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Working paper

Three Demographic Theories with Predictive Power: Demographic Metabolism, Demographic Transition, and Demographic Dividend

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Abstract

The discipline of demography has an ambivalent relationship to theory despite of the widely acknowledged view that every self-respecting scientific discipline needs to have a body of foundational theories. Based on Popper's definition of a theory as containing predictive power and the definition of demography as studying changing population size and structures, this paper considers as demographic theories in the strict sense of these definitions theories that can predict population size and structures, i.e. focus on macro-level outcomes. The theory of demographic metabolism (a notion introduced by Norman Ryder) captures the essence of social change through cohort replacement in addition to transitions over the life cycle of cohorts and can deliver quantitative predictions in the context of multi-dimensional demographic modelling. The theory of demographic transition is the oldest and most prominent demographic theory, although its predictive power is limited to its irreversibility. Finally, the theory of a demographic dividend has probabilistic predictive power through the prediction that a relative increase of the more productive proportion of a population increases the chance of economic growth and improvements in wellbeing generally. In a final effort these three theories are combined towards a Unified Demographic Theory.

About the author

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Acknowledgments

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Introduction

Demography, as a scientific discipline, has a complex relationship with theories. While it is precise in measurement and modeling, there is no clear consensus on the most important demographic theories. Some argue that demography does not need theories, while others view models like the life table as theories in themselves. This paper aims to define and discuss three key demographic theories—demographic metabolism, demographic transition, and demographic dividend—and work toward integrating them into a Unified Demographic Theory.

Currently, we observe an increase in interest in demography, particularly in low fertility countries. While a few decades ago, hardly any journalist knew what demography was, today they write about demographic challenges almost on a daily basis. But as the interest in demography rises, the discipline itself seems to suffer from an identity crisis. Already Nathan Keyfitz (1984) noted that demography was retreating from its own domain, allowing economists, sociologist, and other disciplines to take over key demographic questions. Ron Lee (2001) argued that demography was losing its core in formal macro-level demography, and many demographers tend to associate themselves with other established scientific disciplines. More generally, Schofield and Coleman (1986) begin their book on the state of population theory with the sentence that “Any subject which finds it necessary, or indeed possible, to consider its material divorced from an appropriate body of theory must be in trouble” (p.1). Thus, demography seems to be in trouble. This is why this paper makes the ambitious effort to define a comprehensive theoretical foundation of the disciple. Even tough not every demographer may agree with the views presented, it hopes to trigger a new discussion about demographic theories and contribute to strengthening the discipline.

What Is a Demographic Theory?

Defining a demographic theory requires first clarifying what is meant by “theory” and then specifying the meaning of the adjective “demographic.”

The Cambridge Dictionary broadly defines a theory as “a formal statement of the rules on which a subject of study is based or of ideas that are suggested to explain a fact or event or, more generally, an opinion or explanation” (Cambridge Dictionary, 2025). However, this definition does not distinguish a well-founded scientific theory from an informed opinion. In modern philosophy of science, the dominant approach—often labelled as critical rationalism—stems from the work of Karl Popper (1959), who asserts that scientific theories must be falsifiable and capable of making predictions that could potentially be disproven. This paper adopts that definition, emphasizing that a key characteristic of a scientific theory is its testability. Thus, a theory, to be testable, must have predictive power.

In the social sciences, the notion of theory is not only used in terms of predictive capabilities but also for explanatory and descriptive power. Many so-called theories retrospectively explain known phenomena or just provide classifications, but under the strict criterion of predictive power, they do not qualify as scientific theories (Lakatos, 1978; von Wright, 1971)[1]. Unlike more qualitative social sciences and the humanities, demography, as a quantitative discipline, benefits from measurable variables, making it easier to specify and test predictions.

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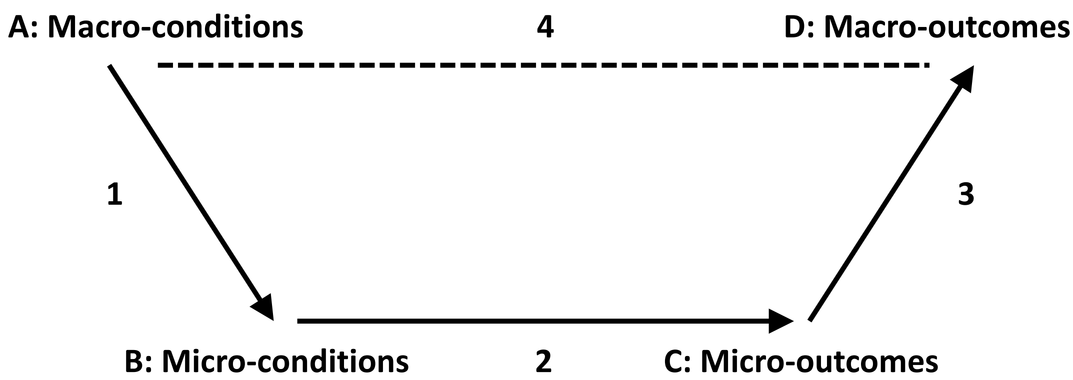
[1] Although Karl Popper to my knowledge never wrote explicitly about theories in demography, I had the opportunity in 1984 to discuss the topic with him over a cup of tea in his house outside London. Some of the views expressed here reflect this discussion.

What, then, qualifies for the label “demographic”? Demography is traditionally defined as the “scientific study of changing population size and structures.” The term “structures” is explicitly plural, implying that demography encompasses more than just age distributions. Foundational textbooks, such as the monumental Methods and Materials of Demography by Shryock and Siegel (1976), explicitly refer to age, sex, residence, education, labor force participation, and race/ethnicity as key demographic variables that are typically collected in censuses. While demographic change is often equated with shifts in age structure alone, a broader perspective—reflected e.g. in media discussions about the changing demographics of the electorates of certain countries—also considers these further demographic dimensions such as ethnicity, education, and place or residence. Multi-dimensional demography (Keyfitz, 1980; Lutz, 2021) thus focuses on how populations evolve across these multiple characteristics.

Like the social sciences in general, demographic analysis also needs to pay attention to processes both at the individual and aggregate level. This has been prominently highlighted by Coleman (1987) pointing at the interactions between these two levels (see Figure 1). In demography, micro-level choices and events over the individual life cycles—influenced both by micro- and macro-level conditions—lead to micro-level outcomes (e.g. births) which then aggregate up to population level birth rates and together with other demographic forces to changing population size and structures. And by its very definition, the key focus of demography is on those macro-level outcomes. Thus, while analyzing individual-level transitions over the life course is essential for understanding the drivers of the changes, in the end a demographic perspective should bring it back to aggregate-level structures. Etymologically, “demography” derives from the Greek “demos,” referring to the collective population as opposed to the individual (“idiotes”), and “graphein”, meaning to write or record. This linguistic origin clearly denotes demography’s macro-level orientation.

