Yet Another Brick in the Wall

Investigating whether education is causally related to dementia

Second year master's thesis

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Abstract

This paper empirically investigates the relationship between education and risk of developing dementia. From a large body of literature, it is well known that higher education associates with better health. This is true both for health in general, but also for more specific diseases like Alzheimer's. However, the question of whether the link between years of education and dementia is causal or not, remains unclear. While a possible explanation to the noted association between education and dementia is that there is causal link between years of schooling and dementia, and that education serves as a protective and compensating mechanism, such association could also follow from that people with larger brain volume are more likely to take on more education, while also having more physical resources that enable them to compensate for the underlying pathology of dementia. Using an instrumental variable (IV) approach, where changes in compulsory school leaving ages across countries is used as a proxy for education, this research attempts to address the problem of endogeneity. The paper uses individual, cross-sectional data from The Survey of Health, Aging and Retirement in Europe (SHARE), covering respondents from 21 European countries which undergone changes in compulsory schooling between the 1930's and 1970's. The results suggest that education cannot significantly predict the risk of developing dementia or adult cognitive ability, when using compulsory schooling reforms as an instrument for educational attainment. These results contradict most of the work that has been completed in this field of research.

Keywords: Dementia, education, causal estimation, compulsory schooling reforms, health economics

Table of contents

1. Introduction

Dementia is one of the major causes of disability and dependency among older individuals. Approximately 50 million people around the world have dementia, and almost 60 percent of these live in low- or middle-income countries (World Health Organization (WHO), 2020). With an average annual cost above 50,000 dollars per person, dementia is also considered to be one of the most expensive diseases. The main reason for the high costs is that there currently is no cure available for dementia, leading to a large share of the costs being associated with home-based assistance for the remained of the affected person's life (National Association for Biomedical Research (NABR), 2020).

Dementia is anticipated to have an increasing impact on the world in the near future. The percent of the world's population that is above 65 years old is expected to almost double from 8.5 in 2015, to 16.7 in 2050. With a rapidly aging population, the number of people suffering from dementia can so much as triple by 2050. The costs associated with this are estimated to be close to three trillion dollars (Irwin, Sexton, Daniel, Lawlor & Naci, 2018). This illustrates the importance of further research, not least to increase our knowledge regarding how dementia can be prevented. This paper examines whether years of education is causally related to dementia.

Dementia is a general term for the condition in which someone develops cognitive difficulties due to changes in the brain. There are over 400 types of dementia, where the most common one is Alzheimer's Disease, contributing to about 60-70 percent of all cases, followed by Vascular Dementia and Lewy body dementia (Alzheimer's Association, 2021). The symptoms vary across types of dementia, but the most common ones are memory loss and reduced practical abilities. Apart from this, people with dementia often experience problems with language, decreased judgement, disorientation in time and place, and trouble with concentrating and making decisions. As a result, people with dementia often withdraw from social activities and work (Prince, Albanese, Guerchet & Prina, 2014). At later stages, the symptoms can be severe, with complete unawareness of time and place, difficulty walking and need for assisted self-care. Dementia can therefore result in tremendous losses in physical, psychological, economic and social ways; not only for the person who has it, but also for his or her relatives (WHO, 2020).

Many studies have focused on determining risk factors for developing dementia. Even though the disease is generally associated with ageing, dementia is not a normal part of becoming older. Increasing age is, however, the largest risk factor for developing the disease, and out of those experiencing symptoms of dementia, around 90 percent are above 65 years old. Depression, smoking, drinking harmful levels of alcohol, being obese and living a sedentary lifestyle are other risk factors listed by WHO (2020). In addition, low educational attainment has been declared as one of the main risk factors for developing dementia. Education and health have for a long been known to strongly associate. The theoretical framework developed by Grossman (1972), view health as a form of capital that individuals produce. Since education is said to improve production efficiency, this implies that people with more years of schooling are better at generating health given the resources available. Income, in turn often associated with education, is also identified to be one of the largest determinants of both health and health behaviors (WHO, 2013).

The relationship between education and dementia is usually explained by the concept of cognitive reserve. This theory states that measures of reserve, such as occupational activity or education, serves as protective and compensating mechanisms against brain damage (Stern, 2002). A large body of literature has investigated the concept of cognitive reserve in the context of different types of dementia. In a systematic review, Meng and D'Arcy (2012) consider 133 studies published between 1980 and 2011, using both cross-sectional and longitudinal data from a wide range of countries. Their findings suggest that high education in early life significantly relates to lower incidence of dementia and that this evidence is robust across studies.

Although many studies find a significant relationship between education and dementia, there remains disagreement about whether these factors are causally linked. An alternative explanation to the cognitive reserve hypothesis is that people with larger brain volume are more likely to stay in education, while also having superior physical resources that enable them to compensate for the underlying pathology of dementia. Another potential pathway is that individuals with higher educational attainment have a higher socio-economic status and therefore lives healthier lifestyles with access to better healthcare (Prince et al., 2014). The essential of this is that education generally is not randomly given, and that the choice often is determined by intellectual ability. By simply regressing years of schooling on dementia, one faces the risk of confusing the effect of physical resources (or brain volume) with the effect of education. Failing to account for the non-randomness of education will therefore likely lead to biased estimates.

A few recent studies have tried to handle the endogeneity problem. First, some studies include regressors for family dementia association or cognitive ability, trying to remove brain size effects from the error term (e.g., Brent, 2018; Foverskov et al., 2020). The results suggest that low education still seem to have a significant effect on the risk of developing dementia. Second, some studies apply an IV approach, using either using genetic variants or compulsory schooling reforms as instruments for years of education, coming to mixed conclusions. Larsson et al. (2017) and Nguyen et al. (2016), find evidence of a significant, causal relationship between education and risk of developing dementia, while Seblova et al. (2020) only find very small or negligible effects.

The aim of this study is to examine the relationship between education, adult cognitive ability and dementia. To identify a causal effect, I apply an IV approach, where changes in compulsory school leaving ages across European countries is used as an instrument. Since changes in mandatory schooling laws provides exogenous variation in years of education, this should decrease the risk of endogenous estimates. This paper contributes by applying this particular IV estimation, with a multi-country dataset, to the field of research on risk factors for developing dementia. To my knowledge, this has not been done before. The results are discussed relative to previous research and the Grossman (1972) model.

The empirical analysis uses individual data from The Survey of Health, Aging and Retirement in Europe (SHARE) from wave 2 and 4-7. The survey provides longitudinal microdata on public health and socio-economic living for Europeans that are 50 years and above, including information on incidence of dementia, cognitive ability, demographics, and education. I complement the survey data with an extensive database created by Hofmarcher (2019) on compulsory schooling reforms that took place in Europe during the 20th century. With this information it is possible to distinguish individuals born around the thresholds for the birth cohorts affected by each reform. The complete dataset covers almost 30,000 individuals, including 21 European countries in which 26 education reforms occurred between the 1930's and the 1970's.

The results suggest that education cannot significantly predict the risk of developing dementia or adult cognitive ability. Cognitive ability does, however, significantly relate to the incidence of dementia. Additionally, other factors that are known to be associated with dementia, does not seem to have been affected by the reforms in question. It is possible that changes in midlife conditions are required to retain effects on cognitive ability and dementia prevention in adult life. Lastly, when separating the sample by gender, income, and educational level, the results indicate that men, individuals with lower education and higher adult income, seem to have been more strongly affected by the compulsory schooling reforms in question. However, education still cannot significantly predict dementia within these groups.

