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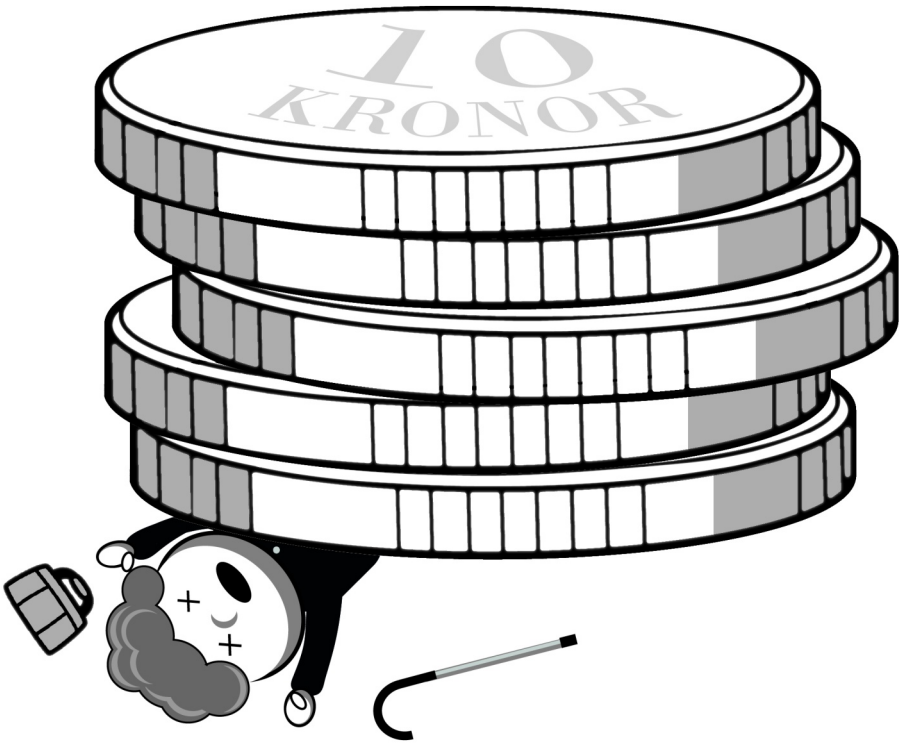
Inequalities in life and death

Income and mortality in an ageing population

Johan Rehnberg



Doctoral Thesis in Public Health Sciences at Stockholm University, Sweden 2019

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Income and mortality in an ageing population

Johan Rehnberg

Academic dissertation for the Degree of Doctor of Philosophy in Public Health Sciences at Stockholm University to be publicly defended on Monday 27 May 2019 at 10.00 in De Geersalen, Geovetenskapens hus, Svante Arrhenius väg 14.

Abstract

Income serves as an indicator of success relative to others, and provides individuals with resources that strengthen their capability to face challenges and benefit from opportunities. Out of all social determinants of health, income is one of the strongest predictors of health outcomes. The positive association between income and health in the working-age population is well established; those with higher income tend to have better health. Less is known about the association between income and health among older persons. Several studies have observed that in old age, health inequalities decrease and the relationship between income and health weakens. However, at what point in the ageing process the association starts to weaken, and to what extent, is debated.

The ageing process highlights the need for several theoretical considerations in studies on income and health. Societies are stratified by age, as manifested through transitions in and out of education, work, and retirement. Moreover, the individual experience of the ageing process involves biological processes of decline. Many health problems, and particularly death, are uncommon events during most of adulthood. In old age, however, health decline becomes a normative experience, and in Sweden, more than 90 percent of all deaths occur among people aged 65 or older. The characteristics and magnitude of age-related changes in the association between income and mortality constitute one of the prime concerns in this thesis. I have used two contending perspectives to understand the empirical results: the cumulative (dis)advantage theory and the age-as-leveler hypothesis.

In this thesis, I have investigated the association between income and mortality across ages, with a focus on later life. More specifically, I studied the shape and magnitude of the income-mortality association across the life course. Furthermore, I tested two potential mechanisms that may shape this association in old age: health decline and mortality selection. Overall, this thesis shows to what extent and in what ways the association between income and mortality is maintained in old age

This thesis includes four empirical studies. Study I, II, and IV are based on data from Swedish national registers (n = 801,017 – 5,011,414). Study III used survey data (LNU and SWEOLD) linked with data from administrative registries (n = 2619). The results from Study I showed that the income-mortality association was curvilinear with diminishing returns of income in both mid-life and late-life. Study II showed that relative mortality inequalities in income decreased with age and absolute mortality inequalities in income increased with age up to age 85-90, after which the mortality inequalities decreased. The results from Study III showed that health decline partly explained the weakened income-mortality association among the oldest old. Finally, Study IV showed that selective mortality had a substantial impact on poverty rates in old age; poverty rates were consistently and substantially lower for those who survived than those who died. Furthermore, selective mortality had the largest influence on the surviving population when mortality rates were at their highest.

Keywords: *income, health, mortality, ageing, inequality, age-as-leveler, cumulative disadvantage.*

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In this thesis, I have investigated the association between income and mortality across ages, with a focus on later life. More specifically, I studied the shape and magnitude of the income-mortality association across the adult life course. Furthermore, I tested two potential mechanisms that may shape this association in old age: health decline and mortality selection. Overall, this thesis shows to what extent and in what ways the association between income and mortality is maintained in old age

This thesis includes four empirical studies. Study I, II, and IV are based on data from Swedish national registers and includes persons aged between 30 and 101 (n = 801,017 – 5,011,414). Study III used survey data (LNU and SWEOLD) linked with data from administrative registries on persons aged between 54 and 93 (n = 2619). The results from Study I showed that the income-mortality association was curvilinear with diminishing returns of income in both mid-life and late-life. Study II showed that relative mortality inequalities in income decreased with age and absolute mortality inequalities

in income increased with age up to age 85-90, after which the mortality inequalities decreased. The results from Study III showed that health decline partly explained the weakened income-mortality association among the oldest old. Finally, Study IV showed that selective mortality had a substantial impact on poverty rates in old age; poverty rates were consistently and substantially lower for those who survived than those who died. Furthermore, selective mortality had the largest influence on the surviving population when mortality rates were at their highest.

Sammanfattning

Inkomst är en resurs med vilken man kan stärka sin förmåga att möta svårigheter och tillgodose sig fördelar, samt en indikator på framgång i relation till andra. Det finns flera sociala bestämningsfaktorer för hälsa, inkomst är en av de faktorer som uppvisar starkast relation till hälsa. En positiv relation mellan inkomst och hälsa bland personer i arbetsför ålder är väl dokumenterad, personer med högre inkomster tenderar att leva längre liv med bättre hälsa. Vi vet mindre om relationen mellan inkomst och hälsa bland äldre personer. De få studier som har undersökt sambandet i hög ålder har funnit att det avtar bland de allra äldsta och observerat minskade hälsoojämlikheter jämfört med samma samband bland yngre personer. I vilka åldrar och i vilken utsträckning som sambandet börjar minska är ännu oklart.

Studier som undersöker inkomst och hälsa i olika åldrar måste ta hänsyn till åldersrelaterade processer. Bland de starkaste processerna i moderna samhällen är institutioner som är starkt knutna till kronologisk ålder; övergången mellan utbildning till arbete, likväl som övergången mellan arbete till pensionering. Vidare är den individuella upplevelsen av ålder nära knuten till biologiska processer som i hög ålder främst karakteriseras av nedbrytning. Många hälsoproblem och i synnerhet döden är ovanliga företeelser bland yngre personer. Detta förändras i och med hög ålder, där hälsoproblem snarare blir det förväntade. Likaså blir även döden närstående, i Sverige inträffar 90 procent av alla dödsfall bland personer som är 65 år eller äldre. Åldersrelaterade processer och dess betydelse för sambandet mellan inkomst och hälsa är central i denna avhandling. Jag har använt mig av två motsatta perspektiv för att förklara de empiriska resultaten: *the cumulative (dis)advantage theory* och hypotesen om *ålder-som-utjämnare*.

I avhandlingen har jag undersökt sambandet mellan inkomst och dödlighet i olika åldrar, med fokus på de äldsta. Mer specifikt har jag studerat formen och omfattningen av sambandet mellan inkomst och dödlighet genom det vuxna livsloppet. Vidare har jag även testat två potentiella mekanismer som kan påverka sambandet i hög ålder: försämrad hälsa och selektiv dödlighet. Övergripande kan sägas att den här avhandlingen visar i vilken utsträckning och på vilket sätt som sambandet mellan inkomst och hälsa kvarstår i hög ålder.

Avhandlingen består av fyra empiriska studier. Studie I, II och IV är baserade på information från svenska register, vilka inkluderar mellan 801 017 och 5 011 414 personer i åldrarna 30 till 101. Studie III omfattar 2619 personer i åldrarna 54 till 93 med information från två surveyundersökningar: Levnads-

nivåundersökningen (LNU) och undersökningen om äldre personers levnadsvillkor (SWEOLD). Till dessa undersökningar länkas information om inkomst från svenska register. Resultaten från Studie I visade att sambandet mellan inkomst och dödlighet är kurvlinjärt, där inkomst visade avtagande effekter i sambandet till dödlighet både när inkomst mättes mellan åldrarna 50 och 60 liksom mellan 65 och 75. Studie II visade att relativa ojämlikheter i inkomst och dödlighet minskade med stigande ålder och att absoluta ojämlikheter i inkomst och dödlighet ökade med stigande ålder. Resultaten från Studie III visade att försämrad hälsa delvis förklarade det avtagande sambandet mellan inkomst och dödlighet i hög ålder. Slutligen visade resultaten från Studie IV att selektiv dödlighet hade betydande effekter på fattigdom i hög ålder. Fattigdomen var genomgående lägre för de som överlevde jämfört med de som dog.

List of studies

I. Rehnberg, J., & Fritzell, J. (2016). The shape of the association between income and mortality in old age: A longitudinal Swedish national register study. *SSM - Population Health*.

II. Rehnberg, J., Fors, S., & Fritzell, J. (2019). Divergence and Convergence: How Do Income Inequalities in Mortality Change over the Life Course?. *Gerontology*.

III. Rehnberg, J. What levels the association between income and mortality in later life: age or health decline?. Manuscript.

IV. Rehnberg, J., Fors, S., Almquist Y.B. & Fritzell, J,.Poverty after 63: the impact of selective mortality. Manuscript.

Contents

Introduction

Given the central role money plays in society, it may not come as a surprise that income is closely intertwined with the human life course. Income not only serves as an indicator of success relative to others, but also provides individuals with resources that strengthen their capability to face challenges and benefit from opportunities. The disadvantages individuals with lower incomes encounter are well-documented (Kawachi, Kennedy, Lochner, & Prothrow-Stith, 1997; Marmot, 2002). Income has been found to be strongly associated with well-being, health, and longevity (Chetty et al., 2016; Kawachi, Adler, & Dow, 2010). Compared with other classical indicators of socioeconomic position, income is the strongest predictor of mortality (Darin-Mattsson, Fors, & Kåreholt, 2017; Geyer, Hemström, Peter, & Vågerö, 2006). Even in modern welfare states such as Sweden, where measures are taken to reduce inequalities, alleviate poverty, and provide universal health care, the importance of income to health inequalities persists (Huisman, Kunst, & Mackenbach, 2003; Mackenbach et al., 2017).

The majority of empirical studies on the association between income and health have focused on the working age population, while less attention has been paid to older persons. During the last century, life expectancy has increased dramatically (Mathers, Stevens, Boerma, White, & Tobias, 2015; Oeppen & Vaupel, 2002); the extension of the life course, however, does not necessarily mean that individuals spend more years in good health (Salomon et al., 2012). The ageing of populations brings about challenges for the welfare state in terms of financing pensions and old-age care. This process has changed, and will continue to change, the level of redistribution in and between age groups necessary to maintain a sustainable and fair distribution of resources across the life course.

Against this backdrop, the link between income and health outcomes in old age warrants further scrutiny. Generally, the same social determinants as in the working age population apply: those with higher socioeconomic position and income tend to have better health throughout their life courses and into old age. Yet the ageing process highlights the need for several theoretical and practical considerations. First, societies are stratified by age, as manifested through transitions in and out of education, work, and retirement. These processes are connected to earnings and socioeconomic position in several steps. In young adulthood, people establish themselves on the labour market, which is followed by a long period of adulthood that is characterised by work and the accumulation of income. Second, the individual experience of the ageing

process involves biological processes of bodily deterioration and physical decline. Many health problems, and particularly death, are uncommon events during a large part of adulthood. In old age, however, health decline becomes a normative experience and the event of death gains proximity. According to this reasoning, ageing can modify the association between income and health outcomes in several ways.

This thesis will examine several aspects of the income-health association from the perspective of ageing. One key question is whether the association is strengthened or weakened in old age. In answering this question, the accumulation and distribution of income, and the individual experience of health decline in old age, are considered. Overall, this thesis contributes to knowledge about ageing-related processes by studying income and mortality across the adult life course and into old age.

Aim

The overall aim of this thesis is to explore the income-mortality relationship in old age. In order to do this, four empirical studies have been conducted, each of which focuses on the association between income and health across the life course and addresses common theories of ageing. Study I analyses both the shape of the association and whether it differs between mid-life and late-life income. Study II describes the magnitude of inequality across the adult life-course by analysing absolute and relative income inequalities in mortality. Study III addresses both the age-as-leveller hypothesis and whether health status can explain the age patterns in the association between income and mortality predicted by the hypothesis. Study IV investigates the impact of mortality on the surviving population in old age in terms of low income and poverty rates.

