Dimensions in Global Projections: An Overview

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Abstract – The addition of dimensions beyond age and sex in multistate population projections has two major objectives: first, to increase the accuracy of the projected population by capturing the heterogeneity present in the population that could affect the overall system; secondly, and more importantly, to increase the level of information provided by the projections. This article reviews the main dimensions that have been projected in the past, emphasizing global projections of educational attainment, which have been used largely in modeling exercises outside of the demographic realm. Furthermore, we propose some other dimensions that could be projected in a multistate fashion, possibly for most countries.

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Population projections have existed for a very long time. Beyond mere extrapolations, already several examples of population projections were carried out at the end of the 17th century with essays from John Graunt in 1662 (Graunt, 1665) and William Petty in 1682 (Petty, 1984), both projecting the population of London based on innovative statistical methods for their times.[1] In 1699, Sébastien Le Prestre de Vauban projected the Canadian population to 1970 – accurately despite false assumptions (Vauban, 1842). The projections that followed were greatly improved in terms of methodology. The cohort component method[2] (Whelpton, 1928) was developed in the 1920s and is widely used today. Nevertheless, most projections were for a long time not global. They were mostly implemented at the national or sub-national levels by national statistical offices and scientists.

We can speculate about several reasons for that. First of all, the absence of data for the base-year (needing a census or a survey) and for the fertility, mortality and migration components of the projections for a large number of countries, although many countries have been carrying out censuses already since the end of the 19th century. The second reason that might have been limiting the spread of global population projections is the computing capacity and time constraint to carry out the projections. However, most likely, the main reason might have been the absence of "global thinking", which came about with the emergence of the demographic transition theory, formulated in full by Notestein in 1945 but already elaborated by others (see Kirk, 1996). This theory, by assuming a continued global generalization of trends across countries, opened the door for global projections that were first developed by Notestein himself (Notestein, 1945). He became the first director of the United Nations Population Division, which for many decades was the main provider of global population projections. Then other large organizations joined in the production of global population projections, such as the World Bank, the Census Bureau, the Population Reference Bureau and the International Institute for Applied Systems Analysis (IIASA) to name the most prominent ones (see Lutz & KC, 2010 for a summary and timeline of global population projections and O'Neill *et al.*, 2001).

Global population projections are particularly needed for the inclusion of population in assessment models, usually as an exogenous variable, which helps to quantify the impact of the number of humans on other parameters. A relevant example of global population projection use is the work of the Intergovernmental Panel on Climate Change (IPCC), where population enters models that consider the vulnerability of populations to climate change, or that quantify economic activity by sector. Moreover, population being at the center of the development challenges of the coming century, it will affect the progress toward the realization of many sustainable development goals in 2030 and beyond, and therefore requires quantification.

For decades, global population projections have only included the dimensions of age and sex at the country level, mostly because there was no demand for more dimensions. Two research episodes revolutionized this apparent setting. In the 1980s, Andrei Rogers and a team of researchers working at IIASA developed the methodology of regional population projections (Rogers & Land, 1982). The researchers were concerned about taking into account demographic disparities between regions into a single projection model. A few years later, Nathan Keyfitz (1985) formalized the possibility to introduce additional dimensions in the projections, opening the door to a broader application of the multistate methodology. In short, the rational for adding dimensions to the projections follows the same rational as adding age and sex as dimensions in the projections, recognizing that the composition of the population can influence the results of the projection since different people have different demographic behaviour in terms of fertility, mortality, and migration. In other words, by adding granularity, the results of the population projections become more insightful, and secondly the projection results could be more exact by accounting for compositional effects in the projected population.

The multistate projection methodology relies on an extension of the cohort component method of population projection using the Leslie Matrix, as described in Keyfitz (1977) or Wunsch & Termote (1978). In the multistate extension, each Leslie matrix scalars for fertility and mortality are replaced by a matrix in each age group, which includes transitions between states. The transitions are one of the specificities of multistate projections that allow 'movements'

1. Further back in time, Aristotle (384-322 BC) had already understood some of the principles of population projections as shown from this quote: "One would have thought that it was even more necessary to limit population than property; and that the limit should be fixed by calculating the chances of mortality in the children, and of sterility in married persons." (Book II, 1263b.15).

2. In short, the cohort component method divides the population to be projected into sex and age cohorts/groups to which are applied, year after year, different mortality, fertility, and migration rates.

between states within the projection period, e.g. from primary education level to lower secondary level when states relate to educational attainment, or from rural to a urban areas when states relate to place of residence.[3]

In the first section of the paper, we will summarize briefly what dimensions have been projected. This section relies mostly on the literature that has been compiling such work. In the second section, we review the prerequisites to use a particular dimension as developed by Lutz *et al.* in 1998, and argue that some of the criteria could be relaxed and updated. In the third section, we suggest a few dimensions that could be projected and that could satisfy the criteria developed in section 2. In the final section, we discuss some of the challenges that producers of multidimensional projections should be aware of, before concluding.

1. What Have We Projected?

While multistate or multidimensional population projection[4] models are quite well known and well used nowadays, they are rarely implemented at the global level, where unidimensional population projections are still mostly being implemented. In an article in the *Philosophical Transactions of the Royal Society*, Lutz & KC (2010) reviewed some of the dimensions that have been projected at a global level, such as place of residence (e.g. United Nations 2018 for the latest round of projections from the United Nations), household composition (e.g. Habitat, 1996; Ironmonger *et al.*, 2000), educational attainment (e.g. Lutz *et al.*, 2018), marital status (e.g. Kantorová, 2013), religious affiliation (e.g. Pew Research Center, 2015), labor force participation (ILO, 2017 and 2018) and health (e.g. Global Burden of Disease Collaborative Network, 2016).

