UNIVERSIDAD COMPLUTENSE DE MADRID
FACULTAD DE CIENCIAS ECONÓMICAS Y EMPRESARIALES

TESIS DOCTORAL

Healthy Ageing, Productivity, and Social Protection

Envejecimiento Saludable, Productividad, y Protección Social

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

Diego Wachs

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HEALTHY AGEING, PRODUCTIVITY, AND SOCIAL PROTECTION

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DIEGO WACHS

Ph.D. Dissertation

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Introduction

This doctoral dissertation is divided in three chapters that advance our understanding of the relationship between population ageing, productivity, and social protection. The study starts at the root of these issues, by reviewing the definition of ageing. According to the World Health Organisation's (2015) authoritative report, ageing at the individual level is related to social and biological characteristics that negatively affect a person's capacity to pursue whatever they value. These characteristics are not necessarily linked to an individual's age. However, the most common indicators of aggregate population ageing are exclusively based on the age structure of a population. Consequently, in Chapter 1, I compare age-related indicators with our own measure of population ageing. Our measure corrects age-based indicators by including biological characteristics proxied through disability prevalence. The analysis of Chapter 1 sets the tone for the rest of the study. In subsequent chapters population ageing will incorporates health characteristics.

In Chapter 2, I study the relationship between population ageing and productivity. Typically, this analysis looks at the relative size and age composition of the labour force, assuming a constant age-productivity profile for different cohorts. I challenge the latter assumption by looking at the future health and education of different cohorts. Last, I turn to the effects of population ageing over social spending. Chapter 3 considers how increased life expectancy raises the number of pension system's beneficiaries to the detriment of fiscal sustainability. In response, many countries have adopted a pension system entitled automatic adjustment mechanisms (AAMs) that, among other options, can link the retirement age to life expectancy. Again, we incorporate the concept of ageing based on health characteristics to this topic, comparing standard AAMs with a mechanism that links eligibility for retirement to disability-free life expectancy.

Chapter 1. A Literature Survey of Dependency Ratios

Over the last two centuries, extraordinary improvements in life expectancy coupled with decreasing fertility have triggered a phenomenon called "population ageing", one of the most significant features of current global demography. Across all regions around the world, populations pyramids are mutating into thinner obelisks. Many studies have warned that this unprecedented shift in the age distribution of populations will affect societies in significant ways (Borsch-Supan 2003; Bloom and Canning 2004). All else equal, population ageing might increase dependency (Harwood, Sayer, and Hirschfeld 2004), harm productivity (Feyrer 2007), and push social spending to unsustainable levels (Acosta Ormaechea, Wachs, and Espinosa-Vega 2017).

However, the demographic transition might also be paired with changes in the distribution of attributes and behaviours along life. For example, increasing life expectancy may be accompanied by improving non-fatal health characteristics, allowing people to remain independent (Scherbov and Sanderson 2016), stay productive (V. Skirbekk, Loichinger, and Weber 2011), and work until older ages (Bussolo, Koettl, and Sinnott 2015). Unfortunately, although there is strong evidence that life expectancy is increasing at old age, the quality of life during those extra years of life is quite unclear. Furthermore, findings vary from one country to another and even for sub-demographics within countries (World Health Organization 2015).

In Chapter 1, I propose an indicator that quantifies population ageing based on the characteristics approach developed by Sanderson and Scherbov (2013) which uses qualitative characteristics of individuals to weight the components of the ratio. My indicator, the disability dependency ratio, uses health attributes proxied through disability prevalence rates from the Global Burden of Disease database (Institute for Health Metrics and Evaluation 2017) and population projections by age groups from the United Nations (United Nations, Department of Economic and Social Affairs 2019). Similar indicators have been proposed in other studies (V. Skirbekk, Loichinger, and Weber 2011; Sanderson and Scherbov 2010; Harwood, Sayer, and Hirschfeld 2004); however, my work expanded previous literature by extending the sample of countries analysed to almost all UN members (186 from 193 current members), and by proposing and comparing multiple scenarios for the trajectories of health projections.

In line with similar studies, my results showed that the pace of population ageing differs when health characteristics are used to weight the population. We also depicted how countries that rank older under when measured with age-fixed characteristics might rank younger using a qualitative indicator instead. Last, I found substantial differences in the projections depending on the assumptions of health trajectories, which demonstrates the risk of using ageing indicators that make implicit assumptions about health characteristics.

Chapter 2. A review of ageing and productivity: empirical evidence for Argentina

Chapter 2 analysed how population ageing may affect economic growth, one of the most discussed issues related to ageing populations. I started with a literature review to update what is known about the ageing-growth relationship. I proposed four clusters to categorise the literature based on their data, methods, and channels analysed. (1) Ageing and productivity per worker using survey data of firs or workers' demographic characteristics and indicators of their productivity; (2) Ageing and productivity per worker using country level data of the population's age-structure and average productivity; (3) Growth-accounting models that measure the effects of changes in labour participation due to population ageing over growth; and (4) Studies that analyse how population ageing can affect growth through the individual behaviour.

The survey showed that there is no unique path for the ageing-growth relationship. The outcome will vary for different countries depending on specific parameters including the speed and intensity of the demographic transition (Borsch-Supan 2003; Gragnolati et al. 2015; Feyrer 2007), economic and labour market institutions (Aiyar, Ebeke, and Shao 2016; Bloom and Williamson 1998), and the future trajectory of individual attributes that influence productivity -health and education (Bussolo, Koettl, and Sinnott 2015; Vegard Skirbekk et al. 2013; Lutz et al. 2007; V. Skirbekk, Loichinger, and Weber 2011). Furthermore, these parameters present significant variation from one country to another. Thus, there is a need for a standardized mean that can be used to assess numerous economies.

In a second stage of Chapter 2, I built over the insights from the literature survey to propose a series of methods and indicators that can assess how population ageing will impact productivity. These are exemplified by applying the indicators to Argentina. The results for this country showed noteworthy but not alarming future negative effects of population ageing on productivity. Argentina is still enjoying the demographic dividend provided by the second stage of a typical demographic transition. The support ratio is expected to pick around 2040 and then decrease very slowly by 3 percent between 2040 and 2100. Two methods that project productivity per worker where reviewed, a regression analysis of productivity on the age composition of the labour force, and an approximation of productivity using a distribution of salaries by age groups. Both methods project that demographic dynamics will have a positive impact on average productivity for the next decades and then decrease for the rest of the projections.

An important assumption behind these results is that the age-productivity profile of the population is maintained constant throughout the projection period; however, we learned in Chapter 1 that this might an unrealistic assumption. Looking only at the population age structure instead of the characteristics that are better correlated with an individual's capacity to work will bias the results. I'm not the first to state the importance of this consideration when looking at the effects of ageing over productivity. For example, many studies discuss how cohort effects will change the underlying characteristics of the labour force (Lutz 2009; Bussolo, Koettl, and Sinnott 2015). In the last section of Chapter 2, I complemented the analysis described in previous paragraphs with projections of indicators that could affect the productivity of different age-groups -educational attainment and disability prevalence.

Chapter 3. An application of our DDR to pension systems with automatic adjustment mechanisms and endogenous growth

In response to population ageing, many countries have reformed their pension systems using automatic-adjustment mechanisms (AMMs). AMMs create links between demographic or economic developments and pension system parameters (OECD 2012). In other words, they alter pension benefits and/or contribution formulas to account for fiscal pressures arising from demographic changes or other

variables that affect the system's cashflow. Moreover, AAMs can also ameliorate fiscal repercussions associated with uncertainty over projections by incorporating all possible future scenarios into the calibration of parameters (Furman 2007).

By definition, AMMs free regulators from the responsibility of maintaining pension systems' fiscal health. Yet, there is scarce research on non-fiscal consequences of AAMs, such as adequacy and fairness (Alonso-García, Boado-Penas, and Devolder 2018). AAMs do not eliminate the cost of future adverse demographic conditions. Costs are simply reassigned, and who bears them depends on the mechanism's rules. Moreover, if the impact of AAMs over adequacy is too strong, policy-makers can be tempted to bypass them altogether, as seen in Spain and Germany short after the introduction of these reforms (Boersch-Supan and Wilke 2004; de la Fuente, García Díaz, and Sánchez 2017).

AAMs are also controversial when reforms target eligibility. While increasing the retirement age could be interpreted as a natural extension of improving life expectancy, the extent to which workforce participation can be pushed into later years is worthy of consideration. As explored in previous chapters, life expectancy is a measure of quantity of life and is significantly longer than measures of quality of life such as healthy life expectancy and disability-free life expectancy (Sinclair, Moore, and Franklin 2014; Souza, Queiroz, and Skirbekk 2019).

I address the issues described above with an overlapping generations model that measures how pension system participants are affected by AAM reforms. I look at three scenarios differentiated by the mechanisms indexing the retirement age: linking eligibility to the pensions fiscal balance, constant life expectancy after retirement, and constant disability-free life expectancy after retirement. The latter is calibrated using the qualitative ageing indicator developed in Chapter 1. Additionally, Growth is exogenous in my standard model; however, I explored an alternative model with endogenous productivity partially determined by ageing. The alternative model is calibrated using the methods developed in Chapter 2.

I applied the model to Argentina's public pension system as an example. The results showed that an automatic adjustment mechanism based on either increases in life expectancy or disability-free life expectancy would not be enough to compensate the projected growth in the pension system's deficit due to population ageing. In addition, I found that changes in productivity have a limited effect on pension indicators, although the method used to index benefits can amplify or reduce such channels.

Chapter 1

A Literature survey of dependency ratios and a comparison of approaches to measure population ageing

Abstract

Although people are living longer, there is no discernible pattern about the quality of life in an increasing lifespan. This restricts our capacity to predict and prepare for the consequences of population ageing. Accordingly, we propose a population ageing indicator that combines demographic and disability prevalence data through a characteristics approach and explore different scenarios to account for uncertainty in life quality projections. Our results, available for 186 countries, show that countries that rank older under conventional chronological ageing measures may rank younger under our qualitative measure. Additionally, we find substantial differences in our projections depending on different health assumptions, demonstrating the risk of using ageing indicators that make implicit assumptions about health characteristics.

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1.1 Introduction

Until the 18th century, the global population was relatively static; however, in the last centuries, its size and structure have undergone extraordinary changes. Most of the historical rise reflects declines in infant and child mortality due to public health interventions, related to water and sanitation, and to medical interventions such as vaccine coverage and use of antibiotics. However, the life expectancy gains observed over the past few decades and projected into the future are predominantly associated with reductions in age-specific death rates at middle and older ages. (Bloom, Canning, and Sevilla 2004).

Improvements in health were accompanied by a decline in fertility that is attributed to many causes, including changing cultural attitudes toward family size, increases in some of the costs related to having children, economic shocks that reduce the size or certainty of household income, the availability of modern contraceptives, and the economic, policy and institutional environment surrounding the education and employment of women (Bussolo, Koettl, and Sinnott 2015).

The combination of raising life expectancy and decreasing fertility triggered a phenomenon called population ageing, which is typically defined as the increase in the population's median age or in the share of the population above a certain age threshold (Sanderson and Scherbov 2015). For example, between 1950 and 2015, the median age of the world's population increased from 23 to almost 30 (United Nations 2017). This phenomenon has not slowed down, in fact, it might be the most significant feature of current global demography, with every country projected to experience an increase in the share of people aged 60 and over in the coming decades (Bloom and Sousa-Poza 2013).

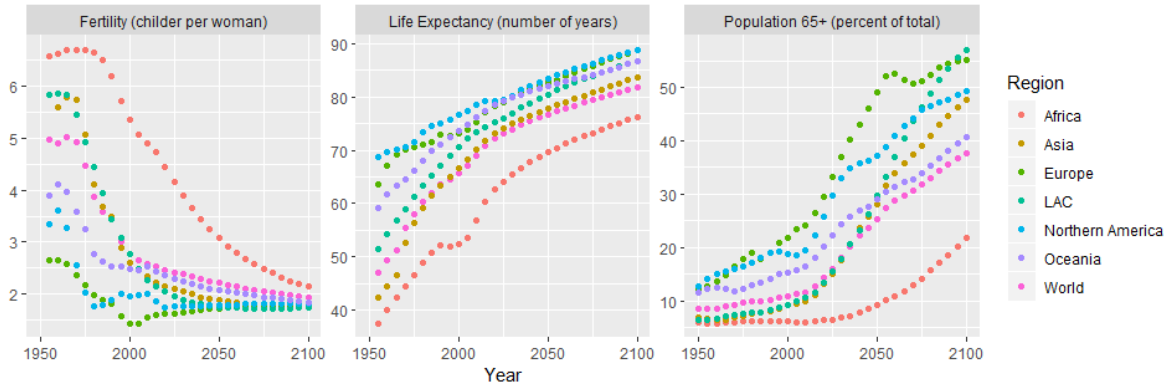

Figure 1.1 World average life expectancy, fertility, and percent of population above 60 (1950-2100)

Source: United Nations, Department of Economic and Social Affairs (2019)

Note: LAC stands for Latin America and the Caribbean

Many studies have warned that a shift in the age distribution of the population will affect societies in significant ways, as individuals have attributes and behaviours that can be linked to different stages in

their life. For example, a typical life cycle model assumes that we first educate ourselves, then work and save, and finally retire living (in part) from the savings generated in the previous stage (Börsch-Supan et al. 2015). Thus, a significant change in share of the working age population could alter the average saving rate of the economy, affecting investment and growth (Bloom, Canning, and Graham 2002).

One of the most common indicators used to measure population ageing and its consequences are Dependency Ratios (DRs) which are calculated as a ratio between different groups of the population. These ratios express numerical relationships between the productive and the dependent components of the population (Adamchak and Friedma 1983). For example, its most used and known version, the old-age dependency ratio (OADR) is defined as the ratio between the old-age population and the working age population. Typically, it is calculated as the ratio between the population above 65 years of age and the population between 20 and 64 years of age; although, there are variations where the age thresholds slightly change, for example, from 65 to 60, or from 20 to 15.

DRs first appeared in 1913, on a book by a Latvian political scientist named Karl Ballod who was trying to measure the ratio of people who were in the labour force to those who were not (Ballod 1913; Sanderson and Scherbov 2015). Ballod divided the population of different countries into age groups, where each group had a different weight according to its capacity to work. Then, he calculated the Coefficient of Burden as the ratio of children (below 14) and the very old (71) to prime-age adults (21-59).

Since then, DRs have been broadly used to show how population change affects societies in many ways, including, among other issues, productivity, innovation, disability and dependence, and social security sustainability (Feyrer 2007, 2008; Acemoglu and Restrepo 2017; Sanderson and Scherbov 2010; Amaglobeli and Shi 2016). Many of these studies have used DRs based on one characteristic of the individual, their chronological age. In other words, an individual is assigned to one group or another depending on their age, implicitly assuming that other characteristics of an individual are fixed by age.

However, ageing is a complex concept associated with physical, social, and behavioural characteristics that are only partially associated with chronological ageing. Thus, while some 70-year-olds may enjoy good physical and mental functioning, others may be frail or require significant support to meet their basic needs. In part, this is because many of the biological mechanisms of ageing are random. But it is also because these changes are strongly influenced by the environment, institutions, and behaviours of the individual (World Health Organization 2015; Bussolo, Koettl, and Sinnott 2015).

The same issues apply to the gains in life expectancy seen in the last decades. Even though life expectancy is increasing, some critical aspects of health might not follow the same trend. For example, many studies are questioning if, while life expectancy raised, disability prevalence for older individuals has decreased, stayed constant, or even increased (Crimmins 2004; Crimmins and Beltrán-Sánchez

2010; World Health Organization 2015). In other words, it is possible that we are extending life expectancy, but not healthy life expectancy.

If the additional years of life are lived in good health, population ageing will be associated with a growing human capital that could contribute to society in many ways. This can be summarized as "the 70s are the new 60s". However, if people live longer, but experience limitations in their health, at similar or higher levels than their parents at the same ages, older people will be more limited in their ability to contribute (Bussolo, Koettl, and Sinnott 2015). Understanding which of these scenarios is underway is very important for effective policy design. However, many studies based on DRs make implicit assumptions about these dynamics without considering their validity.

The objective of this chapter is to help understand and assess the uncertainty surrounding population ageing when measures of health are incorporated. We start in section two introducing definitions for terms used throughout this study. In section three, we survey the use of DRs in economics with a focus on the transition between chronological DRs and improved versions that incorporate corrections for health characteristics. Similar indicators have been proposed by other studies (Harwood, Sayer, and Hirschfeld 2004; Sanderson and Scherbov 2010; V. Skirbekk, Loichinger, and Weber 2011; Chang et al. 2019; Balachandran and James 2019).

Most of these indicators produce projections using a unique trajectory for health characteristics. Our work expands previous literature by quantifying our indicator under alternative scenarios based on different assumptions of the population's future health characteristics and its relationship to mortality. We include a constant prevalence by age scenario, a scenario that links disability to life expectancy, a scenario that projects disability using average growth rates from historical data, and a catch-up between countries scenario (complete description in the methods section). In section four, we propose a new DR that weights individuals according to health indicators. Section five contains a discussion of results and section six concludes.

1.2 Definitions

In this section we define ageing, health, and other concepts that are key to interpret this work. Understanding the ageing process is fundamental, as an incorrect interpretation may lead to a biased use of dependency ratios. From the factors influencing ageing, we pay special attention to health because its dynamics ultimately determine an individual's physical and mental capacities and functioning (World Health Organization 2015).

Ageing

The definition of **ageing for an individual** in this work is based on that of the World Health Organization Ageing Report (2015) which describes it in terms of social and biological dimensions. At the biological level, ageing is associated with the gradual accumulation of a wide variety of molecular

and cellular damage. Over time, this damage leads to a gradual decrease in physiological reserves, an increased risk of many diseases, and a general decline in the capacity of the individual. Ultimately, it will result in death (World Health Organization 2015).[1]

At the social level, ageing is associated with behavioural changes. For example, the decision of senior citizens to retire from the labour force. These decisions are not always personal or based on rational optimization of time allocation by an individual. They are also heavily influenced by a social role assigned or expected at certain ages (Coile 2015). Many times, the roles assigned are based on incorrect assumptions about older people. Although there is substantial evidence that older people contribute to society in many ways, they are instead often stereotyped as frail, out of touch, burdensome or dependent. These ageist attitudes negatively influence the way in which ageing issues are handled (World Health Organization 2015).

Population ageing it is usually defined and measured as the increase in the population share that possess the behavioural and biological characteristics associated with individual ageing. The aggregation of individuals is complex because they may experience their own behavioural and biological changes at different rates. For example, biological changes are neither linear nor consistent, and they are only loosely related to mortality (World Health Organization 2015).

Health

Health is a state of complete physical, mental and social well-being. For quantitative purposes, it is usually divided in measurable subcomponents (WHO 1946; Crimmins and Beltrán-Sánchez 2010). Understanding the relationship between different health subcomponents is key for this study because most population ageing indicators make implicit assumptions about their relationship; however, there is high uncertainty about these dynamics (Crimmins and Beltrán-Sánchez 2010).

For example, the most common DRs are based on chronological ageing. An individual is old if they are over a certain age threshold, assuming that, all other relevant characteristics of an individual are fixed by age. Thus, a reduction in mortality rates at old age generates would be completely unrelated to changes in other health characteristics (Sanderson and Scherbov 2008).

Health and Mortality

The theoretical discussion about mortality and health status was developed through three main scenarios (Crimmins 2004). Chronological DRs would fall inside the "expansion of morbidity" scenario, which

[1] On top of social and biological changes, whether older individuals can achieve the things they value is also determined by the environment they inhabit. For example, people with limitations in their physical capacity may still have the mobility they need if they use an assistive device and live close to public transport that provides access for people with disabilities. Another person with the same physical limitation but who lives in a less enabling environment may find it much more difficult. This final combination of the individual and their environments, and the interaction between them, is the individual's functional ability (World Health Organization 2015).

assumes a rise in life expectancy for persons with chronic conditions without a reduction in the incidence of these conditions. Thus, the expansion of morbidity scenario leads to a deterioration in population health (Gruenberg 1977) .

A second scenario, "Compression of morbidity", assumes that mortality at the older ages would reach a limit beyond which there could be no further decline; however, we would see compression of morbidity into a smaller number of years at the end of life (Fries 1980). As we will see in the next section, dependency ratios based on mortality or life expectancy assume that gains in mortality or life expectancy are translated into gains in other characteristics of health. Hence, these indicators could be included under the Compression of Morbidity scenario (Sanderson and Scherbov 2008).

The third scenario, called "dynamic equilibrium", is situated somewhere between the other two. It assumed that the severity and rate of progression of chronic disease would be related to mortality changes so that, with mortality reduction, there would also be a reduction in the rate of the deterioration of the vital organ systems of the body. Hence this could result in more disease in the population, but the disease would be at a lower level of severity (Manton 1982).

A comprehensive review of the evidence supporting or disproving these scenarios can be found in Crimmins (2004), Crimmins and Beltran Sanchez (2010), and Christensen et al. (2009). They explore the theoretical clarifications of the scenarios described above and the data available depicting how population health changes while mortality is reduced at older ages.

Subcomponents of Health

To measure the relationship between health and mortality, most papers followed a framework that classifies health into different dimensions. For example, on top of mortality, Crimmins (2004) looks at changes in the elders' levels of risk factors, disease prevalence, functioning loss, and disability. Trends in any one of them have been used as evidence of health trends overall, but they represent quite different aspects of health and may be affected by different processes (see Figure 1.2).[2]

Figure 1.2 Health Dimensions

Source: Crimmins, 2004

[2] Crimmins original figure had the dimensions ordered from left to right and connected by arrows, indicating a linear relationship. Nevertheless, he warmed that the certain relationships may not always follow such a pattern. This figure provides a simplified view of health change in a population, not change within individuals. Individuals do not have to pass through all phases of health deterioration. For example, cognitive deterioration is not always linked to a recognized disease process, and it is not always accompanied by impairment. In addition, individuals can move in and out of some of these health states: Disability and functioning loss may be transitory, and people can return to full functioning and ability.

Unfortunately, although there is strong evidence that older people are living longer, the quality of life during these extra years is quite unclear. Furthermore, these patterns may also change from one country to another (World Health Organization 2015). Hence, in this study, we will include different assumptions for life quality at old age. This is exercise results in two important outcomes. First, it will provide a range of possible outcomes depending on the assumptions for health dynamics at old age. Second, a possible magnitude for the error existing in projections based on uncertain health assumptions. In other words, a benchmark for all the studies made considering only one assumption for the dynamics of health characteristics.

Disability

This paper will focus on the fourth component of Figure 1.2 (disability), as there are widely available cross-country comparable databases, which will allow us to generate comparisons and projections for a great number of countries. Additionally, according to recent surveys, disability together with functioning are the most common domains used to measure healthy ageing (Lu, Pikhart, and Sacker 2019). Disability is defined as the inability to perform an expected social role. For older people, this has generally been defined as independent living and self-care (Crimmins 2004).

Functioning loss and disability are sometimes difficult to differentiate; however, an important difference arises from the potential influence of the environment. Functioning loss is related to a deficit in the individual, while disability is an inability to perform within an environment. Disability can be affected by conditions external to the person. For instance, moving to a house without stairs or a home with a walk-in shower might allow someone to live independently who could not do so with different housing characteristics (Crimmins 2004).

Healthy ageing

We are introducing the term healthy ageing in this section because it is a relatively modern term used to described different ageing paths in similar ways to what we described above. The WHO defines it as the process of developing and maintaining the functional ability that enables well-being in older age (World Health Organization 2015). The functional ability is determined by health-related attributes that enable people to be and to do what they have reason to value. For our purposes, healthy ageing matters as it has been the term used in many recent publications analysing the link between ageing and different health components (Dormont et al. 2007; Lara et al. 2013; World Health Organization 2015; Lu, Pikhart, and Sacker 2019).

1.3 Literature survey

In this section, we surveyed different DRs that have been used or proposed in economic research. We prioritised a structure based on functionality over one in chronological order (Table 1.1). Hence, the survey was organized according to the characteristics that define the components of the ratio, including age, labour force participation, mortality or life expectancy, or other qualitative characteristics like, education, disability, and functioning. The reasoning for structuring the survey this way is that, the evolution of ageing indicators did not follow a logical, linear and chronological pattern. Instead, different measures were proposed according to either, the curiosity and specialization of the scholars or the issues relevant at the time.[3]

Table 1.1 Structure of Survey: DRs according to the components of the ratio

Chronological DRs	• DRs focused on the individual's age
Based on labour force participation	• Studies that criticised the problems of using dependency ratios based in fixed groups determined solely by their age
DRs based on mortality or life expectancy	• DRs that approximated changes related to health characteristics using mortality and life expectancy
DRs based on qualitative characteristics	• DRs based on qualitative characteristics such as education, disability, and functionality
DRs based on dynamic equilibriums	• DRs based on theoretical scenarios

Source: Authors own work

A third option would have been to organize the survey based on the indicator's purpose. However, the current structure is better suited for the objectives of Chapters 2 and 3 of the thesis. To improve DRs based on qualitative characteristics and better assess and manage the uncertainty of population ageing. A review based on the purpose of the indicator can be found in Sanderson and Scherbov (2015).

[3] For examples, the first proposed dependency ratio defined age thresholds based on assumptions of capacity to work and productivity. This was a logical outcome for a scholar, working on economics, statistics and demographics, concerned about the capacity of the economy to satisfy the general population's needs (Ivars 2009). In comparison, as population ageing became a fret for the sustainability of welfare systems of many countries, some methodologies defined age thresholds based on social security eligibility.

1.3.1 Chronological DRs

1.3.1.1 Creation and popularization of DRs

Chronological DRs are focused on the individuals' age. In other words, a person is included in one or other category based solely on their age. Chronological DRs (and DRs in general) first appeared in 1913, on a book by a Latvian social scientist named Karl Ballod who was trying to quantify the ratio of people who were in the labour force to those who were not (Ballod 1913; Sanderson and Scherbov 2015). Before publishing this book, Ballod worked on a combination of issues, all tangential to dependency ratios and ageing. Between 1893 and 1895 he served as a Lutheran minister and spent time collecting demographic data, especially on mortality. Later, between 1895 and 1899 he did further graduate work in economics and statistics at the universities of Munich, Berlin, and Strassburg. The result of this degree developed and substantiated the idea that proper nutrition and longevity go hand in hand (Nicholas Balabkins 1974).

In 1913, Ballod published a Handbook of Statistics, *Grundriss der Statistik: Enthaltend Bevölkerungs-, Wirtschafts-Finanz,-und Handels-Statistik*, which can be translated as Statistical Outlines, Including Demographic, Economic, Financial, and Commercial Statistics, was originated upon a series of lectures delivered by the author during the years 1900-1912 at the University of Berlin. The book touched some of the most essential principles of statistics theory and included a compendium of data with a section on population statistics. As a statistician, Ballod's considered that the main goal of an economy was to satisfy peoples' basic needs and that those needs could be calculated statistically (Ivars 2009). Hence, on his book, he included an indicator called *Belastungskoeffizienten* (or coefficient of burden) that measured the number of individuals supported per every worker aged 21-59 in the economy.

Ballod divided populations by country into five age groups, children aged 0-14, teenagers aged 15-20, adults fully capable of working aged 21-59, elderly with reduced capacity for work aged 60-70, and the very old aged 71 or more, who are assumed to be incapable of working. He assumed that teenagers (15-20) and older people with reduced capacity for work (60-70) were only able to support themselves. But, children (below 14) and the very old (above 71) where not even capable of supporting themselves. So, adults aged 21-59 were responsible for the latter two groups. Thus, he calculated the coefficient of burden as the ratio of children and the very old to prime-age adults (Sanderson and Scherbov 2015).

The first use of the term total dependency ratio was in Notestein et al. (1944). There, the total dependency ratio was calculated as sum of people aged 0-14 years and those aged 65 or more, divided by those aged 15-64. The same publication contained graphs with the youth dependency ratio and the old-age dependency ratio, however, those terms did not appear until later. Notestein et al. (1944) explained their selection of age thresholds as an arbitrary solution for uniform treatment of countries. Despite this caveat, current publications from the United Nations use the same age thresholds for its projections (United Nations, Department of Economic and Social Affairs 2017).