Specific objectives

1. To analyse the income-mortality relationship in old age (Study I, Study II)
2. To describe the magnitude of the income-mortality relationship across ages (Study II, Study III)
3. To test the hypothesis that health decline overtakes the effects of income in relation to mortality in old age (Study III)
4. To investigate how compositional change due to mortality in old age influences low income and poverty rates (Study IV)

Theories and concepts

This thesis revolves around income, mortality, and age. Below, different perspectives on income are presented and contrasted. This is followed by a discussion of how income is associated with health, focusing on theories of social causation versus selection. Next, a rationale for using mortality as an indicator of health is outlined. The concept of ageing is subsequently discussed, particularly in terms of how income and mortality vary with age. Finally, the combined use of the three concepts of age, income, and mortality in this thesis is explained.

Income

Social stratification and economic resources

Societies are made up of people. People within societies share characteristics and patterns of behaviour that are constantly repeated and performed in everyday life. The aggregate of these patterns is what forms social structure. The empirical study of societal structures has mapped how commonly valued resources are shared, resulting in theories of social stratification. Social stratification can broadly be defined as the ranking of positions within a social system based on aspects considered to be socially important (Kohn, 1999; Parsons, 1940). The definition of socially important or valued resources in societies varies; in modern societies, acquired economic resources are one of the central dimensions of social stratification. This is reflected in the literature, as social stratification scholars often cite income and wealth as central outcomes of the stratification process (see, for example: Dahrendorf, 1968, pp. 151–178; Parsons, 1940; Wright, 2009).

Theoretical perspectives on social stratification build on ideas of how rewards are distributed unequally between individuals in the labour market. The dominant perspective in empirical sociology during the last decades has focused on power relations in the labour market, between employers and employees (Goldthorpe, 2007; le Grand & Tåhlin, 2013). The fundamental conflict in this relation is between those selling their labour and those buying that labour. One influential theory is Goldthorpe's class theory, in which wage inequality is generated by different power relations in the formation of labour market contracts. This perspective emphasises the labour market as a zero-

sum game in which different parties compete for the same resources, thus generating inequality between positions.

Functionalist perspectives on social stratification, which tend to emphasise efficiency as the main driver behind economic inequalities, have also been prominent. One central mechanism in this perspective is productivity, where the basic premise is that higher productivity yields proportionally higher wages. Productivity is both a positional and individual trait; different occupations have varying degrees of productivity, and individuals have varying degrees of skill levels that affect their productivity (Farkas, 2003; le Grand & Tåhlin, 2013; Tåhlin, 2011). Thus, from this perspective, differences in productivity between individuals and between occupations are what generate the unequal distribution of income.

In addition to being one component in the social stratification process, income is also a resource. Income as an economic resource does not have intrinsic value; money does not directly reflect living conditions or material standards, but can be an indicator of these circumstances (Headey, 2008; Ringen, 1988). It is not until economic resources are transformed into goods and services that they provide intrinsic value, through the consumption of food that provides nutrition or by buying a house that provides shelter, for example. Thus, income as an economic resource is an indirect indicator of material standards or living conditions. Amartya Sen (1983) has developed an approach to the concept of resources and their relation to living conditions based on 'capabilities', in which a person's available resources determines the capability of being able to live under some specific living condition. From this perspective, income has the characteristics of a transferable resource, enabling the *capability* of consuming certain goods and services that have some type of *utility*. Thus, income is a requirement to enable the capability to consume goods and services that are directly related to living conditions and material standards.

This brief introductory section on income reveals a relative and absolute aspects of income: as a rank order in a stratified hierarchy, and as a resource enabling a certain standard of living, respectively. The distribution of incomes, the individual position in a rank order, and the absolute level of income have profound implications for how individuals live their lives. Below, I continue with a discussion on how income may affect the health of individuals.

Income and health: social causation

Better living conditions, higher education, favourable working conditions, health-related behaviours and previously good health are all associated with better future health. The association between income and health is one of the most recognised regularities in the social sciences, and has been scientifically documented for at least 200 years (Deaton, 2002; Marmot, 2002). In order for the study of an association to be of value, however, a discussion about possible

mechanisms is warranted. When it comes to the income-health relationship, there are many reasons to believe there are causal connections between the two. In the previous section, two perspectives were presented: income as an indicator of the individual's position in a social system, and income as an individual resource. Two of the dominant theoretical frameworks focusing on the connection between income and health can also be conceptualised along these lines.

The first framework focuses on relative position or standing in the income distribution, and highlights the relative position as important for health outcomes. This notion is supported by the evidence suggesting that the association between income and health continues well above poverty levels. It has been proposed that the mechanisms linking relative position to health function by means of psychosocial pathways. One such process is social comparison, which produces negative, stress-related consequences and feelings of psychosocial disadvantage, (Marmot, 2005; Pham-Kanter, 2009). The perception of low relative standing is in large part determined by a comparison group, and does not necessarily imply a low relative position when the society as a whole is considered. It is known that people tend to compare their positions and define themselves in relation to others, and this comparison works both upward and downward in the social hierarchy (Festinger, 1954; Suls, Martin, & Wheeler, 2002). In addition, people tend to affiliate with others who have similar social standings and characteristics as themselves (McPherson, Smith-Lovin, & Cook, 2001). This implies that someone with a high education and an income above the national average might be (or even tend to be) surrounded by others in similar positions, and compare his own standing to that of others within that group. Therefore, it is possible that this mechanism is connected to health throughout the entire range of the income distribution.

Studies on relative income position have found that it also influences health after adjusting for absolute income, and after creating relevant comparison groups based on personal characteristics (Åberg Yngwe, Fritzell, Lundberg, Diderichsen, & Burström, 2003; Pham-Kanter, 2009; Yngwe, Fritzell, Burström, & Lundberg, 2005).

In studies that examine the income-health association, the exact psychosocial mechanisms that connect relative income position and health are often vaguely formulated and seldom tested directly. There is evidence that the stress response is linked to adverse health outcomes (McEwen, 1998; Pearlin, Schieman, Fazio, & Meersman, 2005; Steptoe & Kivimäki, 2012). The link between social comparison and stress response is less clear; nevertheless, there is a range of animal studies that strengthen the biological plausibility of this pathway. A connection between social rank and biological markers of stress has been shown to be present in primates (Sapolsky, 1989, 2005) as well as rodents (Beery & Kaufer, 2015).

The other dominant perspective on the link between income and health focuses on income as a resource that enables the capability of achieving a certain

level of living and material conditions, which in turn is related to health. This notion is derived from traditional perspectives on the absolute lack of basic resources that are vital for survival, such as the need for enough food to prevent starvation, or shelter to survive the forces of nature. However, in most rich countries, the welfare state guarantees a basic level of protection, suggesting that the lack of basic shelter or starvation may not necessarily be the most common causes of poor health among those with low incomes. Therefore, the theory on material explanations concerning more than the most basic needs for survival is often presented as the neo-material explanation. Material conditions often mentioned in the literature include nutrition, housing, transportation, clothing, and health care (see, for example: Deaton, 2002; Glymour, Avendano, & Kawachi, 2014; Lynch et al., 2004). Higher incomes allow for safer modes of transportation, potentially better nutrition, and higher quality health care. In addition to direct effects due to income levels, there may also be indirect effects: for example, living in a deprived area with low neighbourhood-wide material conditions, such as unsafe environments and potentially lower quality stores could affect health-related consumption and behaviour. Although these effects might potentially influence health across the entire income distribution, they are more likely to be at their strongest at the lower end. For example, the maximum safety a car provides does not scale linearly with price, and it is even plausible that expensive cars may be less safe than moderately priced cars. Similar scenarios can be applied to effects related to housing and healthcare consumption, where health benefits at some point reach a threshold.

As mentioned earlier, the realization of income as a resource occurs when money is transformed into goods and services; in other words, through consumption. The income-health relationship, therefore, is mediated by behaviour. Higher income may enable certain health-related behaviours, either directly through income or indirectly through previous consumption that was enabled by a certain level of income. The discussion above on neighbourhood resources is an example of such a process. Generally, harmful health behaviours are more common in low-income groups. Studies on the prevalence of binge drinking and smoking show substantially higher prevalence among low-income groups (Martikainen, Mäkelä, Peltonen, & Myrskylä, 2014). However, higher income does not necessarily lead to health-promoting consumption; for example, evidence from studies on lottery winnings and inheritance in the United Kingdom has shown that positive income shocks are instead associated with increased drinking and smoking (Apouey & Clark, 2015; van Kippersluis & Galama, 2013).

The two dominant perspectives on the income-health association presented above are not mutually exclusive; on the contrary, they both contribute to explaining the association. Scholars have accordingly suggested an integrated approach that combines psychosocial and material factors and sees them as command over resources that can be both intangible and tangible (Fritzell,

Lennartsson, & Lundberg, 2006; Lundberg, Fritzell, Åberg Yngwe, & Kölegård, 2010). The psychosocial and material explanations have in common that both focus on resources that enables control over the conditions in which people live in. Therefore, the effects related to relative position through psychosocial mechanisms and the lack of economic resources will both have simultaneous effects on health as material conditions overlap with status effects. For example, living in a more expensive area can, in addition to material effects, enable psychosocial effects through status comparison mechanisms. In fact, most material conditions related to improved living conditions and better health are also signals of higher status. This combined effect could be one explanation for the diminishing effects of increased income on health. At lower levels of income, there is a possible interaction between material and psychosocial mechanisms that may generates exponentially worse health outcomes compared to similar effects at higher levels of income.

Income and health: selection

The previous section described some of the possible links between income and health. There are certainly other important pathways, one of which is reversed causality, which suggests that health affects income (Deaton, 2002; Kawachi et al., 2010). This is not only theoretically plausible because of the strong connection between labour market participation, earnings, and disposable income (Kawachi et al., 2010; Smith, 1999), but has also been well-documented in the literature. Disability, disease, and mental health problems often impede the ability to work to varying degrees. Complicated lifelong health problems exert larger influences on labour market earnings while less problematic health issues may have a limited impact on earnings. Regardless, this implies a direction of causality going from health to income. Those unable to work are often found at the bottom of the income distribution, possibly contributing a great deal to the strong association seen between income and health. There is also the possibility of an interacting effect with the type of work, where manual workers with physically demanding work tasks have relatively low incomes and more rapid health deterioration, leading to early labour market exit due to functional decline (Case & Deaton, 2005).

Another alternative explanation that needs to be addressed is the notion of additional pathways: the association between income and health is confounded by other factors, such as education and occupation (Kawachi et al. 2010, Link et al. 2008). It is well known that education and occupation are closely related to income. Education is an important determinant for earnings (Autor, Katz, & Kearney, 2005, 2008), partly mediated through occupation; a higher educational level increases the opportunities for working in an occupation that generates higher income (Cutler & Lleras-Muney, 2006; Lahelma, 2004). Moreover, the influences of education, occupation, and income on health partly operate via shared pathways (Darin-Mattsson et al., 2017; Geyer

et al., 2006). Education is suggested to be connected to health by learned effectiveness (Mirowsky & Ross, 2005; Östergren, 2015), whereas occupation may impact health through the physical work environment and how work is organised (Geyer et al., 2006; Lahelma, 2004). Not only do these pathways tend to co-vary, they may have synergistic effects. For example, it has been shown that the strength of the association between income and mortality is modified by educational level (Östergren, 2018). Östergren (2018) speculated that education could be related to decision making, which is especially important when income is low and each resource allocation decision is particularly important. Thus, the separate mechanisms between income, education, occupation and health could additionally buffer against negative health effects when one dimension is lacking.

Another possible set of confounders for the income-health relationship encompasses individual characteristics. Education, occupation, and income are influenced by individual traits and characteristics such as cognitive and non-cognitive abilities (Farkas, 2003; Gottfredson, 1985; Heckman, 2008). Cognitive abilities are partly biologically determined and partly shaped by environmental factors, and are greatly influenced by childhood conditions (Heckman, 2008). Non-cognitive traits and abilities such as personality, conscientiousness, and sociability are likewise formed during childhood and early adolescence (Farkas, 2003). Non-cognitive traits are not only important for success in school but also later in the labour market, where skills such as social ability and leadership ability are rewarded (Edin, Fredriksson, Nybom, & Öckert, 2018). These traits and skills are influenced by parental socioeconomic background: children from advantaged homes enter the educational system better prepared compared to children from disadvantaged homes (Heckman, 2008). Some suggest that this process can accumulate throughout the educational system, and carries over onto the labour market, further strengthening the stratification process and creating barriers for children from disadvantaged backgrounds. (Heckman, 2008; Kerckhoff & Glennie, 1999).

To fulfil the requirement of a confounder, a causal relationship to the outcome (i.e. health) is also required. Intelligence is suggested to be linked to health through a variety of mechanisms, such as health literacy, disease and injury prevention, and socioeconomic position (Deary, Weiss, & Batty, 2010; Gottfredson, 2004). Similar effects may be true for non-cognitive skills, although the evidence of the effect of non-cognitive skills on health remains uncertain (Smithers et al., 2018). Thus, the connection shown above between cognitive and non-cognitive abilities and both income and health indicates a confounding effect in the income-health association.

Social causation versus selection: empirical support

There is a massive amount of research on the relationship between income and health, not least within the fields of public health, epidemiology, and medical sociology. Over 46,000 studies were identified in the first step of a systematic review that examined the impact of income on children's outcomes (Cooper & Steward, 2013). There is no lack of studies on the working age population either: studies examining the association between adult income and health are numerous (e.g. Chetty et al., 2016; Dowd et al., 2011; Fritzell, Nermo, & Lundberg, 2004; Marmot, 2002; Martikainen et al., 2014). Significantly fewer studies have covered the relationship between income and health in old age, but those that have often find that the association persists (Cullati, 2015; Huisman, 2004; Korda, Paige, Yiengprugsawan, Latz, & Friel, 2014; Mortensen et al., 2016). Studies on income and health tend to implicitly or explicitly assume that the association is generated through social causation. However, the empirical evidence supports the opposite direction of causality as well: O'Donnell et al. (2015) summarized the literature regarding the effects of health on wages and concluded that ill-health has a modest effect. This effect can partly be attributed to the effects of health on the ability to work; for example, García-Gómez (2011) found that health had an effect on the probability of employment in nine European countries.

