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Three essays on social and spatial differences in health and mortality in contemporary Spain: New demographic perspectives to old questions

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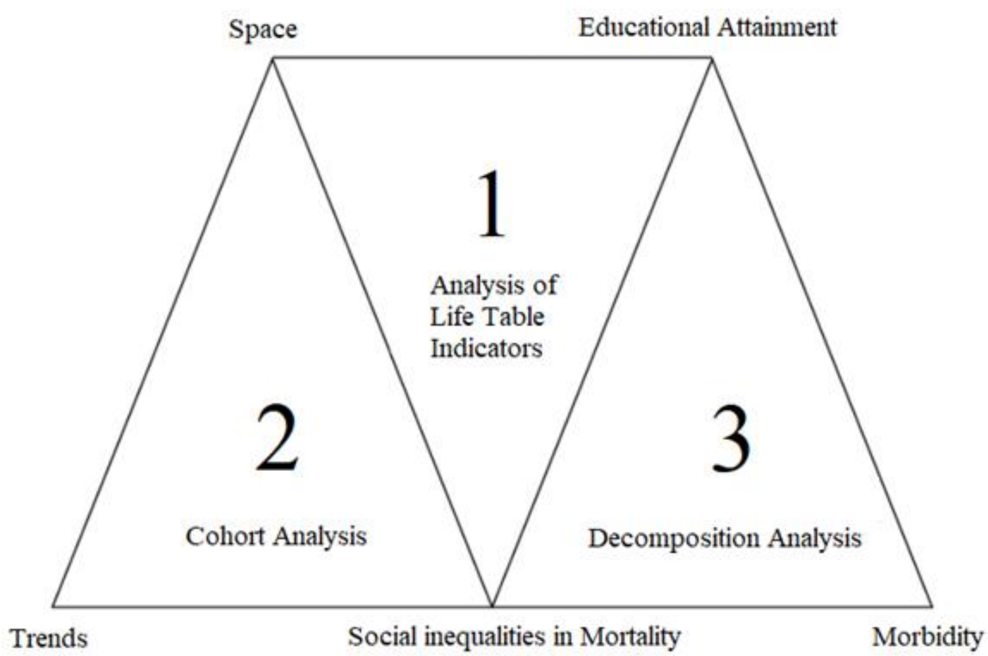

Doctoral Thesis submitted to obtain the Degree of Doctor of Demography

Three essays on social and spatial differences in health and mortality in contemporary Spain. New demographic perspectives to old questions.

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Preface

The following doctoral dissertation consists in three essays that delve into the topic of health disparities in contemporary Spain. While perfect health equality is almost an unachievable goal given the existence of heterogeneity among many other factors, it is still a goal worth pursuing for ethical, economic, and political reasons.

The three essays are motivated by the fact that socioeconomic position, the place of living, and exposure to certain events across the life course (manifested in a variety of proxies) are determinants of health inequalities. And that implies a series of disadvantages that can manifest in multiple negative health outcomes, including (but not limited to) mortality. While this association between a worse social standing and poor health outcomes has been thoroughly established in the literature, this dissertation wants to explore the extent of these inequalities in some critical aspects that, in contemporary Spain, have largely remained underexplored to this day.

The first essay is a cross-sectional study whose focus was on the regional variation of educational disparities in mortality in Spain during the 2014-2018 period. While previous studies have calculated mortality indicators such as life expectancy (a summary measure that tries to approximate the average longevity of a population) by educational attainment across regions, they have not focused on lifespan variability indicators (how equitable are lifespans and how likely is for an individual to reach its expected length of life). In other words, this study explores from a demographic perspective differences in mortality heterogeneity considering space, educational attainment, and sex. Furthermore, it analyzes the relationship of such heterogeneity (lifespan variability measures) with mortality intensity (life expectancy).

The second essay also focuses on spatial disparities in mortality, considering generational (cohort) inequalities in mortality. Specifically, lung cancer mortality among females between the years 1980 and 2019. The reason behind this singular choice is that, unlike the majority of causes of death that experienced significant improvements in the last decades, lung cancer is one of the few cases in which mortality has increased during the last

40 years among females. Therefore, establishing if generational factors might be related to such particular trends (and doing so from a comparative regional perspective, something that to the best of my knowledge has not been done in the past) might offer new perspectives on the dynamics of female mortality in Spain.

The third essay shifts from longevity (how long individuals live) to healthy longevity (how long individuals live without poor health) by educational attainment. Specifically, it tries to disentangle how much of the advantage in healthy life expectancy that higher-educated individuals have is the result of higher longevity (being alive) and how much is an advantage in prevalence (being healthy) during the 2012-2017 period. It also studies how this contribution changes by age, sex, and educational attainment, separately for five different groups of frequent conditions instead of relying upon a catch-all global indicator of good/poor health.

While eminently descriptive, the findings of the three essays point out a clear fact: despite all improvements in health that Spain has experienced during the last 50 years, significant social, spatial and even generational inequalities in health and mortality persist. The three essays helped to identify which are more vulnerable populations and the extent of their health disadvantages in a variety of ways, which hopefully would lead to designing policies that mitigate such disparities, which would result in a more efficient health system and a fairer society.

The three essays that are the core of this dissertation were conducted between the three years of the doctoral program in Demography (Starting in October 2020 to this day), and this dissertation was carried with the support of an FI-2021 Doctoral Grant of the AGAUR (Agència de Gestió d'Ajuts Universitaris i de Recerca) and from the HEALIN-ERC Consolidator Grant (Healthy lifespan inequality: Measurement, trends, and determinants. Ref. H2020-ERC-2019-CoG-864616. PI: Dr. Iñaki Permanyer).

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To the staff of the Masters in Social Demography at the Universidad Nacional de Luján, where everything started. Especially to Dr. Carlos Grushka, who thought that I could have a career in academic research someday. He served both as a great boss in the National Administration of Social Security and as a great mentor during my Masters. But also he was gracious enough to help me to apply to Doctoral programs, including the Doctoral School of Demography, while showing me the ropes of the academic environment and its opportunities. And more broadly, to all the Latin American population scientists that acknowledged me as one of them and encouraged me to go further in my studies.

The European Doctoral School of Demography (EDSD) took a chance on an Argentinian who had a part-time Masters and was already in his 30s. In this era where newly minted doctors are younger and younger, I remember being hesitant about doing a one-year program because that would mean that if I went through the EDSD, I was worried about being unable to secure a Ph.D. position at all. Or even doing a doctorate at all, since that would imply choosing a different career path than the one that I had gone through. All it took was a small email exchange with José Manuel Aburto (whom I'm glad to consider a good friend after all these years) who convinced me almost immediately to accept and take a chance on myself.

I am thankful to Albert Esteve, for opening up the doors of the CED and finding a way to ensure I could study and learn here after my EDSD fellowship ended (in the middle of a Pandemic no less!). And to Mariona Lozano and Elisenda Rentería for their support during the EDSD and afterward.

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To my office mates at CED who were part of this journey, and who also became my friends and family as well: Silvia, Carlos, Paula, Maida, Nicolás, Laura, Mariana, Sabi, Min, Parminder, Evgeniya, Jianji, Anna, Osama, Mireia, Federica, Chiara, Huifen, Rita, Christian, Carlos (I know, we have two Carlos but I don't like the idea of using Carlos I and Carlos II because it sounds monarchic and I think that might be quite a sensitive issue, so I'd rather spread them out in the acknowledgments), and to the visiting researchers who also became part of this community as well. Thank you for all that you have done for me.

To the people in El Colegio de México, where I did my three-month research stay, and especially to Dr. Vìctor García-Guerrero who hosted me. I am very glad about the work that we did during my time there and about my experience in *Ciudad de México*, which ended up being one of the happiest times in my life.

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To P., for her determination and scientific integrity (and adorable shyness). And for making me smile every day just by being who you are. That part is pretty amazing, to be honest. I'm hopeful we can keep it that way.

To my family, my mother Viviana, and my siblings, Lucas and Alejo. And to my father, Juan José, who for the last 22 years has been on another plane of existence but I still remember him every day.

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1 Introduction

1. Overview

The core of this dissertation is based on three original research essays that circle the idea of social and spatial disparities in health in contemporary Spain. Elements from Formal Demography, Sociology, Social Epidemiology, and Population Geography are present in all of them.

Living longer lifespans has stopped being an exclusive privilege, turning into a common outcome across populations. Spain has currently one of the highest life expectancies (a synthetic summary measure of period mortality) in the world, after a sustained increase that occurred during the last decades: between 1960 and 2019, the indicator rose from 59.3 years to 79.6 years for males and from 64.2 years to 85.1 years for females (Permanyer & Bramajo, 2022). One of the main drivers of such improvement is the decline in infant mortality. According to the latest World Population Prospects produced by the United Nations infant mortality in Spain has decreased from 47 deaths per 1000 live births in 1960 to 2.01 in 2023 (United Nations Department of Economic and Social Affairs, Population Division, 2022). Because of this, analyzing disparities in adulthood and later life became crucial to understand current health inequalities in Spanish society.

While most individuals successfully reach advanced ages, that does not necessarily mean that health is equally distributed across a population. There are a series of social and spatial factors that may determine how long people live on average, and also how long is the extent of their healthy lives. Population aging is one of the key challenges of the 21st Century, so identifying the sources and extent of disparities in population health is critical to our understanding of the processes that affect Spain and possibly other countries in a similar situation.

Measuring the extent of such disparities and the drivers behind them has been a long-term goal of demographic analysis. However, since population dynamics are ever-changing, the question keeps constantly being reintroduced and reanswered, with different methods, different results, and different implications. While this dissertation explores many topics and themes (as most essay-oriented dissertations do), some of the core questions of this investigation are the following:

-What is the magnitude of the social and spatial inequalities in population health and mortality in contemporary Spain?
-Which are some of the lenses through which these inequalities have not been explored yet?
-What are the implications of the existence of those inequalities in the 21st Century?

I heard once Alberto Palloni saying that Demography is a discipline of time. One of the core aspects of the discipline is the capability of producing synthetic measures that combine the intensity of a given phenomenon and their lasting impact on time: life expectancy and healthy life expectancy are two prime examples of this. They try to approximate in a time-based measure (generally expressed in years of life) the magnitude of a given outcome (mortality, disability, prevalence of a given condition, and many others).

Demography has relied on easily-interpretable, strong indicators such as age-standardized mortality, age-specific mortality, or life expectancy to compute and estimate the overall magnitude of mortality and its disparities. Complementarily, age-standardized prevalence, age-specific prevalence, and healthy life expectancy are their counterparts when focusing on the quality of life or condition-based metrics (based on diseases, disabilities, or health conditions).

Most of these methods are powerful, simple, and have a straightforward interpretation that has helped research and policy-oriented decisions for decades when addressing social inequalities in health and mortality. However, those indicators, as robust as they are, also have some limitations, because no measure is perfect. Some of the three research essays that conform to the core of this dissertation expand some aspects of what is beyond those indicators by focusing on less obvious topics that may be hidden and somewhat overlooked under the strengths of such measures. We hope to provide new insights into the extent of some of the social and spatial inequalities in health and mortality in contemporary Spain.

This chapter is based on three sections, being the first a brief introduction to the thesis. The second is a small overview of social and spatial inequalities in health and mortality and its relationship with Spain. The third is a brief overview of the research essays and how they were conceived to make this a cohesive essay-oriented dissertation.

2. Inequality in health and why does it matter

Ideally, fair societies offer the same opportunities and resources to each one of its participants. In reality, there is a differential allocation of wealth, education, location, and other key resources among a given population. In this uneven distribution of resources, we can say that health is distributed unevenly as well (Graham, 2004). This results in a health gradient across gender, socioeconomic status, or geographical area, that are mostly driven by social aspects rather than biological ones (Marmot, 2005). In other words, the core of such disparities is explained by non-medical factors (Braveman et al., 2011).

The social nature of these inequalities makes them feel avoidable and something that hopefully can be corrected with fair and adequate policies, which probably makes them more unfair. The cost of inequalities in health is not only philosophical (how much inequality is acceptable in a society?) but also political and economical: many institutions in modern societies, somewhat inadvertently, tend to favor individuals with a higher social standing. Labor productivity and lifetime earnings are also affected by a range of conditions that affect the quality of life and the ability and availability to work (chronic physical and mental conditions). Furthermore, having more individuals who can reach healthier ages helps by lessening the burden of intergenerational caregiving, and such time into other activities that can be considered more “productive”.

Link and Phelan’s seminal paper brought the theory of fundamental causes as a key aspect of health inequalities (1995). The article mentions that despite diverse technological and sanitation improvements over time -that were thought they were responsible for disparities in health across groups-, socioeconomic differences in health and mortality persisted. They argue that the notion of socioeconomic status involves a variety of resources, involving wealth, power, knowledge, prestige, and social connections that protect health (Phelan et al., 2010). The authors mention that a fundamental cause of health can influence multiple health outcomes (including but not limited to mortality) and multiple risk factors. Furthermore, the association between a fundamental cause and health outcome is reproduced over time by intervening mechanisms that can be replaced by other mechanisms no matter what. Therefore, a disadvantaged socioeconomic status (SES) is indeed a fundamental cause of potentially multiple health disparities.

Generally speaking, one of these key proxy variables that is explored when analyzing social disparities in health is education (and its implications). The causal mechanisms between education and health are complex and somewhat unclear, and the existence or not of such an association seems to be dependent on a given circumstance rather than a general law (Hayward et al., 2015).

Since the 1960s, Spain has undergone major socioeconomic, demographic, political, and cultural transformations, rapidly changing its population composition and structure. In 1960, a large majority of individuals had no formal education and only a small group of individuals could have access to middle or higher education. However, in the last decade, having no formal education became a rarity while getting secondary education or college was something that the majority of people pursued, courtesy of the educational expansion (Permanyer et al., 2018).

In this dissertation, we do not assume that education does necessarily bring a higher social standing by itself in contemporary Spain, but access to higher education implies a better chance to get favorable opportunities across the life course: better salaries, better healthcare, a higher wealth, jobs that are physically less demanding, and less exposure to a myriad of negative health behaviors and outcomes (Cutler et al., 2006; Jasilionis & Shkolnikov, 2016). And more opportunities are the result of more freedom and that implies better outcomes across the life course (Sen, 1999). A higher social standing does not only imply an average longevity/health advantage. It also means a lower variability (or lower uncertainty) in the time lived, implying higher equity in the lifespan, while individuals with lower social standing tend to have a higher heterogeneity, living more uncertain lives (Permanyer et al., 2018; Sasson, 2016; van Raalte et al., 2011; van Raalte et al., 2014; van Raalte et al., 2018).

Higher uncertainty in lifespans has a series of implications, potentially affecting the fairness of policies that are responsible for the overall well-being of the population. We mentioned before that some institutions helped inadvertently individuals from a higher standing. For instance, Spain has a pay-as-you-go (PAYG) pension scheme, in which individuals earn a fixed pension amount during their remaining lifespan after they decide to leave the job market and retire. However, individuals in a higher social standing tend to live longer and probably have a more stable working life to fulfill the contribution requirements.

This probably means that they earn a (higher) pension compared to individuals with a less smooth working trajectory, they take benefit of their pension income for a longer time, and with a higher degree of certainty that they will reach more advanced ages. In Spain, while the magnitude of health disparities has changed over time and by measure, access to higher education has traditionally been associated not only with larger average lifespans (Miqueleiz et al., 2015; Permanyer et al., 2018; Regidor et al., 2011; Reques et al., 2015) but also with longer healthy lifespans as well (Solé-Auró et al., 2022; Solé-Auró & Alcañiz, 2015). However, studies focusing on how equitable are those lifespans have been less considered, and only at a national level, without considering regional heterogeneity (Permanyer et al., 2018; Trias-Llimós & Spijker, 2022).

This is mentioned because the environment is also a key determinant of health (Dahlgren & Whitehead, 2021; Lynch et al., 2000). Social relationships do not happen in thin air but occur in a socially determined space (Soja, 1985). Across a given space diverse political factors, power, and disparity of resources and access to them come into play and can shape in a variety of ways an array of outcomes. A lack of social, physical, or health care resources on the spatial dimension involves a differential exposure to health risks which can shape in a variety of ways a negative health outcome. Therefore, while these relationships are not always obvious, it can be expected that more developed regions can provide some sort of health advantage to their inhabitants due to their higher material and intellectual network of resources (Smith, 2000).

In the Spanish case, the autonomous community of Madrid (where the capital city is located) presents some of the highest life expectancies in the world (according to the National Institute of Statistics, life expectancy at birth in 2019 was 82.4 and 87.2 years for males and females respectively). On the other hand, Andalusia, where almost 20% of the population in the country lives, presents some of the lowest values in the nation (79.6 years for males and 84.5 years for females in 2019). Some studies argue that oceanic, border provinces have higher mortality than central provinces, with a pattern that goes from higher mortality in the south to lower mortality in the north (i.e., Reques et al., 2015). However, with many outliers of this pattern and without a clear overall tendency, I think is somewhat safe to say that Spain has a clear heterogeneous profile in terms of health at a regional level. Unlike other countries, like the United States or Brazil, in which clear regional patterns can be identified at a larger scale, Spain's spatial heterogeneity in health makes it complex to determine macro-areas that go above the level of the autonomous community, the maximum sub-national political entity. Therefore, we believe is critical to keep in mind the regional dimension of Spain when comprehending disparities in both overall longevity and mortality variability.

Apart from SES and space, gender is also a key concept to understanding health disparities. Today it is an acknowledged fact that males tend to die more and at earlier ages than females. However, evidence suggests that male mortality is a relatively recent historical construction (Henry, 1988; McNay et al., 2005), which indicates that the role of gender is also a socially mediated construct as a health determinant. While is possible that a part of the gender gap is due to non-social factors, the consensus seems to suggest that risk factors and risky behaviors that might be related to previous and current life decisions (acknowledging that not all of them are easily avoidable) are partly responsible for the difference (i.e. Austad, 2006; Cutler et al., 2006). However, the females' advantage in mortality is not necessarily accompanied by an advantage in healthy longevity. The health-survival indicates that while females have a longer life expectancy than males, they also spend a larger proportion of their lives in poor health due to a higher prevalence of disabilities (Di Lego et al., 2020; Van Oyen et al., 2013). In a country with a high life expectancy such as Spain, gender gradients in morbidity becomes an important domain of health disparities to keep in consideration.

There is also another aspect that we explore in this dissertation that is associated with social inequality, albeit in a more subtle, less direct way: the notion of cohorts. Education, income, and wealth could be considered as tangible, structural determinants, in the sense that it is known that having higher education and better wealth should be normatively desirable and probably will result associated to better health overall. The association between those two concepts is clear and evidence about such a link is ubiquitous. However, the role of cohorts when addressing health outcomes is more circumstantial and very dependent on the research question, but not less social. According to Glenn (2005), cohorts are defined as a group of individuals that are exposed singularly to a series of events during their life course, and as a result, they might be affected similarly by a specific outcome. While some of the health improvements can be attributed to continuous change over time that affects everyone, cohorts might carry this distinctive behavior over time. For instance, a cohort that was drafted to a lengthy war, might have and have overall worse health outcomes across their life course than previous and subsequent generations. Cancer is another example of a cohort behavior that might shape negative health outcomes, particularly lung cancer: the distinctive exposure of certain generations to a factor (in this case, smoking or second-hand smoking) might result in a higher likelihood of having lung cancer when compared to other generations (i.e. Alberg & Samet, 2003; de Groot & Munden, 2012; Ezzati et al., 2005).

While some cohorts might be more affected by a certain health outcome, the concept is also less plastic: you can improve your wealth and the health outcomes that are associated with better wealth, but you cannot change the cohort you were born. And favored/unfavored cohorts on a certain outcome can also change across space, time, and event, so the relationship between cohorts and health is not as straightforward as it might be between wealth and health, even if both are social by its nature. Since the concept of cohort relies on collective exposure to a certain event, the notion of space is also critical to analyze and understand such disparities in such events. Both space and time limit the number of people that could be affected by a certain event via several mechanisms (Urry, 1995). A given phenomenon that affects the population living in a certain country at a certain time could easily occur ten years later in a different place with similar consequences. However, for all the benefits the educational expansion and increased wealth have brought to Spain, other less fortunate events have occurred that deteriorated the health of the population. Being one of the most paradoxical the growing prevalence of smoking among adult females between 1970 and 2010 (Fernández et al., 2003; Regidor et al., 2010; Villalbí et al., 2019). Among other factors, the low price of cigarettes and the lack of strong anti-tobacco campaigns can be associated with such growth. The relatively recent decentralization of health care services and health prevention services among regions (a process that began in 1978 with the sanction of a new constitution in Spain but was finalized near 2002) might also be a factor to consider when evaluating the evolution of lung cancer mortality in Spain. A certain policy in a given place may result in its population having an earlier-later exposure to smoking, and, possibly, a different risk of dying from lung cancer. In other words, cohorts that might be more affected by this particular risk are also a dynamic concept that may change across space. Previous studies in Spain following lung cancer mortality with a cohort perspective were only limited to certain populations (A. Cayuela et al., 2004; Franco et al., 2002; Ocaña-Riola et al., 2013), without a spatial comparative focus. Therefore, investigating variations at a regional level was an intriguing path to have a better understanding of contemporary health dynamics in Spain.

3. Outline of the essays and data sources

The three essays, presented in Chapters 2 to 4, deal with different health outcomes (life expectancy and lifespan variation, standardized rates, relative risks, condition-free life expectancies) in contemporary Spain.

The first essay (Chapter 2) explores regional differences in life expectancy and lifespan variation measures in Spain by educational attainment, focusing on the 2014-2018 period. Certainly, addressing differences in health and mortality by considering education as an explanatory variable, is something that has been done on multiple occasions in Spain and many other countries in the past (in the essays the corresponding references to previous works are shown). That being said, studies focusing on educational differences that consider simultaneously these two particular dimensions of demography (life expectancy and lifespan variation, as the demographic synthesis of efficiency and equity of longevity) have not been conducted at a regional level before. Most importantly, this paper provided the opportunity to test the strength of these measures by educational attainment, something that we acknowledge has not been done as well. For this essay, age-specific mortality data by educational attainment was necessary, which was provided by the Spanish National Institute of Statistics (or INE, Instituto Nacional de Estadística). As mentioned in the article, these data sources have been used before in other previously published studies (Permanyer et al., 2018; Trias-Llimós & Spijker, 2022). A final form of this essay (Chapter 2) was published in the Journal Population, Space and Place at the end of 2022, after a lengthy review process. The paper also included contributions from Iñaki Permanyer and Amand Blanes, who both provided the data sources and valuable comments which were very helpful to get the essay published. A previous form of this article was presented as well in the 2022 Population Association of America (PAA) Meeting.

The second essay (Chapter 3) is a solo-authored effort that investigated the role of birth cohorts in lung cancer mortality among females across Spanish regions, from 1980 to 2019. Spain is one of the countries that still presents an ever-growing increasing trend in lung cancer mortality among women during the last forty years, and this happened to occur across all autonomous communities. Just because of that reason I thought that understanding if cohorts had something to do was worth exploring.

The analytical strategy was to conduct an age-period-cohort model and estimate trends in lung cancer deaths, trying to identify cohorts who could have a potentially higher relative risk of death and variations across regions, if any. While this approach has been done in the past to address trends in lung cancer mortality in Spain, this has not been done at a regional level in Spain before, by comparing the different generational risks across subnational units. In other words, was the national pattern reproduced at a subnational level in Spain? Moreover, it is the first article to explore the association between lung cancer mortality trends across cohorts and macro-level factors that could be possibly associated with such trends in Spain at a regional level. If there were indeed any changes in cohort mortality across regions, what are the factors that such changes might be related to?

For this article, I relied on a combination of data sources, all publicly available on the Spanish National Institute (Instituto Nacional de Estadística, also known as INE, given their acronym in Spanish) website. To calculate mortality trends (from which the models were derived), I used cause-specific mortality by age groups and population exposures from 1980 to 2019. I also used other public data available, collected from different surveys and government information, such as economic, health, educational, and spending by region to establish the association between lung cancer mortality by cohorts and such variables. Previous forms of this article were presented at the 4th Conference of the European Society of Historical Demography (2022) and in the 2023 PAA Meeting, and it is revised version is currently under review in the Journal of Population Research.

The third essay (Chapter 4), explores a different health outcome: condition-free life expectancies by educational attainment in Spain (a specific health expectancy). Once again, while studies estimating health expectancies in Spain have been done in the past, the article does two specific things that could be considered as original: on the one hand, it considers five different groups of frequent conditions instead of a global indicator of “poor health” (such as the Global Activity Limitation Index or broad definitions of “Chronic Conditions” as a single item) to analyze the average length of healthy life. On the other hand, it does a decomposition analysis that shows in a clearer fashion which are the drivers behind the differences in health expectancies by educational attainment for each group of conditions.

For this essay, age-specific mortality data by educational attainment was necessary, which again was provided by the INE. Furthermore, to obtain age-specific prevalences by education which are necessary for constructing healthy life expectancies, we relied on a set of pooled surveys: the 2012 and 2017 National Survey of Health of Spain (or ENSE, Encuesta Nacional de Salud de España) and the 2014 Spanish Module of the European Survey of Health (Encuesta Europea de Salud de España). This essay was submitted in an article at the time of submission of this dissertation and is under review. This essay has three additional contributors: Dr. Pilar Zueras, Dr. Elisenda Rentería (two experts on health expectancies), and again, Dr. Iñaki Permanyer who provided valuable comments and thoughts to organize the manuscript. Additionally, Dr. Sergi Trías and Dr. Jeroen Spijker provided valuable feedback as well on informal presentations of the project. Previous forms of this article were presented at the 2022 PAA Meeting and the 2022 European Population Conference.

The three essays are original pieces of research that cover topics of modern formal demography in some capacity: the first by use of lifespan variation indicators, the use of age-period-cohort models to decompose the generational effects in mortality, and the use of mathematical decompositions to determine the contributions of longevity (mortality) and health (morbidity) in a given differential of health expectancies. Furthermore, while I acknowledge the contribution of the aforementioned authors during the dissertation, I take sole responsibility for the theoretical framework, design of the studies, data curation, statistical analysis, and conclusions of each study (and despite the use of academic *pluralis modestiae* instead of using the first-person singular form).

In a way, the three essays behave like three isosceles triangles, with two sides that are symmetrical and one that is different (but still part of the triangle, of course). Two essays use educational attainment as the proxy variable that represents social standing, while the other does not (however, it explores education as a possible macro-factor in the association of variables). Two essays explore differentials across autonomous communities, while the other does not, focusing on disparities at a national level (which, however, is nothing but the sum of all the autonomous communities). Two essays focus on mortality differentials, while the remaining does not (but it explores the overall role of mortality in the average length of healthy life). Two essays focus on a single moment, like a snapshot or an x-ray, while the remaining one analyzes a mortality trend over time (and across cohorts). However, I believe (or, to some extent, I hope) that this somewhat apparent asymmetry complements each other nicely, in a coherent fashion. While some other pieces of research were produced during this period that are related to some extent to the topics of this dissertation (Acosta et al., 2022; Bramajo, 2022a, 2022b; Permanyer & Bramajo, 2022), I decided that the three essays that are in this dissertation represent the most cohesive choice for a thesis. Furthermore, I acknowledge that due to time constraints, some additional papers that were conceived during this period were not finished at the time of submission. I want to mention singularly a paper that is the result of a three-month research stay in El Colegio de México (Mexico City), with the collaboration of Dr. Víctor García-Guerrero and Dr. Iñaki Permanyer. The first version of this paper was presented at the 2023 PAA meeting and later at the 2023 REVES meeting. After the (very positive) feedback received in those conferences, we agreed that there is some work to be done to consider it a publishable article in an international journal. As a result, such work is not part of this dissertation.

Finally, after the three studies are presented, there is a conclusion chapter (Chapter 5) discussing the main findings of the essays and the implications of such findings, along with their limitations, and future lines of research.

Chapter 2: Regional inequalities in life expectancy and lifespan variation by educational attainment in Spain, 2014-2018

Coauthored with Dr. Iñaki Permanyer and Dr. Amand Blanes

Final version available in Population, Space and Place:

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Abstract:

Two important sources of inequality in mortality are regional variation and individuals' socio-economic status. While many studies have investigated the effect that each of these two factors might have had on mortality levels separately, they have rarely been studied simultaneously. Using linked data from the Spanish National Institute of Statistics, we study regional levels of life expectancy and lifespan inequality by sex and educational attainment in contemporary Spain (2014-2018). In all regions, life expectancy was higher (and lifespan variation lower) for individuals with higher educational attainment and among women. We find a negative relationship between life expectancy and lifespan inequality across subnational regions among all sex-education groups. However, the relationship is much weaker among the highly-educated. These findings suggest that spatial conditions still matter as health determinants, but even more among individuals with disadvantaged socioeconomic positions, not only in terms of lower life expectancy but also of higher lifespan variation.

Keywords: Life expectancy, lifespan inequality, educational attainment, spatial inequality, Spain.

1. Introduction

The unprecedented increases in longevity in the 20th century around the world could certainly be considered a success story (Riley, 2005, 2015). Given the almost universal desirability of living long lives, it is important to look not only at "efficiency" – that being how efficient societies are in generating and sustaining years of life (or how long do we live *on average*) – but also at "equity": how (un)equally distributed longevity (or any other health outcome) is. National-level averages inevitably mask some degree of heterogeneity (dispersion) in the underlying distribution of health, so the study of inequalities within countries is becoming a prominent issue in the global policy-making and research agendas. The study of these disparities brings on aggregate value for monitoring the health situation in a given population. On the one hand, regional differences in health are relevant because they reflect contextual factors that might vary within countries: differential provision or access to health, differences in infrastructure, different average living standards, and so on (Cutler et al., 2006). On the other hand, differences in mortality across socio-economic groups (SES) are important because they indicate how those contextual factors affect those individuals from different social standings, revealing the existence of social inequalities and their magnitude (Marmot, 2005). Unfortunately, mortality differentials by SES are not easily measurable because of the difficulty of accurately linking mortality registers with SES indicators, and they have typically been only investigated one population at a time.

When investigating differences across Spanish regions and SES groups, we look at two fundamental health outcomes: life expectancy and lifespan inequality. While the former is a well-known "health efficiency" indicator measuring the average number of years individuals are expected to live, the later informs us about the variability in the ages at which individuals die – thus being a key marker of health heterogeneity that, according to van Raalte et al (2018), is "the most fundamental of all inequalities". Exploring the relationship between life expectancy and lifespan inequality is important, among other things, to assess whether the normatively desirable goals of (i) living longer lives, and (ii) sharing them equitably (i.e., long lives are enjoyed by everyone), can be achieved simultaneously or not. In general, while these two health indicators tend to be negatively related (i.e., higher life expectancy tends to be associated with lower lifespan inequality (Aburto et al., 2020; Smits & Monden, 2009; Vaupel et al., 2011) very little is known about their relationship when we differentiate across

SES groups and the analysis is performed at the regional level. A few studies have investigated the joint behavior of these measures (life expectancy and lifespan variation) either across SES groups (e.g., van Raalte et al 2014, Sasson 2016, Permanyer et al 2018) or at the regional level (Illsley & Le Grand, 1993; Wilson et al., 2020), but not combining both dimensions simultaneously. This is an issue that we aim to address in this paper. Our main research questions are as follows:

1. What are the levels of life expectancy and lifespan variation across Spanish subnational regions? How do these indicators vary by educational attainment? Are they different for women and for men?
2. What is the relationship between life expectancy and lifespan variation across subnational regions by educational attainment group and sex? In which groups is the relationship stronger/weaker?

