of dissolution of the EU as a result (Soros 2014; Culik 2015). The widely used argument is that besides existing economic interdependencies (especially in the banking sector, e.g. Epstein & Rhodes 2014), there is not much that is holding the EU together and that under financial stress as well as the challenges posed by the current refugee inflows, these interdependencies may actually turn into centrifugal forces.

But these commentators focus too narrowly on the institutions and day-to-day politics and tend to overlook the inertia of opinions and more deeply rooted identities of the citizens that Europe is comprised of. The European Commission routinely gathers information of these questions in its Eurobarometer surveys. The relevant question on European identity asks: "In the near future, do you see yourself as [Nationality] only, as [Nationality] and European, as European and [Nationality] or European only?" Since 1996, this question has been asked with unchanged wording more than a dozen times in the EU-15 (members of the EU as of 1995) with national samples of around 1,000 in each round. In 2004, 42 percent of the adult population of the EU-15 above age 18 identified themselves as solely nationals of their own country, whereas 58 percent gave an answer that reflected multiple identities including a European identity. Figure 2 shows a clear decline in the association between having multiple identities and age. Put differently, the older the respondent, the greater the chance that he or she will perceive only a national

identity. While for younger age groups, those with only national identities are a minority, for the population above age 60 they constitute a majority.

Figure 2. Proportions with multiple identities by age as derived from the Eurobarometer Surveys in 1996 and 2004 and projected to 2030 (Source: Lutz et al. 2006)



Does this obvious age pattern allow for the conclusion that as people get older, they tend to develop a stronger national identity and abandon multiply identities they might have had earlier? If this dominance of the age effect were to be true, the massive population aging that will occur over the coming decades simply as a consequence of the current age-structure would suggest a decline in the proportion of citizens with multiple identities. On the other hand, the same pattern could also be interpreted in terms of a cohort effect: young cohorts are being socialized in a way that produces a higher prevalence of multiple identities than found among the older cohorts which they then maintain throughout their lives. As a result, we should observe significant increases in future European identity through demographic metabolism, with the younger, more European-minded cohorts replacing the previous, more nationalistic ones.

Both of these contrasting interpretations are plausible. However, their validity cannot be assessed empirically based on one cross-sectional survey alone. Only panel data that provides age profiles at different points in time allow us to distinguish between

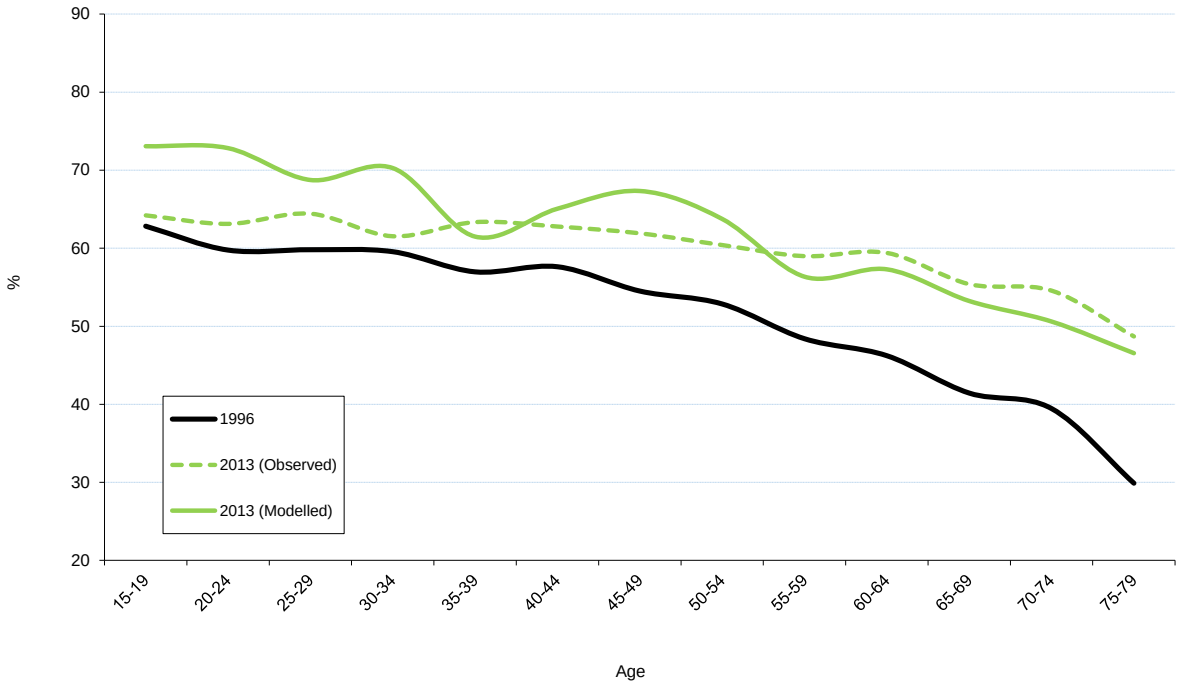
age and cohort effects. Using data from 1996 and 2004, Lutz et al. (2006) find evidence of a highly significant, positive cohort effect which is indicative of a trend toward greater prevalence of multiple identities in the European Union along cohort lines. In other words, cohorts born more recently are socialized in a way that decreases their association with solely national identities and increases the association with multiple identities. These identities are then assumed to be maintained throughout their lives, while for the subsequent younger cohorts, for which no empirical data is available, the authors assume the continuation of the time trend of past inter-cohort increases. Based on this model of demographic metabolism, they predicted that by 2030 the proportions with European identity would come to lie over 70 percent for the younger people and over 50 percent even for the older ones. In terms of absolute numbers, the results predict that only 104 million adult European Union citizens (EU-15) will have strictly national identities in 2030, while 226 million will have multiple identities.