Figure 1: Schema of “Coleman ship” linking micro and macro level



Source: Lutz (2021)

Thus, when considering predictive power in demography, it is important to distinguish between statements at the individual level (as operationalized by micro-simulation or agent-based models) and those at the level of populations (resulting from the sum of individual trajectories). At the macro-level one can further distinguish between predictions of individual demographic components—such as fertility, mortality, and migration—and those that combine them to address “changing population size and structures”. There are numerous theories trying to predict the individual components. But under the strict definition of demographic theory applied here, the term “demographic” will only be used for theories that address aggregate changes in population size and structures rather than those explaining isolated components, which could be labelled as partial demographic theories.

What then are the demographic theories that meet these strict criteria of having predictive power for aggregate level changes in population size and structure. The author has so far only identified three such theories from the literature. And it happens that they all have the term “demographic” in their names: Demographic Metabolism (DM), Demographic Transition (DT), and Demographic Dividend (DD). In the following sections they will be described in more detail and with a specific focus on the question whether they indeed have predictive power. Unlike DT and DD that have been widely discussed in the demographic literature over the past decades, DM has until recently received much less attention and many demographers will still be unfamiliar with it, despite the fact that it was already introduced by Norman Ryder in 1965 (Ryder, 1965). For this reason, it will receive more space here than the two other theories and will be illustrated with two applications.

This list of three demographic theories does not claim to be exhaustive, but the author could not think of another one that meets the strict criteria as outlined. Proposals for further theories that meet these criteria are welcome.

The Theory of Demographic Metabolism (DM)

Demographic metabolism captures the very essence of the demographic approach in directly addressing the mechanisms by which population structures change as cohorts with multiple characteristics move up the age pyramid. It models and predicts how societies evolve through intergenerational replacement. If younger cohorts differ significantly from older ones in key characteristics that are formed early in life and maintained throughout adulthood, the theory provides strong predictive power for social change in a broader perspective.

The concept of demographic metabolism is rooted in a long intellectual tradition. Ancient Greek and Confucian philosophies recognized the role of generational succession in societal change. In modern times, art historians of the late 19th century observed that shifts in artistic styles resulted from the replacement of older generations of artists by new ones (Dilthey, 1900). Karl Mannheim (1952) provided the first comprehensive social science synthesis of this generational perspective, distinguishing between “biological” (i.e. demographic) and “romantic” (i.e. ideational) aspects of historical change through the replacement of generations.

In demography the concept has been implicit in most models of population dynamics including the cohort-component approach introduced by Cannan (1895) and Leslie (1945) and further developed by Keyfitz (1968) and Coale and Demeny (1966). The concept of demographic metabolism was explicitly described by Norman Ryder in his influential 1965 paper, “The Cohort as a Concept in the Study of Social Change” (Ryder, 1965). There he introduced the term and described demographic metabolism as the continuous process of social transformation driven by the births, lives, and deaths of individuals. Ryder’s original framework viewed demographic metabolism as deterministic, assuming that cohort characteristics remain fixed throughout life. Under his assumption that individuals have no flexibility to change, the only way for society to renew itself is through generational succession. This view culminated in the striking statement that “a society where members were immortal would resemble a stagnant pond” (Ryder, 1965 p. 844).

Possibly because of this rather extreme view of complete cohort determination, the concept of demographic metabolism as introduced by Ryder was not picked up in demographic research until it was integrated with the model of multi-dimensional mathematical (multi-state) demography which allows also for transitions from one state to another over the life courses of individuals in addition to cohort replacement. This multi-state model as developed in the 1970s by Rogers, Keyfitz and others is based on a generalization of the life table with increments and decrements and a Markov chain model in which probabilities of transition to another state are only defined by the presence in the current state. Also, age-specific fertility and mortality rates are state-specific. i.e. they can differ from one state to another. This multi-dimensional demographic model thus allows for the numerical operationalization of Ryder's basic idea of cohort replacement in combination with state transitions over the life course. Because of its ability to predict future population size and structures under consistent sets of assumptions, Lutz (2013) labeled it as "Theory of Demographic Metabolism". As will be illustrated in the following examples, this combination of intra-cohort transitions and inter-cohort changes makes the model widely applicable for predictions of social change even beyond traditional demographic analysis.

While the basic structure of the model of DM is true by definition for past, present and future conditions, the specific predictions that can be tested are also based on numeric assumptions whose validity can be assessed. This will first be shown for the case of back- and forward projecting educational attainment distributions. The second example goes far beyond the substantive field of demography by using the DM model for predicting future levels of national versus European identity. Here the testing also involves the validation of the appropriateness of the DM model as compared to simple trend extrapolation or qualitative thinking about future trends.

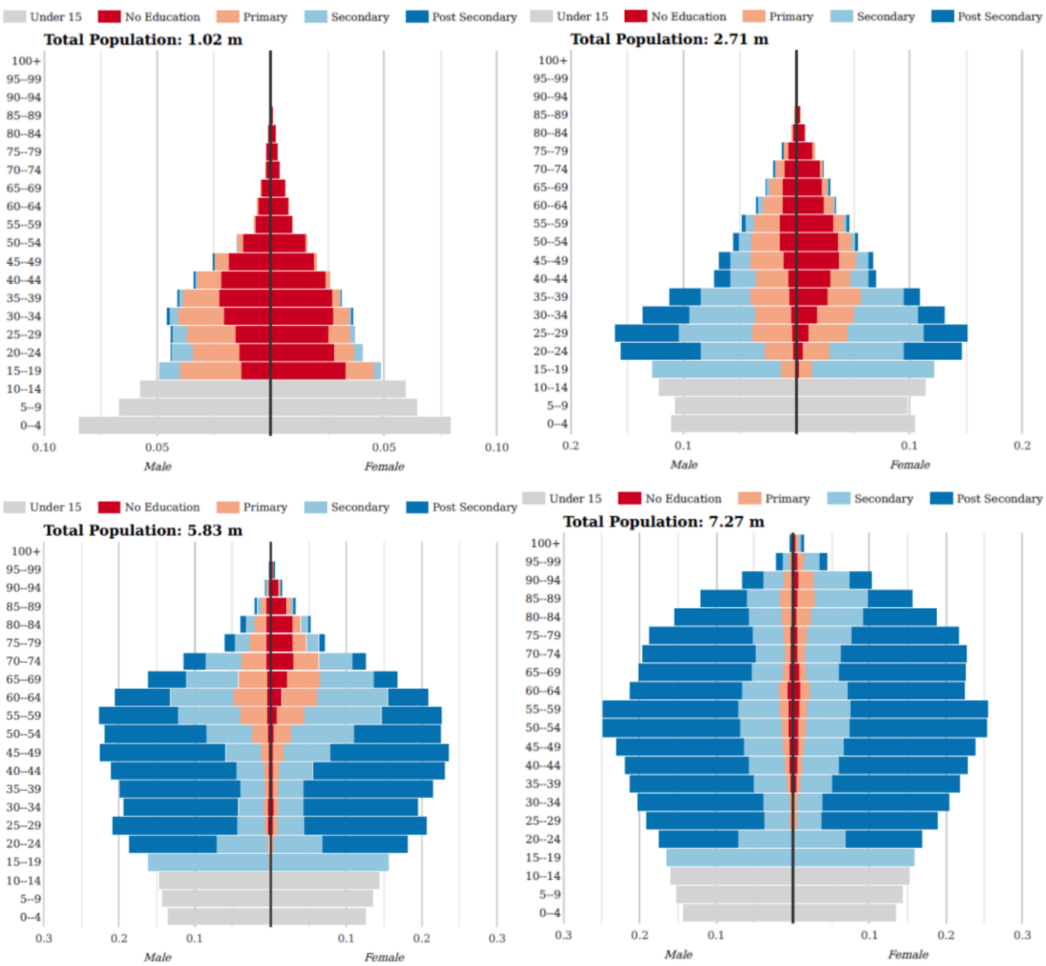
Application 1: The Demographic Metabolism (DM) of Human Capital Formation