Accordingly, based on previous literature on the income-health association, both directions of causality seem plausible. The majority of studies have relied on cross-sectional or longitudinal data, which can establish associations between variables (Glymour et al., 2014). Studies using longitudinal data are able to control for time-varying effects during the period data is collected, providing further evidence of a relationship beyond the ability of cross-sectional data. However, there is always the possibility of omitted variables or prior effects from health or socioeconomic variables (Kawachi et al., 2010). One way to isolate the effects of a variable is to perform experiments in which only the variable of interest is manipulated. Considering the difficulties of assigning random incomes to people, most studies with an experimental design have relied on naturally occurring experiments. This approach has been used in studies of lottery winnings, which replicate a random event in terms of a temporary increase in income. Studies of the effects of increased income from lottery winnings on health outcomes show mixed results (see, for example: Apouey & Clark, 2015; Kawachi et al., 2010; Lindahl, 2005). An important aspect of lottery winnings and other income shocks such as unexpected inheritance is that these are one-time events, as compared to income from work. This was partly controlled for in a study from Sweden (Cesarini, Lindqvist, Östling, & Wallace, 2016) that included a range of different lotteries. One of the included lotteries provided a monthly payment of between 10,000 SEK and 25,000 SEK for 10 to 25 years (for the sake of comparison, the median monthly income before taxes in Sweden in 2017 was 26,500 SEK). The study

found no evidence that lottery winnings had an impact on mortality or health care utilisation, and furthermore, they found no effects or only minor effects on the outcomes for children. One reason for the weak causal effect found in lottery studies could be that the positive income shock these types of income gains generate also promotes negative health behaviours, thereby possibly negating the short-term positive effects of receiving large sums of money (Apouey & Clark, 2015; van Kippersluis & Galama, 2013).

Kawachi et al. (2010) performed a survey of studies examining the income-health relationship using experimental, quasi-experimental, and longitudinal methods. Findings from studies using these designs were mixed, and questions remain about the methodology of the experimental and quasi-experimental designs. Kawachi et al. concluded that the evidence at least supports the hypothesis that raising incomes for the poor will result in better health outcomes, but that any further findings remain uncertain. A similar review of the literature on the causal impact of income on health beyond observational studies was carried out by Glymour et al. (2014). The authors came to similar conclusions regarding the strength of the relationship, with much of the literature suggesting a substantial reversed causality pathway going from health to income in addition to a social causation pathway.

Taken together, studies that use a causal framework or experimental design seem to indicate ambiguous results regarding the causal impact of income and money on health. One interpretation of these studies is that a one-time injection of income or a slight rise in monthly income for persons who live above absolute poverty levels in modern welfare states will have limited to no impact on their health. A potential explanation for the mixed findings may also be the complicated pathways that link income to health; after all, the transformation of income to other resources will only generate better health if those resources promote health. Even unlimited resources cannot improve health if the resources are supported by poor decisions.

Mortality

While death is inevitable, the time spent alive is variable; it can be short or it can be long. A long life is something desired by most. In fact, it is valued so much that lifespan has become a key indicator for the success of societies, and increased life expectancy is one of the past century's success stories (Cervellati & Sunde, 2005; Oeppen & Vaupel, 2002). Delaying death and living long lives is something to which most people ascribe intrinsic value, and, as Sen argued, "this is not only because living as a state of being is itself valued, but also because it is a necessary requirement for carrying out plans and projects that we have reason to value. The dead cannot do much" (Sen, 1998, p. 4). Since death is inevitable, however, there must be a time to live and a time

to die. Studies have shown that the will to live decreases in old age, particularly among those suffering from terminal health problems (Carmel, 2001; Seale & Addington-Hall, 1994). Thus, mortality has independent qualities as an indicator of the value people ascribe to life, and an event that healthy people seek to delay.

In addition, mortality is an indicator of health. A person's death is always attributable to a cause, and that cause is most often health related. The two most common causes of death are cardiovascular diseases and malignant neoplasms. In Sweden, these two causes accounted for 34% and 26% of all deaths in 2017, respectively (Socialstyrelsen, 2018). In contrast, accidents caused only 5% of all deaths occurring in 2017, and only 3% among those aged 65 and above (Socialstyrelsen, 2018). The extremely strong connection with health makes mortality a reliable summary measure of health at the group level (National Research Council, 2010; Parrish, 2010).

It should be acknowledged that all-cause mortality is a crude measure of underlying health status before death. Therefore, cause-specific mortality can be more informative than all-cause mortality in terms of mechanisms or pathways when studying the effects of income on specific health outcomes. The strength of all-cause mortality, rather, lies in the fact that it more extensively captures all underlying health conditions that have led to death. This broad scope is compatible with health as a complex concept. Attempts to define health often arrive at the conclusion that it is not an easy task (Callahan, 1973; The Lancet, 2009), and some even go so far as to say that it is futile to even try (Jadad & O'grady, 2008). Therefore, specific indicators of ill health, like diseases, functional status, or evaluations from a medical doctor, can never encompass all that is health. In contrast, when used at the population level or in large group comparisons, all-cause mortality is an efficient and reliable health indicator.

Age

Ageing is a lifelong process. The term ageing is often used to refer to both chronological and biological ageing. Chronological age refers to the time a person has been alive as measured from birth in days, months, and years. Biological age refers to the development or deterioration of an individual's biological system, which begins at conception or birth and ends with death (Pankow & Solotoroff, 2012). Chronological age affects everyone at a constant rate; from a temporal perspective, one year is one year, regardless of what has occurred during that time. In contrast, the rate of biological ageing varies between individuals (Belsky et al., 2015).

Age is not only an individual characteristic: it is the basis for many institutional arrangements in modern societies. Societal institutions are organised around specific age groups, such as transitions in and out of education, work,

and retirement. This age stratification contributes to expected and normative behaviours associated with chronological age (Dannefer & Kelley-Moore, 2009; Riley, 1971). Moreover, the organisation of age-stratified institutions in societies is influenced by period effects (Riley, 1971). One current example of this process is the upward shift in the retirement age as a result of increased longevity and ageing populations, which may potentially change the expected behaviour on the labour market among future ageing cohorts.

Age and income

While the older segment of the population is the focus of this thesis, people's adult lifespans are also examined. The most defining institution during the adult life course is that of work, and the labour market shows clear age-stratified patterns that start with the transition from education into the labour market, and end with the transition from the labour market into retirement. Moreover, labour market participation is directly related to source and level of income. Young adulthood is characterised by lower incomes and higher volatility; in middle age, on the other hand, incomes tend to be higher and more stable (Björklund, 1993; Böhlmark & Lindquist, 2006; Haider & Solon, 2006). Average income levels reach their highest peak between ages 40 and 60 (SCB, 2018; U.S. Census Bureau, 2018). The transition out of the labour market and into retirement is most often followed by decreasing incomes, and the highest age concentration of poverty is found among the oldest old (Brown & Prus, 2004; European Commission, 2018; OECD, 2017; Smeeding & Sandstrom, 2005).

Figure 1 shows the age pattern in median income levels during two years included in this thesis (1995 and 2005). There are clear age trends showing increased income up to ages 50-64, followed by declining incomes in old age. The difference in income levels between 1995 and 2006 indicates an overall increase in incomes during this period. Furthermore, increased differences in income levels across ages can be seen during this period; income for those in younger age groups increased more between 1995 and 2005 than income for those aged 65 and over.

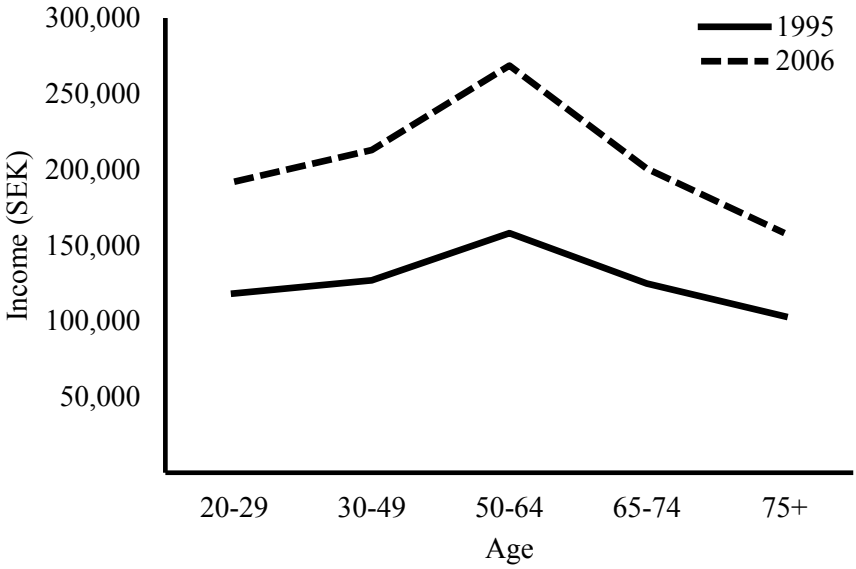

Figure 1. Median annual disposable income during 1995 and 2006 in five age groups; inflation adjusted to 2015. (Source: Statistics Sweden)

Moreover, there are large variations in income by gender in all age groups; women receive lower pensions than men in all European countries (European Commission, 2018). Women's lower pension income is partly due to lower life-time labour force participation and lower wages compared to those of men, especially among older cohorts (Bastos, Casaca, Nunes, & Pereirinha, 2009; Favreault & Sammartino, 2002; Magnusson, 2010). At the top end of incomes, women are severely underrepresented. In the United States, only 1 in 20 households among the top 1% qualified based on the woman's income, and the vast majority of households qualified only based on the man's income (Yavorsky, Keister, Qian, & Nau, 2019) In combination, these factors are responsible for lower accumulated lifetime earnings and lower pensions for older women. Furthermore, these mechanisms are potentially exacerbated in old age, as women tend to live longer lives with lower pensions, and thus spend more years in poverty than men (Dice Database, 2015; Minkler & Stone, 1985; Smeeding et al., 1999).

Age and health

The very idea of growing old is often associated with the notion of declining health. Despite the fact that biological ageing is often defined in terms of cell breakdown or DNA damage, however, the process of ageing should not be confused with disease or ill health (Kelley-Moore, 2010; Priestley, 2003). One

fundamental mechanism in biological ageing is accumulated damage at the cell level (Kirkwood & Austad, 2000), which may, for example, increase the risk of cancer (Adams, 2005). The relationship between ageing and declining health varies by disease type, however, and is still poorly understood.

Rates of the most common causes of death – heart disease, stroke, Alzheimer's, dementia, and many cancers – increase dramatically with age (Kaeberlein, 2013; Lopez & Murray, 1998). In Sweden, an exponential increase in the mortality rate begins between the ages of 30 and 40. Figure 2 shows death rates from the ages of 0 to 100 in Sweden during the year 2000. Only an extremely small share of the total deaths occurs between the ages of 1 and 30, while after the age of 30, mortality increases exponentially. As illustrated by the y-axis in Figure 2, it is not until after the age of 60 that mortality becomes a more frequent event. The first scale value on the y-axis in the figure on the right is 10 times higher than that of the highest scale value in the figure on the left. Thus, mortality is highly uncommon at younger ages, and starts to become an expected event only in old age.

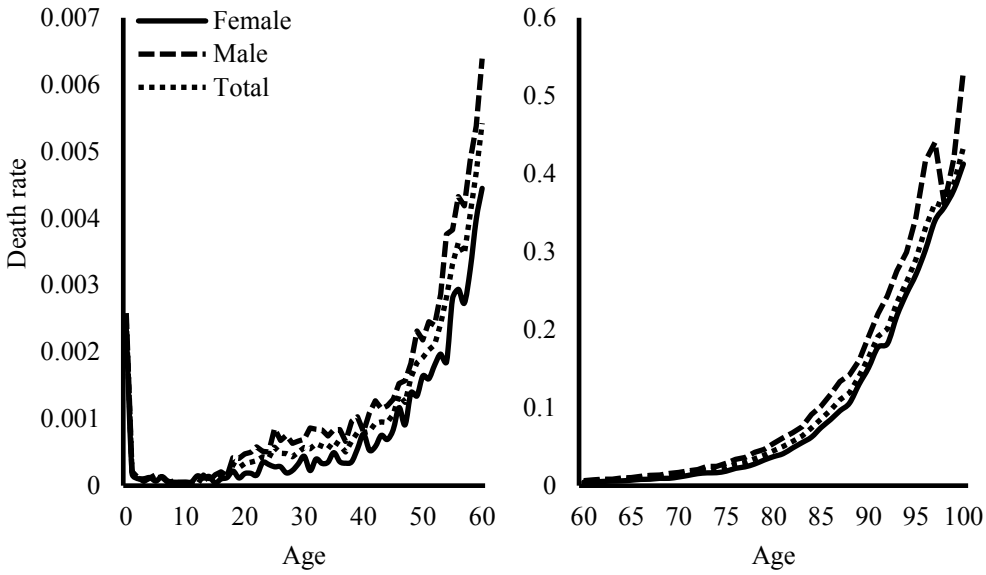

Figure 2. Death rate by sex in Sweden 2016. (Source: Human Mortality Database)

In addition, Figure 2 shows that men have higher death rates at all ages compared to women. Sex differences in life expectancy are well known; women currently outlive men all around the world (Barford, Dorling, Smith, & Shaw, 2006). The extent of sex differences in life expectancy, however, varies over time and between countries. For example, 19th century data from the United States show sex differences in mortality to be fewer than 6 months, but this

difference grew during the 20th century to around 5 years (Goldin & Lleras-Muney, 2018). In contrast, recent trends in Sweden indicate decreasing sex differences in life expectancy (Sundberg, Agahi, Fritzell, & Fors, 2018). Men tend to die more often of fatal and chronic diseases such as heart disease and cancer at younger ages than women, who tend to live longer and suffer from less life-threatening diseases (Rieker & Bird, 2005; Verbrugge & Wingard, 1987). This situation, in which men tend to have shorter lives, but with fewer health problems, and women tend to live longer, but with more health problems, has been called the gender-health paradox.