Since the publication of that paper in 2006, the European Union has gone through turbulent times. As stated above, many commentators in the media think that as a consequence the pattern has fundamentally changed and people now identify less with Europe than before. These views are typically only based on conjectures rather than solid empirical information, when in fact in 2013 the exactly same question was asked to Europeans in the course of another Eurobarometer survey. Thus, whether the projections published in 2006 were far off the mark – as most would expect – or had indeed captured a still ongoing secular trend, can be assessed empirically.

The two green lines in Figure 3 show the age pattern of European identity in 2013 as projected in the 2006 paper (solid) and the actual pattern observed in the 2013 survey (broken). Considering broad age groups, this empirical test of the past predictions shows that for cohorts that are above age 35 in 2013 the forecast was pretty accurate, while for the younger age-groups the forecast was too high. In fact, for the age groups 15-24 the actual proportions with multiple identities were 8-9 percentage points lower than the forecast ones. This clearly shows that the above-stated assumption of continuation in the period trend of inter-cohort increases as observed for the 1994-2004 period to 2013 did not hold. For the new cohorts that had entered adult age during the projection period, clearly the increasing trend had stalled over the last decade. However, for adults of higher ages the assumption of stability of identities along cohort lines essentially held. There is

some noise around the specific smaller age groups, but taken together the European adult population above age 35 in 2013 shows almost exactly the proportion with European identity (57.9 percent) as was projected based on 1996-2004 data for the year 2013 based on the model of demographic metabolism (58.6 percent). This is indeed a strong confirmation of the predictive power of the model of demographic metabolism even during turbulent times when most observers would have expected the opposite.

Figure 3. Proportions with multiple identities by age as derived from the Eurobarometer Surveys in 1996, projected to 2013 (based on the Lutz et al. 2006 model) and actually observed in 2013



These findings suggest that the relentless forces of cohort replacement, through which younger and (up to the most recent cohorts) more European-minded cohorts gradually take the place of the older, more nationally oriented cohorts, produce significant and predictable changes in the pattern of European identity. Since the population aged above 35 constitutes a vast majority of the total European electorate (as well as of decision makers and politicians), these predictable changes in the composition of the adult population will presumably have important long-term implications for fundamental

political and economic developments in Europe, even though short-term politics and market reactions are likely to remain volatile.

Another important finding from this empirical assessment of the predictive power of the model of demographic metabolism for a soft, subjective and potentially changeable characteristic such as expressed identity is that in contrast to stable cohort patterns, the period changes determining the formation of the identities of the younger generations are indeed reversible and there is no guarantee for a continuation of observed period trends. In other words, while the firmly established identities of many adults do not seem to have changed very much in response to the widely publicized and discussed crises of European institutions, these discussions have interrupted the trends with respect to the formation of such identities among the younger cohorts. This leaves us with an important message for forecasting social trends in general: Trend extrapolation is a much less reliable approach to anticipating future developments than decomposing the population into cohorts, assessing the stability of patterns along cohort lines, and then modelling the changing composition of the population through the demographic metabolism.

5 The Changing Pattern of Tolerance toward Homosexuality

The above-described example of identity is rather specific to the European context, although the more general concept of multiple (not only national) identities and their stability and change over time is also relevant for other countries (see also Josselson & Harway 2012; Kivisto 2015). Another very significant value change that has been observed in virtually all industrialized countries in recent decades regards the attitude and tolerance toward homosexuality. This topic will be chosen in the following for another, entirely new application of the model of demographic metabolism. Using data from the European and World Values Survey (hereafter EWVS), we will assess the empirical patterns in selected countries since the 1980s and derive projections of the future prevalence of tolerance toward homosexuality in those countries until 2040.

The EWVS represents the largest collection of data on attitudes and values to date with a total of roughly 500,000 not repeated individual observations. The EWVS has been carried out in six waves since 1981 – the latest of which (2010-2014) has only recently been released and so far not been used for statistical research very widely. In total, representative national surveys with between 1,000 and 3,000 individuals from the entire resident population above the age of 18 have been conducted in almost 100 countries,

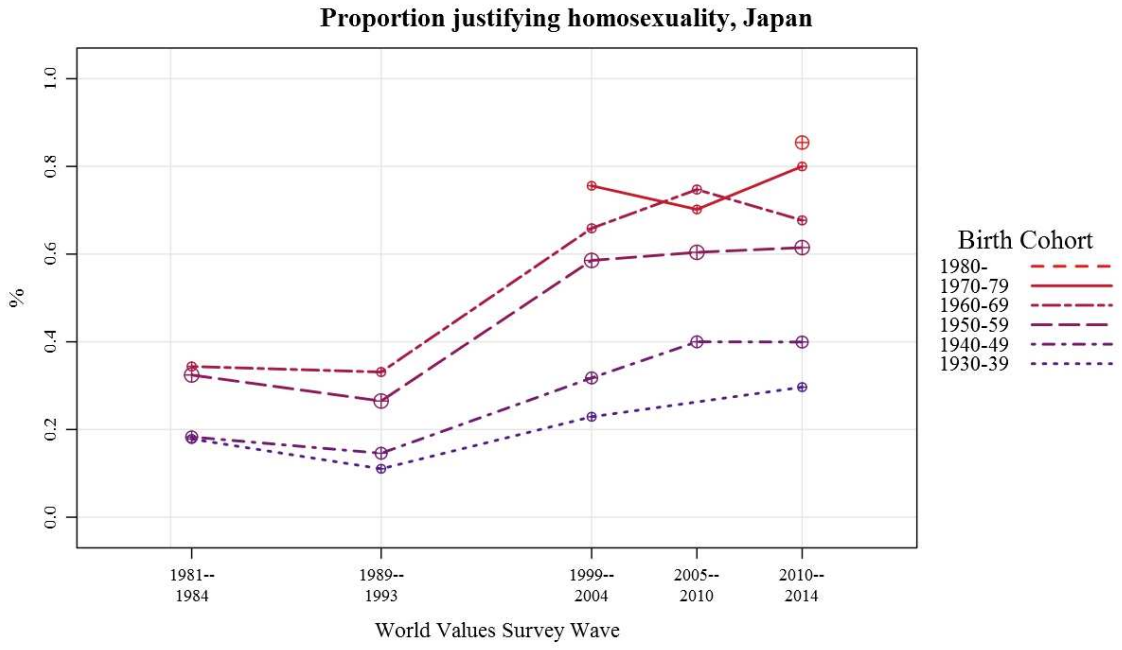
accounting for close to 90 per cent of the world population. Detailed information on the sampling strategy, questionnaire wording, as well as data access and publications making use of this data can be obtained at www.worldvaluessurvey.org.