Three years after Notestein et al. (1944), Frank Notestein became the first director of the United Nations Population Division. Subsequently, his version of the dependency ratio became a standard measure of ageing used by the UN. The dependency ratio and its offshoot, the old-age dependency ratio, are now among the most frequently cited statistics in the discussion of ageing. Since the early days of the dependency ratio, far more data have become available and new approaches to the study of population ageing have been developed (Sanderson and Scherbov 2015).

1.3.1.2 Use of DRs to measure effects of population structure on growth and savings

Notestein et al. (1944) provided an economic motivation for studying the dependency ratio. They distinguished three stages of dependency associated with progression through the demographic transition: (1) heavy youth dependency, (2) light dependency, and (3) heavy old-age dependency. Each of these stages encompassed a different relationship between the size of the labour force in relation to the resources available in the economy. Later, in Notestein (1960) the author hypothesised about the relationship between economic growth and dependency. High fertility during a period of prosperity increased the size of the labour force, putting pressure over productive resources and creating un-employment. This leads into a recessive period with lower fertility. Eventually, the labour force is reduced, and the cycle starts again.

The following decades saw a debate that had this relationship between growth, resources, and demography at its core. The key issue was about the capacity of economies to generate sufficient jobs at reasonable wages, to absorb the rapidly growing populations into productive employment, subjected to a world with scarce natural resources but widespread availability of technology (Bloom and Freeman 1986). Although, much of the discussion regarded limited natural resources, it unavoidable entailed a discussion about the relationship between demographics and economic growth, as these were the main inputs required to model the discussion.

The debate can be broadly summarized between "population pessimists and optimists". On one side, population pessimists stated that rapid population growth is immiserating because it tends to overwhelm any induced response by technological progress and capital accumulation (Bloom and Williamson 1998). For example, Coale and Hoover (1958) hypostatised that, when people had more children, they would have to spend a larger fraction of their income on consumption and would have a smaller fraction left for savings. Thus, as the population growth rate rose, the average propensity to save would fall and this would reduce the growth rate of GDP. The Population Bomb, a controversial and best-selling book by Ehrlich (1968) promoted a similar message on a more alarming tone, indicating that uncontrolled population growth could trigger mass starvation.

On the other side, population optimists stated that rapid population growth allows countries to capture economies of scale and promotes technological and institutional innovation (Bloom and Williamson 1998). For example, Boserup (1968) proposed a theoretical framework for the relationship between

demographic dynamics and technological development where, population change induces inventions and technological change and also facilitates technological change -more people available makes doing things differently possible. Simon (1981) proposed a similar argument in his book The Ultimate Resource, where he hypothesised that, despite population growth, scarcity would impact prices, generating incentives to develop new technologies that would prevent a crisis.

Despite the significant attention attracted by this debate, there was no clear consensus on either a positive or a negative impact from population change on economic growth until the mid-1980s, when a series of papers started modelling the problem in different terms. Instead of population change, these studies looked at the drivers of demographic dynamics, fertility, mortality, and migration. The justification was that fertility and mortality imply very different changes in the age distribution (Bloom and Williamson 1998). Moreover, this framework brought the attention back to the population age structure and dependency ratios.

One of the first papers to adopt such approach was Bloom and Freeman (1986), which made a comprehensive review about the relationship between each population change driver and specific economic outcomes (labour supply and labour absorption). Their most relevant contribution was to distinguish between accounting and behavioural channels. The first channel is related to the size of the working age population with regards to the total population. During the stages of a typical demographic transition (from pre-industrial high fertility and mortality to post-industrial low fertility and mortality) the ratio of the economically active population to the total population (known as the support ratio) will first decrease, then raise, then decrease again.[4] The jump in the support ratio during the second stage of the cycle raises the rates of growth per capita transitionally creating an effect known as the "demographic dividend" or "demographic gift". The second channel is related to individual choices over the life cycle. For instance, how changes in the population structure could affect women's labour force participation, human capital investment, or the average savings rate of the economy.

Another landmark study was Bloom and Williamson (1998) which used a modified Solow-Swam growth model measuring output per capita instead of output per worker. This amendment adds the support ratio between the explanatory variables of the model. Using this specification and panel data across countries, Bloom and Williamson estimated the importance of demographic dynamics in the "Asian miracle" during the 1980s-1990s. According to the authors, both, accounting and behavioural demographic effects are measured through the support ratio.

The authors also included the growth rates of young (below 15) and old (over 65) populations as separated control variables to differentiate the effects of young and old dependency factors. Their

[4] The demographic dividend in the middle phase of the transition may or may not be realized. It represents a growth potential whose realization depends on other features of the social, economic, and political environment (Bloom and Williamson 1998).

hypothesis was that each age group influenced growth at a different stage of the demographic transition. In the first stage of the transition, rising youth dependency is correlated with a decreasing share of working-age adults. As the transition proceeds, falling youth dependency and rising shares of working-age adults produce the demographic dividend. Finally, the economic gift dissipates, as the share of elderly rises. Bloom and Canning (2001) used a similar framework and obtained comparable results are found by

Bloom, Canning, and Graham (2002) develop a similar model to measure the effects of population structure over the savings rate. Their hypothesis was that, improvements in health and longevity are likely to have large impacts on life cycle behaviour as people look forward to longer and healthier lives. Hence, they differentiated young dependents (individuals aged below 20) and older dependents (those above 60) and found that larger proportions of these age groups depressed the savings rate, with the effect of those above 60 being particularly large.

Kelley and Schmidt (2005) improve previous works by separating the terms measuring accounting and behavioural channels. The former was estimated with a ‘‘translation component” that was equivalent to the differential between the growth rates of the workforce and the population. The latter was estimated through a “productivity component” approximated using other demographic components, including old-age and young dependency ratios.

Many other papers addressed the relationship between demographics and productivity using demographic indicators such as life expectancy or the population age structure as explanatory variables (Lindh and Malmberg 1995; Bloom, Canning, and Sevilla 2004; Göbel and Zwick 2012; Gordo and Skirbekk 2013; Mahlberg et al. 2013; and Aiyar, Ebeke, and Shao 2016). We do not expand on these studies because our focus in this section is on dependency ratios.

A final related study worth mentioning is that Bloom and Canning (2004) who warned that theoretical accounting models can only capture the behavioural channel properly if individual behaviour remains contant while the support ratio changes. However, it seems likely that this would not be the case, as large expansions of the labour force are usually accompanied with changes in the population’s average education, health, and labour participation which would in term affect behaviour. For example, the decrease in young-age dependency increases the support ratio trough the accounting channel. However, it may also decrease the need to care for dependents at home, allowing to increase in labour force participation. In other words, they cautioned about possible demographic related effects that may not be addressed in the models described above because they rely on chronological DRs that measure the ratio of individuals according to their age. In comparison, the DRs that we review in Sections 1.1.2, 1.1.3 and 1.1.4 of this chapter are based on other characteristics, including labour force participation and labour force “quality” (health and education).

1.3.1.3 Use of chronological DRs to forecast public social spending

This section covers the use of dependency ratios to forecast public social spending. This has been mostly covered by international organizations (World Bank, IMF, OECD) which developed methodologies based on chronological dependency ratios to measure the effects of demographic changes over pensions, health, and other public social spending accounts.

For example, the World Bank developed a pension reform options simulation toolkit (PROST) to model and forecast pension revenues and expenditures by country over long timeframes (World Bank 2010). The International Monetary Fund has its own model which covers pensions and health spending (Amaglobeli and Shi 2016). In both cases, the population age structure measured through dependency ratios is a central assumption for the projections. Similar studies are regularly carried by the OECD and the EU (OECD 2001; EC Economic and Financial Affairs 2018).

The old-age dependency ratio is used to make pension fiscal projections because, in most countries, the typical retirement age is 60 or 65. Moreover, spikes in the retirement age distribution at these exact ages are, in some cases, not explained by pension plan incentives, suggesting a "focal point" of a "normal retirement age" created by social conventions (Coile 2015). Thus, the number of contributors and beneficiaries in pension systems are highly determined by the shares of the population below and above these age thresholds which in term affects the aggregated pension revenue and spending.

The use of the old-age dependency ratios (which is assumes a fixed old-age threshold at 60 or 65) to project public health spending has been much more debated than its use for pension projections. This is because the categorization of individuals according to pension eligibility is a much more intuitive exercise than their categorization according to their health status. In fact, the bibliography debating the links between population ageing and health status gives excellent examples of the general debate regarding chronological and other DRs (de Meijer et al. 2013).

At a certain point in time, cross-sectional studies show a clear and defined, positive relationship between age and health spending (OECD 2016). Based on this relationship, studies like Longman (1987) and Amaglobeli and Shi (2016) used cross-sectional age profiles of health expenditure and population projections by age group to forecast total public health expenditure. Their results project rising unsustainable deficits in many countries due to population ageing. However, this method assumes that gains in longevity do not influence age-specific subcomponents of health. Hence, the increase of the old-age population proportionally translates into an increase in health spending. As we see in later sections, these models are challenged by studies showing a different relationship between longevity and health spending. Alternatively, they could be understood as models that predict only demographic effects.

Some papers also suggest that population ageing could slightly reduce expenditure on other items such as education. For example, assuming unchanged spending per student, fewer children per working-age

population would reduce education spending to GDP. Hence, the youth dependency could be used to approximate the fiscal effects of demographic change over education spending (Gupta et al. 2016).

1.1.1 Based on labour force participation

While the debate between population pessimist versus optimists described in Section 1.3.1.2 was unfolding, a series of studies started to point out the problems of using dependency ratios based in fixed groups determined solely by age.

Several publications appeared in respond to a report by the government of United States in May of 1980 which stated that, the projected increase in the ratio of the old age to the working age population would have serious implications for the pension system (President's Commision on Pension Policy 1980). The reasoning behind the government's report was that introduced in Section 1.3.1.3, where an increasing fiscal burden results from the decline in the proportion of persons in productive ages with respect to those over the retirement age.

Among the studies challenging the government's report was Adamchak and Friedman (1983) which indicated that the projections made by the government were based on static assumptions, with no change in composition of the labour force over time. In contrast, they proposed a dynamic framework, which allowed for compositional change. Thus, they calculated a dynamic DR where the groups were defined according to labour force participation. Adamchak and Friedman (1983) used labour force participation projections from Fullerton (1980) which raised over time due to increased participation of woman and ethnic minorities. Their results showed that dependency projections change critically if labour force participation is allowed to change. Calasanti and Bonanno (1986), made a similar argument by comparing scenarios based on labour force participation of woman.

A more current version of labour force dependency ratios was developed by Bloom, Canning, and Fink (2011). They calculate the ratio of labour force participants to non-participants (the inverse of the ratio calculated by Adamchak and Friedman) for the world. As a baseline, Bloom, Canning, and Fink used UN population projections and maintained the rates of labour participation constant by country. Under such assumptions, their results show a decrease in their ratio (a decrease in the productive groups of the population with respect to the adult population). However, the projection is inverted when they use the total population in the denominator, a result that they attribute to the continued decline in fertility rates. Moreover, they propose a second scenario where female labour force participation increases in response to drops in fertility. As expected in such a case, their ratio of labour force to total population ratio increases even more.

Sanderson and Scherbov (2015) applied labour force participation rates forecasts made by the International Labour Organization to UN age group population projections and calculated the ratio of non-workers to workers. In line with the studies reviewed above, their results show that, the magnitude

of the increase in the DRs is always lower when labour force participation is allowed to change. Moreover, in some countries the direction of the change is reversed.

The disadvantage of the DRs reviewed in this section is the difficulty to project labour force participation. Furthermore, there is a simultaneity problem, as dependency ratios are included as explanatory variables in models that estimate labour force participation (Bussolo, Koettl, and Sinnott 2015). As population ages, the labour force participation of older citizens will depend on their health; however, there is uncertainty of how non-fatal health conditions will evolve with increasing longevity. We explore this uncertainty in later sections of this work.

1.1.2 DRs based on mortality or life expectancy

Chronological population ageing is partly a consequence of increases in life expectancy or reductions in mortality at older ages.[5] However, many scholars argue that increases in life expectancy cannot be separated from other improvements in health. For example, time to death studies model health expenditures as a function of the time away from death instead of years elapsed since birth (Fuchs 1984; Seshamani and Gray 2004; Häkkinen et al. 2008). Other studies suggest that increases in life expectancy will trigger behavioural changes, as individuals will modify their life cycle behaviour to adapt to the new reality. For example, they will have to save more to prepare for longer periods of retirement or retire at a higher age (Coile 2015; Bussolo, Koettl, and Sinnott 2015).

These are the main arguments behind the use of DRs based on mortality or life expectancy. Defining DRs in terms of mortality or life expectancy implies that other individual characteristics (like health, labour participation, or saving) will follow the same dynamics. Under this assumption, when life expectancy at 65 increases, individuals over that age of age are not only growing in absolute numbers but are also become healthier. This phenomenon is referred to by demographers and health specialists as the "compression of morbidity" (Bloom, Canning, and Fink 2011). This line of reasoning does not only affect the way we think about dependency ratios, but also about the process of ageing itself.

According to Sanderson and Scherbov (2013), the first paper that proposed such an approach was Ryder (1975), who suggested measuring the degree of human deterioration and dependence not in terms of years elapsed since birth, but rather in terms years remaining until death. In other words, an individual would be considered old when they reach the age at which their remaining life expectancy is 10 years or less. Siegel and Davidson (1984) adopted Ryder's approach in a report for the United States' Census Bureau about demographic and socioeconomic aspects of ageing and calculated the proportions of the population with a remaining life expectancy of 10 years or less, and 15 years or less.

Sanderson and Scherbov (2005) calculated dependency ratios for Germany, Japan and the United States, where the age thresholds used to divide the population groups (the start and end of the working age

[5] The other possible causes are decreasing fertility and migration.

phase) were adjusted over time in proportion to changes in life expectancy from 2000 onward. Sanderson and Scherbov (2008) extended their previous work for the world population. They also introduce the concept of prospective age as a way to compare people who live in periods and places where life expectancy differs. The prospective age assigns ages to people on the basis of their remaining life expectancies in comparison to a reference year. To illustrate the concept, Sanderson and Schervob calculated the conventional and prospective ages of a French woman in 2005 using 1952 as the base year. A French woman who was 40 years old in 2005 had a prospective age of 30, because she presented the same remaining life expectancy as 30-year-old French women in 1952.

Additionally, Sanderson and Scherbov (2008) calculated a prospective old-age dependency ratio (POADR). To define it, they first find an old-age threshold for a base year—the age at which remaining life expectancy falls below 15 years in a particular year. Then, the POADR equals the ratio of the population above the old-age threshold to the population between 20 and the old-age threshold. The age threshold is recalculated every year and most likely increasing, in line with raising life expectancy.

In essence, the POADR does not differ from the indicators prosed by Ryder (1975) or Siegel and Davidson (1984). Sanderson and Schervob's real contribution was to propose a standard methodology to compare ageing indicators. In Sanderson and Scherbov (2013) the authors developed this methodology called the characteristics approach. The key feature in their methodology is the inclusion of time-varying age-specific characteristics that separates which individual is included in either the denominator or numerator of the ratio. In other words, it allows to weight different population groups according arbitrary characteristics, which do not need to be constant by age.

Spijker and MacInnes (2013) combined the economic support ratio with the POADR and calculated the number of people with a life expectancy of 15 years or less and divided it by the number of people in employment. In comparison with the OADR, their measure shows that dependency has fallen by one-third over the past four decades and will continue to do so until 2020 (Sinclair, Moore, and Franklin 2014).

DRs based on life expectancy and mortality are easy to calculate with data available for almost every country. However, the assumption about mortality and life expectancy been good proxies of other health characteristics might be too optimistic. If non-fatal health characteristics like disability or functionality were not improving as fast as life expectancy, these indicators would sub-estimate the pace of population ageing. An alternative is to use other qualitative indicators such us morbidity, disability or functionality (de Meijer et al. 2013; World Health Organization 2015).

1.1.3 DRs based on qualitative characteristics

The importance of ageing's multiple dimensions for population studies has been recognised a long time ago. Already in their 1984 publication, Siegel and Davidson made a clear distinction between ageing

indicators that measured changes in quantity (for example, those looking at reductions in mortality rates) and indicators that measured progress in life quality (for example, those looking at changes in the incidence and prevalence of morbidity).

Ageing proceeds at different rates for different individuals if we define it in physiological, psychological, behavioural, or sociological terms rather than chronological terms. Physiologists will look for signs of ageing in the loss of functional efficiency of various bodily organs. Psychologists will look for signs of ageing in the decline in neuromuscular skills, learning ability. judgement, memory, and sensory acuity. Behavioural scientists and sociologists will look for signs of ageing in the individual's disengagement from social roles and growing inability to live independently. (Siegel and Davidson 1984, page 1).

However, to be reliable, qualitative indicators require datasets that are rarely broadly available, that typically have comparability issues, and should be available for different age groups. This might be the reason why, to our knowledge, there was no example of a qualitative ageing indicator before Harwood, Sayer, and Hirschfeld (2004). Since then, researchers have published DRs based on characteristics such as education, disability, and functionality.

Harwood, Sayer, and Hirschfeld (2004) used data from the Global Burden of Disease Study and calculated dependency ratios based on disability prevalence by age. Then, they used projections of the population age structure to forecast levels of dependency by country. Their findings suggested great increases in the number of dependants; however, the only source of variation for their projections comes from the age structure of the population, as disability prevalence by age is kept constant at its last available value.

Lafortune et al. (2007) calculated a similar indicator, however, in comparison to Harwood, Sayer, and Hirschfeld (2004), they allowed dynamic changes in the prevalence of disability. This was achieved by using the historical growth of the prevalence rate instead of the actual rate. The authors then compared this scenario with a static case where the prevalence rate was kept constant at its last available value for each country.

Sanderson and Scherbov (2010) created a similar ratio, the adult disability dependency ratio (ADDR), defined as the number of adults with disabilities divided by the rest of the adult population. They used historical data to estimate average disability prevalence using demographic variables and country fixed effects. The estimates showed a negative relationship between disabilities rates and life expectancy which partially explains why their ADDR projections increase much slowly than the OADR. One important issue with their approach is that their estimates do not include time fixed effects. Moreover, changes in life expectancy and disability could be simultaneously explained by a third factor. For example, cohort effects due to increasing education could explain both, increasing life expectancy and decreasing disability.

An example of the importance of cohort effects is available in Lutz et al. (2007) and Lutz (2009). Both papers use education to estimate an activities of daily living scores indicator, a measurement that quantifies self-reported scores for difficulties in daily life activities. Given the negative relationship between these variables and that younger age cohorts have higher average education, the prevalence of difficulties in daily life activities was projected to decrease in the future, at the individual level. However, future reductions in the prevalence of these health conditions among older people will not be enough to offset the rising demand for long-term care that will result from increasing life expectancy.

Skirbekk et al. (2013) made arguments similar to those of Lutz et al. (2007) for cognitive functioning based on the Flynn effect.[6] They did not calculate DRs; however, their projections show that, if observed cognitive improvements by cohort continue, the average cognitive functioning of populations will keep rising until 2042, in spite of population ageing.

Skirbekk, Loichinger, and Weber (2011) proposed a cognition adjusted dependency ratio that categorizes individuals according to their age and cognitive capacity, measured by the immediate ability to recall a number of words. Hence, an individual who, based on their age, would be considered part of the retired population, is reclassified as working population if their cognitive capacity is above a certain threshold. Instead of projections over time, this work compares countries according to their dependency using the old age dependency ratio and the cognition adjusted dependency ratio. They find that, although continental European countries have a larger population share above the age of 65 than China or India, their lower cognition adjusted dependency ratio suggests that they are effectively younger. That is, they have a lower share of seniors with poor cognitive performance.

1.1.4 DRs based on theoretical scenarios

The last type of DR that we address are indicators that measure theoretical scenarios. Instead of measuring actual levels of dependency based on underlying characteristics, these indicators first calibrate the characteristics based on a given target. Then, the calibrated characteristics are used to calculate the dependency ratios.

For example, Sanderson and Scherbov (2015) derive a pension cost dependency ratio based on a *intergenerationally equitable retirement age*. The characteristic calibrated is the intergenerationally equitable retirement age which is defined as the retirement age at which (1) members of each cohort receive as much in pension pay-outs as they pay into the pension plan; (2) the generosity of the pension system is the same for all cohorts; and (3) the pension tax is the same for all cohorts. Once Sanderson and Scherbov have estimated this theoretical retirement age, they use it as the age threshold that separates individuals into the numerator or denominator of the pension cost dependency ratio.

[6] The Flynn effect is a phenomenon of rising IQ scores in high-income nations over the 20th century. It relates to a historical increase in mental abilities related to planning, organization, working memory, integration of experience, spatial reasoning, unique problem-solving, and skills for goal-directed behaviours (Baker et al. 2015).

1.4 Our qualitative ageing indicator

This section was led by Diego Wachs and Jorge Onrubia Fernandez, and co-authored with the support of Dr Andres Roman Urrestarazu and Dr Carol Brayne from the Institute of Public Health at the University of Cambridge.

Our survey showed us the importance of having qualitative ageing indicators. DRs purely based on demographics may be over estimating the pace of population ageing, as they assume a constant prevalence of health conditions across time. DRs based on life expectancy or mortality might be on the other side of the spectrum, sub-estimating the pace of ageing. In this section, we propose our own qualitative ageing indicator and compare it with the old-age dependency ratio.

1.4.1 Methodology and data

1.4.1.1 The characteristics approach

We propose a DR, the Disability dependency ratio (DDR), that measures population ageing based on health characteristics of the population. The indicator is developed following the characteristics approach developed by Sanderson and Scherbov (2013) which provides a method to build DR based on qualitative and demographic characteristics of populations. Developing a characteristics approach, means that each age group of the population is weighted by multiplying the number of individuals in the group by a matrix of qualitative indicators. Following this methodology facilitates the interpretation, comparability and decomposition of ageing indicators. For each country, we apply the characteristics approach by multiplying five-year population groups by the group's average disability prevalence rate. Thus, our indicator is affected by both, the age structure and the disability prevalence of the population (Siegel and Davidson 1984). A limitation of this approach is the unidimensional and purely biomedical definition of healthy ageing (Cosco et al. 2014; Balachandran and James 2019). However, under a multidimensional operationalization, data constraints would severely narrow our sample. The detailed protocol describing our application of this approach can be found in the supplemental online appendix for reproducibility.

Following the notation of Sanderson and Scherbov (2013), the general form of the indicators is given by:

$$MN_t = g\big(S(a,t), H(a,t)\big) \tag{1.1}$$

Where, MN_t is the ageing measure at time t, $S(a,t)$ is a vector that contains the age structure of the population, and $H(a,t)$ is a vector of age-specific characteristics. Vector S can be broken up by sex or other demographic dimensions of the population, if required. Vector H could include physiological,

psychological, behavioural, or any other characteristic that would add qualitative information about the ageing process that it is not present in purely chronological indicators.[7]

The "Elder Ratios" are ageing indicators based on the characteristics approach. Elder Ratios sum the age population groups s multiplied by the vector of age-specific characteristics h, and divide the summatory over the rest of the population. Both s and h vary over time t.

$$Elder\ Ratios_t = \sum_a s_{a,t} h_{a,t} / \sum_a s_{a,t} (1 - h_{a,t}) \quad (1.2)$$

The key to use Elder Ratios is to understand the schedule of characteristics h, which varies over a and t. For example, the prospective dependency ratio divides the population with less than 15 years of life expectancy over the rest of the adult population (those over 19 years of age). In this case, the schedule of characteristics indicates the exact age at which life expectancy goes below 15, at each moment t. Suppose that this number equals 68 in a particular year for the studied population. Then, h would be a dichotomic variable where $h = 1$ for $a \geq 68$ & $h = 0$ for $20 \leq a < 68$ (Sanderson and Scherbov 2008)

For our indicator, matrix H contains does not contain dichotomic values (0 or 1) based on age thresholds, but the values of the characteristic itself. Namely, the average disability prevalence in age group a at time t, in percent of the age-group's total population. Following Sanderson and Scherbov (2010) who proposed a DR based on disability where those with at least 20 years old and disabilities are divided by those with at least 20 years and without disabilities. The indicator is multiplied by 100 as the United Nation's OADR.

1.4.1.2 Data

We use the United Nation's Population Prospects database for the demographic characteristic of our indicator (the total population in each age group). The qualitative characteristic is obtained using morbidity data from the Global Burden of Disease (GBD) database which provides estimations of disability prevalence by age group, sex and cause, for the 1990-2017 period and 195 countries (Li et al. 2018). After multiplying each age-group by its prevalence rate, we follow Sanderson and Scherbov (2010) and calculate the DDR as the number of adults (20+ years of age) with disabilities over the number of adults without disabilities for all 195 countries with available data in the GBD database.

1.4.1.3 Cross-sectional comparison and projections

With the data available, we can compare how the ranking of countries changes according to different ageing indicators for the 1990-2017 period. Then, we generate projections of the DDR under different assumptions. For each country, we use the United Nation's Population Prospects database to project the

[7] MN stands for new measure, as Sanderson and Scherbov were comparing it with conventional measures (MC) of population ageing.

demographic components of our indicators (the total population in each age group) and different scenarios for the disability prevalence of the population, including: (1) DDR constant prevalence: we keep the prevalence rate constant for each age group at its last historical value available, as in Harwood, Sayer, and Hirschfeld (2004); (2) DDR past trends: we project prevalence rate for each age group by setting the average annual percentual change in the prevalence rate equal to the observed average percentual change in historical data, as in Lafortune, Balestat, and The Disability Study Expert Group Members (2007); (3) DDR life expectancy: we estimate the relationship between disability prevalence and life expectancy using a panel regression for each age-group and then forecast the prevalence rates using life expectancy projections from the UN, as in Sanderson and Scherbov (2010); and (4) DDR catch-up: the disability prevalence rate of each age group "catches-up" between 2015 and 2100 at a constant rate, with the rate of the country with the lowest prevalence in 2015.

From the 195 countries with data available at the GBD database, the projections are available for 184 countries. Nine are dropped due to data availability at the United Nation's Population Prospects database (Taiwan, Bermuda, Puerto Rico, Dominica, Northern Mariana Islands, Andorra, American Samoa, Marshall Islands and Greenland) and two are dropped because they are not included in the World Bank's country income groups (Fed. States of Micronesia and State of Palestine).

1.4.2 Results

1.4.2.1 Cross-sectional comparison of DRs

Figure 1.3 shows how the Old-age and the Disability DRs differ across countries. The left panel shows the OADR in the horizontal axis and the DDR on the vertical axis for all countries with available data in the GBD database. The best-fit curve is flatter than the 45-degree line partly because countries on the bottom left of this distribution have a higher standardized disability prevalence than countries on the top right. However, even though there is cross-sectional evidence of the compression of morbidity (Mathers et al. 2004) the longitudinal evidence for this relationship is unclear; thus, countries on the bottom-left region of the distributions will not necessarily follow the exact path of countries on the top-right. In other words, as countries keep ageing and moving right over the horizontal axis, we do not know how close to the best fit line they will stay.

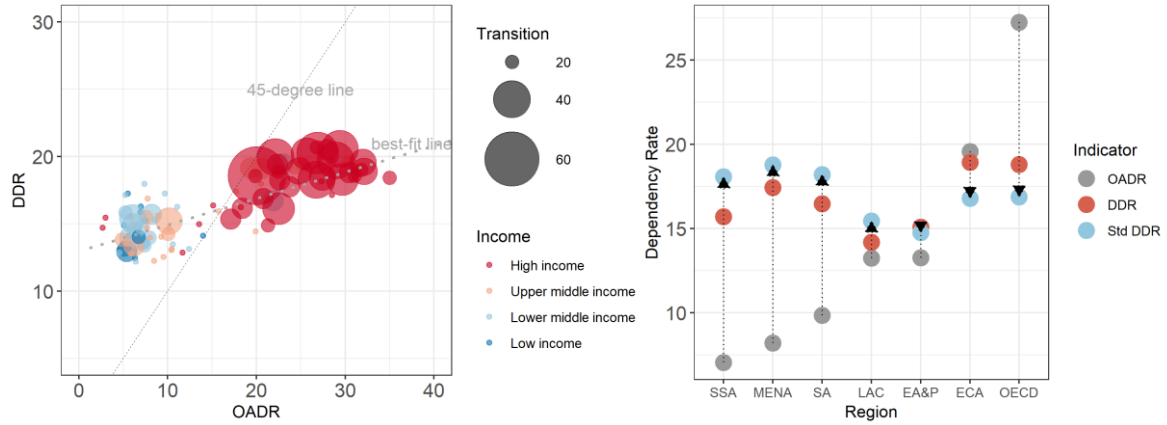

Figure 1.3 Old-age and disability dependency ratios by country and region (2015).