There are many possible explanations for sex differences in mortality and morbidity rates, and both biological and social determinants contribute to these differences. Possible biological explanations include the genetic and hormonal differences between men and women; for example, women tend to have a higher risk of autoimmune and genetic immune suppression disorders than men (Rieker & Bird, 2005). The great variability in mortality over time and between contexts, however, indicates that social and behavioural differences between men and women can explain many of the observed disparities (Oksuzyan, Juel, Vaupel, & Christensen, 2008). For example, smoking patterns have been linked to both increasing and decreasing sex differences in mortality rates (Preston & Wang, 2006).

Income, age, and mortality

In the previous sections, the literature on the income-health relationship, mortality, and age was discussed. It is evident that income, health, and mortality vary over the life course and that the causes of this variation are attributable to widely different and complex mechanisms. The characteristics and magnitude of age-related changes in the association between income and mortality constitutes one of the prime concerns in this thesis. The theories and hypotheses that have been used to interpret the empirical results in this thesis can be divided into two categories: the first accounts for patterns of *decreasing* health inequalities with increased age, and the second focuses on patterns of *increasing* health inequalities with increased age. These theories and hypotheses are presented below.

Levelling

The age-as-leveler hypothesis has been used to explain observed decreases in old age inequalities. The literature on this hypothesis can be traced to the 1960s and 1970s, when it was used to illuminate the possibility of declining race inequalities in old age (Dowd & Bengtson 1978; National Urban League, 1964). This was followed by an increasing amount of studies on ageing and

health during the 1980s that included the age-as-leveler explanation for decreased health inequalities (Belgrave, Wykle, & Choi, 1993; Dowd & Bengtson 1978; Ferraro, 1987; George, Okun, & Landerman, 1985). Since then, it has become an oft-cited hypothesis in social gerontology and studies examining health inequalities in old age (Dupre, 2007; Ferraro & Farmer, 1996; House et al., 1994; Kim & Durden, 2007; Lynch, 2003). The hypothesis proposes that age acts as a leveller of inequalities between groups; in other words, age modifies the relationship between income and health. Three processes for the impact of age have been suggested: social processes, biological age or health decline, and selection. The specific mechanisms mentioned in the literature vary from study to study, as does the emphasis on which is the main process. Below, however, each of them is presented as part of the age-as-leveler hypothesis.

Biological mechanisms

The first set of mechanisms are biological or health-related effects in old age, which are closely related to theories of biological ageing. Biological ageing can refer to a multitude of processes and theories that focus on the decay or breakdown of cells or bodily functions over time. One theoretical framework that focus on biological decline in old age has been developed by Baltes and colleagues (Baltes & Singer, 2001; Baltes & Smith, 2003; Baltes, Staudinger, & Lindenberger, 1999). As a basic premise, Baltes et al. proposed that human evolution has primarily focused on developing the first half of the human lifespan in order to guarantee and promote the reproduction of the human species. In contrast, the later part of the human life course has been less susceptible to evolutionary selection because historically, few people reached old age. Thus, humans are biologically ill equipped to grow old and are increasingly vulnerable in old age. The biological limitations of the human body ultimately result in death, which at some point in the ageing process becomes independent from social influences (House et al. 1990, Liang et al. 2002). These processes imply a weaker association between income and health at later ages, as the biological ageing process overtakes most of the effects that social conditions may have on health.

Social processes

The second set of mechanisms relating to the age-as-leveler hypothesis concern age-varying social processes. Many welfare states have shifted to a pro-old model, with more extensive and universal health care for the old as well as income redistribution from the working population to support benefits and social care in old age (Birnbaum, Ferrarini, Nelson, & Palme, 2017; Dupre, 2007; Hoffmann, 2011; Preston, 1984). The income side of the argument relies on the hypothesis that the connection between income and health may be severely weakened when incomes are to a large extent supported by pensions

based on previous work life, and redistributions from the working age population to current pensions. During working age, having a stable and secure income is reliant upon the ability to participate in the labour market. Those unable to work for whatever reason (e.g. job shortages, lack of education, or health problems) often end up living in poverty. Retirement can thus favour those at the bottom of the income distribution by raising the minimum income levels in the most disadvantaged segment of the population. This idea finds some support in Swedish data: Figure 3 shows the percentage of individuals whose income is less than 50% of the total population's median income in different age groups. The lowest share is found among those aged 65-74 and those aged 50-64, yet the median income is substantially higher in those aged 50-64 (not shown). This indicates a compression of incomes in the lower half of the income distribution after retirement age, and maintenance, or even an increase, in the minimum income levels. However, this compression is only visible among the younger-old age groups (65-75). After age 75, pension incomes tend to become lower relative to incomes in other age groups, and the highest age concentration of poverty is found among the oldest segment of the population (Smeeding & Sandstrom, 2005).

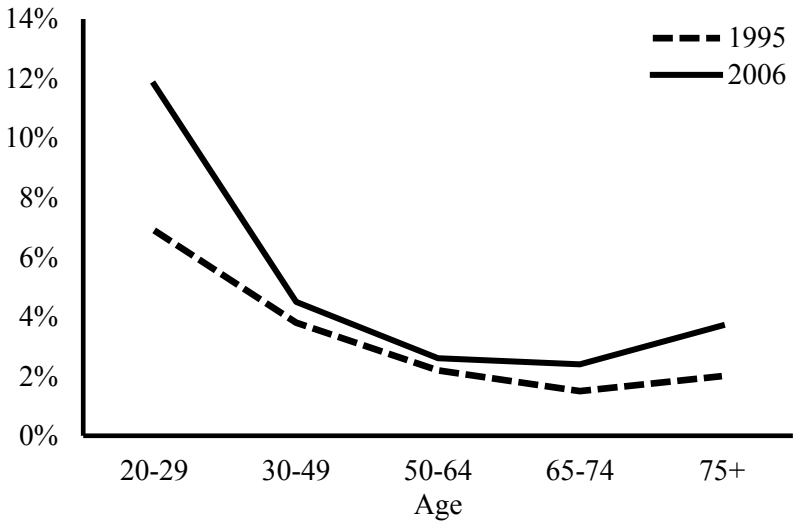

Figure 3. Percentage of persons with an income less than 50% of the median income in 1995 and 2006. (Source: Statistics Sweden)

The health side of the argument relies on ideas of more equal health care policies in old age compared to other ages. Dupre (2007) and Preston (1984) argued that Medicare in the United States might be such an example. Evidence from the United States has shown that individuals with higher incomes and greater wealth tend to pay for more and better health care when such options

are available (Kim & Ruhm, 2012; Moran & Simon, 2006; Tsai, 2015). Therefore, social policies that provide public health coverage for the old might result in more equal health care utilisation and, by extension, more equal health outcomes. This example is less applicable to the Swedish case, where universal healthcare is provided at all ages. Despite having universal health care, however, there is nevertheless some degree of prioritisation in health care investments. For example, more general health care investments in Sweden might have effects that have benefited the old to a disproportionate degree, such as nursing homes and elder care facilities, thus reducing inequalities in old age compared to younger age groups.

Overall, the social and institutional circumstances that influence the income-health relationship are very much determined by policy, and can therefore vary between and within countries over time. Societies choose how to redistribute resources between the old, the working age population, and children (Preston, 1984). The increasingly ageing population has created strong interest groups that are pro-old biased, which has led to stronger incentives for increased redistribution toward the older segment of the population (Birnbaum et al., 2017; Kotlikoff & Burns, 2014; Preston, 1984). Studies show that in the wake of population ageing, a larger share of social spending has gone to the older population, and this process may lessen the effects of income on health in old age. Thus, the equalising effect of this process in the age-as-leveler hypothesis relies very much on the fact that the welfare state has a bias that generates disproportionately large public spending on the older segment of the population.

Selective mortality

The third pathway, which has sometimes been highlighted as the main explanation in the age-as-leveler hypothesis, is selective mortality or selective survival (Dupre, 2007; Ferraro & Farmer, 1996; Vaupel & Yashin, 1985). This selective process is the result of socially patterned mortality (i.e. socioeconomic inequalities in mortality). The higher mortality risk in lower socioeconomic groups leaves a surviving population that is healthier and has a higher socioeconomic position than it would, had no one died. The effect can be thought of as purely compositional, wherein the composition of a population is affected by population entry or exit (Hobcraft, Menken, & Preston, 1982; Vaupel & Yashin, 1985). Therefore, processes that are examined in populations affected by compositional changes should be evaluated with the acknowledgement that the original population differs from the surviving population (Vaupel & Yashin, 1985). Furthermore, in cases of compositional changes, caution should be taken when making inferences from population level patterns to the individual level. The individual level patterns may very well look substantially different from the population-level patterns in a scenario where the composition of the population changes.

For mortality to be a selective process in the income-mortality association, only one condition needs to be fulfilled: that deaths are not distributed at random over the income scale. There is an overabundance of evidence suggesting that socioeconomic position is strongly related to mortality and, accordingly, most of the mortality within a population also changes the composition of the surviving population. The extent to which compositional changes affect the observed results to any substantial or significant degree nevertheless relies on the strength of the selective process and the number of individuals affected. For example, a strong association between income and mortality when only a very small fraction of the population dies will have minor impact on the surviving population, with no statistically significant effect and no meaningful implications of the change. In an ageing cohort, this would imply that a strong social gradient in mortality at working age will have only a limited impact on the surviving population if mortality rates are low. However, as mortality rates increase, the impact on the surviving population will grow. From this reasoning it follows that there is an inevitable convergence as the rate of selection accelerates: the surviving population will continuously become more homogenous, and the difference for each time unit will become smaller; in other words, the social gradient will weaken.

An example of this process is illustrated in Figure 4, which is based on the total population register data used in Studies I, II, and IV. The figure shows the average income over 17 years (1990-2006) for those who died within a three-year period (2007-2009) in each age category as a percentage of the average income over 17 years for everyone in the same age category. In other words, the figure shows the average income among those who died compared to the average income of everyone for each age category.

The difference in income between the complete population and those who died within the three-year period is strongest at age 60, indicating a strong social gradient in mortality. This difference continuously decreases with increased age and increased mortality rates, until the income difference between those dying and the complete population converges completely. Vaupel (1985) described this process in terms of robustness: "the dependence of the cohort hazard rate on the sub cohorts' hazard rates is thus mediated by the changing proportion of the population that is in the one or the other of the sub cohorts. Over time, the observed hazard rate will approach the hazard rate of the more robust sub cohort" (p. 176). In Vaupel's terms, the changing composition in the dying sub cohort will become more similar to the composition of the surviving sub cohort, resulting in a convergence between the groups. In other words, the social gradient in mortality will weaken when the causal mechanisms that link income to mortality have played out their roles, and the surviving population is for one reason or another no longer affected by them.

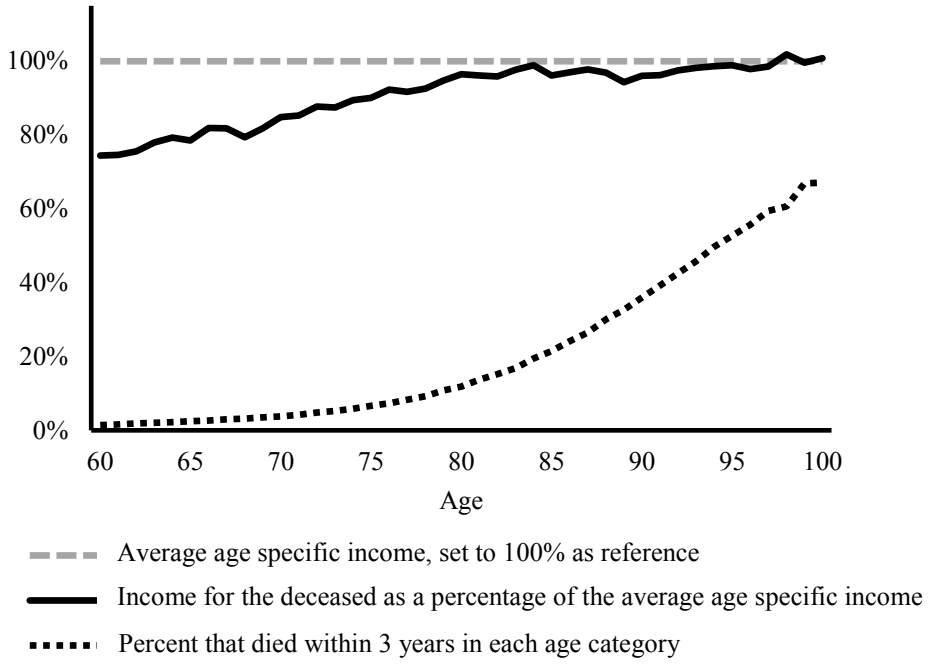

Figure 4. Average income for those who died within three years as a percentage of the age specific average income (reference) in each age category, and death rate within three years of each age category.

Accumulation

In social gerontology, cumulative (dis)advantage theory is often used to explain patterns of increased inequality in old age. The theory suggests that the accumulation of advantage and disadvantage leads to greater diversity within cohorts as time passes (Dannefer, 1987, 2003; Kim & Durden, 2007; O'Rand, 1996; Rowe & Kahn, 1987). Theories on the accumulation of advantage originated from Merton's (1968) so-called 'Matthew effect', where he describes a process of disproportional credit given to established researchers compared to less well known researchers for a comparable contribution. The mere presence of a recognised name on a research paper can in itself increase the paper's impact and visibility. The processes at work are similar to a self-fulfilling prophecy: a famous scientist publishes a finding; based on the premise that she has contributed important findings in the past, others believe this finding must also be important; because the finding is believed to be important, it will be read more carefully; and the more carefully it is read, the more impact it will exert on the reader. On the basis of this Matthew effect, the accumulation

of advantage and disadvantage has been generalised to age-related social processes that causes intra-cohort heterogeneity with increased age (Dannefer, 1987, 2003; Ferraro & Morton, 2016).