This paper is disposed as follows: Chapter 2 gives a selection of the relevant literature, both on the relationship between education and health and the relationship between education and dementia. Chapter 3 presents the theoretical framework and Chapter 4 presents the data. Chapter 5 discusses the empirical strategy och Chapter 6 includes the main results of the paper. This is followed by concluding discussions in Chapters 7.

2. Literature review

Before turning to literature on dementia risk factors, it is important to note that the casual impact of education on health in general is far from settled. Galama, Lleras-Muney and van Kippersluis (2018) systematically review evidence and specifically focus on results from randomized controlled trials, twin studies and quasi-experiments. One of their main conclusions is that education decreases mortality, but that this result is sensitive to the choice of population and time period. They also conclude that, across all studies, methods and outcomes, there seems to be considerable differences between genders and that the outcomes of men are much more dependent on education in comparison to outcomes of women. The paper illustrates that there is a substantial effect of education on mortality in certain contexts, but also that previous literature has yielded inconclusive results (Galama et al., 2018).

Brent (2018) investigates the per-year impact of schooling on dementia with US data and use this estimate to evaluate the monetary benefits of education on independent living and consequently caregiving costs. To establish whether education is a causal determinant, thus making it a feasible intervention for providing benefits trough reduced dementia symptoms, the author includes parental and sibling dementia association as control variables. In this way, Brent

(2018) reduces the risk of having hereditary brain size effects in the error term. The findings of this research indicate that education significantly decreases the risk of dementia and that this provides sizable monetary benefits. In addition to this, the estimated effect on dementia for each year of schooling is presented. The largest effect of reduction in dementia is found when moving from zero to one year of schooling, and this effect declines for each additional year of education.

Larsson et al. (2017) investigate socioeconomic, lifestyle/dietary, cardiometabolic and inflammatory risk factors for developing Alzheimer's Disease. Attempting to prove causality between education and Alzheimer's, the authors conduct a Mendelian randomization analysis. This is an epidemiological method that exploits genetic variants that influences a certain risk factor, in order to make an unbiased estimate of the association between the risk factor and the disease. To do this, the authors use European data on DNA sequence variation in the form of single-nucleotide polymorphisms (SNP). This has frequently been predictive of education in earlier literature. Their results indicate that higher educational attainment is related to lower risk of developing Alzheimer's. However, they also point out the potential risk of genetic variants being associated with different risk factors, which thus could violate the exclusion restriction (Larsson et al., 2017).

Nguyen et al. (2016) also use genetic variants of SNP as an instrument for education. They examine the impact of education on dementia probability score, and also use changes in state policies as a separate instrument for years of schooling. This is created by linking year and state of each respondent's birth to compulsory schooling laws that has occurred between 1906 and 1978 in the US. Dementia, in turn, is measured by a continuous score for cognitive ability. The results indicate that education lowers the probability of developing dementia, both when using genetic variants and school policies as an instrument. The coefficients when using SNP are, however, quite small and, similar to Larsson et al. (2017), the authors emphasize the risk of the instrument influencing cognitive function in a way that does not go through education (Nguyen et al., 2016).

Seblova et al. (2020) use exogenous variation in years of schooling to examine the causality of the relationship between education and dementia. The variation originates from a Swedish compulsory schooling reform that took place between 1939 and 1949, which increased education by one year for 70 percent of the population. Identifying incidence of dementia diagnosis using several health registers, the authors merely find evidence of very small effects of education. They also conclude that the reform only had minor impacts on adult socioeconomic outcomes. This implies that the estimated effects can be seen as direct causes of one additional year of compulsory schooling on cognitive performance, rather than effects mediated through continued education, income or pensions (Seblova et al., 2020).

While genetics has been found to be predictive of years of education, it is also well-known that specific genes can be associated with dementia. Cook and Fletcher (2015) investigate whether higher educational attainment can "rescue" biological liabilities in the brain function that have been shown to be strongly associated with dementia and Alzheimer's Disease. These liabilities occur because of inheritance of a "risky" variant of the Apolipoprotein E (APOE) gene that possesses around 15 percent of the population. By using a between-sibling design, the authors attempt to separate genetic and environmental influences, and thus explore variation in educational attainment to find out the effects on cognitive decline. The results show that the negative, genetic effects of the APOE gene are absent in individuals who has a college degree, and present for most people that only has attended high school. This suggests that education has a protective role of cognitive decline for individuals that has inherited the APOE variant (Cook & Fletcher, 2015).

Table 1: Summary of relevant literature on the relationship between education and dementia.

Author(s)	Research	Explanatory variables	Region	Main findings
Brent (2018)	Investigate the effect of education on dementia and evaluate the monetary benefits.	Parental and sibling dementia association (APOE gene), age, gender, race, independence living level.	US	Education decreases the risk of dementia and the largest effect is found when moving from zero to one year of schooling.
Cook and Fletcher (2015)	Investigate whether higher educational attainment can reduce the risk of Alzheimer's disease among individuals with biological liabilities in the brain function that have been shown to be strongly associated with the disease, using a between-sibling design.	Number of E4 genes, gender, birth year and order.	US	The results show that the negative, genetic effects of the "risky" genes are absent in individuals who has a college degree and present for most people that only has attended high school.
Larsson et al. (2017)	Investigate risk factors for developing Alzheimer's Disease by conducting a Mendelian randomization analysis.	Smoking, alcohol consumption, coffee consumption, vitamin levels, intelligence.	Europe	Higher educational attainment is related to lower risk of developing Alzheimer's Disease.
Nguyen et al. (2016)	Examine the impact of education on dementia probability score and use genetic variants of SNP and changes in state school policies as instruments for education.	Gender, race, school characteristics, term length, student-teacher ratio, cognitive test scores.	US	Education decreases the probability of developing dementia, both when using genetic variants and school policies as an instrument.
Seblova et al. (2020)	Use exogenous variation in years of schooling, stemming from a Swedish compulsory schooling reform, and investigate the causality of the relationship between education and dementia diagnosis.	Age, gender, highest achieved educational degree.	Sweden	Education only has very small or negligible effects on dementia and only limited effect on other adult socioeconomic outcomes.

3. Theoretical framework

3.1 Health as human capital

One of the earliest, and most important, theoretical frameworks in health economics is the Grossman (1972) model, which is a theory that builds on the assumption that health is a form of capital good that is given at birth and depreciates over the life cycle. This is something that is known to be empirically true; as we grow old, we develop more health problems. However, Grossman (1972) also says that health can be produced by the individual. This can be done either through consumption of health care or through spending time living a healthy lifestyle, for instance by exercising or eating nutritious food.

Grossman (1972) says that individuals demand health since it enables them to live a better life, while also being able to work more and thus produce more earnings. Health care, or investments in health are, in contrast, only derived from the demand for health. Assuming that individuals are rational and forward-looking, they will allocate their time and budget to maximize their lifetime utility $U(H, C, X, \varepsilon)$. This is a function of the health stock H of an individual, consumption C of other commodities, exogenous and observable factors X, like age and sex, and unobserved factors ε, such as ability or genetics.

While the Grossman (1972) model provides a structure of how to understand the individuals' investments in health, while separating that it both can be produced and is due to unobserved factors, it is based on very restrictive assumptions. For instance, it assumes that there are no unexpected shocks to the health stock or to the depreciation of health. Because of this, a lot of focus throughout the years has been put on developing the model, attempting to make it fit better with the empirical evidence. An extension made by Zweifel, Breyer and Kifmann (2009) incorporate marginal efficiency of capital elasticity into the Grossman model. They show that education improves production efficiency, implying that people with more years of schooling are better at generating health given the resources available. Higher levels of education could thus lead to a lower demand for health care (Zweifel et al., 2009).