Source: UN Population Prospects, Global Burden of Disease Databases and World Development Indicators.
Note: OADR defined as those 65+ over those between 20 and 64. DDR defined as explained in our methodology section. Std DDR stands for standardized DDR using the world population. The size of the bubbles indicates the (actual or projected) number of years that took for the 60+ population to grow from 15 to 20 percent of the total population. The colour separates countries according to World Bank income groups.

In fact, there are important differences between those countries, some of which can be observed in the size and colour of the bubbles of Figure 1.3. The colour separates countries according to World Bank income groups while the size represents the number of years it took (or will take) for them to transition from a lower to a higher proportion of elders in the population. The image shows a clear pattern. In general, the countries on the top-right are richer and had longer periods of time to age. This means that the necessary adaptation that countries on the bottom left will need to go through, will have to be carried out much more quickly than was often the case in the past (World Health Organization 2015).

Some oil producer countries escape the GDP ageing pattern. The bright red bubbles on the bottom left region are six rich oil producers with young populations including Bahrain, Brunei, Equatorial Guinea, Kuwait, Oman, Qatar, Saudi Arabia, Turkmenistan and United Arab Emirates. Typically, net-oil exporters are excluded from growth studies, including those focused on demographic factors (Feyrer 2007; Bloom et al. 2015). Most likely, due to a unique channel through which sustained natural resource windfalls create outliers in the “typical" developmental process of a country, including the fertility-growth relationship. However, understanding this channel exceeds the purpose of this paper.

The right pane of Figure 1.3 has a comparison of the same indicators for countries grouped in geographical regions. Consistent with Skirbekk et. al. (2011), the chart reveals how the “ageing” ranking changes depending on the indicator (Skirbekk, Loichinger, and Weber 2011). Regions are ordered from left to right according to their OADR (the grey marker) in 2015. In contrast, the red marker shows their DDR in 2015. The first thing that emerges from the chart is how chronologically younger countries become older under the DDR, while chronologically older countries become younger.

Furthermore, the relationship is inverted for some regions. Latin America and East Asia and Pacific are now younger than Sub-Saharan Africa, Middle East & North Africa, or South Asia.

As time goes by and all regions keep chronologically ageing, the final ranking will be determined by the evolution of their disability. For the regions on the left, if disability prevalence decreases fast enough, they may end with a DDR similar to that of regions on the right. However, if their share of senior citizens keeps increasing but disability prevalence does not decline, they will end up with even higher dependency than regions on the right. This is depicted by the blue markers in the right pane of Figure 1.3, which represent the DDR standardized using the world population.

As there is great uncertainty about the expected dynamics of disability and chronological ageing across-countries, the next section explores how ageing may unfold under different scenarios.

1.4.2.2 Projections

Figure 1.4 shows the projections of our DDR under the four scenarios described in the methodology section and the OADR (right axis) for the world and different income groups. The projections start in 2015, and all series are re-based to the same year to obtain comparable indexes (2015 = 100). The range of the OADR is greater than the range of the rest, hence it is plotted on the secondary axes. This issue shows how the pace of ageing greatly differs under different definitions. Furthermore, the OADR projections show an increase in dependency for most of the projection period and for all countries, while that is not the case for DDR, depending on the scenario.

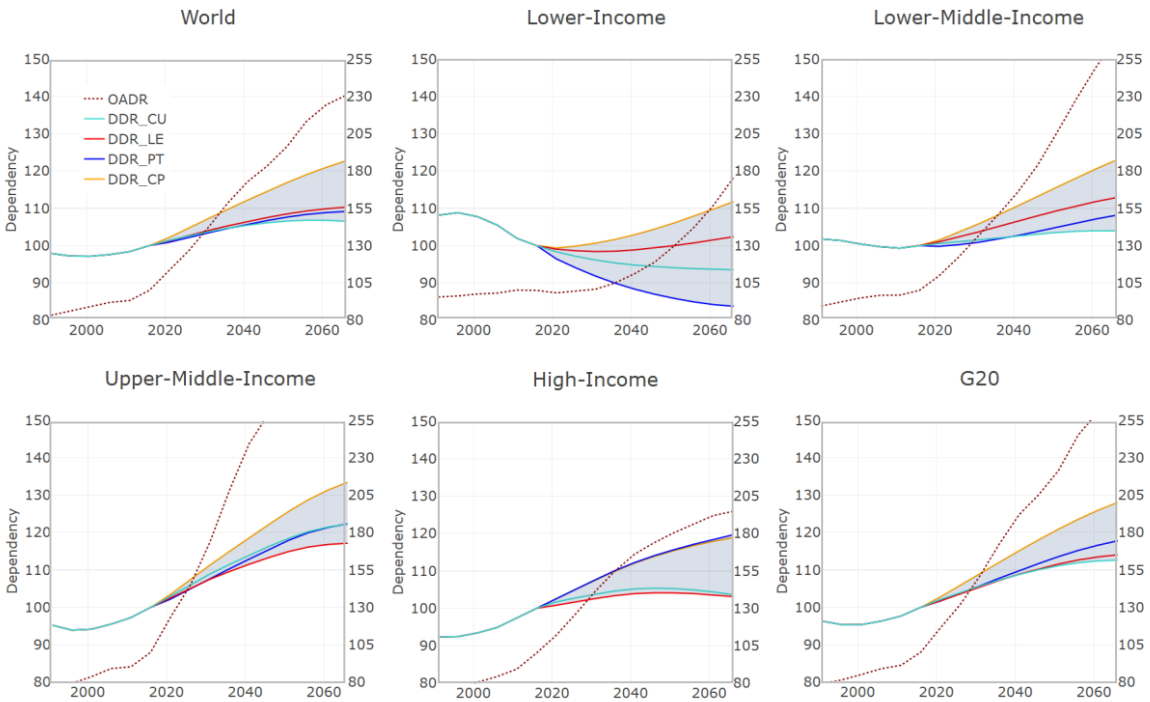

Figure 1.4 Old-age and disability dependency ratios by region (2015-2065).

Source: UN Population Prospects, Global Burden of Disease Databases and World Development Indicators. Note: DDR_CP refers to the constant prevalence scenario, LE to the life expectancy, PT to the past-trends, and CU to the catch-up scenario. OADR is plotted on the right axes and defined as those aged 65+ over those between 20 and 64. DDR defined as explained in our methodology section. Series for the World include 186 countries for which there is data from all sources. The composition of the all regions is available in our online appendix.

The area in light blue within the DDR scenarios depicts the range of expected ageing under our different projections. The variation for the world is modest but not trivial. The growth in dependency would be almost three times faster under the constant prevalence scenario (top bound of the ageing range) than under the catch-up scenario (lower bound).

The world's top bound is consistent across regions and delineated by the constant prevalence scenario in all cases except for high-income countries where the constant prevalence and the past-trends line almost perfectly match through the whole projection. This implies that on average (and weighted by population size) disability prevalence has not changed in the historical period for high-income countries, according to GBD data.

The world's lower bound is almost equally matched by the other three scenarios; however, the pattern is not consistent across regions. The past-trends scenario for the world is driven down by low income countries, where, in contrast with high-income countries, disability prevalence rates have been decreasing on average at a fast pace. This pattern can be appreciated in the chart for low-income countries, where the population is actually "getting younger" under the past-trends scenario. Nonetheless, it is unlikely that disability prevalence rates will continue decreasing at the same pace for the whole projection period, as rates would reach zero percent for some age groups. The prospects are also good for low-income countries under the catch-up scenario were the population is also getting younger for the whole projection.

Lower-middle-income countries show a pattern similar to that of low-income countries, although the past-trends and catch-up scenarios are inverted. Upper-middle-income countries show the most worrisome projections, with population ageing under all scenarios.

We include one panel that shows the projections for the G20 which in 2018 accounts to more than 85 percent of the world's gross domestic product (IMF 2019a). In comparison with high-income-countries, the G20 excludes many small (by gross domestic product standards), young, oil producers but includes big medium income countries like India, China, or Brazil.

1.5 Discussion

As in Skirbekk, Loichinger, and Weber (2011) our results show that a multidimensional approach to ageing can significantly change the characterization of countries around the world. Countries that rank older under conventional measures (like the OADR) may rank younger under qualitative measures. This result helps reconciling the growth-ageing contradiction (Acemoglu and Restrepo 2017). Additionally, like Sanderson and Scherbov (2010), we find that, if improvements in health continue, ageing might be less worrisome than what other non-qualitative ageing indicators like the OADR project. Nevertheless, given the lack of sustained evidence from longitudinal studies on life quality improvements at old age, caution should be taken with too optimistic projections as the ones from the dependency ratios based on life expectancy. The variation in our projections resulting from different health assumptions is substantial which evinces the risk of making implicit assumption for health characteristics.

In comparison with other studies, extending the sample of countries allows us to generate projections for different income groups. For low-income countries we find that, even though, they will undergo a faster chronological demographic transition, if they maintain past (or even less successful) gains in health, their qualitative ageing indicator will not increase for several decades. In contrast, high-income countries show considerable ageing under the constant prevalence or past-trends scenario and upper-middle-income countries are projected to age in all scenarios.

An important issue with our projections is the absence of variation resulting from inequality within countries. Our results are based on average aggregated projections; however, health inequality within countries could add variation that we are unable to explore. Another limitation of this approach is the unidimensional and purely biomedical operationalization of healthy ageing in our indicator, which contrasts with multidimensional theories discussed in the literature (Cosco et al. 2014). Restricting research to only biomedical studies may bound the advancement of successful ageing conceptualization, research, and public policy. This is in part, due to the unrealistic prospect of elderly individuals ageing in perfect physical condition. Other relevant individual characteristics, including psychosocial components, could be incorporated to obtain a more comprehensive measure (Crimmins 2004). However, the data requirements of such an approach would significantly narrow our sample of countries. Additionally, disability is one of the most common concepts used in the literature to operationalize healthy ageing (Cosco et al. 2014; Lu, Pikhart, and Sacker 2019).

It would be interesting to explore how our results could be used to address research on ageing and productivity as in Lozano et al. (2013) and Aiyar, Ebeke, and Shao (2016). These papers develop a methodology to assess how labour productivity is affected due to health deterioration as a consequence of population ageing. Our indicator could be used to assess worst-and best-case scenarios.

Our results can also be used to compare and assess eligibility reforms in pension systems. Many pension systems have implemented increases in retirement age based on projected raises in life expectancy

(Alonso-García, Boado-Penas, and Devolder 2018). Our indicator could be used to compare those with reforms based on projected raises in disability-free life expectancy.

1.6 Conclusion

The changes that constitute and influence ageing are complex and involve many characteristics of individuals that are loosely correlated with chronological ageing. However, the most common ageing indicators are based solely on the population's age, assuming that other characteristics such as health stay constant by age group. In contrast, some studies proposed ageing indicators where gains in health expectancy are translated into gains on other health characteristics. Nevertheless, there is no discernible pattern about the quality of life in an increasing lifespan.

Our work proposes a new population ageing measure that weights individuals using health characteristics. Although similar indicators have been proposed in other studies, our work expanded previous literature by extending the sample of countries included to almost all UN members, by using the Characteristics Approach to ease the decomposition and comparability of our indicator, and by comparing multiple scenarios for the trajectories of health projections.

In line with similar studies, our results showed that the pace of population ageing differs when health characteristics are used to weight the population. We also depicted how countries that rank older under measures were characteristics are fixed by age may rank younger under a qualitative indicator of population ageing. Last, we found substantial differences in the projections depending on different health assumptions, which demonstrates the risk of using ageing indicators that make implicit assumptions about health characteristics.

Chapter 2

A review of ageing and productivity: empirical evidence for Argentina

Abstract

One of the most discussed consequences of population ageing is its impact on economic growth. According to the literature on the topic, there are multiple underlying conditions driving this relationship and they vary significantly from one country to another. Thus, there is a need for a standardized way to assess and compare these conditions for numerous economies. The purpose of this chapter is to propose a series of methods and indicators that can meet such need. We began with a literature survey on what is already known about the ageing-growth relationship. A thorough review yielded four major literature strands, based on the underlying data, methods, and channels analysed: productivity per worker using micro data, productivity per worker using macro data, growth-accounting models and labour participation, and behavioural effects. In addition, we identified data broadly available across countries for the first three clusters and carried an empirical analysis for Argentina to exemplify their application. The results showed noteworthy but unalarming effects of population ageing on productivity for this country. Our framework is applicable to almost 150 economies and we predict it could be particularly useful for public and international organizations working across countries. An interesting application of the framework would be into the modelling of pension and healthcare systems, the main sectors to be impacted by population ageing.

2.1 Introduction

The objective of this chapter is to assess the relationship between population ageing and economic growth, and how it can be incorporated in our pension system model in Chapter 3. We start with a literature review of the ageing-productivity relationship. Then, we develop an empirical analysis based on the takeaways from the first section to assess expected ageing and productivity trends in Argentina. We choose this country because we carry further analysis on its pension system in Chapter 3. We put emphasis in empirical evidence that connects ageing to productivity through changes in health which is a key topic connecting the three chapters of this thesis.

2.2 Literature review

Our review allowed us to identify four clusters of research that divide the literature according to the channels analysed and data used (Figure 2.1). Studies included in groups one and two analyse how ageing can affect productivity per worker. Papers in group one use micro-data (survey data of workers or firms and indicators of their productivity) to assess if there is a productivity pattern across the life of an individual. Papers in group two use macro-data, cross-country panel data of the population age-structure and average productivity. Studies included in group three use growth-accounting models to calculate the effects of changes in labour participation over aggregate production. Last, group four includes studies that analyse how population ageing can affect growth through the behaviour of individuals.

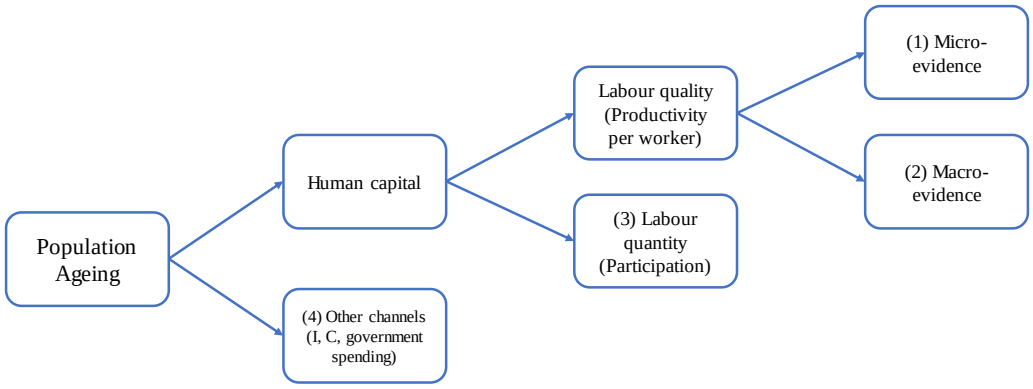

Figure 2.1 Literature review structure according to channels and data

Note: Investment (I), Consumption (C).

2.2.1 Labour quality: Productivity per worker

We begin the literature review with a section that summarizes studies analysing how the *capacity* or *quality* of workers is related to their age. In other words, is there an age-productivity profile? If this is the case, the following question is if the profile is static or if it changes across time. Most of the literature can be divided between studies that find an inverted U-shape profile and studies that find no significant

relationship between the two variables. The section is divided in two subsections according to the evidence used for the study, micro or macro-data.

2.2.1.1 Productivity per worker using micro-data

Four types of micro-data evidence have been analysed in relation to ageing and productivity -employer-employee matched datasets, piece rates, earning profiles, and studies of workers health characteristics. Below we describe keynote studies for these categories, a theoretical framework that helps interpreting the studies' results, and additional evidence that counters the initial findings.

- Evidence type 1: Employer-employee matched datasets

Employer-employee matched data-sets use information of both the companies value added and employees' individual demographic characteristics to isolate how the production of a firm is affected by its age profile. Many employer-employee studies find an inverted u-shaped describing such relationship, that is, productivity increases with age until it peaks at a certain age and starts decreasing again (Haegeland, Klette, and Salvanes 1999; Haltiwanger, Lane, and Spletzer 1999; Crépon, Deniau, and Pérez-Duarte, n.d.; Ilmakunnas, Maliranta, and Vainiomäki 2004; Prskawetz et al. 2006; Prskawetz, Mahlberg, and Skirbekk 2007; Mahlberg, Freund, and Prskawetz 2009)

This method is less subjective than studies based on supervisors' ratings and suffer from less sample selection problems than studies based on piece-rates (see below). However, it is not exempt of problems, the main challenge been how to isolate the effect of the employees' age from other influences on a company's value added. Another problem is that most studies use cross-sectional evidence, which may not capture variations that occur across time. For example, company's success can increase the number of new employees and lead to a younger age structure, which could lead to wrong estimates since a young age structure could be the consequence rather than the cause of a company's success (Prskawetz, Mahlberg, and Skirbekk 2007).

- Evidence type 2: Piece rates

Another type of evidence comes from studies known as "piece rates" which analyse the output of workers and authors of artistic work across their life. Studies based on this approach usually find that older employees have lower productivity levels (Mark 1957; Kutscher and Walker 1960; United States Department of Labor 1957; Miller 1999). Piece rate analysis has also been applied to the output of researchers and entrepreneurs which may be important determinants of productivity through innovation. The results also suggest that productivity decreases at old age (Lehman 1953; Bayer and Dutton 1977; Levin and Stephan 1989; Oster and Hamermesh 1998; Bratsberg, Ragan, and Warren 2003; Feyrer 2008); nevertheless, this age-profile may not be constant in time (see the next sub-section presenting counterevidence).

- Evidence type 3: Earning profiles

A third type of evidence comes from earning profile studies which assume that earnings are a good proxy for productivity. This method is benefited by the vast literature studying the relationship between earnings and individual attributes (including age) the most famous being Mincer's earnings function that relates individual earnings to measures of schooling and experience (Mincer 1974). Most of these studies find an inverted U-shape relationship between age and earnings with bounded decreasing earnings at old ages. Nevertheless, empirical evidence that challenges how well earnings reflect productivity usually indicates that the latter peaks before wages, a fact that would accentuate the inverted U-shape (Mahlberg et al. 2013).

- Evidence type 4: Workers characteristics

The last type of evidence discussed here is found by measuring if there is an age profile for underlying characteristics such as experience and mental and physical abilities that are determinant for an individual's output (Vegard Skirbekk 2008; Bussolo, Koettl, and Sinnott 2015). The explanation behind this idea is very intuitive, on one side, ageing is associated with accumulated experience, thus it increases productivity. On the other side, ageing is associated with a gradual decrease in an individual's intrinsic capacity – that is, the composite of all the physical and mental capacities that determine not just individual productivity, but our ability to achieve well-being (World Health Organization 2015).

- Theoretical framework

Figure 2.2 depicts an example based on the relationship described by many studies that find a significant age-productivity profile (see for example Vegard Skirbekk 2008). Productivity increases gradually as experience is accumulated throughout an employees' working life; however, health (physical and cognitive abilities) are reduced with ageing.[8] At same point, the effects from the latter become more important than gains from increasing experience; thus, the productivity starts decreasing.

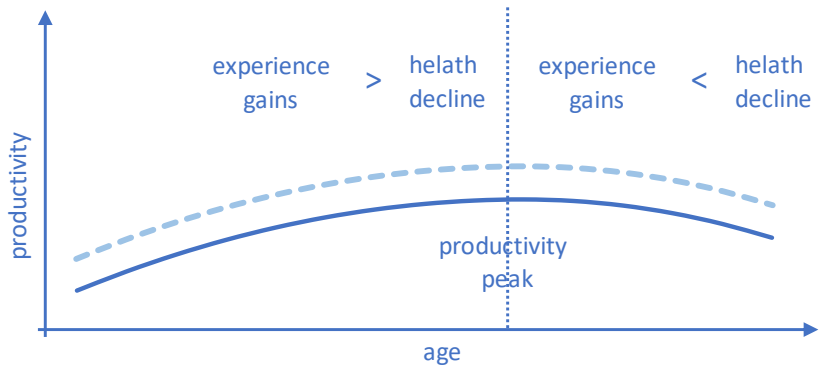

Figure 2.2 Age-productivity curve.

[8] Not all abilities decrease through life, see below in this section.

Source: Authors own work. Note: In line with much of the evidence described in this and next sections, the productivity peak is skewed to the right of the working life and the decrease after the peak is smaller than the increase before it; however, different studies find varying profiles.

Even though, the age of workers is important for individual productivity it may be misleading to speak about an aggregated age productivity profile because productivity is a system attribute rather than a property of individual inputs (Prskawetz et al. 2006). This distinction is important because systemic changes may impact individual productivity. For example, technological changes could alter the interaction between workers and capital, increasing the importance of skills that deteriorate less with age (see the counterevidence section below). In such case, the productivity peak in Figure 2.2 would move to the right. Technological changes could also require fast adaptation to new technologies, a capacity that young workers seem to possess more than their older counterparts. Thus, it could also imply a movement of the productivity peak to the left (Vegard Skirbekk 2008).

- Counterevidence

The relationship depicted in Figure 2.2 seems intuitive; however, empirical evidence does not fully support it. Some studies that use employee-employer data sets find a flat or non-decreasing relationship between productivity and age (Göbel and Zwick 2012; Mahlberg et al. 2013). The discrepancy may be due to a specification problem. For example, the inverted u-shape could be the result of endogeneity issues (Aubert and Crépon 2006; Goebel and Zwick 2009).

It is also possible that age does not determine an absolute productivity advantage or disadvantage, but rather suggests a pattern of comparative advantage across activities. The old may be worse than the young at certain things, but better at others (Bussolo, Koettl, and Sinnott 2015). For instance, not all cognitive skills are negatively affected by ageing. Table 2.1 contains a summary of the effects of ageing over cognitive functions made by Bussolo, Koettl, and Sinnott (2015) based on the reviews by Cai and Stoyanov (2016) and Wieczorkowska-Wierzbinska (2014). As shown in the table, while many functions decline with ageing, others remain stable and two even improve.

Table 2.1 Effects of ageing on Various Basic and Higher-Level Cognitive Functions

Function	Subfunction	Impact of Ageing	Remarks
Working Memory	Attention resource allocation	Negative	Impaired for various tasks that require high attention.
	Speed of information processing	Strongly negative	Could affect the processing of more complex tasks.
	Inhibitory control	Unclear	Unclear if older people can suppress irrelevant information.
Memory	Episodic memory	Strongly negative	Ability to remember context declines.
	Semantic memory	Positive	Older people have larger knowledge set.
	Autobiographical memory	Stable	Some decline in remembering context.
	Procedural memory	Stable	Ability to keep existing and acquire new skills and procedures is preserved.
	Implicit memory	Stable	The brain can draw on accumulated experience at older age.
	Prospective memory	Negative	Can be improved with reminders.
	Short-term memory	Stable	
Attention	Ability to concentrate	Stable	
	Selective attention	Weakly negative	Older people require slightly more time to focus selective attention.
	Dual tasks	Negative	Older people require more time to divide or switch attention.
Perception	Hearing and vision	Negative	Hearing and vision impairments can often explain age-related gaps in cognitive performance.
Higher-level cognitive functions	Language and speech	Strongly positive	Discourse skills especially improve with age.
	Decision making	Unclear	Older people rely more heavily on prior knowledge and less on new information.
	Executive control memory	Unclear	Fluctuations in efficiency over time, with a possible increase in inefficient episodes with age.

Source: Bussolo, Koettl, and Sinnott (2015)

Moreover, the brain has a remarkable ability to compensate for specific cognitive functional decline throughout improved performance in other functions, for example by compensating age-related memory decline with greater reliance on accumulated experience (Bussolo, Koettl, and Sinnott 2015). Similarly, although motor functions, physical strength, and perceptional capacity (seeing, hearing, feeling) decline with ageing, the body has the ability to maintain functions that are needed routinely. A good example is grip strength: while grip strength peaks at the age of 35 and declines quickly thereafter in the general population, this might not be true among workers who rely on their grip strength every day (Bussolo, Koettl, and Sinnott 2015).

- Cohort effects

Even if the curve has a u-shape at one point in time, some papers state that cohort effects may lessen the effects of population ageing over productivity because subsequent cohorts may be better educated and healthier.

For example, Lutz (2009) uses global population projections by age and education level to show expected changes in the educational composition of the elderly. His results indicate that population ageing will be accompanied by increasing education attainment. Given the strong relationship between education and health, Lutz predicts that this trend will be accompanied by decreasing levels of disability. Furthermore, increasing levels of education are also correlated with improving cognitive skills. Hence, even though future populations will be chronologically older, based on cohort improvements they may be cognitively younger (Baker et al. 2015; Vegard Skirbekk et al. 2013).

Incorporating cohort effects can also important help avoiding wrong interpretations about productivity and ageing that arise when looking at cross sectional data. For example, Bussolo, Koettl, and Sinnott (2015) exemplify this using a distribution of workers by age and industry in Poland. When they look at cross-section data, they find that the average worker in agricultural and elementary sectors is older than in the service sector, which could be interpreted as younger workers been relatively more productive in

the service sector. However, if the relative youth of service sector occupations is the consequence of age characteristics, then different cohorts should move away from services as they age, which is not the case.

Cohort effects can be interpreted using Figure 2.2 as an upward parallel shift of the productivity profile, where workers are more productive at all ages. This means that, an increase in the share of workers of less productive age groups could still affect average productivity; however, the upward shift in the profile "hides" the effect of ageing. In the end, the observable level of productivity per worker will depend on the interaction between these and other effects, including capital levels and technological change.

- Environment change

In addition to the conflictive evidence described above, the labour environment is not static and the characteristics that are relevant for productivity may change. For example, Sharpe (2011) suggests that the importance of physical strength and bodily coordination has been outranked in the labour market by cognitive abilities (analytical, numerical and communications skills) which are less afflicted by age, reducing negative consequences of population ageing.

Gordo and Skirbekk (2013) study how technological changes have affected age and cohort work specialization and also indicate that physical work has generally declined for most age groups. Workers in their 50s experienced a more rapid growth in cognitively intense tasks (including tasks that require higher fluid cognitive ability) which they interpret as evidence against studies suggesting that technological change leads to negative relative lower productivity for older workers.

2.2.1.2 Productivity per worker using macro-data

This section surveys studies that analysed the age-productivity profile using macro-data. All of them introduced the population age structure into growth accounting frameworks. The main mechanism is the same as in the previous section, individual workers have productivity age-profiles; thus, changes in the age composition of the labour force should affect average productivity.

For example, Lindh and Malmberg (1999) analysed how changes in relative size of age-groups in the general population affect productivity. In line with the evidence described in the previous section, their results also suggest an inverted u-shaped age-productivity profile; however, in comparison to the previous and this section (see below), the prime work-age is higher. Additionally, Lindh and Malmberg look at GDP per capita which does not give information about the channels behind the relationship or what is happening to productivity per worker. Both issues are addressed by Feyrer (2007) and Feyrer (2008) which are the most cited paper from those discussed in this section.

Feyrer (2007) regresses output per-worker on the proportion of age-groups in the labour force. Again, in line with evidence supporting an inverted u-shape profile, Feyrer found that an increase in the share

of middle-aged workers (40-50) increases average productivity, while the share of young (20 to 39) and older workers (50+) does the opposite. Additionally, using a growth-accounting approach, output per worker is decomposed into the contribution from physical capital, human capital, and total factor productivity (TFP) to show that the main effect takes place through changes in the latter. Feyrer (2008) extends his previous work by incorporating evidence of two channels connecting ageing and productivity, innovation and management. For example, the paper examines the age distribution of patent holders in the United States which presents the same inverted u-shape age profile.

An important disadvantage of macro-studies measuring cross-country income differentials is the difficulty to overcome endogeneity in factor accumulation variables. For example, it could be argued that productivity effects immigration or labour force participation. To overcome this issue, Feyrer (2007) and Feyrer (2008) use lagged population proportions as an instrument for labour force proportions.