The present thesis focuses on the role of age in the income-health relationship, and thus deals with two concepts that vary simultaneously as well as separately over time: income and health. This type of accumulation has been referred to as an extrinsic type of process wherein accumulation of one phenomenon affects another phenomenon (Ferraro & Morton, 2016). Below, I further describe three types of accumulation processes to which the income-health relationship is subject over the life course.

The first process is that of income accumulation, which, according to the theories of accumulation, may lead to increased intra-cohort heterogeneity in individual resources over time. This is seen in savings, for example, where low-income households save less than high-income households (Grinstein-Weiss, Wagner, & Ssewamala, 2006), thus leading to larger inequalities in financial assets over time. Similarly, the accumulation of capital has been shown to grow exponentially and to favour those who already have large capital assets (Piketty & Saez, 2014). Pension incomes are a direct reflection of the lifelong accumulation of income from work, and therefore measures of income during one year in old age may better capture the concept of accumulated resources than, for example, measures of income during one year in middle age.

The second process is the effect of health accumulation over the life course: those with multiple health problems (i.e. multimorbidity) tend to be at a greater risk of death, disability, functional decline and other adverse health-related outcomes (Marengoni et al., 2011; Salive, 2013). Moreover, exposure to health risks could accumulate over time, with adverse effects postponed until old age, since many health problems take time to develop. For example, the time between exposure to asbestos and the development of asbestos-related types of cancer is typically more than 20 years (Lanphear & Buncher, 1992). Similarly, the time between exposure to air pollution and the development of lung cancer could be as long as 20 years (Nyberg et al., 2000). Thus, the accumulation of health and health-related exposures could generate increased heterogeneity in health status with increased age, and especially so among older persons.

The third process is the accumulated effect of the interaction between both income and health across the entire life course, possibly resulting in an exponential effect of the combined exposures from both dimensions. This process is often described in the income-health literature as a bi-directionality in the relationship between income and health, and sometimes recognised as a lifelong process (see, for example: Deaton, 2003). In the context of age-related accumulation, the direction of causality is not of primary concern; instead, the central notion is the divergence of intra-cohort trajectories in the income-

health relationship. The two idealised types of accumulation that create divergence might, on the one hand, be reflected by individuals who remain in good health and have high incomes throughout their life courses and, on the other hand, those who have health problems and experience low income throughout their lives. These exposures will over time result in larger income and health differences in old age.

Levelling and accumulation: empirical support

Empirical support for the age-as-leveler hypothesis versus the cumulative (dis)advantage theory is often presented in the form of decreasing versus increasing health inequalities with increased age (see, for example: Beckett, 2000; Leopold, 2016; Lynch, 2003; van Kippersluis, O'Donnell, van Doorslaer, & Van Ourti, 2010). However, the results are conflicting in terms of whether income inequalities in health level off or accumulate with increased age. These conflicting results can most likely be attributed to differences between studies in the choice of time period, country, age range, health outcome, socioeconomic indicator, and type of inequality measure. Because of this, it is difficult to give a comprehensive overview of the literature. Nevertheless, time period and country should not distort the overall patterns of age-related inequalities if the underlying income-health mechanisms are somewhat similar throughout both time and place. The literature on health inequalities indeed shows that such patterns are prevalent in all of the developed world, and studies on accumulation also suggest that they could be independent of place (Leopold, 2016; van Kippersluis et al., 2010).

Still, the age range and the types of measures used in the studies are important aspects to consider when reviewing the literature. First, the inclusion of the oldest old is critical when evaluating age effects in the income-mortality relationship. This requirement limits the suitable data, as few surveys include the old, and among those that do, the representativeness of the data is often questionable. Regarding the types of measures used to determine the income-mortality association, differences can broadly speaking be quantified as absolute differences or relative differences. When the prevalence of the outcome measure varies by a large degree, so does the context in which the measure should be interpreted (Harper et al., 2010; Mackenbach, Martikainen, Menvielle, & de Gelder, 2016). This is the case in studies of age and mortality, as was shown above: mortality is a rare event before age 60 and starts to become a commonly experienced event only after age 70. The choice of measure is seldom explicit in studies that evaluate levelling or accumulation, and relative measures are the most commonly used. In 2009, 75% of studies on health inequalities published in leading medical, public health, and epidemiology journals reported only a relative measure (King, Harper, & Young, 2012).

Empirical studies of the income-mortality association that include the oldest old remain scarce. This is especially true for studies that include both relative and absolute inequalities. Table 1 shows an overview of studies that examine the income-mortality association across ages and include the older segment of the population. Mortensen et al. (2016) examined the shape of the association between income and mortality in all Nordic countries using population data. The income-mortality gradient measured as relative differences increased with age for those aged 25 to 64, but decreased with age for those 65 and over. The absolute measure indicated larger differences in the income-mortality relationship in old age compared to younger age categories. Elo and Preston (1996) included income as a covariate in logistic models that predicted five-year mortality, and found that the relative effect between income and mortality was stronger for those aged 25 to 64 compared to those aged 65 to 89. Hoffman (2011) found that the relative mortality risk by income group decreased with age. Age was compared using 10-year intervals as categories: 59-69, 70-79, 80-89, and 90-99. Reques et al. (2015) used indicators of material wealth to estimate relative differences in mortality in an older Spanish population, and found that differences decreased in old age.

The evidence indicates that the income-mortality association measured by relative differences declines in old age. While empirical studies using absolute measures remain scarce, however, studies on education and mortality in 11 European countries (Huisman, 2004) are in line with the findings from Mortensen et al. (2016) showing that the absolute differences increased in old age.

Table 1. Overview of studies that describe the income-mortality association across ages, including the oldest.

	Mortensen et al. 2016	Hoffmann 2011	Elo, Preston 1996	Reques et al. 2015
Period	1995-2000, 2003-2008	1980-2002	1979-1985	2001-2011
Country	4 Nordic countries	Denmark	USA	Spain
Age	25+	58+	25-89	65+
Type	Absolute, relative	Relative	Relative	Relative
Conclusion	Absolute: increased; Relative: decreased	Decreased	Decreased	Decreased

Levelling and accumulation: combined effects

The literature on the income-health association seems to indicate that more than one mechanism is operating simultaneously at different levels of aggregation and at different times. For example, it is reasonable to assume that social benefits in pro-old welfare states weaken the income-health relationship in old age by reducing social inequalities or by reducing health differences by

providing health-related services. At the same time, the accumulated exposure to income and health during the life course could still have an effect, and result in a strengthened income-health relationship in old age. The overall effect of the different mechanisms has the potential to vary over time and context; societies change in terms of welfare generosity as well as in terms of which age groups are targeted. Such changes can modify the strength of the income-mortality relationship.

Another complicating factor is the influence of mortality selection, which could hide individual-level mechanisms by altering the composition of the surviving old age population. Individuals who survive into old age are systematically different from those alive at younger ages and, in general, frailer individuals tend to die at a younger age (Vaupel, 1998). As a result, the surviving old age population, which consists of more robust individuals, might be less susceptible to the influence of socioeconomic conditions on health, and the causal mechanisms that linked income to health at younger ages might be weaker or non-existent in the robust surviving population. This observation was made by Dupre (2007), who found evidence for a combination of accumulation and levelling in educational inequalities in health. According to Dupree, selective mortality influences the composition of the surviving population and causes decreasing inequalities at the aggregate level. At the individual level, however, socioeconomic effects on health accumulate. This led Dupre to argue that the effect of socioeconomic position (in this case, education) on health does not change with increased age; rather, the decreased association is attributable to aggregate changes in the composition.

Health inequality: conceptualisation and measurement

Inequality can be defined as the unequal distribution of some type of resource between persons (Grusky & Weisshaar, 2014; Treiman, 1970). For example, the income inequality in a group of people is determined by how income is distributed within that group. Larger inequalities generally reflect resources being concentrated in the hands of a smaller group of people, whereas in contrast, smaller inequalities indicate that resources are less concentrated and more equally shared. Health inequalities can be understood in similar terms: namely, as the dispersion of health in a group of people (Kawachi, Subramanian, & Almeida-Filho, 2002; Murray, Gakidou, & Frenk, 1999). In common use, however, the term health inequalities has come to be equivalent to social group differences in health. This perspective adds an additional dimension to the concept of inequality, since it refers to the distribution of health in groups defined by a set of resources (the resource in this thesis being income). As a consequence, a definition of health inequalities that connects resources to health adds an inherently normative aspect to health inequalities (Murray et al., 1999).

The distribution of health between groups of people has often been quantified. A prevailing tradition in epidemiology has been to compare relative differences when assessing causality, and this tradition has been 'handed down from one generation to the next, without citation or critical reflection, as though [its] truth were self-evident' (Poole, 2010, p. 3). Poole (2010) showed that the arguments that were originally in favour of the risk ratio in assessing causality are flawed, and that under several conditions a rate difference measure is equally valid. The discussion of absolute and relative measures has appeared in the assessment of health inequalities and, as in epidemiology, studies on health inequalities have strongly favoured relative effect measures. King et al. (2012) conducted a review of studies that examined health inequalities in 10 leading medical and public health journals, concluding that only 7% of the articles included in the review reported both absolute and relative measures, whereas 75% of the articles reported only relative measures. One of the main arguments for reporting both absolute and relative measures of health inequalities is that the interpretation of these measures may differ substantially (Eikemo, Skalická, & Avendano, 2009; Houweling, Kunst, Huisman, & Mackenbach, 2007; King et al., 2012; Mackenbach et al., 2016). This is especially the case under conditions in which the underlying prevalence of the outcome is changing; such conditions have been common during the last decades for many health outcomes (Mackenbach et al., 2016). Generally, health has improved for everyone, and the prevalence of diseases and mortality rates have declined in many Western countries.

One example of a questionable interpretation of changes in relative inequalities was highlighted by Vågerö & Erikson (1997) more than 20 years ago. The study they referred to (Mackenbach, Kunst, Cavelaars, Groenhof, & Geurts, 1997) claimed that, based on relative inequalities, there was no support for the hypothesis that health inequalities are smaller in more egalitarian countries. Vågerö & Erikson argued that a relative measure of inequality could be misleading when evaluating the impact of egalitarian policies on population health; the public health relevance of such policies may better be evaluated with absolute inequalities, which reflect the actual health status of a population, rather than the relative distribution of health.

Similar problems arise when health inequalities at different ages are of interest, such as in this thesis. Health problems and mortality rates increase dramatically as people age. Therefore, in order to evaluate the magnitude of inequalities at different ages, both relative and absolute inequalities need to be taken into account.

One central question, then, is what differs in the interpretation between absolute and relative inequalities. Mackenbach et al. offered one reasonable answer to this question:

> Using relative measures implies a strictly egalitarian position, in which what matters is equality in itself, independent of other considerations such as the absolute rates of disease for each group. Using absolute measures implies the pragmatic view that absolute rates matter most for people in lower socioeconomic groups, and that a smaller absolute mortality excess is thus to be preferred even if it goes together with a larger relative mortality excess (Mackenbach et al., 2016, p. 6).

This position highlights the fact that relative measures are independent of the prevalence of the underlying measure, while absolute measures are not. Furthermore, since absolute measures are directly reflective of the health status of the population, the public health relevance is often higher for absolute measures than for relative measures.

This can be illustrated with an example from the cumulative (dis)advantage theory, which postulates growing intra-cohort variability with the passage of time. A hypothetical cohort is presented in Table 2 and Figure 5. The cohort is aged between 30 and 90 and health status is measured from 0 to 100, in which 0 represents the best possible health status and 100 represents the worst possible health status. Furthermore, the cohort is divided into two income groups, one high-income group and one low-income group. The health status differs slightly by income at age 30 and, for each additional year, the average health status in both income groups grows worse. In accordance with predictions made by cumulative (dis)advantage theory, for each additional year, the health status of the low-income group becomes increasingly worse compared to the health status of the high-income group. In other words, the rate of health decline is faster in the low-income group than in the high-income group. This leads the intra-cohort variability in health status to grow with increased age. However, this is only reflected in the absolute measure; the relative measure even suggests that the difference between the income groups declines (see Table 2 and Figure 5). This implies that the evaluation of increasing or decreasing inequalities in terms of the cumulative (dis)advantage theory should be based on an absolute scale that reflects the health status of the observed population rather than a relative change in health status.

Table 2. The hypothetical distribution of health in a cohort divided in a low-income and a high-income group from age 30 to age 90. Health varies between 0-100, 0 represents the best health and 100 represents the worst health.

Age	Health status in the high income group	Health status in the low income group	Relative difference	Absolute difference
30	10	16	160%	6
40	20	30	150%	10
50	30	44	147%	14
60	40	58	145%	18
70	50	72	144%	22
80	60	86	143%	26
90	70	100	143%	30

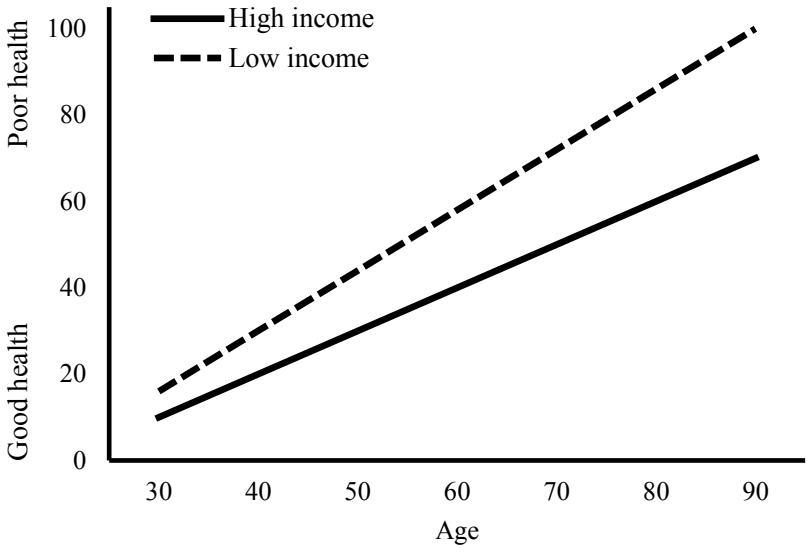

Figure 5. The hypothetical distribution of health in a low-income and a high-income group from age 30 to age 90. Based on data from Table 2.