Respondents in all survey waves of the EWVS so far were asked with the precisely same wording to give an assessment of their "Tolerance for homosexuality" on a 10-level scale: "Please tell me whether you think it can always be justified (10), never be justified (1), or something in between." The EWVS does not provide the respondents with the possibility to distinguish between male and female homosexuality, nor does it ask for the respondent's own sexual orientation, both of which has been shown to be of high relevance when assessing sexual prejudice (Kite & Whitley 1996; Yost & Thomas 2011; Friedman et al. 2014). However, we control for the respondent's sex in all regression models. Due to the risk of differential item functioning, i.e. subjective assessments regarding one's level of tolerance might not be comparable across different national and cultural contexts, we study only individual countries, rather than pooling the data across all countries available. From the many countries that are included in the EWVS, we select three for which long series of data exist, which show distinctly different patterns and also have very different cultural and religious backgrounds, namely Japan, Spain and the United States of America.

Before going into the statistical analysis, we first visually inspect the trends and patterns in these countries in a form that already decomposes the pattern into different birth cohorts. The following Figures 4-6 show the time trends in the proportions of respondents stating that homosexuality can be justified for different birth cohorts in the years in which the surveys were taken. This allows us to visually distinguish the change that is due to changing attitudes within birth cohorts over time (shown by the slope of the lines) and the change resulting from younger cohorts being on average more tolerant (vertical difference between the lines). While the statistical analysis is carried on the basis of the full 10-point scale, the figures dichotomize this scale for easier presentation with values of 5 or higher to correspond to tolerance. The size of the circles around each data point corresponds to the number of observations. If there were less than 150 observations, the data point was not plotted in the figure. Note that both for the oldest cohorts in the most recent waves, as well as for the youngest cohorts in the earliest waves, the number of observations was sometimes either no longer, or not yet high enough.

Figure 4 shows the empirical pattern for Japan. It indicates that in the early 1980s, among the cohorts born before 1950 less than 20 percent expressed tolerance toward homosexuality, while for the cohorts born 1950-1969, 30-40 percent expressed tolerance. In the most recent round of surveys taken after 2010, all cohorts show a somewhat higher proportion tolerant than 20 years before, i.e. they somewhat changed their views over time into the direction of more tolerance with most of the change happening during the 1990ies. But the inter-cohort difference is a significant part of the picture. The ranking of the cohorts with respect to tolerance follows exactly their age where the difference between those born in the 1940s and in the 1950s seems to be particularly large, i.e. almost 20 percentage points.

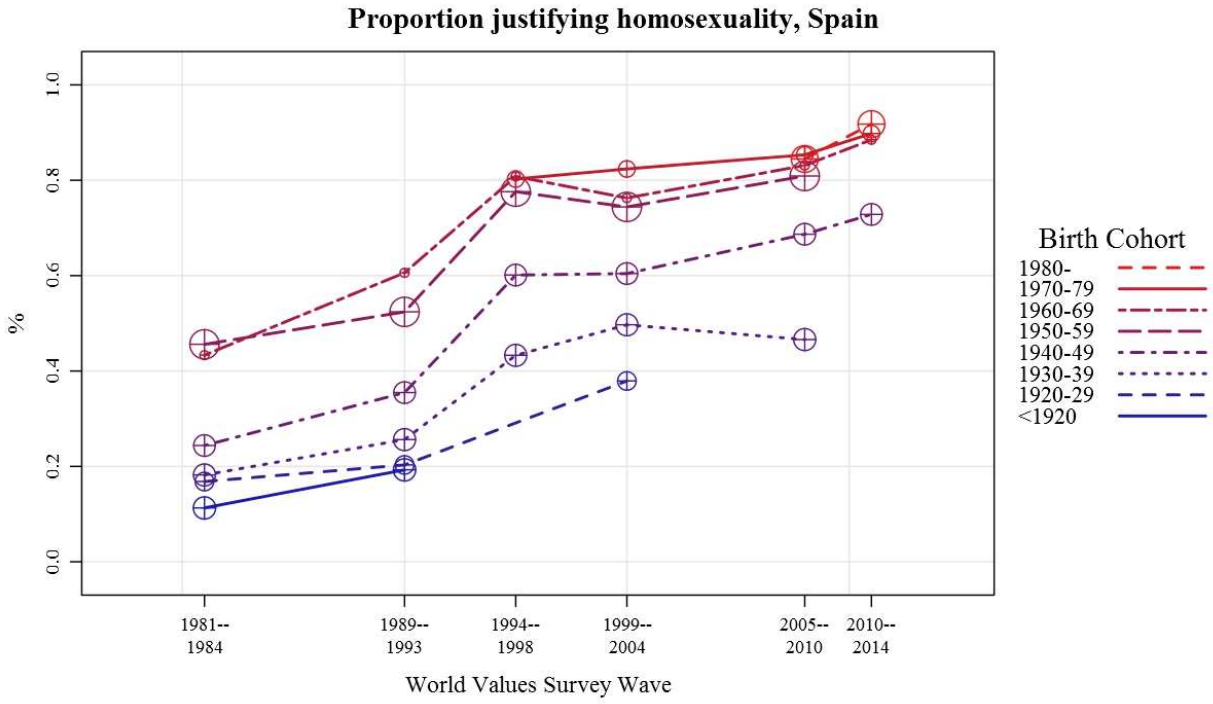
Figure 4. Evolution of proportions tolerant to homosexuality (answer 5 or above) in Japan over survey waves by birth cohorts