The quantitative operationalization of DM through the multi-dimensional cohort-component model is particularly appropriate for analyzing and projecting characteristics that are acquired at younger age and then remain stable throughout adulthood. Formal educational attainment is a good example for this, making it an ideal characteristic for demographic forecasting. While higher education can be pursued later in life, the vast majority of educational transitions (moving from no formal education to incomplete primary, complete primary, and so on) tend to occur early in life. By the age of 25 most people have reached their highest educational attainment (with some exceptions for tertiary education) which they then maintain throughout the rest of their lives. Changes in the educational composition of—e.g. the population aged 40-50—happen almost exclusively through cohort replacement, when as a consequence of expanding school enrollment with the passing of time the less educated 40-50-year-olds will be replaced by a more educated younger generation.

Education pyramids for countries with rapid educational expansions can illustrate this nicely in graphical form. Figure 2 depicts the sequence of such educational attainment and age pyramids for Singapore from 1950 to 2050. With women on the right and men on the left the pyramids show people ordered by age and with color indicating their highest educational attainment (red for no formal education, yellow for primary, light blue for secondary and dark blue for post-secondary education).

Viewed over longer time periods the fundamental social changes resulting from this change in proportions educated becomes even more apparent. In 1950, most women above the age of 35 in Singapore had never attended school, and the population was largely uneducated with the island being a desperately poor and unhealthy place. By 1985, a stark generational divide emerged: younger cohorts, benefiting from post-1950s educational expansion, had near-universal secondary education, while older generations remained largely illiterate. As a visitor to Singapore in 1985, one could observe this dual society—well-educated, English-speaking youth embracing technology versus elderly individuals speaking only Chinese, living in a parallel world. Unlike self-reproducing class structures, this divide was purely cohort-based and thus temporary. Over time, as older, less-educated cohorts aged out of the population, Singapore underwent predictable, structural social change through demographic metabolism. And this dramatic change in the educational attainment structure was a key driver of Singapore's rise from poverty to the richest country in the world today, as will be discussed below.

Figure 2: Education and age pyramids, Singapore, 1950, 1985, 2020, and 2050



Source: Wittgenstein Centre (2018)

By 2020, most uneducated older cohorts had passed away, and the younger population—especially women—achieved world-leading education levels, with around 80% attaining post-secondary education. Since this multi-dimensional cohort component model can also incorporate the fact that women with different education levels tend to have different fertility rates and almost universally more highly educated men and women have lower mortality, the changing sizes and age-structures appearing in this sequence of pyramids also illustrates the interactions between education, fertility and mortality. The narrow bottom of the pyramid for 2020 thus is a direct consequence of low fertility that has been associated with higher female education and the extension of the pyramids at the top with more and more people in the higher age groups in part reflects the higher life expectancy of more educated men and women. This integration of education into population dynamics by age and sex—with different levels and age schedules for fertility, mortality and migration—thus makes population projections by age, sex and education in their outcomes different from the conventional approach of considering only age and sex structures (Lutz, Butz, et al., 2014; Lutz & KC, 2011).

The data behind Figure 2 stems from a systematic reconstruction and projection of global educational attainment distributions by age and sex for most countries in the world based on the multi-dimensional DM model as described above (Lutz, Butz, et al., 2014; Lutz et al., 2018). The model applies backward projection, filling in historical gaps where direct data based on censuses are missing. This multi-dimensional model based on the DM approach has thus produced consistent time-series in 5-year intervals on full educational attainment distributions by 5-year age groups and sex that helped resolve long-standing debates over human capital's role in economic growth, health and other benefits of education. Previous studies on the effect of education on economic growth mostly relied on mean years of schooling of the entire adult population as the education indicator, which masked differences between poorly educated older generations and highly educated youth. In Singapore—as illustrated above—economic growth surged when better-educated cohorts entered the workforce while at the same time older cohorts still had lower education levels. Differentiating by age cohorts thus produces a clearer statistical signal than the averages across all adult ages and therefore results—unlike many earlier studies—in highly significant coefficients for education in economic growth regressions (Lutz et al., 2008). In addition to confirming the general importance of education for growth the availability of the full attainment distributions also allows to assess different mixes with the result that broad based secondary education in addition to primary education is critical for poverty eradication, surpassing the impact of tertiary education in otherwise largely uneducated societies. This insight also contributed to the discussions leading to a replacement of the Millennium Development Goal of universal primary education to the United Nations Sustainable Development Goals (SDGs), now emphasizing universal secondary education alongside primary education (Lutz et al., 2008; Lutz & KC, 2011).

Beyond economic growth, the new cohort-specific educational attainment data also helped to assess education influences on multiple social, demographic and environmental change related outcomes. With respect to institutional changes, it could be shown that expanding youth education strongly correlates with democratic transitions in a way that education expansion tends to come before the institutional changes (Lutz et al., 2010). It could also help to disentangle the complex triangular interactions between education, health and income by avoiding the problem of simultaneous effects through differentiating temporal effects: education mostly comes at young age while the benefits in terms of better health and income typically come decades later (Lutz & Kebede, 2018). This new data also helped to understand and model the important effect of female education as will be discussed below. As will be shown, educated women generally want fewer children, have better contraceptive access and end up having fewer children (Bongaarts, 2010; Lutz & KC, 2011; Lutz & Skirbekk, 2014). Finally, with these new cohort-specific data it could be shown that education is a stronger predictor of disaster preparedness than income, enhancing societies' ability to adapt to climate change (Lutz, Muttarak, et al., 2014).

Aside from reconstruction, the model of DM can also be used to forecast future education distributions based on certain transparent assumptions. Figure 2's 2050 projection for Singapore demonstrates this model's ability to predict future education distributions and resulting social change along cohort lines. Based on this approach the Wittgenstein Centre 's global human capital scenarios following the assumptions of the Shared Socioeconomic Pathways (SSPs) gives scenarios for all countries in the world by age, sex and level of educational attainment to 2100 (Wittgenstein Centre, 2024). They provide the "human core" of the wider SSPs which alternative future pathways of mitigative and adaptive capacity in climate change and are very widely used in climate change related analysis as shown by the most recent IPCC Report (IPCC, 2023).