However, most of the dimensions above mentioned have not been projected in a multistate fashion, meaning that they do not fully model the demographic and dimensional interactions, and rely on a methodology based on prevalence often derived from econometric models (e.g. for labor force participation) or trend extrapolation. This is the case for instance of the United Nations urbanization prospects (United Nations, 2018) that provide population by place of residence up to 2050 for all countries. There are many difficulties in projecting place of residence, primarily because the definition of urban and rural zones is country-specific and changes over time. This brings an additional difficulty for multistate projections that model the mobility between urban and rural areas within the projections. This is also the case for other indicators, such as those related to global projections of poverty (e.g. Manuel *et al.*, 2018).

Projections that attach prevalence rates to existing cohort-component projections usually do so in view of the difficulties to model the dynamic of the system, as mentioned in the case of place of residence. Another reason is that some dimensions are not very stable over the lifetime, as individuals might be mobile between dimensions. This is the case for place of residence but also for health status. Those types of projections usually assume scenarios with stable and changing prevalence/incidence rates over time and across regions, also modeling sometimes the risk factors affecting the dimensions.

The dimensions enumerated above particularly fit the list of criteria developed by Lutz *et al.* (1998) to be used to include a particular dimension in a projection, beyond age and sex. They were of three sorts:

1) The dimension should be "interesting in its own right and therefore desirable as an explicit output parameter" (Lutz *et al.*, 1998 p. 42), giving precious information to the projection user. For instance, the number of one-person households, based on several dynamics such as patterns of divorce and leaving parental home, is an appealing parameter.

2) The dimension should be a source of demographic heterogeneity. It means that the fertility, mortality, and migration patterns of individuals should vary along that particular dimension. It is for instance the case with place of residence where the fertility of urban women tends in most cases to be much lower than that of rural women. This is linked to women's wider access to many resources such as family planning, education and health services, that would have a deterrent effect on their fertility, while at the same time adding constraints in terms of space availability to raise large families. Particularly, in low-income countries, the changing pattern of the differences will influence the future fertility depending largely on the urbanization rate. Impact of place of residence can also be found on mortality and on international migration. Education has also been

3. For a summary of the multistate methodology, see for instance Rogers (1981) or the Technical Note 1 in Goujon & Wils (1996).

4. In this paper, we do not differentiate between multi-dimensional and strict multistate projections (and use both terms interchangeably) where transitions between dimensions or states are either expressed as respectively probabilities or rates. We understand that the choice of one or the other will impede on the results, but this is not the purpose of the paper. Instead, we consider all population projection models where the population is decomposed further than by age and sex along one or more dimensions.

shown to have a large impact on demographic determinants, most of the time a negative effect on fertility, mortality and a rather positive effect on migration. The demographic heterogeneity introduced by the dimension, when taken into account, will have an impact on the dynamic of the system. For instance, Goujon & McNay (2003) and KC *et al*. (2018) have shown in the case of India the large impact of the granularity of the data in terms of state or place of residence and education.

3) While the first two criteria refer to the rationale behind adding a dimension to population projections, the third one is more practical and relates to the feasibility in terms of data availability (population, fertility, mortality, migration for each dimension, and transitions between the dimensions) and tools. Multistate population projections softwares have existed for some time: LIPRO,[5] which was developed originally for household projections[6] by the Netherlands Interdisciplinary Demographic Institute (NIDI), can also be used for a wide range of calculations in multistate demography. Additionally an R-package (MSDEM) is available for subnational multistate population projections.[7]

2. Population Projections by Levels of Education

Population projections of educational attainment are a rare case of global multistate population projections. They have been primarily developed at IIASA, starting with a first case study in the Mauritius Island (Lutz, 1994), followed by several applications at the national and regional level (e.g. Wils, 1996; Yousif *et al*., 1996; Goujon, 1997). In 2001, Goujon & Lutz (2004) projected for the first time population and education globally, for the world divided in 13 world regions. In 2010 were produced the first projections for a large number of countries, i.e. 120 countries, and four levels of educational attainment, to 2050 (KC *et al*., 2010). The number of countries was further increased to 171 in 2015, together with an increase in the number of categories to six, and a longer projection period up to 2100 (Lutz *et al.*, 2014). The latest update was published in 2018 (Lutz *et al*., 2018; WIC, 2018[8]). The dataset now contains some 185 countries that comprised 99% of the world population in 2015. In the two latter exercises, the scenarios are based on both modeling and expert assessment about the future of fertility, mortality, migration, and education.