3.2 Effects of compulsory schooling on health

Based on the Grossman (1972) model, Galama et al. (2018) develop a theoretical framework to investigate the relationship between human capital, schooling, mortality and health behaviors. An important dissimilarity from the classical model is that health, skills, health behaviors, education and longevity all are assumed to be endogenous and dependent on initial endowments, such as genes or parental characteristics. They then review how exogenous variation in schooling, stemming from the role that laws and institutions has on education, can predict health outcomes. They declare that the effect of a minimum school-leaving age S on the optimal length of life T can be expressed in the following way:

$$\frac{\partial T}{\partial S} = f\left[\beta_{1,T}\frac{\partial qA(T)}{\partial S};\ \beta_{2,T}\frac{\partial \theta}{\partial S};\ \beta_{3,T}\frac{\partial q_{h/a}(T)}{\partial S}\right] \tag{1}$$

Galama et al. (2018) explain that each of the three terms in the parenthesis show a predicted effect of compulsory years of schooling on longevity, mediated through different channels. The first term is the wealth effect, which is the impact of education on lifetime assets $qA(T)$. This could, for instance, occur as an effect of increased cognitive or non-cognitive skills developed by schooling, which is valued in the labor market. This term could either be positive or negative, given that individuals with more resources both can afford to use some of their resources to increase their life expectancy, or choose to spend some of their assets on unhealthy consumption, thus leading to a decreased life expectancy.

The second term on the right-hand-side demonstrates the effect of skill accumulation θ, which could be boosted by an increase in education. This would improve both the skill and health production, while also increase earnings, which therefore would lead to better lifetime resources and better health, thus corresponding with a longer life. The third and last term represents the effect of education on the relative marginal value of health $q_{h/a}(T)$. Diminishing returns to wealth and skills, together with an improved health knowledge, is assumed to imply that individuals with higher education also value health more in comparison to their wealth, thus leading to more investments in health and longer lives. Summarizing these three terms, the increase in minimum school-leaving age could impact health and longevity through different channels. The relative importance of each term will therefore determine the magnitude of the effect of compulsory schooling laws on health outcomes (Galama et al., 2018).

3.3 Cognitive reserve

The relationship between education and dementia usually is explained by the concept of cognitive reserve. This is a theory which refers to the capacity to tolerate changes and disease-related pathologies in the brain. The general idea is that people develop a reserve during their life, which serves to protect them against cognitive losses that can occur either through ageing or through specific diseases, like Alzheimer's or Vascular dementia. The amount of cognitive reserve will therefore differ between individuals, where people with a high amount of mental and physical stimulation throughout their lives are believed to have an increased cognitive reserve. Experiences such as higher educational achievement, having a complex occupation or other types of stimulating activities, are thought to build our cognitive reserve and could therefore account for differences seen in the prevalence and incidence of dementia. The cognitive reserve hypothesis therefore states that there exists a causal relationship between education, cognitive reserve and ultimately dementia (Stern, 2002).

The idea behind cognitive reserve is that there does not seem to be a direct link between the degree of brain decline and the outward signs of this. This is because of the underlying ability to manage changes in the brain, which comes from the cognitive reserve (Stern, 2002). This means that two people with the same cognitive ability, can have very different amounts of changes in the brain. Correspondingly, individuals experiencing the same changes in their brains, can perform differently on cognitive tasks. The theoretical explanation is illustrated in Figure 1 below. The idea is that the point at which the cognitive ability begins being affected comes later in time for individuals with a high cognitive reserve, in comparison to individuals with a low cognitive reserve. The reason for this should be that people with higher cognitive reserve can tolerate more pathology before it affects their cognitive ability (Stern, 2012).

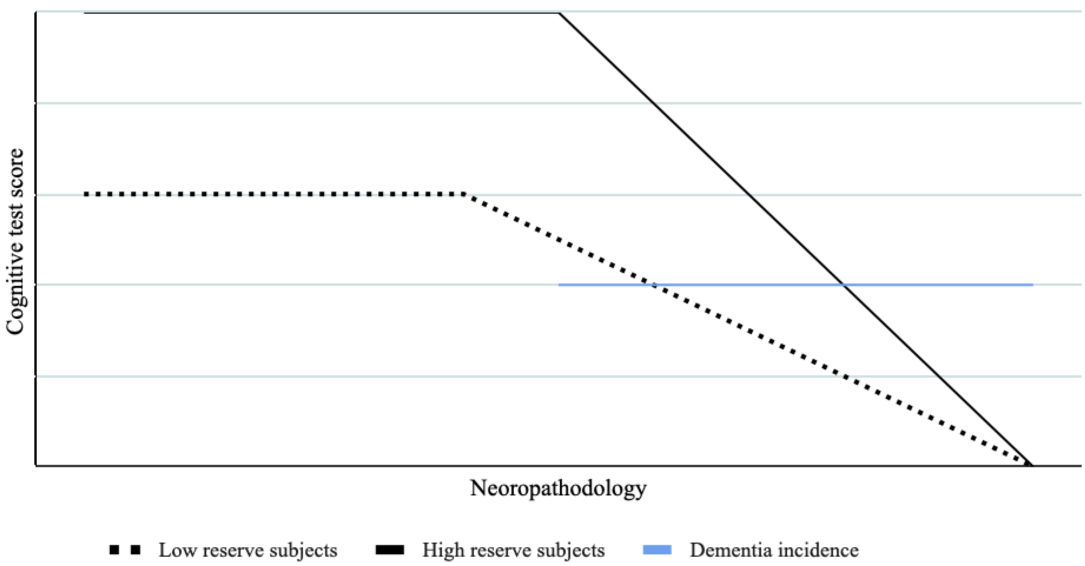

Figure 1: Illustration of how cognitive reserve can impact cognitive ability over time (adapted from Stern, 2012)

4. Data

The data used in the empirical analysis comes from SHARE, which is a cross-national panel dataset including over 140,000 individuals from European countries and Israel. This survey provides longitudinal microdata on public health and socio-economic living for individuals that are 50 years and above. The data is collected through computer-assisted personal interviewing, where the participants use a laptop and conduct face-to-face interviews. For each wave, earlier participants that has stayed within the same country since the last one, are re-interviewed. Each wave also includes a refreshment sample with completely new individuals. All household members to the selected individual are also eligible for an interview.[1]

I use wave 2 and 4-7 of SHARE, excluding the third wave (which focused on the respondents' life histories and did not include questions on whether the person was diagnosed with specific diseases), and the first wave, which did not include a question on whether the person was diagnosed with dementia. The choice of using several waves was made to maintain a sufficiently large sample when excluding individuals born far away from affected birth cohorts. Apart from this, some questions, for instance regarding education, are only collected in the baseline interview. Information from earlier waves is therefore necessary for individuals that has participated more than once. Given that the purpose of the analysis is to use a cross-sectional sample with exogenous variation in education, all variables are computed using the latest answer available for each variable and individual rather than using the longitudinal sample.

4.1 Compulsory schooling reforms

The cognitive reserve hypothesis states that the relationship between years of education and incidence of dementia is causal. This stems from the idea that higher educational attainment helps to create a cognitive reserve that protects against changes in the brain. Since education is an endogenous factor, I use an instrument that is considered to credibly predict education: the number of years of compulsory education. Following schooling reforms, this variable varies across countries and cohorts.