Multi-dimensional demographic projections by age, sex, and educational attainment based on the DM model are spreading to many applications, even if Ryder's original terminology is rarely cited. They go beyond conventional population projections by age and sex in two important ways: Firstly, they explicitly incorporate education as an additional source of population heterogeneity, thus impacting overall fertility and mortality trends and the resulting projection outcomes in terms of size and age structures; secondly, they provide additional information about education structures that are of interest in their own right. While the first is more relevant for technical demographers, the second greatly enhances the relevance of demographic projections for a large array of applications as indicated above. And the applications of this framework of DM extend beyond demography and education offering predictive insights for social change more broadly, including variables that are beyond demographic questions, as shown in the following section.

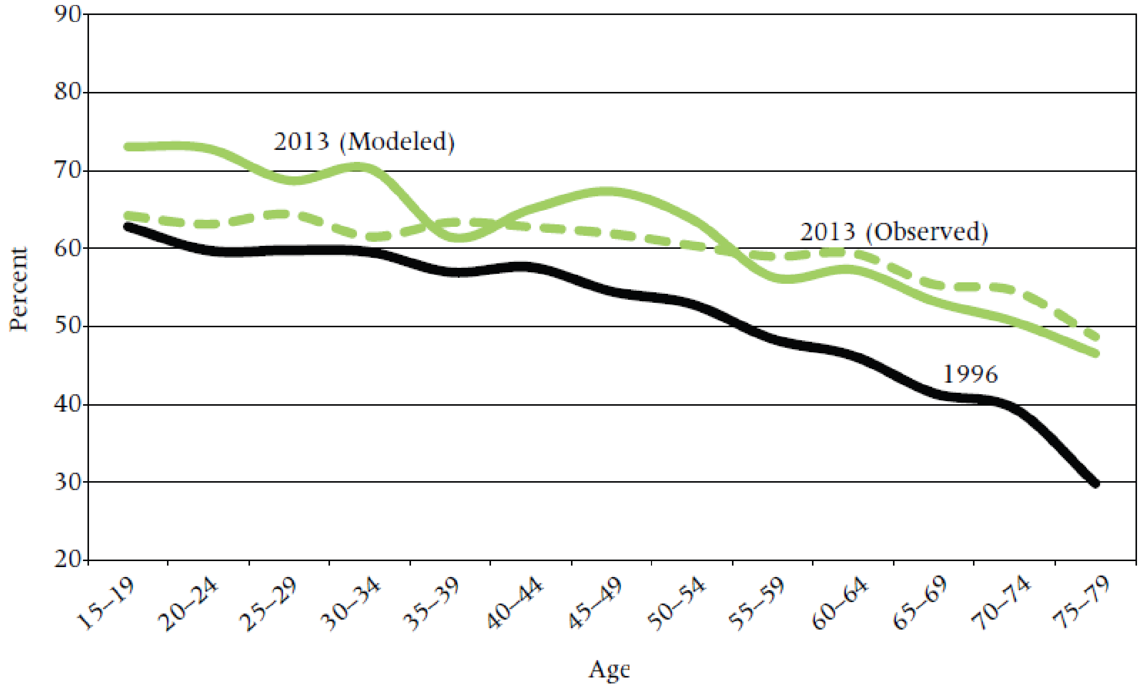
Application 2: The Demographic Metabolism of European Identity

Demographic characteristics such as educational attainment, age, and sex are often considered "hard" variables due to their rather unambiguous definition and verifiability through official records. However, softer subjective characteristics—such as political or cultural identities—can also be analyzed statistically, provided they fall into clearly defined categories and exhibit some persistence over the life cycle. The example discussed here has already been published in PDR (Lutz, 2013) and therefore is only summarized briefly to illustrate the high relevance of the DM model to other disciplines.

Since 1996, the Eurobarometer survey regularly asks respondents for their national identities: "*Do you see yourself as [Nationality] only, [Nationality] and European, European and [Nationality], or European only?*" In 2004, 58% of adults in EU-15 countries identified with a European component, while 42% identified solely with their nationality. The UK had the lowest proportion of multiple identities (~40%). Figure 3 plots these proportions with respect to age of the respondents showing a clear age gradient: older respondents were more likely to identify only with their nationality, while younger cohorts exhibited a stronger European identity.

When looking at the strong decline with age as shown in Figure 3 for 1996 the question arises whether this is an effect of getting older or it reflects a cohort effect with younger cohorts being less nationally minded? If the former, the overall ageing of European populations would lead to decreasing multiple identities in the future. If the latter, European identity would continue growing as younger, more European-minded generations replace older, more nationally focused cohorts.
To distinguish between age and cohort effects, Lutz et al. (2006) analyzed Eurobarometer data from 1996 to 2004. Their findings indicated a strong cohort effect: younger generations were socialized with a higher prevalence of multiple identities, which they tended to maintain into later adulthood. Assuming this trend continued, their projections suggested that by 2030, more than 70% of young Europeans and over 50% of older Europeans would state multiple identities.

Figure 3: Proportions of EU-15 population aged 15 and above with multiple identities, by age group, as derived from Eurobarometer Surveys in 1996, projected to 2013 (based on Lutz et al., 2006), and observed in 2013



Source: Striessnig and Lutz (2016)

After the 2006 study, the EU experienced major political turbulences. During the 2008/09 economic crisis, many commentators predicted a resurgence of nationalism and possible disintegration of the EU. This argument is based on institutional and political developments leading many to speculate that European identity had also declined. However, Eurobarometer 2013 asked again the same question on identity and therefore provided the opportunity to directly test the model's predictions. Figure 3 compares the predicted European identity levels for 2013 (solid green line) and the actual 2013 Eurobarometer results (broken green line). For cohorts aged 35+, the predictions aligned closely with reality. However, for younger age groups, the model overestimated the increase in multiple identities. This suggests that while cohort effects remained stable, the previous upward trend of recruitment of new cohorts into European identity—which was extrapolated in the model—had in fact stalled for incoming cohorts. Nonetheless, the model correctly captured the persistence of European identity among cohorts which at the beginning of the period already had an established identity, confirming the predictive power of demographic metabolism even amid political turbulence.

These results highlight the wide applicability of the generational replacement model. The comparison of predicted vs. observed trends in soft characteristics like identity also offers an important lesson for forecasting; Simple trend extrapolation—as it was done for the younger cohorts entering adult age over the period—is less reliable than the demographic metabolism approach, which decomposes populations into cohorts for forecasting stable characteristics such as identities. And due to the length of the human life span such predictions can go for decades into the future which hardly any other social science discipline can offer. DM changes societies slowly but surely.

The Theory of Demographic Transition (DT)

The concept of demographic transition (DT), has been succinctly summarized by Demeny (1968) in three short sentences: “In traditional societies, fertility and mortality are high. In modern societies, fertility and mortality are low. In between, there is demographic transition” (Demeny, 1968). This seemingly clear definition is also ambiguous and imprecise. It does not contain clear information about the conditions for and the timing of the onset of demographic transition. It is also unspecific about the sequence of stages of DT and at what levels of fertility and mortality when the transition will come to an end. This is why it seems to contain little or no predictive power and classification as a theory remains controversial.