Data and methods

Data

Two types of data were used in this thesis: register data and survey data. Swedish population register data was used in all studies, whereas survey data from the Level of Living Survey (LNU) and the Swedish Panel Study of Living Conditions of the Oldest Old (SWEOLD) was used in Study III.

The register data used in Studies I, II, and IV were extracted from The Swedish Work and Mortality Database (HSIA). The HSIA consists of multiple national registers that are linked at the individual level. The data in the HSIA cover all individuals living in Sweden in 1980 and/or 1990, and yearly information is available from 1990 to 2009. The number of individuals in the analytical samples in Studies I, II and IV ranged from 801,017 to 5,011,414. In Study III, income data from the Swedish tax and cause of death register were linked to the LNU and SWEOLD survey data with information on income and year of death.

The SWEOLD and LNU are longitudinal, survey-based data materials that are sampled to be representative of the Swedish population. The surveys contain a wide assortment of questions about living conditions, such as family background, health, education, economic situation, and work life. The two surveys can be combined to follow individuals from early working life into old age, with retrospective questions about childhood conditions. The LNU has been carried out in six waves (1968, 1974, 1981, 1991, 2000, and 2010) with nationally representative samples of individuals aged 18 through 75 years in Sweden. After age 76, individuals that were part of the LNU sample were included in the SWEOLD, which has been conducted in five waves (1992, 2002, 2004, 2011, and 2014). Together, these two datasets enable a longitudinal follow-up for up to 46 years. Study III included a sample (n=2619) of respondents born between 1910 and 1949 who participated in at least one of the following survey-waves: LNU 1991, SWEOLD 1992, LNU 2000, or SWEOLD 2002.

Response rates in the surveys are high: in the LNU they range between 72% and 91%, and in the SWEOLD, between 84% and 95%. However, high response rates do not guarantee a representative sample for all variables in the survey. Therefore, in Study III, additional analyses were performed to compare the income-mortality association in the LNU/SWEOLD sample to the complete Swedish population. The results from a revised version of this test can be seen in Figure 6. The figure shows the average marginal effect of income on mortality across ages. The associations are similar in both the smaller

survey sample and in the complete population register sample; increased income is associated with lower mortality. The effect becomes stronger with increased age; however, among the oldest old the effect changes direction and declines. In the population register sample, the association shifts upward in age and the weakened association between income and mortality is not seen until after age 93. This shift could potentially be caused by the inclusion of a broader age and cohort range in the register data, as well as the increased number of persons in the highest age categories, which contributes to more stable estimates. Despite some discrepancies in the exact shape of the associations between the two samples, this sensitivity analysis indicates that the LNU and SWEOLD can be considered representative of the general population when estimating the income-mortality association.

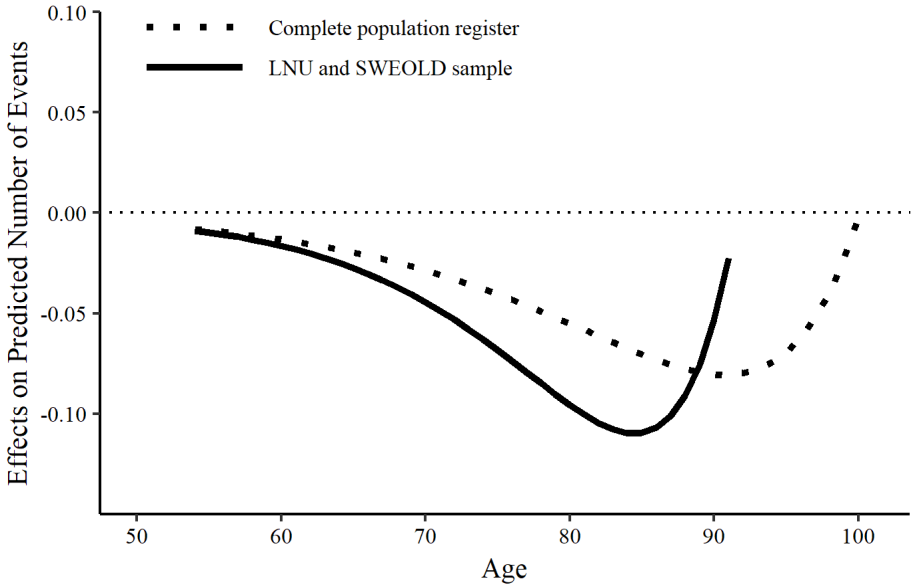

Figure 6. Average marginal effects of income on mortality by age in the LNU and SWEOLD sample (solid line) and a complete population register sample (dotted line). Predictions based on two Poisson regressions with mortality as outcome, controlling for age and sex.

Income

In Studies I-IV, income was measured as an aggregate variable that consisted of all after-tax income, including income from work, transfer payments, and capital gains; in other words, a measure of the respondents' disposable income. Income in this thesis was primarily conceptualised from the perspective of income as a resource, and disposable income better captures the available

economic resources as compared to, for example, income from work. In Studies I, II, and IV, disposable income was measured at the household level, and in Study III, disposable income was measured at the individual level.

The household level was the preferred choice of measure in this thesis based on the fact that resources are shared within households. Data from the European Union Statistics on Income and Living Conditions (EU-SILC) show that in Sweden, 70.6% of respondents report that all incomes are treated as common resources within the household, 23.9% report that household incomes are partly pooled, and 5.5% report that no incomes are shared (Ponthieux, European Commission, & Eurostat, 2013). In addition, EU-SILC data show that older persons are more likely to fully pool their incomes compared to younger people. Given that incomes are pooled, the whole household's incomes need to be taken into account when assessing an individual's available resources. On a related note, the broader use of the household versus the individual as the basic unit for stratification has been much debated. Erikson (2006) examined individual and household class positions in relation to mortality in Sweden: the results showed that household class was more strongly associated with mortality than individual class, and Erikson concluded that in Sweden 'the family can still be regarded as the unit of class composition' (p. 2159).

The use of household income introduces the problem of how best to compare the individual's share of the household's total income and, by extension, how to compare households with different compositions. The economic resources available in a household containing only one person can be estimated in terms of a single income. However, persons living together in other constellations, for example a married couple, will inevitably share resources within the household. The per capita expenditure necessary to achieve a given standard of living for a two-person household is therefore estimated to be lower than the expenditure for a single-person household. In other words, the cost per person to achieve a certain standard of living varies depending on the composition of the household. Simply dividing the household income by the number of household members will thus give an incorrect estimate of the household's standard of living. In the economic literature, the pooling of income and expenditures within the household is referred to as the household's 'economies of scale' (Logan, 2011; Nelson, 1988). A common procedure for standardising income across different types of households is the use of weights that adjust for the household's composition (Martin, 2017). These weights are sometimes estimated in terms of spending on food, housing, childcare, and other necessities that are deemed basic in the specific context.

Studies I and II utilized a square root scale, wherein the square root of the number of household members is used as a score. The square root scale has been used by the Organisation for Economic Co-operation and Development (OECD) in a number of reports comparing income inequality and poverty between countries (Martin, 2017; OECD, 2008, 2011). Study IV used the same

procedure as Statistics Sweden: the first person receives a score of 1, the second person a score of 0.51, and each additional adult a score of 0.6. This scale assumes that a two-person household shares 24.5% (0.49 ÷ 2) of its expenses. The difference between the square root scale and the scale used by Statistics Sweden can be seen in Table 3. Implications of the choice of scale are mainly seen in the weighting of larger household versus smaller households, where the income of larger households will be weighted down more in scales that add additional members linearly – such as the scale used by Statistics Sweden – and less with the square root scale. This becomes less of a concern in households of older persons in Sweden, as it is uncommon to live in large households including several generations. Therefore, the vast majority of people aged 65 and up live in households of one or two persons.

Table 3. Equivalence scales in different types household.

Household composition	Statistics Sweden	Square root
1 adult	1.00	1.00
2 adults	1.51	1.41
2 adults, 1 child	2.03	1.73
2 adults, 2 children	2.45	2.00
2 adults, 3 children	2.87	2.24

The use of household income and the estimation of the household's economies of scale rest on certain assumptions of within-household behaviour. One much-criticized assumption is that there is no within-household inequality and that all resources are shared equally. This assumption has not held up under empirical testing (see, for example: Attanasio & Lechene, 2002; Susanne Elsas, 2013). Therefore, a measure using a unitary assumption of how resources are shared within the household is likely flawed. However, given the limited knowledge about the behaviour of households, there is no way to accurately estimate the within-household sharing of resources. The option of using individual income instead relies on an assumption in which *no* resources are shared, which is possibly even more misleading than assuming a unitary distribution of resources.

In Study III, disposable individual income was still used, since the register information connected to the SWEOLD did not include information about household income. In addition, Study III examined an individual-level process, where health status was used to explain a weakened association between income and mortality among the oldest old. Processes related to other household members may possibly confound the association between household income and mortality. For example, the death of a household member or the entry of one or more household members into retirement will affect household income, and may be related to the individuals' mortality risk. Nevertheless, in a sensitivity analysis (not shown), an approximation of household income was

calculated based on information about the respondent and the possible partner of the respondent. A complete household income measure was not possible due to the fact that annual information on household composition other than partner was lacking. The results from this sensitivity test indicated a near identical result to that of the main results. This is not surprising, given that the relative rank position of household income and individual income correlates in the data for the older segment of the population

Mortality and health

Studies I-IV included information on all-cause mortality retrieved from the Causes of Death register. The mortality information in the Causes of Death register is reliable, as all deaths are reported to the authorities and recorded in this register (Brooke et al., 2017; Johansson, Björkenstam, & Westerling, 2009).

In addition to all-cause mortality, Study III utilized health status measures from the LNU and SWEOLD surveys. Four self-reported indicators of health status related to mortality were included: problems related to cardiovascular disease (CVD), metabolic conditions, psychological distress, and self-rated health. Problems related to CVD were measured using questions on chest pain, heart attack, stroke, heart failure, and high blood pressure. Problems related to metabolic conditions were measured using questions about weight and diabetes. Psychological distress was measured using two indicators: anxiety and depression. Finally, self-rated health was measured using one question with three response alternatives: 'good', 'neither good nor bad', and 'bad'.

Methods

Several statistical techniques were used in this thesis. Study I utilized Cox proportional hazards regression analysis with p-splines to illustrate the shape of the association between income and mortality. Cox proportional hazards regression analysis is a commonly used statistical technique for estimating regressions with time to event (survival) data (Cox, 1972). The measure of effect is the hazard rate, which is the rate of failure (death) during a given time unit. In multivariate Cox proportional hazards models, the coefficients are estimated as the ratio between the compared groups' hazard rates. The use of splines in regression models allows for accurate visualizations of the shape of the examined variables, as well as statistically testing non-linear assumptions (Eilers & Marx, 1996). This technique divides the regression into several parts and estimates the best fitting regression coefficient for each part separately with the assumption that the intercept connects where the previous part ended. The connections between the separate regressions are called knots, and the

number of separate parts (knots) can be either manually specified or estimated under certain assumptions.

Study II employed methods for calculating mortality risks and illustrating income differences for the probability of having died at each age at ages 31-99 between 1990 and 2009. The accumulated probability of death for each age was calculated for two income groups. This was performed in several steps: first, the average income during the follow-up period for each individual was calculated and then divided into top 10% and bottom 10% income groups. Second, the status (dead or alive) was recorded for each person during each year between 1990 and 2009 with no left censoring. Third, the age-specific probability of being dead was calculated for every age between 31 and 99. In sum, this gave the accumulated probability of dying in a synthetic cohort aged between 31 and 99. Inequality in the probability of having died between the income groups was compared by examining relative inequality with risk ratios, and by examining absolute inequality with percentage point differences.

Study III used Poisson regression to examine the association between mortality, income, age, and health status. Poisson regression is based on a log-linear regression with a log link function that estimates counts or number of events. The exponent of the log-linear coefficients in Poisson models allows the coefficient to be interpreted as a rate ratio, which is the ratio between two incidence rates, and estimates associations on a multiplicative scale. When using an outcome such as mortality – an event that can occur only once for each individual – the results in a Poisson regression may become biased. One way to correct for this is to use the time under risk as an offset, which makes the Poisson model comparable to Cox proportional hazards regression analysis (Hutchinson & Holtman, 2005).

In Study III, the analyses included the interaction between age and the income-mortality relationship, and therefore one main concern was how to best illustrate the effect of interacting variables. Since the coefficient from an interaction term in a multiplicative model is conditional on the estimated value of the other variables in the model, it is not informative to interpret the interaction coefficient directly (Brambor, Clark, & Golder, 2006). One option is predicting the outcome from the regression model at relevant values of the variables of interest. In this case, average marginal effects were used to estimate the effect of income on mortality for all observed ages in the data, thus illustrating the age interaction in the models. Marginal effects predicted from logit models are interpreted as the probability of the outcome occurring. Furthermore, marginal effects from a Poisson regression (the predicted number of events) provide estimates on the additive scale, and allow the effect on the dependent variable to be interpreted as absolute change (Liao, 1994).