2. Background

2.1 Social and Spatial Differences in Mortality

In a way, mortality represents the final chapter of the biographies of individuals, and as a result, it is considered the ultimate indicator of the health of individuals (Rosero-Bixby & Dow, 2009). The existence of a positive relationship between health and socioeconomic status or position of individuals is not surprising and is something of common knowledge. But as Preston & Taubman (1994) point out, identifying the magnitude of such association is critical for the scientific dimension.

In health research, the socioeconomic position of individuals refers to their standing in a hierarchical social structure and is related to a series of social and economic factors that influence or determine such standing (Galobardes et al., 2006; Lynch et al., 2000). Those factors are usually associated with income, wealth, educational attainment, and other aspects relevant to the well-being of individuals (Brown et al., 2003). Since those aspects that indicate the social position are generally correlated, they have been used alternatively for different studies in the matter as proxies. The social position of an individual does not necessarily work by itself as a causal mechanism that results in better health (Brown et al., 2012; Hayward et al., 2015; Hummer & Lariscy, 2011). But certainly a higher education could be related to the possibility of adopting certain technologies that are critical for ensuring their good health (Fogel & Costa, 1997). Furthermore, by being exposed to a certain accumulation of risks across the life course (e.g., working in physically demanding jobs, engaging in activities that may be detrimental for health like alcohol or drug consumption), individuals may present better or worse health outcomes that are socially mediated (Marmot, 2005).

It is also apparent from the latter that the aspects that are linked with poor health outcomes cannot be purely individual, but often the structural, material, and social conditions of the environment in which people live their lives must also be considered. Spatial inequalities in health, as their name suggests, are the result of unequal access to new technologies and distribution of resources (health provisions, medical care, sanitation, food rich in nutrients). From a population standpoint, those inequalities usually manifest in several negative health outcomes, including mortality (Chetty et al., 2016; Regidor et al., 2016; Reques et al., 2015; Vierboom et al., 2019). Even with similar deprivations at a household level or a similar individual socioeconomic position, individuals who have access to proper health facilities or even good, paved roads could have a health advantage when compared to those lacking such access. Social relationships happen in space, and social inequalities occur at a spatial level as a result, in an existing material context (Lynch et al., 2000). In this approach, inequalities come from differential exposure to certain life-long experiences and situations that negatively impact the health of individuals. This exhibition is usually accompanied by a lack of resources of different kinds (social, physical, or health), both individually and at the general level, combining human, cultural and sociopolitical processes (Lynch et al., 2000; Montez et al., 2016). And many times, it is the presence and aptitude of health, technology, and social protection systems throughout the territory that have played a leading role in increasing not only the length but also the quality of life of individuals (Behrman, Sickles and Taubman, 1998). Henceforth, considering the spatial dimension is critical for identifying health inequalities.

2.2 Key Measures of health and mortality: the need to go beyond averages.

Traditionally, life expectancy at birth has been used as one of the key indicators to compare mortality levels across populations by demographers, actuaries, and other professionals and scientists. Life expectancy is a construct that is derived from an artifact known as a life table or mortality table (Preston et al., 2001). Life expectancy enjoys well-deserved popularity because it has some important properties that make it desirable for analysis. Not only it can deal with differential age-structure components and give a net measure of mortality (unlike crude death rates), but life expectancy also offers an easily interpretable indicator that is conventionally measured in years.

This measure, while undeniably powerful and useful to measure the mean level of mortality, also has some limitations. One of such limitations is based around the idea that life expectancy is a measure that gives an average value. Why this could be seen as a limitation? Because it assumes a given cohort would live a certain quantity of time on average, but it does not tell us about the dispersion of mortality (van Raalte et al., 2018). Two populations can have the same life expectancy but very different patterns in terms of the distribution of deaths in a life table: mortality can be expanded, with a larger proportion of deaths occurring at younger ages, or compressed, with a larger proportion of deaths population occurring at older ages (Kannisto, 2000)

While some individuals from a more disadvantaged socioeconomic position may outlive others from a more advantaged socioeconomic position (Vaupel et al., 2021), lower life expectancies are associated with higher variabilities at the time of death (Németh, 2017; Vaupel et al., 2011), resulting in a double burden: those who had higher mortality, also tended to have a higher age-of-death variability, which can be related with a higher number of premature deaths (Permanyer et al., 2018; Seaman et al., 2019)

The increase in heterogeneity (expressed in a larger group variation) also allows identifying worse health conditions for a particular group, usually associated with preventable causes. For instance, most pension systems are designed by considering average life expectancy, but in a high variability scenario with some strong inequalities in lifespan, such design may be unbalanced, favoring some individuals with better health and increasing social inequality, working regressively (Brønnum-Hansen, 2017). This implies that the study of variations in lifespan and health is not only theoretically important for understanding demographic dynamics in a given population, but also for very practical reasons. From a policymaker's point of view, it may allow a more efficient allocation of resources in health, to the design of pension systems that regard equity as an important principle. From an individual standpoint, higher knowledge of how uncertainty in lifespan operates could provide insights into some critical decisions, such as applying for a mortgage or getting particular life insurance (Edwards, 2013).

Therefore, in the last years researchers focused on the importance of individual lifespans as a focal point for inequalities and developed a series of indicators to consider lifespan variability in a population (Edwards & Tuljapurkar, 2005; van Raalte & Caswell, 2013; Vaupel et al., 2011). However, it should be noted that lifespan inequality indicators do not seek to replace life expectancy, but to provide an additional dimension to the health situation of a particular population, with an emphasis on variability. After all, just like life expectancy, lifespan inequality measures are derived from a life table, so they are not entirely independent from each other (Aburto et al., 2019). Broadly speaking, current empirical evidence indicates that life expectancy and lifespan variation measures are negatively correlated (Edwards, 2011; Permanyer & Scholl, 2019; Smits & Monden, 2009; Vaupel et al., 2011; Vigezzi et al., 2022) although a decline in mortality may not necessarily result in a lower lifespan variation.

2.3 Previous contributions

Health inequalities across space and social class have been very well documented in the literature by using efficiency-based measures such as life expectancy or relative risks in mortality (Brønnum-Hansen, 2000; Gallo et al., 2012; Lariscy, 2011; Mackenbach et al., 1997; Montez, Zajacova, et al., 2019; Regidor et al., 1995; Reques et al., 2015). The general consensus found that educational attainment is one of the main drivers of health disparities, but that association sometimes varied by region or other important contextual factors (Kemp & Montez, 2020; Montez, Hayward, et al., 2019): for instance, regions with higher levels of deprivation in Spain also tend to present higher mortality, arguably due to their less than optimal provision of services to the population among other factors (Regidor et al., 2015; Reques et al., 2015). A previous study also found that Spain has one of the thinnest educational disparities in mortality across Europe (Mackenbach et al., 2019), but only focusing in national averages. Likewise, the literature on lifespan inequality has been expanding considerably since the turn of the 21st century, with many studies focusing on trends at a national level (Aburto & van Raalte, 2018; Illsley & Le Grand, 1993; Le Grand, 1987; Permanyer & Scholl, 2019; Seaman et al., 2016; Vaupel et al., 2011). However, studies investigating differences in life expectancy and lifespan variability simultaneously across sub-national regions or socioeconomic (SES) groups are much scarcer. On the one hand, studies by different proxies of SES (educational attainment, occupational class, disposable income) were done previously at a national level (Brønnum-Hansen, 2017; Permanyer et al., 2018 Sasson, 2016; van Raalte et al., 2014; Van Raalte et al., 2018). Furthermore, some studies were conducted in the United States comparing lifespan variability by race/ethnicity groups, such as Hispanic populations, non-Hispanic whites and non-Hispanic blacks (Firebaugh et al., 2014; Lariscy et al., 2016). In both cases, the authors found that the groups with the lowest mortality had lower lifespan variability (this being, less heterogeneity in mortality) as well. On the other hand, studies conducted at subnational level have not considered the SES component but mostly focused on the spatial variation of mortality and lifespan variation (Illsley & Le Grand, 1993; Wilson et al., 2020; Xu et al., 2021). Seaman et al. (2019) also analyzed lifespan variation at a subnational level, differentiating by deprivation-based areas as a proxy of the overall SES of those spatial units.

Other relevant research directly discusses the interplay between socioeconomic status and the role of space. For instance, evidence from England and Wales indicates that higher educational attainment and social class reduce rural-urban mortality disparities, working as a protective factor regarding environmental exposures (Allan et al., 2019). Elo and colleagues (2019) also point out that education and mortality are negatively correlated, and this association stands true across all areas in the United States, either metropolitan or non-metropolitan. Moreover, greater social cohesion and a growing economic environment seem to diminish inequalities in women's mortality across space (Montez et al., 2016).

Life expectancy in Spain was among the lowest in Europe during the first half of the 20th century. However, dramatic mortality reductions in the last decades have placed Spain among the world's most longevous countries. Previous studies indicate, though, that, despite these accelerated improvements, significant differences in mortality persist at a regional level (Gispert et al., 2007; Miqueléiz et al., 2015a; Regidor et al., 1995, 2011; Reques et al., 2015), indicating that autonomous communities (the name used to define first-level political and administrative in Spain) such as Andalusia or Extremadura (some of the poorest of the country) had a higher mortality than the average of the country. These inequalities were also evident when considering differential educational attainment (Blanes & Trias-Llimós, 2021; Permanyer et al., 2018; Reques et al., 2015), with a higher mortality in lower educated individuals. In Spain we can identify a rather clear geographic pattern of mortality, with the Southern and Western regions experiencing higher amenable mortality (Benach & Yasui, 1999; Regidor et al., 2015; Reques et al., 2015). On the contrary, the Northern provinces, despite their overall lower mortality and higher education, tend to present a higher mortality attributable to conditions such as cancer (Aragonés et al., 2009; García-Torrecillas et al., 2019; Santos-Sánchez et al., 2020)

Studies on Spain that focus on socioeconomic differentials at an individual level have been scarce, given the difficulties to obtain individual level data on mortality at national level. This has meant that previous studies studying socioeconomic differences on mortality focused on some particular regions (Huisman et al., 2004; Mackenbach et al., 2008) and that were performed using aggregate-level data (Miqueleiz et al., 2015a; Regidor et al., 2016; Reques et al., 2014, 2015). Some of these studies (Mackenbach et al., 2009; Reques et al., 2014) indicated that mortality differences by educational attainment in Spain seemed to be smaller when compared to other European countries. Furthermore, other studies indicate that there is a clear geographical pattern in death rates for the lower-educated population across autonomous communities in Spain, but not for the higher-educated (Miqueleiz et al., 2015b; Reques et al., 2015). This would suggest that space is a stronger determinant of mortality for the lower-educated people than the higher educated in Spain. However, the role of lifespan inequality and its relationship with life expectancy across regions remains unknown.

Previous studies have found that reductions in mortality at young ages simultaneously contribute to increase life expectancy *and* reduce lifespan variation (Aburto et al., 2020; Nigri et al., 2021; Permanyer & Shi, 2022) thus leading to a negative relationship between both indicators (i.e., higher longevity associated with lower lifespan inequality). In turn, mortality improvements at older ages contribute to an increase in both life expectancy and lifespan variation, thus conducing towards a positive relationship between both indicators. Given this, and since deaths among the highly educated tend to occur at older ages than those with lower education (van Raalte et al., 2012, Sasson, 2016, Permanyer et al., 2018), we hypothesize that the relationship between life expectancy and lifespan variation across subnational regions might be more negative among the lower educated (see below). Furthermore, the choice of lifespan variation indicators may alter the strength and even the direction of the relationship between life expectancy and lifespan variation (Vigezzi et al., 2022). For this reason, we explore if there is any difference in this relationship when considering both absolute and relative measures of lifespan variation.

2.4. Research hypotheses

Following the discussion from the previous sections, we now present the research hypotheses corresponding to our research questions (applied to the Spanish case).

Hypothesis 1: Life expectancy is higher for highly educated groups and for women across subnational regions. Lifespan variation is higher for lower educated groups and for men across subnational regions.

Hypothesis 2: The association between life expectancy and lifespan variation across regions is stronger for individuals with lower educational attainment, owing to the higher prevalence of deaths occurring at younger ages for that group.

Hypothesis 3: The relationship between life expectancy and lifespan variation might differ when inequality is measured in absolute or relative terms.

3. Materials and Methods

For this analysis, we used a combination of data sources. We performed a cross-sectional type of analysis considering deaths and population exposures by sex and educational attainment in each Autonomous Community (the first-level political and administrative units) of Spain.

Population exposures resulted from summing the reported population from 2014 to 2018 (having 1st of July of 2016 as the center point for population exposure) and deaths for the same period, both provided by the Spanish National Institute of Statistics (Instituto Nacional de Estadística or INE). The mortality file from INE provided death counts and population exposure by sex and educational attainment for each one of the autonomous communities in Spain, which correspond to the European standard NUTS-2 classification: Andalusia, Aragón, Asturias, Balearic Islands, Canary Islands, Cantabria, Castile and León, Castile – La Mancha, Catalonia, Valencian Community, Extremadura, Galicia, Madrid, Murcia, Navarra, Basque Country, La Rioja, Ceuta and Melilla. For our analyses, Ceuta and Melilla have been merged into a single unit due to data constraints. Figure 1 presents the geographical distribution of those autonomous communities in the country. INE used a matching algorithm linking registered deaths to population databases, including censuses, municipal population registers, the ministry of education, and the Public State Employment Service, to obtain the deaths according to educational attainment, when possible. This mortality data was used successfully by previous studies (Blanes & Trias-Llimós, 2021; Permanyer et al., 2018; Trias-Llimós & Spijker, 2022) to measure both life expectancy and lifespan variability trends by educational attainment in Spain (at a national level). The INE also provided the total estimates of the population by sex, age, and educational attainment in Spain. With these registers, we can determine, at an aggregate level and for each autonomous community, death counts and population exposures in the chosen period.

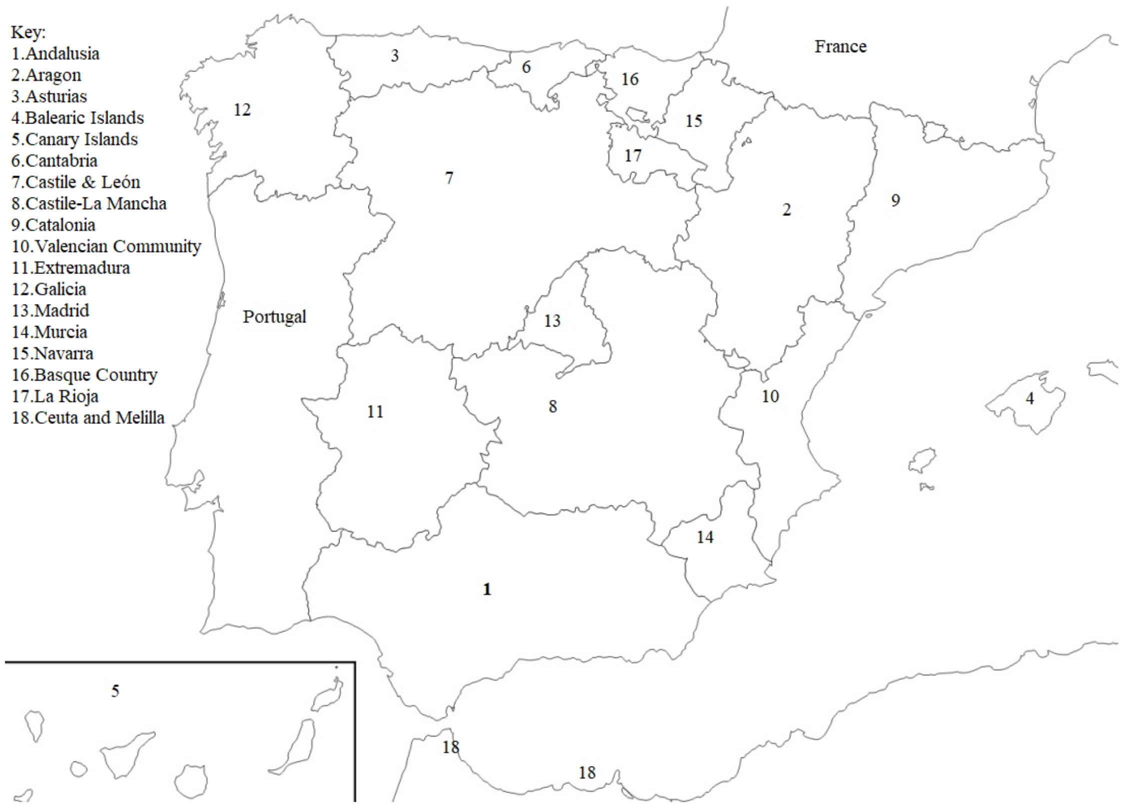

Figure 1: Map of Spain by Autonomous Communities.

Legends Key: 1 (Andalusia), 2 (Aragon), 3 (Asturias), 4 (Balearic Islands), 5 (Canary Islands), 6 (Cantabria), 7 (Castile and León), 8 (Castile-La Mancha), 9 (Catalonia), 10(Valencian Community), 11 (Extremadura), 12 (Galicia), 13 (Madrid), 14 (Murcia), 15 (Navarra), 16 (Basque Country), 17 (La Rioja), 18 (Ceuta & Melilla)
Source: Author's elaboration

The bottom truncation for the estimations was set at age 35, to give a reasonable amount of time for individuals to complete their educational attainment. To make comparisons as robust as possible we decided to establish two separate groups in terms of educational attainment as a proxy of socioeconomic position. As previously stated, education, income, and aspects that suggest individuals' social position are often strongly correlated. However, educational achievements are considered a more stable attribute, while income is often a more fluctuating feature throughout the life course (Smith, 2004). We opted to split between individuals with "lower educational attainment" (individuals who, at most, completed the first cycle of secondary education, which is equivalent to 8 years of mandatory schooling, or level 2 in the normalized ISCED-2011 classification) and individuals with "higher educational attainment" (who had more than 8 years of education, or ISCED-2011 level 3 and above). This is partly due to relative data scarcity in some autonomous communities, but also, due to strong compositional differences regarding the value of education in terms of socioeconomic position: some years ago, having a university degree was less frequent, and earning a secondary degree was enough to relate to a strong socioeconomic position. That being said, and despite the rapid expansion of education in Spain, many adults still have not reached eight years of education, making the cutoff point reasonable and robust enough for the analysis.

Accurate measures of lifespan variation (like 'life disparity' and 'life table entropy' – see below) generally demand a high level of granularity. In order to have consistent life tables (which are based on single-age deaths and population exposures for each educational category), a large number of observations are required. For this reason, having three educational groups (based on years of education) in all regions was not feasible for this study, particularly for the smallest regions with low exposures at the older age groups. We decided to prioritize a greater coverage (by including all regions) at the expense of, potentially, some accuracy in our estimations by having only two educational levels (factually splitting the middle education age groups into lower and higher). To better illustrate this point, in part of the supplementary material (Figures 1S and 2S), we added death rates and population exposures for three autonomous regions where this problem becomes evident. One of these cases was Andalusia (the largest region of Spain, containing almost 20% of the population), where the distribution of death rates by age and educational attainment suggest a better consistency when considering two educational categories instead of three. We also added some of the smallest regions like La Rioja and Ceuta and Melilla, where using a two-group approach offers more reasonable mortality estimates as well. This was mostly because of the rather small population exposure at higher ages in those cases, not only because higher male mortality results in fewer survivors, but also because there may be fewer females with access to high education at the oldest ages).

From now on we will refer to these two groups as Low education/High education (in terms of educational attainment, strictly). Educational attainment could not be identified in less than 1% of the overall deaths. Therefore, a single mean proportional imputation was used to establish the educational attainment for those cases. We will be using the open-end interval for ages 100 and above as the closing value for the life table (top truncation).

Given that we are dealing with single-age interval death counts and exposures, fluctuations may occur at a given age in regards to the distribution of deaths. Therefore, we opted for smoothing the death counts following standard procedures commonly used in the literature, i.e., assuming that mortality follows a Poisson probability distribution (Scott, 1981). We fitted death counts with a one-dimensional Poisson P-spline, specially tailored for mortality data, using the *MortalitySmooth* package (Camarda, 2012). Once death counts were smoothed, death rates by single age intervals were simply calculated as the quotient between the smoothed deaths and the given population by educational attainment.

In the analyzed period, a total of 1.626.092 deaths were reported: 806.057 for females and 820.035 for males. Population exposures by sex and educational attainment can be found in the appendix (see Table 1A), along with the population distribution in Spain by age (Figure 1A in the appendix) – where it can be seen that, as age increases, the absolute number of individuals with higher educational attainment decreases.

Longevity and lifespan variation indicators

We estimated life expectancy at age 35 using standard life table methods (see Preston et al., 2001).

In the last years, several indicators of lifespan inequality have been developed, using both absolute and relative measures (for a good review of those indicators and methods, see van Raalte and Caswell, 2013). Those measures tend to be strongly correlated to each other and offer similar results in terms of interpretation. The debate on whether lifespan inequality should be measured with absolute or relative indicators is long and inconclusive, as it all depends on (inherently subjective) value judgments regarding what transformations should leave inequality unchanged (e.g., translations or rescalings). Therefore, we opted to present a pair of measures that are highly related to each other: life disparity and the life table entropy index (an absolute and a relative inequality measure, respectively).

Life disparity (colloquially known as e-dagger, or $e^{\dagger}$) is an absolute measure of inequality (i.e., its values are not affected when the same constant is added to all elements of the distribution) that expresses the number of life-years lost due to death (van Raalte & Caswell, 2013; Vaupel et al., 2011; Vaupel & Canudas Romo, 2003). The smaller the value, the smaller the variation of the age at death in a given population. In the limit, if everyone died at the same age, $e^{\dagger}$ would be zero. Life disparity is defined as the sum of deaths times the remaining life expectancy at all different ages above 35, or in formal terms:

$$e^{\dagger}(35) = \frac{1}{\ell_{35}} \sum_{y=35}^{\omega-1} d_y \bar{e}_y$$

with ℓ_{35} being the number of survivors at age 35, d_y the life table death distribution and $\bar{e}_y$ the remaining life expectancy at a given age y.

The Life Table Entropy (also known as $\overline{H}$ or Keyfitz-Leser entropy) was first derived by (Leser, 1955) but it was proposed as a lifetable function by Keyfitz (1977) and can be considered as the relative counterpart for life disparity. Life Table Entropy is a relative measure of inequality (i.e., its values remain unchanged when all elements of the distribution are re-scaled by the same constant) that is obtained simply by dividing the life disparity index $e^{\dagger}(x)$ by the value of life expectancy e_x at a given age (in this case, age $x = 35$). Just like life disparity, a higher value of $\overline{H}$ indicate a larger inequality in the corresponding age-at-death distribution. This measure has the property to capture the dimensionless variation in the length of life when compared to life expectancy at birth or at a given age (35 in our case).

$$\overline{H}(35) = \frac{{e^{\dagger}}_{35}}{e_{35}}$$

We also calculate the overall standard deviation (SD) of life expectancy and lifespan inequality indicators across autonomous communities. Finally, we explored the correlations between life expectancy and lifespan variation indicators across autonomous communities separately by sex and educational attainment together with linear graphical associations.

Other relevant information such as the absolute distribution of deaths, death rates and the population exposures by educational attainment and sex for Spain can be found in the appendix (see Figures 1A to 3A). As expected, death rates for males are higher than for females, independently of educational attainment, and the Low education group has a higher mortality than the High education group (Figure 2A). It also can be seen that at younger ages, the majority of the population has a higher educational attainment, but near age 55 and above the situation is reversed (Figure 3A). This composition change is the result of the greater access to education that has occurred in Spain (and in many other societies around the world) in the last decades.

4. Results

Figure 2 maps the results of the estimates for life expectancy at age 35, separately by sex and educational attainment for each autonomous community. The values used to generate this map are presented in Table 2A (see Appendix). As can be observed, in all cases life expectancy at age 35 is higher for individuals with high education in comparison to their low education counterparts. Those differentials are larger for males than for females: differences are between almost 2 and 3.3 years for males, and between one and two years in the majority of cases for females. At the national level, the average difference in life expectancy by educational attainment is 2.6 years for males and 1.6 years for females. The autonomous communities of Madrid, Castile & León, Basque Country, La Rioja and Navarra have the highest life expectancies, and Andalusia, Murcia, Extremadura and Asturias the lowest.

When comparing males with females who have the same educational attainment, we can observe that differences in life expectancy at age 35 are larger in individuals who are part of the low education group than those who are in the high education group. The standard deviation of the life expectancy indicator across autonomous communities is larger for individuals in the low education group when compared to their higher education counterparts (i.e., there is more variability in life expectancy across regions among the low-educated). SD is larger for males than for females in the high education group (0.58 vs 0.48 SD respectively), and interestingly enough, the opposite occurs at the low education group (0.81 SD for males and 0.89 SD for females). This seems to indicate that lower educated females have the highest heterogeneity for this indicator, and higher educated females are the more homogeneous of the four combinations.

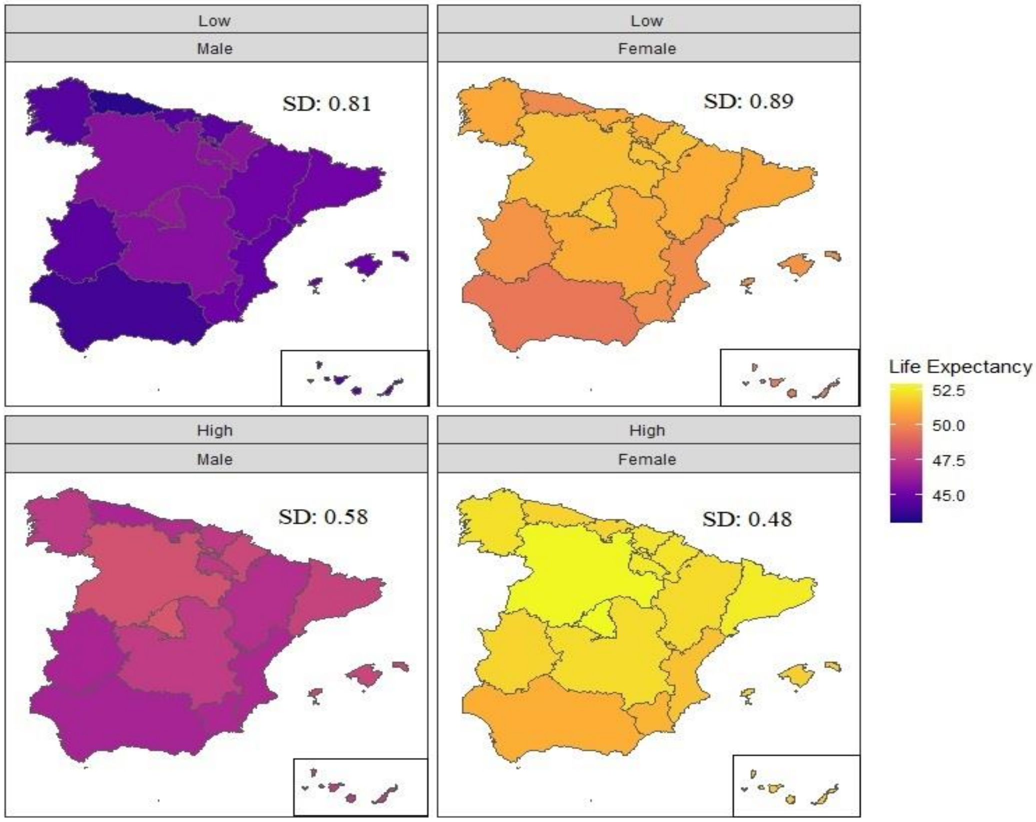

Figure 2: Life expectancy at age 35 and above by sex and educational attainment in Spanish autonomous communities (Source: author´s calculations based on INE).

Figure 3 presents the results of the estimations for life disparity at age 35 and above across autonomous communities by sex and educational attainment (the values used to generate these maps are shown in table 3A – see Appendix). In general terms, Murcia, Castile-La Mancha, La Rioja and Basque Country have the lower values of life disparity, and Galicia and Asturias the higher values. Individuals in the low education group tend to present higher levels of lifespan inequality (ranging from 9.7 and 10.7 years for males and 7.9 to 9 years for females) than their counterparts in the high education group (with values between 8.8 to 9.5 years for males and 7.2 to 8.1 years for females). When considering the overall estimation for Spain, the gap in variability by educational attainment for males (slightly above one year) practically doubles the estimation made for females (0.5 years) – see table 3A. As expected, the sex gaps at a national level are wider for individuals belonging to the low education group (with a nearly 1.9 years differential) than for the high education group (the sex gap being 1.38 years in that case). In terms of variability across regions, SD is larger for males and females with low education (0.29 and 0.27 SD respectively) when compared to their high education counterparts (0.21 SD both for males and females), which may imply that the latter group is more homogeneous, independently of sex.

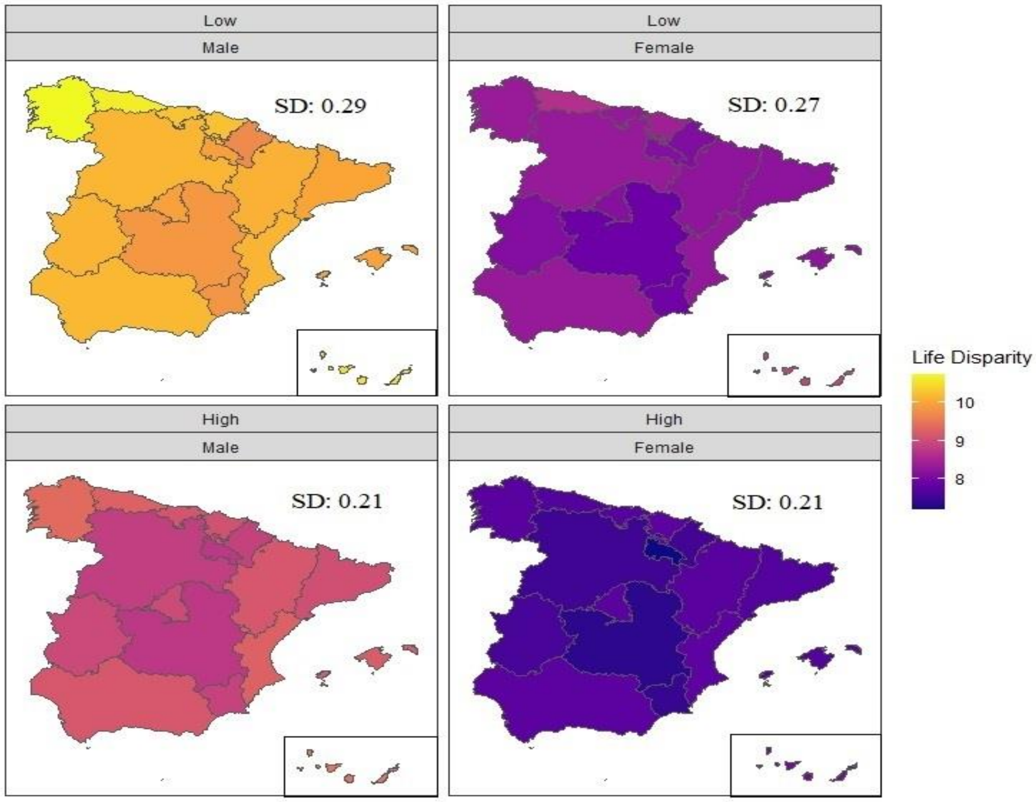

Figure 3: Life disparity at age 35 and above by sex and educational attainment in Spanish autonomous communities (Source: author´s calculations based on INE).