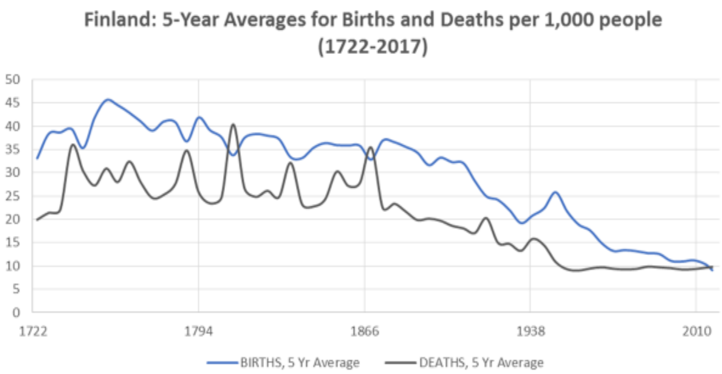
The intellectual history of DT dates back to thinkers like the Marquis de Condorcet (1743-1794) who believed that continued education and female empowerment would lead to lower birth and death rates and solve most problems through behavioral and technological innovation. On the other side of the Channel, John Stuart Mill (1806-1873) argued along a similar line and rejected the pessimism of Thomas Robert Malthus (1766-1834) about population growth surpassing food supply by stressing that the increase in national wealth can keep pace with population growth which can be moderated by voluntary fertility control based on universal female education. These early views by Condorcet and Mill influenced later conceptions of DT, in particular the concept of cognition-driven demographic transitions as summarized below.

In the 20th century, scholars such as Warren Thompson, Adolphe Landry, and Frank Notestein further developed the concept (Thompson, 1929; Landry, 1934; Notestein et al., 1944; Notestein, 1945, 1953). Notestein, in particular, is considered one of the key figures in the development of DT theory. He also translated the vague and still rather qualitative concept of DT into specific numerical assumptions for actual global population projections. Based on specific assumptions on future trajectories of fertility and mortality declines he projected in 1944 that the global population would grow to 3.3 billion by 2000 (Notestein et al., 1944). Given that it actually turned out to be 6.1 billion in 2000 shows that he greatly underestimated the mortality decline and overestimated the fertility decline over the second half of the century. This also illustrates that the vague nature of the concept of DT only provides poor guidance for actual numerical predictions.

Hauser and Duncan (1959) explicitly classified DT as “non-theory” due to its general nature and reliance on observed trends rather than causally supported explanations. In this context, a key controversy in DT was the expected temporal sequence of mortality decline preceding fertility decline, which Notestein suggested as a universal feature and the key reason for modern population growth. It has, indeed, been often assumed that a sustained decline in mortality necessarily precedes a sustained decline in fertility (Caldwell, 2001). On the other hand, critiques of this position argue that this view overlooks cases, such as 19th century France, where fertility and mortality rates declined simultaneously. This criticism also applies to Africa today where analyses of survey data (Defo, 1998; Lindstrom & Kiros, 2007) indicate that the generally assumed direct relationship based on a target of surviving children with a child death resulting in an extra birth for compensation, mostly does not seem to hold. At least there seems little empirical evidence for this in the early phases of DT, with somewhat more evidence in the later phases of transition (Lutz, 2021). It is thus questionable whether the often assumed fixed sequence of mortality decline preceding fertility can be seen as a universal and predictable element of DT. Alternatively, one could assume a separate underlying driver of both the fertility and mortality transitions (such as female education) that would typically take longer to translate into fertility declines due to deeply entrenched cultural norms than into mortality declines where people are happy to reduce child mortality as soon as possible.

Empirical studies of long demographic time-series further illustrate the complexities of DT which do not always show the smooth trajectories included in many textbooks. Figure 4 shows birth and death rates for the world's longest annual time-series going back to 1722 for Finland (Lutz, 1987). Death rates fluctuated strongly but remained on average high until the late 19th century when a sustained decline began after a major famine in 1867. Birth rates showed a first modest decline already in the 18th century which has been associated with a possible transition in the marriage patterns from Eastern to European (Hajnal, 1965; Lutz, 1987) before the real fertility transition, which began in the early 20th century. The transition was interrupted by a baby boom in the mid-20th century, followed by a drop in birth rates below replacement level. Many demographic transitions in the global South during the second half of the 20th century show much more regular patterns. But still major discontinuities in the trends of death rates (e.g. due to the AIDS pandemic) and birth rates (e.g. fertility policies in China or stalled fertility declines in SS-Africa) can be observed highlighting the great heterogeneity of country-specific DT trajectories.

Figure 4: Five-yearly averages of Finnish birth and death rates per 1000 of population 1722-2024 (this will be updated with the most recent Birth and Death Rates from Statistics Finland)



Source: Lutz (1987) and recent data by Statistics Finland

Given this broad range of different trajectories of DT, is there any element that is universal in nature and is predictable, hence possibly justifying the classification of DT as a theory? Here it is argued that it is the irreversibility of the mortality and fertility transitions that can be seen as a predictive element that justifies calling DT a theory. This is more modest than attempts to predict the onset, typical course or ultimate levels of birth and death rate. But it still is a non-trivial substantive claim that limits the range of possible future trends as the following examples will illustrate.

While many scholars in demography take it for granted that the fertility decline in demographic transitions is irreversible, others evidently do not share this assumption. The prominent *Limits to Growth* study by the Club of Rome (Meadows et al., 1972) is based on an interactive systems model (World3) in which birth and death rates are assumed to depend on a number of other model parameters, including food supply, economic output and pollution. In this model fertility trends are a function of economic output and resource availability, assuming that even after having previously declined to very low levels, under conditions of declining resources birth rates would be increasing again. Notably, World3 projected a major global crash for the year 2017 resulting in multiple disasters, and as a consequence a sharp increase in birth rates was predicted for the following years. Hence, this model assumed a symmetry in the causal link between resources and fertility and no irreversibility. More recently, Burger and DeLong (2016) also challenged the irreversibility assumption from an evolutionary perspective arguing that fertility decline is a function of sufficient resources (and associated energy use) per person. There prediction is that when resources per person decline in the future due to ecological limits, fertility would increase again.

The irreversibility of DT as argued here, does not focus primarily on changes in the levels of fertility and mortality. The term transition points beyond mere rate changes over time to fundamental shifts in the structure of determination which in turn have consequences on average rate levels. The theoretical grounding of the concept of fertility transition refers to a transition from natural to controlled fertility. This is also reflected in the shapes of age-specific fertility curves associated the emergence of parity-specific fertility control, something that has also been termed family limitation. This concept was developed in the 1960-70s by Henry (1961) and further developed around the Princeton European Fertility Project (Coale & Trussell, 1974; Coale & Watkins, 1986). Parity in demography denotes the number of births a woman has already experienced in her lifetime (from Latin *partus* = birth) and parity-specific fertility analysis studies the rates of having an additional birth for women of different parities. The essence of parity-specific fertility control is, that women stop having additional births once a certain parity is reached, while according to Henry's (1961) definition, in a natural fertility regime, an additional birth does not depend on parity. This transition to family limitation is a fundamental regime change that is not 1:1 reflected in fertility levels. There are examples of natural fertility among Hunter and Gatherer populations with rather long birth intervals (due to extended breast feeding) that have lower overall fertility levels than some populations with shorter birth intervals but clear evidence of parity-specific fertility control (Lutz, 1984, 2021). The "index of family limitation" as introduced by Coale and Trussell (1978) can quantify this emergence of family limitation based on the shape of age-specific fertility curves (deviations from typical natural fertility curve) that is conceptually independent from the overall level. Hirschman (1994) points at significant variability in the empirical evidence and warns against viewing DT theory based on the concept of family limitation as a single monolithic pattern of modernization but does not question the general concept. Based on this concept of a departure from natural fertility the irreversibility of the fertility transition assumes that once the index of family limitation has ever reached a level clearly indicating parity-specific control (a value of "m" of above .3-.4) the fertility of this population will not go back to uncontrolled natural fertility, even when total fertility levels should fluctuate somewhat. This is a theory-based prediction that can be tested.