[1] In Wave 1, only household members of 50 years or above were allowed to participate. The datasets contain a small number of individuals that were younger than 50 at the time of the interview. These are excluded from the analysis, since I want to focus my analysis on older individuals.

I identify how many years of compulsory schooling that applied to each individual in my dataset, by using external information on national schooling reforms from Hofmarcher (2019). He provides a database of compulsory schooling reforms that has taken place in 32 European countries between 1936 and 2011. This is the largest database on European schooling reforms, and it includes both extensions and reductions in years of schooling. It is also based on original reports and articles written by country-level experts, which indicates that is has a high level of credibility. The database covers reforms at International Standard Classification of Education (ISCED) level 1 and above, which in Sweden corresponds to grades 1-6 and upwards. It also includes information on first birth cohort affected by each reform, which enables me to identify which observations that were affected by a change in compulsory schooling.

The latest data from SHARE, wave 7, was conducted in 2016/2017 and covered cohorts born 1966 at the latest. Schooling reforms that affected birth cohorts before 1966 are therefore suitable to focus on. This implies that I can use 43 schooling reforms implemented in 23 countries. I also exclude reforms that affected birth cohorts very close to 1966. In a few countries, several reforms occurred close in time, and in those cases the latest of the reforms are excluded, in order to obtain clear treatment- and control-groups.[2] After this exercise, 26 reforms in 21 countries remain, including Austria, Germany, Sweden, Netherlands, Spain, Italy, France, Denmark, Czech Republic, Poland, Luxembourg, Portugal, Slovenia, Estonia, Croatia, Lithuania, Bulgaria, Latvia, Malta, Romania and Slovakia. Table 2 provides a summary of the compulsory schooling reforms[3].

[2] I also exclude all foreign-born individuals since I cannot ensure that these were subject to the national school laws in question.
[3] For a comprehensive review of the reforms, see Hofmarcher (2019).

Table 2: Summary of countries and compulsory schooling reforms (amended from Hofmarcher, 2019)

Country	Wave(s) in SHARE	Years of compulsory schooling	Reform date	First birth cohort affected
Austria	1-7	8 to 9	1962	1952
Germany	1-7	8 to 9	1967	1953
Sweden 1	1-7	6 to 7	1936	1923
Sweden 2	1-7	7 to 9	1962	1951
Netherlands	1-7	7 to 8	1947	1937
Spain	1-7	7 to 8	1970	1958
Italy	1-7	5 to 8	1962	1952
France	1-7	8 to 10	1959	1953
Denmark	1-7	7 to 9	1972	1958
Czech Republic 1	2-7	8 to 9	1948	1934
Czech Republic 2	2-7	8 to 9	1960	1947
Poland	2-4 and 6-7	7 to 8	1961	1952
Luxembourg 1	5-7	7 to 8	1945	1932
Luxembourg 2	5-7	8 to 9	1963	1950
Portugal	4 and 6-7	3 to 4	1956/1960*	1950
Slovenia	4-7	4 to 7	1945	1935
Estonia	4-7	7 to 8	1958	1945
Croatia	6-7	4 to 7	1945	1935
Lithuania	7	7 to 8	1958	1945
Bulgaria 1	7	7 to 8	1959	1946
Bulgaria 2	7	8 to 9	1969	1958
Latvia	7	7 to 8	1958	1945
Malta	7	8 to 10	1974	1960
Romania	7	4 to 7	1958	1947
Slovakia 1	7	8 to 9	1948	1934
Slovakia 2	7	8 to 9	1960	1947

Note: * The reform became effective year 1956 for boys and 1960 for girls.

4.2 Variables

4.2.1 Years of compulsory education

Changes in compulsory schooling reforms across countries and cohorts is used as an instrument for education. Since some countries changed the length of compulsory schooling several times during the period of interest, it is also important that the window around the pivotal cohorts only is affected by the change in question, and not previous or subsequent ones. As mentioned earlier, I exclude the latest schooling reform(s) when several of them occur close in time. The bandwidth of the early reforms is also adjusted accordingly when there is less than five years between them, so that it does not include birth cohorts where another reform has been affective. I will as a robustness test increase and decrease the sample window to see whether the results are sensitive to this.

By using Hofmarcher's (2019) database, it is possible to identify the number of years of compulsory schooling that applies to each individual in the dataset. For each country and reform, a treatment group and a control group are composed. The treatment group are individuals who have experienced a change in years of compulsory schooling and the control group are individuals who has not. As can be seen in Table 4, years of compulsory schooling ranges from 3 to 11 in the 21 selected countries, with a mean of approximately eight years.

4.2.2 Years of education

The endogenous variable in question is education. Here I use the variable *Years of education,* which is included in all of the SHARE waves. With questions on education only asked in the baseline interview, I create a new variable, consisting of information from the baseline interview for each individual on the question of years of education. Observations with answers that are obviously incorrect, such as implausible large values, along with answers coded to indicate different types of missing values, are dropped from the dataset.[4] Table 4 presents the summary statistics of years of education and shows that average education is approximately 11 years. Figure A1 also give a graphical illustration of the frequency of years of education in my sample, where most individuals attended about 10 to 15 years of education.

4.2.3 Dementia

A part of the SHARE questionnaire is devoted to different aspects of people's health and includes a question on whether the individual "is diagnosed, or currently has, Alzheimer's disease, dementia or senility". From here on I refer to this variable as *Dementia,* since both Alzheimer's disease and the more old-fashioned term "senility" are subcategories or synonyms to the general term. The variable is binary, equaling 0 if respondent is not diagnosed with or have dementia, and equaling 1 if the respondent is diagnosed or has dementia.

[4] I also exclude outliers, stating to have between 25 to 35 years of education.

An obvious drawback with the dementia variable is that it does not separate different types of dementia. Another disadvantage is that it does not necessarily correspond to an actual diagnosis, but instead to the person's own judgement. A potential risk with this is that not only people who have dementia, but also individuals experiencing "normal" levels of forgetfulness that can be associated with ageing, also will state that they have it. According to WHO (2020), approximately 5-8 percent of the population above 60 years old have dementia. As can be seen in Table 4, approximately 2 percent in the sample answer that they have AD/dementia/senility. The corresponding number when excluding the sample to only include individuals above 60 years old is 2.4 percent. This indicates that the variable more likely is underestimated, which speaks for that the sample does not include many individuals that falsely stated that they have dementia. However, since the variable possibly suffers from downward bias, this must be considered when interpreting the results.

4.2.4 Cognitive ability

The pathway between education and dementia is believed to transfer through cognitive reserve, leading to people exhibiting similar changes in their cognition to be able to perform at different levels in cognitive tests. I therefore want to test the association between cognitive ability and dementia, as well as the association between education and cognitive ability. To do this, I will use SHARE's cognitive function module. This includes measures of cognitive ability which are based on tests of numeracy, verbal fluency and memory. The tests are bases on the Mini-Mental State Exam (MMSE), which often is used to test cognitive function among elderly and identify dementia. *Numeracy* is tested by asking the respondent a few questions concerning simple arithmetical calculations based on real life situations. The respondents are graded from 1-5 depending on their overall performance on the tests. As can be seen in Table 4, the average numeracy score is approximately three.