Figure 4 presents the results of the life table entropy index, or $\overline{H}$, at age 35 for the different autonomous communities (the values used to create these maps are shown in table 4A – see Appendix). Just like the previous case, the same autonomous regions are highlighted by their more extreme values. Results in figure 4 indicate that males are those who had a higher variability, and also that differences by educational attainment tend to be higher for males than for females. It also has to be noted that, like the previous cases, differences by sex for the low education group are larger than for the high education group across regions. Standard deviation, as was the case for previous indicators, is larger for those with a lower educational attainment (0.010 SD for males and 0.008 for females) and smaller for those with a higher educational attainment (0.006 SD for males and 0.004 for females) across autonomous communities.

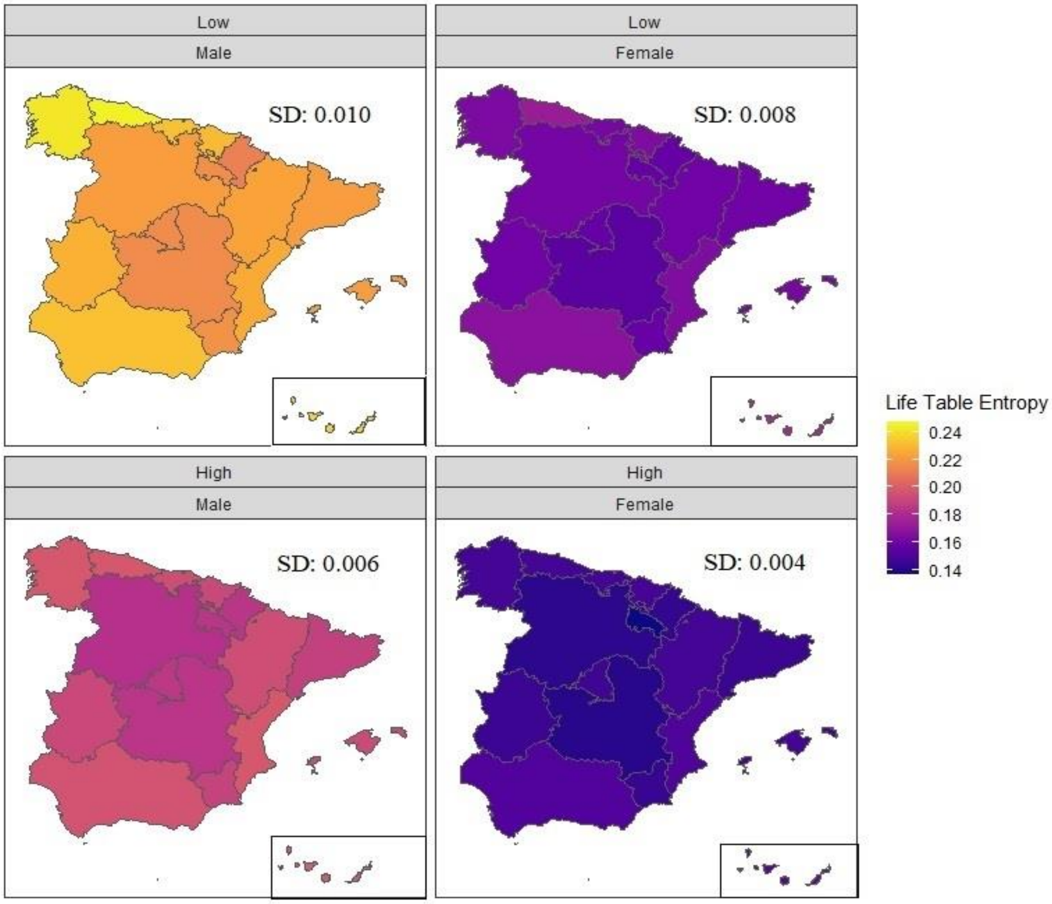

Figure 4: Life Table Entropy between ages 35 and above by sex and educational attainment in Spanish autonomous communities (Source: author´s calculations based on INE).

To summarize the health situation of the autonomous communities individually, Figure 5 shows the difference of the values obtained for each of them minus the value of the national average for the analyzed indicators. Positive differentials indicate a higher value than the national average (which is normatively desirable for indicators like life expectancy) and negative values indicate a lower value as compared to the overall country (which for life disparity or the life table entropy should mark a better performance than the national average). This was done for all the four available combinations of sex and educational attainment.

As can be seen in Figure 5, some autonomous communities systematically perform above the national mean in terms of life expectancy and below the national mean in terms of lifespan inequality (e.g., this is the case of Navarre, Madrid and Castile & León). At the other extreme, other communities systematically perform worse than the national mean (i.e., below the national mean in terms of longevity and above the national mean in terms of lifespan inequality) across most sex-education combinations analyzed in this study (e.g., this is the case of Ceuta & Melilla, the Canary Islands or Andalusia). The relationship between life expectancy and lifespan inequality is not clear in many cases, given that in certain communities there was a degree of heterogeneity in the differentials: Extremadura or Murcia, for instance, have lower life expectancies than the national average but also a lower life disparity at age 35 when compared with the average. Another example of this could be seen in Basque Country and La Rioja, where females fared better when compared to the national average both in life expectancy and lifespan variation, but this was not the case for males. Interestingly enough, in many autonomous communities, some indicators, like life expectancy, present positive differentials when compared to the national average for the low education group, but negative for those in the high education group, as it seems to be the case for Aragon, Canary Islands or the Valencian Community, to name a few examples of this trend. In other words, this acts as a remainder of the complexity of how health indicators fare for different combinations of sex and educational attainment when considering the spatial dimension.

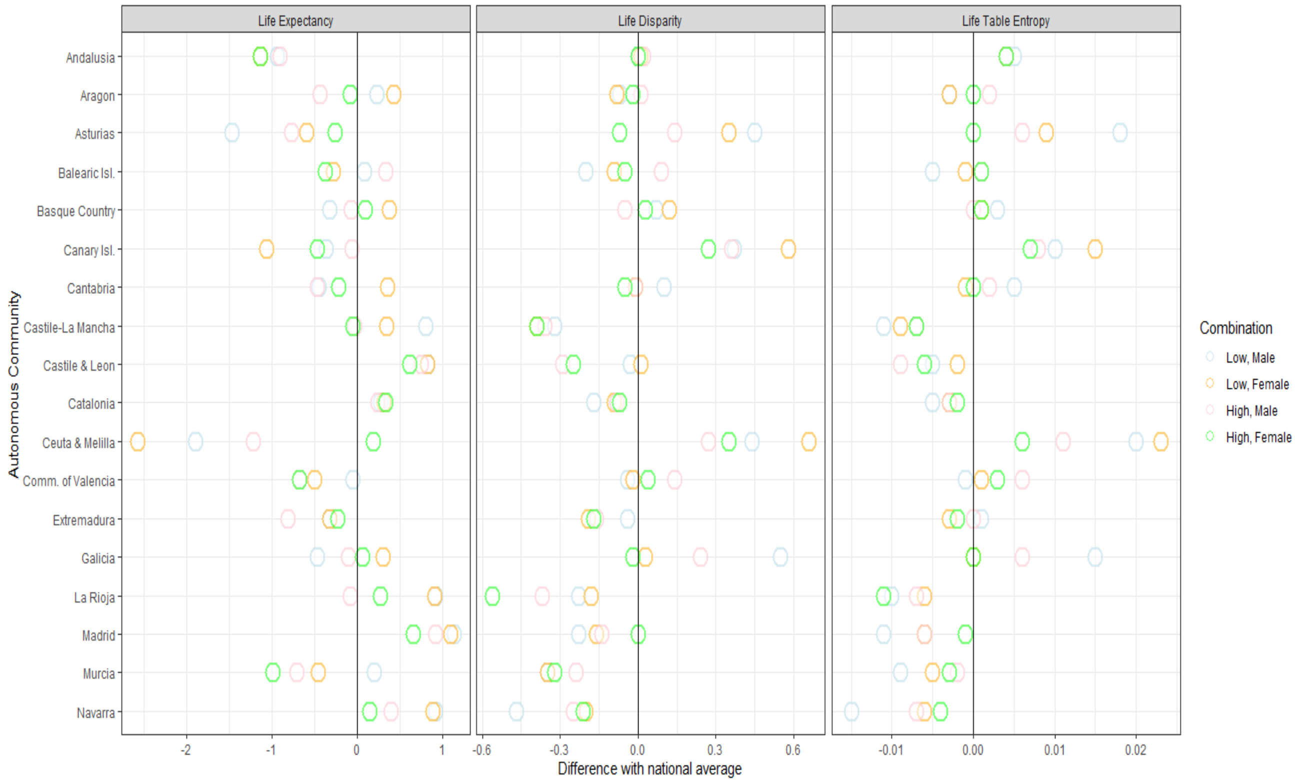

Figure 5: Difference for selected indicators at age 35 between the autonomous communities and Spain (Source: author´s calculations based on INE).

To visualize the relationship between remaining life expectancy at age 35 and life disparity at age 35 and above, we did a simple series of cross-sectional scatterplots (separately by sex and educational attainment, given the scale disparities), as shown in Figure 6. Correspondingly, Figure 7 presents the relationship between life expectancy and life table entropy. This was done to explore the relationship between life expectancy and lifespan variation measures for each combination of sex and educational attainment and sex. The figures indicate that, at least at an ecological level, there does seem to be a significant association between life expectancy and life disparity in individuals with lower educational attainment (with the slope of the line indicating that higher life expectancy correlates with lower life disparity), and considering the values of the adjusted R^2, it is even stronger for the life table entropy, presented in figure 7. However, this was not the case for individuals with higher educational attainment in both sexes and types of measures, where the association between life expectancy and lifespan variation measures was considerably weaker. When using life disparity as a measure of lifespan inequality, the R^2 coefficient drops from 0.59 to 0.08 for males and from 0.41 to 0.04 for females when comparing the low vs. the highly educated. When lifespan inequality is assessed via the life table entropy index, the R^2 coefficient drops from 0.83 to 0.44 for males and from 0.7 to 0.11 for females.

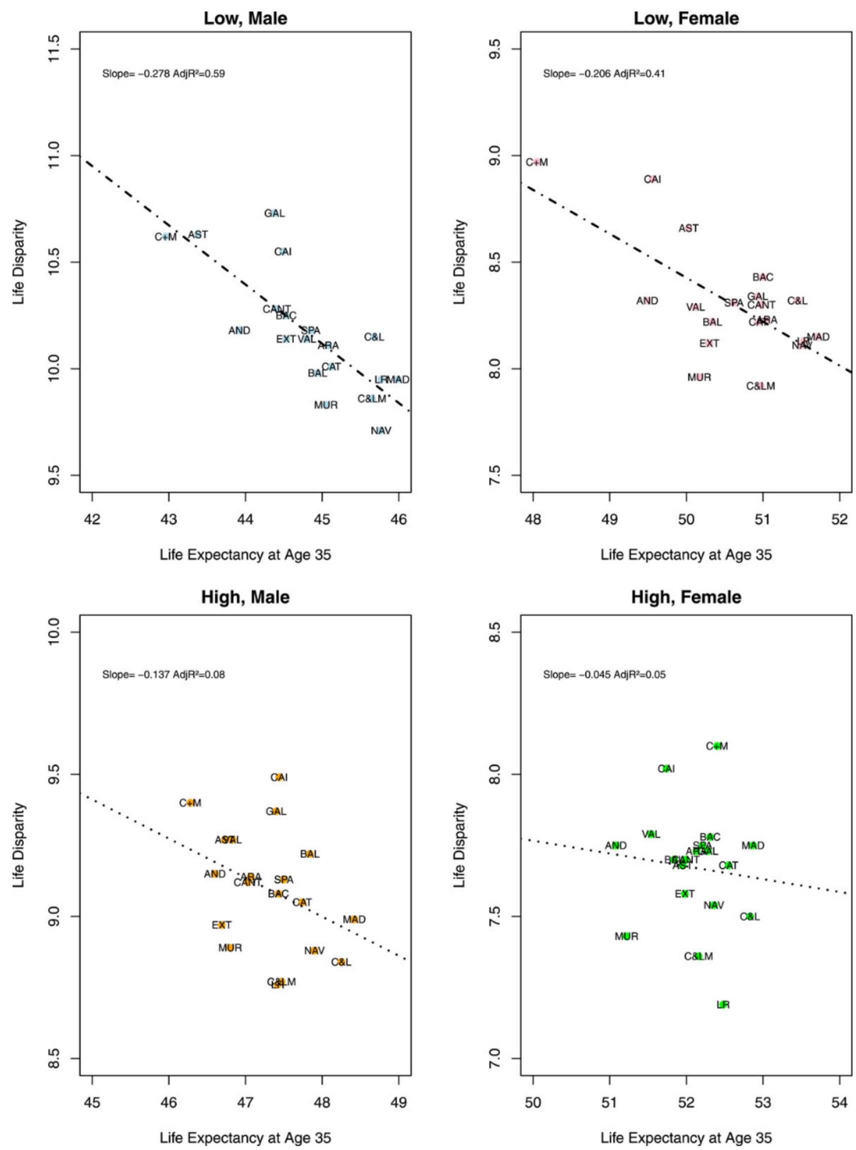

Figure 6. Scatterplot Between Life Expectancy and Life Disparity by sex and educational attainment across autonomous communities, Spain 2014-2018. Legends Key: AND (Andalusia), ARA (Aragon), AST (Asturias), BAC (Basque Country), BAL (Balearic Islands), CAI (Canary Islands), CANT (Cantabria), CAT (Catalonia), C+M (Ceuta & Melilla), C&L (Castile and León), C&LM (Castile-La Mancha), EXT (Extremadura), GAL (Galicia), LR (La Rioja), MAD (Madrid), MUR (Murcia), NAV (Navarra), VAL (Valencian Community) (Source: author´s calculations based on INE).

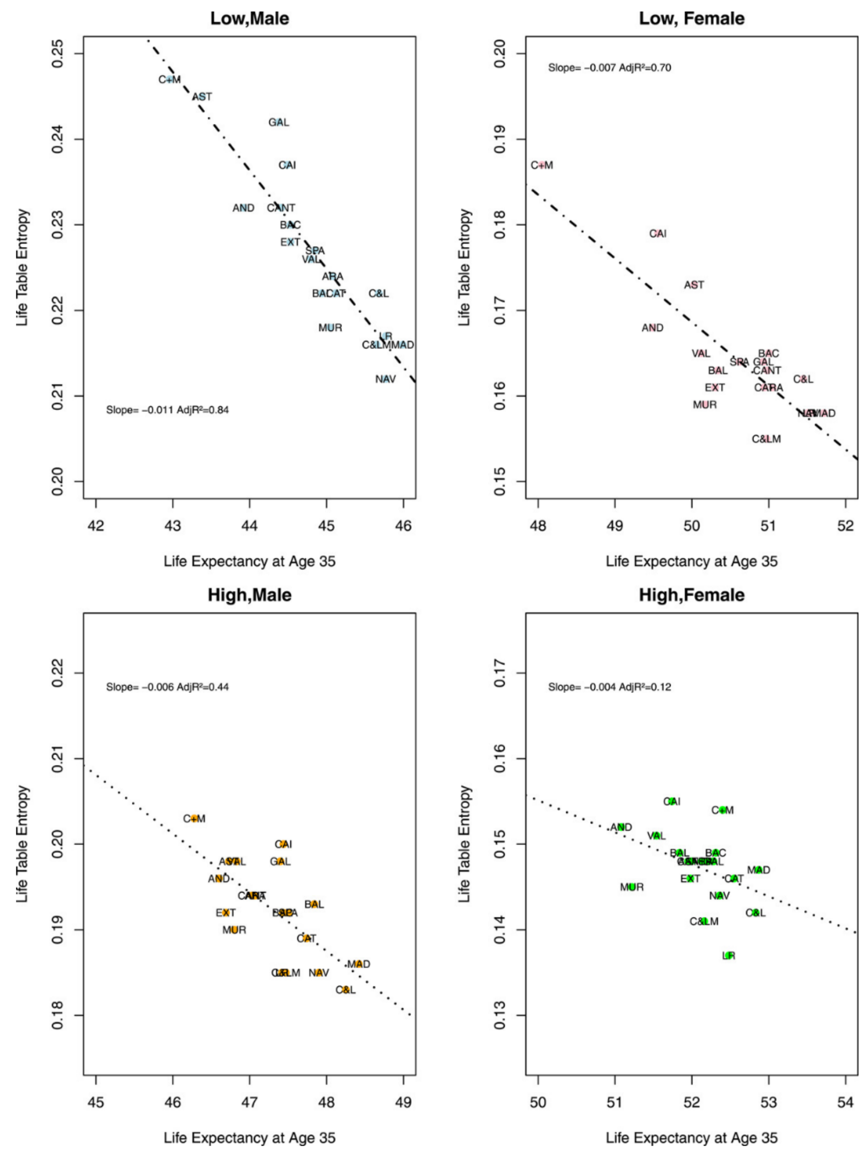

Figure 7. Scatterplot Between Life Expectancy and Life Table Entropy by sex and educational attainment across autonomous communities, Spain 2014-2018. Key: AND (Andalusia), ARA (Aragon), AST (Asturias), BAC (Basque Country), BAL (Balearic Islands), CAI (Canary Islands), CANT (Cantabria), CAT (Catalonia), C+M (Ceuta & Melilla), C&L (Castile and León), C&LM (Castile-La Mancha), EXT (Extremadura), GAL (Galicia), LR (La Rioja), MAD (Madrid), MUR (Murcia), NAV (Navarra), VAL (Valencian Community) (Source: author´s calculations based on INE).

5. Discussion and Conclusions

In this article, we have investigated regional variations in life expectancy and lifespan inequality by educational attainment and sex in contemporary Spain. As expected, we observe that the remaining average life expectancy at age 35 is lower for those individuals with lower educational attainment. The gap favoring those individuals with higher educational attainment, on average, is 2.6 years for males and 1.6 years for females at a national level, but with differences between 1.65 and 3.3 years in some autonomous communities for the former and between 1 and 2 (with a clear outlier of 4 years in the small overseas territories of Ceuta and Melilla) for the latter. These gaps seem to be small when compared to some European countries, such as Denmark or Finland (van Raalte et al., 2011; van Raalte et al., 2018) or other countries like the United States (Montez, Zajacova, et al., 2019; Sasson, 2016), but are on par with other western European countries, such as Belgium or the Netherlands (Mackenbach et al., 2019) – with the added value of presenting lifespan variation indicators, reflecting how heterogeneous mortality is across the country. We also have to keep in mind that the disparities presented in this paper are contingent upon the chosen criterion to define the educational groups (which does not necessarily coincide with the criteria used in other papers).

When comparing the sex gap in individuals with similar educational attainment, we see that differentials (females minus males) are larger for those with lower educational attainment, and narrower for those with higher educational attainment. This finding is consistent with the notion that a better socioeconomic position may be more "protective" in general for males in terms of life expectancy gains (Gallo et al., 2012; Kitagawa & Hauser, 1973; Permanyer et al., 2018; Van Raalte et al., 2012). Furthermore, the higher standard deviation of life expectancies across regions among the lower educated indicates a greater degree of heterogeneity in that group, while the opposite happens among the highly educated. However, the gaps between regional and national levels of life expectancy and lifespan inequality often change direction when looking across the different sex-education group combinations, reminding us about the unique role that space has when shaping mortality differentials – especially when interacting with other dimensions.

In a similar fashion as differences in life expectancy, the educational gap (high education minus low education) was wider for males than for females, and wider for males than females with a similar educational attainment. Our findings are thus in line with the results of Seaman and colleagues (2019), who report that variations in age-at-death were larger for the more deprived areas, and that for the least deprived areas the age-at-death distribution tended to be more concentrated. Another of the main findings in this article is that we identified a strong negative linear relationship between average remaining life expectancy and remaining lifespan variability for those individuals with a lower educational attainment (i.e., lower life expectancy tends to be associated with higher age-at-death variability) across autonomous communities, but such relationship is not as strong for those who have a higher educational attainment, where a linear relationship is not apparent. While such relationship between life expectancy and lifespan variation measures was tested previously at a cross-national level (Aburto et al., 2020; Vaupel et al., 2011) or at a regional level (Wilson et al., 2020), the differential strength of such relationship at the regional level by educational attainment was never explored before. It is noteworthy that the negative association between life expectancy and lifespan variation measures is stronger (both in terms of R-square and slope) among the lower educated individuals independently of sex, even if females in the low education group have a lower mortality than males in the high education group. This is possibly explained by the fact that a greater dispersion (as shown in the higher average standard deviation between regions for the lower educated) may result in a stronger correlation between life expectancy and lifespan variation measures.

We also have to mention that the relationship between life expectancy and lifespan variability is stronger when inequality is measured with relative indicators rather than absolute ones. This owes to the fact that relative measures, like the life table entropy, are typically normalized, including life expectancy at age 35 in the denominator, thus increasing the strength of the relationship between both indicators. In a way, this is a reminder of the advantages and disadvantages of using absolute and relative measures when addressing lifespan variation and other measures of inequality (Wilson et al., 2020). On the one hand, relative measures are not as affected as absolute ones by the choice of the (sometimes arbitrary) bottom age at which we cap the age-at-death distributions (35 in this paper). On the other hand, correlations might be amplified when using relative measures because of their own normalization properties (Aburto et al., 2020).

In terms of mortality inequality across regions, the study conducted by Reques et al. (2015) indicates that inequalities in age-adjusted mortality rates were the lowest in the central provinces of the Iberian Peninsula and the highest in the outside provinces. Correspondingly, some of the largest gaps in life expectancy at age 35 in this paper were found in the regions that border with the Mediterranean Sea (Andalusia, Asturias, Galicia, Catalonia, the Canary and Balearic Islands and Overseas territories). The fact that inequalities in mortality are the largest could be related to the fact that access to healthcare is more uneven in these regions. However, this was not the case for lifespan variation, where a clear pattern of differences by region is not as evident, possibly due to the heterogeneity in mortality of the higher educated individuals.

These results suggest that space matters, but even more so for individuals with a lower educational attainment when discussing, not only health and mortality on average, but also its heterogeneity. The weaker relationship between life expectancy and lifespan inequality among the highly-educated suggests that space may be comparatively less relevant in terms of mortality and lifespan variation for those with a more advantaged socioeconomic position. As the differential variability of our indicators suggest, the higher educated individuals are part of a more homogeneous group than those with lower education. The goods and services that directly or indirectly promote health might be more easily accessible to highly educated individuals, irrespective of where they live and the specificities of local contexts. These results have public policy implications, given that lifespan inequality as a concept is also relevant to certain institutions. From a pension standpoint, this could imply that more equity on the system could be achieved with a dedicated focus on individuals with larger remaining lifespan variability (in this case, individuals with a lower educational attainment that live in particular autonomous regions). A greater heterogeneity, manifested in higher risks of premature mortality and a more unequal distribution of deaths, make also harder for certain individuals to adequately plan for their future or amass savings or other assets (van Raalte et al., 2018). Apart of the potential exclusions from the labor market, gender disparities and difficulties on getting a good pension, this means lower educated individuals then face another additional burden across their life course given the way these institutions are designed in Spain (Domínguez-Rodríguez et al., 2020). From a healthcare and public policy perspective, more resources for these particular groups could possibly reduce variability in health across regions.

This paper has some limitations. It is important to remember that the 'low' and 'high' educational attainment groups created in this paper are somewhat arbitrary and not completely homogeneous. A different definition of these groups could lead to different results: for instance, comparing only individuals with no education with those with post-university degrees would probably give a wider differential in life expectancy. Therefore, an average differential of 2.65 years in life expectancy (the average differential in life expectancy presented in males for those with higher education minus lower education) across two given groups may be hiding a greater degree of inequality in mortality, and the association between life expectancy and lifespan inequality may have a different strength if another educational categorization was presented instead. However, as mentioned in the methodological section, the granularity required for adequately capturing lifespan variation measures forced us to consider only two categories if we wanted to include all regions.

The education expansion experienced in Spain (and many other countries around the world) has affected the age composition of the different educational attainment groups over time, with the low educated being increasingly prevalent in older birth cohorts. Such compositional change, though, is unlikely to overly affect the main conclusions of this paper because (1) we are only inspecting health outcomes at a fixed point in time, and (2) our life table-based health indicators (life expectancy and lifespan inequality) are not affected by the structure of the population.

There is also the fact that the role of educational attainment as a proxy for socioeconomic position, while reliable, is imperfect: since we are analyzing outcomes at an individual level (mortality by the educational attainment of individuals), we are not able to measure any effects related to the household composition, income, or any differential assets that they may have that might affect their socioeconomic positions, limiting the scope of the conclusions. There is also the nature of causation when considering the impact of educational attainment: is education just a proxy for socioeconomic position, or does it offer by itself some mechanisms that directly affect the probabilities of dying? More educated individuals may choose to avoid exposure to behaviors that may be detrimental for their own health (Cutler et al., 2006; Marmot, 2005; Smith, 2004; Soares, 2007), but this could explain only a part of all of the differential shown here. With the data at hand, we are not able to decipher which causal mechanisms are operating here.

We also would like to highlight the matter of age truncation used to produce the estimates. Spain is considered a low mortality country, therefore, choosing age 100 and above as the top truncation may produce slightly different estimates than if we tried to model the mortality curve for the centenarians with other statistical procedures (that could inevitably rely in strong and potentially unjustified assumptions). But since the number of survivors after age 100 is relatively small, we believe that the produced estimations are a very reasonable reflection of the overall mortality of each group and any potential differences with a different truncation would be minimal (and irrelevant to the trends and gradients presented in this paper).

We have to mention as well that the data given and produced by the INE is calibrated with their own protocols, but unfortunately, we have no manner to test the precision of the data by ourselves. Other studies for the United States found disparity in record linkage for some population subgroups (Lariscy, 2011). Overall, though, the matching algorithm used by the INE produces reasonable and consistent results (i.e., we observe the spatial, sex and educational gradients in death rates and life expectancy going in the expected direction), so we do not have reasons to think that there might be a sensible difference in the results due to inaccuracy in the matching records.

Finally, there is also the question of temporal availability: unfortunately, the provided data were good enough to perform a single estimate in a given period, instead of a trend analysis, as is the case with other studies in Spain (Permanyer et al., 2018 the clearest example), limiting the scope of our findings and potentially not considering other aspects that may be playing part in mortality differentials, such as birth cohorts. However, unlike the Permanyer et al. (2018), study, we were available to provide estimates for each autonomous community in Spain and to verify the relationship between life expectancy and lifespan variation by educational attainment. Furthermore, we were able to explore how the relationship between life expectancy and lifespan variation changes its intensity for different levels of educational attainment, something that has not been documented before at the regional/subnational level. Future research should be focused on (i) Exploring the mechanisms that result in such variation, and also considering the critical role of space as a key health determinant (both in terms of average mortality and variability) for individuals with a lower socioeconomic position, and (ii) unraveling how much of the variations in these health indicators is attributable to space, socio-economic status, or other determinants.

Appendix A for Chapter 2:

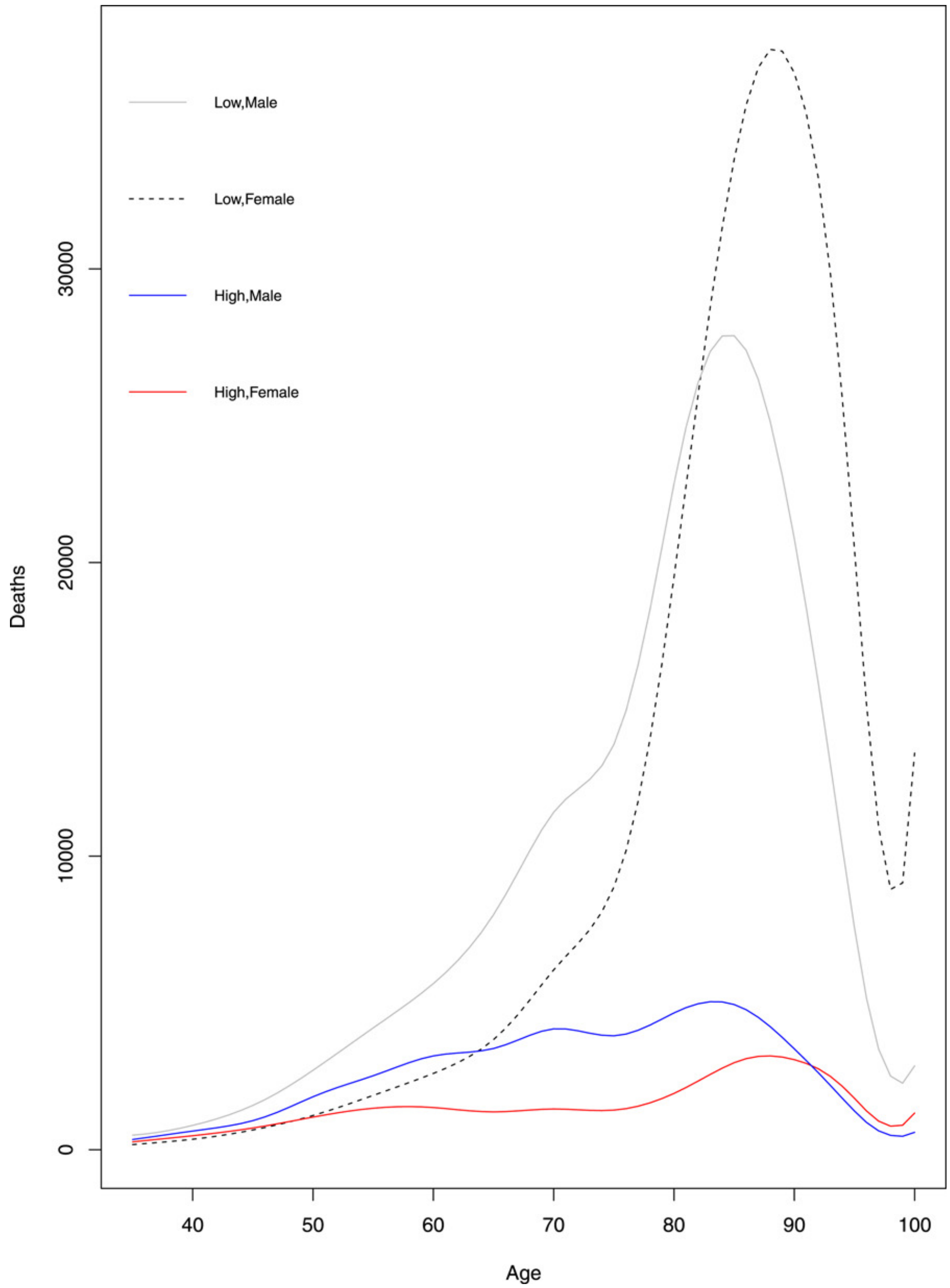

Figure 1A: Smoothed distribution of death counts by sex and educational attainment for Spain, 2014-2018 (Source: author´s calculations based on INE).