The National Research Council (2013) made a study about the implications of ageing for the United States. About Feyrer's work, the report stated its results showed an implausible pattern of coefficients -workers in the 40-49 age group have a "productivity bonus" of a factor of 10 relative to workers aged 30-39 and of a factor of 8 relative to workers 50-59, which it is much higher than what earning-profile statistics suggest. Thus, they re-estimated Feyrer's equations using linear, quadratic, and cubic functions of the average age. This results also showed a hump-shaped productivity-age curve; although, with a more realistic profile when compared to micro-data.

Maestas, Mullen, and Powell (2016) replicated and extended Feyrer's study with similar results using United States' data at the state level. Their sample within the same country is advantageous because states are affected by the same national pension systems, labour market institutions, and cultural retirement norms. Additionally, by decomposing GDP, they can distinguish and assign two-thirds of the reduction in growth to decreasing labour productivity and one-third to decreasing labour force.

Aiyar, Ebeke, and Shao (2016) used the same growth accounting framework, however, its focus is on older workers, measured by the ratio of workers aged 55+ to the total workforce. They find that an increase in this ratio is associated with a significant reduction in the growth rate of labour productivity. They also extend previous work by adding a new instrumental variable through lagged birth rates.

Jaimovich and Siu (2009) developed a similar analysis, but instead of economic growth, their focus aws on the impact of the labour force age-composition on growth volatility. Previous studies already indicated that younger and older workers are subjected to higher work volatility (Clark and Summers 1981; Rios-Rull 1996; Gomme et al. 2004). However, Jaimovich and Siu (2009) showed that, all else equal, there is greater cyclical volatility in market work and output when an economy is characterized by a large share of these workers.

In comparison to these studies, Mahlberg et al. (2013) did not find the same age-profile when applying similar methods to EU data. For example, their results showed that an increase in the share of younger workers is associated with increasing GDP per capita growth rates. By disaggregating labour force age groups according to their educational attainment, the authors argue that this finding could be explained by increasing education of younger cohorts. Nevertheless, part of the effect persists. Furthermore, the coefficients of older-age groups are insignificant.

2.2.2 Labour quantity: Workers as a share of population

Similar to the studies in the previous section, the ones included here use growth-accounting models to measure how population ageing will affect growth. However, the focus is on quantity (the size of the labour force) instead of quality (individual productivity).

Bloom and Freeman (1986) made a theoretical but important contribution through their comprehensive review of the relation between population change components (fertility, mortality, and migration) and economic outcomes (labour supply and labour absorption). Specifically, the authors where the first, to our knowledge, to distinguishing between pure accounting and behavioural demographic channels.

The accounting channel (the one we address in this section of the review) is related to the size of the working age population with regards to the total population. During the stages of a typical demographic transition (from pre-industrial high fertility and mortality to post-industrial low fertility and mortality) the ratio of the economically active population to the total population (known as the support ratio) will first decrease, then raise, then decrease again. The jump in the support ratio during the second stage of the cycle can inflate the rates of growth per capita transitionally creating an effect known as the "demographic dividend" or "demographic gift".[9] The second channel distinguished by Bloom and Freeman is based on choices over the life cycle. For instance, how changes in the population structure could affect human capital investment or the average savings rate of the economy. We address this type of effects in the next section.

Other studies followed the same framework, separating accounting and behavioural channels. This was facilitated by introducing demographic indicators in the theoretical growth framework developed by Barro (1991). For example, Bloom and Williamson (1998) modified this framework to measure output per capita instead of output per worker. This rearrangement yields the support ratio between the explanatory variables of the model. With this specification and panel data across countries, Bloom and Williamson estimated the importance of demographic dynamics in the "Asian miracle" during the

[9] The demographic dividend in the middle phase of the transition may or may not be realized. It represents a growth potential whose realization depends on other features of the social, economic, and political environment (Bloom and Williamson 1998).

1980s-1990s. A very similar framework is found in (Bloom and Canning 2001; Radelet, Sachs, and Lee 1997; Bloom, Canning, and Graham 2002; Bloom and Canning 2004; Kelley and Schmidt 2005).

The last stage of the demographic dividend is very much a consequence of population ageing. Work participation has a well-known age profile that is also shaped as an inverted u, -younger and older age-groups engage less in productive activities than middle-aged individuals. Thus, population ageing can reduce the support ratio and bring the demographic dividend to an end. Based on this dynamics, Borsch-Supan (2003) made a simple but illustrative exercise using population and labour participation projections by age groups to estimate the effects of future demographic dynamics on Germany's economic growth. His results showed that the decline in the working-age population would "eat-up" around one third of long-term productivity growth. A similar exercise was performed by Bloom, Canning, and Fink (2011) who decomposed the growth rate of GDP per capita into changes in income per worker and changes in the support ratio. Both, Borsch-Supan (2003) and Bloom, Canning, and Fink (2011) considered different scenarios for the projections of labour participation by age groups. For example, considering catch-up in participation between sub-demographics or by estimating the effects of fertility over female participation.

Over the last decade, many studies have been using health data to estimate how certain health conditions affect economic growth through the accounting channel. Abegunde and Stanciole (2006) used data from the Global Burden of Disease database to measure how the labour force is depleted by selected chronic diseases, heart disease, stroke and diabetes. Then, they introduce this information in a Solow based accounting economic model to measure the impact of health conditions in terms of Gross National Income lost. This methodology has been expanded by similar studies (World Health Organization; World Economic Forum; Harvard School of Public Health 2011; Bloom et al. 2013; Lozano et al. 2013; Dare et al. 2015).

All these studies found that chronic conditions will be very costly in terms of lost output; however, they measured lost gross national income instead of income per-capita. The distinction is important because a decrease in death rates from chronic diseases would rise both, the working and non-working populations. Hence, even though income increases because there are more workers in the economy, income per capita may not, as the denominator (total population) also increases. In other words, a decrease in mortality at old age without a change in the rate of labour participation of older individuals would reduce the support ratio, decreasing income per capita.

Additionally, these papers address the impact of diseases through mortality but not morbidity. Their models simply assume that sick individuals either do not work or die instantaneously; there is no spectrum of productivity associated with the severity or type of illness. This last limitation was addressed by Bloom et al. (2017) which expanded the framework incorporating effects of morbidity on labour force participation.

2.2.3 Behavioural effects: Consumption, saving, work, and leisure

The last channel that we discuss in the literature review relates to changes in the population age-structure that may affect productivity through patters in individual behaviour. Usually, individuals follow a defined sequence for the allocation of time and resources (work, leisure, consumptions, saving, etc.) along their life-cycle. For example, older individuals may have a lower average saving rate; thus, population ageing could, decrease the economy-wide average saving rate, slowing down economic growth.

2.2.3.1 Population age-structure and savings

Already in 1958, Coale and Hoover hypothesised about the relationship between population change and savings. Their study postulated that high dependency due to an increase of younger or older individuals raises consumption at the expense of savings. During the 1990s, many publications confirmed this relationship analysing macro data (Collins 1991; Harrigan 1996; Higgins 1998; Kang 1994; Kelley and Schmidt 1995; Taylor 1995; Taylor and Williamson 1994).

A subsequent wave of studies that we addressed in the previous section which built over growth accounting models, pushed forward the analysis, connecting dependency and savings with economic growth (Bloom and Williamson 1998; Bloom and Canning 2001; Radelet, Sachs, and Lee 1997; Bloom, Canning, and Graham 2002; Bloom and Canning 2004; Kelley and Schmidt 2005). In addition to the accounting channel explained previously, these studies explored the behavioural channel by introducing old and young-dependency ratios in their econometric analysis. Their findings suggest that dependency rates play an important role boosting or slowing economic growth thorough aggregated saving.

Malmberg (1994) also proved the significance of this channel using growth accounting models, albeit with a different estimation strategy divided in three steps. The author first estimated the relationship between growth and the population age structure using Swedish macro-data and found the hump-shaped pattern that we mentioned many times in this review. In a second step, Malmberg used the same specification but replaced the dependent variable by the gross savings rate of the economy and found a similar but not equal relationship, suggesting that savings rates variation is not the only factor involved. In the last step, the author separated the effects of the population structure related to savings from other channels by estimating the same relationships but controlling for the former.

Given the results from Malmberg (1994) and those described before, one may be tempted to generate projections of future aggregated savings using a distribution of saving rates for different age-groups and demographic projections. However, this exercise entails great uncertainty, as we do not know how young and middle-aged will respond to changes brought on by an aging population. They may save at a higher rate than past generations if they anticipate reductions in public health and retirement benefits because of increased longevity. On the other hand, they might save less if they plan on working longer (National Research Council 2013). Moreover, the paths for individual and aggregated consumption and

investment differ considerably under different contexts of interregional financial flows. For example, population aging has significantly less influence on these macroeconomic variables in an open economy than in a closed economy where the average variation of financial flows is lower (National Research Council 2013).

2.2.3.2 Population age-structure, health, and capital accumulation

A cross-section comparison between individual health spending and age shows high positive correlation between the two variables (OECD 2016). If this relationship stays constant in time, population ageing would substantially increase total health spending (Longman 1987; Amaglobeli and Shi 2016; Acosta Ormaechea, Wachs, and Espinosa-Vega 2017). Many studies have criticised this idea suggesting that individual health spending may be explained by mortality rather than age. Given that one of the causes of population ageing is decreasing mortality at old age, the aggregated change in health spending may be lower (Dormont et al. 2007; de Meijer et al. 2013). Although, this debate is not closed; the constant age spending relationship could be interpreted as a worst-case scenario indicating how much would total spending increase if everything expects the size and age structure of the population stays constant.

A substantial increase in public health spending due to population ageing would crowd out spending from other productive activities. For example, by diverting investment in education and infrastructure, impeding the accumulation of physical and human capital. The studies that we covered in Section 2.2.2 which estimated how health conditions affect economic growth through the accounting channel also looked at this channel by introducing these dynamics in a Solow based growth model (Abegunde and Stanciole 2006; World Health Organization; World Economic Forum; Harvard School of Public Health 2011; Bloom et al. 2013; Dare et al. 2015).

2.2.3.3 Population age-structure and consumption

Borsch-Supan (2003) and Albuquerque and Lopes (2010) analysed the connection between population ageing and consumption patterns across life to identify future trends in the composition of consumption, however, the authors did not extend the analysis to possible implications for economic growth. Both studies used cross sectional consumption data and demographic projections for different age-groups to identify industries that are likely to be affected by population ageing.

Cutler et al. (1990) used data of fertility, mortality, and labour force participation rates, and spending of different age groups to calculate a sort of support ratio, age groups are weighted by their relative consumption needs. Their projections for the United States showed that dependency will increase faster if consumption needs are taken into consideration. Sheiner (2014) introduces this ratio in a growth model with changing demographic structure to determine a consumption possibilities frontier. A type of budget constraint that illustrates what level of consumption can be maintained given a level of capital per-worker and population age-groups projections. The results of these studies depend on both, accounting and behavioural effects. The former, because the consumption possibilities frontier is

determined by the ratio of workers to consumers in combination to available capital. The latter, because consumption and savings by age are key behavioural assumptions determining the level of capital per worker in.

2.3 Empirical analysis for Argentina

In this section we explore the channels described in the literature review using Argentinian data. We start by analysing where Argentina is in the demographic transition; thus, we look at the size of the working force in relation to the total population. Then, we analyse how the age composition of the labour force may affect productivity using two frameworks described in the literature review, Feyrer (2007) and Borsch-Supan (2003). Both models generate projections of productivity by aggregating labour force age groups weighted by a productivity factor; however, they rely on strong assumptions about the age productivity profile of workers. Hence, in the last section, we complement the analysis with projections of qualitative indicators that should affect the productivity of those age groups - educational attainment and disability prevalence.

2.3.1 The support ratio

This section analysis how the change in the ratio of the labour force to the total population (the support ratio) will affect productivity, i.e., the accounting channel (Bloom and Freeman 1986).To measure the ratio, we used demographic projections from the United Nations (United Nations, Department of Economic and Social Affairs 2019) and labour force participation by age group from ILO (ILO 2017). The latter provides projections until 2030, so we kept the last available number constant for the remaining years. Figure 2.3 shows the results for Argentina between 2015 and 2100. The country is still enjoying the demographic dividend provided by the second stage of a typical demographic transition, when the ratio of the economically active population to the total population is still growing. The increase is projected to pick around 2040 and then decrease very slowly, only by 3 percent between 2040 and 2100.

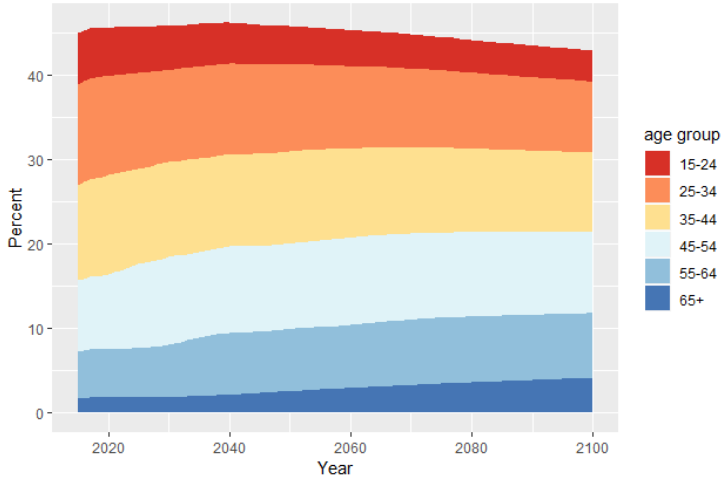

Figure 2.3 Labour force as a percent of total population, by age group (2015-2100)

Source: Population projections from United Nations, Department of Economic and Social Affairs (2019), labour force participation rates from ILO (2017), and authors' own calculations as explained in the data section and online appendix.

To assess the impact of the changes of the support ratio on productivity, we used a typical Solow-Swan growth model that defines GDP per capita in terms of labour capital and total factor productivity. Then we compare two scenarios, one using our projections of the support ratio and one that maintains the ratio constant until 2100. The results indicate that, in 2100, the working population will need to be around 5 percent more productive than in 2015 to maintain the production per capita of consumer and capital goods, which equals an increase in the historical total factor productivity growth rate of 0.06 percentage points, from 1.2 to 1.26 percent, (Borsch-Supan 2003).[10]

Figure 2.3 also shows the decomposition of the ratio into labour force age groups. The decrease in the number of younger workers (those below 44) is compensated by an increase in the number of older workers. This process has been occurring for the last decades and it is a consequence of two factors. A decrease in the population share of youth combined with a decrease in their labour participation, due to the demographic transition and longer periods in education. The opposite is happening with older age groups, increasing in number and their participation, the latter incentivised by changes in health and in the social security system (Gragnolati et al. 2015). Although, this age groups dynamics will help maintaining a stable ratio of workers to the total population, the changes in the composition of the labour force may have an impact on productivity itself. Hence, the next sections dig into this channel.

2.3.2 Labour force age composition following Feyrer 2007

In this section, re replicate the work of Feyrer (2007) which, to our knowledge, is the most cited study using macroeconomics and demographic data to study the relationship between productivity and

[10] The historical TFP growth rate comes from Feenstra, Inklaar, and Timmer (2015).

population change. As described in the literature review, Feyrer uses a Solow model augmented with human capital (Equation 2.1 below).

$$y_{i,t} = k_{i,t}^{\alpha}\left(A_{i,t}h_{i,t}\right)^{1-\alpha} \quad (2.1)$$

Where $y_{i,t}$ is production per capita in country i at time t, $k_{i,t}^{\alpha}$ is the level of capital per worker, $A_{i,t}$ is the total factor productivity and $h_{i,t}$ is human capital per worker. This equation can be re-written as:

$$y_{i,t} = \left(\frac{K}{Y}\right)_{i,t}^{\alpha/(1-\alpha)} A_{i,t}h_{i,t} \quad (2.2)$$

Applying logarithm to Equation 2.2 we get:

$$\log\left(y_{i,t}\right) = \frac{\alpha}{1-\alpha}\log\left(\frac{K}{Y}\right) + \log A_{i,t} + \log h_{i,t} \quad (2.3)$$

Equation 2.3 can be used to decompose movements in output. We focus on the most important channel according to Feyrer and other studies which is the effect of demographic changes over $A_{i,t}$. Following Feyrer, we will measure the following expression:

$$\Delta \log A_{i,t} = c + \beta_a \Delta \sum_{a=10}^{60} W_{a,i,t} + \beta_{OADR}\Delta OADR_{i,t} + f_i + \eta_t + \epsilon_{i,t} \quad (2.4)$$

Where, for a every country (i) and year (t) the change in the logarithm of TFP is explained by the differential of 10-year age groups shares ($\Delta W_{a,i,t}$) in the total labour force, the old-age dependency ratio, country fixed effects (μ_i), time fixed effects (η_t), and an error term ($\epsilon_{i,t}$). Notice the subscript a that refers to the age-groups. The goal below will be to estimate coefficients β_a and β_{OADR} and combine them with population and labour participation projections to generate productivity projections for Argentina.

2.3.2.1 Data and methods

We use productivity data from the Pen World Tables (Feenstra, Inklaar, and Timmer 2015). The OADR is calculated using UN population data (United Nations, Department of Economic and Social Affairs 2019). The shares of the labour force by age group are obtained using ILO standardized participation rates (ILO 2017) by age group in combination with UN population prospects data. The age-groups included are the same used by Feyrer (10 year age-groups, from 10-19 to 50-59, and workers with 60 or more years of age), except for the bottom age-group which ranges from 15 to 20 instead of 10 to 20 due to data limitations.

Since the shares of the labour force ($W_{a,i,t}$) are proportions that for each country-year pair add-up to one, a group is excluded. Feyrer chose to exclude $W_{40-49,i,t}$ because the 40 to 49-year-old age group generally has the highest coefficient when included. By excluding them, significant coefficients on the

other age groups indicate that they are significantly different from the implied zero coefficient on $W_{40,i,t}$.

We run our estimates for many samples including all available countries, OECD countries, and non-oil-exporters[11]. Additionally, As Feyrer, we use panel and time fixed effects including dummies for every country and year. Detailed information about data sources, a complete dataset, and our Stata codes can be found in an online appendix. In addition, we remind the reader that the purpose of this section is not to reinvent Feyrer's study, but to apply his analysis to assess one specific country, in combination with other methods. However, it is impossible to apply his design without replicating its analysis. Thus, to a lesser extent, this study re-tests the original hypothesis with updated data.

2.3.2.2 Results

Table 2.2 shows our regression results with the simplest specification, including all countries with data. We run the same regression for samples of non-oil exporter and OECD countries obtaining very similar results; although statistical significance of coefficients drops substantially for the latter. In comparison to Feyrer, our analysis consistently results in the highest coefficient for the 50-59 age-group, thus we choose to exclude this group in the regression. Consequently, significant coefficients of the labour force shares indicate that they are different from the implied zero coefficient on the 50-59 group. It could be argued that this discrepancy is related to structural changes in the labour market, which might be adapting to an average older labour force, as such evolution is discussed in the literature (Bussolo, Koettl, and Sinnott 2015). Following this reasoning, an interesting extension to this study would be to test for a structural brake in the ageing-productivity relationship. However, the data used for our study does not extend until the period covered by Feyrer (2007). Our main restriction are the standardized labour force participation rates from ILO that start in 1990.

Table 2.2 Regression of productivity on workforce age structure

ΔW15	-5.322
	(1.292)***
ΔW20	-2.848
	(0.911)***
ΔW30	-3.167
	(0.925)***
ΔW40	-3.197
	(0.835)***
ΔW60	-5.774
	(1.178)***
ΔDR	-0.341
	(1.214)
year = 1995	-0.054
	(0.028)
year = 2000	0.012
	(0.025)
year = 2005	0.029
	(0.023)
year = 2010	0.000
	(omitted)
year = 2015	0.000
	(omitted)
Observations	463
R-squared	0.283

Standard errors in parentheses.

Country dummies are ommited

**significant at 10%*

***significant at 5%;*

****significant at 1%*

Source: PWT, ILO, UN demographic data, and authors' own calculations as explained in the data section and online appendix.

According to the estimates, a 5 percentage point shift from the 30-year age group to the 50-year age group is

[11] The list of non-oil exporters comes from Grigoli, Herman, and Swiston (2017).

associated with over a 15 percent increase in the productivity growth rate. This result is similar to those presented by Feyrer; however, three important differences that are consistent in all our estimations should be mentioned. First, as mentioned above, we consistently find across all specifications and samples that the 50-59 age-group has the highest coefficient when included. Second, our coefficients are lower (more negative) for the bottom and top groups. In other words, our results show that a change in the composition of the labour force will have a higher impact over productivity. Third, the coefficient for $W_{60,i,t}$ is higher than that of younger age-groups. This is important because in an ageing labour force, this age-group may grow substantially.

The importance of these differences is determined by the specific change in the labour force composition that each country will experience. In the next sections we will explain this in detail by making projections for Argentina using our and Feyrer's main results.

2.3.2.3 Out of sample GDP growth projections

As Feyrer we generate out of sample projections to compare the predictions of our regression analysis against historical GDP growth rates. We obtain the projections using a regression between population age-groups shares and real GDP growth rates. The regression includes the whole sample of countries and years except for the last lustrum (2010-15) for which we generate the predictions. Figure 2.4 below depicts the comparison of projected and historical data. Additionally, a regression between the projections and the historical data yields a coefficient that is not significantly different from one and significantly different from zero at a 1 percent confidence level. However, the level of association and the significance of the coefficient are highly influenced by the sample of countries used.

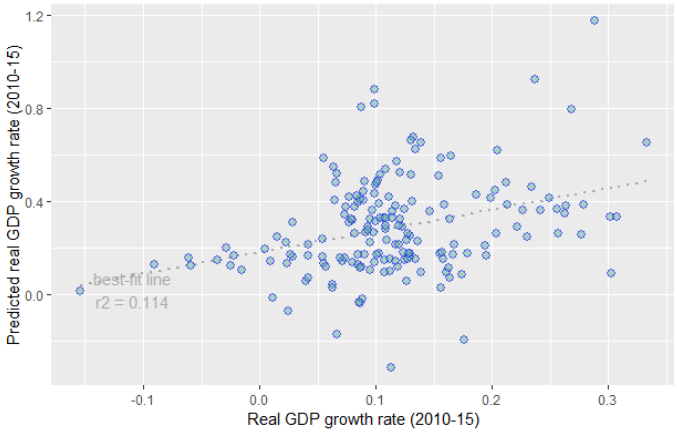

Figure 2.4 Out-of-sample projections of RGDP growth rate and RGDP growth rate (2010-15)

Source: PWT, ILO, UN demographic data, and authors' own calculations as explained in the data section and online appendix.

2.3.2.4 Projections

In this section, we show what our results mean for productivity and economic growth in Argentina. A similar exercise is performed by Aiyar, Ebeke, and Shao (2016) for OECD countries; however, their paper focuses on the effect of an increase in the oldest share of the working force. In their regression analysis, Aiyar, Ebeke, and Shao (2016) divides the working force in two groups, those above and those below 55 years of age, clustering all other age groups. We think that such approach would be incomplete, as the age-groups are too broad. An increase in the share of 60+ workers due to a decrease in the 30-59 group does not have the same effects as a reduction in the share of workers 15-29.

Figures 2.5 shows the data used for the projections of TFP. Notice in the left pane that Argentina is undergoing a rapid population ageing process (in chronological terms) as the share of 60+ workers is increasing at the expense of those below 39. However, the groups with the highest productivity according to Feyrer's and our analysis, 40-49 and 50-59, are projected to slightly increase, cushioning the negative effect of demographic change over TFP.

Figure 2.5.a Share of labour force age-groups. Argentina, 2015-2100

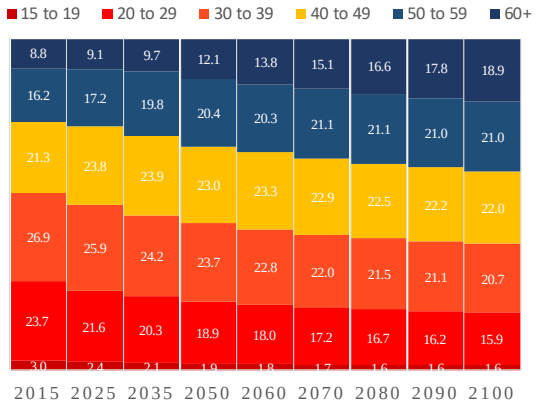

Figure 2.5.b Coefficients from regression analysis

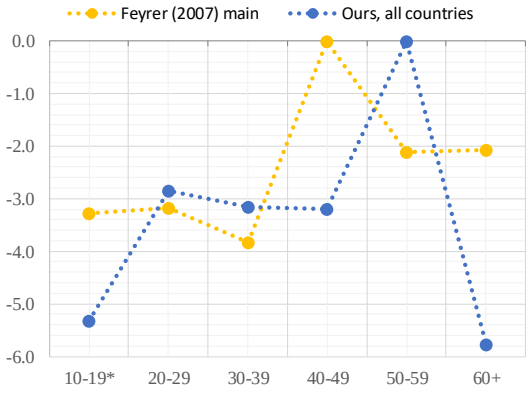

Figure 2.5 Assumptions for TFP projections, all figures in in percent.

Source: UN Population Prospects data; ILO standardized labour participation rates; and Feyrer (2007) table 1, column 2; and authors' own calculations. (*) We use data for the population aged 15-19 as this is the bottom age group in ILO standardized labour force participation rates.

Using the labour force projections in Figure 2.5.a, the coefficients yielded by the regression analysis Figure 2.5.b, and Equation 2.3 we obtain the estimations of future TFP growth rates that are displayed in Figure 2.6. The exercise yields two projections based on our and Feyrer's coefficients. In addition, we include projections based on constant TFP growth equal to the historical average in Argentina between 1990-2014. Figure 2.6.a shows TFP growth rates in the three scenarios. As the share of workers aged 40-49 and 50-59 is projected to increase in the close future, growth rates generated using Equation 2.3 actually increase in the first years of the projection; however, soon they drop below the historical average. Around the year 2065, the labour force age-structure and so does growth.

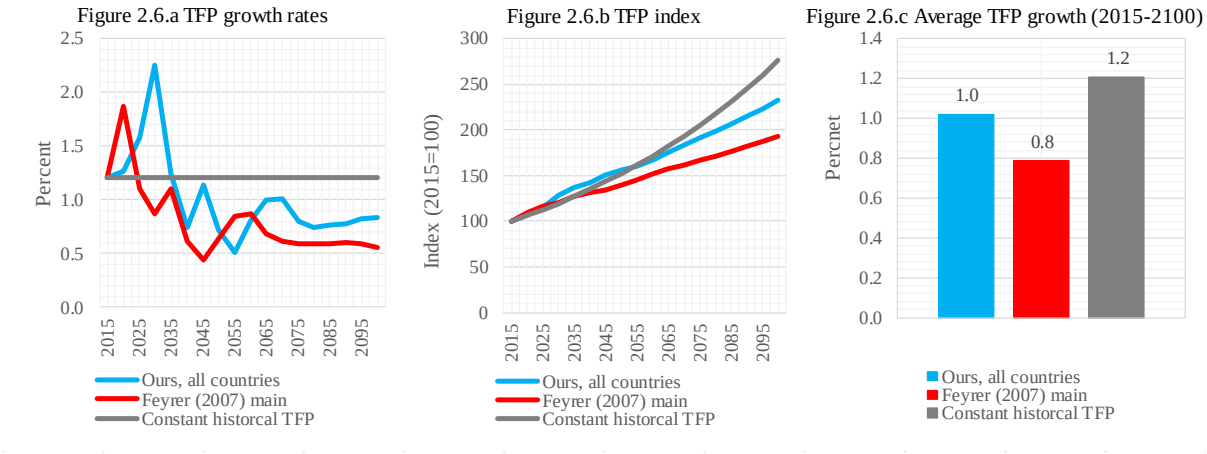

Figure 2.6 TFP projections based on three scenarios -constant historical growth rate, using Feyrer's coefficients, and using our coefficients in Figure 2.5

Source: Authors' own calculations. Note: Historical TFP growth is 1.2 percent during the period analysed in our main regression (1990-2014).