The mortality transition in historical perspective has been more gradual, making it harder to define a clear-cut transition threshold. There is also no direct equivalent to the emergence of conscious family limitation in fertility. When assessed on the basis of age-specific mortality rates, it is possible to distinguish between early phases of mortality decline, when decreases in child mortality typically dominate and later phases when child mortality already reached very low levels and further increases in life expectancy are mostly due to declines at older ages. Another approach for structuring the mortality transition is the concept of epidemiological transition, which describes the shift in the causes of death from an initial dominance of infectious diseases to a later dominance of chronic and degenerative diseases (Omran, 2005). This shift has been observed for most countries over time, although there are challenges in classifying and defining transition stages due to variations in patterns across countries. Also, recent upturns in mortality due to HIV/AIDS and COVID were based on the spread of infectious diseases, and we currently hear warnings about new and possibly even more deadly pandemics in the future (Smil, 2005). This seems to rule out the assumption of a lasting decline in infectious disease as a testable prediction. But what else could be a predictable element in the mortality transition?

One key difference between the mortality and fertility transitions is the role of public health, medical technology, and scientific knowledge in driving mortality decline (Cutler et al., 2006). In this view a lasting decline in mortality goes beyond changes in individual behavior and involves strong institutional support, particularly in improving public health. In this context it can be helpful to look at the very beginning of the global mortality transition in 19th century Sweden. While in economic terms Sweden at the time was not so different from other European countries, it started to show declines in infant mortality already in the first half of the 19th century, earlier than in any other country for which reliable data exist. What distinguished Sweden from other countries at the time was a rapid increase in female literacy and early public health efforts. This included the development of an effective network of midwives as well as government pamphlets related to childcare, health and hygiene based on the most advanced medical insights. Thanks to advancing female literacy these instructions were understood and put into practice (Högberg, 2004). As over the late 19th century and the 20th century the mortality transition spread over the entire world, the discussion about the relative contributions of medical advances and public health, individual empowerment and education and general improvement of living conditions remains still unresolved, there is no question that medical knowledge played an indispensable role (Cutler et al., 2006).

Can this insight be translated into a predictive element of the mortality side of demographic transition? Even though it is difficult to argue for an irreversible transition in terms of the prevalence of infectious diseases or even the diminishing amplitude in short-term mortality fluctuations, virtually no one would expect a possible return to 18th century mortality conditions. This has to do with an irreversible gain in scientific knowledge about the causes of disease and its treatment. The germ theory of disease has contributed to save millions and millions of lives, and it is here to stay. It is virtually unthinkable that humanity would revert back to conditions under which this theory and much of the following progress in micro-biology and medicine could be forgotten again. It is thus the irreversibility in the knowledge base of humanity that is the basis for the assumption of the irreversibility of the mortality transition.

The Hypothesis of Cognition-Driven Demographic Transition

The notion of Cognition-Driven DT suggests that education, literacy and associated cognitive advance/knowledge—at individual and population level—are central determinants of both the fertility and mortality transitions (Lutz, 2021). While education in the social sciences is often seen as merely one indicator of socioeconomic status (SES) which also includes occupation, income and wealth, this hypothesis goes deeper by emphasizing how education enhances cognitive skills like abstract thinking, rational decision-making, and planning. In other words, it goes beyond the effect of education on our living conditions and SES and addresses the effect on our minds and the way we think, interpret the world and guide our behavior. It is labelled as an hypothesis here because it still requires more empirical testing despite the strong supporting evidence and the clear conceptual disposition briefly summarized below.

Cognitive abilities have been shown to play a crucial role in influencing fertility and mortality transitions. With respect to fertility, education, particularly literacy and numeracy, equips individuals with cognitive capacity to make informed choices about reproduction. This has been recognized as an essential precondition for the onset of the fertility transition from its first appearance in France to the still ongoing transitions in Africa. In terms of summarizing the drivers of the global fertility transition, the specification of three necessary preconditions for a lasting fertility decline given by Ansley Coale (1973) are still relevant today. The first of these preconditions is that fertility must be "within the calculus of conscious choice". This directly and explicitly relates to cognition and the transition from a fatalistic acceptance of "as many children as God gives me" to a forward-looking planning perspective and decisions based on rational choice. The other two necessary preconditions refer to (economic) advantages of family limitation and the availability of acceptable means (depending on culture) for birth control. While these two further conditions refer to mostly external conditions influencing fertility, the first condition refers to cognitive changes in the human mind making women "ready" in the words of Lesthaeghe and Vanderhoeft (2001) for conscious decisions about the number of offspring. In the extensive literature on the drivers of the fertility transition this position has also been labelled ideational theory as opposed to trends induced by economic changes (Cleland & Wilson, 1987). While the notion ideational is mostly interpreted to refer to cultures and attitudes, it can also be interpreted as including the cognitive dimension more broadly.

Studying historical European fertility transitions as well as modern African ones, Van de Walle (1992) found that in societies with low numeracy, women were more likely to leave family size decisions to fate, rather than actively planning them. He found that the ability to conceptualize an ideal family size emerged only shortly before fertility transitions began, highlighting the role of cognitive development in these demographic changes. This is also fully in line with the social historian Philippe Aries who stated: "The great change came when husband and wife began to plan their own lives and the births of their offspring. They introduced foresight and organization where formally there had been only automatic, unplanned behavior and resigned surrender to impulses and destiny" (Aries, 1980, p. 2). This is indeed a succinct summary of the basic idea of cognition driven demographic transition.

Cognitive development not only influences fertility decisions but also plays a role in mortality decline. This decline involves individual knowledge about health rated behavior as well as public health awareness and institutional arrangements in public health. They are influenced by education at the individual level and at population level. The counterhypothesis to the cognition driven transition is the view that improving economic conditions including nutrition are the main drivers of mortality decline. When studying the global level associations between per capita income and life expectancy over time Preston (1975) identified a strong non-linear relationship with higher incomes being associated with smaller gains in life expectancy. This pattern known as the "Preston curve" also reveals an upward shift of the curves over time with the same income associated with higher life expectancy at a later time, something that Preston attributed to public health improvements. Revisiting the Preston curve 43 years later Lutz and Kebede (2018) not only replicated the global curves of the GDP per person to life expectancy relationship for recent decades—finding essentially a continuation of the pattern as described by Preston (1975)—but also plotted the gains in life expectancy against mean years of schooling in the population as opposed to per capita income. The appearing pattern with respect to education was very different: life expectancy showed an almost perfectly linear association with mean years of schooling and there also was no unexplained upward shift of the curve over time. In other words, education turned out to explain life expectancy much better than per capita income, a finding that was also solidified by applying sophisticated statistical models. A policy brief summarizing these new results stated as headline: "When it comes to survival, mind matters more than money" (Lutz, 2018).