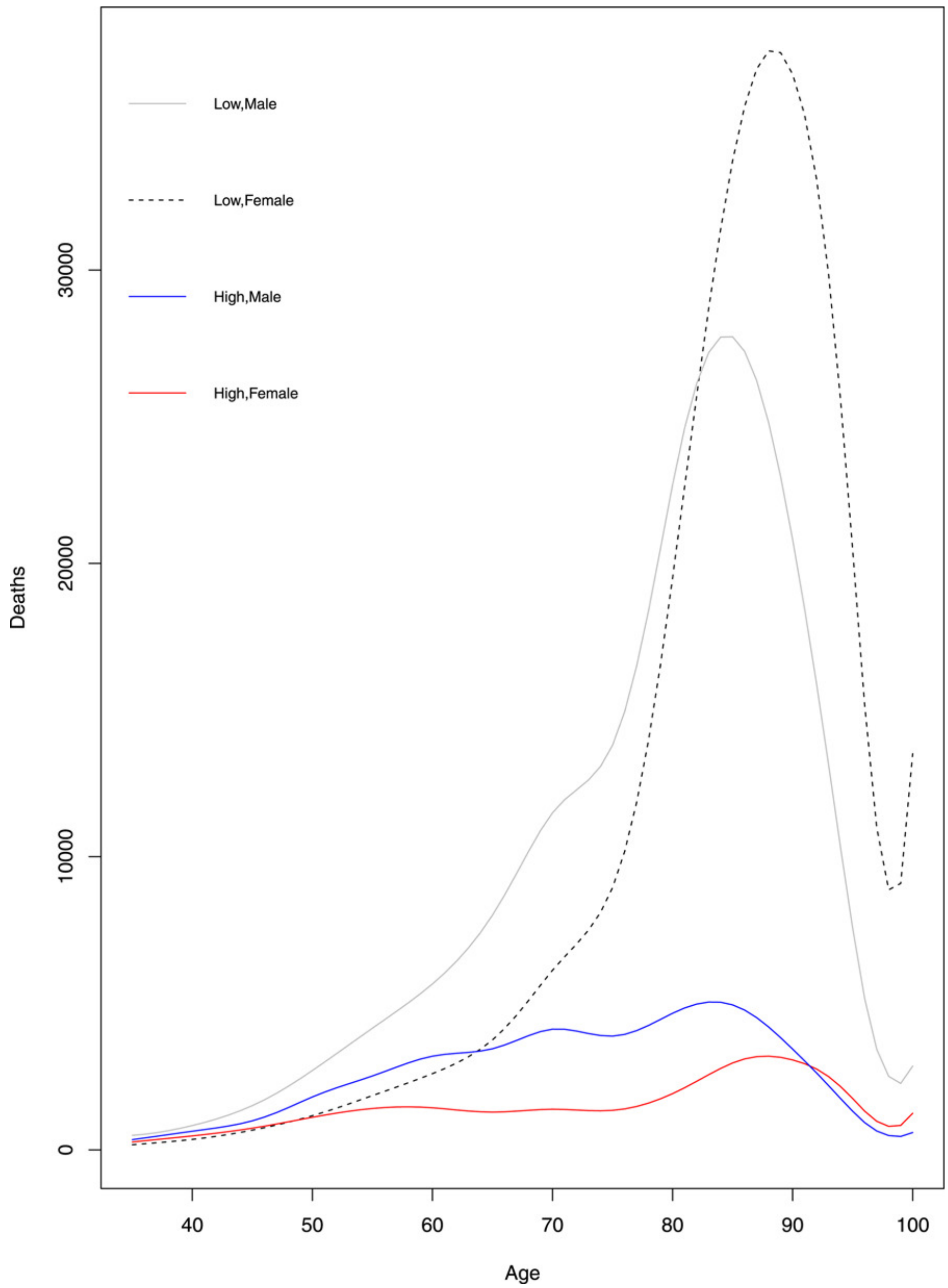

Figure 2A: Smoothed Death Rates by sex and educational attainment for Spain, 2014-2018 (Source: author´s calculations based on INE).

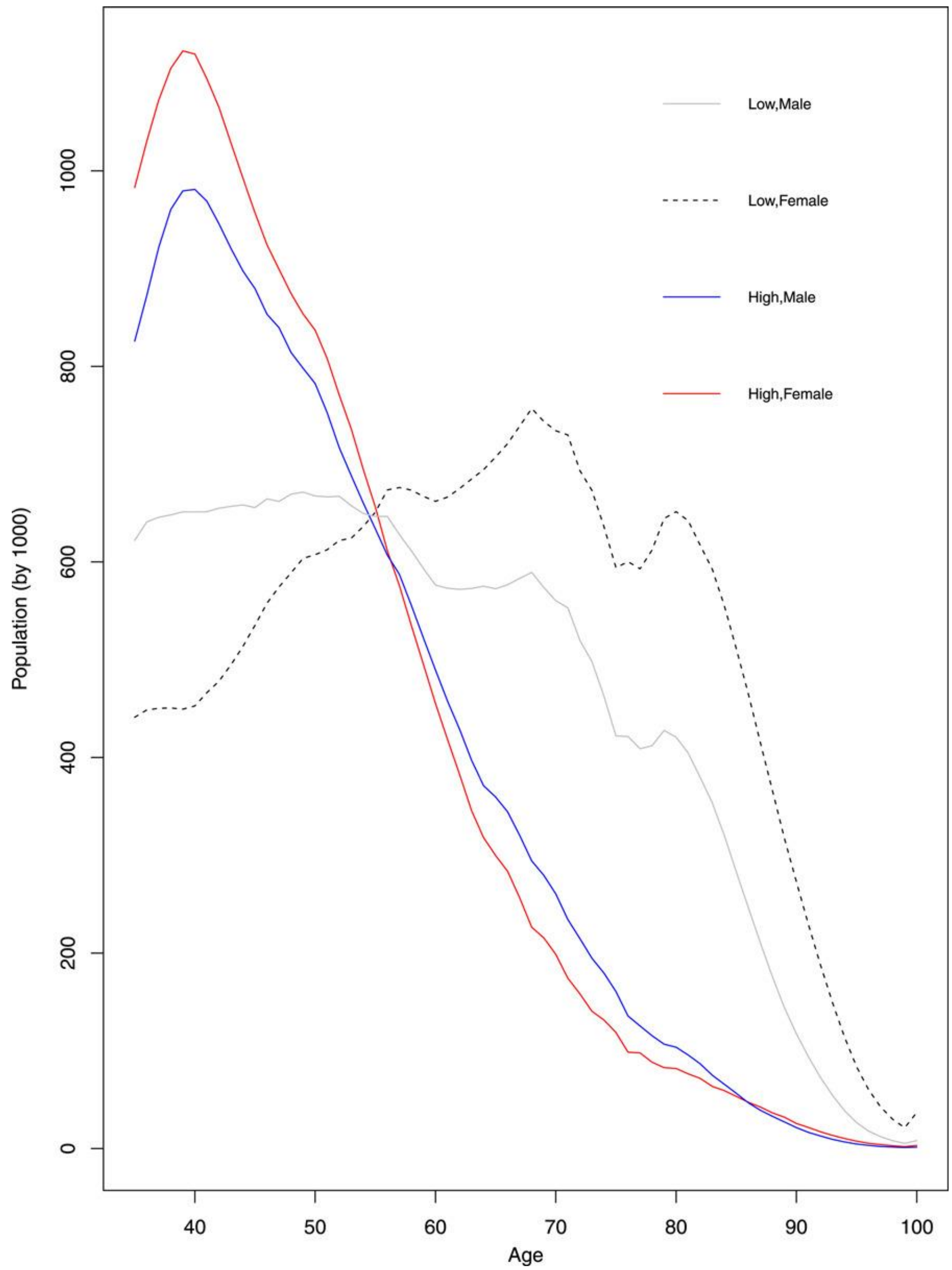

Figure 3A: Population exposures (by thousands) by age, sex and educational attainment in Spain, 2014-2018 (Source: author´s calculations based on INE).

Autonomous Community	Sex	Low Education	High Education	Autonomous Community	Sex	Low Education	High Education
Andalusia	Female	6445472	3968366	Valencian Community	Female	3828733	2614802
	Male	5845334	3879646		Male	3553056	2487877
Aragón	Female	969632	798273	Extremadura	Female	921506	474049
	Male	855882	814719		Male	879383	445165
Asturias	Female	868292	713754	Galicia	Female	2418500	1545269
	Male	689646	688085		Male	2079526	1438246
Balearic Islands	Female	740665	652364	Madrid	Female	3777202	4743290
	Male	727641	633220		Male	2932183	4491890
Canary Islands	Female	1512654	1179128	Murcia	Female	1059735	675234
	Male	1478159	1132293		Male	1022953	666089
Cantabria	Female	426083	389916	Navarra	Female	419610	407107
	Male	364494	377865		Male	383265	403021
Castile and León	Female	1976932	1485780	Basque Country	Female	1487264	1569084
	Male	1837312	1425567		Male	1122746	1622858
Castile- La Mancha	Female	1651764	894128	La Rioja	Female	223429	191833
	Male	1609617	882271		Male	209509	184595
Catalonia	Female	5041236	4646264	Ceuta & Melilla	Female	53134	33372
	Male	4396655	4498358		Male	49693	39826
				Spain	**Female**	**33873823**	**27011262**
					Male	**30037054**	**26111591**

Table 1A: Distribution of population exposures by sex and educational attainment in Spanish Autonomous Communities 2014-2018 (Source: author´s calculations based on INE).

Autonomous Community	Males		Dif	Females		Dif	Difference by Sex	
	LE	HE	HE -LE	LE	HE	HE -LE	LE	HE
Andalusia	43.92	46.60	2.68	49.49	51.08	1.59	5.57	4.48
Aragon	45.08	47.07	1.99	51.05	52.13	1.08	5.97	5.06
Asturias	43.38	46.73	3.35	50.03	51.95	1.92	6.65	5.22
Balearic Islands	44.94	47.84	2.90	50.34	51.84	1.50	5.40	4.00
Canary Islands	44.49	47.44	2.95	49.56	51.74	2.18	5.07	4.30
Cantabria	44.41	47.03	2.62	50.98	51.99	1.01	6.57	4.96
Castile and León	45.68	48.25	2.57	51.45	52.83	1.38	5.77	4.58
Castile-La Mancha	45.65	47.47	1.82	50.97	52.16	1.19	5.32	4.69
Catalonia	45.12	47.74	2.62	50.94	52.55	1.61	5.82	4.81
Valencia	44.80	46.83	2.03	50.12	51.54	1.42	5.32	4.71
Extremadura	44.53	46.69	2.16	50.30	51.98	1.68	5.77	5.29
Galicia	44.38	47.40	3.02	50.93	52.28	1.35	6.55	4.88
Madrid	45.99	48.42	2.43	51.72	52.87	1.15	5.73	4.45
Murcia	45.05	46.80	1.75	50.17	51.22	1.05	5.12	4.42
Navarra	45.77	47.90	2.13	51.51	52.36	0.85	5.74	4.46
Basque Country	44.53	47.43	2.90	51.00	52.31	1.31	6.47	4.88
La Rioja	45.77	47.42	1.65	51.53	52.48	0.95	5.76	5.06
Ceuta and Melilla	42.96	46.28	3.32	48.05	52.40	4.35	5.09	6.12
Spain	44.85	47.50	2.65	50.62	52.21	1.59	5.77	4.71
Standard Deviation	0.81	0.58	0.23	0.89	0.48	0.41	-0.08	0.10

Table 2A: Life expectancy at age 35 and above by sex and educational attainment in Spanish autonomous communities. Key: LE=Low education, HE=High education (Source: author´s calculations based on INE).

Autonomous Community	Males		Dif	Females		Dif	Difference by Sex	
	LE	HE	HE -LE	LE	HE	HE -LE	LE	HE
Andalusia	10.18	9.15	-1.03	8.32	7.75	-0.57	-1.86	-1.40
Aragon	10.11	9.14	-0.97	8.23	7.73	-0.50	-1.88	-1.41
Asturias	10.63	9.27	-1.36	8.66	7.68	-0.98	-1.97	-1.59
Balearic Islands	9.98	9.22	-0.76	8.22	7.70	-0.52	-1.76	-1.52
Canary Islands	10.55	9.49	-1.06	8.89	8.02	-0.87	-1.66	-1.47
Cantabria	10.28	9.12	-1.16	8.30	7.70	-0.60	-1.98	-1.42
Castile and León	10.15	8.84	-1.31	8.32	7.50	-0.82	-1.83	-1.34
Castile-La Mancha	9.86	8.77	-1.09	7.92	7.36	-0.56	-1.94	-1.41
Catalonia	10.01	9.05	-0.96	8.22	7.68	-0.54	-1.79	-1.37
Valencia	10.14	9.27	-0.87	8.29	7.79	-0.50	-1.85	-1.48
Extremadura	10.14	8.97	-1.17	8.12	7.58	-0.54	-2.02	-1.39
Galicia	10.73	9.37	-1.36	8.34	7.73	-0.61	-2.39	-1.64
Madrid	9.95	8.99	-0.96	8.15	7.75	-0.40	-1.80	-1.24
Murcia	9.83	8.89	-0.94	7.96	7.43	-0.53	-1.87	-1.46
Navarra	9.71	8.88	-0.83	8.11	7.54	-0.57	-1.60	-1.34
Basque Country	10.25	9.08	-1.17	8.43	7.78	-0.65	-1.82	-1.30
La Rioja	9.95	8.76	-1.19	8.13	7.19	-0.94	-1.82	-1.57
Ceuta and Melilla	10.62	9.40	-1.22	8.97	8.10	-0.87	-1.65	-1.30
Spain	10.18	9.13	-1.05	8.31	7.75	-0.56	-1.87	-1.38
Standard Deviation	0.29	0.21	-0.08	0.27	0.21	-0.06	-0.02	0.00

Table 3A: Life disparity at age 35 and above by sex and educational attainment in Spanish autonomous communities. Key: LE=Low education, HE=High education (Source: author´s calculations based on INE).

Autonomous Community	Males		Dif	Females		Dif	Difference by Sex	
	LE	HE	HE -LE	LE	HE	HE -LE	LE	HE
Andalusia	0.232	0.196	-0.036	0.168	0.152	-0.016	-0.064	-0.044
Aragon	0.224	0.194	-0.030	0.161	0.148	-0.013	-0.063	-0.046
Asturias	0.245	0.198	-0.047	0.173	0.148	-0.025	-0.072	-0.050
Balearic Islands	0.222	0.193	-0.029	0.163	0.149	-0.014	-0.059	-0.044
Canary Islands	0.237	0.200	-0.037	0.179	0.155	-0.024	-0.058	-0.045
Cantabria	0.232	0.194	-0.038	0.163	0.148	-0.015	-0.069	-0.046
Castile and León	0.222	0.183	-0.039	0.162	0.142	-0.020	-0.060	-0.041
Castile-La Mancha	0.216	0.185	-0.031	0.155	0.141	-0.014	-0.061	-0.044
Catalonia	0.222	0.189	-0.033	0.161	0.146	-0.015	-0.061	-0.043
Valencia	0.226	0.198	-0.028	0.165	0.151	-0.014	-0.061	-0.047
Extremadura	0.228	0.192	-0.036	0.161	0.146	-0.015	-0.067	-0.046
Galicia	0.242	0.198	-0.044	0.164	0.148	-0.016	-0.078	-0.050
Madrid	0.216	0.186	-0.030	0.158	0.147	-0.011	-0.058	-0.039
Murcia	0.218	0.190	-0.028	0.159	0.145	-0.014	-0.059	-0.045
Navarra	0.212	0.185	-0.027	0.158	0.144	-0.014	-0.054	-0.041
Basque Country	0.230	0.192	-0.038	0.165	0.149	-0.016	-0.065	-0.043
La Rioja	0.217	0.185	-0.032	0.158	0.137	-0.021	-0.059	-0.048
Ceuta and Melilla	0.247	0.203	-0.044	0.187	0.154	-0.033	-0.060	-0.049
Spain	0.227	0.192	-0.035	0.164	0.148	-0.016	-0.063	-0.044
Standard Deviation	0.010	0.006	-0.004	0.008	0.004	-0.004	0.002	-0.002

Table 4A: Life Table Entropy between ages 35 and above by sex and educational attainment in Spanish autonomous communities. Key: LE=Low education, HE=High education (Source: author´s calculations based on INE).

Other Supplementary Material for Chapter 2

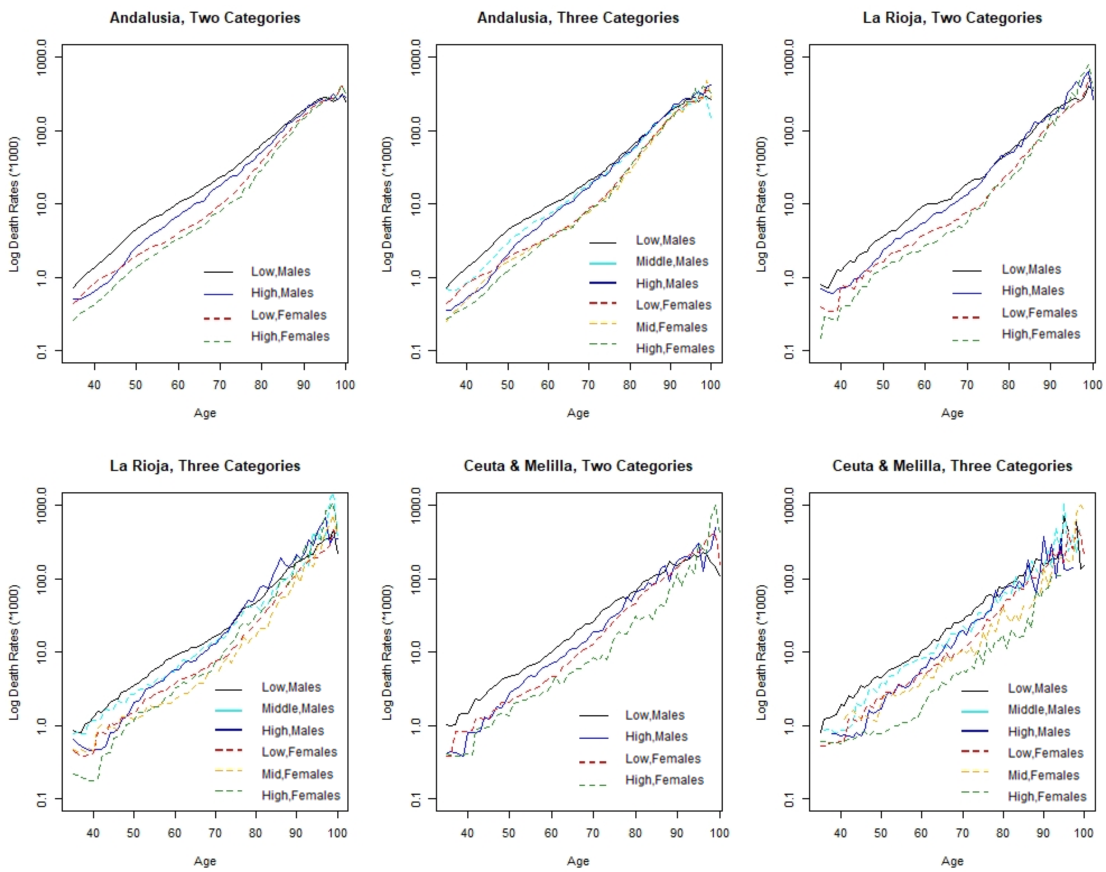

Figure 1S: Death Rates for Andalusia, La Rioja and Ceuta & Melilla for two and three educational cutoffs, 2014-2018 (Source: author´s calculations based on INE).

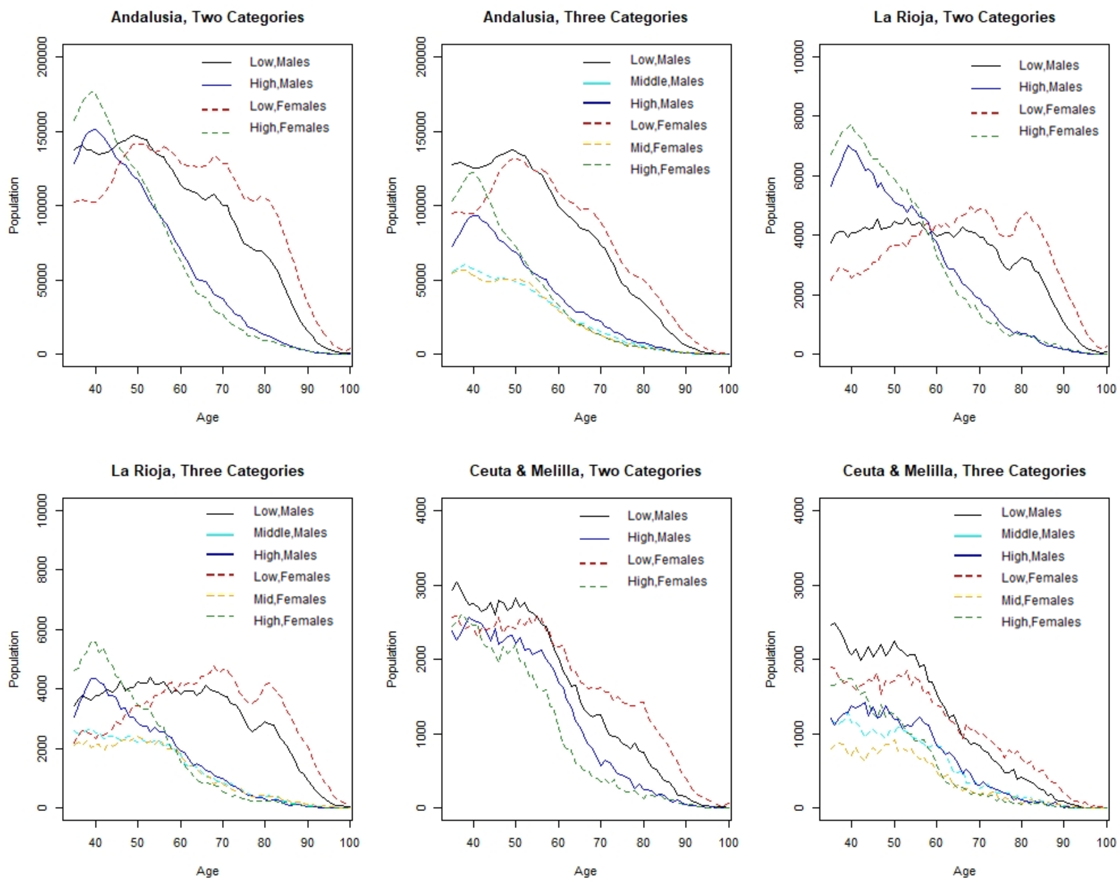

Figure 2S: Population Exposures for Andalusia, La Rioja and Ceuta & Melilla for two and three educational cutoffs, 2014-2018 (Source: author´s calculations based on INE).

Chapter 3: Lung cancer mortality trends among women across Spain. The role of birth cohorts in diverging regional patterns and factors associated with them.

Abstract:

Smoking among Spanish women has increased during the last 50 years and is considered by some authors a modern epidemic. However, mortality risk by cohorts may differ at a regional level, given that health prevention competencies are decentralized. We applied an Age-Period-Cohort model to identify birth cohort effects on female lung cancer mortality in Spain. We found a strong linear increase in lung cancer mortality during the 1980-2019 period in all regions, both in linear trends and in age-standardized death rates.

Cohorts born between 1935 and 1955 presented a higher relative risk of death at a national and subnational level. However, we found diverging cohort patterns across regions afterward, with some regions presenting a non-linear mortality improvement in their youngest cohorts, while some others did not present such a trend. Factors such as education, GDP per capita, and a decline in smoking were positively associated with mortality improvement in younger cohorts. This suggests that inequalities in lung cancer mortality in Spain among women are not only generationally based, but that generational risks also vary across space, with factors associated with structural conditions and adoption of healthy behaviors.

Keywords: Descriptive epidemiology, Social epidemiology, Cohort studies, Cancer, Mortality

1. Introduction

Cancer is one of the leading causes of death in Spain. In particular, lung cancer is one of the most fatal cancers, as well as one of the most common (Alonso et al., 1996; A. Cayuela et al., 2011). The increase in lung cancer female mortality has been documented in the literature, particularly at younger ages (Bosetti et al., 2012; Janssen et al., 2021; Levi et al., 2007; Rafiemanesh et al., 2016)) and could be considered by some authors as a modern epidemic (Bray & Weiderpass, 2010; MacRosty & Rivera, 2020). Many studies previously mentioned that male mortality from lung-related cancer has decreased over the last few years in Spain, while female mortality has increased instead (A. Cayuela et al., 2007; Izarzugaza et al., 2010; Ocaña-Riola et al., 2013). While male mortality is still above the levels of female mortality, the direction of the ongoing trends for women is certainly a reason for concern.

Cigarette smoking (and other forms of tobacco consumption) is one of the main drivers that can cause not only lung cancer but also larynx, bronchial, and other respiratory tumors as well (which we will broadly consider as lung cancers in this article). And changes in lung cancer mortality are mainly considered a result of changes in smoking patterns (Franco et al., 2002). Smoking is currently one of the main hazards in population health in Spain, being responsible for a significant number of disability-adjusted life years and deaths (Haeberer et al., 2020; Soriano et al., 2018).

Since smoking is an acquired habit, it is considered an avoidable risk behavior and is also well-known that prevalence and consumption are heavily mediated by generational components (associated with birth cohorts). This study aims to investigate the different risks of lung cancer mortality among cohorts of females across Spain and its regions and to identify factors associated with potential divergences in mortality risk across birth cohorts.

2. Background

It is accepted that the smoking epidemic in many Western societies began at the end of the 19th Century and the beginning of the 20th Century (Proctor, 2004; Slade, 1992). However, in the case of Spain, cigarette consumption was fairly limited before 1960, because many smokers were facing poverty and cigarettes were a rather expensive product (Villalbí et al., 2019). Later on, along with the economic growth, consumption increased, along with the expansion of the *Tabacalera*, a state-owned monopoly that made anti-tobacco regulations a difficult task. Furthermore, the Francoist government failed to prevent an increase in mass consumption by neglecting the health hazards induced by cigarettes, when some of the first studies finding associations between cigarette smoking and lung cancer were published (Villalbí et al., 2019). From the early 1970s (when democracy in Spain was restored) until 2007, consumption of tobacco has increased for females aged 45 and above, while also decreasing for males of all ages (Fernández et al., 2003; Regidor et al., 2010). The later expansion of tobacco consumption when compared to other Western countries, the increased smoking prevalence among females, and the lagged effects on health after the habit made lung cancer a health problem not only in contemporary Spain (L. Cayuela et al., 2020a; Fernández et al., 2003; Franco et al., 2002) but also in its regions (A. Cayuela et al., 2004, 2011). This made lung cancer one of the few conditions among females that presented a mortality increase instead of a decline over time, making it a relevant phenomenon to study.

However, not everyone has the same propensity to develop lung cancer. Generally, the concept of a cohort is associated with the collective exposure of a certain group to a certain phenomenon (Glenn, 1976; Ryder, 1965) that has (or has not) differential outcomes when compared to other cohorts who had a different exposure. In this case, cohort effects would imply that some birth cohorts have a greater risk of dying of lung cancer than others, either because of smoking or because of exposure to other health hazards. Therefore, a cohort approach to analyze long-term mortality trends in Spanish females would investigate generational differences in lung cancer mortality and regional variations. Even in the light of some anti-tobacco policies that tried to mitigate active and passive consumption (Pinilla & Abásolo, 2017), diseases like cancer are the result of developing long-term exposures. In other words, birth cohorts have special consideration when analyzing trends of lung cancer mortality, revealing inequalities in health that otherwise may remain hidden given the generational association between lung cancer and cohorts.

Furthermore, the smoking propensity is not equal among socioeconomic statuses. Factors such as educational attainment or income (classic proxies of socioeconomic position) are strongly associated with tobacco use, with individuals with a lower social standing presenting higher levels of consumption in developed nations (Cavelaars et al., 2000; Huisman, Kunst, & Mackenbach, 2005a). However, that was not always the case: the tobacco epidemic smoking in developed nations (Giskes et al., 2005; Graham, 1996) began as a habit associated with individuals with higher social standing before individuals with a lower position also coped up (as tobacco became more affordable). After that, divergence was present again, but with higher individuals presenting a lower prevalence, as awareness of negative health outcomes of smoking became more widespread (Pärna et al., 2014; Regidor, Gutierrez-Fisac, et al., 2001). That does not mean that consumption is absent in higher-educated women and differences in prevalence are small, particularly for the older generations (Cavelaars et al., 2000; Haeberer et al., 2020; Huisman et al., 2005b; Regidor, Gutierrez-Fisac, et al., 2001). Evidence also points out that reducing or quitting smoking may result in lower lung cancer mortality (Godtfredsen et al., 2005; Hecht et al., 2004). In other words, behavioral changes (expressed in changes of prevalence at a population level) may be associated with the choice of smoking and, ultimately, with developing lung cancer mortality. And those behavioral changes may be associated with structural factors, such as the social standing of groups of individuals or public policies limiting consumption.

Since the sanction of the new Spanish Constitution in 1978, a slow process that was completed in 2002 indicated a decentralization of health care, policy and prevention services into the autonomous communities, the largest subnational government unit in Spain (Marqués Fernández, 2003). The first Spanish legislation that acknowledged tobacco as a harmful substance was sanctioned in 1988, with the Royal Decree Nº192 (Sasco et al., 2003), but no strong anti-tobacco laws such as Law 28/2005 (Peruga et al., 2021; Pinilla & Abásolo, 2017) were sanctioned until 2005. Indicating that the responsibility to deal with the prevention and regulation of tobacco consumption fell mostly into the regional autonomic health care systems. Historically, the success of treatments in dealing with lung cancer has been limited so far (Jones & Baldwin, 2018).

Hence, prevention and early detection are critical markers to improve the health situation of a population. And those aspects (or many other possible health determinants) can vary critically by different spatial dimensions, with Spain not being an exception to that fact (Borrell et al., 2010; Rottenberg et al., 2019; Santos-Sánchez et al., 2020). Factors such as gross domestic product (La Torre et al., 2018) or public health expenditure (Crémieux et al., 1999; Martín Cervantes et al., 2019; Nixon & Ulmann, 2006; Rentería & Zueras, 2022) may also be related with effective policies that result in a lower mortality or morbidity mortality and morbidity

In Spain, lung cancer mortality trends across cohorts have been described and investigated, but only at a national, aggregate level (Bray & Weiderpass, 2010; Franco et al., 2002), or only at a specific province or autonomous community level (A. Cayuela et al., 2007; Ocaña-Riola et al., 2013). Considering that some of those females that could be exposed to lung cancer were born at the dawn of the 20th Century, we expect to identify differential risks across cohorts (in this case, females born between the years 1900 and 1975): Franco et al. (2002) identified an increase in the relative risk of lung cancer deaths between the cohorts of 1935 and 1955 but did not consider cohorts beyond that point.

Therefore, it is critical to determine if the mortality risks across cohorts continued to increase or declined afterward, to establish better healthcare policies, and identify which cohorts are more at risk, not only at a national level but also at a regional level as well, given the heterogeneous nature of mortality across space. To the best of our knowledge, there are no studies analyzing and comparing patterns of lung cancer across autonomous communities in Spain from a cohort perspective, identifying which are the most vulnerable birth cohorts at a regional level, nor trying to identify factors associated with regional divergences in mortality in the country. While we can expect that lower lung cancer mortality is associated with some factors at a macro level by regions (lower overall consumption, higher GDP per capita, higher expenditure on healthcare, higher overall education, lower prevalence of smoking), the temporal and generational nature of the smoking epidemic makes such associations less obvious when considering mortality across cohorts. Therefore, this study is more interested in broadly describing and understanding the dynamics of mortality across cohorts of females in different regions of Spain.

3. Materials and methods

For this study, we used a combination of data sources, all publicly available on the Spanish National Institute (Instituto Nacional de Estadística, also known as INE, given their acronym in Spanish) website.

We considered lung, bronchial, and trachea cancer (cause 018 in the Spanish mortality file classification, and groups C34 for lung and bronchus and group C33 for trachea in the ICD-10 classification), larynx malignant tumors (cause 017 in the Spanish mortality file classification and group C32 in the ICD-10 classification), and other respiratory and thoracic-related tumors (cause 019 in the Spanish mortality file classification and group C76.1 in the ICD-10 classification) deaths as lung/respiratory cancer deaths[1]. We also obtained the population exposures at a given year as the denominator to estimate death rates (on July 1st of each year)[2].