In comparison to the historical average of 1.2 percent, the average geometric growth rate drops by 0.2 using the projections generated with our estimations and by 0.4 percent when using Feyrer's coefficients. These are non-negligible figures, if TFP grew at its historical average by 2100, GDP would be 18 percent higher than in the scenario based on our coefficients and 44 percent higher than when using Feyrer's coefficients.

2.3.3 Labour force age composition using age productivity approximated through wages

Another method that we addressed in the literature review which projects productivity using the age composition of the labour force is to multiply the share of workers by age group by an index of productivity (Borsch-Supan 2003). This was done for Argentina by Gragnolati et al. (2015); however, their measure is expressed in aggregated terms, reflecting also changes in the size of the labour force which we already presented on section 2.3.1. Instead, our interest is on changes productivity per worker due to fluctuations in the labour force composition.

In practical terms, Gragnolati et al. (2015) calculates an index of total productivity $G_t = \sum_{e=15}^{E} l_{e,t} N_{e,t} EAP_{e,t}$ where $l_{e,t}$ is productivity, $N_{e,t}$ is population size, and $EAP_{e,t}$ is participation, all by age group e and at time t. We amend this measure dividing the index by the total labour force $\sum_{e=15}^{E} N_{e,t} EAP_{e,t}$. As $l_{e,t}$ is assumed constant over time, the only factor affecting total productivity is the age composition of the labour force.

Using the specification describe above, the salary index for Argentina from Gragnolati et al. (2015), and the labour force projections already presented in the Section 2.3.1 we find that, by 2100, the working

population will need to be around 2.3 percent more productive than in 2015 to maintain the production per capita of consumer and capital goods. This is equivalent to an increase in the historical total factor productivity growth rate of 0.03 percentage points, from 1.2 to 1.23 percent (Borsch-Supan 2003).

The projections of the sections above assume that the age-productivity profile of the population (either, the salary index, or coefficients β_a in Equation 2.3) stays constant through time; however, as discussed in our literature review, there are many reasons to believe this will not be the case. In the next section we use Argentinian data to discuss some of the most important arguments against this assumption.

2.3.4 Cohort effects through education

Figure 2.7 uses data from the Human Capital Explorer which contains projections of educational attainment by age group and country (Lutz et al. 2018). The projections for Argentina are auspicious, population ageing will be accompanied by increasing education attainment. For all age groups, the average years of education will increase substantially; however, the greatest increase will be experienced by the population aged 60+ (almost 1.6 folds, from 8.2 in 2015 to 12.6 in 2100).

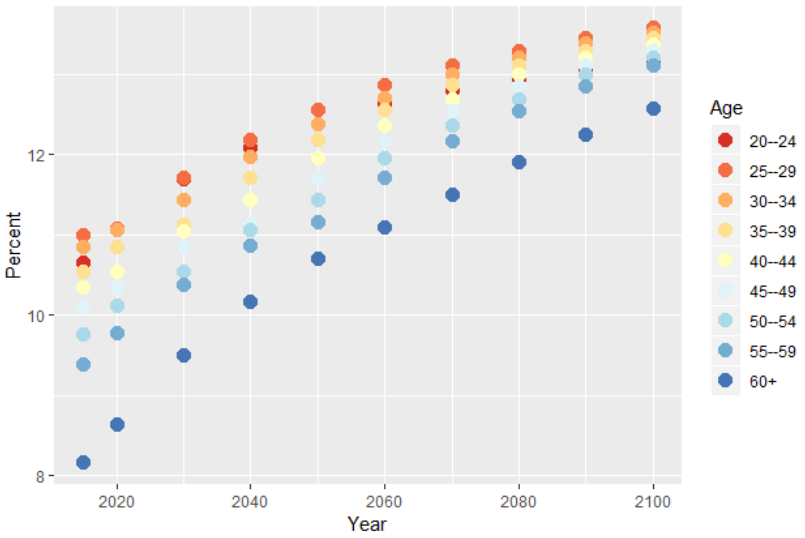

Figure 2.7 Average years of education by age group. 2015-2100.

Source: Human Capital Explorer (Lutz et al. 2018)

Figure 2.8 depicts the same type of evidence with a different scale. Both charts on the left contain Argentina's population stocks (60+ bottom and 15-69 top) divided by levels of educational attainment. Levels below or equal to "lower secondary" are in shades of blue and those above it are in shades of red. This colour partition is not arbitrary, by 2015, one half of the population aged 15-59 and more than two thirds of those 60+ have an attainment level equal or below "lower secondary". By 2100, these shares are projected to decrease to around 9 and 13 percent, respectively. Moreover, the shares of the

respective populations with higher attainment levels (those in red) are expected to increase at the expense of those in blue, except for "lower secondary" in the population 60+.

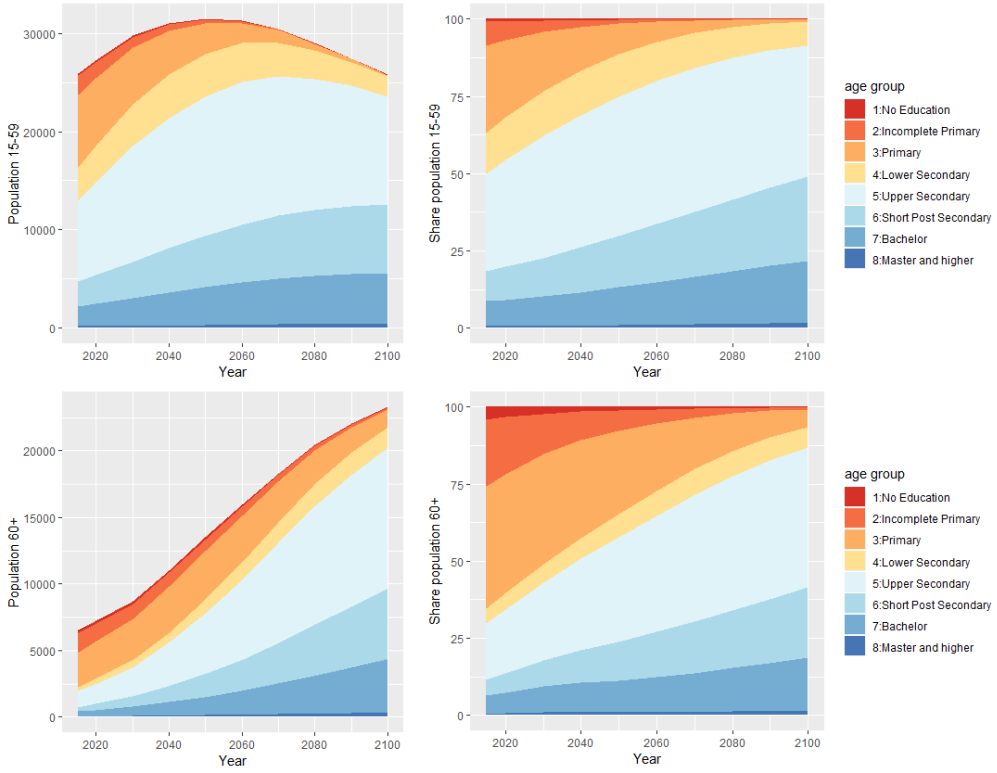

Figure 2.8 Argentina, stocks of education. Population 15+ and 65+. 2015-2100.

Source: Human Capital Explorer (Lutz et al. 2018)

The groups at the top and bottom of the figures are difficult to analyse visually, as they encompass small shares; however, their evolution is also worthy of note. Those with no education will drop from 1 (population 15-59) and 4 percent (population 60+) to 0.02 and 0.2 percent, while the share of the population with master's or higher attainment will increase two and three folds, respectively.

As mentioned in the literature review, increasing education levels may be associated with higher cognitive skills. Hence, even though future populations will be chronologically older, based on cohort improvements they could be cognitively younger (Baket et al 2014; Skirbekk et al. 2013 (paper about Flynn effect)). Moreover, given the strong relationship between education and health indicators, this transition could be accompanied by decreasing levels of disability (Lutz 2009).

2.3.5 Cohort effects through health

Figure 2.9 contains data comparing changes in life expectancy and morbidity for the Argentinian population. The panel on the left depicts historical and projected changes in life expectancy for different age groups. For example, life expectancy is around 3 years higher for someone aged 20 today than for a person aged 20 in 1990, and it is projected to increase by another 10 years by 2100.

Increases in life expectancy are generally considered a sign of development; however, the same trend contains a hidden risk. The rate of non-fatal health conditions, like disability, generally increases with age; thus, without a change in rates of prevalence, living until older ages may be accompanied with increasing disability among the population. Such scenario would limit the capacity of older people to stay active.

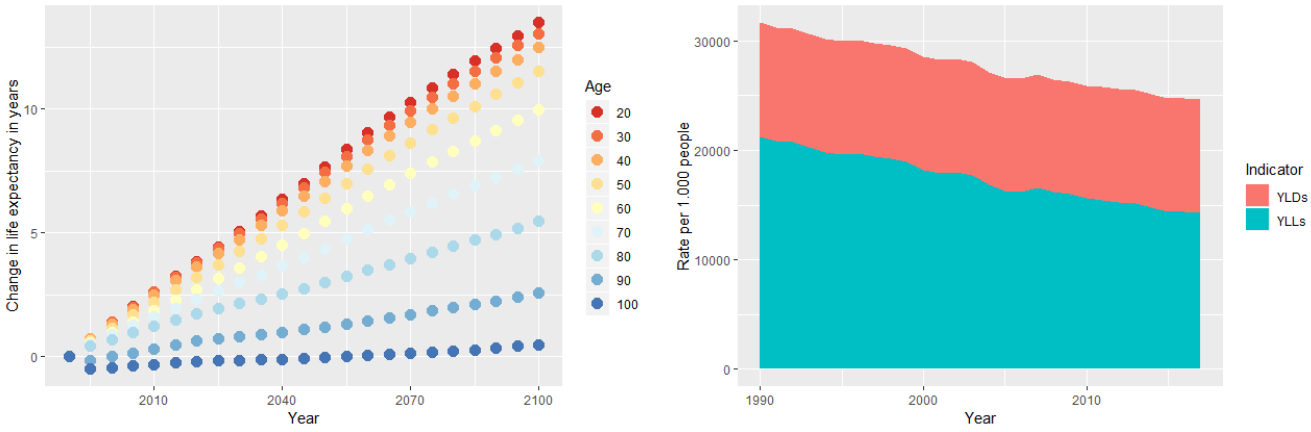

Figure 2.9 Change in life expectancy (1990-2100) and DALYS (1990-2017), in Argentina

Source: Life expectancy data from United Nations, Department of Economic and Social Affairs (2019) and disability data from Institute for Health Metrics and Evaluation (2017). Note: Disability indicators on the right pane are age-standardized.

The right pane in Figure 2.9 depicts the evolution of disability adjusted life years (DALYS) in Argentina. DALYS is an indicator of healthy life lost due to disability or premature mortality. Thus, the sum DALYs across the population can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability.[12] On average, in the 1990s, an Argentinian person would lose more than 30 years due to disability or premature mortality; however, that number has decreased steadily for the past 25 years reaching around 25 years in 2017.

[12] More information about how DALYS and its components are calculated can be found here https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/

DALYS can be disaggregated in its components of mortality (YLLs) and disability (YLDs) which are represented by the red and green areas on the right pane of Figure 2.9, respectively. Following this decomposition, we can see that between 1990 and 2017, DALYs have dropped due to an increase in years lived (a decrease in YLLs) while YLDs stayed almost constant. In the context described on the first paragraph of this section, this could be interpreted as good news. The increase in years lived was not accompanied by an increase in the prevalence of disability. Thus, at least through this measure, the numbers of years lived in good health (healthy life expectancy) has been increasing for almost three decades.

In fact, similar data was use by Souza, Queiroz, and Skirbekk (2019) as an argument in favour of increasing the retirement age in Argentina and other Latin American countries. The authors compared historical data on mortality risk and overall disease burden with labour force participation for different age cohorts across time and concluded that health does not present a barrier to raising the retirement age in Latin America.

For the last image of this section (Figure 2.10), we borrow the qualitative indicator of population ageing that we developed in our first chapter, the disability dependency ratio, which uses the data depicted in figure 8 to project future dependency. The disability dependency ratio combines the rates of YLDs for different age groups with the share of those age groups in the total population and then calculates the ratio of individuals aged 20 or higher with disability to the rest of the population aged 20 or higher. We use age group population projections from the UN and different scenarios for the rates of disability prevalence, including (1) constant prevalence (DDR_CP), where we keep the disability prevalence rate constant for each age group at its last historical value available; (2) past trends (DDR_PT), where we project prevalence rate for each age group by setting the average annual percentual change in the prevalence rate equal to the observed average percentual change in historical data; (3) life expectancy (DDR_LE), where we estimate the relationship between disability prevalence and life expectancy using a panel regression for each age-group and then forecast the prevalence rates using life expectancy projections from the UN; and (4) catch up (DDR_CU), where the disability prevalence rate of each age group "catches-up" between 2015 and 2100 at a constant rate, with the rate of the country with the lowest prevalence in 2015.

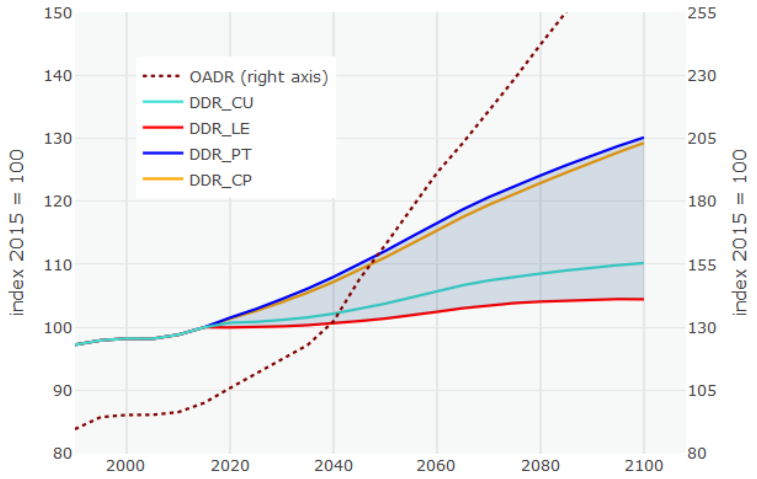

Figure 2.10 Qualitative dependency ratios for Argentina. 1990-2100

Source: United Nations, Department of Economic and Social Affairs (2019) and Institute for Health Metrics and Evaluation (2017), and authors' own calculations. Note: Methods described in Chapter 1. OADR measured on the right axis.

The lines in Figure 9 represent different DDR scenarios (all re-escalated to 2015=100 to ease comparability) and the OADR which is measured on the right axis. The blue area covers the range between the bottom and top scenarios. All DDR scenarios depict a slower pace of ageing than the OADR, which is consistent with or finding in Chapter 1. The best and the worst scenarios for Argentina are found when disability prevalence is predicted by changes in life expectancy and past trends, respectively. Unfortunately, predicting what scenario will prevail is a complex task that exceeds the scope of this chapter. At most, we can state that, if Argentina is able to improve its health indicators to catch-up with countries that display lower levels of disability, the pace of dependency may be considerably slowed.

2.4 Discussion

A comprehensive review of data and channels for Argentina shows noteworthy but not alarming future effects of population ageing on productivity.[13] Argentina is still enjoying the demographic dividend provided by the second stage of a typical demographic transition. The transition is expected to pick around 2040 and then decrease very slowly by 3 percent between 2040 and 2100. Using a Solow-Swan growth model the projections show that, in 2100, the working population will need to be around 5 percent more productive than in 2015 to maintain the level of production per capita. This is equivalent

[13] This review is focused on productivity. Other direct consequences of population ageing like its effects over the fiscal sustainability of public pension and health care systems are more dramatic (International Monetary Fund 2016; Acosta Ormaechea, Wachs, and Espinosa-Vega 2017).

too an increase in the historical total factor productivity growth rate of 0.06 percentage points, from 1.2 to 1.26 percent (Borsch-Supan 2003).[14]

A regression analysis using Feyrer's method showed that the long-term annualized productivity growth rate may be reduced between 0.2 and 0.4 percent, depending on the assumptions. These are non-negligible figures, if TFP grew at its historical average, by 2100, GDP would be 18 percent higher than in the scenario based on our coefficients and 44 percent higher than when using Feyrer's coefficients.

We carried a similar analysis using a fixed distribution of salaries by age group for Argentina from Gragnolati et al. (2015) and labout force projections. This method yielded less worrying results, by 2100, the working population will need to be around 2.3 percent more productive than in 2015 to maintain the production per capita of consumer and capital goods. This is equivalent to an increase in the historical total factor productivity growth rate of 0.03 percentage points, from 1.2 to 1.23 percent (Borsch-Supan 2003). However, using salaries as an approximation for productivity may sub-estimate the impact of ageing, as the right side of the salary curve may be flatter than productivity (Mahlberg et al. 2013).

These projections assumed a constant age-productivity profile; however, as shown in the literature review, many studies challenge this assumption. Thus, we complemented the analysis based on the age-structure of the population with projections of qualitative indicators that should affect the productivity of those age-groups -educational attainment and disability prevalence.

Projections of educational attainment for Argentina showed that, in the next decades, all age groups will substantially increase their average years and level of education. Moreover, the increase is particularly important for individuals aged above 60. Currently, less than a third of them have an education of "upper secondary" or above; however, by 2100, this share is expected to be around 90 percent.

Health projections also bring positive news. A qualitative analysis proved to be less worrying than a purely chronological examination of dependence, as the pace of ageing in Argentina is much slower using our DDR than the OADR. However, the exact path of future dependence is unsure, and a lot will depend on the capacity of the country to decrease rates of disability prevalence.

2.5 Conclusion

In this chapter I analysed how population ageing and economic growth are related. A literature review allowed me to identify four clusters of research according to the channels and data analysed. (1) Ageing and productivity per worker using survey data of firs or workers' demographic characteristics and

[14] The historical TFP growth rate comes from Feenstra, Inklaar, and Timmer (2015).

indicators of their productivity; (2) Ageing and productivity per worker using country level data of the population's age-structure and average productivity; (3) Growth-accounting models that measure the effects of changes in labour participation due to population ageing over growth; and (4) Studies that analyse how population ageing can affect growth through the individual behaviour.

The conclusion from the literature review is that there is no consensus about the ageing-growth relationship. However, we were able to identify specific parameters that influence the shape of the relationship and could determine the path for different countries, including the speed and intensity of the demographic transition, economic and labour market institutions, and the future trajectory of individual attributes that influence productivity -health and education. Building over the channels and data identified in the literature review, I carried an empirical analysis for Argentina that found noteworthy but not alarming future effects of population ageing on productivity. A natural extension of this study would be to apply the same empirical analysis to several countries, which could help identifying policies that improve the probability of a successful demographic transition in economic terms.

Chapter 3

An application of our DDR to pension systems with automatic adjustment mechanisms and endogenous growth

Abstract

In response to population ageing, many countries have adopted automatic adjustment mechanism reforms that link retirement to life expectancy. In this chapter, we used an overlapping generations model to analyse the effects of such reforms over fiscal sustainability, adequacy, and fairness of public pension systems. We looked at three scenarios defined by the mechanisms indexing retirement age: a constant pensions fiscal balance, constant life expectancy after retirement, and constant disability-free life expectancy after retirement. Growth is exogenous in our standard model; however, we explore an alternative model with endogenous productivity partially determined by ageing. We applied our model to Argentina's public pension system as an example. Our results show that an automatic adjustment mechanism based either on increases in life expectancy or disability-free life expectancy would not be enough to restrict the projected growth in the pension system's deficit. We also find that changes in productivity have limited effect on pension indicators, although the indexation system can amplify or reduce such effects.

3.1 Introduction

Chronological ageing and the associated raise in the old-age dependency ratio (OADR) implies that the number of potential pension beneficiaries will increase with respect to the number of potential contributors (United Nations 2017). For many countries, this implies that, ceteris paribus, public pension spending will increase while contributions decrease (Figure 3.1).

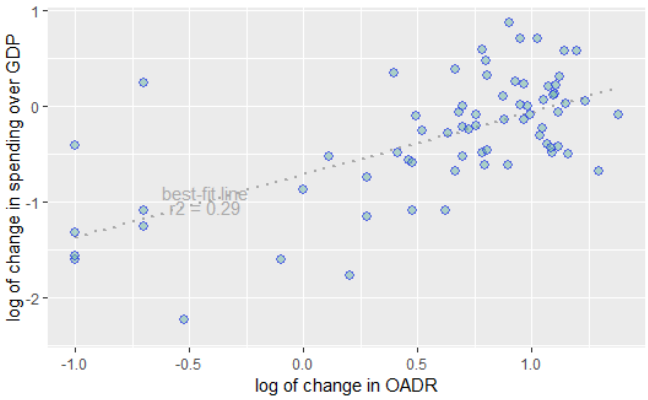

Figure 3.1 Projected increase in pension spending over GDP and OADR by country, 2018-2030.
Source: (IMF 2019b), United Nations World Population Prospects database, and authors own calculations
Note: Dotted line shows the best fit line. Negative numbers are omitted to generate a logarithmic conversion.

Consequently, many countries adopted automatic-adjustment mechanisms (AAMs). AAMs create automatic links between demographic or economic developments and pension system parameter, particularly benefit levels (OECD 2012). In other words, they alter pension benefits and/or contribution formulas to account for pressures arising from demographic changes or other variables that affect the system's cashflow. Therefore, AAMs not only have the capacity to eliminate fiscal imbalances but can also ameliorate fiscal repercussions associated with uncertainty over projections by incorporating all possible scenarios into the calibration of parameters.

Other advantages of AAMs include their capacity to solve time inconsistency issues between the government (as the regulator of the system) and the system participants. The fiscal sustainability of pension systems is a long-term problem that requires discounting contributions and expenses throughout the life of its participants. However, governments have short-term incentives based on electoral cycles that usually last between four and seven years. Furthermore, austerity policies such as reducing pension benefits or raising contributions are politically unpopular. AAMs help solving this inconsistency by withdrawing the political cost of pension systems reforms from the government.

AAMs do not eliminate the cost from future adverse demographic conditions. Costs are only reassigned and who will bear them depends on the mechanism's rules. For example, AAMs, that affect the contribution rate will impact contributors and those that modify the indexation formula will impact the

beneficiaries. Furthermore, if the impact over these groups is too strong, policy-makers will be tempted to by-pass AAMs. Examples of this unintended consequence are the strong political backlashes in Spain and Germany after their incorporation of such mechanisms (Boersch-Supan and Wilke 2004; de la Fuente, García Díaz, and Sánchez 2017). Nevertheless, there is scarce research on non-fiscal consequences of AAMs, such as the effects over adequacy and fairness of the reforms (Alonso-García, Boado-Penas, and Devolder 2018).

AAMs is are also controversial when they target eligibility. While increasing the retirement age appears to be a natural extension of improved life expectancy, the extent to which workforce participation can be pushed into later years is worthy of consideration. Life expectancy is a measure of quantity of life and is significantly longer than measures of quality of life such as healthy life expectancy and disability-free life expectancy (Jagger et al. 2008; Marmot and Bell 2012; Souza, Queiroz, and Skirbekk 2019).

The objective of this chapter is to develop a methodology to measure the fiscal consequences of AAMs as well as those over the system participants. For this task, we develop an overlapping generations model (OLG) that incorporates one of the most common AAM, an automatic increase in the retirement age. Our model tracks the contributors and benefits from different age-cohorts. Then, we use those projections to measure how some of the most common pension indicators of adequacy and fairness are affected.

We incorporate the characteristics approach into our model to calibrate the increase in retirement age based on qualitatively indicators of population ageing (Sanderson and Scherbov 2013). We compare four cases, (1) a baseline scenario with no change in eligibility conditions, (2) an indexation of retirement age to life expectancy, (3) an indexation to disability-free life expectancy, and an increase in the retirement age that fixes the pension system fiscal balance to its last historical value.

In our standard model, growth is exogenously determined using historical data; however, we consider a robustness scenario by including a channel through which the age-structure of the labour force can affect total factor productivity (TFP). We build this link on the work done by Feyrer (2007), and other papers with similar methodologies (National Research Council 2013; Maestas, Mullen, and Powell 2016)

The following section describes our methodology including the model and the AAMs based on the characteristics approach. In section three, we apply our model to Argentina's public pension system as an example. We choose this country for its simple defined benefit system and data availability which allows us to focus on the results. Section four runs robustness scenarios incorporating the ageing-productivity link. Section five contains a discussion.

3.2 Methodology

In this section, we describe our model, how we measure adequacy and fairness, and how we incorporate the AAMs into a pension model. Our standard model is based on previous work from (Alonso-García, Boado-Penas, and Devolder 2018) which develops an overlapping generations model to assess the impact of AAMs that affect the contribution rate and/or indexation of pensions. In comparison to their study, we focus on reforms that increase the retirement age and use a characteristics approach to design our AAMs, which allows us to connect retirement to qualitative ageing indicators.

Our method also adds to the literature by exploring how the ageing-productivity relationship may affect pension systems. Many papers have pointed to negative but small effects, the evidence is conflicting (Acemoglu and Restrepo 2017; Bussolo, Koettl, and Sinnott 2015; Prskawetz et al. 2006; Sharpe 2011; Nagarajan, Teixeira, and Silva 2016). Thus, in our simplest model, we assume an exogenous and constant growth rate for productivity during the projection period. However, in section four, we consider a robustness scenario linking ageing and productivity. To differentiate this extension and compare results with our main model, we label them as the standard and the endogenous growth models.

3.3 Model description

We start by defining the government's pension revenue (R_t) as function of the number of contributors (co_t), the average wage (w_t), and the contribution rate (cr_t).

$$R_t = co_t * w_t * cr_t \tag{3.1}$$

The number of contributors evolves in line with the working age population (those below the retirement age and over 20) wp_t, the labour force participation rate pr and the formality level f of the economy.[15] The average wage is determined by the gross domestic product (Y_t), the wage share (ws), and the size of the labour force (lf_t).

$$co_t = wp_t * pr * f \tag{3.2}$$

$$w_t = Y_t * ws/lf_t \tag{3.3}$$

In our standard model, the domestic product grows at a constant exogenous rate $g_t = \bar{g}$ for all t. However, Section 3.5 contains a robustness scenario where g_t is transformed into a function $g_t = f(A, T)$ determined by the age structure of the population (vector A) and the productivity of each age group (vector T).

The number of total retirees (re_t in Equation 3.4) evolves with the population above the retirement age rp_t, the labour force participation rate and the formality rate of the economy. Retirees are divided

[15] The definition of formality used for the calibration of our model in section 3.4 is the percentage of employees paying contributions to the pension system.

between new beneficiaries (nr_t, those retiring in t), and existent beneficiaries (er_t those retired in previous years and still alive in t). This division is required because the benefits of each group are calculated differently and because certain reforms could affect only new retirees but not those already retired. For the same reason, we introduce a supra-index c to distinguish between cohorts of beneficiaries according to their retirement year.

$$re_t = rp_t * pr_t * f_t = nr_t + er_t \quad (3.4)$$

The government's pension spending (S_t) equals the sum of benefits paid to new retirees and existent retirees.

$$S_t = nr_t * w_t * rr_t + \sum_c er_t^c * p_t^c \quad (3.5)$$

The sum of benefits for new retirees are calculated as the number of new retirees (nr_t) multiplied by the average wage and by the replacement rate (rr_t). For existing retirees, total benefits are calculated by adding-up the benefits corresponding to each cohort c, multiplying the average pension (p_t^c) of each cohort by the number of retirees in each cohort (er_t^c).

As shown in Equation 3.6, the average pension for any cohort c at any time t is obtained by multiplying their initial average pension $rr_{t-age_c+ra_c} * w_{t-age_c+ra_c}$ (where $t - age_c + ra_c$ refers to the retirement year of the cohort) by a product of the system's indexation parameter (γ_t). The indexation parameter is determined by local rules. For example, if pensions are indexed to inflation, γ_t would equal the inflation rate.[16]

$$p_t^c = rr_{t-age_c+ra_c} * w_{t-age_c+ra_c} * \prod_{t=t-age_c+ra_c}(1+\gamma_t) \quad (3.6)$$

Equations 3.2 to 3.6 are enough to calculate most indicators of interest. As shown in the next section, Equations 3.2 and 3.4 are used to project the coverage of the system, Equations 3.1 and 3.5 to project the fiscal flow of the pension system, and Equations 3.4 and 3.6 contain the variables to project the adequacy and fairness of the system.