Memory is based on a "ten words list learning" test. This examines how well the respondent can recall a list of 10 words and is carried out twice. The first test is conducted immediately after being informed about the words and the second test is conducted a few minutes later (at the end of the cognitive function module). In the first two waves of SHARE, the same list of words was used for all respondents, while in the subsequent waves, the respondents were randomly assigned to one of four sets of words. As a general measure of these tests, I add the individual scores of the two tests, resulting in a variable ranging from 0 to 20. In Table 4, we see that the average respondent managed to remember nine words. The third measure of cognitive ability is *Verbal fluency*, which is tested by counting how many different animals the respondent can name in a minute. As can be seen in Table 4, the average respondent managed to name 20 animals.

To summarize the variables into a single measure of cognitive ability, I use principal component analysis (PCA). This is a method that is used to reduce the dimensionality of large sets of variables into a smaller one that still contains most of the information. The basic idea is that the variables are strongly interrelated, and by compressing their size one can simplify the interpretation of the results (Jolliffe & Cadima, 2017). This method has also been used specifically to summarize information from cognitive tests (e.g., Mazzonna & Peracchi, 2017; Cawley, Heckman & Vytlacil), since it is a useful tool for extracting patterns in the data.

Principal components are new variables, constructed as mixtures or linear combinations of the original variables. In this case, I have three variables of cognitive ability which gives three-dimensional data and up to three different principal components. The PCA analysis attempts to include as much information as possible into the first component, then the maximum retaining information in the next one, and so on. To do this, eigenvectors and eigenvalues are used. In short, these are numbers and vectors associated with square matrices. The eigenvectors are the directions where most of the variance is kept, and the eigenvalues are the coefficients ascribed to each eigenvector (Jolliffe & Cadima, 2017).

I start by conducting the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, which determines whether using PCA is suitable by indicating the proportion of the variance in the chosen variables that may be caused by underlying factors. KMO takes a value between 0 and 1, where a result below 0.5 generally indicates that the variables have too little in common to justify a PCA analysis. Conducting the KMO test gives a result of 0.64, which indicates that a PCA analysis can be a useful tool for my variables.

Table 3 presents the PCA results. The first principal component explains almost 60 percent of the total variance. The standard criterion for the selection of number of principal components is that each should have an eigenvalue larger than one. The first of the three component meets this benchmark. These are also illustrated in Figure A2, which plots the line between the eigenvalues of each component. The blue line indicates the standard criteria of an eigenvalue above 1. We also see that all the factor loadings in the first principal component are positive, which implies that they are positively correlated. I choose to use the first principal component as an index for cognitive ability. In Table 4, we can see that the index has a mean of zero and ranges from approximately -4 to 7.

Table 3: Principal component analysis

	Component		
	1	2	3
Numeracy	0.53	0.85	0.01
Memory	0.60	-0.36	-0.71
Verbal fluency	0.60	-0.38	0.70
Eigenvalue	1.79	0.70	0.52
Explained variance	0.60	0.23	0.17

4.2.5 Other variables

When running a regression with the aim of interpreting a causal relationship, it is important to not include control variables that are themselves outcomes in the experiment. These types of variables are known as *bad controls* and including these in the model could at worst lead to biased estimates that does not say anything about the causality of the relationship (Angrist & Pischke, 2008). When estimating the association between education and dementia, I will therefore only include the control variables *Age* and *Gender*. The average respondent in my sample is 66 years old. Gender is coded as a binary variable, where 1 corresponds to men and 0 to women. The distribution is approximately 45 percent men and 55 percent women in my sample.

Besides investigating the relationship between education and dementia, I will also test whether the instrument for education can be related to other socio-economic and health outcomes known to be linked to dementia. The summary statistics of these can also be found in Table 4. All variables are binary. *Low income* takes the value 1 if the income is the lowest of the four quantiles that determines the respondents' income. This variable is created by dividing the total household income for each respondent by the number of members that contribute to the household income and dividing them into quantiles within each country. About 11 percent of the sample are defined to have low income. *Depression* takes the value 1 if the respondent answered 7 or above on a 13-point scale, ranging from 'Not depressed' to 'Very depressed'. About 25 percent of the sample are depressed using this definition. *Obesity* takes the value 1 if the individual has a BMI of 30 or above, which corresponds to about 24 percent of the sample. *High alcohol consumption* takes the value 1 if the respondent has been drinking six or more units of alcohol for five or more days per week during the last three months. About two percent of the sample have a high alcohol consumption. *Sedentary lifestyle* takes the value 1 if the respondent answered that he/she 'Hardly ever/never' do sports or activities that are vigorous. This corresponds to about 31 percent of the sample. Finally, *Smoking* takes the value 1 if the respondent smoke at the present, which is about 17 percent of the sample.

Table 4: Summary statistics

	Obs.	Mean	Std. Dev.	Min	Max
Education					
Years of compulsory education	28,406	7.76	1.42	3	10
Years of education	28,406	11.28	3.96	0	25
Outcome variable					
Dementia	28,339	0.02	0.13	0	1
Cognitive variables					
Numeracy	22,669	3.45	1.08	1	5
Memory	28,091	9.00	3.66	0	20
Verbal fluency	22,574	21.04	7.74	0	99
Cognitive ability	22,441	0.00	1.32	-4.39	6.64
Other variables					
Age	28,406	65.81	7.75	50	99
Gender	28,406	0.45	0.50	0	1
Low income	28,406	0.11	0.32	0	1
Depression	28,406	0.25	0.43	0	1
Obesity	28,406	0.24	0.43	0	1
High alcohol consumption	28,406	0.02	0.13	0	1
Sedentary lifestyle	28,406	0.31	0.46	0	1
Smoking	28,406	0.17	0.37	0	1

5. Empirical strategy

5.1 The instrumental variable approach

The IV approach relies on the assumption that changes in years of compulsory schooling also change how many years individuals generally attend school. This is intuitive, since the purpose of these reforms is to change the minimum years of education. There are four main requirements for an instrument to be suitable in an IV-analysis, and the first one is *instrument exogeneity*.

This requirement refers to that the instrument should be uncorrelated with the omitted variable(s) and have no partial effect on the dependent variable (also known as the *exclusion restriction*). It is generally not possible to test this constraint, since this would imply that we do have a good proxy for the unobservables, which we then could use as an explanatory variable (Wooldridge, 2012). Since compulsory school leaving age is exogenously given, it should not be related to individuals' socioeconomic status, and thus only affect the outcome variable, dementia, through years of education. One possible concern is, however, if the reforms are correlated with other changes, such as school quality. Previous research has tried to address this and not been able to reject the internal validity of the instrument (Brunello, Fort, Weber & Weiss, 2013; Bolzern & Huber, 2017). Another concern is that individuals systematically could have moved from one country to another, as a response to the reform. Yet, as stated by Hofmarcher (2019), there are language and mobility barriers, which most likely prevent people from moving systematically due to changes in schooling reforms.

The second requirement is *instrument relevance*, which essentially is that the instrument must be correlated, positively or negatively, to the endogenous variable. If the correlation between the variables is high, the instrument has a *strong first stage.* This is important to provide accurate parameter estimates and standard errors (Wooldridge, 2012). Earlier studies have found high correlation between compulsory school leaving ages and years of education (e.g., Brunello, Fort, Schneeweis & Winter-Ebmer, 2015; Nguyen et al., 2016) and it is generally considered as a credible identification strategy (Lochner, 2011). Figure 2 presents a graphical presentation of the first stage with the compulsory schooling reforms used in this paper. All reforms are included in the graph. The vertical axis measures the mean years of education by birth cohort and the horizontal axis show the distance in years from the first birth cohort affected by the reform. As can be seen, there seems to be a discontinuity in years of education at the pivotal cohort, where the average years of education "jumps" at the threshold. This is, however, merely a visual presentation of the first stage, and I will therefore also evaluate the results of the first stage for each regression.