We have to mention here that while there are various indirect methods to describe smoking-attributable mortality, we resorted to what could be identified as the Basic Method, which consists in simply describing lung cancer death rates, and acknowledging that the causes behind such rates may not entirely be due to tobacco consumption (Pérez-Ríos & Montes, 2008). Prevalence-dependent methods to estimate smoking-attributable mortality (Piñeiro et al., 2022 is a good example of this type of study) rely on age-specific smoking rates for the whole period and autonomous communities, which is something we do not have for this study. And other methods that do not rely on prevalence such as the one proposed by Peto et al. (1992), have to rely upon lung cancer death rates for non-smokers in other target populations (using data from other countries such as the United States given the unavailability of such estimates for Spain). Recognizing such limitation, this assumption was used in the past to estimate smoking-attributable mortality in the Spanish case (for instance, see Rey-Brandariz et al., 2022). However, since we are not interested in calculating deaths attributable to tobacco specifically, but simply describing and identifying mortality risks of lung cancer across cohorts and regions, we believe that the use of the basic method is reasonable for our analysis.

Given that lung cancer mortality is relatively scarce before age 40 (there were less than 50 deaths below age 39 at a national level per year in the 1980-2019 period), we decided to model mortality by five age groups between ages 40 and consider the age 80 and above as the upper truncation. This was done because the vital statistics and the INE population estimates are given in five-year age groups, starting at age 40. In cancer epidemiology, age-period-cohort analysis is a widely used technique to identify not only because it can detect how some specific cohorts may have differential risks in a given health outcome (Murphy & Yang, 2018). Similarly, we pooled periods from 1980 to 2019 at five-year intervals, to adequately represent the required tabulation for cohort analysis symmetrically, but also to

[1] Death counts are available in the following link: https://www.ine.es/jaxiT3/Tabla.htm?t=10803
[2] Resident population exposures at 1st July of each year are available in the following link: https://www.ine.es/jaxiT3/Tabla.htm?t=10262&L=0

make sure we had observations (deaths) in all age groups for all periods (something that is required for the modeling tool we used to estimate age, period and cohort effects). Therefore, birth cohorts from 1900 to 1975 are represented in the analysis. Table 1A presents the corresponding tabulation.

We chose all autonomous communities, except for the overseas territories of Ceuta and Melilla, due to their small size. Those autonomous communities correspond to the NUTS-2 level regional classification in Spain. Figure 1A in the appendix presents a map of such regions. To test the relationship between lung cancer mortality and macro-level factors across autonomous communities, we used data available on the INE website (gathered from different surveys that were conducted in Spain) for the year 2017: Per Capita Gross Domestic Product, the proportion of females with higher education (considering post-secondary and above), Average Expenditure in public health and overall smoking prevalence in 2017. Also as a dynamic variable, we considered the average change of regular female smokers between the years 2003 and 2017[3] and the variation of public health expenditure per capita between 2003 and 2017 (no previous data was available) [45].

Before proceeding into the age-period-cohort modeling phase, a set of exploratory procedures were performed, that are customary for this kind of analysis, starting by estimating the age-standardized death rates for each autonomous community. We used the average population structure of Spain in the 2015-19 period as the standard that is necessary to apply the direct method of standardization (considering the population aged between 40 and 80). Furthermore, we performed the classic combination of four plots: age-by-period, period-by-age, age-by-cohort, and cohort-by-age for observed rates (available in the appendix from figures 2A to 5A), to visually inspect the presence of period and cohort effects. In addition, we produced a heatmap to visually inspect the existence of period and cohort effects

[3] Information about smoking prevalence and education data is derived from Spanish National Health Surveys from 2003 and 2017. https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736176783&menu=resultados&idp=1254735573175

[4] Information about per capita health expenditure between 2003 and 2017 was obtained from the National Health System Key Indicators App: https://inclasns.sanidad.gob.es/main.html

[5] Information on Per Capita Regional GDP was available in Contabilidad General de España reports https://www.ine.es/buscar/

Lung cancer death rates were modeled as estimable age, period, and birth cohort functions. We followed Carstensen's procedure (2007), based on Holford's approach (Clayton & Schifflers, 1987; Holford, 1983) to estimate age-period-cohort models.

In this approach, the APC effects are treated as non-linear continuous functions of *f(a), h(c),* and *g(p) respectively, along with a linear trend (drift), whose allocation depends on the chosen parameterization.* While there is no way to solve the linear identification problem (given that age plus cohort equals period), we can identify non-linear effects (also known as second-order effects) on one given dimension, assign the linear trend to a different dimension and estimate the log-rates of the remaining dimension (generally age, because of its higher predicting power when calculating a given phenomenon). In other words, in APC models only second-order (non-linear) effects are fully identifiable from a mathematical standpoint fort the period and cohort dimension. Previous analyses at the national or regional level had presented age-standardized mortality rates with an almost constant growth pattern (A. Cayuela et al., 2004, 2008; L. Cayuela et al., 2020b). Therefore, we assumed explicitly that linear changes in mortality were attributed to period effects (also known as *period-major* parameterization), meaning that birth-cohort effects were estimated in a non-linear fashion, as the relative risks to the average cohort trend (known as "*APC"* parameterization in the *Epi* package), as it was done in lung cancer studies previously (Takahashi et al., 2001).

This means that the dimension of interest (in this case, cohort) is constrained to have a zero slope and a zero average, becoming "detrended" as a result. This dimension is expressed as an interaction of the two remaining dimensions (Chauvel & Schröder, 2014) in a Poisson generalized linear model, with the maximum-likelihood estimations expressing the rate ratio compared to the average trend. That way, those cohorts whose relative risks are above the trend (this being a relative risk equal to 1) represent cohorts that have higher mortality than the average trend, and changes over time in the relative risks would imply changes in the trend direction. The dimension carrying the drift (in this case, period) is presented in terms of the relative risk to a reference period of choosing, considering both linear and non-linear effects altogether. The decision to choose this particular model, while arbitrary was because we wanted to determine the extent of fully identifiable cohort effects despite being second-order (which is the result of the chosen parameterization).

The "*Epi"* package was developed in R software (Carstensen et al., 2021) and provided the necessary tools for the analyses, and allowed the user to choose among a series of options for modeling. Equation 1 presents the basic Age-Period-Cohort equation:

$$\ln\big(d(a,p)\big) = r_{p0}(a) + \delta(p - p_0) + g(p) + h(c) \qquad (1)$$

Where $r_{p0}(a)$ are the age-specific prevalence rates in the reference period p_0; δ represents the slope of the drift relative to the period of reference; *h(c)* is the non-linear cohort function, and *g(p)* is the non-linear period function relative to the period of reference. The sum of period effects is interpretable as the log relative risk to the period of reference p_0. Apart from that, we also presented the contribution of each parameter to deviance reduction, considering the linear trend, the possible presence of non-linear period effects, and a full APC model (Carstensen, 2007; Clayton & Schifflers, 1987). This was done to determine the intensity of the drift (the average linear change over time), which could be potentially useful for the interpretations made. Given that in this approach dimensions are considered as continuous variables, we chose the 1980-1984 period (that has the year 1982.5 as the mid-point) as the reference for the APC model to visualize period changes relative to the beginning of the trend.

However, for a different perspective of the cohort effects we also presented an alternative parameterization, presented in equation 2, which is cohort major ("*ACP"* parameterization in the *Epi* package). In this case, age-specific rates are longitudinal to the reference cohort c_0, the linear trend δ is attached to the cohort dimension relative to the reference cohort c_0, and period effects are detrended and shown as non-linear compared to the average trend. In this case, the reference cohort is the 1935 birth cohort (midpoint of the range between 1932.5 and 1937.5 birth cohorts which are expressed as the difference of period minus age).

$$\ln\big(d(a,c)\big) = r_{c0}(a) + \delta(c - c_0) + g(p) + h(c) \qquad (2)$$

For easier visualization, we chose natural cubic splines to fit the models (Carstensen, 2007). To extract the drift, we chose the standard naïve weights, and five spline knots to fit each one of the age, period, and cohort dimensions.

4. Results

Figure 1 presents the age-standardized death rates for the analyzed period for each autonomous community. Death rates increased across all regions and at a national level. However, death rates were relatively stable until the 1990-1995 period (except for Madrid, which presents an increase right from the start) when they started to increase across all regions of Spain. At the end of the analyzed period, regions such as Cantabria, the Canary Islands, and the Basque Country had the highest death rates, while Andalusia, Castile-La Mancha, and Murcia had some of the lowest death rates.

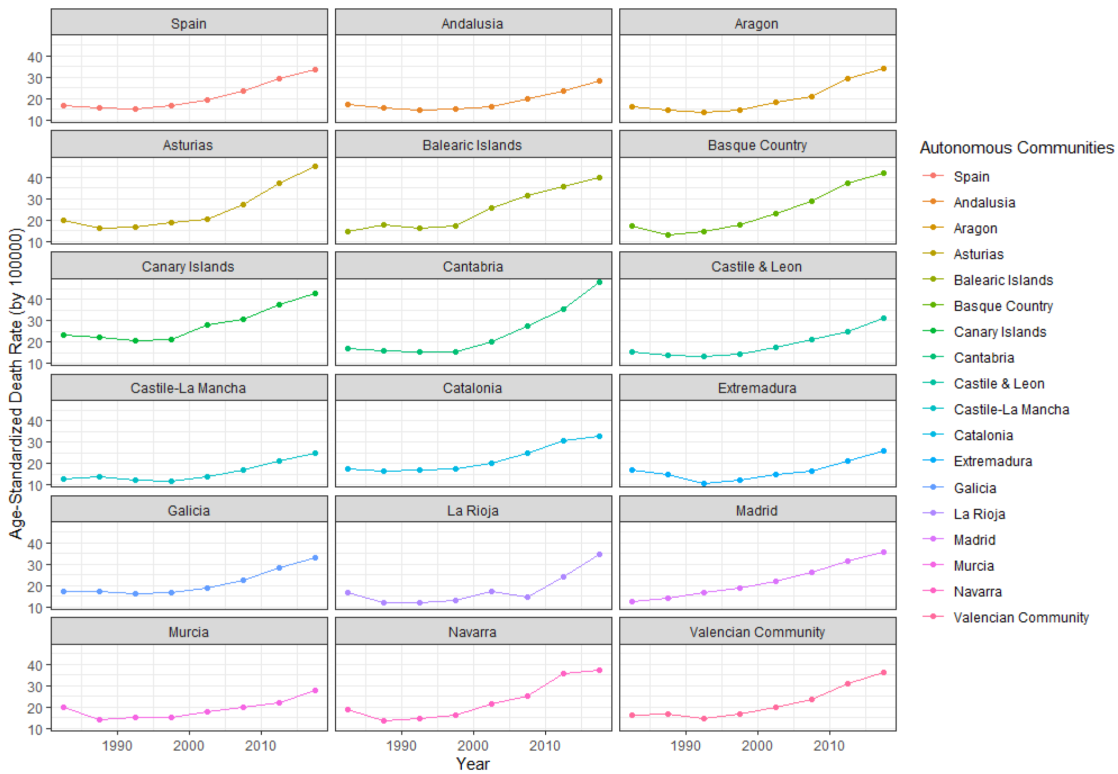

Figure 1: Lung cancer age-standardized death rate in Spanish females by the autonomous community, 1980-2019 (Source: author´s calculations based on INE).

Along with the standardized rates, the traditional set of two-dimensional plots (that can be found in the corresponding appendix in figures 2A to 5A) indicated a combination of period and cohort effects present for females, expressed in the constant crossing of the lines, and the fact that death rates were the highest in certain cohorts (such as the one between 1956 and 1960) that were in the middle of the distribution. Figure 2 indicates the contribution of each additional parameter to the reduction of deviance (when compared to a single-factor age model). Overall, the age-drift model is responsible for almost seventy percent of the deviance reduction of Spain, and the full APC model (which in this case contains the non-linear period and non-linear cohort effects) does account for a quarter of the total reduction (being the largest for Galicia, Murcia, and the Canary Islands) when compared to a single-factor age model. The AP models (considering only non-linear period effects) were relatively small in almost all regions, ranging from virtually non-existent (as the case for Madrid) to a quantity nearing 30 % (as was the case for Extremadura). On average, those effects represented five percent of all deviance reduction when compared to a single age-factor model, meaning that incorporating both non-linear period and non-linear cohort models in a full APC model is a far better alternative when analyzing deviance reduction, as it is shown in Figure 2.

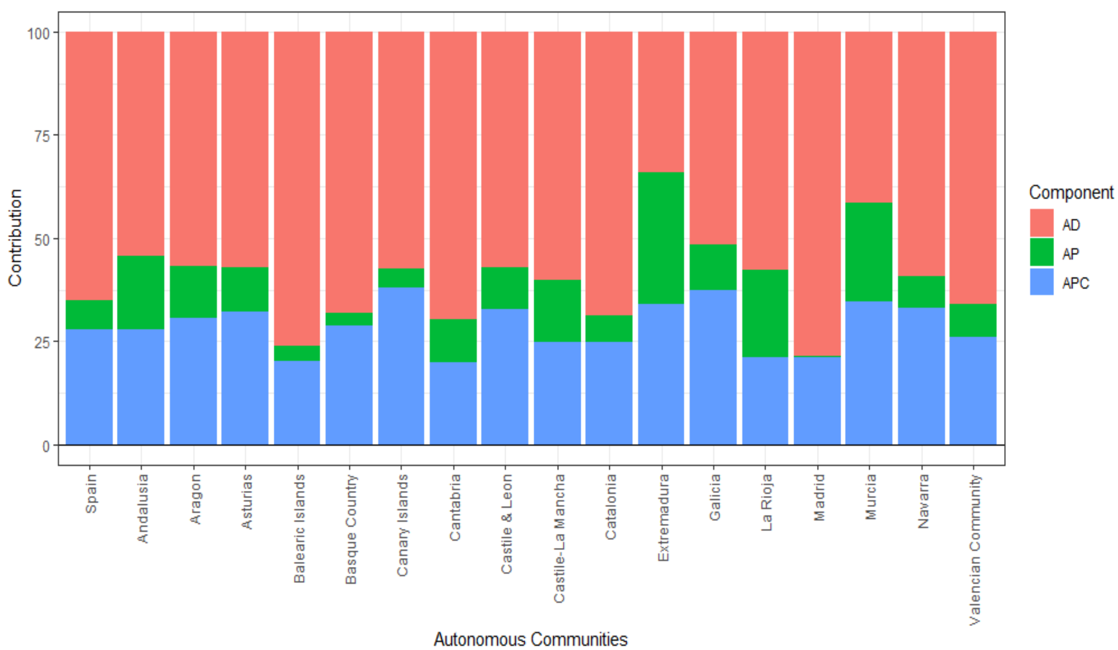

Figure 2. Contribution to deviance reduction between Age and APC models in selected autonomous communities**.** All Parameters have a P-Value <0.0001 (Source: author´s calculations based on INE).

However, while Figure 2 indicates that the linear trend has the larger contribution in terms of deviance, the force of such a trend is not clear. Therefore, Figure 3 presents the maximum likelihood estimates of the drift values (the average linear change in risk by every five years), by considering both the drift in a full APC model (with 95% CI). Figure 3 indicates that for Spain, the average increase in relative risk was slightly above 1.03 times higher by each five-year period (marked with the red vertical line). In some autonomous communities, such as Andalusia, Castile-La Mancha, Extremadura, and Murcia the average linear change was below the national drift. Other regions such as the Basque Country Cantabria, Asturias, and the Valencian Community presented an average linear change above the national trend. Then again, we have to keep in mind that the change of the linear drift in an APC model is a relative measure and not an indicator of the level of overall mortality. In any case, those values are the expression of strong growing linear trends of lung cancer mortality, with the average drift in all regions being above their respective baseline mortality (in the 1980-1984 period).

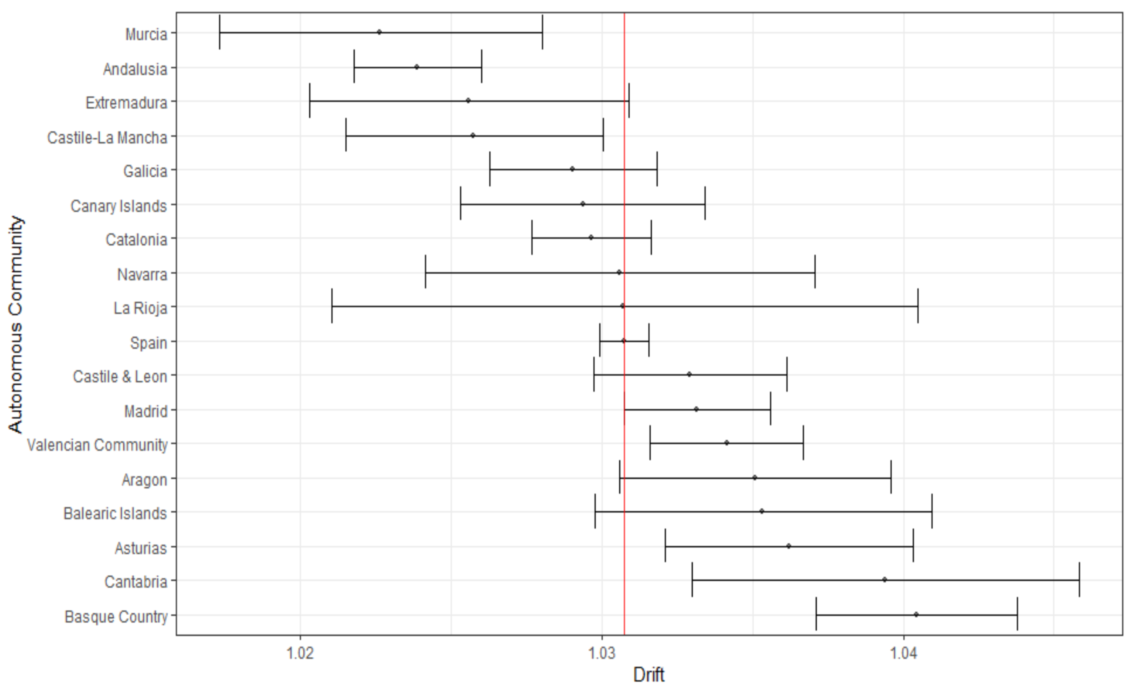

Figure 3: ML-estimated values of the linear drift by autonomous region (Source: author´s calculations based on INE).

Figures 4 to 6 present the different components of the APC model results, as Age, Period, and Cohort effects, respectively. As Figure 4 shows, in all autonomous communities, lung cancer mortality increases exponentially with age (with the 1980-1984 period as a baseline reference). The increase was practically identical in all regions, with a (log) death rate three times higher for the final age group when compared to the 40-44 age group. Figure 6A in the supplementary material, which presents the age effects of the reference cohort (1935), also indicates very similar result as Figure 4.

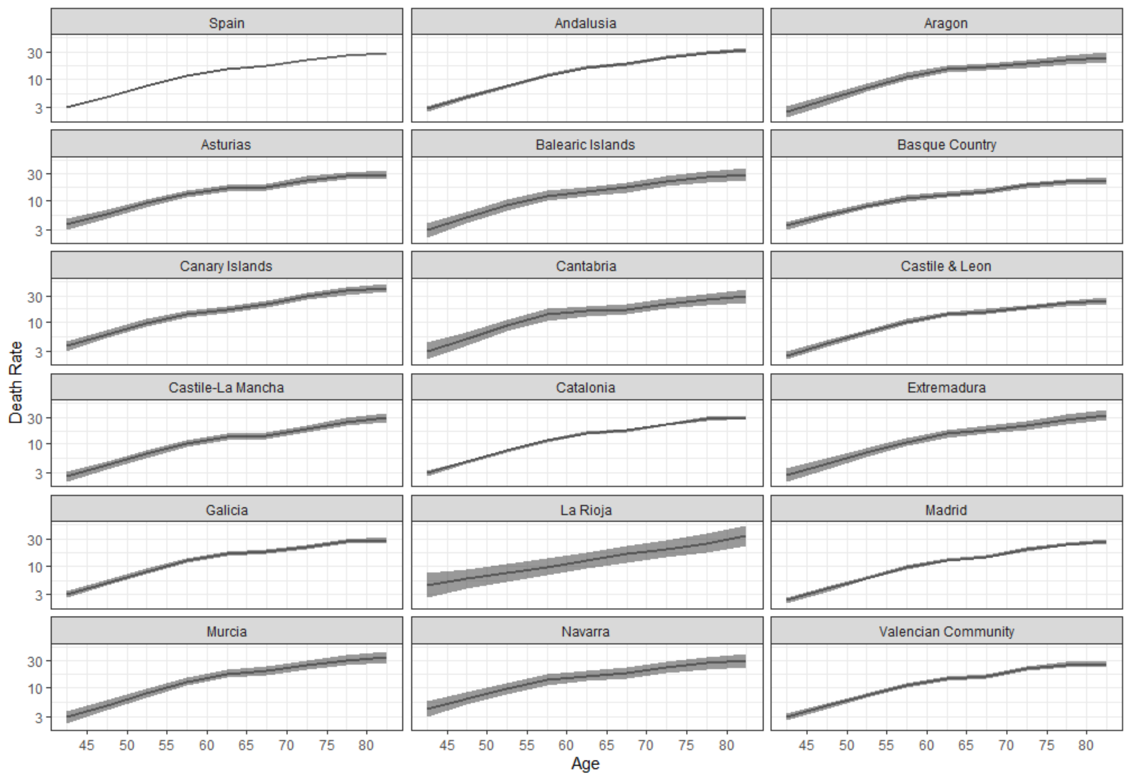

Figure 4. Cross-sectional Age effects (age-specific log death rates) of lung cancer mortality for females across autonomous communities of Spain of the 1980-1984 period (Source: author´s calculations based on INE).

Figure 5 presented the linear (drift) and non-linear period effects. Once again, in all regions is evident that the relative risk of period effects (contextual factors) increased constantly from the reference period of 1980-1984 and afterward (highlighted with the horizontal line). At a national level, in the period 2015-2019, the relative risk was almost three times higher when compared to the baseline. However, there are some temporal divergences: while for Madrid and Catalonia the increase was almost instantaneous after the baseline period, other regions such as Extremadura and Murcia presented a more recent, lagged increase. Despite this, increases in relative risk ranged between two and four times above their respective regional baselines were found in all regions across the analyzed period. Figure 7A in the supplementary material, presents the results of non-linear period effects in there is a small positive period effect during the decade of 1990 in some autonomous communities and at the national level as well.

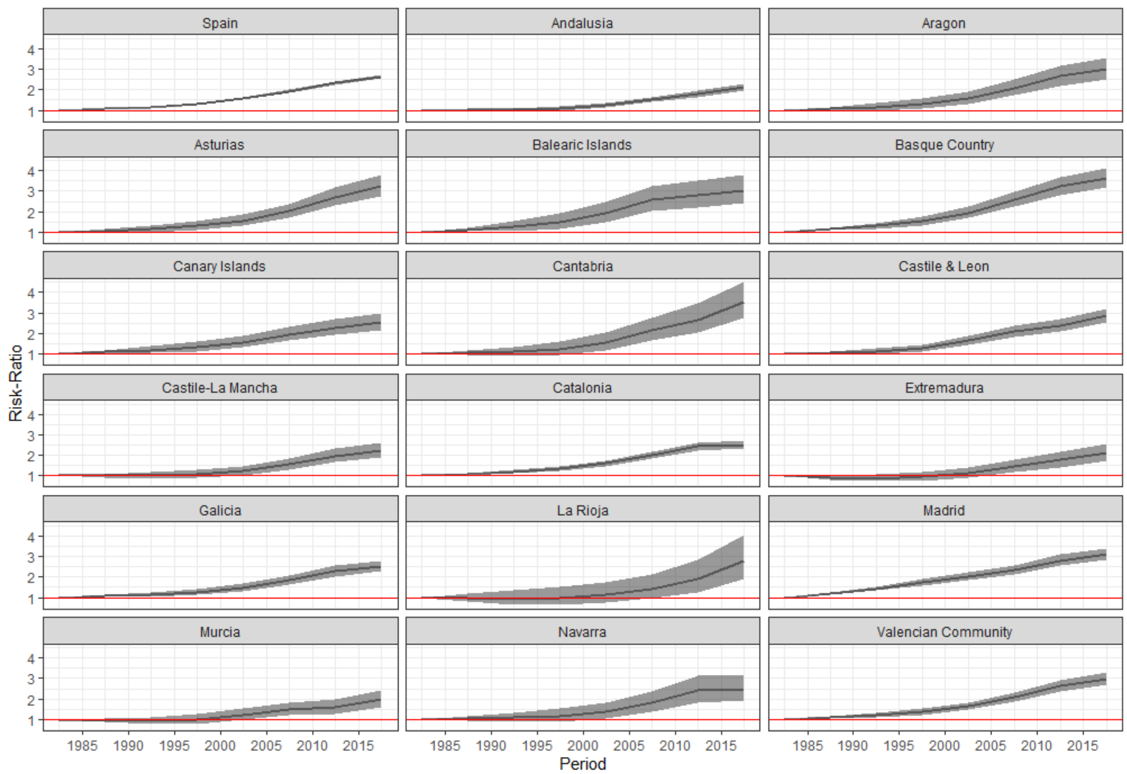

Figure 5. Period effects of lung cancer mortality for females across autonomous communities of Spain compared to the reference period 1980-1984 (Source: author´s calculations based on INE).

Figure 6 presented the non-linear cohort effects (generational factors) in relative risk when compared to the average trend (highlighted in the horizontal red line). Complementarily, Figure 7 presents the cohort effects (relative to the 1935 cohort, with the vertical green line), with the model in which the linear trend is attached to the cohort dimension. From the inspection of those two figures, we found a stable relative risk virtually in all regions and at a national level until the cohorts born in 1935 (highlighted in the green vertical line). Between that point and the 1955 cohort, both figures find an increase in relative risk in all autonomous communities, indicating that such cohorts presented higher mortality in all regions when compared to the older cohorts. However, unlike Figures 4 and 5, we could find regional divergence in the cohorts born after 1955 (highlighted in the blue line). The change in the curve for cohorts born between 1955 and 1975 in the figure indicates divergent non-linear patterns across different autonomous communities: most autonomous communities presented a sharp decline in risk, indicating an improvement in mortality (Basque Country, Asturias, Madrid, Navarra as some examples). Complementarily to that, figure 7 (which presents the linear and non-linear mortality risk compared to the 1935 cohort) indicates stagnation of the increasing mortality, supporting the notion that there is some form of improvement in these regions.

In other communities such as Castile & Leon, Extremadura, and Galicia mortality keeps ever increasing: both Figures 6 and 7 indicate there is an increasing mortality trend for the younger cohorts, driven mostly by linear effects but also by some slight non-linear cohort effects as well.

There is a third scenario, which is the one from Catalonia, Aragon, and the Valencian Community for instance, and to a lesser extent, the average of Spain. In this case, Figure 7 indicates that the linear trend of mortality is increasing for the younger cohorts as well. However, unlike the previous scenario, non-linear cohort effects seem to be on par with the average mortality trend or even show slight improvement, indicating that change in mortality for these cohorts is essentially linear (meaning that can be either attributed to period or cohort from a mathematical standpoint).

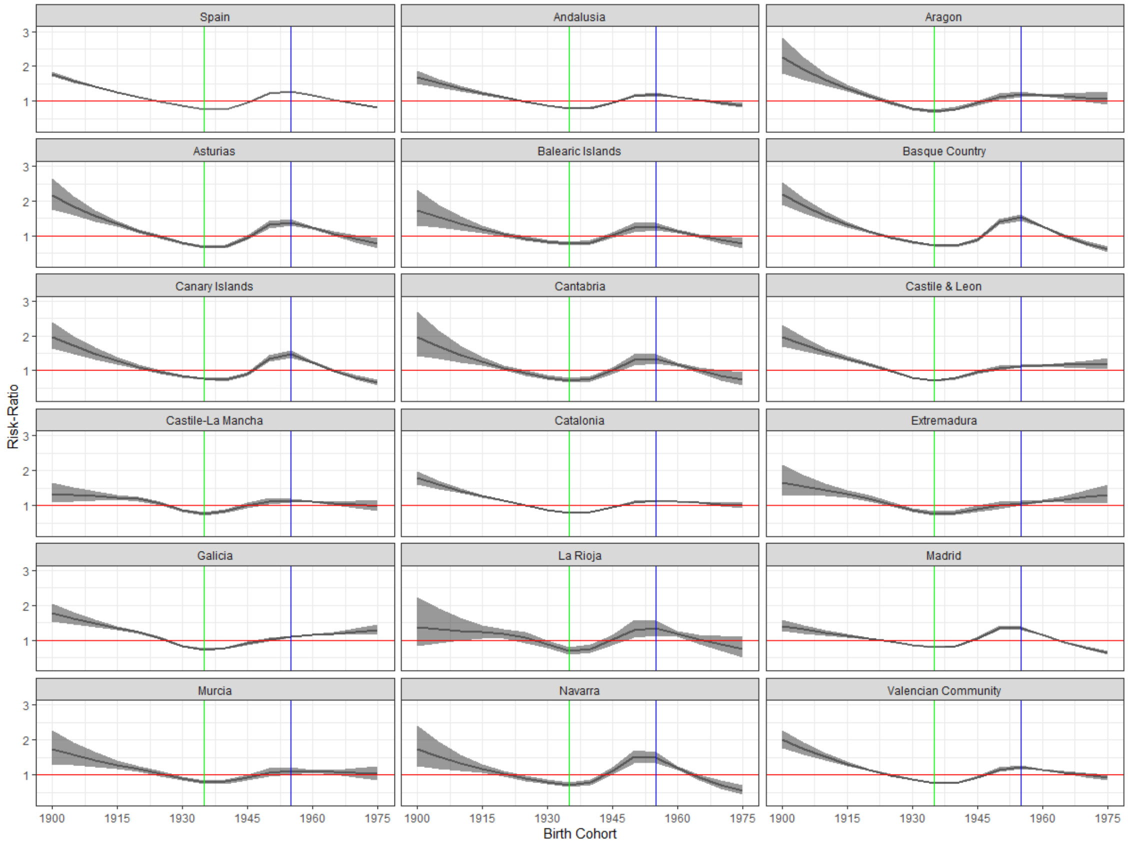

Figure 6. Non-linear Cohort effects of lung cancer mortality for females across autonomous communities of Spain compared to the average trend (Source: author´s calculations based on INE).