The assumptions about the projection are derived in two main steps (Lutz *et al*., 2014). First, expert opinion and models are used to derive the assumptions for the projection parameters overall, not taking into consideration levels of educational attainment, i.e. country level total fertility rates and age specific fertility rates, gender specific life expectancies and age and sex specific survival ratios, in and out migration rates and age and sex specific migration schedules. Country-specific education differentials are then obtained in a second step. For fertility, fertility levels by education for the base-year were obtained from the literature and from census and survey data. Countries with no available data were assumed to have the average fertility differentials of all countries from the broader region to which they belong. Education differentials are assumed to converge over time to certain ratios of TFRs for the different education levels relative to post-secondary education.[9] These values are assumed to be reached by the time TFR reaches 1.8 children per woman. For countries where the maximum differential is below 1.42 in the base-year, the relative ratios are then kept constant at those lower levels. The convergence hypothesis follows the literature showing that, in high-income societies, differentials become smaller in absolute and relative terms. Jalovaara *et al*. (2018) found that among the highly educated societies of Denmark, Norway and Sweden, there are almost to no differentials in the ultimate fertility of women between education categories[10] (see also Beaujouan & Berghammer, 2019).

For mortality, gender-specific education differentials in life expectancy at age 15 are standardized following findings in the literature. The difference in life expectancy at age 15 between the ‘No education’ category and the ‘Post-secondary educated’ population is assumed to be of six years for men and four years for women. Between these extreme points, a two-year difference is assumed between men with a completed primary and a completed lower secondary, and a one-year difference for the remaining levels of educational attainment. For

5. https://www.nidi.knaw.nl/en/research/al/270101 [accessed on 15/7/2019]
6. ProFamy is another existing software for projections of households and living arrangements available at http://profamy.com.cn/en_about.asp [accessed on 29/10/2019].
7. https://r-forge.r-project.org/R/?group_id=2281 [accessed on 15/7/2019]
8. The detailed dataset is available at http://dataexplorer.wittgensteincentre.org/ [accessed on 15/7/2019]
9. The ratios are 1.42 for women with no education, incomplete primary and completed primary education (≤ ISCED 1), 1.35 for women with lower secondary education (ISCED 2), 1.14 for women with upper-secondary education (ISCED 3), and 1 for women with post-secondary education (ISCED 4+) which is the reference category.
10. Interestingly, while highly educated mothers in Nordic countries reach more often higher birth rates at parity 2 and 3 compared to less educated ones, their completed fertility is nonetheless often slightly lower than that of women with less education, due to the later start of their childbearing career (Andersson et al*., 2009).*

women, the differential between the lowest and the highest education category is four years of life expectancy and proportionally split between education levels following the male division. The differentials are kept constant throughout the projection period. Finally, for children up to age 15, differential mortality is introduced through mothers' education.[11] For migration, where the lack of data on the characteristics of migrants is notorious, it is assumed that the education composition of migration flows is equal to that in the origin country.

The system is dynamic through a set of educational transition rates between education categories that are derived from national time series for all countries. These transitions occur between the ages of 15 to 34 years, considering that few people advance to a higher level of education after the age of 35. Because the model does not link individuals with their ancestry, the education transition of children does not depend on the education levels of parents.[12] These limitations among others are discussed in the penultimate section.

The main characteristics of these projections is that as mentioned above, when education is factored in, they tend to result in lower population growth than projections by age and sex. It is the main difference with the United Nations projections that lead to a world of 10.9 billion in 2100 in the medium variant (United Nations, 2019), compared to 9.3 billion according the trend scenario including the education dimension (WIC, 2018). This latter scenario also shows that most of the increase will occur at the level of the population with an upper- and post-secondary education level. This would mechanically affect fertility, which is overall much lower for the most educated categories (Figure I). For instance in Ethiopia in 2014-2016, the total fertility rate of women with no education or a primary education is 5.0 children compared with 2.1 children for those women with a secondary or higher education (according to the Demographic and Health Surveys[13]). While the scenario assumes that the differential gets smaller, in absolute terms, over the projection period, the momentum linked to large differentials has substantial consequences on the total population trends.

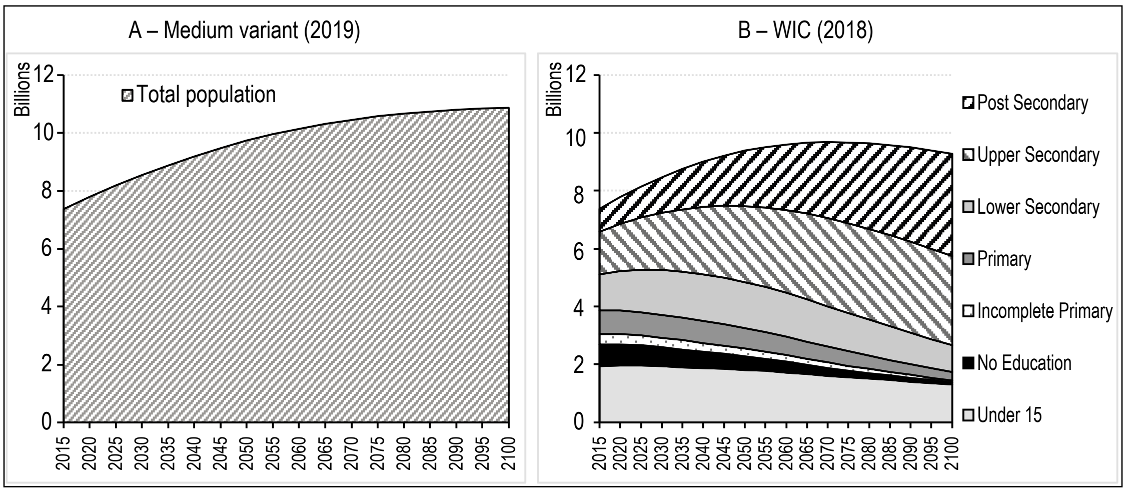
The projections of educational attainment have been applied by the modeling communities of the IPCC who have utilized the different scenarios to assess the relationships between socioeconomic development and climate change (KC & Lutz, 2014) and the role of education to reduce vulnerabilities and increase resilience (UNDP, 2014). They have also been employed to model the potential economic effect of future education paths in low-income countries (Basten & Crespo Cuaresma, 2014) and to model in general the link between education and economic growth (Lutz *et al.*, 2008). More recently, researchers have looked at the impact of education, particularly of women, in mitigating the labor market