In Study IV, poverty rates were calculated for six cohorts over a period of 15 years. The poverty threshold was defined as 60% of the median income at the national level: individuals with incomes less than that value were considered to be living in poverty, whereas individuals with incomes equal to or

greater than the value were not. Information about median income at the national level was derived from Statistics Sweden's income data for the corresponding years. The income data in the study were made comparable to the median income measure from Statistic Sweden by employing an identical adjustment for household size.

In order to assess the impact of selective mortality on old-age poverty rates, a sample of those who survived for 15 years from the cohort baseline in 1990 was selected. This method of comparing a surviving sample of the cohort with the average rates for the cohort has previously been used to reveal the trends in average disability levels among survivors and deceased cohort members (Christensen, McGue, Petersen, Jeune, & Vaupel, 2008; Verbrugge, Brown, & Zajacova, 2017). The only compositional difference between the complete cohort and the 15-year survivors is caused by those who die during each of those 15 years. The compositional difference between the complete cohort and the selected survivors is largest at baseline, and for each successive year the compositional differences become smaller until the survivors and the full sample converge at 15 years from baseline. In other words, this method illustrates the impact mortality has on the cohorts during the follow-up period. The difference between the samples was compared by calculating the percent difference in poverty rate for each year of follow up.

Interaction effects in multiplicative regression models

In Study III, the statistical procedure for examining the relationship between income and mortality at different ages was performed by including an interaction term between income and age in a Poisson regression. This allowed the income estimate in the regression models to vary at different age levels. The interpretation of interaction terms is not always straightforward, and interactions can be evaluated in several ways. An important distinction is whether the interaction is assessed on a multiplicative scale or an additive scale. In a regression model, the interaction is by default estimated on the scale of the regression model. For example, a logistic regression that includes an interaction term predicts the interaction on a multiplicative scale, while a linear regression predicts the interaction term on an additive scale. Interactions on the additive scale assess whether the effect of two factors combined exceeds the effect of each factor considered individually. If the combined effect does exceed the individual effect for each factor, we can say that there are deviations from additivity, and that an interaction on the additive scale is present. Deviations from additivity in this context are also more in line with the intuitive understanding of an interaction between two variables. In contrast, interactions on the multiplicative scale assess whether or not the product term of two exposures exceeds the effects of the individual factors. A multiplicative interaction is thus less intuitive when interpreting in terms of the combined effect of two variables.

As in the discussion on relative and absolute inequalities, the scale of measurement according to which an interaction is evaluated must be considered. Interactions on the additive scale are often argued be more relevant than multiplicative interactions in public health contexts (Knol et al., 2011; Rothman, Greenland, & Walker, 1980; VanderWeele & Knol, 2014); one reason for this is that we are often interested in whether the effect of an exposure generates an additional number of cases in combination with another exposure. Table 4 shows a hypothetical interaction between income and age in which the probability of dying is higher in the low-income group compared with the high-income group. In old age, the probability of death increases in both groups, but the increase in probability is greater for the low-income group. In this case, the number of deaths is dependent on the co-occurrence of old age and low income, and therefore an interaction relevant to public health is present between age and income.

The statistical evaluation of an interaction on the multiplicative scale, however, would indicate that there is no interaction between age and income $[(12/2)/\{(6/2) \times (4/2)\} = 1]$ because the combined effect of low income and old age does not deviate from the expected value in a multiplicative model. On the other hand, if the effect were evaluated on an additive scale $[12 - 6 - 4 + 2 = 4]$, the statistics would indicate that there is indeed an interaction between income and age. Moreover, it is possible to have a positive interaction on one scale and a negative interaction on another (VanderWeele & Knol, 2014).

Table 4. A hypothetical example of interactions. Probability (%) of dying by income and age.

	Highest 10 % of incomes	Lowest 10 % of incomes
Age 50	2 %	4 %
Age 80	6 %	12 %

The possibility of confusing discrepancies between multiplicative and additive interactions illustrates the importance of clarifying what exactly the analysis is testing, and having a theoretical motivation for the scale on which the interaction is evaluated. As mentioned above, assessing deviations from additivity is commonly preferred when analysing the co-occurrence of two risk factors in public health contexts (VanderWeele & Knol, 2014).

When estimating interactions using multiplicative models, another consideration is that the coefficients are conditional on the value of the other variables in the model; as such, the interaction coefficient in a multiplicative model cannot be interpreted as the average effect of a one-unit increase in the underlying variable (Ai & Norton, 2003; Brambor et al., 2006; Braumoeller, 2004). When the variables in the interaction are continuous, this provides many options in terms of how to best present the effect. One option recommended in

the literature is predicting average marginal effects at meaningful values of the variable of interest (Ai & Norton, 2003; Brambor et al., 2006). This was accomplished in Study III by predicting the average marginal effect of income on mortality at every observed value of age. Thus, the average marginal effect has two benefits when predicting interactions: first, it provides estimates on the additive scale, the advantages of which were argued above. Second, it can provide predictions at different values of other co-variates in the model, which allows for a comprehensive evaluation of the interaction effect.

Ethical approvals

The studies in this thesis are covered by the following ethical approvals: the Central Ethical Review Board of Stockholm (decision No. 2012/1260-31); Uppsala University Hospital Ethical Committee (Dnr 247/91 and Dnr 4010-91); the Ethical Research Committee of Karolinska Institutet (Dnr 03-413); and the Regional Ethical Review Board in Stockholm (Dnr 04-314/5, EPN Dnr 2010/403-31/4, and EPN Dnr 2014/1003-31/5). Informed consent was obtained from all participants in the LNU and SWEOLD studies. In cases where the participants were too physically or cognitively impaired to give consent at the time of the interview, a relative (normally a spouse or an adult child) signed the consent form.

Overview of studies

Taken together, the results of this thesis suggest that there is an association between income and mortality, and that the association endures in old age. This finding is the focus of Studies I and II, and is shown in Study III. Studies III and IV focus on examining two processes that affects the income-mortality association in old age: health decline and mortality selection.

Study I: The shape of the association between income and mortality in old age: A longitudinal Swedish national register study

In Study I, the main objective was to investigate the shape of the association between income and mortality in old age. It is well established that the income-mortality association is curvilinear for the working age population; however, the shape of the association after retirement and in old age is less well known. Accordingly, mid-life income (age 50-60) and late-life (age 65-75) income were examined in relation to late-life mortality using Cox proportional hazard regressions and p-splines to allow for non-linear estimations. The study included everyone living in Sweden between the ages of 50 and 60 in 1990 who did not emigrate during the follow-up period (n=801,017).

Overall, the results showed that the income-mortality association was curvilinear, with diminishing returns of income in both mid-life and late-life. The shape of the association in old age was independent of income in mid-life, and showed a stronger mortality gradient than mid-life income (see Figure 7). While the reversed association at the lowest income levels remains unexplained, several possible causes were nevertheless suggested, such as migration, non-taxable income, or tax evasion. The implications for the main results were limited given the relatively few observations at the bottom of the income distribution (see density plot in Figure 7).

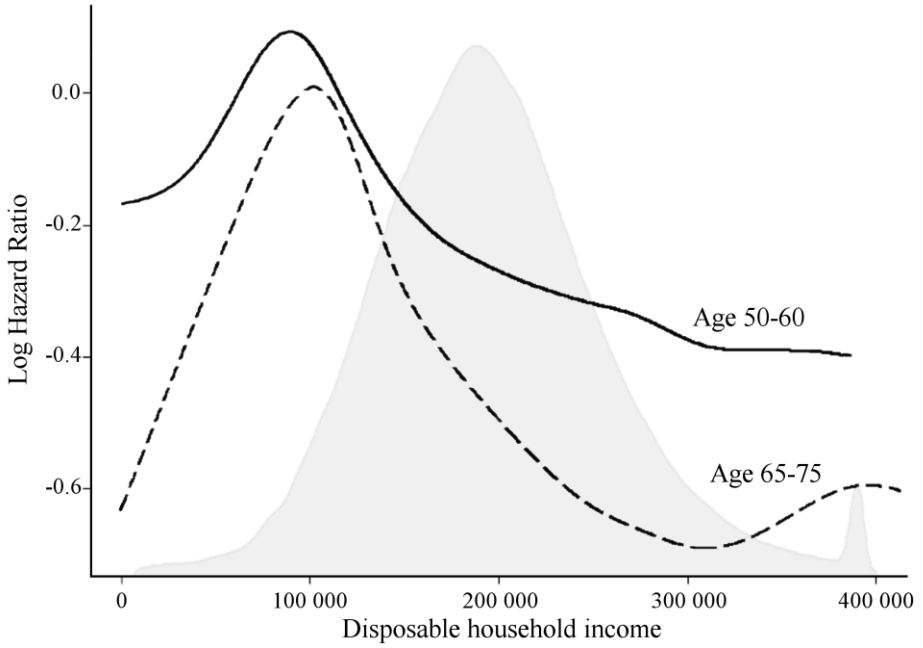

Figure 7. Adjusted smooth log hazard ratio estimates of mortality by yearly disposable household income (SEK) measured in 1990 (solid line) and in 2005 (dashed line). Grey outline: density plot for late-life incomes. The 10th percentile of income was used as the reference.

Study II: Divergence and convergence: How do income inequalities in mortality change over the life course?

The aim of Study II was to investigate income inequalities in mortality across the adult lifespan. There are conflicting viewpoints – and mixed evidence – on the issue of health inequalities in old age: do inequalities increase or decrease during this phase of life? This study has several strengths that combined make it a unique contribution to this debate. First, the study included the entire Swedish population aged between 30 and 99 during the years 1990-2009 (n=5,011,414). Second, the study evaluated both relative and absolute inequalities. Third, the study included deceased persons in the calculation of mortality as a way of accounting for selective mortality during the study period.

Mortality was measured as the probability of having died during the follow-up period. Inequalities were measured with percentage point differences and risk ratios (RR). The top-10% income group was compared to the bottom-10% income group.

The results (see Figure 8) of this study showed that relative inequalities were greatest for men at age 56 (RR: 4.7) and for women at age 40 (RR: 4.1).

The greatest absolute inequalities were found at age 78 for men (19% difference) and age 89 for women (14 % difference). Examining relative inequalities revealed decreasing inequalities with increased age, whereas in contrast, absolute inequalities showed increasing inequalities with increased age up to age 85-90, and then declining inequalities.

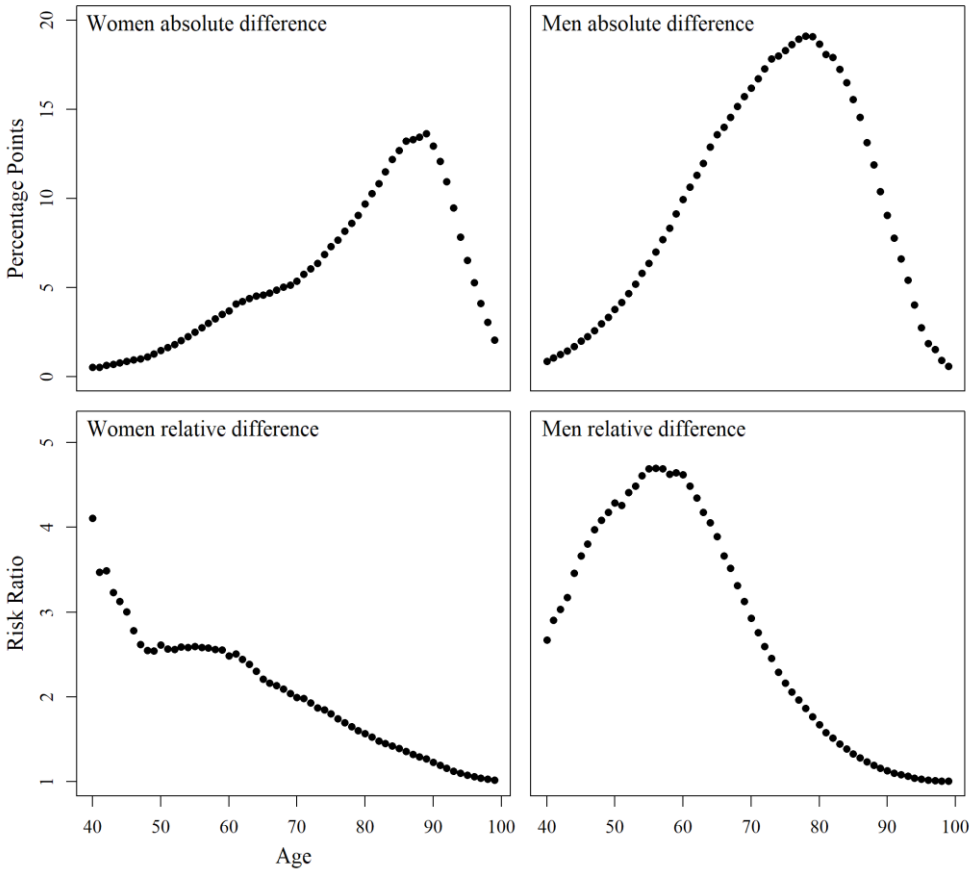

Figure 8. Risk ratio and percentage point differences in probability of having died in low- versus high-income groups at ages 40 to 99 by sex.

Study III - What levels the association between income and mortality in later life: Age or health decline?

The main objective of Study III was to investigate the mediating effect of health on the income-mortality relationship. Declining health status is one of the processes in the age-as-leveler hypothesis, which is frequently used to explain a weakened association between socioeconomic position and health in old age. The empirical evidence, however, is scarce regarding the role of declining health status in the income-mortality association.

This question was investigated in a dataset with 2619 persons aged between 54 and 93 at baseline, and analysed by using Poisson regression and average marginal effects predicted from the regressions. First, the association between income and mortality was examined across ages by including an interaction term between age and income. The results of these analyses showed that the income-mortality association weakened after age 83. Second, four measures of health status were included as covariates in the regression model. The results showed that the income-mortality association weakened for all ages when controlling for health status. In the third and final step, the analyses were stratified by health status between those in good health and those in poor health. The results from these analyses showed that the income-mortality association was strong, and increased up to age 87 among those with good health (see Figure 9). In contrast, the income-mortality association was weak and non-significant for all ages among those in poor health.