In a comprehensive authoritative review of the state of the art entitled "The determinants of mortality", Cutler, Deaton and Lleras-Muney (2006) also stress the primacy of education's role in determining mortality by drawing the evidence cited from both historical and contemporary declines. They see increasing knowledge and its application to health-related innovations as the primary factor enabling both the exercise of a degree of human control over death and generating differences in the degree with which this control is exercised. Specifically, they assert that mortality began to decline in the West only after the Enlightenment due to the direct effect it had on ideas about personal health and hygiene and the role of public administration, as well as its indirect effect on increased productivity that helped to produce better living standards.

In conclusion, there are good theoretical and empirical reasons to view the fertility and mortality transitions both as initially cognition driven. The concept of cognition driven demographic transition can thus be viewed as a strong specific hypothesis under the broader theory of DT, which despite of the evidence cited can still benefit from further empirical testing under different cultural and socio-economic conditions.

The Theory of a Demographic Dividend (DD)

The theory of demographic dividend, as presented here, posits that shifts in demographic structures—namely, an increasing proportion of the more productive segments of the population—are likely to lead to enhanced economic and social well-being. Empirically, the age structures of population as well as their labor force participation and educational attainment structures have been used as proxies for differential productivity. While widely discussed in policy circles, particularly within organizations like the United Nations Population Fund and the World Bank, but also highlighted by many governments—particularly in Africa—the concept of DD has not traditionally been framed as a predictive demographic theory. Unlike the conventional view, which prioritizes changes in age structure as the key trigger of DD, assigning a secondary role to other changes in demographic structures, the multi-dimensional demographic perspective integrating education and labor force participation for joint consideration with age structure significantly strengthens it predictive power. This makes it possible to classify it as a demographic theory with great implications for economic growth and broader sustainable wellbeing.

In historical perspective, the relationship between population changes and economic growth has been debated for over two centuries. Early pessimistic views were championed by Thomas Malthus (1766-1834), who argued that population growth would inevitably outstrip food supply, leading to subsistence-level living standards unless checked by famine, disease, or—as an unlikely ("The passion between the sexes will never diminish") but still theoretical possible alternative—"moral restraint" resulting in lower fertility. In contrast, the Marquis de Condorcet (1743-1794) was an optimist, believing in technological progress and education, particularly for women, as a means to voluntary fertility decline and sustained economic growth. Neo-classical economists introduced a more neutral stance, arguing that while high population growth could dilute capital, well-functioning markets allowed for adjustments that could maintain equilibrium. The Solow-Swan model demonstrated that economic growth depended more on technological progress and productivity than on population changes (Solow, 1956; Swan, 1956).

Following WWII, rapid population growth, particularly in Asia, sparked renewed fears of a "population explosion." Paul Ehrlich's *The Population Bomb* (1968) warned of imminent mass starvation due to resource depletion. Similarly, Coale and Hoover (1958) argued that a youthful population would hinder economic growth by diverting resources from productive investments toward necessities like housing, education, and healthcare. On opposite side, population optimists, such as Esther Boserup and Julian Simon, argued that population pressure spurred innovation and technological advancements (Boserup, 1981; Simon, 1981). They cited historical examples where high population density led to agricultural and social innovations that supported larger populations. Simon also emphasized human capital, asserting that more people meant more ideas and solutions to societal challenges. However, none of these views explicitly included the changing educational composition of populations in their models.

By the mid-1980s, debates on population and economic growth shifted with a highly influential study by the US National Research Council (NAS, 1986). This study found no strong correlation between population growth and economic performance, leading to the rise of the "neutralist" perspective. Empirical differences in economic growth were attributed to other factors, such as institutional quality and education/productivity, which were assumed to play more significant roles than population growth per se. In reaction to these assessments, research on the implications of demographic change on economic growth shifted from a focus on population size to the role of changing age structures. Actually, this view could build on another research tradition with the earliest known contribution to this perspective dating back to 1931 in a German study on birth rates and unemployment (Günther, 1931). More prominently, Coale and Hoover (1958) incorporated age structure into their economic models. Bloom and Williamson (1998) found that an increasing working-age population significantly contributed to economic growth, coining the term "demographic gift." Their cross-country regression analysis suggested that a rising share of the working-age population, as seen in studies of the East Asian tiger states (1965-1990), played a substantial role in economic expansion. In terms of prediction, this body of literature also stressed that this "demographic window of opportunity" was only temporary, as aging populations eventually increase dependency ratios. Kelley and Schmidt (2005) further decomposed the effects of demographic change into a "translation effect" (fewer dependents boosting GDP per capita) and a "productivity effect" (higher output per worker). Declining youth dependency was found to free up resources for health, education, and infrastructure, enhancing long-term economic prospects.

Further studies pointed at other possible mechanisms in which changes in age structure and education can impact economic growth. Bloom et al. (2009) demonstrated that fertility decline increased female labor force participation, reinforcing economic benefits. The concept of a "second demographic dividend" (Lee et al., 2003) suggested that increased life expectancy leads to higher savings and investment, further stimulating economic growth. However, this effect was considered contingent on pension systems and economic policies (Mason & Lee, 2006).

More recent studies have emphasized education as a key determinant of the demographic dividend. A *PNAS* paper entitled "Education rather than age structure brings demographic dividend" (Lutz et al., 2019) compares the relative importance of improvements in human capital as compared to changes in age structure as drivers of economic growth, highlighting the dominating role of education. This follows a tradition of human capital research in the economic growth analysis. Historically, Mankiw et al. (1992) expanded the Solow model by incorporating human capital, significantly improving the explanation of GDP per capita differences. However, subsequent studies (Benhabib & Spiegel, 1994; Pritchett, 2001) questioned these findings due to difficulties in accurately measuring human capital, a problem later addressed through improved data (D. Cohen & Soto, 2007; de la Fuente & Doménech, 2006). Under this approach, human capital influences economic growth not only by enhancing workforce productivity but also by fostering innovation and technology adoption (Benhabib & Spiegel, 1994, 2005). Theoretical support for this view dates back to Nelson and Phelps (1966), who emphasized both the accumulation and stock of human capital. Additionally, education contributes to health improvements (KC & Lentzner, 2010; Lutz & Kebede, 2018; Olshansky et al., 2012) and stronger political institutions (Lutz et al., 2010) all assumed to contribute to higher productivity.