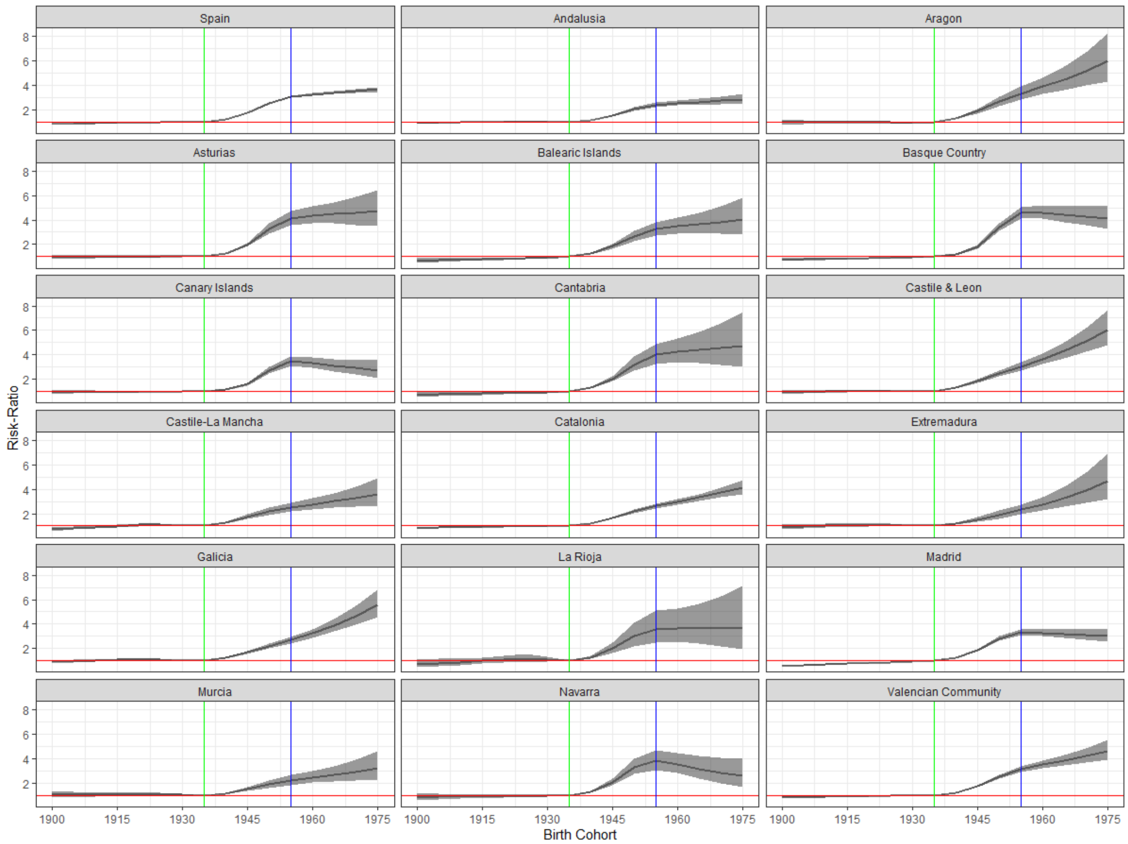

Figure 7. Cohort effects of lung cancer mortality for females across autonomous communities of Spain relative to the 1935 cohort, depicted in a vertical green line (Source: author´s calculations based on INE).

To explore the association of the regional divergence of recent cohorts with some macro-level factors we ran a set of separate seven linear regression models with a single predictor (instead of merging them into a single model we tested some ecological association due to the small number of observations). The difference in the log of the risk ratio of cohorts born between 1975 and 1955 was the outcome variable. This was based on the results of the cohort major model (since log differences of only non-linear cohort risk ratios would have produced invalid results). In this case, a positive value of change in risk indicated an increase in mortality, and those with a negative value an improvement (decrease) in mortality over those years. More details can be found in Table 2A in the corresponding Appendix.

The linear models indicated that the proportion of females with higher education (the variable with the highest correlation), log GDP Per Capita, and the difference of regular smokers among females in the 2003-17 period were the only factors with a statistical significance below 0.10: in all three scenarios, they were negatively correlated, with better GDP, more variation in smoking (less regular smokers) and education associated with lower mortality. A given region with a share of females with higher education five percent higher compared to another region would have a lower relative risk by 0.175. A region with five percent fewer smokers would have a lower relative risk by 0.25. We have to mention that GDP per Capita and Education are structural variables when compared to smoking prevalence, it can be said they have greater inertia over time. Neither Per Capita Health expenditure in 2017 nor their variations (absolute and relative) in the 2003-17 period were significant below 0.1, or the cross-sectional prevalence of female regular smokers in 2017 were associated with the variation in lung cancer mortality risk across younger cohorts.

Variable	**Intercept**	**Slope Estimate**	**Adjusted R^2**	**P-Value**
Per Capita Health Expenditure in 2017 (Euros)	-0,0699	0,0002	-0,05	0,74
Log GDP Per Capita in 2017 (Euros)	7,5765	-0,7320	0,14	0,07
Prevalence of Smoking in 2017 (in %)	0,6892	-0,0252	0,06	0,16
Females with Higher Education (in %)	1,5218	-0,0352	0,25	0,02
Variation in Regular Smoking among females between 2003-17 (in %)	0,4039	-0,0501	0,28	0,02
Variation in Per Capita Health Expenditure 2003-17 (in %)	-0,0542	0,0059	-0,03	0,51
Variation in Per Capita Health Expenditure 2003-17 (in Euros)	-0,0110	0,0005	-0,04	0,57

Table 1: linear association between macro-level variables and variation in lung cancer mortality risks among cohorts born between 1955 and 1975 by region (Source: author´s calculations based on INE).

5. Discussion

This study consisted of a descriptive analysis of female mortality attributed to lung cancer across birth cohorts in Spain, exploring national and regional trends comprehending 40 years of analysis. The results indicate that age-standardized mortality in all regions increased between 1980 and 2019. Linear effects on mortality presented the same pattern. In some cases, like Madrid, the increase in mortality occurred right from the beginning of the analyzed period. The region where the capital is located had one of the highest purchasing powers of Spain and it is possibly the place where smoking was first adopted as a widespread habit in the country. This also could explain why in other regions, like Galicia and Extremadura, the increase in mortality was only observed since the early 2000s. Apart from late adoption, it might be possible that the increase in drug-related mortality that Spain experienced during the 1980s and 1990s which peaked during that period and the resultant strong anti-drug campaigns (Fuente et al., 2006; Miguel-Arias et al., 2016; Sánchez-Niubò et al., 2009) might have a splash effect on the consumption of other substances such as tobacco as well. That could also explain the presence of non-linear period effects during that period.

We also tried to identify factors associated with regional divergences of mortality among younger cohorts (born between 1955 and 1975), given that previously the patterns seemed to be convergent. Before that point, in all autonomous communities, the relative risk of dying tended to decrease for cohorts born before 1935, then increase for the cohorts who were born between the years 1935 and 1955, who arguably were the ones most exposed to the expansion of smoking in Spanish society.

A previous study (Franco et al., 2002) suggested that female cohorts born in 1955 were the ones with the higher relative risks of dying from lung cancer in Spain, albeit it did not indicate what happened beyond. We now know that at a national level, non-linear cohort relative risks stalled after that point, albeit the increasing overall (linear) mortality trend continued. In most communities, such as Madrid or the Basque Country the relative risk among cohorts was contained (around the cohorts born near 1935). This goes on par with a previous study, which supports similar findings for US and the high-income part of Europe (Wensink et al., 2020). However, this was not the case for other communities, such as Galicia or Castile & Leon, whose younger cohorts kept a mortality risk above their respective average trends.

While these diverging cohort trends could be related to the role of those autonomous communities in dealing with and having control of their health policies, the absence of a relationship between lower mortality across younger cohorts and a higher Per Capita Health Expenditure could be indicative that changes may be more associated with other structural factors instead, such as education or income (as proxies of general social standing), indicating overall habits who might result in less exposure to the condition. There is also a significant relationship between a decrease in the prevalence of regular smoking and a decrease in the relative risks of dying from lung cancer: this might be an indication that such behavior (implying that some autonomous communities had fewer regular smokers and others more over the last 15 years) can also be related in those risk divergences. Unfortunately, the small number of observations (18, considering the autonomous communities and the national average) impeded a regression analysis that considered multiple factors, forcing us to look into multiple but singular linear correlations between cohort mortality and those factors.

Among other limitations, we have to consider that we were unable to follow migration patterns, which may result in certain population selection when analyzing mortality (albeit we believe that not enough to change the overall trends that we identified). We have to delve deeper to establish which the drivers behind the differences are across autonomous communities from a causal perspective, and also why the risk across cohorts varies in each autonomous community: maybe the overall expenditure in health is not an accurate indicator by itself when addressing the performance in regards to lung cancer mortality, but specific parts of such budget (destined to preventive campaigns) could be. Furthermore, as we mentioned in the methods section, it has to be considered that, not all lung cancer deaths are due to the direct consumption of tobacco, which could not be identified with the data sources analyzed in this paper, due to the lack of supporting information for the whole period. However, as we also mentioned in the methods section, the main interest of this study was not to establish smoking-attributed mortality but to define the divergent risk that different generations of women face concerning lung cancer as a whole. Also, the role of environmental factors (passive exposure to tobacco smoking) in lung cancer mortality (Lee et al., 2000) is unclear in the analyzed data as well.

We have to remind that since the chosen modeling strategy is dependent on the prior allocation of the drift, the results that we found in this paper are dependent on that particular allocation. However, the figures based on a cohort-major parameterization mostly supported similar conclusions. Due to the strong values of the linear trend, and the scarcity of non-linear period effects (apart from the mentioned non-linear effects during the 1990-2000 period in some regions), we thought inserting the drift in the period dimension offered a clear visualization of the non-linear cohort effects (for instance, as shown in Trias-Llimós et al., 2017).

The findings of this study seem to suggest that female lung cancer mortality is increasing in most regions of Spain (or at least linearly). For some authors, the growing trend in female lung cancer mortality could be considered an epidemic (A. Cayuela et al., 2007; Estève & Coleman, 2009; López-Campos et al., 2014; MacRosty & Rivera, 2020). Determining the threshold of incidence to consider a particular phenomenon an epidemic is a complicated and delicate task and exceeds the purposes of this study. However, we can say that while the linear trends are increasing (and this also stands true if we arbitrarily consider that cohort effects might be linear as well), the non-linear cohort patterns in some autonomous communities might be an encouraging sign that this could be reversed in the not-so-distant future.

It is clear that in Spain some generations of females are more susceptible to die than others because of lung cancer and smoking, due to previous behaviors that were adopted during the second half of the 20th century and part of the 21st century as well. But also, on occasion, the generations that are more susceptible to dying from lung cancer do change across autonomous communities, and structural and behavioral aspects may be playing a part in such distinction. Therefore, this study is a reminder that space not only is relevant from a period perspective to analyze mortality, but also from a cohort perspective as well, and cohort analysis is a useful tool when addressing the consequences of such historical processes.

Appendix B: Chapter 3

Figure 1A: Map of Spain by Autonomous Communities (used for this essay)

Legends Key: 1 (Andalusia), 2 (Aragon), 3 (Asturias), 4 (Balearic Islands), 5 (Canary Islands), 6 (Cantabria), 7 (Castile and León), 8 (Castile-La Mancha), 9 (Catalonia), 10(Valencian Community), 11 (Extremadura), 12 (Galicia), 13 (Madrid), 14 (Murcia), 15 (Navarra), 16 (Basque Country), 17 (La Rioja). Note: Ceuta and Melilla were excluded from the analysis of this paper.
Source: Author's elaboration

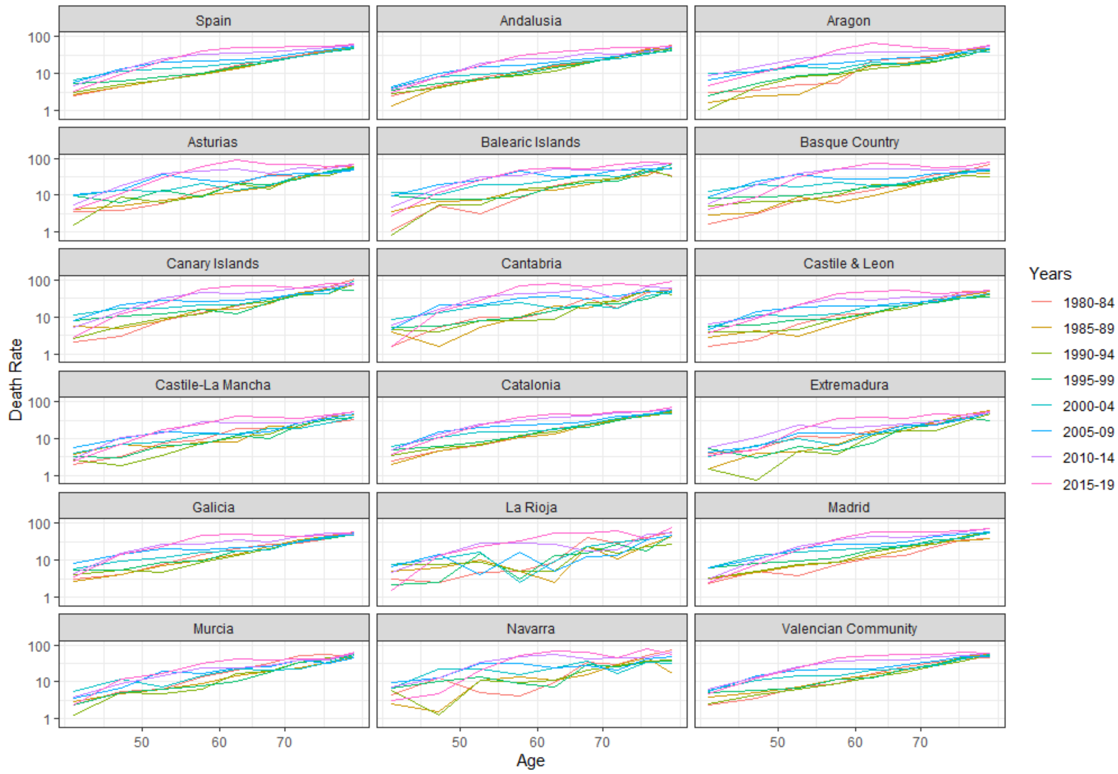

Figure 2A: Period-by-Age lung cancer death rates in Spanish females by autonomous community, 1980-2019 (Source: author´s calculations based on INE).

Figure 3A: Age-by-Period lung cancer death rates in Spanish females by autonomous community, 1980-2019 (Source: author´s calculations based on INE).

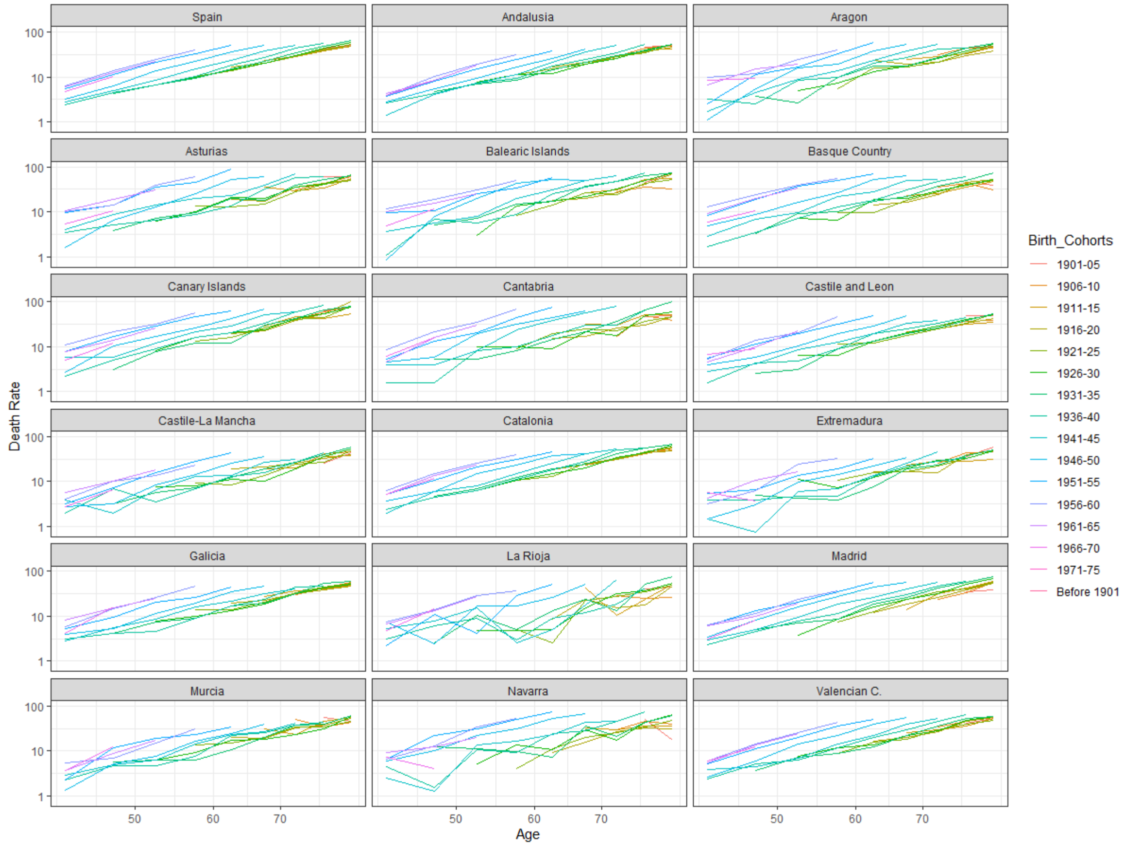

Figure 4A: Cohort-by-Age lung cancer death rates in Spanish females by autonomous community, 1900-1975 (Source: author´s calculations based on INE).

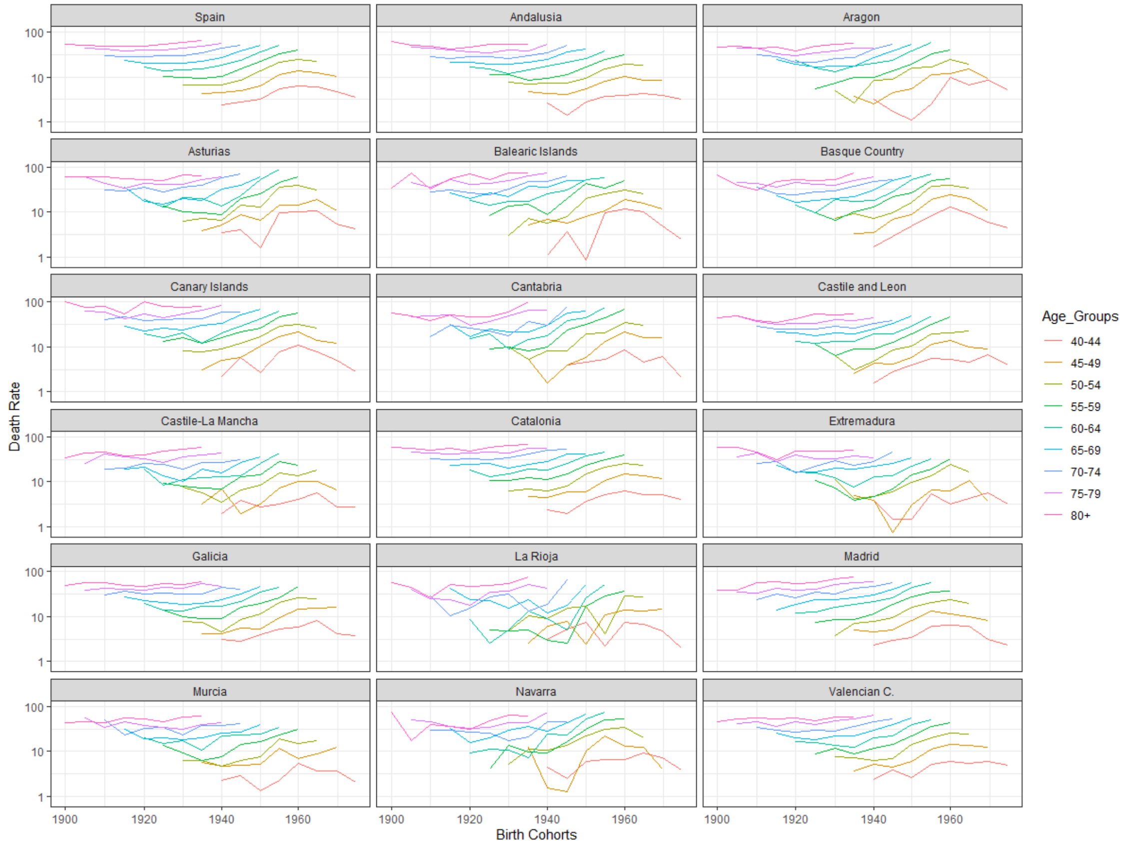

Figure 5A: Age-by-Cohort lung cancer death rates in Spanish females by autonomous community, 1900-1975 (Source: author´s calculations based on INE).

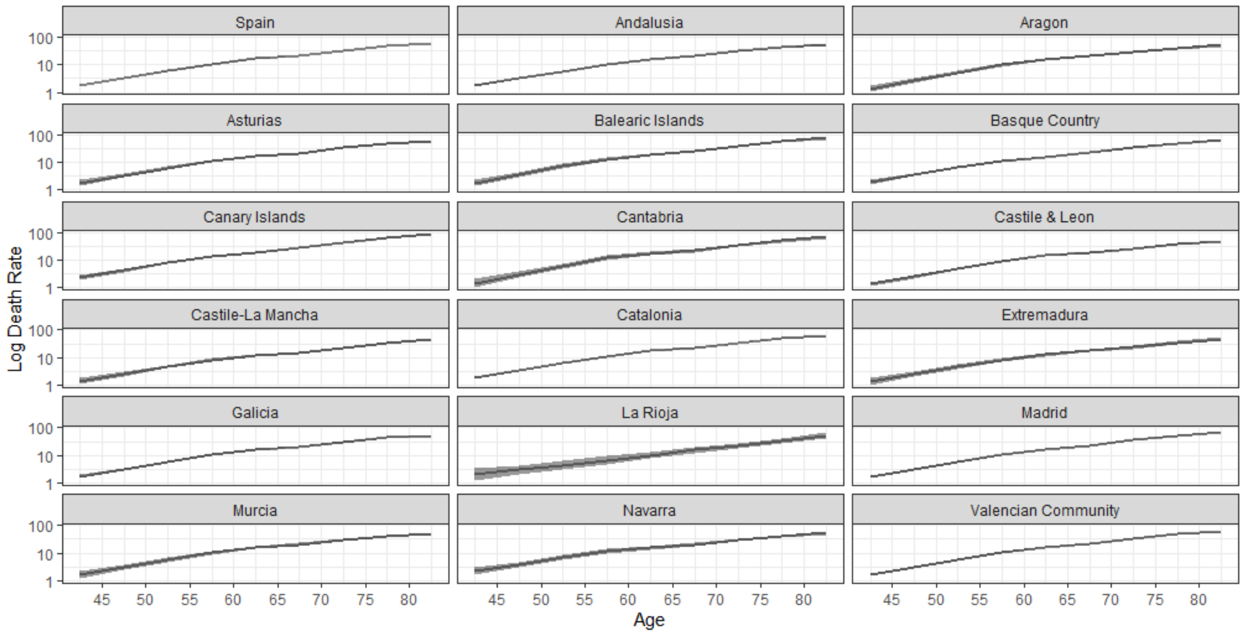

Figure 6A. Age effects (age-specific log death rates) of lung cancer mortality for females for the 1935 birth cohort across autonomous communities of Spain (Source: author´s calculations based on INE).

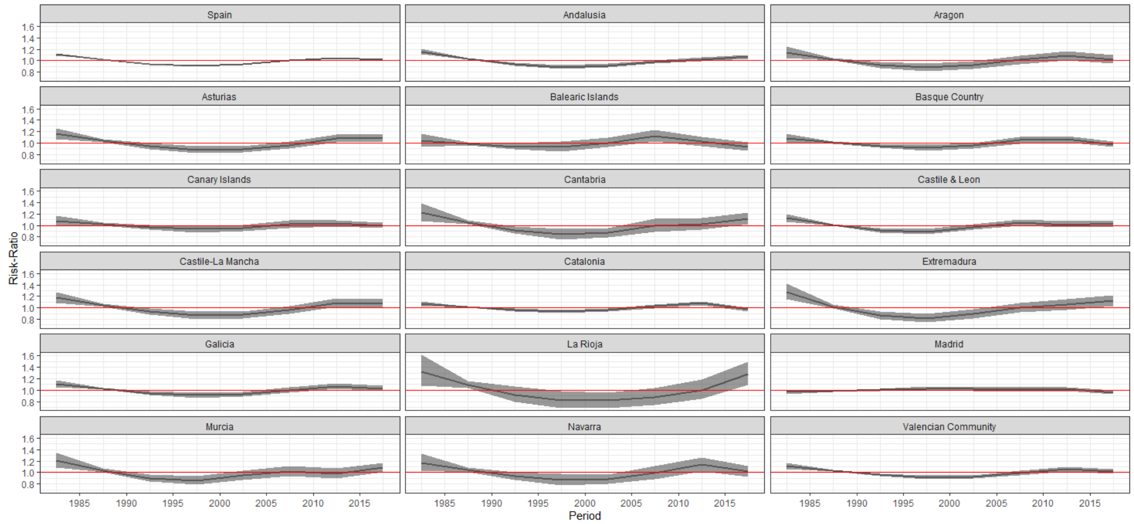

Figure 7A. Non-linear Period effects of lung cancer mortality for females across autonomous communities of Spain compared to the average trend (Source: author´s calculations based on INE).

	5 year Periods	1980-1984	1985-89	1990-94	1995-99	2000-04	2005-09	2010-14	2015-19
	Midpoint	1982.5	1987.5	1992.5	1997.5	2002.5	2007.5	2012.5	2017.5
Age Groups	Midpoint	Birth Cohorts (Midpoint)							
40-44	42.5	1940	1945	1950	1955	1960	1965	1970	1975
45-49	47.5	1935	1940	1945	1950	1955	1960	1965	1970
50-54	52.5	1930	1935	1940	1945	1950	1955	1960	1965
55-59	57.5	1925	1930	1935	1940	1945	1950	1955	1960
60-64	62.5	1920	1925	1930	1935	1940	1945	1950	1955
65-69	67.5	1915	1920	1925	1930	1935	1940	1945	1950
70-74	72.5	1910	1915	1920	1925	1930	1935	1940	1945
75-79	77.5	1905	1910	1915	1920	1925	1930	1935	1940
80-84	82.5	1900	1905	1910	1915	1920	1925	1930	1935

Table 1A: Period-by-Age tabulations of lung cancer death rates in Spanish females by autonomous community, 1980-2019.

Autonomous Community	Variation in log Relative Risk of lung cancer between 1955 and 1975 cohorts (in Risk Ratio)	Log GDP Per Capita. 2017 (in Euros)	Per Capita Expenditure in Health. 2017 (in Euros)	Per Capita Expenditure in Health. 2003 (in Euros)	Proportion of females with higher education (in %)	Difference in Expenditure between 2003 and 2017 (in Euros)	Prevalence of female smokers. 2017 (in %)	Prevalence of female smokers. 2003 (in %)	Difference of regular smokers between 2003 and 2017 (in %)
Spain	0,178	10,053	1410.77	952.25	36.1	458.52	18.02	21.65	3.63
Andalusia	0,164	9,755	1199.24	904.91	31.2	294.33	18.23	24.53	6.3
Aragon	0,585	10,122	1582.94	1067.6	38	515.34	21.66	23.39	1.73
Asturias	0,130	9,927	1640.19	1060.66	37.4	579.53	15.43	19.17	3.74
Balearic Islands	0,223	10,127	1440.7	878.79	34.3	561.91	20.1	26.4	6.3
Basque Country	-0,111	10,310	1692.73	1048.16	44.6	644.57	25.22	29.92	4.7
Canary Islands	-0,236	9,856	1454.32	994.54	31.7	459.78	13.08	15.27	2.19
Cantabria	0,176	9,958	1503.42	1160.4	40.7	343.02	8.84	9.99	1.15
Castile & Leon	0,694	9,981	1572.55	1022.78	35.5	549.77	14.99	12.52	-2.47
Castile-La Mancha	0,364	9,802	1447.19	935.55	29.3	511.64	16.58	10.28	-6.3
Catalonia	0,452	10,227	1443.11	959.78	37.9	483.33	16.53	20.11	3.58
Extremadura	0,706	9,709	1626.94	1056.25	28.1	570.69	17.42	21.72	4.3
Galicia	0,735	9,942	1483.64	980.35	34.6	503.29	16.66	16.95	0.29
La Rioja	0,032	10,145	1434.45	996.89	39.3	437.56	14.75	19.89	5.14
Madrid	-0,084	10,371	1258.89	868.9	43	389.99	23.69	31.1	7.41
Murcia	0,371	9,876	1591.37	972.03	31.6	619.34	16.18	18.71	2.53
Navarra	-0,392	10,258	1651.05	1085.53	45.6	565.52	27	37.03	10.03
Valencian Community	0,394	9,918	1440.2	917.77	35.3	522.43	14.34	17.78	3.44

Table 2A. Selected social and economic characteristics of autonomous communities of Spain. (Source: author´s calculations based on INE)

Chapter 4: Decomposition of life expectancy differentials with (and without) conditions by educational attainment for major groups of causes in contemporary Spain: where is the advantage?

Abstract:

Introduction: Healthy life expectancy is higher among individuals with higher socio-economic standing. However, it is unclear whether such advantage is attributable to longer (i.e., mortality advantage) or to healthier (morbidity advantage) lifespans across different health conditions.

Objective: Estimate the contribution of mortality and morbidity components in differences in condition-free life expectancies (CFLE) and life expectancy with conditions (LEWC) for five major groups of conditions by sex and educational attainment, instead of using a global indicator of morbidity.

Methods: Using the Sullivan Method, we computed remaining life expectancies at age 40, CFLE, and LEWC and applied a stepwise decomposition technique, using data from health surveys along with mortality files, in a cross-sectional analysis.

Results: An educational gradient was present in almost all conditions, with different intensities. For females, morbidity was the main contributor to educational differences in health expectancies. For males, the drivers behind higher health expectancies for high-educated males were evenly distributed across mortality and morbidity.

Keywords: Aging, Social Inequalities, Spain, Morbidity, Mortality.

1. Introduction, research questions, and objective

A deeper understanding of the dynamics of socioeconomic disparities in the health burden of a population is key to identifying and addressing inequalities in health. Despite life expectancy has increased substantially across the globe due to medical breakthroughs, nutritional improvements, better sanitation, and the adoption of healthier behaviors (Deaton, 2005; Fogel & Costa, 1997), this process has shown important disparities across different socioeconomic groups (i.e. Hummer & Lariscy, 2011; Link & Phelan, 1995; Montez et al., 2012). Spain has been no exception to such a trend and is currently one of the countries with the highest longevity in the world, although these improvements tend to favor the wealthier or more educated individuals in the population (Permanyer et al., 2018; Regidor et al., 2015, 2016). The so-called cardiovascular revolution (Vallin & Meslé, 2004) entailed a transition from high cardiovascular disease mortality to increased survival attributed to those conditions in Western countries. This has led to a great improvement in adult mortality rates, setting the tone for a stronger emphasis on the quality of survival and the prevalence of chronic conditions and ailments, both lethal and non-lethal.

The relationship between having a longer lifespan and a healthier lifespan (expressed in terms of disability, morbidity, and prevalence of a disease or any other given indicator) differs by socioeconomic status. However, these processes are not entirely understood yet. While several studies have evidenced that higher-educated individuals have longer and healthier lifespans in Spain (Solé-Auró et al., 2020; 2022; Gumà et al., 2020, among others), the demographic drivers behind such differences are unknown. Are healthier lifespans just the result of lower overall morbidity? Do these mechanisms operate similarly across socioeconomic status, sex, and health conditions? The objective of this paper is to identify whether the advantage of healthy life expectancy among higher educated people in Spain is due to a longer lifespan (reflecting mortality advantages), a healthier lifespan (morbidity advantages), or a combination of both (double advantage). We use educational attainment as a proxy for social standing and analyze a set of common conditions that affect the overall health of the population across their life course.

2. Background

Different theories have been proposed to analyze the dynamics of the relationship between mortality and morbidity, without a single vision imposing over the others (Gruenberg, 1977; Fries, 1984; Manton, 1982; Myers and Manton, 1984). This relationship between the time spent with good health and overall longevity, however, is not as straightforward as it could be expected when looking into differences by sex and socioeconomic status. In what is known as the health-survival paradox (Di Lego et al., 2020; Van Oyen et al., 2013), females have a longer life expectancy than males, but they also spend a larger proportion of their lives in poor health in terms of the prevalence of chronic conditions, morbidity, and disability.