For Spain (see Figure 5) the pattern of change looks somewhat different. Over the 1980s the inter-cohort difference is bigger than in Japan, even when considering that here we also have a high enough number of observations from cohorts born before 1930. There are very little intra-cohort changes visible during the 1980s and since 2000 but a massive shift during the 1990s for all cohorts. This is the time when the Spanish society went through massive modernization and a stronger interaction with Western Europe. Since

2000 most of the change has been through cohort replacement with the cohort lines showing very little increase. It is also worth noting that for the younger cohorts the values are already around 90 percent with not much further increase being possible.

Figure 5. Evolution of proportions tolerant to homosexuality (answer 5 or above) in Spain over survey waves by birth cohorts



The picture for the USA (Figure 6) is very different from Japan and Spain. There is less inter-cohort change and within cohorts, moderate almost linear increases are shown up to 2000. It is also remarkable that, unlike in Japan and Spain, the proportion does not increase beyond 80 percent being tolerant. For the younger cohorts, the average level of tolerance has been essentially stagnant since 2000.

Figure 6. Evolution of proportions tolerant to homosexuality (answer 5 or above) in the USA over survey waves by birth cohorts

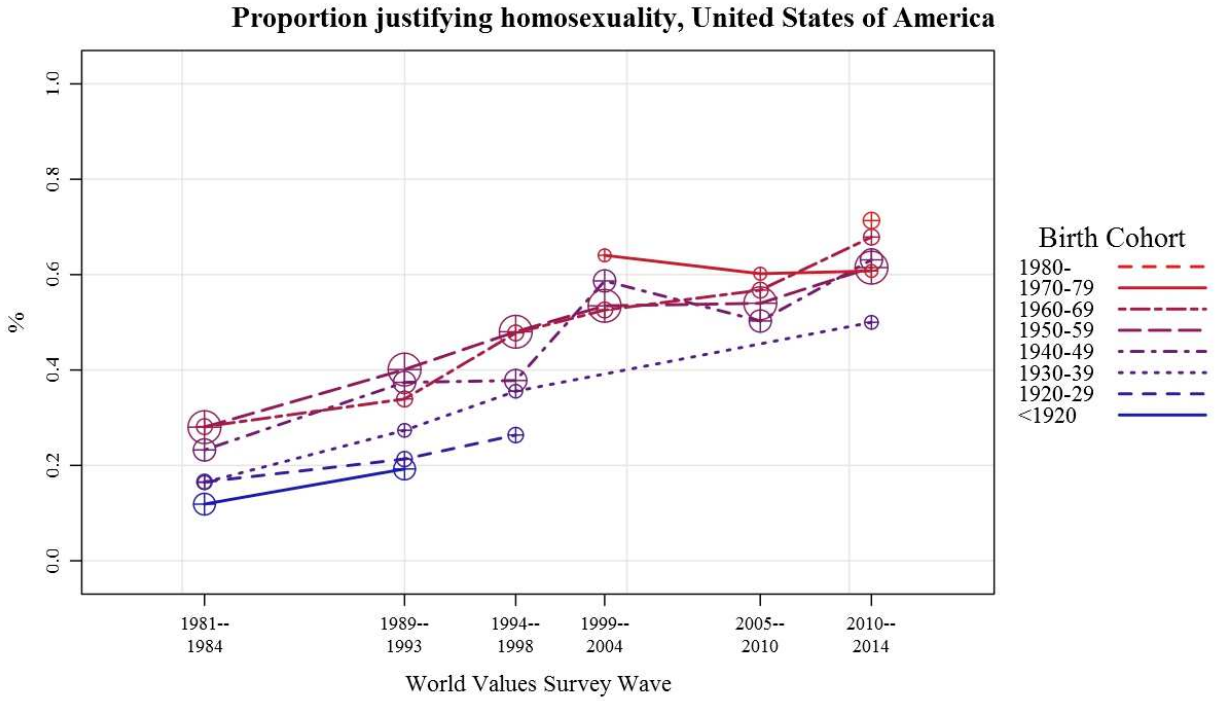


Table 1 shows the results of the full models – including the usual controls and determinates of tolerance toward homosexuality as mentioned in the literature (e.g. Ohlander et al. 2005; Smith 2011; Patrick et al. 2013) – for the three countries. The cohort effects come out particularly strong in Japan and Spain, while in the USA the period effect dominates (measured by survey year). Statistical sensitivity analysis also showed that there is no consistent and significant age effect across the three countries and including age in the models leaves the described patterns of cohort and period effects essentially unaffected. As confirmed by the literature, higher education is strongly associated with greater tolerance and women tend to be more tolerant than men. Also people who categorize themselves as religious are less tolerant. Finally, tolerance to homosexuality is also clearly associated with partnership status, as married and widowed persons show lower tolerance than cohabiting, separated or divorced people.