The above cited comprehensive paper in *PNAS* by Lutz et al. (2019) decomposed growth into age structure, labor force participation, and educational composition. The results show that in the past demographic dividends, such as those highlighted for the Asian tigers, changing age structures often coincided with educational expansions thus making it difficult to disentangle the effects. But a detailed assessment of the different factors including their interactions shows that education improvement rather than an exogenous change in age structure is the gatekeeper for accelerating economic growth. The econometric model that was used in Lutz et al. (2019) separates education from age-structure effects on development outcomes while also estimating the interaction terms for a panel of 165 countries for 1980-2015. The findings show that gains from a rising share of the working-age population are prevalent only when a relatively high share of the population—more than one third—is educated beyond primary schooling. They also provide some numerical illustrations by comparing two countries Nigeria and South Korea who in 1970 had exactly the same proportion of 55% of their populations in working age. In terms of GDP per person the countries were still very similar in 1970, but by 2015 the Korean income per person had increased by a factor of 13 and in Nigeria only by two. Over this period due to a rapid fertility decline in Korea the proportion in working age increased while in Nigeria it remained about constant. But also the education level of the working age population in Korea expanded much more rapidly than in Nigeria. As the statistical decomposition analysis by Lutz et al. (2019) shows, education gains were the dominant driver of Korea's rapid income growth with age-structure changes playing a secondary role.

This paper also presents counterfactual scenarios based on the estimated model parameters comparing trends in Nigeria and South Korea after 1970 based on alternative assumptions. If Nigeria had followed Korea's education expansion since 1970, it would have experienced significantly higher economic growth, especially when combined with an increased share of the working-age population. Conversely, a Korean style rapid fertility decline without parallel educational improvements would have resulted in lower economic growth for Nigeria. Due to the above-mentioned interaction term that requires a minimum level of education for the fertility decline to have a positive impact, this simulation shows that for very poorly educated populations an increase in the share of the population in working age without a parallel increase in education actually has a negative effect on economic growth.

Another recent study by Kotschy et al. (2020) critically addresses the same question with a slightly different model which does not explicitly include labor force participation. It comes up with rather similar results but gives it a somewhat different twist by entitling it "The demographic dividend is more than an education dividend". This is indeed true for the general pattern derived from the set of countries and time periods for which the models have been estimated and in line with the results described above which highlighted the synergies between simultaneously changing age- and education structures. The Kotschy et al. paper also makes a rather strong general statement saying: "A minimum level of education is indispensable for economic growth, as is a sufficiently large working-age population share." (Kotschy et al., 2020, p. 1). Can this be seen as the predictive power of the theory of DD?

There clearly cannot be any deterministic prediction of the highly complex set of factors that jointly result in economic growth. Some of these factors are of purely political or environmental nature and cannot be meaningfully related to demographic changes as drivers of this development. When thinking of possible counter examples that would falsify the DD theory as described above, the experience of Cuba comes to mind which did indeed experience rapid fertility decline together with a strong expansion in education, yet has miserable levels of income, largely due to political constraints. But, if one looks beyond income to other key indicators of well-being such as life expectancy, then Cuba has higher life expectancy than the US, at least according to official statistics.

Hence, put in a nutshell, the definition of DD as given at the beginning of this section, namely, that an increasing proportion of the more productive segments of a population is likely to lead to enhanced economic and social well-being, can be seen as predictive power, although only in a probabilistic sense.

Toward a Unified Demographic Theory

In this last section the ambitious attempt will be made to embed the above described three demographic theories into a broader framework—based on eight propositions—that can lead toward a comprehensive Unified Demographic Theory which forms the theoretical core of demography as a scientific discipline.

To avoid misunderstandings, we need to distinguish "demographic theory" from traditional "population theory," which historically focused on the relationship between population growth and resources. Classical population theories assumed that population growth would be limited by carrying capacity. However, Cohen (1996) and others argued convincingly that no fixed limit exists, as technological and behavioral adaptations continuously reshape constraints. While Malthusian perspectives emphasized homeostasis through mortality or fertility adjustments, contemporary demographic theory extends beyond resource constraints to examine and forecast the drivers and consequences of changes in multi-dimensional demographic structures in addition to population size.

A Unified Demographic Theory can be structured around eight core propositions:

1. **Individuals as Primary Agents**: Humans are the fundamental units (atoms) of any population or sub-population of interest.
2. **Sub-Population Differentiation**: Populations can be divided into distinct sub-groups based on measurable characteristics (such as age, sex, educational attainment and labor force participation) establishing a demographic state space at any point in time.
3. **Transition Between States**: Over their life courses individuals move between demographic states (e.g., place of residence or education levels) through measurable transition rates.
4. **Aggregate-Level Change**: Shifts in the proportions of these sub-group as defined by relevant characteristics cause changes in the nature/mode of operation of the total population thus driving broader social and economic change over time.

These four principles underpin demographic metabolism, which explains how societies evolve as younger cohorts replace older ones and simultaneously people can transition from one state to another. This framework applies universally, illustrating how structural transformations in populations lead to societal change.

A crucial demographic shift occurs through demographic transition, requiring three additional propositions:

5. **Cognitive Development and Conscious Choice**: Literacy and education enhance abstract thinking, foresight, and control over reproductive and health behaviors, as suggested under the hypothesis of cognition-driven demographic transition.
6. **Collective Knowledge and Institutions**: Individuals empowered through education jointly contribute to public health improvements, technological advances, and institutional development providing a context that in turn affects individual behavior.
7. **Diffusion of Ideas and Social Learning**: People also learn from each other with values and behaviors (including state transitions) shifting through interactions with others, influenced by social status and proximity.—The role of diffusion in DT has hardly been discussed above but is being addressed in Adhikari, Lutz, and Kebede (2024).

These three additional principles refer to the mechanisms driving the demographic transition, one of the most fundamental and consequential societal changes on historical scale. They also interact with economic changes and human settlement patterns.

The final component, demographic dividend, examines the economic and broader wellbeing consequences of demographic change and is grounded in the eighth proposition:

8. **Overall Productivity and Population Structure**: With different segments of the population differentiated by labor force participation, education, and health having different productivity, an increase in the share of the more productive segments in any population will be a force toward higher economic and overall wellbeing.

Together, these eight propositions form the foundation of a Unified Demographic Theory, integrating elements of generational replacement, socio-economic transformation, and economic productivity. This approach has been motivated by the Unified Growth Theory, developed by Oded Galor (2011) providing a comprehensive framework to explain the transition of economies from stagnation to growth. It addresses the long-term economic development of societies, integrating key factors such as technological progress, demographic changes, and human capital accumulation. Unlike traditional growth models, Unified Growth Theory captures the entire growth process with a specific focus on the interaction between population dynamics and technological progress. Galor's theory also explicitly incorporates the role of declining fertility in the context of modernization. It tries to explain why some countries successfully transitioned to sustained growth while others lagged behind, highlighting the importance of human capital formation in long-term development.

A next important step could be the integration of the Unified Demographic Theory as sketched above with the Unified (economic) Growth Theory of Galor, given the many structural similarities and identical variables used in both unified theories. It could result in an overall integrated theory of long-term social and economic development. But the more immediate task of this paper in specifying three demographic theories with predictive power has been ambitious enough for the time being. It will hopefully solicit some criticism and a productive scholarly discussion with the aim of further strengthening demography as a scientific discipline and at the same time pointing at its many interactions with other disciplines.

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