In addition to gender differences, there is also a social gradient: individuals with higher social standing live longer and healthier lives when compared to their counterparts with a lower socioeconomic position. The Fundamental Cause Theory proposes a dynamic relationship between socioeconomic status and health, suggesting that there is a clear link between lower social standing and many negative health outcomes that can manifest themselves through a variety of everchanging mechanisms over the life course, but also over time (Link & Phelan, 1995). Better education tends to be correlated with having a higher social standing, which in turn is associated with having more opportunities to make healthier life choices, as well as greater capability to procure goods and services to maintain good health and lesser exposure to risky behaviors and environments (Cutler et al., 2006; Marmot, 2005). Previous research highlighting this link has been conducted in many countries, such as the US (i.e, Hayward et al., 2015; Montez et al., 2012; Nusselder et al., 2005), Europe (i.e. Mackenbach, 2012; van Raalte et al., 2014; Zazueta-Borboa et al., 2023) and Latin America (i.e. Beltrán-Sánchez & Andrade, 2013; Bramajo & Grushka, 2020; Sandoval & Turra, 2015), to name a few examples.

In Spain, people with higher social standing also have healthier lives (Gumà et al.,2019; Solé-Auró et al., 2020, 2022). This has also been found in specific studies of certain regions, such as Catalonia (Cambois et al., 2019; Solé-Auró & Alcañiz, 2015; Walter et al., 2016). More specifically, the educational gap in health expectancies has been estimated in the country, whether using global indicators of health or broad ad-hoc definitions of poor health (Cambois et al., 2016; Solé-Auró et al., 2020, 2022; Solé-Auró & Alcañiz, 2016). In these studies, aggregate indexes (which we refer to here broadly as health expectancies) such as healthy life expectancy (HLE) or condition-free life expectancy (CFLE) have been computed to determine the total health burden in a population over the lifespan. However, the drivers of this health advantage are unclear: given that health expectancy is not independent of life expectancy (van Raalte and Nepomuceno, 2020), it is not obvious to what extent the advantage of the higher educated in Spain (in terms of health expectancy) is the result of lower mortality or lower morbidity. This is relevant because interventions and policies aimed at reducing health inequalities require accurate measurement and estimation. Determining the extent to which disparities in the time lived with a condition is the result of a longer/shorter or a healthier/unhealthier life expectancy is important for a more comprehensive assessment of the overall impact and implications of these disparities.

Furthermore, the health expectancies estimated in the aforementioned studies were generally computed using aggregate, catch-all indicators, such as the Global Activity Limitation Indicator, better known as GALI (Van Oyen et al., 2018), or the presence of limitations in instrumental activities of daily living or IADL (Crimmins et al., 2009; Manton et al., 2006). Few studies have estimated gaps in health expectancies for different major groups of disease causes in other countries such as the US or Belgium (Nusselder et al., 2005; Nusselder & Looman, 2004; Yokota et al.,2019). In Spain, previous studies analyzing disparities in health expectancies have considered different definitions of poor health (Solé-Auró et al., 2022; Solé-Auró & Alcañiz, 2015; Walter et al., 2016) or the presence of one or multiple diseases to establish a poor health status, rather than considering a cause-specific analysis (Solé-Auro et al., 2020; Cleries et al., 2009; Zueras & Rentería, 2020).

However, not every condition or group of conditions has the same social and sex gradient when addressing health disparities. For instance, it has been widely acknowledged that mood and mental disorders such as anxiety or major depression affect more females than males (Blazer & Hybels, 2005; Cardila et al., 2015; Gispert et al., 1998). The same occurs with other conditions such as coronary heart disease (a cardiovascular condition), arterial Hypertension, or Diabetes mellitus (Cordero et al., 2009; Gao et al., 2019; Maas & Appelman, 2010; Mauvais-Jarvis, 2018) where males have a higher prevalence. While some of these conditions are non-lethal per se, they may be associated with multiple negative health outcomes due to their impact on quality of life, including death. Moreover, different conditions affect populations with particular intensity at different stages of life.

Therefore, examining the education gap separately for each cause can provide a broader perspective on how health inequalities operate in Spain. As Nusselder and Looman (2004) point out, knowing which age groups and which diseases contribute the most to differences in population health helps to identify drivers and determinants of such differences is helpful to produce policies to eventually reduce them. Given these gaps in the literature, we wanted to determine whether, for different diseases or health conditions, the health expectancy advantage of the higher-educated individuals (or the disadvantage of their lower-educated counterparts) in Spain was due to a mortality advantage, a morbidity advantage, or both. We did this by considering five major groups of conditions, separately by sex. Life expectancy with and without each chronic condition was estimated using the Sullivan method.

3. Data source and methods

3.1 Data Sources

We relied on a combination of mortality and morbidity data sources to produce the necessary estimates for this study in a given period. For mortality data, we used both a mortality file and the population exposures provided by the National Institute of Statistics (Instituto Nacional de Estadística in Spanish, also known by its acronym INE) for the 2014-16 period. INE used a matching algorithm linking registered deaths to population databases, including censuses, municipal population registers, the Ministry of Education, and the Public State Employment Service, to obtain and provide overall death counts according to educational attainment. The INE also provided the total estimates of population by sex, age, and educational attainment (in a series of different categorical values) in Spain for the analyzed years. This combination of sources has been used successfully in previous studies in the past (e.g., Permanyer et al., 2018).

To obtain the diagnosed prevalence of the selected chronic conditions we used the Spanish National Health Survey (or ENSE, given its acronym in Spanish), which has been conducted periodically from 1987 to 2017, and the Spanish data from the European Health Interview Survey (EHIS). This information is freely available from the Spanish Ministry of Health. Those surveys are cross-sectional, multiple wave representative studies covering the general health situation in Spain at the national and regional (Autonomous Communities, the main administrative unit in Spain) levels among the non-institutionalized population. Hereafter, prevalence refers to the prevalence in the non-institutionalized population. The ENSE and the EHIS are both conducted by the INE. However, the latter is coordinated by Eurostat, with an adapted questionnaire to allow the main indicators of both surveys to be comparable over time. The questionnaires were administered to individuals aged 15 and over living in private households across Spain. Questionnaires collect sociodemographic information and health conditions and determinants of the population, including health service use and lifestyles among others. We worked with five major groups of chronic conditions for our estimations, based on their larger prevalence across the Spanish population: Cardiovascular diseases (CVD) ('High Cholesterol', 'Myocardial Infarction', 'Stroke', and 'other Heart Diseases'); Diabetes; Arterial Hypertension (for practical reasons, we will refer to it simply as 'Hypertension'); Mental Disorders ('Depression', 'Anxiety' and 'other Mental Disorders'); and Respiratory Diseases ('Asthma' and 'Chronic Obstructive Pulmonary Disease', COPD). To consider if the respondent had been diagnosed with the selected condition, we used a criterion similar to the one adopted by Zueras and Rentería (2020). This criterion considered that the respondent had to have the specific health condition in the last 12 months and it had to be diagnosed by a physician as well (however, the condition is self-reported in both situations). The details of the questionnaires for each category can be found in the appendix in Table A1. As discussed by Zueras & Rentería (2020) uneven healthcare access may result in problematic reporting on health conditions. However, Spain has a low percentage of unmet medical needs in terms of diagnosis or treatment (OECD, 2017), so we expect that underreporting errors may be small.

To make the data as robust as possible, we pooled the 2012 and 2017 ENSE survey waves and the 2014 EHIS survey results, assuming that the prevalence estimates were the average for the period analyzed and that abrupt changes in prevalence and diagnosis from year to year are unlikely, given the inertial nature of demographic change. Complementarily, we also pooled mortality data to make a reasonable comparison, centered on 2015.

Educational level was split into three groups: individuals with lower educational attainment (who have completed at most the first cycle of secondary education, which corresponds to level 2 in the normalized ISCED-2011 classification), individuals with mid education (levels 3 and 4 in ISCED-2011 classification) and individuals with higher educational attainment (ISCED-2011 level 5, having completed short-cycle tertiary education, and above). Age 40 was defined as the starting point for the estimates because the prevalence of most conditions was negligible before that age.

3.2 Methods

The life table was top truncated at age 85 (given that sometimes prevalence is hard to estimate beyond that point without some strong modeling assumptions). As a usual practice, we smoothed the death rates in five-year age groups by using a one-dimensional Poisson P-spline, available in the *MortalitySmooth* package (Camarda, 2012).

First, as an exploratory analysis, we plotted age-specific death rates and age-specific prevalence for each condition, separately by sex and education. With these components, we produced a set of life tables (separately by sex and educational attainment) to estimate the remaining life expectancy at age 40 (Preston et al., 2001). The five-age group prevalence estimates of each chronic condition, by sex and education, were applied to the corresponding life table to obtain the condition-free life expectancies (CFLE) at age 40, using the Sullivan method, whose purpose is to compute the proportion of time lived with or without a given condition (Sullivan, 1971) and is the most widely used method for cross-sectional data. We also estimated the life expectancy with the condition (LEWC), representing the number of years lived with the examined condition, which is simply the difference between LE and CFLE. We calculated 95% confidence intervals (CI) for the CFLE and LEWC using the suggested procedure by Jagger et al. (2014). However, given the large population size used for mortality data (a minimum exposure above 15 million for each combination of sex and educational attainment), the range of lower and upper estimates for overall life expectancy was minimal, and as a result, we only presented the point estimate. By using the Sullivan method, we are assuming that the mortality information is constant for all educational groups, given that we do not have cause-specific mortality by education and, therefore, we cannot establish an education gradient to condition lethality, if any. Although this is a limitation of this study, as described below, we believe that this study contributes to a deeper understanding of social inequalities in health expectancies.

Second, we use CFLE and LEWC - aggregate measures of population health with two parameters: mortality (longevity) and morbidity (prevalence) to establish the net contribution of prevalence on the change of a given condition a decomposition procedure is necessary (Nusselder & Looman, 2004; van Raalte & Nepomuceno, 2020). The decomposition can be applied to different moments for a given population (considering compositional changes over time), or to two populations at a single moment (considering different compositions between compared groups). Such techniques identify the contribution of morbidity and mortality components (Andreev et al., 2002; van Raalte and Nepomuceno, 2020), allowing us to appropriately determine the role of each one in the obtained difference in two health expectancies, and which age groups are the ones that concentrate such contributions.

In this case, we relied on the decomposition algorithm of stepwise replacement first described by Andreev et al. (2002). This technique changes the selected components (in this case, mortality and morbidity) sequentially and recalculates the index function to obtain the contribution of each parameter to the aggregate result. Moreover, this procedure allows us to perform an age-specific decomposition for the differences in health expectancy into mortality and morbidity components. Such a procedure is already incorporated in the DemoDecomp package built by Riffe (2018).

The change in the number of years lived without the selected condition (CFLE) between populations 1 and 2 can be broken down as the sum of a mortality (longevity) component (MORT) and a morbidity (prevalence) component (MORB): that is: $CFLE_2$-$CFLE_1$ = MORT + MORB. In our case, populations 1 and 2 would represent the corresponding subpopulations by educational attainment. The final form of the technique is presented in Andreev et al., (2002).

Third, we present the results of these decompositions considering each educational gap. This is the difference between the middle-educated minus the low-educated, and the difference between the high-educated minus the middle-educated group, while the gap between the high-educated and the low-educated would simply be the sum of these two separate gaps. In addition, the value of each component is equal to the sum of their respective age-specific contributions, facilitating an age-specific decomposition.

This was done for each of the six conditions analyzed, for both males and females, and considering the gaps in CFLE and LEWC. Given that CFLE and LEWC are complementary measures, the contribution of morbidity to a given difference in CFLEs should be the opposite of the contribution of morbidity to the corresponding difference in LEWCs (since the prevalence used for one indicator is the complement of the other). For practical reasons, we present only the average decomposition differentials to visualize the contribution of each component. All visualizations in this study were done with ggplot2 package (Wickham, 2015), freely available in R software. All estimations, tables and figures are authors's calculations.

4 Results

4.1 Exploratory analyses

Firstly, we performed an exploration of the data sources (health surveys, mortality files, and population exposures). Table 1 presents the composition of the sample by sex, age, and educational attainment and the prevalence rates of the conditions analyzed, as well as the distribution of the mortality data by educational level and population exposures. The pooled sample included 47,024 observations with 55.3% identified as female, and a mean age of 59.7 years. Among the conditions studied, Hypertension and CVD had a similar average prevalence, of 31.8% and 32% respectively. Mental disorders followed them with a prevalence of 19.1% in the population, and Diabetes a 12%. Respiratory Diseases had the lowest prevalence, with 8.2%. The mortality file presented almost a million deaths, with the majority corresponding to individuals in the low education group, while the population exposures involved more than 61 million person-years (given that multiple years are pooled).

Variable	
Number of pooled observations in surveys (cases)	47024
Share of Males (%)	44.7
Age (mean)	59.7
CVD (%)	32.0
Diabetes (%)	12.0
Hypertension (%)	31.8
Mental Disorders (%)	19.1
Respiratory (%)	8.2
Low Education (average %)	17.6
Middle Education (average %)	56.0
High Education (average %)	26.2
Number of observations in mortality files (deaths)	942234
Low Education (%)	83.2
Middle Education (%)	8.9
High Education (%)	7.9
Population exposures (in person-years)	61076657
Low Education (%)	57.5
Middle Education (%)	17.4
High Education (%)	25.1

Table 1: Descriptive statistics for numeric variables of people aged 40 years or more (Source: author´s calculations based on INE, ENSE & EESE).

Figure 1 shows the age-specific prevalence of each group of conditions separately by sex and by educational attainment across the reported conditions. For males, educational differences in prevalence are small for most of the conditions. Divergences in Respiratory Diseases begin to be notorious from the age of 60 and persist thereafter. Diabetes presents small but persistent gradients across the life course. Mental disorders present the most marked differences in education at younger age groups, before converging at older ages. For females, the educational gradient is more pronounced across the life course. Inequalities are marked and persistent for almost all conditions, with the sole exception of Respiratory Diseases. Narrow differences between the middle and high educational groups are also found for CVD.

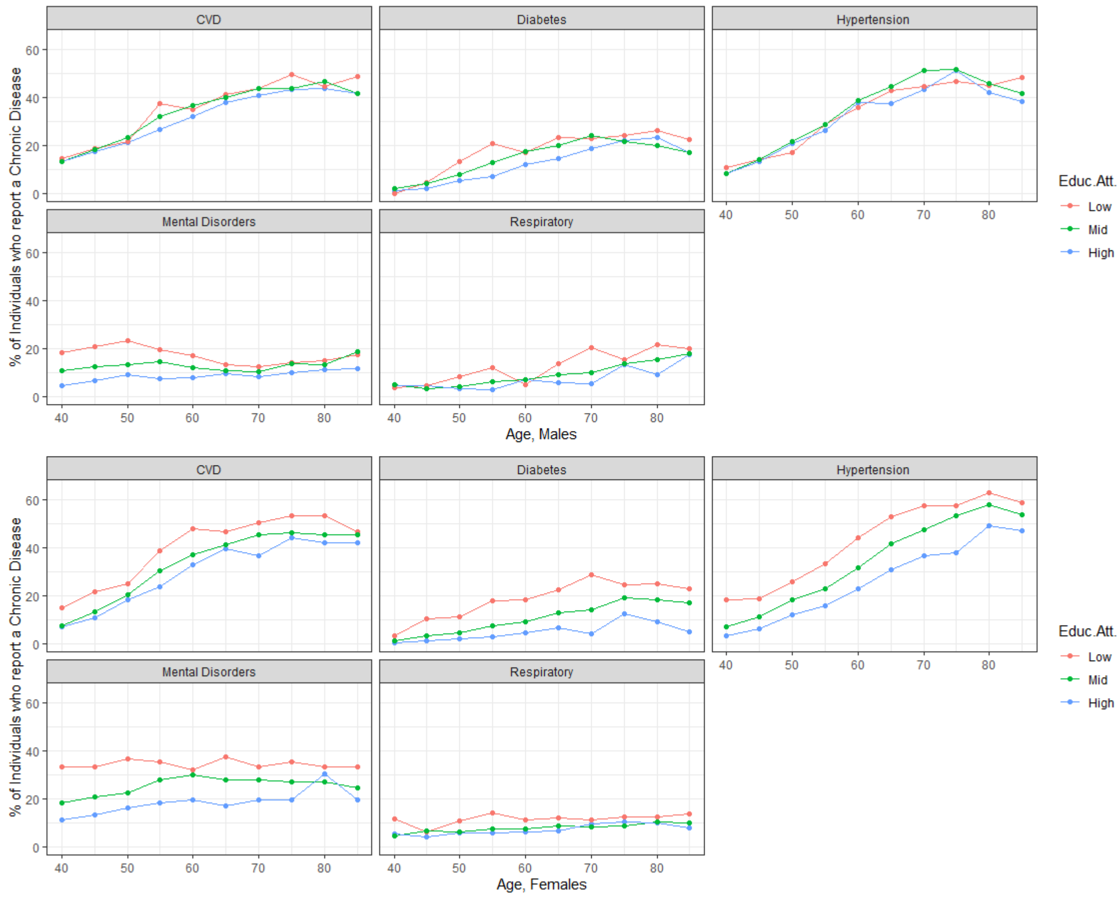

Figure 1: Age-specific prevalence of groups of conditions by educational attainment for ages 40 to 85+, separately by sex. Spain, 2012-2017 (Source: author´s calculations based on ENSE & EESE).

Figure 2 presents the age-specific death rates by educational attainment. While it is evident that low-educated individuals present the highest mortality rate, the initial advantage of high-educated individuals disappears around age 65 for females and age 75 for males. The figure shows a convergence between the high and middle educational groups.

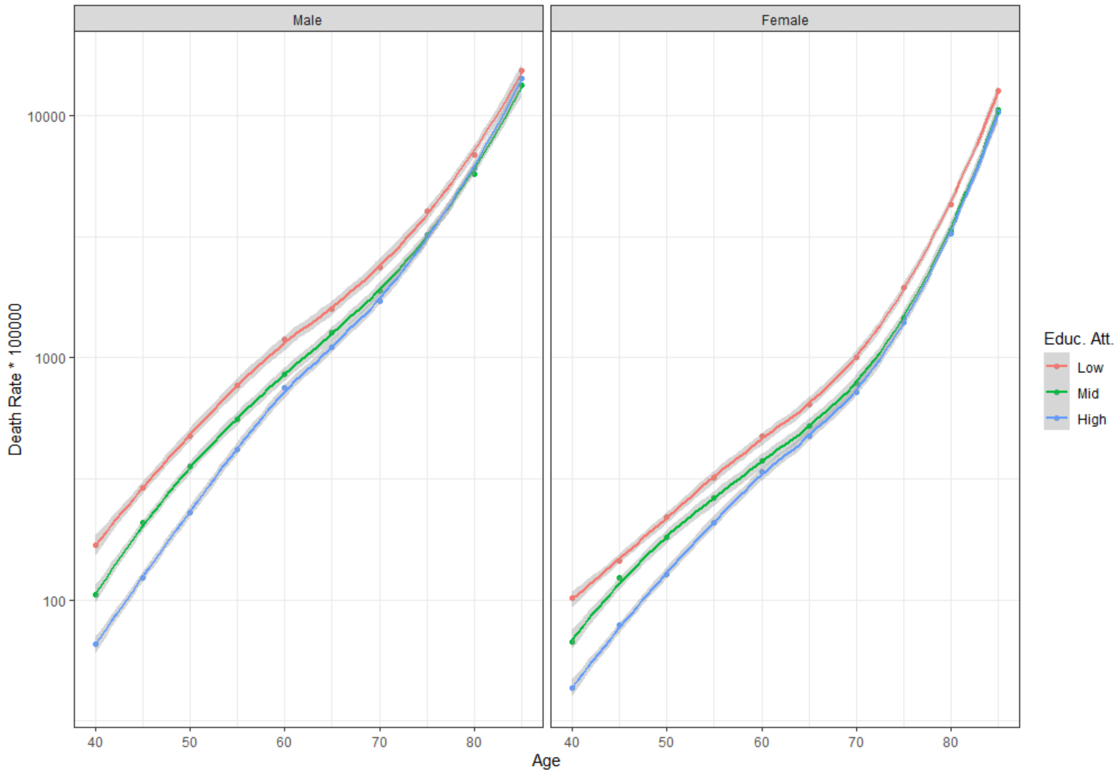

Figure 2: Death Rates (*100000) by Educational attainment for ages 40 to 85+, Spain, 2012-2017 (Source: author´s calculations based on INE).

4.2 Life expectancy, Condition-Free Life Expectancy (CFLE) and Life Expectancy with Condition (LEWC) at age 40

Table 2 presents estimates of the remaining life expectancy at age 40 and the CFLE computed with a 95% confidence interval (CI). This was done for the five selected conditions, by sex and by educational attainment. Results show that females had a higher life expectancy than males, regardless of their educational attainment, with a gap of more than 5 years in each case.

In absolute terms, higher-educated individuals presented a larger CFLE in all conditions. Complementarily, they also presented a lower LEWC. And the opposite can be said for the low-educated individuals: lower CFLEs by each group of causes and higher LEWCs, for males and females. We can also see that for some conditions, such as CVD or Respiratory Diseases, males had a lower CFLE than females. In some conditions, such as Hypertension and mental disorders, males with lower education had a slightly higher CFLE than their female counterparts; and females with high education presented values comparable to those of males with high education, but given their longer lifespan, their LEWC was almost twice as high.

For CVD, mental disorders, Diabetes, and Respiratory Diseases, the middle-educated presented a higher or similar LEWC than their low-educated counterparts. This implies that despite their longer CFLE, the middle-educated also live longer lifespans with these conditions than their low-educated male counterparts. For females, the LEWC for the middle and low-educated groups overlapped their confidence intervals for some conditions: CVD and Respiratory Diseases.

Indicator	Sex	*Males*			*Females*		
	Educational Attainment	*Low*	*Middle*	*High*	*Low*	*Middle*	*High*
	Life Expectancy	40.2	42.7	43.4	46.2	48.5	49.3
CFLE (without condition)	*CVD*	26.7 (25.8-27.5)	27.2 (26.8-27.5)	30.1 (29.5-30.8)	28.1 (27.2-28.9)	31.1 (30.8-31.5)	34.4 (33.4-35.5)
	Diabetes	33.6 (33.0-34.2)	34.6 (34.4-34.9)	38.3 (37.8-38.8)	37.7 (37.1-38.3)	41.3 (41.1-41.6)	46.7 (46.1-47.3)
	Hypertension	27.6 (26.8-28.5)	30.4 (30.1-30.7)	35.0 (34.4-35.6)	26.8 (26.0-27.7)	30.7 (30.3-31.0)	36.1 (35.1-37.1)
	Mental Disorders	33.1 (32.2-33.9)	34.7 (34.4-34.9)	38.3 (37.8-38.8)	30.3 (29.3-31.3)	34.5 (34.1-34.8)	40.0 (39.1-40.9)
	Respiratory Diseases	35.6 (35.1-36.2)	36.9 (36.7-37.1)	40.4 (39.9-40.8)	40.8 (40.2-41.4)	42.6 (42.3-42.8)	45.6 (45.0-46.2)
LEWC (with condition)	*CVD*	13.6 (12.7-14.5)	15.5 (15.2-15.9)	13.3 (12.6-13.9)	18.1 (17.3-19.0)	17.4 (17.1-17.8)	14.9 (13.8-15.9)
	Diabetes	6.6 (6.0-7.2)	8.1 (7.8-8.3)	5.1 (4.6-5.6)	8.5 (7.9-9.1)	7.2 (7.0-7.5)	2.6 (2-3.1)
	Hypertension	12.6 (11.8-13.4)	12.3 (12.0-12.6)	8.4 (7.8-8.9)	19.4 (18.5-20.2)	17.9 (17.5-18.2)	13.2 (12.2-14.2)
	Mental Disorders	7.1 (6.3-8.0)	8.0 (7.8-8.3)	5.1 (4.6-5.6)	15.9 (14.9-16.9)	14.1 (13.7-14.4)	9.28 (8.4-10.2)
	Respiratory Diseases	4.6 (4.0-5.1)	5.8 (5.6-6.0)	3.0 (2.6-3.4)	5.4 (4.8-6.0)	6.0 (5.8-6.2)	3.7 (3.1-4.3)

Table 2: Years of Life Expectancy, CFLE and LEWC (conditional to age 40), separately by cause, sex, and educational attainment (95% CI) (Source: author´s calculations based on INE, ENSE & EESE).

4.3 Decomposition of educational differences in CFLE and LEWC at age 40

Figures 3 and 4 show for each condition the contribution of mortality and morbidity, and the sum of both (total) to the CFLE and LEWC education gaps, respectively. Note that while the life table data used for each decomposition is the same, the area of the mortality component does not need not be the same for each condition, as we are decomposing weighted differences. The top half of each figure shows the male education gap and the bottom half the female gap. Results can be interpreted as it follows: for instance, the total CFLE educational gap of 2.03 years between the middle- and low-educated (M-L) males for CVD is the sum of 1.4 years of the contribution of a larger lifespan (mortality) and 0.63 years due to the contribution of a lower prevalence (morbidity). Therefore, a positive contribution of both components indicates that the CFLE of the reference group (in the example, middle-educated individuals) reflects advantages in both components: they live longer and healthier (considering this particular group of conditions).

CFLE differences between middle and low-educated males showed a greater contribution of the mortality component in all conditions. This mortality gap was larger than the one found for high and middle-educated males. On the contrary, for the latter educational groups, CFLE differences were mostly due to the contribution of morbidity, which was larger than the contribution of mortality. Diabetes and Mental Disorders presented some of the largest educational gaps in CFLE at all educational levels for males, and in these conditions, the morbidity component presented its largest specific contributions.

In contrast, for females (in the bottom half of Figure 3), the morbidity component was the main contributor to CFLE differences between the middle and low-educated for all groups of conditions except Respiratory Diseases. Similarly, the contribution of the morbidity component was also the main driver of differences between the high and middle-educated females.

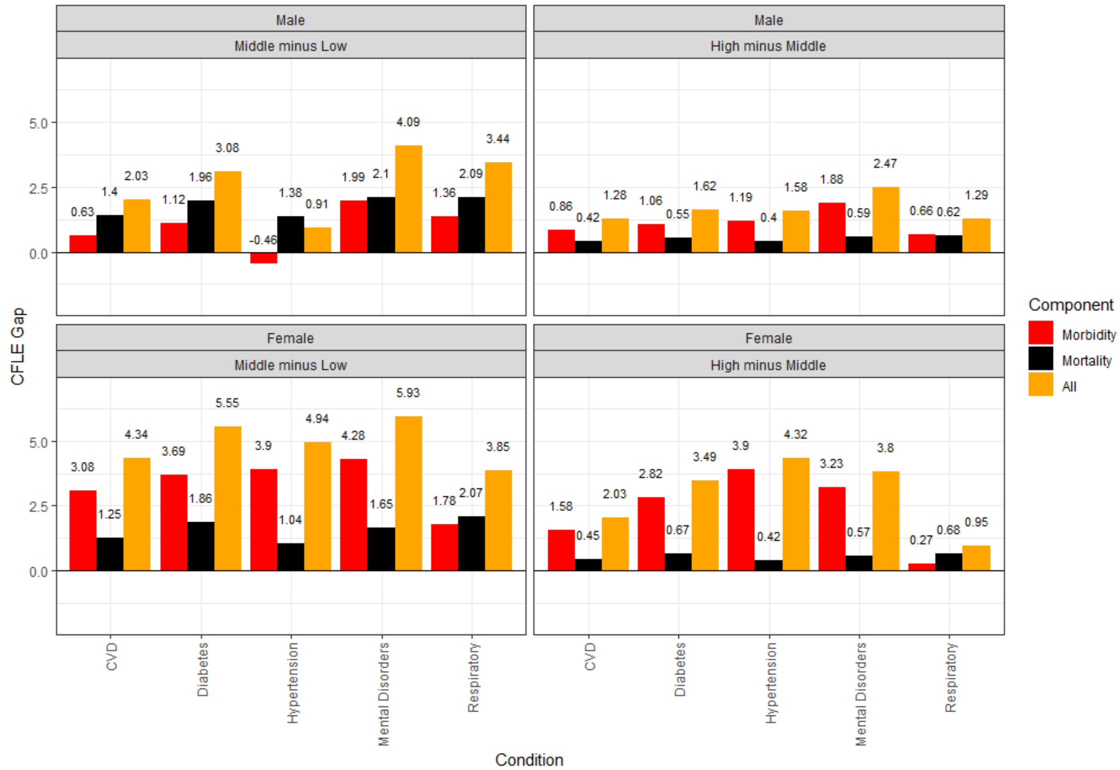

Figure 3: Contribution of Mortality and Morbidity into overall differentials in CFLE by sex and educational attainment, Spain, 2012-2017 (Source: author´s calculations based on INE, ENSE & EESE).

In Figure 4, in most cases the mortality component is smaller in magnitude than the morbidity component, meaning that morbidity explains to a larger extent the lower LEWCs of more educated individuals.

This implies that if mortality had been the same for all groups, the health gaps by education would have been even larger, for both males and females and particularly, for the gap between the middle and low-educated groups, where the contribution of mortality is more important. Thus, mortality masks part of the observed LEWC health gap. The only exceptions are the educational gaps between the middle and low education groups among males for CVD and Hypertension, where the total difference in LEWC is positive (0.46 and 1.57 years respectively). In these cases, middle-educated males (the reference group in this scenario) live more years with these conditions than low-educated males, and the decomposition analysis reveals that the mortality advantage is the component that is the main cause of this.

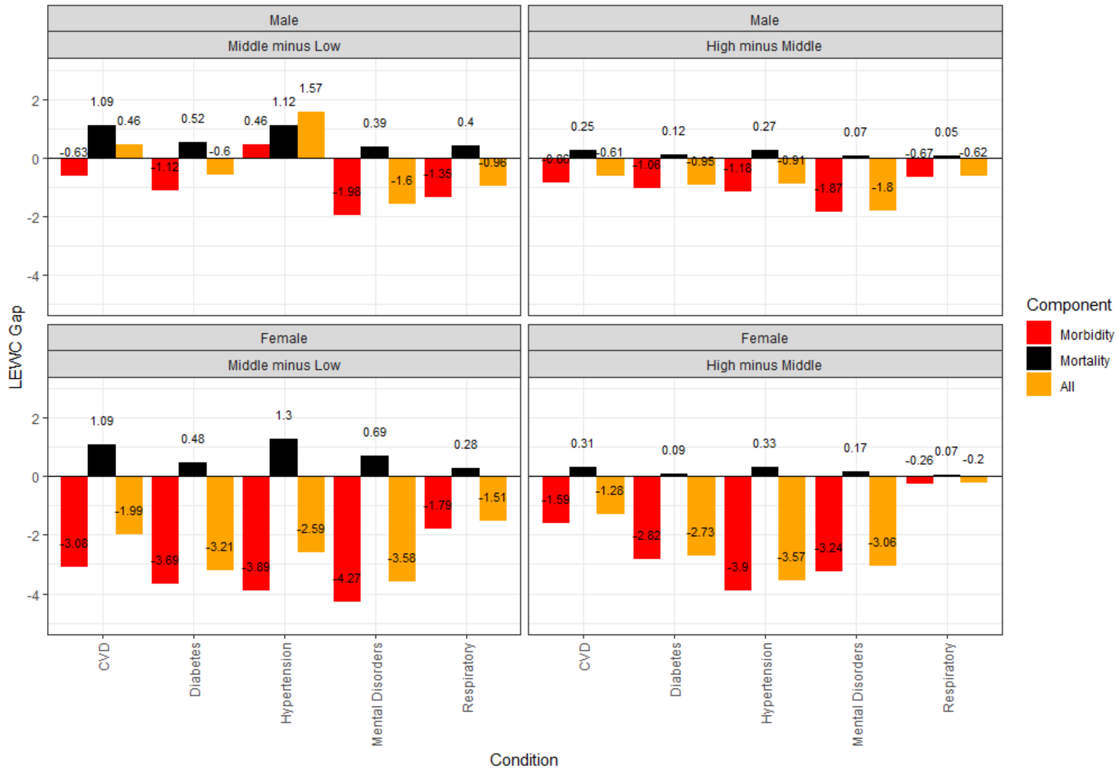

Figure 4: Contribution of Mortality and Morbidity into overall differentials in LEWC by sex and educational attainment, Spain, 2012-2017 (Source: author´s calculations based on INE, ENSE & EESE).