11. The differentials in terms of relative ratio of mortality rates with respect to the completed upper-secondary category are 1.8, 1.7, 1.6, 1.4, 1.0 and 0.8, in ascending order of educational attainment – no education, incomplete primary education, completed primary education, completed lower secondary education, completed upper-secondary education, post-secondary education. These values are based on the averages of under-five mortality rates in the countries where Demographic and Health Surveys have been conducted.

12. In the framework of projections for 13 world regions, Goujon & Lutz (2004) calculated a scenario in which they incorporated a feedback from the level of education of mothers to the enrolment ratios for girls. This self-reinforcing mechanism has a positive impact on average levels of education but might also increase the dichotomy between the lowest – with little chance of moving up – and highest educated in the society.

13. Data from Demographic and Health Surveys *are available here: https://dhsprogram.com/ [accessed on 24/10/2019].*

Figure I – **Projections of the total world population by the United Nations**



Sources: United Nations (2019) and WIC (2018).

consequences of population ageing in the countries of the European Union (Marois *et al.*, 2019).

Although the strength of the dataset on educational attainment is that it relies on the collection and harmonization of existing data on education, one clear disadvantage is that it does not take into account the quality of education, which has been demonstrated to be very different across countries and also within countries for instance by Hanushek & Wößmann (2012). This requires further research in terms of data and modeling. In addition, the projections do not take into account constraints in terms of budget, infrastructure or work force associated with the development of education.

3. What Other Dimensions Have We Not Projected?

The above mentioned list of criteria that was developed to consider a particular dimension in multistate projections, and most notably to justify the inclusion of educational attainment (Lutz *et al.*, 1998) could be partly revised to increase the possibility of including more dimensions in the projections, especially when considering the impact outside the realm of demography. Indeed, that would be the case when a dimension is interesting and is a source of heterogeneity with an impact on the dynamics of the whole system, not necessarily related to demography heterogeneity as stated in the second criteria.

We develop below a list of potential dimensions that could be integrated into global population projections. We have restricted our list to dimensions that could be of interest at the global level – meaning not only for a specific population or for a country or region of the world – and that have not yet been projected at the global level, to the best knowledge of the author.

The rationale for selecting these particular dimensions is based on the following considerations:

- Their timeliness: these dimensions and related issues are present in the public debate and in the political agenda at the international level.
- Their generational (and gendered) features: as stipulated by the demographic metabolism theory (Lutz, 2013), societies change through generational replacement. The dimensions considered tend to be "sticky" along cohort lines, as for instance exemplified by studies and projections of the prevalence of a feeling of European identity in the European Union, and of changing attitudes towards homosexuality (Striessnig & Lutz, 2016a and 2016b).

There are some limitations to the proposed list of dimensions. First, this list does not pretend to be exhaustive and probably many other dimensions could be included. While these dimensions are interesting and their projections could inform about the potential consequences of some dynamics, they could also be seen as less robust as other dimensions such as education or place of residence. They are data intensive if one aims for global coverage and data availability has not been checked for all countries. Moreover, we do not develop in this paper the methodology that would be needed for the multistate population projections of these dimensions as such, assuming that they would be derived from the multistate methodology where most of the modeling needed would be about deriving the transition rates between the suggested states/dimensions.

3.1. Diet

The dimension what earth inhabitants will eat in the future is key to many factors affecting sustainable development. In this area, whether people have access to sufficient food is important.[14] However, beyond the adequacy of food supply, different nutrition behavior could be of importance and determine the ability of humans to live within the planetary boundaries (Rockström *et al.*, 2009). The share of the population that will adopt diets that are less rich in dairy and meat products such as vegan, vegetarian, or flexitarian diets has been shown to potentially have a significant impact on reducing the greenhouse gas emissions especially at the level of industrialized countries (Sandström *et al.*, 2018). Hence, dietary change could be an important tool "to limit global warming to less than 2°C, while providing a nutritious diet to a growing and changing world population" (Aleksandrowicz *et al.*, 2016, p. 1). While several studies have looked at what would be the impact of several dietary changes affecting climate change and the achievement of the Sustainable Development Goals, very few have considered how the propagation of dietary changes could happen in the population. This is particularly important because it is linked to individual characteristics such as age, gender, and possibly other background characteristics such as country of origin, place of residence, education and religion among others. It is also especially relevant for population projections because the changes will most likely follow a diffusion process across cohort lines, for instance

14. It is part of sustainable development goal 2: "End hunger, achieve food security and improved nutrition and promote sustainable agriculture".

from the rather young and more educated to the rest of the population.