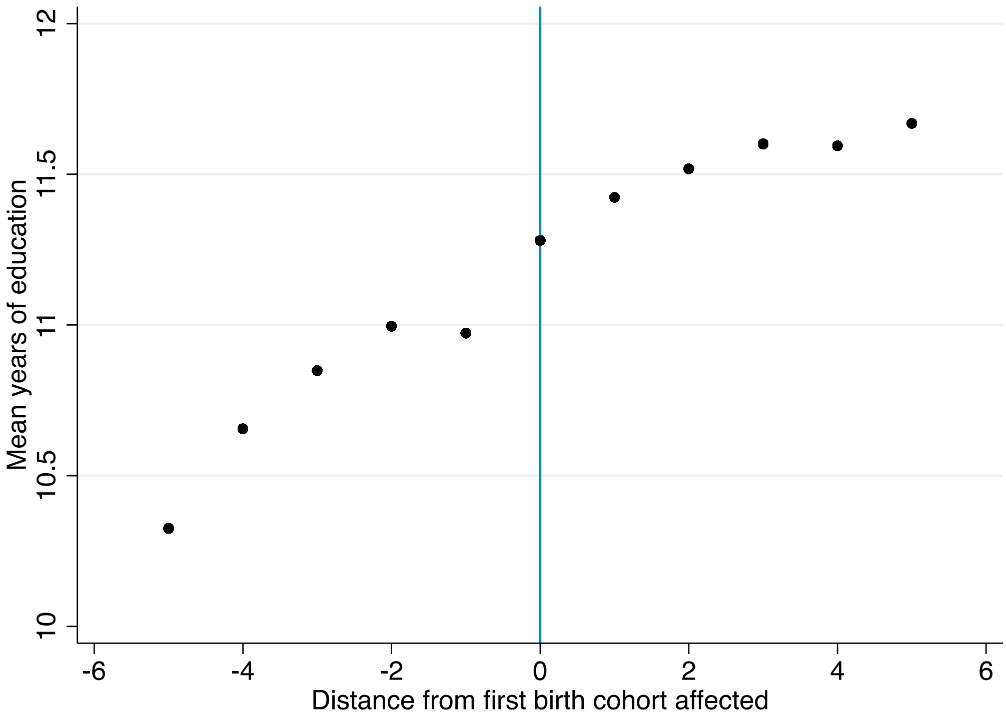

Figure 2: First stage of increases in length of compulsory schooling

The third requirement for an instrument to be appropriate is the *monotonicity assumption.* The meaning of this is that, even though the instrument has no effect on some people, it should impact all of those that are affected in the same way (Angrist & Pischke, 2008). In my analysis this requires that, among all of those that were in fact affected by a compulsory schooling reform, no one changed the length of their education in the opposite direction *due* to the reform. Angrist and Imbens (1995) suggest that the monotonicity assumption can be tested whenever the treatment is not binary. This can be done by plotting the cumulative density functions (CDFs) of the endogenous variable. The monotonicity assumption holds if the distributions do not cross. To test this, the CDF of education pre- and post-reform are plotted (see Figure B1). As the functions do not cross, the monotonicity assumption seems to hold for my instrument.

The fourth and last requirement is that the instrument should be *randomly assigned*. Generally, this is considered to be true when using compulsory schooling reforms as instruments for education. However, one possible pathway in which random assignment would not hold could be if some parents timed the birth of their children in order for them to receive additional years of compulsory schooling and possibly obtain better outcomes in life. However, as is noted by Hofmarcher (2019), all reforms were enacted after the pivotal cohorts.

5.2 Model specification

Since the outcome variable is binary, I use the linear probability model (LPM) to estimate the relationship between dementia and education. The advantages of using LPM, in comparison to using a binary response model like Logit or Probit, is that it is easy to implement and interpret, and does not require the many, sometimes arbitrary, choices that often is associated with nonlinear models. The main disadvantage with using LPM is that we assume that the true relationship between the binary variable and the explanatory variable is linear, which is not always the case. However, as stated by Angrist and Pischke (2008), the difference in average causal effects only seem to matter modestly when comparing the linear model to different limited dependent variable models. Assuming that the instrument for education is valid, the Two-Stage Least Squares (2SLS) method is used to obtain consistent estimations. The following equations for individual *i*, born in year *t* in country *c* are estimated to obtain the main results:

$$D_{itc} = \alpha_0 + \alpha_1 E_{itc} + \alpha_2 \mathrm{X}_{itc} + \gamma_c + \vartheta_t + \epsilon_{itc} \quad (2)$$

$$E_{itc} = \beta_0 + \beta_1 CE_{itc} + \beta_2 X_{itc} + \eta_c + \theta_t + \nu_{itc} \quad (3)$$

$$D_{itc} = \alpha_0 + \alpha_1 \hat{\mathrm{E}}_{\mathrm{itc}} + \alpha_2 \mathrm{X}_{itc} + \partial_c + \delta_t + u_{itc} \quad (4)$$

Equation 2 represents the structural form, or the baseline OLS regression, where D_{itc} is a dummy variable for the incidence of dementia, E_{itc} stands for the number of years of education, X_{itc} is a set of control variables and ϵ_{itc} is the error term. Due to the problem with endogeneity, the risk is that $Cov(E, \epsilon) \neq 0$, which leads to inconsistent estimates unless Equation 2 is instrumented for, using the first-stage regression in Equation 3. This describes the influence of the instrumental variable CE_{itc}, representing years of compulsory education, on E_{itc}. In the 2SLS estimation, the predicted first stage in Equation 3 is substituted into Equation 2, resulting in the reduced form represented in Equation 4. If the instrument is valid, this should yield unbiased and consistent estimates of the effect of education on the risk of developing dementia.

Further, γ_c, η_c and ∂_c are country-fixed effects, which are included to control for national differences of patterns in the incidence of dementia, and ϑ_t, θ_t and δ_t are birth cohort-fixed effects, to control for differences due to birth year. Since the structural form and the reduced form are estimated using LPM, it is essential to use robust standard errors, since this model always is heteroscedastic (Wooldridge, 2012). I cluster standard errors by country and birth cohort, following other papers using a multi-country setup with compulsory education as an instrument for years of schooling (e.g., Brunello, Weber & Weiss, 2017). This is important since it allows for correlation of the error terms for individuals sharing the same country and birth cohort, as compulsory education will vary with these two dimensions.

5.3 Validity and limitations

When using the 2SLS, it is important to note that the local average treatment effect (LATE) is estimated. This stems from a *noncompliance* problem, in which not all subjects in an experiment follow the assigned treatment. In my sample, this means that some people affected by the reform dropped out of school, while others would have gone the additional year to school regardless of the reform (Angrist & Pischke, 2008). The LATE is obtained by dividing the intention-to-treat (ITT) effect by the share of compliers. ITT is the estimated effect of the instrument on the outcome (the reduced form) and compliers are the individuals that do in fact change their behavior when given the treatment (the first stage). This corresponds exactly to the result obtained from a 2SLS regression (Angrist & Pischke, 2008), and should be interpreted as the average effect on those that increased their educational attainment due to compulsory schooling. It is likely the compliers are concentrated among individuals with low levels of education, which could mean that their returns to additional years of schooling is larger than for the average person. Thus, while it still is possible to obtain valid estimates using the 2SLS estimator, the external validity of this research might be limited.