3.3.1 Indicators of interest

3.3.1.1 Coverage

We measure the system's active coverage as the number of contributors over the population between 20 years and the retirement age[17] and the beneficiaries coverage as the number of retirees divided by the population over the retirement age.

[16] If ra_c is the age at which a cohort can legally retire, then the current year minus the age of the cohort ($t - age_c$) equals the year they were born. Thus, $t - age_c + ra_c$ is the year at which they are entitled to retire. We later replace this expression by ret to simplify the equations when we are discussing one specific cohort.

[17] We use 20 as the bottom threshold because it is a common age used in the literature (Sanderson and Scherbov 2015; United Nations 2017).

3.3.1.2 Fiscal sustainability

We assess the fiscal sustainability of the system (FS_{t_0}) by comparing the discounted flow of spending (from Equation 3.5) against the discounted flow of revenue (from Equation 3.1), both in percent of GDP. We discount the flows to a common year, t_0 using a discount rate r_t.[18]

$$FS_{t_0} = \sum_{t=t_0} (R_t - S_t)/Y_t * (1 + r_t)^{t-t_0} \quad (3.7)$$

3.3.1.3 Adequacy and fairness

We follow Queisser and Whitehouse (2006) to define fairness and adequacy indicators. The adequacy for a specific cohort is measured through the gross pension wealth (PW^c) which is calculated as stock of all pension payments discounted using inflation (π_t), time value (using r_t), and probability of survival after retirement for the specific cohort (equivalent to one minus the mortality rate after retirement of each cohort mr_t^c).

$$PW^c = \sum_{t=t-age_c+ra_c} \left[p_t^c * \prod_t \frac{(1-mr_t^c)}{(1+\pi_t)(1+r_t)} \right] \quad (3.8)$$

Pension wealth is typically measured as a ratio over the average wage at retirement $w_{t-age_c+ra_c}$.

The fairness of the system is measured as a ratio between the gross pension wealth and the stock of lifetime contributions discounted using inflation and r_t. $t - age_c + 20$ is the year at which every cohort entered the labour market, assuming all cohorts start working at 20 years of age.

$$F^c = PW^c / \sum_{t=t-age_c+20} [w_t cr_t \prod_t (1 + \pi_t)(1 + r_t)] \quad (3.9)$$

3.3.2 AAM and the characteristics approach in our model

Notice that every time the retirement age appears in our model, it has a sub-index t or a supra-index c. That is because the retirement age is only fixed in the baseline scenario. The following section describes how we set the retirement age in the other three scenarios.

3.3.2.1 Life expectancy and disability-free life expectancy

The characteristics approach is a method develop by Sanderson and Scherbov (2013) to build ageing indicators using demographic and qualitative characteristics of the population. For example, instead of a fixed "older-age threshold" determined by the number of years elapsed since birth, an individual will transition into "older-age" when their life expectancy drops below an arbitrary threshold. The main

[18] Long-run discount rates play a central role for economic valuation of public policy; unfortunately, there is little direct empirical evidence on how households discount payments over very long horizons (Giglio et al. 2014). As a benchmark, for regulatory action with "intergenerational benefits or costs," the U.S. Office of Management and Budget recommends a wide range of discount rates, between 3 and 7 percent (Amaglobeli and Shi 2016). However, a $100 bond that matures in 50 years would be worth almost 6.7 times more today if discounted with a rate of 3 percent than with a rate of 7 percent. For comparatively purposes we will use the rate proposed by Giglio et al. 2014, 2.6 percent, which is the rate used by the IMF on its notes on "how to assess fiscal implications of demographic shifts" (Amaglobeli and Shi 2016).

assumption behind this proposal is that the threshold to "older-age" is not be fixed; instead, it is determined by characteristics that are important for ageing and that are captured or proxied by life expectancy. As life expectancy is projected to increase for many populations, the "older-age" threshold will also increase.

Following this reasoning, many countries proposed reforms to their pension systems that link the retirement age to life expectancy. We introduce the characteristic approach into our model to assess this type of reform.

Following the notation in Sanderson and Scherbov (2013), let $C_t(\alpha_{k,t})$ be a function known as the schedule of characteristics that translates chronological age α_t into characteristics k_t.

$$C_t(\alpha_t) = k_t \tag{3.10}$$

Equation 3.10 can be inverted to obtain the schedule of chronological ages α_t associated with each value of the characteristic k_t at time t. This indicator, $\alpha_{k,t}$, is known as alpha-ages.

$$\alpha_{k,t} = C_t^{-1}(k_t) \tag{3.11}$$

In our model, $\alpha_{k,t}$ will be the schedule for the retirement age conditional on projections of characteristics k_t (life expectancy).

The underlying assumptions for the indicator proposed by Sanderson and Scherbov and for the reforms that index retirement to life expectancy may be over-optimistic. Even though there is a consensus about projected positive trends for life expectancy, the quality of life during the extra years of life is still uncertain. The comparison of different studies is inconclusive with contradictory results for the same populations and even more variation when comparing different countries (World Health Organization 2015; Crimmins and Beltrán-Sánchez 2010). Thus, the extent to which workforce participation can be pushed into later years is worthy of consideration. However, the characteristics approach is a flexible methodology that allows replacing the underlying characteristics k_t with any indicator (or set of indicators) that the researcher considers relevant, for example, disability-free expectancy.

In Chapter 1 of this study, we used disability prevalence data to explore different theoretical healthy ageing scenarios based on several assumptions about the relationship between disability prevalence and ageing. We will use the projections from that chapter to complement our analysis of retirement age indexation in this chapter. Hence, we will replace k_t with a minimum value of disability-free life expectancy and $\alpha_{k,t}$ with the age schedule at which disability-free life expectancy falls below k_t. The assumptions and methods for those calculation using follow the Sullivan method (WHO 2014) are available in our appendix.

Figure 3.2 shows an example of the characteristics approach, comparing a fixed older-age threshold of 65 with two alpha-age indicators, one based on life expectancy and one based on disability-free life expectancy. The solid red line tracks the alpha-age at which disability-free life expectancy is constant across time. The red dashed line does the same but for life expectancy. There is also a yellow line that tracks a constant fiscal balance scenario which is described in the next section.

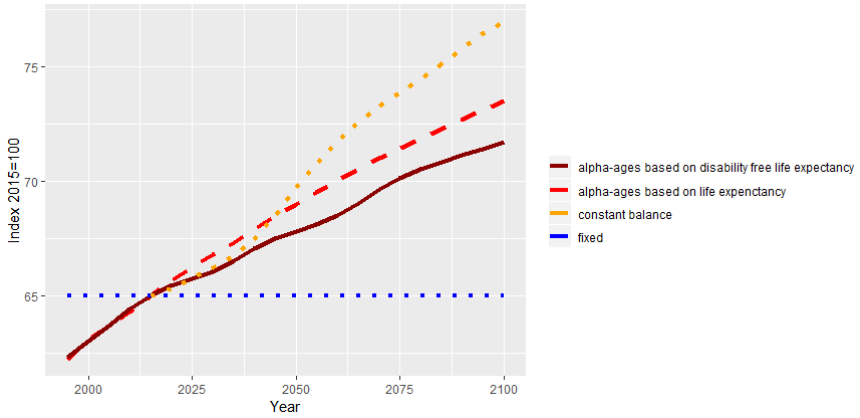

Figure 3.2 Fixed retirement age, constant-balance retirement age, and alpha-age trajectories associated with constant life expectancy and disability-free life expectancy after retirement.

Source: UN Population Prospects Database, Global Burden of Diseases Study, and authors' own calculations.

Note: The calculations of alpha trajectories is described in the methodology and appendix sections.

To make all curves match in 2015, both alpha-trajectories track the age at which the measured characteristics (life expectancy and disability-free life expectancy) equal its value in 2015 for an individual with 65 years of age. For example, a 65 years old individual in 2015 is projected to have the same disability-free life expectancy as 67 years old individual in 2045. The retirement age in the four scenarios of our results section will follow the trajectories of the curves in Figure 3.2.

An important limitation in our model is related to a possible endogenous relationship between health and retirement. The disability-free life expectancy trajectory builds upon disability prevalence projections that do not accounting for feedback from retirement to disability prevalence. However, if, retirement affects health, our alpha ages in Figure 3.2 should not be independent from eligibility reforms.[19]

[19] Eibich (2015) discusses a positive effects of retirement on health channelled through relief from work-related stress and strain, increased sleep duration, and increased physical exercise. Rohwedder and Willis (2010) founds a negative influence of retirement on health through the worsening of cognitive abilities. (Nishimura, Oikawa, and Motegi 2018) explained these and other opposing empirical results on this subject through methodological comparisons, however, there is no unified view on the impact of retirement on various health indexes (Feichtinger et al. 2012).

3.3.2.2 Constant fiscal balance

In our fourth scenario, the retirement age for the projections is the one that maintains the pensions balance over GDP constant at its last historical value.[20]

Using Equations 3.5 and 3.1 we can derive the change in government revenue and spending over GDP as follows,

$$\frac{R_{t+1}}{R_t} = \frac{co_{t+1} * w_{t+1} * cr_t}{co_t * w_t * cr_t} = \frac{co_{t+1} * w_t * (1+g) * cr_{t+1}}{co_t * w_t * cr_t} \tag{3.12}$$

$$\frac{S_{t+1}}{S_t} = \frac{p_{t+1} * re_{t+1}}{p_t * re_t} = \frac{p_t * (1+\rho_t) * re_{t+1}}{p_t * re_t} \tag{3.13}$$

Note that we simplified the calculation of spending using an average pension for all retirees (p_t) instead of the average pension by cohort (p_t^c). The average pension can be derived dividing total spending (Equation 3.5) over the number of retirees (Equation 3.4). Additionally, g_t and ρ_t are the growth rates of wages and pensions, respectively.

To maintain a constant fiscal balance, Equation 3.12 should equal Equation 3.13.

$$\frac{co_{t+1} * (1+g_t) * cr_{t+1}}{co_t * cr_t} = \frac{(1+p_t) * re_{t+1}}{re_t} \tag{3.14}$$

Reorganising terms and assuming that the contribution rate stays constant we get Equation 3.15 which is the necessary condition to maintain a constant balance in the pension system. I e., changes in the ratio of contributors to retirees should match changes in the ratio between the average pension and the average wage growth rates. In our fourth scenario, the retirement age increases in an amount such that this condition is met.

$$\frac{\frac{co_{t+1}}{ret_{t+1}}}{\frac{co_t}{ret_t}} = \frac{(1+\rho_t)}{(1+g_t)} \tag{3.15}$$

Using Equation 3.6 we can see that, if pensions for existing retirees are indexed to wages, then $(1 + \rho_t) = (1 + g_t)$. Thus, to maintain a constant fiscal balance, the contributors-beneficiaries ratio should stay constant across time. If, pensions are indexed to a parameter that grows slower than wages, which is a common case, a constant fiscal balance can be achieved with an increasing contributors to beneficiaries ratio.

3.4 Application of the standard model

In this section apply our methodology to Argentina's public pension system. We choose this scheme because it is typical define benefit system. Additionally, for the past 20 years, the country has

[20] This is an arbitrary target set by the authors; however, it can be understood as a decision by policy makers to maintain the short-term fiscal outlook over the long-term. This is useful as a benchmark for all other comparable reforms that affect the fiscal balance.

experienced a battery of pension reforms and continuous social unrest related to their social spending policy. Nevertheless, its pension system remains fiscally unsustainable in the long term (International Monetary Fund 2016).

3.4.1 Assumptions and data sources

Table 3.1 Argentine pension system assumptions and data sourcessummarises the main assumptions used to calibrate our model for the Argentine pension system. Historical data and projections of demographic variables (population and mortality rates) come from the United Nations Population Prospects Database. Historical data for macro-variables (GDP, consumer prices, and unemployment) comes from the IMF's World Economic Outlook database while projections are based on average historical growth rates. The rest of the variables (contribution rate, replacement rate, beneficiaries coverage rate, retirement age for the baseline scenario, active coverage rate, and the labour force participation rate) come from Argentinian government official sources (Anses, and Infoleg), or from the Inter-American Development Bank's Market and Social Security Information System, and are kept constant at their last historical value during the projection period. Additionally, the labour force entry age is set at 20 as in Acosta Ormaechea, Wachs, and Espinosa-Vega (2017).

Table 3.1 Argentine pension system assumptions and data sources

Variable	Source
population by age	UN, WPPD
mortality rate after retirement by age	UN, WPPD
unemployment rate	IMF, WEO
gross domestic product	IMF, WEO
consumer price index	IMF, WEO
contribution rate	OECD, PAG
replacement rate	OECD, PAG
beneficiaries coverage rate (those with contributary pension)	Anses
retirement age	Anses
average individual pension (annual amount in local currency)	Anses
average individual salary (annual amount in local currency)	Anses
formality rate (employees paying contributions)	IADB, LMSSIS
labour force participation rate	IADB, LMSSIS
labour force entry age	IMF (2017)

Note: National Administration of Social Security (Anses), World population prospects (WPPD), Labour Market and Social Security Information System (LMSSIS), World Economic Outlook (WEO), Pensions at a Glance (PAG), Legislative and Documentary Information (Infoleg). A complete dataset and its application to our model is available in the online appendix.

We start with an initial cohort in 2015 divided in two groups, new and existent retirees in 2015 because historical data of average pension by cohort is not publicly available. The average pension for new retirees is calculated using the average wage and the replacement rate, as in Equation 3.4, and the pension for the existent retirees is calculated as a residual using Equation 3.4 and total pension spending in 2015. The consequence of this approach is that we cannot track the contribution and benefit flows of cohorts retired before 2015.

3.4.2 Results

Figure 3.3.a shows the trajectory of the retirement age under the four scenarios discussed in section 3.3.1: fixed retirement age; retirement age indexed to life expectancy after retirement; retirement age indexed to disability-free life expectancy after retirement; and the retirement age that keeps a constant pension system balance at its last historical value. The detailed description for the calibration of these trajectories is available in the methodology section.

The difference in the retirement age trajectories is substantial. The retirement age that would keep life expectancy after retirement constant increases nine years between 2015 and 2100. However, such increase would not be enough to avoid a raise in the fiscal deficit. To achieve that goal, the retirement age should increase three more years, which would not only be politically difficult, but also biologically challenging, as disability-free life expectancy grows at a lower rate. Of course, there is great uncertainty regarding the projections of disability-free life expectancy and an assessment incorporating uncertainty would be more appropriate to analyse that scenario in detail.

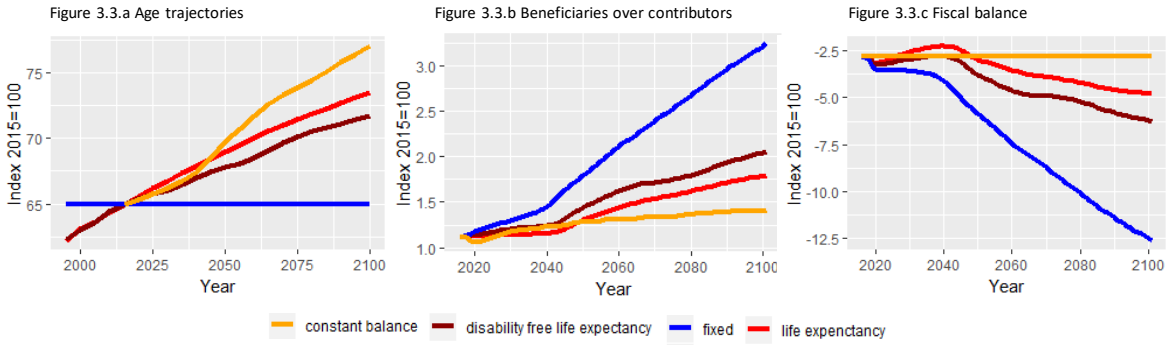

Figure 3.3 Projections for Argentina, (2015-2100)

Source: See Table 3.1 Argentine pension system assumptions and data sources

Figure 3.3.b shows how changes in eligibility affect the beneficiaries to contributors ratio. These projections are obtained using Equations 3.2 and 3.4 of our model. Since the increase in the retirement age decreases beneficiaries while raising taxpayers the order of the curves in Figure 3.3.b is the opposite of that in Figure 3.3.c. Note also that the constant deficit curve in Figure 3.3.b is not flat but has a slight

positive slope. This is because, in Argentina, pensions are partially indexed to the inflation rate. Therefore, a constant balance can be reached even with growth in the beneficiaries to contributors ratio (see Equation 3.15).

Figures 3.4 shows the discounted accumulated fiscal deficit between 2015 and 2100 (Equation 3.7) and indicators of adequacy and fairness for an individual who joins the labour market with 20 years in 2015 (Equations 3.8 and 3.9). A raise in the retirement age increases the contribution period while decreasing the period receiving benefits. Therefore, measures that reduce the deficit also reduce the pension wealth and fairness. This trade-off is visible in Figure 3.4 where scenarios are organized from lower to higher retirement age in 2100.

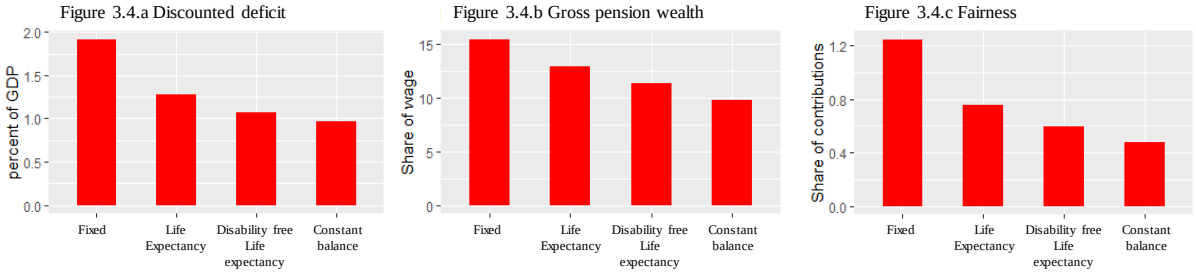

Figure 3.4 Indicators of interest for Argentina, (2015-2100)

Source: See Table 3.1 Argentine pension system assumptions and data sourcesNote: Fairness and Pension wealth measured for an individual entering the labour market at 20 in 2015 and retiring at the ages determined by the specific scenarios. Instead of a ratio, Fairness is displayed as percent of total discounted contributions to measure it on the same axis as the accumulated discounted deficit. Pension wealth measured as a ratio of average wage at retirement, as shown in Equation 3.8. Flows are discounted using CPI and a discount rate of 2.6 percent as in Giglio et al. (2014).

With a fixed retirement age, the discounted accumulated fiscal deficit would amount to almost 200 percent of GDP in 2015, while for the cohort entering the labour market in 2015 the fairness would equal 1.25 and the pension wealth ratio to the average wage would equal 15.5. On the opposite side, with a constant balance, the discounted accumulated fiscal deficit would amount almost 97.2 percent of GDP in 2015, while for the cohort entering the labour market in 2015 the fairness would equal 0.47 and the pension wealth ratio to the average wage would equal 9.8.

3.5 Robustness scenarios with endogenous growth

In our standard model, growth is determined exogenously by a constant rate $\bar{g}$ based on historical data. In this section, we change this assumption and explore what happens if productivity is affected by the age-structure of the labour force.

3.5.1 Method

We follow the work of Feyrer (2007) which, to our knowledge, is the most cited study exploring the ageing-productivity relationship at the macro level. To test this relationship, Feyrer uses panel fixed effects regressions to determine the significance of changes in the shares of labour force age-groups over the growth rate of GDP. Equation 3.16 shows Feyrer's main specification, where the logarithm of TFP (A), in any year (t) and for any country (i), is explained by the share of 10-year age groups ($\Delta W_{a,i,t}$) in the labour force, the old-age dependency ratio ($OADR$), country fixed effects (μ_i), time fixed effects (η_t), and the error term ($\epsilon_{i,t}$).

$$\Delta \log A_{i,t} = \alpha + \beta_a \Delta \sum_{age\ group=10}^{60} W_{a,i,t} + \beta_{OADR} \Delta OADR_{i,t} + \mu_i + \eta_t + \epsilon_{i,t} \quad (3.16)$$

The sub-index a in $W_{a,i,t}$ refers to the labour force age-groups which in Feyrer's specification are divided in 10-year age-groups from 10 to 19 to 50 to 59, plus those older than 60. As the addition of the proportions $W_{a,i,t}$ adds-up to one for each country-year pair, one group must be excluded in the regression analysis. Feyrer arbitrarily chooses the 40 to 49-year-old age group because it generally has the highest coefficient when included. By omitting this group, significant coefficients of other age-groups indicate that they are significantly different from the implied zero coefficient on the 40 to 49 group.

The red dotted line in Figure 3.5 shows the vector of coefficients β_a in Feyrer's main specification. All coefficients are negative and significant at typical confidence levels, which means that an increase in the relative size of the 40-49 group is associated with higher productivity. A value of -3.8 for the 30-39 group implies that a 5 percentage point shift from the 30-year age group to the 40-year age group is associated with over a 19 percent increase in per worker output. In our endogenous model, the effect of the labour force age-structure on productivity is calibrated using the results from Feyrer (2007), Table 1, column 2 (also visible in our figure 3.5). These coefficients are multiplied by the differential in the shares of labour force age-groups ($\Delta W_{a,i,t}$) to project the growth rate of TFP ($\Delta \log A_{i,t}$).

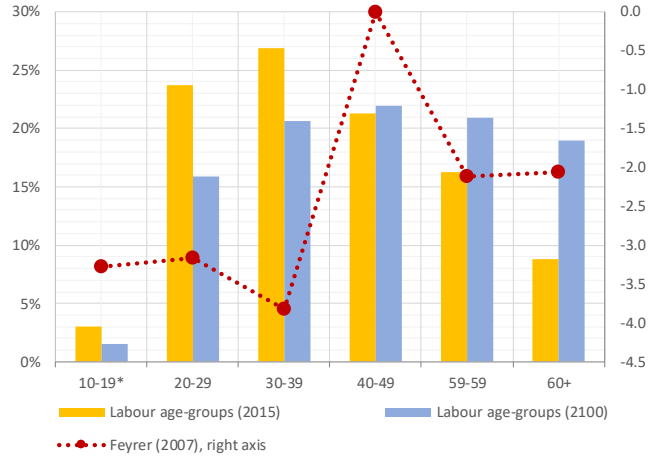

Figure 3.5 Coefficients estimated by Feyrer (2007) and labour force shares in our baseline scenario (2015 and 2100).

Source: Coefficients from Feyrer (2007), Table 1, column 2; labour force age-groups calculated by the authors using UN Population Prospects database and ILO Standardized participation rates.

Note: Feyrer bottom age-group is 10 to 19; however, the youngest age-group in ILO is 15 to 19. The figure shows the age-group according to ILO data.

As the AAM reforms studied in this paper increase the retirement age, we must make an assumption about labour force participation for those individuals in age-groups that were eligible for retirement in the baseline scenario, but that are not under reform scenarios, because their participation can potentially affect growth. For this purpose, first, we calculate the ratio in labour participation between the 60-64 and 65+ age-groups in Argentina. Then, we apply the inverse of this ratio to those individuals that become not eligible for retirement after the reform. As we will see below, given the age-productivity pattern found by Feyrer changes to this assumption have marginal effect on our results.

Figure 3.6 summarises how a reform that increases the retirement age affects the fiscal balance through the channels in our model. Green arrows indicate channels that improve the belance, red arrows indicated those that worsen it, and blue arrows can have both effects. Yellow arrows are for channels that are included when growth is made endogenous.

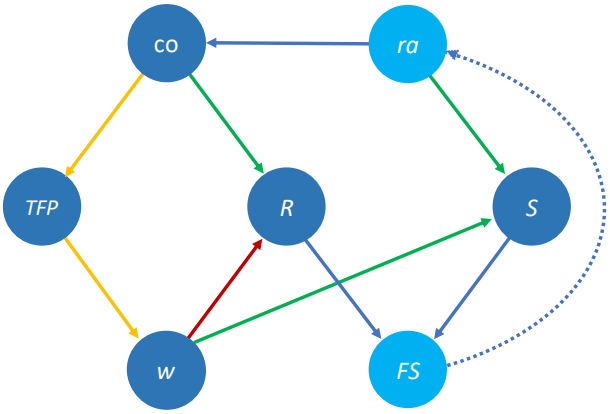

Figure 3.6 Model diagram.

Source: Authors' work.

In our standard model, an increase in the retirement age (ra) decreases the number of beneficiaries, reducing spending (S_t), and increases the number of contributors (co_t), increasing revenue (R_t). Both channels improve the fiscal outlook (FS_t). In endogenous model, the raise in ra increases the share of older workers, affecting TFP growth and wage growth rates. If the effect over TFP is negative, wages' growth rate will drop, reducing contributions, thus worsening the fiscal balance. Lower wages also reduce spending, because benefits at retirement and their indexation are determined by wages.[21] Last, the doted blue line shows the connection between the fiscal balance and the retirement age that is activated in the constant balance scenario.

3.5.2 Results

Figure 3.7 below summarizes the productivity and demographic dynamics in this section. In the baseline scenario with no change in eligibility parameters, the share of workers above the age of 60 will more than double, from 8.8 to 18.9 percent of the total labour force between 2015 and 2100 (Figure 3.7.a). However, most of the increase will be compensated by a decrease in younger workers (those below 39). In addition, workers with the average highest productivity according to Feyrer's productivity profile in Figure 3.5 (those aged 40-49) will peak in 2035 and then slowly decrease. Combining these labour force projections with the productivity profile from Feyrer yields a geometric average TFP growth rate of 0.76 percent between 2015 and 2100 (column two in Figure 3.7.c), which it is substantially lower than the historical annual TFP growth rate of 1.2 percent.

For other scenarios where the AAM raises the retirement age, the share of 60+ workers increases substantially, especially in the constant balance scenario (Figure 3.7.b). However, in the age-productivity profile found by Feyrer, older workers are less productive than those between 40 and 49,

[21] The indexation parameter is key to determine the effect of changes in growth over the fiscal balance. As shown in equation 3.15, if pensions are indexed to wages, the fiscal outlook is unchanged by fluctuations in GDP growth. However, when benefits are indexed to a different rate, e. g. inflation, a decline growth affects only the calculation of the initial pension.

but more productive than all other age-groups. Thus, the increase in the retirement age has a small but positive impact on average TFP compared to the baseline in the endogenous model (columns 3 to 5 in Figure 3.7.c).

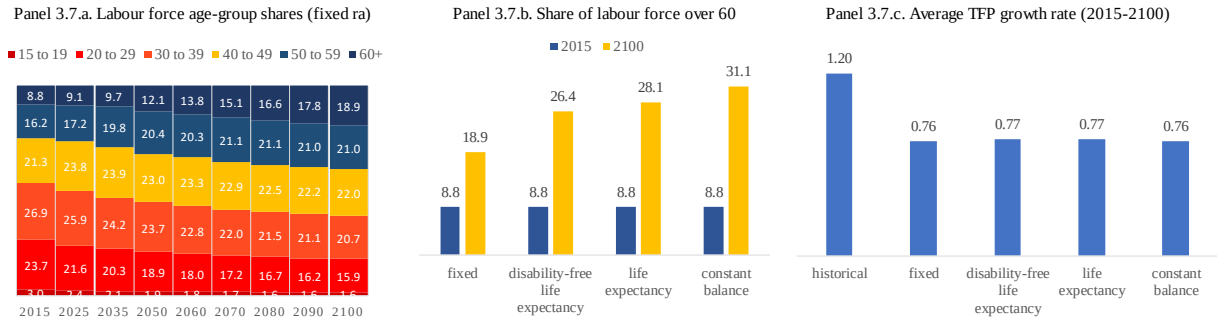

Figure 3.7 Productivity and demographic dynamics in the endogenous model.

Source: Authors' own calculations. Note: Panel 3.7.a assumes a fixed retirement age.

Table 3.2 shows our indicators of interest (fairness, pension wealth and the fiscal deficit) under the different scenarios and comparing the standard and the endogenous models. It follows from the information on the table that lower economic growth has a negative but minor effect on all indicators. Below we explore the algebra of our indicators to explain why this happens.