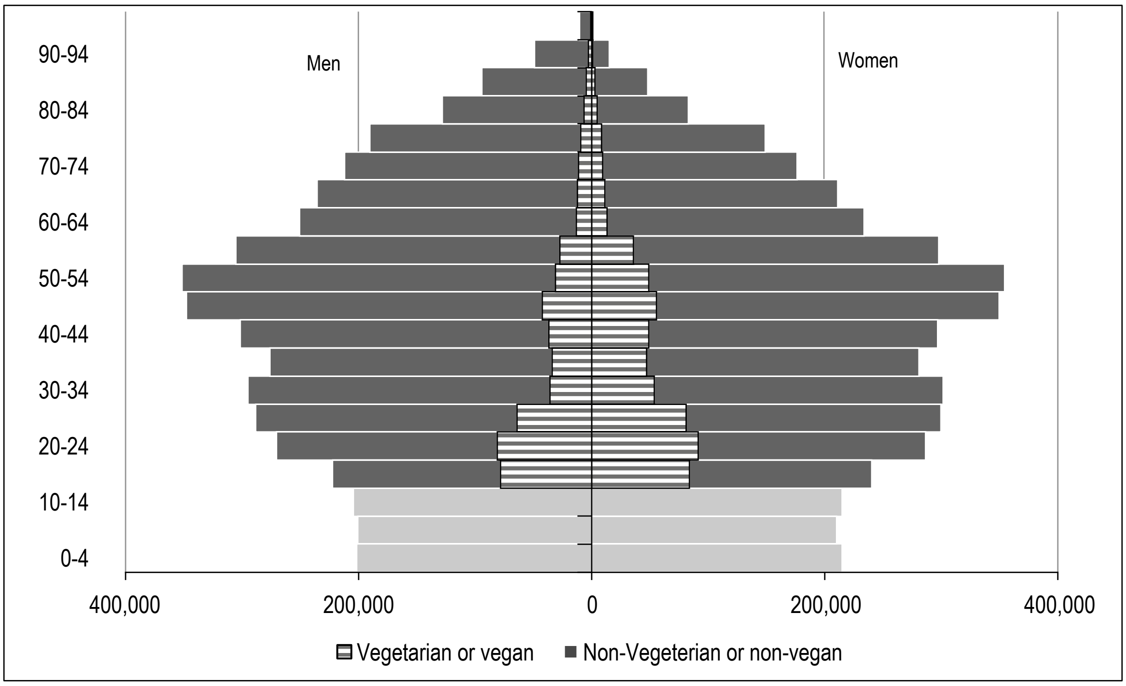
It would also be interesting to see what could be the impact on the demographic behavior. It has been shown for instance that vegan women suffer more often from amenorrhea when they do not supplement with vitamins such as B12 (Wokes *et al.*, 1955). It could also influence fertility for more environmentally concerned people, who often adopt a no- or less-meat diet and who are likely to want a small number of children (Arnocky *et al.*, 2011). The effect on fertility could be also mediated by other factors such as education, although the evidence is mixed on this topic (Allès *et al.*, 2017; Moreira & Padrão, 2004). The impact on mortality could also be substantial by reducing the prevalence of obesity and cardiovascular diseases in the population (Springmann *et al.*, 2018) and of some cancers associated with meat consumptions (Springmann *et al.*, 2016). All these phenomena would be interesting to consider in global population projections, also considering that several datasets on household expenditure surveys detail all the expenditures incurred by a large sample of individual households over a specified period (Leahy *et al.*, 2010), i.e. World Bank's Living Standard Measurement Studies (LSMS). The information is also available for some countries at the individual level, see for instance the estimates of the vegan population by age and sex shown in Figure II.

3.2. Language

While the implications of spoken languages might seem trivial in view of the potential challenges faced by the world population within the next century, it has some important implications at national or sub-national level. Size and concentration of language communities determine linguistic power, which in turn will influence the political power of those communities (Hung Ng & Deng, 2017). This can be seen in Canada (French and English), Belgium (Dutch, French and German) or in China (Mandarin, Cantonese and other languages such as Tibetan, Mongolian, etc.). Spoken languages will be influenced by the demographic vitality of the population speaking it. Internal and international migration would also play a major role in influencing this. While there is, evidently, no causal link between spoken language and demographic behavior, the variable of interest itself will be affected and can be projected using, implicitly or explicitly, other dimensions to determine the potential assumptions about the future demographic behavior of populations according to different languages. For instance, if Arab-speaking women in Israel were for a long time bearing more children than Hebrew-speaking ones in the rest of the country,[15] it is evidently not directly related to

15. *This trend has been reversed in 2016 according to the Central Bureau of Statistics. While in 2002, the TFR of Arab women was 4.19 and that of Jewish women 2.64, in 2016, it is respectively 2.11 and 3.16. See https://old.cbs.gov.il/www/publications/lidot/lidot_all_1.pdf [accessed on 57/2019].*

Figure II – **Estimated dietary preferences by age (from 15 years old) and sex in Austria in 2013**



Sources: Author's calculation based on Institut für Empirische Sozialforschung (2013).

the language but rather to the socio-economic conditions present in the region where these populations are concentrated on top of the political situation. While some researchers have been conducting language projections (e.g. Houle & Corbeil, 2017 and Sabourin & Belanger, 2015, for Canada; Ortman & Shin, 2011 for the United States of America), projections have not been carried out globally to see for instance the vitality of some languages (English or Chinese) as first or spoken languages for instance. Enumeration of population by languages is present in most censuses, whether they list native languages, home languages, and often the knowledge level of those languages, see for instance the distribution of the population in Finland by native language, at two points in time (Figure III). It is worth noting that the share of population whose native language is other than Finnish, Swedish and Sami has been noticeably increasing since 2000, particularly among the younger cohorts.