Table 1. Full model. Weighted ordered logistic regression for Japan, Spain, and USA. Dependent variable: Do you justify homosexuality? All 10 categories used in model. *** p<0.001, ** p<0.01, * p<0.05, standard errors in parenthesis.

	Japan	Spain	USA
survey year	0.019***	0.011***	0.035***
	(0.003)	(0.002)	(0.002)
birth cohort	0.055***	0.028***	0.005**
	(0.003)	(0.002)	(0.002)
educ: med/low	0.169***	0.409***	0.046*
	(0.040)	(0.042)	(0.027)
educ: high/low	0.603***	0.655***	0.759***
	(0.033)	(0.033)	(0.029)
sex: male/female	-0.584***	-0.423***	-0.485***
	(0.064)	(0.046)	(0.049)
religion: religious/not religious	-0.179**	-0.754***	-1.078***
	(0.072)	(0.050)	(0.059)
married: cohabiting	0.051***	0.257***	0.541***
	(0.000)	(0.011)	(0.015)
married: divorced	0.250***	0.321***	0.217***
	(0.003)	(0.003)	(0.019)
married: separated	0.105***	0.278***	-0.052***
	(0.000)	(0.003)	(0.002)
married: single or never married	-0.010	0.012	0.328***
	(0.012)	(0.057)	(0.061)
married: widowed	-0.049***	-0.247***	-0.167***
	(0.004)	(0.011)	(0.011)
Log-likelihood	-6842.920	-12652.227	-10459.111
Deviance	13685.839	25304.453	20918.221
AIC	13725.839	25344.453	20958.221
BIC	13848.710	25479.679	21090.998
N	3441	6382	5646

While such a model is useful for studying the various determinates of differentials in attitudes, it is not directly helpful for forecasting because we do not know the future trends of the independent variables. When producing the forecasts, we thus disregard education, marital status and religion and follow the concept of demographic metabolism, basing our scenarios exclusively on the mechanism of cohort replacement, assuming some stability in attitudes within cohorts. To be more precise, we do as a minimum assume that tolerance within cohorts does not decline over time. This seems to be a rather uncontroversial assumption because in none of the cohorts studied in any of the countries we found a lasting decline (aside from temporary dips that may also be due to small

numbers of cases). On the other hand, as we have seen in the analysis above most countries experienced some intra-cohort increase over time in the proportion expressing tolerance. But it is not clear whether this trend will continue in the future. For this reason, we specify two alternative scenarios in our forecasts, one in which proportions tolerant will be constant within cohorts over time and another one where an extrapolation of the observed trend – in the form of the estimated period effect – will be superimposed to the increase that results purely from cohort replacement. Apart from that, we do not assume that people's attitudes to homosexuality affect future fertility, mortality or migration and model the population by age and sex in accordance with the middle-of-the-road scenario (SSP2) from the above-described SSPs.

Table 2 shows the results of the model estimating period, cohort and gender effects for the three countries which are then used to produce the forecasts. Again, in Japan and Spain the cohort effects come out very strongly and do not diminish when period (survey year) is included into the model as an additional control. In the USA, as confirmed by the model above and the descriptive analysis, the cohort effect comes out much weaker with the period effect dominating. In all three countries there is a significant gender effect which is strongest in Japan and weakest in Spain. This will also be used to produce forecasts that are differentiated by sex (see Figure 7 and Figure 8 below).

Table 2. Reduced model for forecasting. Weighted ordered logistic regression for Japan, Spain, and USA. Dependent variable: Do you justify homosexuality? All 10 categories used in model. *** p<0.001, ** p<0.01, * p<0.05, standard errors in parenthesis.

	Japan			Spain			USA		
	m1	m2	m3	m1	m2	m3	m1	m2	m3
birth cohort	0.06***	0.06***		0.04***	0.04***		0.02***	0.01***	
	(0.00)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)	
survey year		0.02***	0.05***		0.02***	0.05***		0.04***	0.05***
		(0.00)	(0.00)		(0.00)	(0.00)		(0.00)	(0.00)
sex: male/female	-0.45***	-0.46***	-0.45***	-0.23***	-0.22***	-0.13***	-0.32***	-0.33***	-0.31***
	(0.06)	(0.06)	(0.06)	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)
Log-likelihood	-6942.38	-6940.06	-7355.33	-12888.97	-12880.63	-13496.49	-10844.65	-10791.73	-10839.72
Deviance	13884.75	13880.12	14710.65	25777.93	25761.27	26992.98	21689.29	21583.46	21679.43
AIC	13906.75	13904.12	14732.65	25799.93	25785.27	27014.98	21711.29	21607.46	21701.43
BIC	13974.44	13977.96	14800.33	25874.32	25866.42	27089.51	21784.33	21687.14	21774.47
N	3474	3474	3474	6393	6393	6473	5651	5651	5651

The results of the two different scenarios to 2040 are given in Table 3 for the three countries that are studied here. The forecasts are shown for the entire adult population (20+) and for the population above age 45. While forecasts for the younger adult age groups in 2040 require additional assumptions about the trend in the tolerance levels over time, attitudes for age groups above age 45 are already based on empirically measured levels of tolerance and are only based on the assumption that those cohort-specific levels stay invariant over time. The distinction between these two different levels of uncertainty (with the younger cohorts being more uncertain due to the need of additional trend assumptions) has been inspired by the findings from the previously discussed trends in European identity, where the assumed persistence of once established cohort levels turned out to be very robust but the assumption of a trend in the level for new cohorts did not hold. The dichotomized categories are presented in the same way as in the figures above (grades 5-10 considered tolerant), although the projections themselves were carried out for the full 10 grade scale.