By using an instrument for education, it is possible to estimate the effect of years of schooling on the incidence of dementia, while ruling out the risk of the omitted variable bias and endogeneity. However, this does not rule out the possibility that the effect of education is mediated through other pathways, for instance socio-economic status and health behaviors. To test this, I will therefore also estimate the effect of education on several health and health behavior outcomes.

6. Results

6.1 Main results

I start by graphically illustrate how the variable for dementia changes around the pivotal cohort. In Figure 3, the vertical axis measures the mean incidence of dementia for each cohort and the horizontal axis measures the distance in years from the first birth cohort affected by the reform. Comparing this to the graph where the first stage was illustrated, there is no clear discontinuity in dementia at the threshold. Instead, there seems to be a quite smooth, linear trend, where the mean dementia association decreases with time. This indicates that there is no distinct effect on dementia incidence among individuals that exhibited a compulsory schooling reform, in comparison to those who did not.

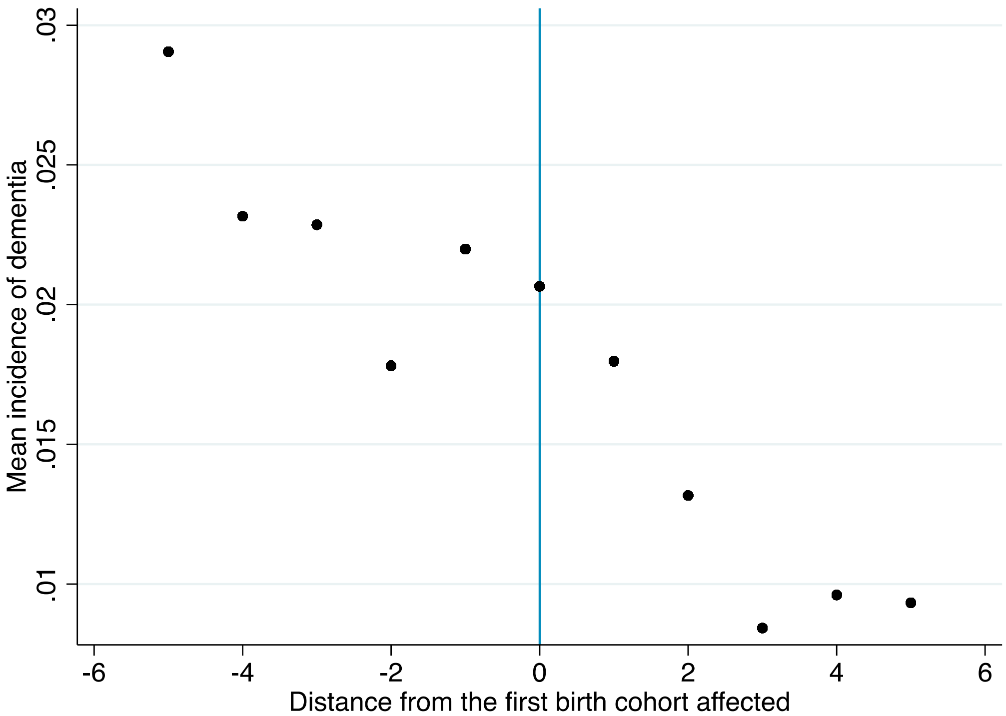

Figure 3: Mean incidence of dementia per cohort around the threshold.

I continue by presenting the main results on the effect of education on the dementia, using compulsory schooling as an instrument. It is important to note that the estimated regression coefficients should be interpreted as probabilities. Table 5 shows the main results, where both the OLS, 2SLS, and first stage estimates are reported. This allows me to compare the results and evaluate the instrumental relevance. I use two different specifications for each estimation; one that only regress education on dementia, and one where controls for sex and age are included. Reassuringly, the first stage is significant in both 2SLS estimates, indicating that years of compulsory education has a predictive effect of years of education attended in both regressions. Increasing compulsory schooling by one year, on average, increases years of education by 0.23 to 0.24 years. These estimates are quite similar to those obtained by Brunello et al. (2015), who use a comparable IV strategy with data from SHARE. It can also be seen that the first stage has an F-statistic of approximately 19, so it meets the rule of thumb, requiring an F-value above 10 for a strong first stage.

Table 5 shows that the OLS estimate is significant and positive in both models, but the 2SLS estimates are positive and insignificant. In line with expectations, age has a positive and significant effect on the risk of developing dementia. The fact that the OLS model, which includes the endogenous variable for years of education, reveals significant effects on dementia, while the 2SLS estimate does not, indicates that that there might be reasons to suspect that the pathway between the variables is not causal. It should, however, be noted that the coefficient of the two OLS estimations is very small when compared to results obtained by previous studies (e.g., Brent, 2018). I will therefore continue by more closely examining the relationship.

Table 5: Main results – incidence of dementia

	(1)		(2)	
	OLS	2SLS	OLS	2SLS
Years of education	-0.001***	0.001	-0.001***	0.001
	(0.000)	(0.006)	(0.000)	(0.006)
Age			0.001***	0.001***
			(0.000)	(0.000)
Gender			0.002	0.001
			(0.001)	(0.004)
First stage		0.235***		0.231***
.		(0.054)		(0.053)
F-statistic		19.02		18.89
Observations	28,339	28,339	28,339	28,339
R-squared	0.046	-	0.046	-

Notes: The dependent variable is *dementia*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses. These are clustered in all regressions and clustered by country and birth cohort in the 2SLS estimates. The sample window is five years before and after each reform. *** p < 0.01, ** p < 0.05, * p < 0.1.

6.2 Heterogeneous effects

With the IV approach it is possible that the compliers are concentrated among certain groups of individuals. This means that the first stage estimate could differ between different samples, leading to diverse estimates. It is also possible that the impact of education on dementia differs within different groups. I therefore split my sample according to a few characteristics, to evaluate the heterogeneity of the main results. I begin by running the regressions for men and women separately (Table 6). The first stage meets the requirement of an F-statistic above 10 in both samples, although with a weaker first stage in the female sample. This indicates that women were not as strongly affected by the chosen compulsory schooling reforms, compared to men. Apart from this, the results of education on dementia are similar to the results obtained when regressing the whole sample. The OLS estimates indicate that there is a significantly negative effect of education on the probability of developing dementia. All 2SLS estimates remain insignificant. Age seems to have a similar positive and significant effect, compared to the whole sample, except in the male sample when running the 2SLS estimation. The results do not change when excluding control variables.