3.3. Political Allegiance and Ideology

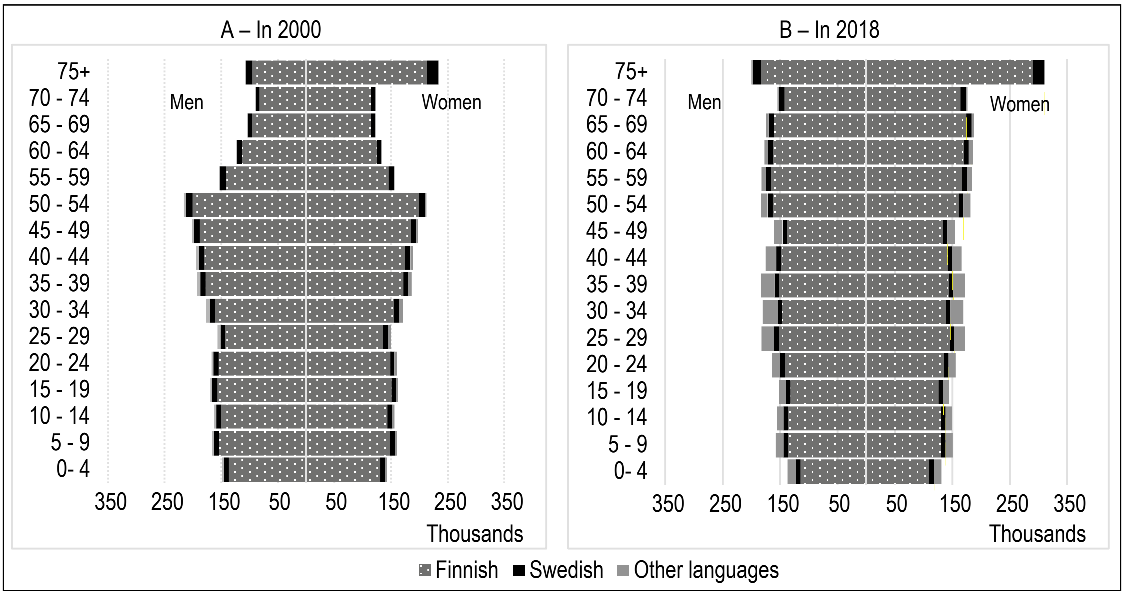
Few works have investigated the impact of differences in demographic behavior on socio-political variables, and even more so in a prospective manner, one exception being the work by Kaufmann *et al*. (2010) (Figure IV). However, in many societies, the tendency is for the electorate to cast increasingly their votes for populist parties (see Figure V). Research carried out for *The Guardian* estimates that the number of Europeans living under governments with at least one populist in cabinet has increased 13-fold between 1998 and 2018.[16] There are interesting demographic features about the voting behavior related, for instance, to age, gender (Harteveld *et al.*, 2015) and socio-economic characteristics (Rooduijn, 2018) especially education and place of residence, that could influence the future. Moreover, intergenerational transmission of ideology from parents to children (Jennings & Niemi, 1981; Abramowitz & Saunders, 1998; Jennings *et al*., 2009; Murray & Mulvaney, 2012) provides supplementary ground to study the dimension in a multistate manner in the sense that there is some stability in the system and less volatility than could be expected. Kaufmann *et al* (2010) present the rationale for projections of political ideology (distinguishing between liberals, moderates and conservatives) in the context of the United States of America, by stating that “if party allegiances are enduring and formed in early adulthood, much of the story of future American partisanship has already been written.” (p. 12). However, it is not meant that the ideologies of the future depend solely on the demographic behavior of the population. “Pressures of the times” for young voters who first enter the electorate (Beck & Jennings, 1991, p. 742) and throughout their life time will also have an influence on determining the political ideology at the individual level.

3.4. Childlessness and Grand Childlessness

While many household projections exist and have looked at the composition of the households, few

16. *https://www.theguardian.com/world/ng-interactive/2018/nov/20/revealed-one-in-four-europeans-vote-populist [accessed on 17/7/2019]*