Table 3. Proportion justifying homosexuality - among the entire population aged 20+ (left) and among the population above the age of 45 (right) in two scenarios: Constant (attitudes frozen at cohort-specific levels) and Time Trend (attitudes becoming increasingly more tolerant following the time trend), Japan, Spain, and United States of America, 2010 - 2040.

		Population above age 20			Population above age 45		
Attitudes	Year	Japan	Spain	USA	Japan	Spain	USA
Constant	2010	0.62	0.78	0.62	0.48	0.69	0.58
Constant	2015	0.66	0.81	0.64	0.54	0.73	0.59
Constant	2020	0.70	0.83	0.66	0.60	0.77	0.61
Constant	2025	0.74	0.85	0.68	0.65	0.80	0.62
Constant	2030	0.77	0.87	0.71	0.70	0.82	0.64
Constant	2035	0.81	0.88	0.73	0.74	0.84	0.65
Constant	2040	0.84	0.90	0.75	0.78	0.86	0.67
Time Trend	2010	0.62	0.78	0.62	0.48	0.69	0.58
Time Trend	2015	0.68	0.82	0.68	0.56	0.75	0.64
Time Trend	2020	0.73	0.85	0.73	0.63	0.80	0.69
Time Trend	2025	0.78	0.88	0.77	0.70	0.84	0.74
Time Trend	2030	0.82	0.90	0.82	0.76	0.87	0.79
Time Trend	2035	0.86	0.92	0.85	0.81	0.89	0.83
Time Trend	2040	0.89	0.93	0.88	0.86	0.91	0.86

The upper panel of Table 3 (“Constant”) lists the projection results for the three countries based on the rather conservative assumption that cohorts do not change their level of tolerance once established. Still, for people above age 45 in Japan this model shows an increase from currently 52 percent tolerant to 80 percent in 2040, thus a very strong projected increase in the average attitude to homosexuality based on rather robust assumptions. Including the younger adult population (with an assumed increase of tolerance for younger cohorts) the average would increase to 84 percent. If this is still combined with the estimated period trend of increases within cohorts, as shown in the lower panel of Table 3 (“Time Trend”), the results suggest an increase to an average of 89 percent tolerant in Japan in 2040. In Spain, where the overall proportion tolerant already today is much higher than in Japan, equally high proportions would be reached in 2040 even without adding a time trend. The resulting age pyramids for Japan and Spain in the scenario without time trend are given in Figure 7.

The USA is quite a different case. As the above described analysis already revealed, there the time trend is more important than the inter-cohort cohort changes. Consequently, under the scenario assuming constant proportions for cohorts the proportion tolerant among the population aged 45 or above would only increase from the current 59 percent to 69 percent in 2040. Adding the time trend to the projection would result in 87 percent by 2040. The corresponding evolutions of the age pyramids for the two different scenarios for the US are given in Figure 8.

The application of the demographic metabolism approach to the topic of attitudes regarding homosexuality in an international perspective thus clearly shows a changing pattern towards increasing tolerance. In all three presented country cases, younger cohorts tend to be less disapproving than older ones and it should not come as a surprise, therefore, that in all those countries also legislation with respect to homosexual partnerships have changed over recent decades, as the less tolerating older cohorts were replaced by more tolerating young cohorts. As we have quantitatively illustrated here, this tendency is likely to continue for the coming decades.

Figure 7. Age pyramids for Spain and Japan by age and sex-specific proportions tolerant to homosexuality in 2010 and as projected to 2025 and 2040 based on the scenario assuming constant proportions within cohorts over time. The population below age 45 is shown in lighter shading due to the additional assumption discussed above