Figures 5 and 6 display the age-specific contributions to the CFLE and LEWC differentials, respectively. As in the previous case, the sum of the two partial differences is equal to the total gap between the high and low education groups (in other words, the total bar height equals the difference between the high and low education groups).

The left half of Figure 5 shows the age-specific decomposition for males. There, we can observe the significant contribution of morbidity particularly in Mental Disorders and Diabetes, where the CFLE gaps are larger, and in specially in the younger age groups. For all conditions, the mortality gradients seem to be more evenly distributed across the life course, although we can observe a sustained increase in the contribution of the mortality gap between middle and low-educated males.

The right half of figure 5 presents the age-specific decomposition for females. The age-specific CFLE gap between the high and the middle-educated groups varies by condition, with a high presence in the younger age groups for Mental Disorders, a larger contribution in the oldest age groups for Diabetes, and a larger presence in the middle age groups for Hypertension. The contribution of morbidity is also more present in the younger and middle age groups in most conditions, particularly in the gap between the middle and low-educated groups. However, we also note that the final age group has sometimes the largest contributions of mortality (particularly between the difference in the middle minus low educated group) given the fact that there is still a significant portion of females who are still alive at age 85.

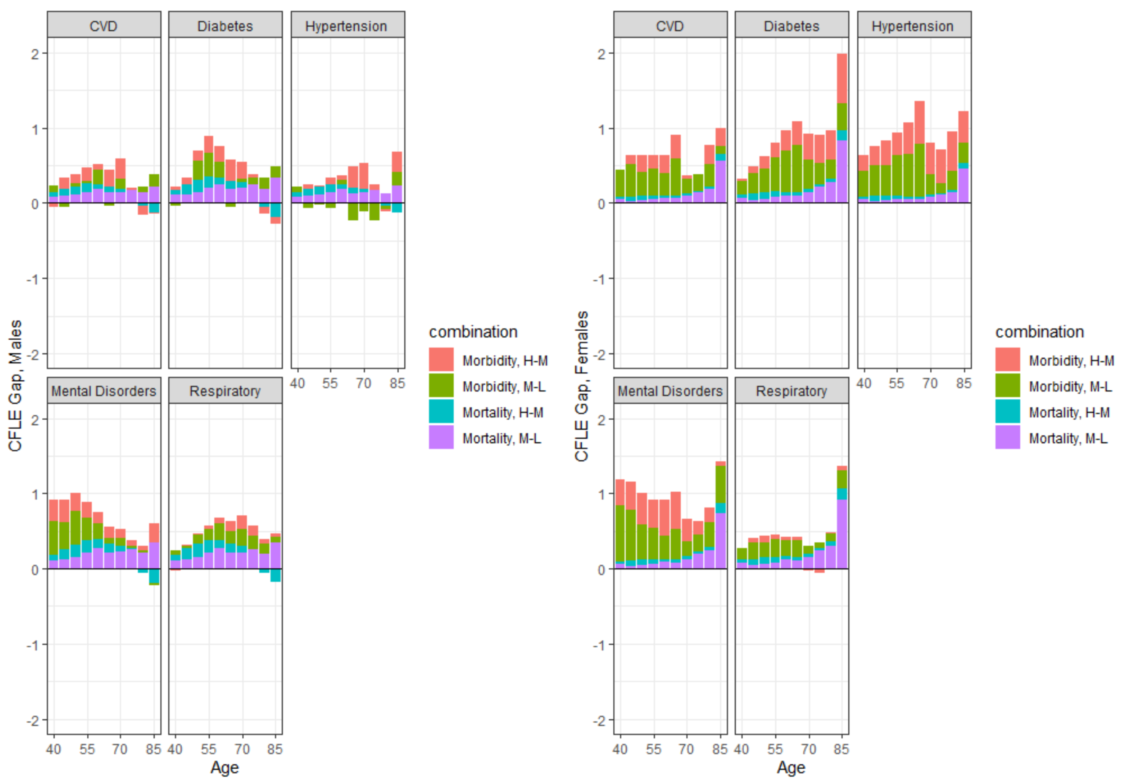

Figure 5: Age-Specific Contribution of Mortality and Morbidity into overall differentials in LEWC by sex and educational attainment, Spain, 2012-2017 (Source: author´s calculations based on INE, ENSE & EESE).

Figure 6 shows the age decomposition of the LEWC educational differences. As mentioned above, the contribution of the morbidity component is the opposite of its CFLE counterpart, so we focus in the analysis of the mortality components. Among males, the mortality contribution was positive and larger for the gap between those with middle and low education. Regarding age patterns, no clear age pattern was found for the small mortality differentials for the majority of chronic conditions. For females, most of the mortality differentials in the LEWC were concentrated in the oldest age groups (suggesting that the gap in LEWC in earlier age groups was due to morbidity differences alone), mostly driven by the gap between those with middle and low education.

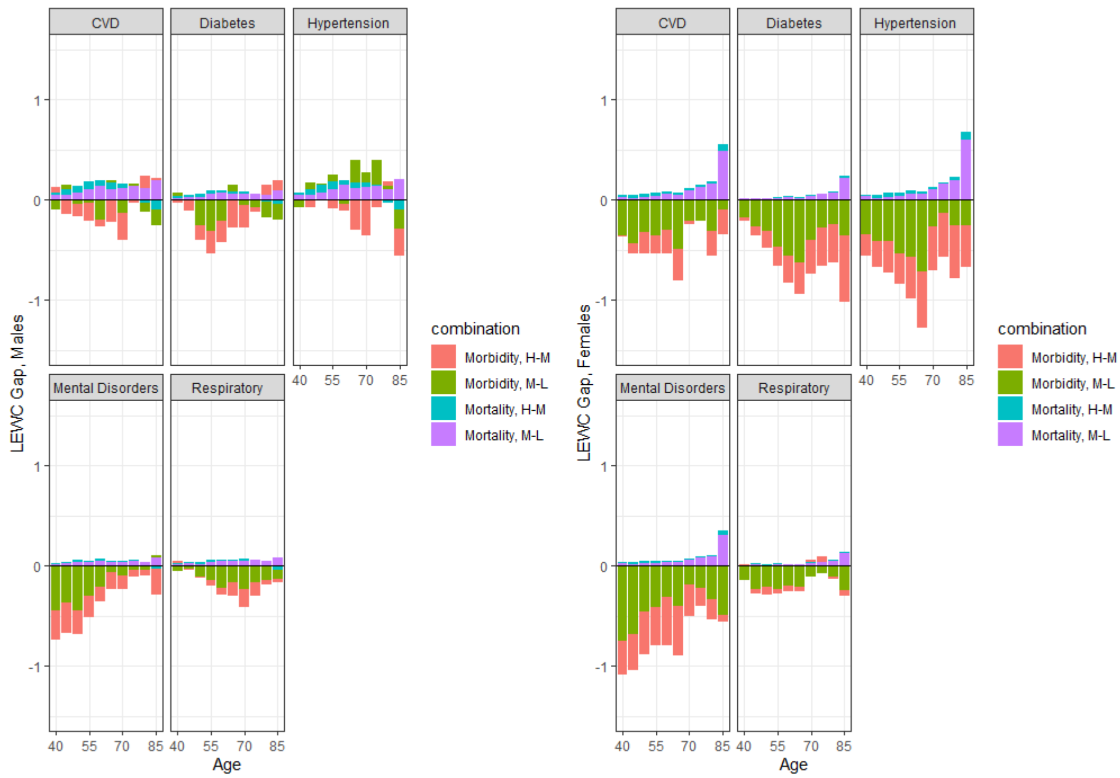

Figure 6: Age-Specific Contribution of Mortality and Morbidity into overall differentials in LEWC by sex and educational attainment, Spain, 2012-2017 (Source: author´s calculations based on INE, ENSE & EESE).

5. Discussion and final comments

In this study, we investigated the contribution of mortality and morbidity components to differences in CFLE (condition-free life expectancy) and LEWC (life expectancy with the condition) at age 40 by educational attainment for males and females in Spain. We analyzed several groups of high-prevalence conditions on health expectancies, identified the morbidity and mortality components responsible for such disparities, and highlighted which age groups were the ones that contributed the most to such differences. This is important because it provides policymakers with valuable information to understand and mitigate the health inequality dynamics behind life expectancy spent in good and in poor health, which may differ across social strata and by sex.

First of all, we have to mention that health expectancies are generally not independent of mortality dynamics. In the Spanish case, we identified a convergence in death rates between individuals in the middle-educated group and the high-educated group around the age of 70. Two are two plausible, albeit speculative, explanations for this convergence. On the one hand, the effects of the educational expansion in Spain might be relatively recent, as getting a university degree was a rather rare event in the past. Therefore, the expected gains in life associated with a higher social standing and education associated with a college degree might not come to fruition, suggesting that simply post-primary education might represent a similar advantage in health (Permanyer et al., 2018). On the other hand, cohort effects might be playing a part in mortality convergence, specifically with certain causes of death such as lung cancer. Previous studies have pointed out that cohorts born between 1940 and 1960 were particularly affected by lung cancer due to the expansion of smoking that occurred in Spain since the second half of the 20th Century. (Franco et al., 2002; Ocaña-Riola et al., 2013).

As was the case for many countries, is possible that the forerunners of the habit in Spain might have been individuals from a more advantaged economic position before it became widespread in the whole society (Giskes et al., 2005; Graham, 1996). Regarding the healthy life expectancy of adults in Spain, we found a clear educational gradient for both males and females and all the health conditions examined (CVD, Diabetes, Hypertension, Mental Disorders, and Respiratory Diseases). However, unhealthy life expectancies did not show such a gradient and results differed by sex and were particularly interesting among males. Middle-educated males had longer life expectancy with CVD, Diabetes, and Respiratory Diseases than those with higher and, also, with lower levels of education. In addition, several estimates of LEWC for males and females were not significantly different. This study, by decomposing educational differences in healthy and unhealthy life expectancies for given conditions into the mortality and morbidity components and by age, contributed to providing insights into the main drivers of such educational gaps.

The educational gradient in the prevalence and cause-specific CFLEs was present in all of the conditions analyzed. This is in line with previous research, where educational gradients have been found when analyzing aggregate measures or indicators such as the GALI or indexes in limitations in daily activities (ADL) in Spain (Gumà et al., 2019; Solé-Auró et al., 2020, 2022; Solé-Auró & Alcañiz, 2016).

For males, we identified that differences in CFLE between the middle and low-educated groups in Spain are mainly explained by mortality components, while differences between higher and middle-educated groups are mainly explained by morbidity components. In other words, the advantage of more educated males over their less educated counterparts is attributed to both their longevity and healthier lifespans, but depending on their educational position, it can be predominantly due to one component over the other. This also meant that while higher-educated males had the shortest unhealthy lifespans overall, middle-educated individuals lived longer, but on occasion had longer unhealthy life expectancies when compared to the low-educated group because of their lower mortality. This could be indicative, in theory, that the increase in life expectancy for higher-educated males does not translate into an increase in the time lived with conditions, given the lower disease prevalence that goes with such an increase in longevity, but this is not the case for middle-educated males.

For females, morbidity was the main driver of educational differences in CFLE for most conditions (except Respiratory Diseases). Mortality also played a role in the gap between the middle and low-educated groups. For the CFLE gap between the higher and middle-educated groups of females, mortality differences were modest. These results are in line with the findings of other studies that have focused on this issue, albeit with different magnitudes, we can see that the contribution of the mortality component to health expectancy differentials is smaller for females than for males (Nusselder et al., 2005; Yokota et al., 2019). In the Spanish case, this is mainly because educational differences in mortality for females tend to be smaller than for males in Spain. (Huisman, Kunst, Bopp et al., 2005; Reques et al., 2014). Simply put, while for males the CFLE advantage that higher educated individuals had was because of a combination of mortality and morbidity components (implying both longer and healthier life expectancies), for females, the morbidity component was the main determinant of the difference.

The cause-specific analysis showed educational inequalities for all conditions, but greater for Hypertension, Mental Disorders, and Diabetes. The clear educational gradient in

Diabetes, for both males and females, is consistent with the previous evidence showing these disparities in Spain (Reques et al., 2014; Ruiz-Ramos et al., 2006). This is likely due to the adoption of risky behaviors, a greater proportion of obese people among the educated, and poorer food quality consumption. It is also the only condition in which the sex gap in morbidity favors females: apart from their longer lifespans and CFLE, the LEWC for middle and highly-educated females is smaller than for males, because of their lower overall prevalence.

In Mental Disorders we found some of the largest educational gaps in prevalence and in CFLE for both males and females. It is worth mentioning that the higher prevalence in females implied that, despite their longer life expectancy, the years of CFLE were the same for both sexes. However, the age-specific decomposition indicated that most of the morbidity gap by education was concentrated in the younger age groups, especially for males, and before the age of 65. For females, educational differences in morbidity were found in all age groups, and with a high intensity in the younger ones. This is consistent with previous literature stressing the relationship between occupational status, educational attainment, and mental health, which is mostly present during the active years (Bell, 2014; Kessler et al., 2010).

For CVD, we found some of the lowest CFLEs of all our estimations for both males and females, particularly among those with higher education, who had the highest CFLE compared to other conditions in the same level of education. Furthermore, among males, the morbidity gap between levels of education was one of the smallest of all the conditions analyzed, with most of the differences concentrated in the younger and mid-adult ages before converging at older ages.

In Hypertension, we found that females had a higher prevalence than males, and as a result, their LEWC is higher despite a similar CFLE. In addition, we found that the educational gap in morbidity is small for males but large for females, is evenly distributed across the life course, and persists into the oldest ages. Note that there may be some underreporting of prevalence due to the way the survey collects information on conditions such as CVD and Hypertension. This may be especially true for lower-educated individuals at younger ages, where routine medical checkups or other forms of detection may be less frequent, and the impact of these two groups of conditions on overall health may not be as obvious as in the case of back pain or mental health conditions (Everett & Zajacova, 2015; Ong et al., 2007; Spitzer, 2020).

Finally, for Respiratory Diseases, we found the highest CFLE for both males and females and, correspondingly, some of the lowest LEWC. In both cases, most of the (rather modest) differences in morbidity were found between the middle and the lower-educated groups, suggesting that there were only small differences between the higher-educated and the middle educated. The early appearance of Respiratory Diseases in childhood (Newacheck & Taylor, 1992) and the overall low prevalence of COPD and asthma may explain the lack of differences between educational groups.

While educational and sex disparities in some conditions such as Mental health in Spain were documented previously (Balanza Galindo et al., 2009; Cardila et al., 2015; Raya-Tena et al., 2021; Rocha et al., 2015), they were rarely compared with other causes of disease. In this regard, another interesting finding of our study is the larger social gaps for some specific groups of causes when compared to others, and the magnitude of the social gradient at certain age groups. The fact that Mental Disorders presented larger educational disparities in health, may also be related to the fact that lower educated individuals are more at risk of such conditions (due to their exposures across the life course), or are more affected by them in their perceptions of health.

This study was not exempt from limitations, which are openly acknowledged. First of all, even by pooling three health surveys, the relatively small sample size forced us to consider three categories of educational attainment, possibly ignoring more subtle layers of analysis if more categories were used, although arguably facilitating the interpretations of the decomposition analysis. In addition, this study does not consider the institutionalized population. According to the National Institute of Statistics, this group represented the 1% of the whole population in Spain in 2011 – (*this information should be updated as soon as it is available for the 2021 census)*. However, more than 5% of males and 7.5% of females aged 80 and above were living in collective residences such as nursing homes. However, while we acknowledge that the prevalence of chronic conditions at the final age groups may be somewhat underestimated as a result, this particular subgroup does not seem to be large enough to substantially alter our summary estimations, especially if we consider only individuals aged 40 and over and that there should not be very strong compositional changes in this population, as pointed out by Zueras and Rentería (2020). We have also presented the results at the country level without considering any regional spatial differentiation, although this is something to consider for future studies. It should also be mentioned that although most of these conditions were diagnosed by a doctor, the registered answers are still reliant on the veracity of the respondent, which means that in some conditions there may be some underreporting. This could be the case for Hypertension or cardiovascular conditions in males with low education. Furthermore, the ailments that make up the different conditions we grouped together may also introduce their own degree of heterogeneity. However, since we pooled observations into a single large observation, we can somewhat mitigate large differences in prevalence within groups.

Most importantly, the methodological approach has its shortcomings, which we openly acknowledge and address. The Sullivan method relies on the assumption that morbidity and mortality rates are subject to the same life table, and in this case, we must assume that individuals with different health conditions are subject to a similar lethality by education. However, since Spain is a country with overall low levels of amenable mortality, we believe that such an assumption should not significantly alter our estimates. Previous studies (e.g., Imai and Soneji, 2007, Mathers and Robine, 1997) have shown that in the absence of abrupt changes in population health, the estimates produced by the Sullivan method are similar to those produced by other techniques that require longitudinal or repeated cross-sectional data (e.g. Guillot and Yu, 2009). Furthermore, since the Sullivan method is still widely used in research (e.g. Canudas-Romo et al., 2017, Yokota et al., 2019, Solé-Auró et al., 2022, di Lego et al., 2020), we believe that it is a valid option for estimating health expectancies while acknowledging these limitations.

Despite such limitations, we believe that the findings presented in this paper prove the advantages of considering chronic conditions separately when investigating the health burden in a population, particularly by identifying the mechanisms behind the differences in cause-specific health expectancies by educational attainment in Spain.

These results suggest that aggregate measures (i.e. health expectancies based on the presence of one or more conditions in the same measure) mask certain heterogeneities in health in Spain (Voigt et al., 2020). Additionally, it brings a word of warning, because grouping categories of chronic conditions and global indicators of disability could lead to an underestimation of educational disparities in health indicators. Possibly, separating Mental Disorders from physical conditions could be an interesting approach to visualize social inequalities in population health when analyzing health inequalities in the future.

More importantly, the results suggest that the gaps in morbidity play a more prominent role in explaining differences in health expectancies for many conditions as mortality tends to converge across populations, given the rather small magnitude of differences in life expectancy in Spain. In other words, if differences in mortality tend to decrease in the future, we should expect morbidity to be the main driver of overall differences in health expectancies. Therefore, adequate monitoring of the health burden of each chronic condition separately would provide a more accurate picture of social inequalities in health and allow for the design of adequate policies to mitigate or adapt to them.

Appendix C, Chapter 4:

Group	Condition	Questions in ENSE 2012	Questions in ENSE 2017	Questions in EESE 2014
Cardiovascular Diseases	Myocardial Infarction	G21b-2, G21c-2	G25b-2, G25c-2	G25b-2, G25c-2
	Stroke	G21b-22, G21c-22	G21b-23, G21c-23	G21b-23, G21c-23
	Other Heart Diseases	G21b-3, G21c-3	G25b-3, G25c-3	G25b-3, G25c-3 G25c-4, G25-c4
	High Cholesterol	G21b-14, G21c-14	G25b-15, G25c-15	G25b-15, G25c-15
Respiratory Diseases	COPLD	G21b-10, G21c-10	G25b-11, G25c-11	G25b-11, G25c-11
	Ashtma	G21b-9, G21c-9	G25b-10, G25c-10	G25b-10, G25c-10
Diabetes	Diabetes	G21b-11, G21c-11	G25b-12, G25c-12	G25b-12, G25c-12
Hypertension	Hypertension	G21b-1, G21c-1	G25b-1, G25c-1	G25b-1, G25c-1
Mental Disorders	Depression	G21b-19, G21c-19	G25b-20, G25c-20	G25b-20, G25c-20
	Anxiety	G21b-20, G21c-20	G25b-21, G25c-21	G25b-21, G25c-21
	Other Mental Disorders	G21b-21, G21c-21	G25b-22, G25c-22	G25b-22, G25c-22

Table 1A: Classification of Chronic Conditions based on ENSE and EESE Questionnaires. (Source: author´s calculations based on ENSE & EESE).

5 Conclusions

1. Outline:

The three essays presented in this dissertation uncovered and described inequalities in health and mortality in contemporary Spain, a country that has one of the highest life expectancies in the world. But not every individual has the same chance of enjoying long and healthy lives. Therefore, the main contributions of this dissertation were centered on determining the magnitude and extent of inequalities in health and their potential implications for the overall well-being of Spanish society in the 21st Century.

To some degree, the essays presented a somewhat less evident aspect of inequality that has not been explored previously in the country, either at a regional level (in the first two essays) or at a national one (in the third).

Each of the three essays has a clear theme, differentiated from the others. The first essay is about the role of heterogeneity (between and within groups) in regional differences in mortality by educational attainment. The second essay delves into the role of birth cohorts in mortality differences across regions, and how generational risks might be telling about past, present, and future trends of mortality. The third essay explores to which extent the differences in time lived without a chronic condition are differences in overall longevity and to which extent are differences in good health. In other words, it looks into the contribution of mortality and morbidity in differences in health expectancies by educational attainment. However, the three essays consider different social dimensions (either by education, by space, or by cohort) as critical aspects of their motivation, conception, analysis, and discussion.

The three studies were conducted using, cross-sectional data, and using mostly aggregate, group-based measures (except for the health surveys analyzed in the third essay). The only data that was provided upon request were the mortality and population exposures data provided by the Spanish National Institute of Statistics (INE) for essays 1 and 3, which essentially were a set of aggregate cross-tabulations of deaths by educational attainment. The remaining data that was used for this dissertation is publicly available (and I am happy to share the code in which the statistical analysis was conducted here as soon as I am able to on https://github.com/onbramajo/).

2. Key Findings of Essays and Discussion:

The first essay (second chapter) documented disparities in life expectancy and lifespan variability measures across regions (autonomous communities) of Spain during the 2014-2018 period. The necessity of going beyond life expectancy as a measure of longevity and providing values of lifespan variability at a subnational level as alternative indicators of health were the main motivations in this chapter. Specifically, in estimating individual differences in the length of life within groups by educational attainment as a complement to life expectancy. And the extent of the magnitude of the relationship between those indicators across space in Spain.

The key findings of the second chapter are a mix of confirmation of the previously known and novel insights on health inequalities in mortality. The low-education group has a lower life expectancy than their higher-educated counterparts, and males have a lower life expectancy than females in all regions of Spain, just as previous studies found in the past (Permanyer et al., 2018; Regidor et al., 2016; Reques et al., 2014, 2015). Educational differences of 2.6 years of life expectancy (for those who survived at age 35) were found for males and 1.6 were found for females on average.

The low-education group presents a higher heterogeneity in mortality, not only across autonomous communities (expressed in a higher standard deviation of the analyzed indicators) but also within the autonomous communities (expressed in higher lifespan variability measures, both absolute and relative). The higher educated group, correspondingly, tends to present a more homogeneous length of life, with lower variability.

This means that somewhat independently of where they live, the devices, mechanisms, and technologies that help individuals with a higher social standing to reach more advanced ages are, indeed, available for them for such a purpose. As mentioned before, this indicates that space is not only a determinant of how long people live, but also how uncertain are their lifespans (in other words, how likely is that they achieve their expected length of life). And particularly this strikes true when considering individuals with lower education: across regions of Spain an important correlation between lower life expectancy and a higher variability can be found, which implies that their lives are not only shorter, but more uncertain, and such uncertainty is mediated by space.

Some of the largest gaps in life expectancy in this essay were found in the regions that border the Mediterranean Sea, consistent with the previous literature (Reques et al., 2015). Uneven access to healthcare or certain accumulated risks determined by their own spatial and societal dynamics might be associated with such differences. However, we could not find any evident pattern for lifespan variation measures.

The second essay (third chapter) also focused on spatial disparities in mortality but with a rather uncommon cohort perspective. It found out that in the last 40 years, lung cancer mortality has risen among females for all autonomous communities in Spain, turning into one of the leading causes of death. This is probably the unfortunate result of increases in smoking prevalence among females, as previous research has found.

However, behind that increase that would only be apparent if we followed the variation over time, some non-linear risk differences across cohorts were spotted that could be indicative of possible new emerging trends. The cohorts born between 1935 and 1955 presented a higher mortality risk all over the country. This was also found in a previous study (Franco et al., 2002). Those cohorts were arguably the ones exposed the most to the expansion of smoking in Spanish society. However, this increase in cohort mortality was also found for all its autonomous communities/regions, something that was unknown before. After that point, the majority of the regions (and the average of the country) presented non-linear improvements across cohorts, implying that increases in lung cancer mortality have somewhat stagnated in those cases during the last years (if we combine period and cohort effects), hoping that future generations of females will benefit from lower mortality at some point. Despite that apparent improvement, in some regions the lung cancer death risk by cohorts is ever increasing, without any sight of decline any time soon. This indicates that unless some strong actions are taken to reduce smoking consumption (changes in smoking prevalence were positively associated with mortality improvement at an ecological level), these regions would expect even larger disparities in mortality when compared to the national trend (that also presents higher cohort risks when compared to females born in 1935).

Furthermore, considering the results of the first essay, all regions whose younger cohorts failed to show improvements in lung cancer mortality were from the coastal part of the country, enhancing the notion that there are strong spatial heterogeneities in health in Spain that are based on the idea of center-periphery. While speculative, that could be an indication that lung cancer might be one of the factors that play a part in the magnitude of the mortality disparities that were found in the first essay.

The idea that some cohorts are currently more vulnerable than others in Spain also appears in the third essay (fourth chapter) and helps to put in context the overall findings of the essay. While this essay focuses on life expectancy in good/poor health by educational attainment for five groups of different chronic conditions, such indicators are not independent of mortality dynamics.

The findings of the third essay also show at advanced ages the death rates of individuals with middle and high education tend to converge (which in turn mostly correspond to the more vulnerable cohorts from the second essay). As a result, differences in health expectancy for these educational groups are mostly driven by differences in morbidity (prevalence). For differences in health expectancy (of the five groups of causes) between the middle-education and low-education groups, the mortality component contributes the most to the gap, particularly for males. While this also occurs for females, the contribution of morbidity in this group is higher than the contribution of mortality.

Furthermore, the age-specific decomposition of those differences in health expectancy indicates that also the morbidity differentials vary sensibly for each group of conditions. For instance, the contribution of morbidity to differences in health expectancy for males tends to be mostly concentrated in the younger age groups, particularly for mental disorders and diabetes. However, for females, prevalence differences in most conditions were evenly distributed along the life course.

Putting in perspective the three essays, one of the main takeaways is that despite all the improvements in mortality and health that Spain experienced over the last 50 years, social, spatial, and gender inequalities in health persist nowadays.

To contextualize why it is still important to conduct research that is concerned with the topic of social inequalities in mortality, we should look no further than the recent COVID-19 pandemic. It is, arguably, the single most significant public health crisis in the last decades, impacting negatively multiple spheres of societies all over the globe. When looking at its impacts on life expectancy, Spain has suffered a drop in life expectancy ranging nearly 1.5 years in 2020 (Aburto et al., 2022; Spijker & Trias-Llimós, 2023; Trias-Llimós & Bilal, 2020). While the distribution of deaths caused by the pandemic might be different than the all-cause mortality explored in this dissertation, the educational differences in mortality found in Essays 1 and 3 are even wider than the loss of life caused in the COVID-19 period. While Essay 1 mentions that the educational gaps in mortality in Spain are rather small when compared to other countries (van Raalte et al., 2011, van Raalte 2018, Sasson 2016), the fact that such differences are even wider than the loss of life caused by the pandemic provides a clear insight that socioeconomic position is still a very strong health determinant and is a major force behind health inequality.

On top of that, it can be argued that having rather small differences in mortality might not be enough to ensure long, healthy lives for those who have a lower social standing in Spain. On the contrary, the results of the three essays hint that such a situation puts them on a quadruple burden: they have shorter lifespans, more uncertain lifespans, shorter healthy lifespans, and, as Permanyer et al (2022) made the case for, more uncertain healthy lifespans as well. Therefore, taking care of the health necessities of the more vulnerable members of Spanish society remains a key aspect of present and future health policies.

I also think that the results of this dissertation hint indirectly that a shift in the mortality patterns in Spain might be possible: the cohort effects present in advanced age mortality could dissipate in the not-so-distant future. And as a result, (while somewhat speculative), additional interest in time lived in good/poor health might emerge as a major health barometer of the Spanish population. This is particularly relevant since depression is expected to be a leading cause of disability worldwide in 2030 (Ferrari et al., 2013). And, as shown in the third essay, mental disorders are one of the conditions that presented not only a higher overall prevalence but also some of the widest educational disparities. Therefore, monitoring the prevalence of such conditions and others with a high prevalence in Spanish society would be critical to better understand and plan adequately for future health policies that cope with such challenges.

3. Limitations and epilogue.

The three essays present a series of limitations and other considerations that will be discussed in this section (apart from other limitations that were discussed in the core of the essays).

We mentioned earlier in this chapter that the data used for this dissertation is cross-sectional, and mostly were group-based counts and indicators. While this dissertation offered three descriptive pieces of research that present the association between social position, space, gender, cohort, and negative health outcomes in Spain, it is not able to establish any causal mechanisms of the drivers between such associations. In other words, while it is acknowledged and established that social disadvantage (expressed in many proxies in this dissertation) is a broad determinant of health inequalities, it is not clear what are the exact mechanisms behind this link. Probably high-quality longitudinal data from administrative records or other sources could provide a clear-cut causal approach to establish the impact of social determinants on mortality in the Spanish case.

For instance, in this dissertation, the essays were unable to disentangle the effects of income, wealth, household composition, or other social relationships on mortality. In the second essay, unfortunately, I could not rely upon educational mortality for lung cancer nor smoking prevalence risks for the whole period of analysis to adopt an indirect method of smoking-attributed mortality, which is another limitation of the study (although I could make an ecological approximation to establish an association between structural variables of each region and the recent changes in mortality trends). Furthermore, the third essay resorted to the Sullivan method (a prevalence-based life table approach) to estimate condition-free life expectancy, instead of using a multi-state approach that would be feasible with longitudinal data (Mathers & Robine, 1997; Rogers et al., 1989). This was mostly because we counted with a single observation of mortality, which forced us to model transitions from being healthy to having a chronic condition and then passing away. However, it has been acknowledged that both the Sullivan or multistate methods at lower ages offer quite similar results to estimate a given health expectancy (Mathers & Robine, 1997; Murakami et al., 2018).

All the articles, while they study a period that happened before the COVID-19 pandemic, also acknowledge its existence, since the pandemic was on its course while I was writing the articles. Arguably the COVID-19 pandemic was the single most disruptive event in global health in the last 50 years, not only because of the enormous death toll that was caused by the disease, but also by its lasting psychological and physiological effects in society (albeit probably there is some recency bias operating in this assumption). We still do not know the magnitude and scope of inequalities in health that were shaped by the effects of the pandemic. I mentioned before that several studies were conducted about the impacts of the pandemic on the loss of life expectancy in Spain. However, the aspects of inequality that were studied in this dissertation (and many others that go beyond the scope of this thesis) are not yet fully embraced in research that also considers the impacts of COVID-19, suggesting future lines of research that can be followed.

However, despite these limitations, this dissertation provides three chapters that bring solid evidence of the extent of social inequalities in Spain and its negative health outcomes. It also offers insight into future aspects of inequality that have to be followed closely to establish policies that mitigate them. Moreover, the core of this dissertation can also be a valuable benchmark for future studies that want to identify health inequalities in the post-pandemic setting and emerging trends in health.

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