Figure III – **Population of Finland by age, sex and native language**

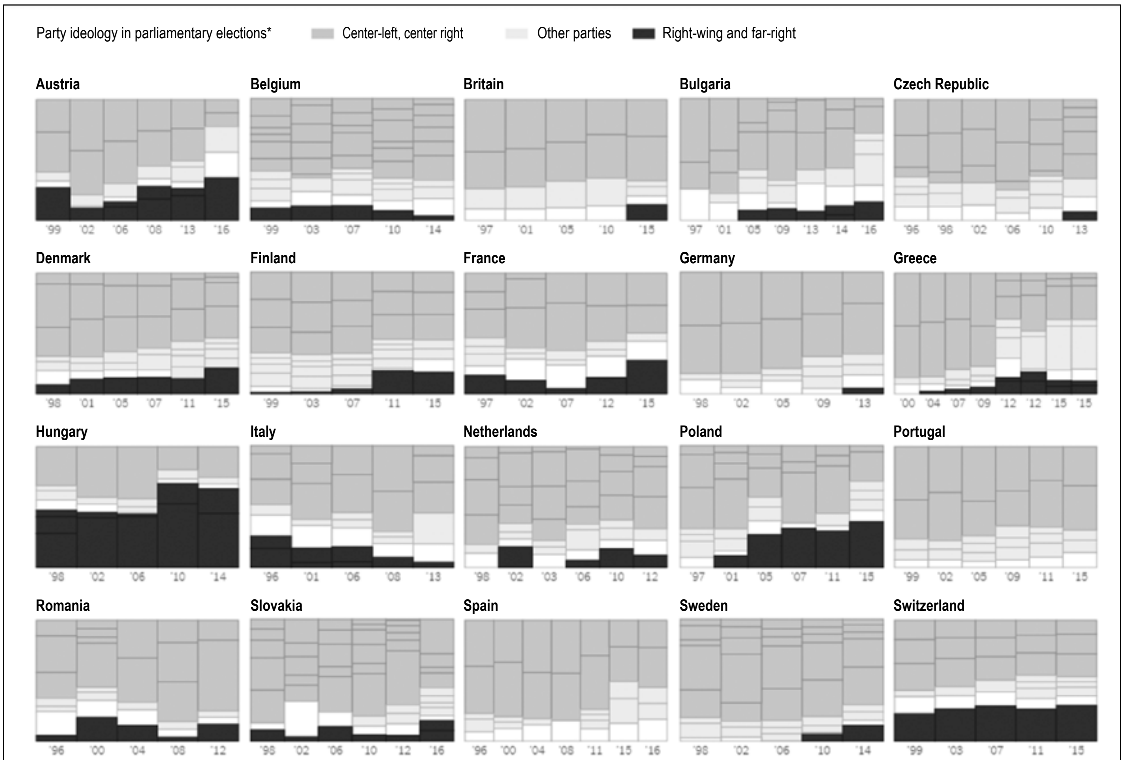


Sources: Author’s calculation based on Population by age, sex and language, Statistics Finland (2018).

Figure IV – **Population pyramid of political allegiance in the United States, estimates (2003) and projections (2043)**

Notes: Children under age 21 inherit the political allegiance of their parents.
Sources: Kaufmann *et al.*, 2012 based on US General Social Surveys (2000-2006).

Figure V – **Party ideology in parliamentary elections, 1990s to 2010s, selected European countries**



*The 2016 presidential elections in Austria and Bulgaria and the 2015 French regional elections are included to add a more recent result for those countries.

Sources: New York Times (2016).
https://www.nytimes.com/interactive/2016/05/22/world/europe/europe-right-wing-austria-hungary.html

have looked at the changing repercussions of some recent trends across cohorts and generations. One interesting example of that is levels of childlessness that have been increasing in recent decades in Europe and in the Global North. It is particularly acute in Austria, Germany and Switzerland that are forerunners regarding this phenomenon, with more than 20% of women without children at the end of their reproductive career (Kreyenfeld & Konietzka, 2017). The occurrence of childlessness is spreading to other countries, first in Northern Europe, but also to Southern and Eastern Europe, and to East Asia.[17] Regardless of the causes explaining the absence of children into a man's or woman's life, this is likely to have consequences over their life course, particularly when they reach old age,

17. *Childlessness is also on the increase in almost all world regions (United Nations, 2015).*

missing that potential support. On the other hand, it is possible that elderly people do have children who do not have children themselves, therefore missing the experience of grand-parenting, which has implications in terms of not having descendants[18] (Margolis, 2016). This dimension could be studied along cohort lines as shown in Figure VI.

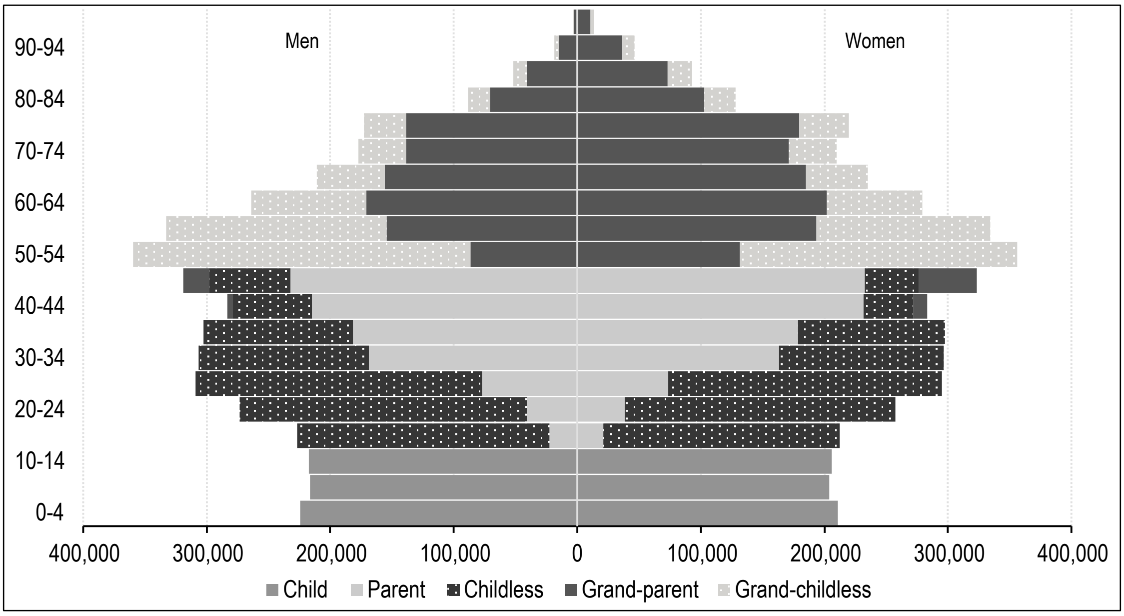
4. Potential Issues with Multistate Population Projections