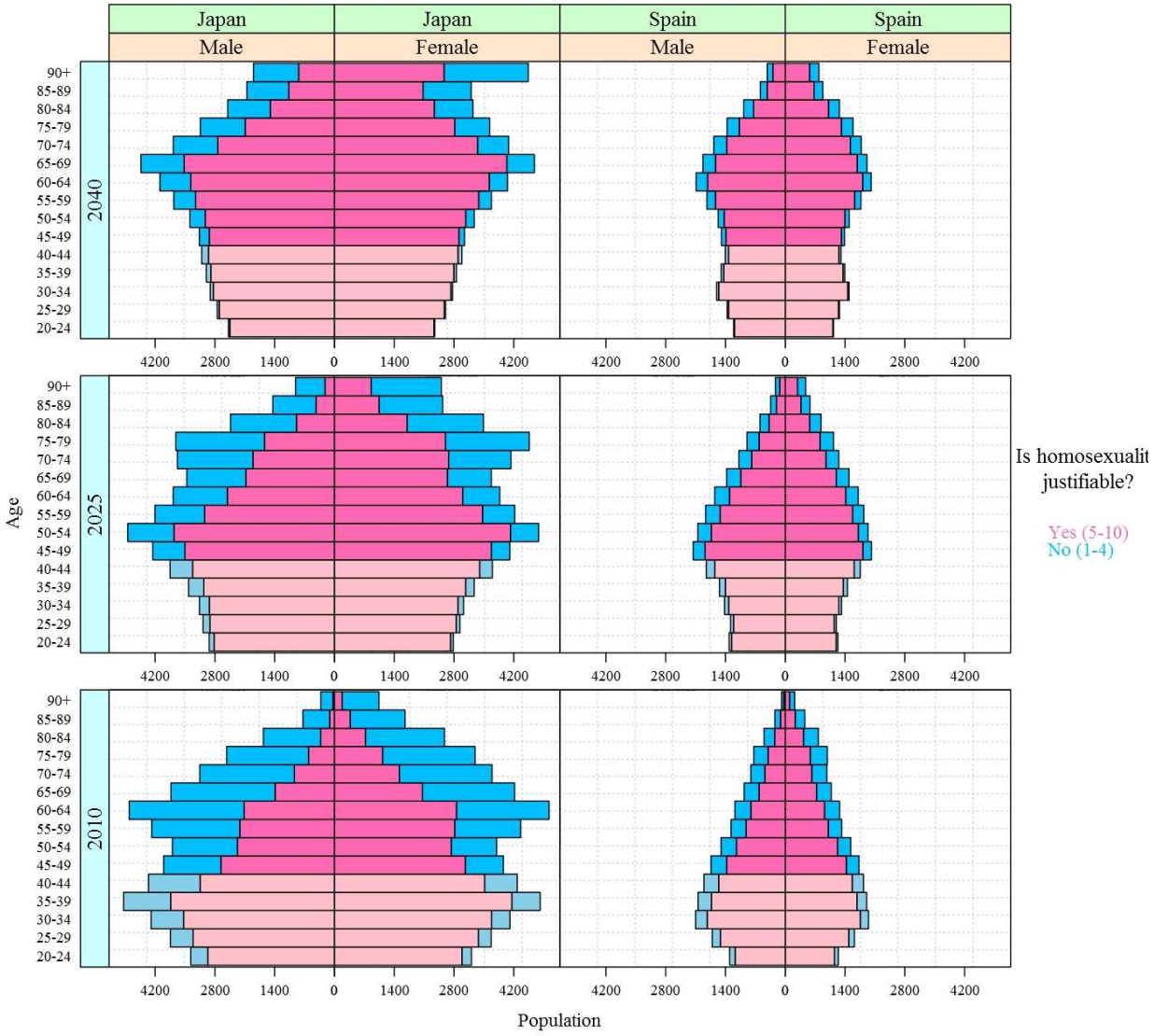
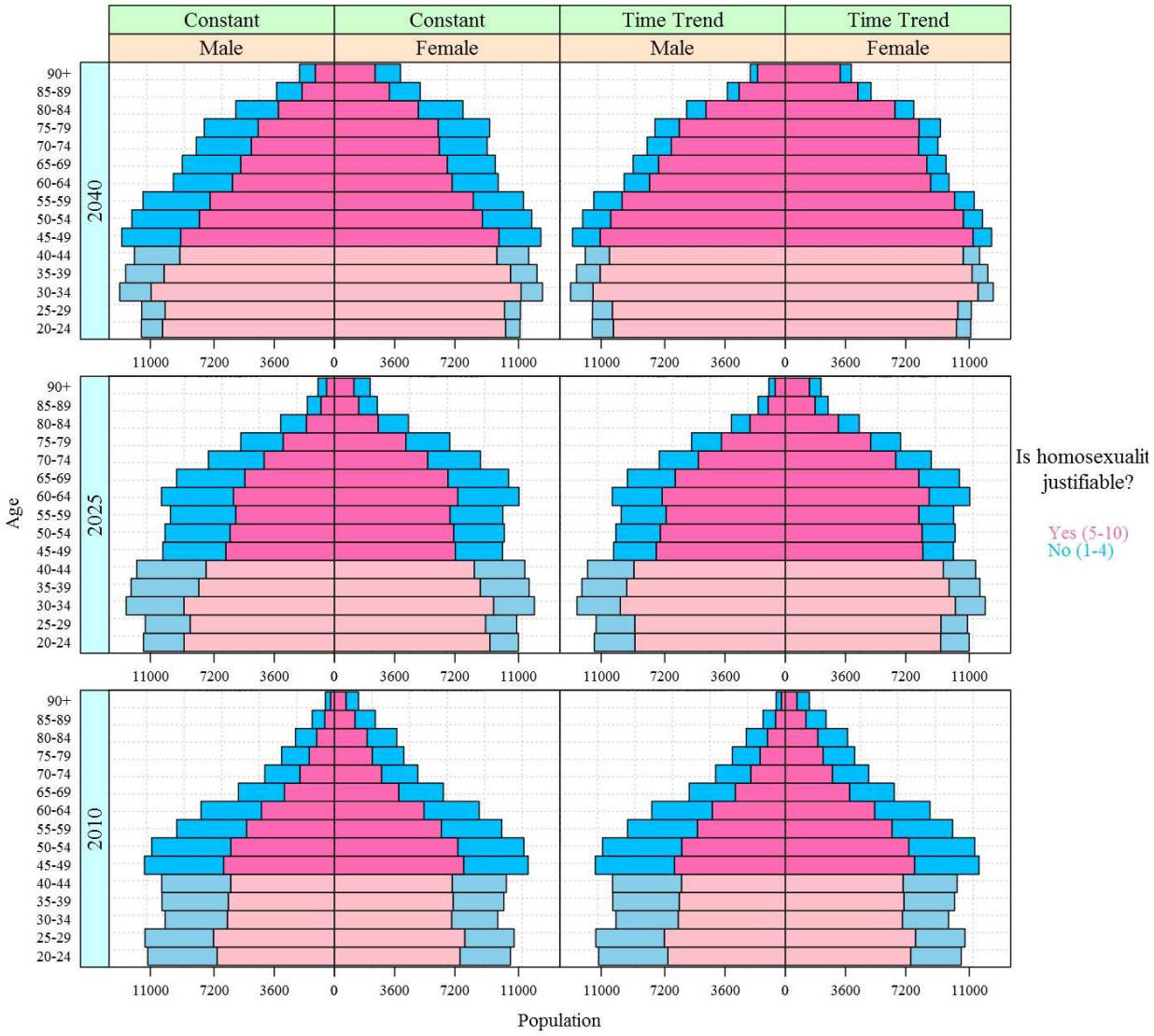