Table 3.2 Indicators of interest under standard and endogenous growth models

Scenario	Fairness		Adequacy (gross pension wealth)		Discounted deficit (2015-2100)	
	Standard	Endogenous	Standard	Endogenous	Standard	Endogenous
Fixed	1.2	1.1	15.5	15.2	192%	200%
Disability-free LE	0.8	0.7	12.9	12.8	128%	134%
LE	0.6	0.5	11.3	11.3	108%	113%
Constant balance	0.5	0.4	9.8	9.8	97%	97%

Source: Authors' own calculations.

The indicator of adequacy, expressed by Equation 3.8, measures the stream of benefits received by an individual over average wage at retirement. Using Equation 3.6 we can re-write it as:

$$\frac{PW^c}{w_{t.ret}} = \frac{\sum_{t=ret}\left[rr_{ret} * w_{ret} * \prod_{t=ret}(1+\gamma_t) * \prod_t \frac{(1-mr_t^c)}{(1+\pi_t)(1+r_t)}\right]}{w_{ret}} \quad (3.17)$$

To simplify, we replaced sub-index $t - age_c + ret.age_c$ by ret indicating parameters measured at time of retirement. This expression can be further simplified, as w_{ret} is a constant term that appears both in the numerator and denominator. The only remaining place where growth could be present in Equation 3.17 is the indexation parameter, γ_t. Hence, lower growth can reduce adequacy because it

affects the growth rate of pensions for a retired individual. In Argentina, pensions are only partially indexed to wages; hence, slower growth slightly lowers adequacy. The decline would be higher if pensions were totally indexed to wages and null if pensions were indexed to inflation.[22]

Our indicator of fairness can also be re-written using Equation 3.6. However, the analysis is more complicated than for adequacy because the denominator is determined by the stream of contributions paid throughout the life of a worker, which is a function of all wages earned (Equation 3.18). Thus, a drop in growth lowers the numerator of Equation 3.18 (pension wealth) but also the denominator (the present value of contributions).

$$F^c = \frac{\sum_{t=ret}\left[rr_{ret} * w_{ret} * \prod_{t=ret}(1+\gamma_t) * \prod_t \frac{(1-mr_t^c)}{(1+\pi_t)(1+r_t)}\right]}{\sum_{t=t-age_c+20}[w_t * cr_t \prod_t (1+\pi_t)(1+r_t)]} \quad (3.18)$$

If pensions are indexed to wages, lower growth will most likely reduce fairness because slower growth affects the initial pension ($rr_{ret} * w_{ret}$) and the indexation parameter (γ_t), both factors that determine the value of pension wealth. However, if pensions are not indexed to wages, the outcome will depend on the sign and magnitude of the relationship across time between the labour force age-structure and productivity -i.e. how population ageing affects the trajectory of contributions ($w_t * cr_t$) and the initial pension ($rr_{ret} * w_{ret}$). A strong negative relationship would create a higher differential between wage growth rates while contributing and at retirement; thus, a worsening of fairness by definition.

Last, the easiest way to understand what happens to the fiscal balance when growth changes is by looking at Equation 3.15. If pensions are indexed to wages, we get $(1 + \rho_t) = (1 + g_t)$; thus, a change in growth does not alter the condition for a constant balance. In other words, the balance is decupled from growth. However, the equation also shows that, if pensions grow at a slower pace a drop in g_t worsens the fiscal balance.

An easier way to understand these dynamics is by looking at changes in benefits and contributions. In our model, lower growth will always deteriorated government revenue, as contributions are carved from wages and wages are linked to growth. However, this is not the case for spending, as benefits are not always indexed to wages. In Argentina, the effect of growth is nuanced because pension benefits are only partially indexed to wages. Table 3.2 shows that this is the case in all our scenarios, except by obvious reasons, in the constant balance scenario.

3.6 Discussion

As expected, our model shows the trade-off between different objectives of pension systems. All else equal, the higher the retirement age, the greater the improvement in the fiscal balance, and the higher

[22] A key assumption in these dynamics is that wages are a linear function of growth (equation 3.3). Further research may propose other functional forms for this relationship or even utilize a distribution of wages to explore how inequality affects the sustainability, adequacy, and fairness of pension systems.

the impact over the adequacy and fairness for pension system participants. Consequently, the model can be calibrated to find the space that meets a series of criteria regarding fiscal and adequacy goals. On one extreme, the model can be calibrated set the retirement age at a level that assures a maximum deficit. On the other, the model could be inversely calibrated, fixing a minimum adequacy and obtaining the associated retirement age and fiscal result.

Our endogenous growth model provides important insights on the interaction between population ageing, productivity, and pension systems. We find limited effects of ageing through the productivity channel over pension indicators; however, the indexation system is a key parameter regulating this relationship. In general, countries where pensions are fully indexed to growth will experience higher variations in fairness, adequacy, and fiscal sustainability due to changes in growth.

The results from the endogenous growth model should be taken with caution, as these are obtained assuming a fix age-productivity profile across time. Part of the literature suggests this relationship may be improving across time, those aged 70 today have the characteristics of those aged 60 in the past. Hence, a fix profile could be interpreted as a wort case scenario.

3.7 Conclusion

The world is undergoing a demographic transition which for many countries entails an increase in the ratio of pension beneficiaries to contributors. In response, many governments adopted AAMs which put the parameters of pension systems in auto pilot, assuring fiscal sustainability even under changes on demographic or economic conditions. Nevertheless, almost any measure that addresses fiscal issues will be to the extent of pension system participants. In this study, we develop an overlapping generations model that tracks the contributions and benefits of pension system participants by cohort to measure the impact of AAMs on the adequacy and fairness of the system.

We focus on AAMs that increase the retirement age which is the most common type of AAM. Most AAMs affecting eligibility are linked to life expectancy which is an important factor behind population ageing. However, reductions in mortality may not be associated with improvements in non-fatal health characteristics, for example disability. We incorporate the Characteristics Approach into our model to calibrate our AAM using different health characteristics related to ageing. We look at two different reforms, one that fixes life expectancy after retirement and one that fixes disability-free life expectancy after retirement.

Previous literature has explored the possibility of an endogenous relationship between health and retirement. For our model, this would imply that an increase in the retirement age based on our disability-free or life expectancy scenarios could potentially affect the alpha trajectories. We acknowledge the limitation of our model to incorporate this endogenous process. The model could also be expanded to include within-cohort health heterogeneity. For example, a methodology as the one

developed by Tyrowicz, Makarski, and Bielecki (2018) could be used to study the effects of AAM reforms over inequality due differences in disability prevalence. Another natural extension would be to look at other types of AAMs.

Conclusions

This section wraps-up the thesis by describing its main results and conclusions, policy recommendations, limitations and suggestions for further research. This dissertation analyses two of the main consequences of population ageing: productivity and social protection. Substantial literature exists on these topics; however, this thesis provides a unique perspective because all chapters are built upon a definition of population ageing that incorporates health characteristics. This approach is better suited to understanding effects of demographic change on productivity and social protections, than conventional indicators of population ageing (V. Skirbekk, Loichinger, and Weber 2011; World Health Organization 2015).

Chapter 1. A Literature survey of dependency ratios and a comparison of approaches to measure population ageing.

Chapter 1 discusses the indicators used to measure population ageing. According to the World Health Organization (2015) , ageing is based on certain biological and social attributes that determine an individual's capacity to pursue the things they value. For example, an individual's health may determine their capacity to stay active and participate in the labour force. The same report defines population ageing as an increase in the share of the population that possess the attributes relate to ageing at the individual level.

Population ageing is usually quantified using dependency ratios, the dependent or old-age population over the rest of the population (United Nations 2017). The most common variant of dependency ratios is the old-age dependency ratio (OADR), a chronological measure that categorises individuals into the dependent and non-dependent groups according to their age. The problem with the OADR is that an individual's age may be a flawed proxy to their biological capacity to pursue the things they value, especially when it is unclear how future increases in life expectancy will affect non-fatal health conditions. Hence, relying on such chronological measures can create a bias in the way we understand population ageing and its consequences (Sanderson and Scherbov 2008).

Accordingly, in Chapter 1, we propose a dependency ratio entitled the Disability Dependency Ratio (DDR). It categorises individuals according to their biological capacity or health, by using disability prevalence rates that vary across different age groups. DDR's are among those labelled qualitative indicators because they rely on the underlying qualities that determine an individual's capacity (Siegel and Davidson 1984).

In Figure 1.3 we show that our qualitative indicator appears to be positively correlated with the chronological OADR when compared in a specific moment on time and across countries. However, we also show that there are important differences between "younger" and "older" countries.

On average, the former have lower income and will likely undergo a faster demographic transition. This means that the necessary adaptation that "younger" countries will need to go through will have to be carried out quicker than was often the case in the past (World Health Organization 2015). In the same figure, we show that chronologically younger countries (as per OADR) become older under the DDR, while the opposite happens to chronologically older countries. Furthermore, the ageing ranking is inverted for some regions. For instance, Latin America and East Asia and Pacific are chronologically older but qualitatively younger than Sub-Saharan Africa, Middle East & North Africa, or South Asia.

While Figure 1.3 shows how chronological and qualitative measures differ at this point in time, Figure 1.4 shows how they differ when making predictions. We have ample evidence indicating that for all regions, the OADR will increase in the next decades (United Nations 2017). However, it is uncertain how health conditions like disability will respond to changes in fertility, life expectancy, and migration (World Health Organization 2015). Thus, it is more difficult to predict what will happen to the DDR. Accordingly, in Fig 1.4 we explore several scenarios based on different assumptions about the relationship between age and disability prevalence across time. The results from this exercise show that the OADR may overestimate the pace of ageing, as it increases for most of the projection period and for all countries, while that is not the case for DDR, depending on the scenario.

Our analysis is limited in many ways, which suggests opportunities for further research. For example, we do not explore health inequality within countries, which could lead to more variation in the results. Another limitation is the unidimensional operationalization of qualitative ageing in our indicator. While disability is one of the most common concepts used in the literature to operationalize healthy ageing (Cosco et al. 2014; Lu, Pikhart, and Sacker 2019), other relevant individual characteristics associated with capacity could be incorporated to obtain a more comprehensive measure (Lutz 2009; Vegard Skirbekk et al. 2013; Cosco et al. 2014). The main limitation of the so-called "multi-dimensional approach", is data requirements, which would significantly narrow our sample of countries.

Further research could explore the dynamics of ageing in major oil producing countries. Typically, net-oil exporters are excluded from growth studies because they escape the GDP ageing pattern depicted in Figure 1.3 (Feyrer 2007; Bloom et al. 2015). It is possible that sustained natural resource windfalls create outliers in the "typical" developmental process of a country, including the fertility-growth relationship. However, understanding these outliers exceeds the purpose of this paper.

Finally, the most consequential takeaway for policy from this chapter is that efforts and research should not be focused on predicting the path of population ageing. Instead, policy should strive to answer how we can move towards the most desirable scenario, and how we should prepare our institutions according to how DDR's evolve. These are the key questions behind Chapters 2 and 3.

Chapter 2. A review of ageing and productivity: empirical evidence for Argentina

A change in the age of a country's population may affect the relative size and the age composition of the labour force. Hence, many studies argue that population ageing will impact productivity (Borsch-Supan 2003; Feyrer 2007; Bloom and Sousa-Poza 2013; Nagarajan, Teixeira, and Silva 2016). Consequently, the objective of Chapter 2 is to identify data and methods to assess how ageing will impact economic growth in a way that can be easily replicated across countries. Our perspective of ageing based on healthy characteristics is important because it complements an analysis of productivity based on the size and age structure of the labour force, with characteristics directly associated with an individual's capacity to work. This becomes even more clear when we address cohort effects later in this section.

We start Chapter 2 with a thorough review that yields four major literature strands, those that analyse: productivity per worker using micro data, productivity per worker using macro data, growth-accounting models and labour participation, and behavioural effects. The review also suggests that there is no single path for the relationship between ageing and growth across countries. Each country's path depends on various parameters, including: the speed and shape of the demographic transition, economic and labour market institutions, and the trajectory of individual attributes that influence productivity, like health and education. The role of each of these parameters is exemplified through the case of Argentina. This exercise allows us to identify the data and methods useful in evaluating the ageing-productivity relationship.

The empirical analysis starts by generating a projection of the ratio of the effective labour force over the rest of the population, known as the support ratio (Bloom and Williamson 1998). This exercise shows that Argentina is still enjoying its demographic dividend, provided by the second stage of a typical demographic transition, when the ratio of the economically active population to the total population is still growing. The ratio is projected to peak around 2040 and then decrease very slowly, only by 3 percent between 2040 and 2100.

Following similar studies we input our projections into a modified Solow-Swan growth model where GDP per capita is measured in terms of labour, capital, total factor productivity, and demographic variables (Bloom and Williamson 1998; Borsch-Supan 2003). The results indicate that, to maintain the production per-capita of consumer and capital goods, the total factor productivity growth rate will need to increase 0.06 percentage points, which it is a small discrepancy, considering a historical value of 1.2 percent.[23]

This result is the consequence of the mild decrease in the support ratio which reflects two phenomena that have been and will keep shaping the structure of the labour force over the coming decades in

[23] The historical TFP growth rate comes from Feenstra, Inklaar, and Timmer (2015).

Argentina and other economies. A decrease in the share of younger workers due to lower fertility and longer periods of education is combined with an increase in the share of older workers driven by changes in health and in social security eligibility (Gragnolati et al. 2015). Although these age group dynamics will help maintain a stable ratio of workers to the total population, the changes in the composition of the labour force may not be neutral to productivity. Hence, the next sections dig into this channel. Thus, we turn to the evidence connecting productivity and the labour force age structure, regardless of its size.

To achieve this, we replicate the work of Feyrer (2007) by estimating this relationship at the macro level using a panel dataset composed by the growth rate of total factor productivity, the age structure of the labour force, time and country fixed effects. The results of this estimation are combined with projections of the support ratio's age structure to generate predictions of future growth (Aiyar, Ebeke, and Shao 2016). The results indicate that, ceteris paribus, the average geometric growth rate of total factor productivity will drop by 0.2 percentage between 2015 and 2100 due to changes in the support ratio's age structure.

A key limitation of this analysis is that that the age-productivity profile of the labour force is assumed to stay constant over the projection period; however, an important point discussed in the literature review is that this may not be the case because of cohort effects that can change the underlying characteristics of the labour force (Lutz 2009; Bussolo, Koettl, and Sinnott 2015). Hence, in the last section, we consider education and health, two indicators related the characteristics of workers.

The prospects regarding education in Argentina projected by the Human Capital Explorer (Lutz et al. 2018) are auspicious. Population ageing will be accompanied by increasing education achievements. For all age groups, the average years of education attainment will increase substantially, with the highest rise expected for those aged 60+ (almost 1.6 folds, from 8.2 years in 2015 to 12.6 in 2100).

To look at health, we borrowed the DDR, a qualitative indicator of population ageing that we developed in Chapter 1. This indicator is projected under many scenarios based on different assumptions about the relationship between age and disability prevalence. The exercise shows that if Argentina is able to improve its health indicators and catch-up with countries that display lower rates of disability, the pace of dependency may be considerably slowed.

Overall, the assessment for Argentina suggests noteworthy but not worrying effects of ageing over productivity. Given the smoothness of its demographic transition, the effect of a change in the relative size of its labour force is projected to be minimal. The effects of changes in age composition based on Feyrer's method are non-negligible, yet these could be interpreted as a worst-case scenario based on the strong assumption of no changes in the underlying characteristics of workers. As discuss, given the expected increase in education attainment at all ages, this is unlikely.

The data used in this chapter is available to almost all UN countries. An interesting extension of this study would be to expand the empirical analysis to several countries, which could help identifying policies that improve the probability of a successful demographic transition in economic terms.

Chapter 3. An application of our DDR to pension systems with automatic adjustment mechanisms and endogenous growth

Together with productivity, increasing public social spending is among the most discussed issues related to population ageing (European Commission Economy Series 2015; IMF 2011). The change in the population age structure increases the share of potential public pension beneficiaries at the expense of potential tax contributors. In response, many countries have reformed their pension schemes by installing automatic adjustment mechanisms (AAMs) which link the system's parameters to the evolution of demographic or economic variables (OECD 2012). For example, a relative increase in the older age population can be automatically compensated with a decrease in benefits, an increase in contribution rates, or an increase in the retirement rate.

In Chapter 3, we address two issues of AMMs that the literature has left unattended. First, if the impact of AMMs over the adequacy (how well beneficiaries are covered) and fairness (how much an individual receives against how much they contribute) of the pension system is too strong, it can leave participants unprotected, trigger social unrest, and tempt policy-makers to bypass AAMs. Second, a popular AAM reform links eligibility to life expectancy, however we showed in Chapter 1 that future increases in life expectancy may not necessarily be accompanied by improvements in health. Thus, the extent to which workforce participation can be pushed into later years is worthy of consideration (Jagger et al. 2008; Marmot and Bell 2012; Souza, Queiroz, and Skirbekk 2019).

In order to address both issues, we develop an overlapping generations model that tracks the contributions and benefits of a defined benefit pension systems. Then, we measure how the fiscal sustainability, adequacy, and fairness of the model change under different scenarios. The baseline scenario assumes no change in eligibility requirements, while two other scenarios contain an AAM that links the retirement age to changes in life expectancy and disability-free life expectancy. A third scenario links the retirement to the pension cash flow in order to maintain the fiscal balance constant.

Chapter 3 also strengthens the connection between the analytical chapters of the thesis in two ways. First, disability-free life expectancy is projected using the methodology that we developed in Chapter 1. Second, we compare results under two versions of our model, the standard model, where productivity is exogenous, and the endogenous model, where productivity is determined by the age structure of the population. The latter is developed using the method proposed by Feyrer (2007) and replicated in Chapter 2.

As an example, we calibrate our model to the Argentine pension system and show the results of the standard model in Section 3.4.2. We find substantial variation in the projected retirement age trajectories under the different scenarios. When eligibility is linked to life expectancy, the retirement age increases almost one decade between 2015 and 2100, from 65 to 74. However, such rise would not compensate projected losses to the fiscal balance. To achieve that, the retirement age should increase three more years, which it is not only politically difficult but also biologically challenging, as disability-free life expectancy grows at a lower rate from 65 to 72 years of age in the same period.

The results for the standard model also show that a constant pensions fiscal balance can be achieved even with a small increase in the ratio of beneficiaries to contributors in Argentina. This finding depicts an important corollary from our model, easier to interpret by looking at Equation 3.15, which expresses the condition for a constant pension fiscal balance: changes in the ratio of contributors to retirees should match changes in the ratio between the average pension and average wage growth rates. In other words, if wages grow faster than pensions, the fiscal balance can stay constant even with some degree of population ageing. In Argentina, pensions are partially indexed to and thus grow in line with inflation. As long as inflation grows at a slower rate than wages, a constant fiscal balance can be achieved with an increasing contributor to beneficiaries ratio.

Last, the results of the standard model also show the trade-off between the adequacy and fiscal balance of a pension system. A rise in the retirement age increases the contribution period and reduces the period receiving benefits. Therefore, measures that improve the balance also reduce the system's adequacy and fairness.

The results described above are based on the standard model where growth is exogenous and determined by historical data. The endogenous model assumes that economic growth is affected by the population age structure. The comparison of our results under this version and the standard model suggests that the impact of changes in growth on pension indicators is limited. All indicators deteriorate when growth is endogenous; however, the change is trivial.

An algebraic analysis explaining why this happens that we developed in Section 3.5.2 yields very important takeaways from our model. Again, the indexation of pension benefits plays a key role behind these dynamics. Take the fiscal balance for example. In general, lower growth will always deteriorate government revenue, as contributions are carved from wages and wages are linked to growth. However, this is not the case for spending, as benefits are not always indexed to wages. In Argentina, the effect of growth is nuanced because pension benefits are only partially indexed to wages. The same reasoning explains the mild deterioration in adequacy and fairness, as both indicators are a function of pension benefits.

The dynamics described above reveal a clear limitation of our model and an important case for further research. Our model assumes that wages are a linear function of growth. Further research may propose

other functional forms for this relationship or even utilize a distribution of wages to explore how inequality affects the sustainability, adequacy, and fairness of pension systems.

Other limitations of our analysis relate to the projections of disability-free life expectancy used to calibrate which yield an opportunity for further research. We based our projections on the methods developed on Chapter 1, using one of the many assumptions for the relationship between age and disability across time. Although changing this assumption for Argentina does not generate much variation in our projections of disability-free life expectancy, an assessment incorporating uncertainty would an appropriate way to further analyse this scenario in detail.

It would also be valuable to explore how inequalities in health within the population could affect these dynamics. A considerable share of the population may lay well below the average disability-free life expectancy. This would stretch the gap between a retirement age trajectory based on life expectancy and what is physiologically feasible (Marmot and Bell 2012).

At the same time, the issues mentioned prove the benefits of AAMs calibrated to healthy ageing. Whatever happens to future health, an automatic respond can be pre-programmed in the mechanisms. This does not mean that AAMs are a silver bullet to the fiscal repercussions of ageing populations. An inappropriate calibration may lead to excessive adjustments over adequacy and fairness. This could be avoided by using a model like the one we developed to explore the consequences of AAMs under different demographic and economic trajectories, and by programming restrictions into AAMs based on minimum requirements of adequacy or fairness.

Abstract

Healthy ageing, productivity, and social protection

This doctoral dissertation is divided in three chapters that advance our understanding of the relationship between population ageing, productivity, and social protection. The study starts at the root of these issues, by reviewing the definition of ageing. According to the World Health Organisation's (2015) authoritative report, ageing at the individual level is related to social and biological characteristics that negatively affect a person's capacity to pursue whatever they value, including their participation in the labour force. Across time, these characteristics are not necessarily linked to an individual's age. However, the most common indicator of aggregate population ageing, the old-age dependency ratio (OADR), is exclusively based on the population age structure. Relying on such age-based (also called chronological) measures can create a bias in the way we understand the consequences of population ageing.

In Chapter 1, I propose my own measure of population ageing, the disability dependency ratio (DDR) which corrects age-based indicators by including biological characteristics proxied through disability prevalence. Our results, available for 186 countries, show that chronologically younger countries (as per OADR) become older under the DDR, while the opposite happens to chronologically older countries. Furthermore, the ageing ranking is inverted for some regions. For instance, Latin America and East Asia and Pacific are chronologically older but qualitatively younger than Sub-Saharan Africa, Middle East & North Africa, or South Asia.

Chapter 1 also generates projections of population ageing under several scenarios based on different assumptions about the relationship between age and disability prevalence across time. The results from this exercise show that the OADR may overestimate the pace of ageing, as it increases for most of the projection period and for all countries, while that is not the case for DDR, depending on the scenario. Additionally, we find substantial differences in our DDR projections depending on different health assumptions, demonstrating the risk of using ageing indicators that do not explicitly discussing the assumptions about health characteristics. This outcome provides the most consequential takeaway for policy from this chapter: efforts from Policy makers and researchers should not be focused on predicting the path of population ageing. Instead, policy should strive to answer how we can move towards the most desirable scenario of ageing, and how we should prepare our institutions according to how DDR's evolve. These are the key questions behind Chapters 2 and 3. Chapter 1 also sets the tone for the rest of the study. In subsequent chapters population ageing will incorporates health characteristics.

In Chapter two, I review one of the most discussed consequences of population ageing, its impact on economic growth. According to the literature on the topic, there are multiple underlying conditions

driving this relationship and these vary significantly from one country to another. Thus, there is a need for a standardized way to assess and compare these conditions for numerous economies. The purpose of this chapter is to propose a series of methods and indicators that can meet such need.

We began with a literature survey on what is already known about this relationship. A thorough review yielded four major literature strands, based on the underlying data, methods, and channels analysed: productivity per worker using micro data, productivity per worker using macro data, growth-accounting models and labour participation, and behavioural effects. In addition, we identified data broadly available across countries for the first three strands and carried an empirical analysis for Argentina to exemplify their application. The results showed noteworthy but unalarming effects of population ageing on productivity for this country. Our framework is applicable to almost 150 economies and we predict it could be particularly useful for public and international organizations working across countries. An interesting application of the framework would be into the modelling of pension and healthcare systems, the main sectors to be impacted by population ageing. This is developed in Chapter 3 of the thesis.

Together with decreasing productivity, unsustainable public social spending is among the most discussed consequences of population ageing. In response to population ageing, many countries have adopted automatic adjustment mechanism reforms that link retirement to life expectancy. In Chapter 3, we developed an overlapping generations model to analyse the effects of such reforms over fiscal sustainability, adequacy, and fairness of public pension systems. We looked at three scenarios defined by the rules indexing retirement age: a constant pensions fiscal balance, constant life expectancy after retirement, and constant disability-free life expectancy after retirement.

Chapter 3 also strengthens the connection between the analytical chapters of the thesis in two ways. First, disability-free life expectancy is projected using the methodology that we developed in Chapter 1. Second, we compare results under two versions of our model, the standard model, where productivity is exogenous, and the endogenous model, where productivity is determined by the age structure of the population. The latter is developed using the methods studied in Chapter 2.

We applied our model to Argentina's public pension system as an example. Our results show that an automatic adjustment mechanism based either on increases in life expectancy or disability-free life expectancy would not be enough to restrict the projected growth in the pension system's deficit. We also find that changes in productivity have limited effect on pension indicators, although the indexation system can amplify or reduce such effects.

Resumen

Envejecimiento saludable, productividad y protección social

Esta tesis doctoral se divide en tres capítulos que avanzan nuestra comprensión acerca de la relación entre el envejecimiento poblacional, la productividad y la protección social. El estudio comienza en la raíz de estos temas, revisando la definición de envejecimiento. Según el reporte de 2015 de Envejecimiento Poblacional y Salud la Organización Mundial de la Salud, el envejecimiento a nivel individual está relacionado con características sociales y biológicas que afectan negativamente la capacidad de una persona para perseguir lo que valora, incluida su participación en la fuerza laboral. El mismo informe muestra que, a lo largo del tiempo, estas características no están necesariamente vinculadas a la edad de un individuo. Sin embargo, el indicador más utilizado para medir del envejecimiento de la población a nivel agregado, el índice de dependencia de la vejez (OADR), se basa exclusivamente en la estructura etaria de la población. Utilizar etas medidas basadas exclusivamente en la edad de las personas (llamadas cronológicas) puede crear un sesgo en la forma en que entendemos las consecuencias del envejecimiento de la población.

En el Capítulo 1, propongo mi propia medida de envejecimiento poblacional, el índice de dependencia de la discapacidad (DDR) que corrige los indicadores cronológicos al ponderarlos mediante características biológicas representadas por la prevalencia de la discapacidad. Nuestros resultados, disponibles para 186 países, muestran que, regiones cronológicamente más jóvenes (según el OADR) envejecen bajo el DDR, mientras que lo contrario sucede para las regiones cronológicamente mayores. Adicionalmente, el ranking de envejecimiento se invierte para algunas regiones. Por ejemplo, América Latina y el Este de Asia y el Pacífico son cronológicamente mayores pero cualitativamente más jóvenes que África Subsahariana, Oriente Medio y África del Norte o el Sur de Asia.

En el Capítulo 1 también generamos proyecciones de envejecimiento poblacional bajo varios escenarios basados en diferentes supuestos sobre la relación entre la edad y la prevalencia de discapacidad a lo largo del tiempo. Los resultados de este ejercicio muestran que el OADR puede sobreestimar el ritmo de envejecimiento ya que aumenta durante la mayor parte del período de proyección y para todos los países, mientras que ese no es el caso para DDR, dependiendo del escenario. Además, encontramos diferencias sustanciales en nuestras proyecciones del DDR dependiendo de los supuestos acerca de la relación entre discapacidad y edad a través del tiempo, lo que evidencia el riesgo de usar indicadores de envejecimiento sin discutir explícitamente los supuestos sobre dicha relación.

Este resultado proporciona la conclusión más importante de este capítulo en términos recomendaciones de política pública: los esfuerzos de los formuladores de política no deben centrarse en predecir el camino del envejecimiento de la población. En cambio, la política debería esforzarse por responder

cómo podemos aproximarnos hacia la trayectoria de envejecimiento más deseable y cómo debemos preparar nuestras instituciones de acuerdo con la evolución del DDR. Estas son las preguntas clave detrás de los Capítulos 2 y 3. El Capítulo 1 también establece el tono para el resto del estudio. En capítulos siguientes, el envejecimiento poblacional incorporará características de salud.