Figure 9. Average marginal effects of income on mortality by age. Good health status sample: solid line. Poor health status sample: dotted line.

Study IV - Poverty after 63: The impact of selective mortality

The aim of Study IV was to investigate poverty rates and the effects of mortality on poverty rates in old age. The percentage of older people with low income at risk of poverty is substantial. The European Commission (2018) has raised concerns about maintaining income at adequate levels in the face of ageing populations, especially among women, who live longer with lower pensions. One key process in ageing populations is that of selective mortality: individuals who live in poverty tend to die before those who do not live in poverty, which decreases the observed poverty rates among the survivors.

Poverty rates were calculated for six cohorts aged between 63 and 101 during 1990 to 2006. The impact of mortality on these cohorts was investigated by comparing the poverty rates in the complete cohort with a sample of those who survived for the duration of the cohort's follow-up period.

The results showed that poverty rates in all six cohorts increased during the follow-up period. Women had consistently higher poverty rates and larger increases in poverty rates compared to men during the follow-up period. Period effects across the cohorts indicated that poverty rates were stable during 1990 to 1995, and increased substantially during 1995 to 2006. Those who survived during the 15-year follow-up period had 8%-32% lower poverty rates at baseline compared with those for the complete cohort. In men, mortality had a greater impact on poverty rates in the younger cohorts than in the older cohorts. In contrast, for women, mortality had a greater impact in the older cohorts than in the younger cohorts.

Discussion

Death is the destiny of every living person, and has been described as 'the great equaliser'; in death, everyone is equal (Carr, 2018). The timing of death, however, is largely decided by a person's social circumstances. While inequality in longevity and mortality is well documented among children and in the working age population, fewer studies have focused on the older segment of the population. Studies that do focus on health inequalities in old age tend to find that inequalities persist (Huisman 2004, Kordo 2014, Mortensen 2016). Many uncertainties about the association between income and mortality in old age still remain, however, some of which have been addressed in this thesis.

The aim of this thesis was to investigate the income-mortality association in old age. First, I examined whether the association in old age was curvilinear, with diminishing returns of income on health. Second, I examined age variations in the income-mortality association and whether the association became stronger or weaker with age. Finally, I examined two potential mechanisms that may shape the association in old age: health decline and mortality selection. Together, the results from this thesis show to what extent and in what ways the association between income and mortality is maintained in old age.

Is the shape of the income-mortality association curvilinear in old age?

The association between income and mortality has been overwhelmingly found to be curvilinear in the working age population, with a strong association at low incomes and an increasingly diminishing effect on mortality with increased age (Dowd et al., 2011; Fritzell et al., 2004; Rodgers, 1979). Evidence of the curvilinear shape of the association between income and mortality in old age is scarce. Old age income is to a large part determined by pensions and capital income, which reflect lifelong accumulation of wealth and income. Therefore, it is reasonable to assume a similar shape for the association between income and mortality in old age and in working age.

The results from Study I supported this hypothesis for people aged 65 to 75. Furthermore, income in later life showed a deeper and more pronounced association with late life mortality than income in middle age. Given that pensions reflect lifetime income, this result is consistent with theories of accumulation, which hypothesize that accumulated exposure leads to larger intra-cohort differences in health over time.

The reversed association between income and mortality at the lowest incomes observed both for income in middle age and late life has previously

been observed in the working age population based on Swedish register data (Fritzell et al., 2004). Fritzell at al. observed that the reversed pattern was robust across gender, ethnicity and age (25-64), and the results from Study I further showed that the reversed association was also present in those aged 65-75, as well as in a number of sensitivity analyses. It must be noted that relatively few persons are present in this part of the income distribution. Moreover, much of the reversed association occurs below the minimum income levels received from social assistance programs. The persons who contribute to the reversed association are, in other words, a selected group in which register-based income likely does not reflect true economic resources. The sensitivity analyses did not reveal any possible cause for this association; nevertheless, a number of causes have been suggested, such as migration, non-taxable income, or tax evasion.

Do income inequalities in mortality increase or decrease with age?

One prevailing question in the field of social gerontology is whether the strength of the association between social exposures and health increases or decreases with age. The empirical literature on health inequalities and ageing is inconclusive in this respect. Several possible reasons for conflicting results were listed in the section 'Levelling and accumulation: empirical support', and were related to differences in the choice of time period, country, age range, health outcome, socioeconomic indicator, and type of inequality measure. The period studied in this thesis ranged from 1990 to 2009 in Sweden, the outcome was mortality, and the socioeconomic indicator of choice was income. The inclusion of a broad range of ages in the thesis (from 30 to 101) enabled a comprehensive evaluation of inequalities across different ages. Lastly, the thesis included both absolute and relative measures of inequality. Based on these premises, did the results in this thesis show that inequalities increased or decreased with age? The simple answer is that relative inequalities decreased, and absolute inequalities increased up to the oldest old (age 85-90), and then decreased.

Such a pragmatic answer leads to the next question: in which inequalities should one be interested? This is seldom explicitly expressed in studies on health inequalities. In epidemiology, relative measures have sometimes been recommended to assess causality, while absolute measures are better suited for assessing public health significance. However, this position has been criticised for relying on faulty premises (Poole, 2010), and it has been argued that absolute effect measures are preferable when evaluating mechanistic processes with interaction effects (VanderWeele & Knol, 2014). Ultimately, the choice of inequality measure is dependent on the researcher's aim. Many public health theories and hypotheses make predictions about changes in absolute health status and not changes in relative health status. For example, cumulative (dis)advantage theory predicts that with the passage of time, the intra-

cohort variability in health will increase because of accumulated exposure to some risk factors. The theory predicts change in actual health status, predicting that the absolute difference in health status between one or more groups will grow over time. A hypothetical example of this process was given in the section '*Health inequality: conceptualisation and measurement'*. Thus, if the aim is to test or evaluate inequalities from the perspective of cumulative (dis)advantage, an absolute effect measure should be used, a strategy that was chosen in Studies II and III.

In more general terms, relative inequalities can be said to reflect an egalitarian position where equality is in focus (Mackenbach, 2015). From this perspective, the results from Study II, which showed lower relative inequalities in old age, can be interpreted in terms of mortality being more *equally* distributed between income groups in old age than in younger age groups.

In addition to theoretical reasons for choosing either a relative or an absolute measure of inequality, there are inherent mathematical properties in the measures that affect the interpretation. Absolute measures are constrained by floor and ceiling effects; for example, it is impossible to observe large absolute differences in a setting where there is a low prevalence of the outcome in both comparison groups. Relative measures are less dependent on the prevalence of the outcome. Nevertheless, the absolute change that is required for a relative measure to change is still dependent on the rate of the outcome. When the prevalence of the outcome is low, small absolute differences can generate large relative changes, but when the prevalence rises, large absolute differences are needed to generate any substantial relative differences.

In Study II, the absolute measure of inequality was greatly affected by the age-bound increases in mortality rates, and showed the largest differences in the age groups with the highest mortality, and the smallest differences in the age groups with the lowest mortality. The opposite pattern was observed for the relative inequality measure, which showed larger relative inequalities in the younger age groups that had lower mortality rates. Thus, the relative inequality was clearly affected by the prevalence of the outcome, with small absolute differences leading to extremely large relative differences. Both the relative and absolute inequality measures followed the expected changes given the rate of the outcome.

Given the conceptual and mathematical differences between absolute and relative measures, it is important to have a solid theoretical rationale for choosing one or the other when evaluating inequalities.

Accumulation or levelling through health decline

Two theories on the effects of ageing on socioeconomic inequalities in health were used in this thesis: the cumulative (dis)advantage theory and the age-as-leveler hypothesis. In Study II, the magnitude of the absolute measure of mortality inequalities increased up to age 80-90. Thus, up to these ages the results

were consistent with the predictions based on the cumulative (dis)advantage theory. However, after age 85-90 the magnitude of the absolute measure of mortality inequalities decreased, consistent with predictions based on the age-as-leveler hypothesis. Similar results were found in Study III. In other words, both theories were supported by the results in this thesis. The accumulated exposure to low income and low socioeconomic position could generate the patterns observed up to age 90 in Study III, with increasing differences in mortality. The decreased effect of income on mortality after age 90 can be explained by one of the mechanisms from the age-as-leveler hypothesis: namely, that health declines begin to supersede the effects of accumulated social exposures (i.e. income). Neither the accumulation hypothesis nor the health decline hypothesis was directly tested in Study II, and the possible mechanisms are only speculations based on the observed inequality patterns.

Theories of accumulation in social gerontology are well developed, and a number of studies have examined accumulation and health in old age (e.g. Dannefer, 2018; Dupre, 2007; Leopold, 2016; Mirowsky & Ross, 2008; Walsemann, Geronimus, & Gee, 2008). In contrast, studies examining the mechanisms in the age-as-leveler hypothesis are few, and only one study has previously investigated the mediating effect of health on the income-mortality association in old age (Hoffmann, 2011). Because of this, the effects of health decline in old age were examined in Study III.

Income is related to mortality through a variety of complex mechanisms, and health decline is a factor that often precedes mortality, especially in old age. In Sweden, 97% of deaths among those aged 65 and over had an underlying cause that was health related (Socialstyrelsen, 2018). The mediating effect of health can be expressed in terms of transitions from good health to poor health, and ultimately death. Social influences are proposed to be strongest in the transition from good health to poor health, and less important for the transition from poor health to mortality, especially in affluent countries where access to acute health care is universal. In old age, the timing of the transition from good health to poor health is associated with income and socioeconomic position. However, at some stage in the ageing process, a majority of the older persons will have experienced the transition from good to poor health, and at this stage, the previously accumulated social influences will matter less for predicting mortality.

In Study III, health status did indeed explain parts of the association between income and mortality. Furthermore, the analyses stratified by health status showed a strong association between income and mortality among those in good health, and no association among those with poor health. These results support the hypothesis that income is a strong predictor in the transition from good to poor health, but when health is poor, the income-mortality association is weak. Thus, health decline is partly responsible for the declining inequalities that are observed beyond age 90.

Is mortality selection shaping the associations between income, age, and mortality?

In ageing populations, the process of selection generally occurs when frailer persons die, and when those persons have lower socioeconomic status than the surviving population. From previous research on health inequalities we know that mortality is correlated with social conditions, and therefore we know that some degree of selection occurs. The number of deaths and the degree of social patterning affects to what degree mortality will influence the composition of the surviving population. In old age, mortality rates increase exponentially, and therefore mortality's influence on the composition of the surviving population is potentially large.

In this thesis, mortality has been the main outcome, and if income has a causal influence on mortality, there must also be some degree of mortality selection. Furthermore, when selection has caused a large enough compositional change, the causal process between income and mortality will eventually disappear. This is not necessarily because the causal mechanism has weakened, but because the surviving population is more resilient or less affected by the causal effects observed in the original population; this issue is well known in studies on ageing populations. Studies examining the impact of mortality on health inequalities in old age, however, have produced conflicting results. Ferraro and Farmer (1996) found that selective mortality had an impact on health inequalities by including deceased respondents in their analyses. In contrast, studies by Beckett (2000) and Celeste and Fritzell (2018) that also included deceased respondents in their analyses found that selective mortality had no effect on health inequalities in old age.

Mortality selection was accounted for in Study II using a cumulative measure that included deceased individuals in the mortality calculations. The mortality measure included deaths at all previously observed ages rather than a standard age-specific mortality risk that is commonly used. Therefore, the mortality measure was interpreted as the probability of having died at each age; in other words, the probability of surviving until a specific age. This method incorporated the compositional change caused by mortality on the sample, and the results were therefore not affected by selective mortality that occurred during the follow-up period. It was necessary to use a synthetic cohort in order to include observations on ages from the complete adult lifespan, and despite a long follow-up period of 19 years, the sample was inevitably exposed to mortality selection before the first year of observation; the impact of this selection will have been especially strong in the older segment of the sample. In order to account for the complete compositional effect caused by selective mortality, complete cohort data is needed, which is not possible since Sweden's annual income registers extend back only to 1990.

Study IV directly evaluated mortality's influence on poverty rates in six cohorts aged 63-86 at baseline. The results indicated that selective mortality

had a substantial impact on poverty rates in old age. Thus, the results support the idea that selective mortality changes the composition of the surviving population in the sense that non-poor older adults survive longer and make up an increasing portion of the ageing cohorts. Furthermore, the impact of mortality was strongest in the cohorts where the absolute mortality rates were highest: the cohorts aged between 70 and 85. Thus, the study confirmed that selective mortality had a substantial influence on the surviving population when mortality rates were highest.

Concluding remarks

This thesis has contributed new knowledge about the association between income and mortality in old age. First, findings concerning the shape and strength of the income-mortality association have added another piece to the puzzle regarding health inequalities in old age. Second, evidence on the processes that affect health inequalities in old age has been lacking, and this thesis has increased knowledge of the impact health decline and selective mortality have on the income-mortality association in old age.

Many aspects of health inequalities in old age remain unknown, and the processes causing age-related changes in the income-mortality association require further study. Detailed investigations into both the separate and bi-directional accumulation of income and health throughout life and into old age are needed. More comprehensive knowledge about the processes specified in the age-as-leveler hypothesis is also required, such as to what extent egalitarian welfare policies after retirement could generate smaller health inequalities in old age, and whether social circumstances earlier in life are more important for health outcomes than for example equality-promoting policies in old age.

In the face of ageing populations, the future social conditions among the oldest segment of the population are of prime concern. This thesis showed that health inequalities persist and are even exacerbated in old age. Societies will need to closely monitor and be ready to act upon the increasing health inequalities and rising poverty rates that may follow as a larger portion of the population grows old.

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