Fig. 8 Age Pyramids for the USA by age and sex-specific proportions tolerant to homosexuality in 2010 and as projected to 2025 and 2040 based on the scenario assuming constant proportions within cohorts over time (left side) and assuming a continuation of the period trend of increases within cohorts (right side). The population below age 45 is shown in lighter shading due to the additional assumption discussed above



6 Outlook and Discussion

In this paper, we showed how the age-old wisdom that societies change through generational replacement can be transformed into a formalized model that allows quantitative forecasting of societal changes for decades into the future. Using the term "Demographic Metabolism", which was introduced by Ryder 50 years ago, we demonstrated how the blend of this concept with the methods of multi-dimensional population dynamics results in a model with strong predictive power, particularly for characteristics that once established tend to be sticky along cohort lines. Against the background of already existing applications of this model in the field of population dynamics by level of education we reassessed an earlier application of the model to the diffusion of European identity within the EU and presented an entirely new application, namely to the spread of tolerance towards homosexuality.

Of the three different applications of the demographic metabolism model discussed in this paper, the modelling of the changing composition of population by highest level of educational attainment is the best established and most widely used. Since highest educational attainment by definition cannot decline over the life cycle, there is no need for empirical validation of a cohort effect. The only thing that needs to be empirically assessed for the past and assumed for the future are the age-specific transition rates to higher educational categories. This model has proved to be very useful for quantitatively capturing the momentum of improvements in the average educational attainment of the adult population. Also, the comparison of different scenarios, assuming either rapid increases in future educational transition rates or no further improvements in school enrollment rates, sheds light on the range of possibilities for education policies in influencing future human capital. Furthermore, while not yet widely noticed in the social research community so far, modeling alternative future population trends by age, sex and level of educational attainment according to the demographic metabolism has been very rapidly adopted by the international climate change modelling community: Not only do their new SSP scenarios (described above) utilize the empirical association of economic growth with past human capital expansions that were derived from back projections of educational attainment distributions based on the demographic metabolism. Also, the alternative pathways of future economic growth for all countries result from the

combination of demographic metabolism-based human capital scenarios with alternative assumptions on total factor productivity (Crespo Cuaresma 2015).

In order to further explore the applicability of the approach in social research, we also focused on two topics that are usually considered to be far away from demography and where one would not expect mathematical demographic methods to be of great use. Nevertheless, the paper could clearly demonstrate that projections based on the model of demographic metabolism accurately predicted the future evolution of European identity among cohorts whose identities had already been established prior to the major discontinuity caused by the recent economic crisis. For the other "soft" social characteristic, namely tolerance toward homosexuality, we estimated the cohort effects in past trends and presented two alternative scenarios for Japan, Spain and the US which either assume the cohort replacement mechanism of the demographic metabolism alone or superimpose an additional period trend. We will have to wait at least another decade to empirically assess the validity of this forecast.

An important finding from the empirical evaluation of the forecasts for European identity was that the demographic metabolism part of the overall change is much more stable and predictable than extrapolations of past period trends. If this finding is generalized to other dimensions of social change that should be anticipated, then the implication clearly is that compared to forecasting the average level of a certain characteristic of interest (mostly based on the assumption of homogeneity of the population), the accuracy of the forecast will be greatly increased by decomposing the population into different cohorts, empirically assessing the strength of cohort effects in past trends and then building the stable element of the forecast on the demographic metabolism. The more uncertain period effects can be captured through alternative scenarios or probabilistic ranges. In case the empirical assessment[1] of past trends of a specific characteristic shows only a weak or insignificant cohort effect, then the demographic metabolism approach will not be of much help for this characteristic and one will be left with a broad range of uncertainty. If on the other hand there is almost complete cohort determination – as in the case of highest educational attainment after a certain age –, then the forecast based on cohort replacement is a near certainty (with only

[1] The broad and controversial literature on estimating age-period-cohort effects (e.g. Yang & Land 2008; Luo & Hodges 2015) is a separate topic not to be reviewed here.

minor uncertainty introduced through future mortality and migration). In most cases the cohort effects will lie somewhere between these two extremes.

Some readers may wonder why in this paper so much emphasis is placed on forecasting. Norman Ryder did not explicitly mention forecasting as an important field of application for the demographic metabolism. One possible reason for this is that the conceptual model as presented by Mannheim and Ryder were not yet realistic or operational enough to be used for quantitative forecasts that could be tested. Mannheim's model did not leave room for heterogeneity within generations (different members of one cohort having different characteristics) while Ryder's view was based on strict cohort determinism (people will not change established characteristics over their life course). As described in this paper, only the more recent combination of these qualitative approaches with the mathematical model of multi-dimensional population dynamics could produce a model with predictive power in numerical terms.

In fact, it is a major problem in many fields of research that policy changes often lag behind the changing social realities by many years. They tend to be based on past experience that may no longer be valid when finally implemented, such that the problem that should be addressed might already have changed. Hence accurate forecasting, or at least defining a plausible range of uncertainty for likely future trends, is an absolutely necessary prerequisite for designing and implementing efficient and effective policies to influence societal developments into desired directions.

The process of demographic metabolism itself is neutral like a natural law. It describes the process of change without judging whether it is to the better or worse. But it seems reasonable to assume that in many cases it is the dominant mechanism through which change operates since the degree to which people can or are willing to change at a higher age is often limited. This is particularly true for skills or deeply rooted attitudes resulting from formative experiences made during earlier parts of one's life. As we have tried to argue in this article, the changing composition of societies with respect to such fundamental characteristics is one major reason for social change. The model of demographic metabolism provides the social sciences with a powerful new tool to better understand, model, and forecast such social changes.

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