En el Capítulo dos, reviso una de las consecuencias más discutidas del envejecimiento poblacional, su impacto en el crecimiento económico. Según la literatura sobre el tema, existen múltiples condiciones subyacentes que conducen esta relación y estas varían significativamente de un país a otro. Por lo tanto, existe la necesidad de un método estandarizado que permita evaluar estas características para numerosas economías. El propósito de este capítulo es proponer una serie de métodos e indicadores que cumplan con dicha necesidad.

Comenzamos con una revisión bibliográfica que resume lo que se sabe sobre la relación entre el envejecimiento y el crecimiento económico. Una exploración exhaustiva arrojó cuatro grupos principales de literatura, basadas en los datos subyacentes, métodos y canales analizados: productividad por trabajador usando micro datos, productividad por trabajador usando macro datos, modelos de contabilidad de crecimiento y participación laboral, y efectos de comportamiento. Simultáneamente, identificamos una serie de datos y métodos relacionados a los tres primeros grupos y disponibles para múltiples países. Estos son ejemplificados mediante un análisis empírico para Argentina.

Los resultados mostraron efectos notables, pero poco alarmantes del envejecimiento poblacional en la productividad de este país. Nuestro marco analítico es aplicable a casi 150 economías y prevemos que podría ser particularmente útil para organizaciones públicas e internacionales que trabajen con múltiples países. Una ampliación interesante de este estudio es su incorporación en la modelización de los sistemas de pensiones, uno los principales sectores afectados por el envejecimiento poblacional. Esto es desarrollado en el tercer capítulo de la tesis.

Junto con la ralentización del crecimiento, el gasto social público insostenible se encuentra entre las consecuencias más discutidas del envejecimiento de la población. En respuesta al envejecimiento de la población, muchos países han adoptado reformas del mecanismo de ajuste automático que vinculan el retiro con la esperanza de vida. En el Capítulo 3, desarrollamos un modelo de generaciones superpuestas para analizar los efectos de tales reformas sobre la sostenibilidad fiscal, la adecuación y la equidad de los sistemas públicos de pensiones. Observamos tres escenarios definidos por las reglas que indexan la edad de jubilación: balance fiscal de pensiones constante, expectativa de vida constante después de la jubilación y expectativa de vida libre de discapacidad constante después de la jubilación.

El Capítulo 3 fortalece la conexión entre los capítulos analíticos de la tesis de dos maneras. Primero, la esperanza de vida libre de discapacidad se proyecta utilizando la metodología que desarrollamos en el Capítulo 1. Segundo, desarrollamos dos versiones de nuestro modelo, el modelo estándar, donde la productividad es exógena, y el modelo endógeno, donde la productividad está determinada por la

estructura etaria de la población. Este último se desarrolla utilizando los métodos estudiados en el Capítulo 2.

Aplicamos nuestro modelo al sistema público de pensiones de Argentina como ejemplo. Nuestros resultados muestran que un mecanismo de ajuste automático basado en el aumento de la esperanza de vida o la esperanza de vida libre de discapacidad no sería suficiente para restringir el crecimiento proyectado en el déficit del sistema previsional. También encontramos que cambios en la productividad tienen un efecto limitado en los indicadores de pensiones, aunque el sistema de indexación puede amplificar o reducir dichos efectos.

Appendix: Our disability dependency ratio (DDR)

We propose a DR that measures population ageing based on health characteristics of the population. The indicator is built following the "Characteristics Approach" developed by Sanderson and Scherbov (2013) which provides a method that facilitates comparability with other ageing indicators. Following their notation, the general form of their indicators is given by:

$$MN_t = g\big(S(a,t), H(a,t)\big) \quad (1)$$

Where, MN_t is the ageing measure at time t, $S(a,t)$ is a vector that contains the age structure of the population, and $H(a,t)$ is a vector of age-specific characteristics. Vector S can be broken up by sex or other demographic dimensions of the population, if required. Vector H could include physiological, psychological, behavioural, or any other characteristic that would add qualitative information about the ageing process that it is not present in purely chronological indicators (Siegel and Davidson 1984).[24]

The "Elder Ratios" are ageing indicators based on the characteristics approach. Elder Ratios sum the age population groups s multiplied by the vector of age-specific characteristics h, and divide the summatory over the rest of the population. Both s and h vary over time t.

$$Elder\ Ratios_t = \sum_a s_{a,t} h_{a,t} \Big/ \sum_a s_{a,t}\big(1 - h_{a,t}\big) \quad (2)$$

The key to use Elder Ratios is to understand the schedule of characteristics h, which varies over a and t. For example, the prospective dependency ratio divides the population with less than 15 years of life expectancy over the rest of the adult population (those over 19 years of age). In this case, the schedule of characteristics indicates the exact age at which life expectancy goes below 15, at each moment t. Suppose that this number equals 68 in a particular year for the studied population. Then, h would be a dichotomic variable where $h = 1$ for $a \geq 68$ & $h = 0$ for $20 \leq a < 68$ (Sanderson and Scherbov 2008).

For our indicator, matrix H contains does not contain dichotomic values (0 or 1) based on age thresholds, but the values of the characteristic itself. Namely, the average disability prevalence in age group a at time t, in percent of the age-group's total population. Following Sanderson and Scherbov (2010) who proposed a DR based on disability where those with at least 20 years old and disabilities are divided by those with at least 20 years and without disabilities. The indicator is multiplied by 100 as the United Nation's OADR.

[24] MN stands for new measure, as Sanderson and Schervob were comparing it with conventional measures (MC) of population ageing.

Scenarios

The following section describes our assumptions and calculations for each scenario. Under all scenarios, the population for each country grows according to UN demographic projections (United Nations 2017). The only difference derives from the assumptions for disability prevalence projections.

(1) Constant Prevalence Scenario

Under this scenario, the rate of disability prevalence for each age group is keep at its 2015 value during the projection period (2015-2050).

(2) Past-Trends Scenario

For this scenario, we calculate the average percent change in disability prevalence rates by age group and country, for the 1990-2015 period. Then, we assume that disability prevalence rates continue growing at the historical average rates during the projection period.

(3) Life Expectancy Scenario

For this scenario, we regress disability prevalence rates (explained variable) over life expectancy (explanatory variable), for the 1990-2015 period. A visual inspection of the data shows that the relationship increases with age, (Figure 1). Thus, we regress each age group separately. We consider that countries may have unobservable characteristics that correlate with disability prevalence, for example, higher income levels or better healthcare systems may reduce disability prevalence rates. The Hausman test reinforces this hypothesis, thus we run a linear and a fixed effects panel model.

The estimated coefficients under the fixed effects model are smaller but close to the those under the simple linear regression. Thus, we use the once obtained in the latter option and interpret the result as a best-case scenario, where increases in life expectancy do not only affect disability prevalence directly but also indirectly through the unobservable country characteristics. For example, as life expectancy increases, countries with low life expectancy catch-up with the rest in other dimensions such as income or health spending.

We use the results to predict future levels of disability prevalence rates, by country and age group, based on the UN's projections of life expectancy (United Nations 2017). We do not use the predictions of the model but apply the growth rates of the predictions to the projection period.

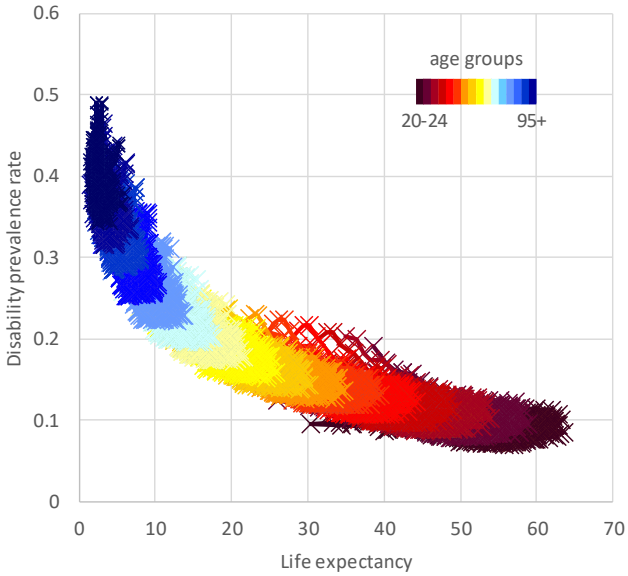

Figure A.1 Disability prevalence rates and life expectancy by age group and country (1990-2017)

Source: UN and GBD

Table A.1 Results of panel regression for life expectancy scenario

age group	variable		constant		N	R2
	coefficient	standard error	coefficient	standard error		
20-24	-0.0708***	0.0055	12.78***	0.29	1116	0.13
25-29	-0.1018***	0.0070	15.13***	0.33	1116	0.16
30-34	-0.139***	0.0079	17.3***	0.34	1116	0.22
35-39	-0.1818***	0.0089	19.38***	0.35	1116	0.27
40-44	-0.2147***	0.0099	20.93***	0.34	1116	0.30
45-49	-0.2697***	0.0111	22.91***	0.34	1116	0.35
50-54	-0.3158***	0.0124	24.24***	0.32	1116	0.37
55-59	-0.3789***	0.0143	25.86***	0.32	1116	0.39
60-64	-0.4559***	0.0175	27.72***	0.32	1116	0.38
65-69	-0.5916***	0.0224	30.56***	0.33	1116	0.39
70-74	-0.7394***	0.0282	33.03***	0.33	1116	0.38
75-79	-0.9171***	0.0366	35.38***	0.33	1116	0.36
80-84	-1.0817***	0.0473	37.74***	0.32	1116	0.32
85-89	-1.1291***	0.0601	39.21***	0.30	1116	0.24
90-94	-1.1928***	0.0811	40.84***	0.29	1116	0.16
95+	-1.243***	0.1117	42.46***	0.30	1116	0.10

Source: UN and GBD and own calculations.

*Notes: Disability prevalence rate expressed in percent for the regression. The coefficient indicates the change in the rate when life expectancy increases in one year. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.*

(4) Catch Up Scenario

In this scenario, the disability prevalence rate of each age group linearly transitions from its historical value in 2015 to a target value in 2100. The value in 2100 corresponds to the minimum rate for the correspondent age group across all countries in 2015.

Results by Country

The countries included in the analysis were determined by data restrictions. The Global Burden of Disease database provides data for 195 countries. 11 of them were dropped because there was no population or income group data. Figure 3 shows the results of the projections by country and the composition of the Income groups.

Table A.2 DDR projections for all countries.

Region	2015 DDR_CP	2050 DDR_CP	2015 DDR_LE	2050 DDR_LE	2015 DDR_PT	2050 DDR_PT	2015 DDR_CU	2050 DDR_CU
World	**16.2**	**18.9**	**16.2**	**18.4**	**16.2**	**17.5**	**16.2**	**17.3**
Low income	**15.9**	**16.8**	**15.9**	**16.3**	**15.9**	**13.6**	**15.9**	**14.9**
Afghanistan	21.8	23.4	21.8	22.7	21.8	19.6	21.8	18.7
Benin	15.7	16.2	15.7	16.0	15.7	11.0	15.7	14.5
Burkina Faso	14.6	15.3	14.6	14.7	14.6	8.4	14.6	13.8
Burundi	15.2	15.7	15.2	15.1	15.2	16.0	15.2	14.1
Central African Republic	17.9	18.3	17.9	16.6	17.9	15.2	17.9	15.7
Chad	16.3	16.7	16.3	16.1	16.3	14.7	16.3	14.6
Comoros	13.7	14.9	13.7	14.5	13.7	11.1	13.7	13.8
Dem. People's Republic of Korea	15.0	18.2	15.0	16.7	15.0	19.1	15.0	17.1
Democratic Republic of the Congo	17.4	17.7	17.4	16.7	17.4	14.6	17.4	15.2
Eritrea	16.2	17.5	16.2	16.2	16.2	10.2	16.2	15.4
Ethiopia	14.2	15.6	14.2	14.6	14.2	10.8	14.2	14.3
Gambia	15.8	16.3	15.8	16.0	15.8	14.9	15.8	14.4
Guinea	15.4	16.1	15.4	15.0	15.4	13.8	15.4	14.4
Guinea-Bissau	16.0	17.1	16.0	16.5	16.0	15.2	16.0	15.0
Haiti	16.3	18.1	16.3	17.7	16.3	17.6	16.3	16.2
Liberia	19.1	19.8	19.1	18.7	19.1	20.2	19.1	16.6
Madagascar	14.5	15.6	14.5	14.6	14.5	13.6	14.5	14.2
Malawi	14.4	15.4	14.4	14.2	14.4	12.4	14.4	14.0
Mali	15.6	16.0	15.6	15.3	15.6	12.0	15.6	14.1
Mozambique	16.8	17.0	16.8	16.0	16.8	15.9	16.8	14.9
Nepal	16.8	19.6	16.8	17.8	16.8	16.1	16.8	17.3
Niger	14.6	14.1	14.6	13.5	14.6	11.7	14.6	12.9
Rwanda	14.9	16.4	14.9	15.5	14.9	16.2	14.9	14.9
Senegal	14.8	15.9	14.8	15.0	14.8	13.7	14.8	14.4
Sierra Leone	15.8	16.8	15.8	16.0	15.8	15.3	15.8	14.8
Somalia	14.8	15.0	14.8	14.3	14.8	13.7	14.8	13.5

South Sudan	17.4	18.4	17.4	17.3	17.4	16.8	17.4	15.8
Syrian Arab Republic	17.3	19.6	17.3	17.3	17.3	20.8	17.3	17.2
Tajikistan	14.1	16.5	14.1	15.4	14.1	16.0	14.1	15.1
Togo	15.2	15.9	15.2	15.7	15.2	13.3	15.2	14.3
Uganda	14.7	15.4	14.7	14.6	14.7	7.5	14.7	13.8
United Republic of Tanzania	14.1	14.7	14.1	13.7	14.1	11.0	14.1	13.6
Yemen	19.1	21.1	19.1	20.4	19.1	18.7	19.1	17.5
Zimbabwe	16.1	18.0	16.1	16.8	16.1	18.0	16.1	15.7
Lower middle income	**16.0**	**18.5**	**16.0**	**18.1**	**16.0**	**16.8**	**16.0**	**16.6**
Angola	16.6	17.1	16.6	16.5	16.6	14.8	16.6	14.8
Bangladesh	15.7	19.5	15.7	17.4	15.7	17.7	15.7	17.6
Bhutan	14.5	18.7	14.5	17.0	14.5	15.1	14.5	17.2
Bolivia (Plurinational State of)	14.7	16.5	14.7	15.6	14.7	14.6	14.7	15.5
Cabo Verde	14.1	16.7	14.1	15.5	14.1	15.2	14.1	15.6
Cambodia	14.4	17.8	14.4	16.2	14.4	14.3	14.4	16.1
Cameroon	16.0	16.8	16.0	15.8	16.0	12.5	16.0	14.9
Congo	17.1	17.8	17.1	16.7	17.1	14.2	17.1	15.5
Côte d'Ivoire	15.4	15.7	15.4	15.0	15.4	11.3	15.4	14.1
Djibouti	13.5	15.9	13.5	15.5	13.5	15.4	13.5	14.9
Egypt	17.5	19.5	17.5	18.2	17.5	18.8	17.5	17.0
El Salvador	14.3	16.9	14.3	15.4	14.3	15.8	14.3	16.2
Georgia	17.7	20.3	17.7	18.4	17.7	21.4	17.7	18.6
Ghana	15.0	16.0	15.0	15.6	15.0	13.6	15.0	14.6
Honduras	13.2	16.1	13.2	15.2	13.2	16.1	13.2	15.3
India	16.7	19.7	16.7	18.7	16.7	17.5	16.7	17.4
Indonesia	14.3	17.2	14.3	16.4	14.3	16.1	14.3	16.0
Kenya	14.0	15.9	14.0	14.8	14.0	16.6	14.0	14.6
Kiribati	17.1	19.1	17.1	18.3	17.1	21.8	17.1	16.6
Kyrgyzstan	14.7	16.9	14.7	16.0	14.7	14.8	14.7	15.6
Lao People's Democratic Republic	13.3	16.0	13.3	15.1	13.3	13.6	13.3	15.0
Lesotho	19.6	20.9	19.6	19.3	19.6	25.6	19.6	17.3
Mauritania	14.4	15.6	14.4	15.3	14.4	13.2	14.4	14.2
Mongolia	14.9	18.0	14.9	16.8	14.9	18.1	14.9	16.3
Morocco	18.6	21.9	18.6	19.7	18.6	21.2	18.6	19.1
Myanmar	15.0	17.5	15.0	17.2	15.0	14.2	15.0	16.1
Nicaragua	13.2	16.7	13.2	15.1	13.2	14.0	13.2	16.0
Nigeria	16.0	16.4	16.0	15.5	16.0	15.1	16.0	14.5
Pakistan	15.2	17.1	15.2	16.8	15.2	16.5	15.2	15.4
Papua New Guinea	17.3	19.0	17.3	18.6	17.3	19.4	17.3	16.4
Philippines	14.7	16.7	14.7	16.1	14.7	15.7	14.7	15.3
Republic of Moldova	18.0	22.1	18.0	20.6	18.0	20.0	18.0	19.8
Sao Tome and Principe	14.2	15.4	14.2	15.1	14.2	14.5	14.2	14.2
Solomon Islands	15.5	17.6	15.5	16.0	15.5	19.3	15.5	15.7
Sri Lanka	15.0	18.6	15.0	17.0	15.0	16.9	15.0	17.7
Sudan	17.2	18.1	17.2	17.7	17.2	16.9	17.2	15.7
Swaziland	18.8	20.4	18.8	19.9	18.8	25.2	18.8	17.1
Timor-Leste	15.0	15.3	15.0	14.3	15.0	11.7	15.0	13.9
Tunisia	17.2	20.6	17.2	18.6	17.2	20.2	17.2	18.5

Ukraine	20.3	23.2	20.3	21.3	20.3	22.4	20.3	20.5
Uzbekistan	14.5	17.8	14.5	17.0	14.5	16.6	14.5	16.3
Vanuatu	16.3	18.6	16.3	17.1	16.3	19.3	16.3	16.4
Viet Nam	13.6	18.0	13.6	16.3	13.6	15.9	13.6	17.3
Zambia	14.5	15.4	14.5	14.5	14.5	14.0	14.5	14.0
Upper middle income	**15.1**	**19.0**	**15.1**	**18.4**	**15.1**	**17.8**	**15.1**	**17.9**
Albania	17.7	22.3	17.7	19.8	17.7	21.7	17.7	20.3
Algeria	16.8	20.2	16.8	18.5	16.8	19.3	16.8	18.0
Armenia	16.8	20.6	16.8	18.8	16.8	19.2	16.8	18.9
Azerbaijan	15.0	18.7	15.0	17.9	15.0	18.7	15.0	17.2
Belarus	19.8	22.5	19.8	20.7	19.8	21.9	19.8	20.0
Belize	13.5	15.4	13.5	14.4	13.5	15.7	13.5	14.6
Bosnia and Herzegovina	20.6	25.2	20.6	22.4	20.6	26.1	20.6	22.0
Botswana	17.7	21.0	17.7	19.3	17.7	21.8	17.7	17.9
Brazil	16.2	19.8	16.2	18.0	16.2	18.5	16.2	18.4
Bulgaria	20.2	23.2	20.2	21.5	20.2	22.2	20.2	20.8
China	14.1	18.5	14.1	16.9	14.1	17.2	14.1	17.9
Colombia	13.0	16.2	13.0	15.2	13.0	14.3	13.0	16.1
Costa Rica	13.6	17.5	13.6	15.7	13.6	16.8	13.6	17.2
Cuba	15.1	19.5	15.1	17.5	15.1	18.3	15.1	19.1
Dominican Republic	14.1	16.6	14.1	15.4	14.1	16.8	14.1	15.9
Ecuador	13.9	16.6	13.9	15.2	13.9	15.8	13.9	15.9
Equatorial Guinea	15.8	17.0	15.8	15.8	15.8	13.2	15.8	14.9
Fiji	17.0	19.6	17.0	18.6	17.0	20.4	17.0	17.4
Gabon	16.8	18.5	16.8	17.4	16.8	16.6	16.8	16.3
Grenada	13.9	16.7	13.9	15.6	13.9	16.0	13.9	16.0
Guatemala	13.5	15.7	13.5	14.5	13.5	13.2	13.5	14.9
Guyana	15.8	17.4	15.8	16.9	15.8	16.6	15.8	15.9
Iran (Islamic Republic of)	18.1	22.9	18.1	20.2	18.1	23.2	18.1	20.0
Iraq	17.8	19.1	17.8	18.4	17.8	15.7	17.8	16.3
Jamaica	14.7	18.1	14.7	16.8	14.7	19.1	14.7	17.3
Jordan	16.0	18.5	16.0	17.3	16.0	17.1	16.0	16.4
Kazakhstan	16.2	18.1	16.2	17.1	16.2	16.4	16.2	16.5
Lebanon	18.6	23.7	18.6	20.8	18.6	23.5	18.6	20.7
Libya	18.0	22.1	18.0	20.7	18.0	24.4	18.0	19.0
Malaysia	12.9	16.5	12.9	15.0	12.9	15.8	12.9	15.8
Maldives	11.8	16.9	11.8	14.4	11.8	11.7	11.8	16.2
Mauritius	17.0	21.3	17.0	19.6	17.0	22.2	17.0	19.4
Mexico	13.9	17.5	13.9	15.9	13.9	17.6	13.9	16.6
Montenegro	19.1	22.8	19.1	20.3	19.1	23.3	19.1	20.4
Namibia	16.6	18.5	16.6	17.1	16.6	17.9	16.6	16.1
Paraguay	15.1	17.3	15.1	16.7	15.1	17.2	15.1	16.0
Peru	13.2	15.8	13.2	14.4	13.2	14.4	13.2	15.5
Romania	20.2	23.8	20.2	21.8	20.2	21.2	20.2	21.1
Russian Federation	19.9	22.4	19.9	21.1	19.9	21.5	19.9	19.8
Saint Lucia	14.8	18.6	14.8	16.9	14.8	17.3	14.8	17.9
Saint Vincent and the Grenadines	15.0	18.1	15.0	17.1	15.0	18.5	15.0	17.0
Samoa	15.8	17.9	15.8	15.8	15.8	19.1	15.8	16.3

Serbia	20.3	23.1	20.3	21.3	20.3	22.7	20.3	20.5
South Africa	18.1	19.8	18.1	18.8	18.1	21.2	18.1	17.2
Suriname	14.8	17.0	14.8	16.1	14.8	17.9	14.8	16.0
TFYR Macedonia	18.1	22.3	18.1	20.2	18.1	22.0	18.1	20.0
Thailand	14.8	19.4	14.8	17.6	14.8	17.7	14.8	18.7
Tonga	16.1	17.6	16.1	16.2	16.1	18.6	16.1	15.9
Turkey	17.0	20.4	17.0	18.1	17.0	18.1	17.0	18.5
Turkmenistan	13.9	16.2	13.9	15.8	13.9	15.1	13.9	15.1
Venezuela (Bolivarian Republic of)	13.3	16.1	13.3	14.8	13.3	15.8	13.3	15.6
High income	**19.1**	**22.0**	**19.1**	**21.2**	**19.1**	**22.1**	**19.1**	**20.1**
Antigua and Barbuda	14.8	17.8	14.8	16.4	14.8	17.2	14.8	16.9
Argentina	16.4	18.2	16.4	16.6	16.4	18.4	16.4	17.0
Australia	18.9	21.2	18.9	19.2	18.9	21.2	18.9	19.2
Austria	19.2	22.2	19.2	20.3	19.2	22.2	19.2	20.6
Bahamas	14.1	17.3	14.1	16.0	14.1	17.1	14.1	16.8
Bahrain	15.6	19.2	15.6	17.7	15.6	17.9	15.6	17.0
Barbados	15.7	18.1	15.7	16.5	15.7	18.4	15.7	17.6
Belgium	20.5	22.8	20.5	20.6	20.5	23.5	20.5	20.6
Brunei Darussalam	13.5	18.3	13.5	16.6	13.5	16.7	13.5	17.3
Canada	18.3	21.0	18.3	19.0	18.3	21.2	18.3	19.5
Chile	17.2	20.8	17.2	18.5	17.2	20.6	17.2	19.1
Croatia	20.8	24.6	20.8	22.0	20.8	23.9	20.8	21.8
Cyprus	16.8	20.2	16.8	18.0	16.8	19.4	16.8	18.8
Czechia	20.9	25.5	20.9	22.8	20.9	24.7	20.9	22.2
Denmark	19.2	21.1	19.2	19.0	19.2	21.3	19.2	19.5
Estonia	20.5	23.5	20.5	21.2	20.5	22.1	20.5	21.1
Finland	20.4	22.0	20.4	20.1	20.4	21.5	20.4	20.1
France	18.2	20.2	18.2	18.3	18.2	19.9	18.2	19.2
Germany	19.7	22.6	19.7	20.2	19.7	22.1	19.7	20.8
Greece	19.3	22.8	19.3	20.5	19.3	22.8	19.3	21.2
Guam	16.3	19.9	16.3	17.4	16.3	22.9	16.3	18.2
Hungary	20.9	24.6	20.9	22.6	20.9	22.0	20.9	21.5
Iceland	17.8	20.6	17.8	18.6	17.8	20.0	17.8	19.1
Ireland	18.3	21.2	18.3	19.1	18.3	21.4	18.3	19.4
Israel	17.3	18.8	17.3	17.1	17.3	18.1	17.3	17.3
Italy	19.3	22.4	19.3	20.2	19.3	21.2	19.3	21.1
Japan	18.4	21.5	18.4	19.4	18.4	22.2	18.4	20.7
Kuwait	15.4	18.9	15.4	17.6	15.4	18.9	15.4	17.0
Latvia	21.3	24.1	21.3	22.2	21.3	23.0	21.3	21.3
Lithuania	21.6	24.2	21.6	22.3	21.6	24.2	21.6	21.3
Luxembourg	19.4	21.9	19.4	19.7	19.4	21.1	19.4	19.6
Malta	18.7	22.0	18.7	19.5	18.7	22.4	18.7	20.3
Netherlands	19.4	22.1	19.4	20.0	19.4	21.7	19.4	20.3
New Zealand	20.2	23.4	20.2	21.1	20.2	24.0	20.2	20.7
Norway	19.8	21.8	19.8	19.9	19.8	21.6	19.8	19.7
Oman	14.6	19.7	14.6	17.4	14.6	17.9	14.6	17.4
Panama	13.5	16.2	13.5	14.9	13.5	16.0	13.5	15.9
Poland	19.7	25.0	19.7	22.6	19.7	23.8	19.7	22.1

Portugal	19.9	23.4	19.9	21.0	19.9	21.8	19.9	21.6
Qatar	14.2	18.9	14.2	17.2	14.2	16.9	14.2	16.8
Republic of Korea	16.2	22.0	16.2	19.6	16.2	19.4	16.2	20.9
Saudi Arabia	15.4	19.3	15.4	17.9	15.4	18.1	15.4	17.4
Seychelles	14.4	18.5	14.4	16.8	14.4	18.7	14.4	17.5
Singapore	14.4	19.1	14.4	17.1	14.4	16.8	14.4	19.0
Slovakia	19.4	24.4	19.4	22.3	19.4	23.4	19.4	21.5
Slovenia	21.6	26.6	21.6	24.1	21.6	25.6	21.6	23.2
Spain	17.8	21.5	17.8	19.5	17.8	20.5	17.8	20.6
Sweden	19.2	20.9	19.2	18.9	19.2	21.1	19.2	19.3
Switzerland	19.0	21.8	19.0	19.7	19.0	20.8	19.0	20.1
Trinidad and Tobago	15.6	18.3	15.6	17.5	15.6	17.8	15.6	17.2
United Arab Emirates	15.6	19.7	15.6	18.0	15.6	20.1	15.6	17.3
United Kingdom	20.0	22.2	20.0	19.8	20.0	23.5	20.0	20.1
United States of America	20.9	23.5	20.9	21.2	20.9	24.6	20.9	20.6
United States Virgin Islands	16.5	19.2	16.5	17.1	16.5	19.9	16.5	18.7
Uruguay	17.1	19.1	17.1	17.5	17.1	19.2	17.1	17.9

Source: GBD, World Bank, UN, and authors' calculations

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