Certain issues need to be considered when implementing multidimensional projections. First, a balance has to be reached between the number of variables that are necessary to improve the population projections results and the assumptions that will need to be made if more dimensions are considered. Indeed, with each additional dimension come a number of assumptions that have to be provided, related to the behavior of individuals in terms of fertility, mortality and migration. The availability of data for the base-year could become a limitation, especially when multiple dimensions are taken into consideration, e.g. education, place of residence and regions. While one can always revert to the assumption of no differentials in the absence of data, e.g., people in dimension 1 have the same fertility as those in dimension 2 and more, it would hamper the validity and relevance of the projections. Therefore, in developing multistate population projections, researchers need to use common sense to decide on the number of states. A possible compromise is to model the dimensions with existing data and a theoretical model and apply/model other population characteristics using prevalence rates without entering the projections as categories which, as we have shown, is being implemented in many forecasting exercises, e.g. projections of labor force participation based on multi-state projections of educational attainment (Loichinger & Marois, 2018).

Moreover, scenarios also model the relation between the chosen dimensions and the demographic determinants in the future, whose evolution can differ from what was observed in the past or in the present. For instance, as much as levels of educational attainment were and are a factor of heterogeneity explaining substantial parts of the changes in fertility across different countries, it is difficult to know what the role of education will be in the future, and what influence it will have on demographic behavior, assuming that most societies would be knowledge societies where information and knowledge would be the most important factor of production. Even when education still plays a major role, it will most likely not be the same education, as we

18. *Lineages without descendant disappear. As a result, people who have children but no grand children cannot become a numerically important category in the population. Especially when the variance of the number of children is low.*

Figure VI – **Hypothetical representation of childlessness and grand-childlessness by age and sex, in Austria in 2019**



Notes: The data presented on the graph are not real except for the age and sex structure of Austria in 2019. The distribution of the population between the different categories is simplified, assuming for instance that parenthood would be happening only between the ages of 15 to 49 years.
Sources: Author's concept.

understand it nowadays. In that sense, whether by adding granularity the results of the multistate population projections become more accurate depends highly on the ability of the model to predict changes in the link existing between the dimension and the demographic determinants. This caveat could be seen as deterrent to using multistate projections. However, we claim that it provides an opportunity to explore the sensitivity of the projections to different patterns of change of the relationship between the dimension and the demographic behavior of individuals along that dimension.

Not unrelated to the previous matter, the other challenge to be considered is that of causality that is underlying the projections at all time. While including the dimension in the projections influences the result because the dimension is a factor of heterogeneity, it does not necessarily mean that the dimension influences the demographic determinant in a causal way. A good example of that is the case of population projections of religious affiliation. In Europe, Muslim women's fertility is higher than that of Christian women for instance; however, this is not necessarily a direct effect of the religious affiliation but rather of the socio-economic background of these women within the different affiliations. When implementing a scenario, its interpretation has to be carefully formulated. Lutz & Skirbekk (2014) observe that "the assessment of causality in the social sciences is context-specific" (p. 18). They develop the idea that strong causality in intervention sciences, aimed at understanding "how the most important forces of change function in order to predict the future evolution of the system" (id., p. 18), is rather difficult to establish. On the other hand, social scientists should strive for functional causality – which differs from strong causality – that entails "strong empirically observed associations", supported by "plausible narratives about the mechanisms", and the elimination of "other obvious competing explanations" for the association observed between two factors (id., p. 19). They further show that, in that way, functional causality can be demonstrated from higher education to lower mortality and fertility "at least over the course of the demographic transition" (id., p. 28).

Another issue with multidimensional population projections models is the need to ensure consistency both internally (e.g. the problem of genders with projections of marital status) and externallly (e.g. when regional population projections should add up to national projections). Several algorithmic solutions exist to adjust each demographic component in order to minimize deviations (Keilman, 1985). Other research has looked at the issue of coherence particularly related to the modeling of future mortality patterns using the fact that differences between closely related populations are unlikely to increase in the long term. Therefore, projections of mortality (or of other determinants) for a sub-region or a sub-group could be improved by taking into account the patterns of a larger group (Li & Lee, 2005).

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The field of multidimensional projections is a thriving one. It is particularly active regarding education that has been projected in all kind of contexts and is used more and more in the global context as a proxy for development level, autonomy of women, and innovative and adaptive capacity. There are reasons to expect that the characteristics/dimensions of human beings will be interesting to project in a world that is keener on information about the future. It is also likely that studies about the future population will take more and more advantage of the availability of big data that could shed some lights on human behavior.

Like classical cohort-component projections, multistate population projections are more than forecasting tools as such, since they offer a tool to explore the future based on future assumptions looking at different scenarios based on "what if" narratives. In this sense, these scenarios look at the sensitivity of the projections to different assumptions. What those projections add to classical cohort-component projections is the influence and sensitivity of dimension that can be of importance for the projections itself. ☐

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