Table 6: Heterogeneity of results across genders – incidence of dementia

	Men				Women			
	(1)		(2)		(1)		(2)	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
Years of education	-0.001**	0.009	-0.001**	0.008	-0.001***	-0.007	-0.001***	-0.008
	(0.000)	(0.008)	(0.000)	(0.008)	(0.000)	(0.010)	(0.000)	(0.010)
Age			0.001***	0.001			0.001***	0.002***
			(0.000)	(0.001)			(0.000)	(0.001)
First stage		0.253***		0.248***		0.212***		0.209***
		(0.066)		(0.066)		(0.066)		(0.066)
F-statistic		14.66		14.06		10.32		10.01
Observations	12,842	12,842	12,842	12,842	15,496	15,496	15,496	15,496
R-squared	0.046	-	0.046	-	0.055	-	0.056	-

Notes: The dependent variable is *dementia*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses. These are clustered in all regressions and clustered by country and birth cohort in the 2SLS estimates. The sample window is five years before and after each reform. The sample is divided by gender. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

I continue by testing for heterogenous effects across levels of education. As can be seen in Figure A1 most participants have about 10-15 years of education. I therefore choose to separate the sample accordingly: Low education (0-10 years), Medium education (10-15 years) and High education (15-25). Table 7 display the results separately for each group, controlling for age and gender. As a first observation, only the Low education-group has a strong first stage. With an F-statistic of 16.88, and a significant, positive effect on years of education, it seems as if compulsory education has a predictive effect on those with education between 0 and 10 years. It does not, however, meet the requirement in either the middle education or the high education group. This seems quite reasonable, given that compulsory education most likely had the largest effect on those individuals that otherwise would have dropped out of school as soon as possible. As was seen earlier, the compulsory schooling reforms in my sample ranges from 3 to 10 years, which implies that any further years of education was not due to any requirements made by national school laws.

Neither the OLS nor the 2SLS reveal any significant effect on the probability of developing dementia. The results are similar when running the regressions without controlling for age and gender. It is thus the endogenous variable for education that differs from the main results when dividing the sample into groups by educational level. A possible explanation for this is that the variable only varies from 5 to 10 years within the groups, which possibly reduces the estimated effect.

Table 7: Heterogeneity of results across educational level – incidence of dementia

	Low education		Middle education		High education	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Years of education	-0.001	-0.012	-0.000	-0.183	-0.001	0.141
	(0.001)	(0.014)	(0.001)	(0.232)	(0.001)	(0.916)
Age	0.002***	0.002***	0.001**	0.004	0.001***	-0.000
	(0.000)	(0.001)	(0.000)	(0.004)	(0.000)	(0.010)
Gender	-0.002	0.000	0.003*	-0.003	0.009***	-0.244
	(0.003)	(0.004)	(0.002)	(0.010)	(0.003)	(7.670)
First stage		0.207***		-0.021		0.003
		(0.042)		(0.024)		(0.067)
F-statistic		24.46		0.83		0.00
Observations	8,379	8,379	12,313	12,313	4,420	4,420
R-squared	0.079	-	0.060	-	0.066	-

Notes: The dependent variable is *dementia*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses. These are clustered in all regressions and clustered by country and birth cohort in the 2SLS estimates. The sample window is five years before and after each reform. The sample is divided by educational level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

As a third heterogeneity test, I split my sample by individual income level. The low-income group are individuals within quantile categories 1 and 2, and the high-income group are individuals within quantile categories 3 or 4. As mentioned in the data section, this variable is adjusted according to the number of household members contributing to the total household income and is ranked within each country. The first stage is quite strong in the high-income group, whereas it does not manage to fulfil the criteria in the low-income group. This indicates that individuals with higher income as adults were more strongly affected by the compulsory schooling reforms that occurred during their youths. A possible explanation could be that the individuals that were not as affected by the reform ended up with a lower income, in comparison to those who were more strongly affected. Similar to the results above, we see that the OLS estimates reveal small but negative effects of years of education on the risk of developing dementia, while the 2SLS estimates show no significant effects at all. The overall results of this heterogeneity analysis indicate that there is no causal, negative effect on dementia. This implies that even though the treatment effect of compulsory schooling seems to differ between groups, the effect of education remains unchanged.

Table 8: Heterogeneity of results across income level – incidence of dementia

	Low income		High income	
	OLS	2SLS	OLS	2SLS
Years of education	-0.002***	0.005	-0.001***	-0.002
	(0.000)	(0.012)	(0.000)	(0.008)
Age	0.002***	0.001**	0.001***	0.001**
	(0.000)	(0.001)	(0.000)	(0.001)
Gender	0.001	-0.001	0.002	0.003
	(0.003)	(0.006)	(0.002)	(0.004)
First stage		0.205**		0.225***
		(0.089)		(0.061)
F-statistic		5.38		13.63
Observations	6,799	6,799	21,540	21,540
R-squared	0.057	-	0.051	-

Notes: The dependent variable is *dementia*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses. These are clustered in all regressions and clustered by country and birth cohort in the 2SLS estimates. The sample window is five years before and after each reform. The sample is divided by income level. *** p < 0.01, ** p < 0.05, * p < 0.1.

6.3 Cognitive reserve

The noted small, but significant and negative OLS association and the non-significant 2SLS estimate indicates that endogeneity might play a role in the seemingly "protective" role of education on dementia that was found in much of the previous literature. Next, I explore how cognitive ability relates to dementia, following the common explanation that education creates a cognitive reserve, leading to a stronger protection against cognitive decline and ultimately protection against dementia. As a first illustration, the mean cognitive ability for each cohort is plotted around the threshold in Figure 4. Similar to the graph illustrating the incidence of dementia, there is no clear discontinuity of cognitive ability around the pivotal cohort, but instead a positive and linear trend over time.

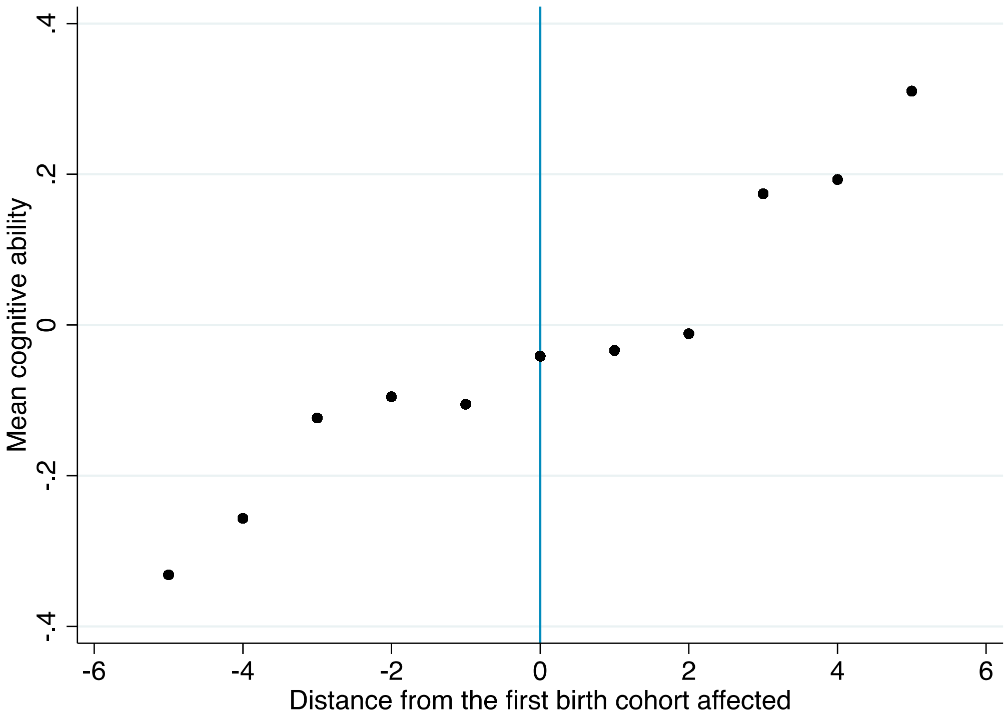

Figure 4: Mean cognitive ability per cohort around the threshold.

I proceed by empirically investigating the relationship between cognitive ability and dementia. Table 9 presents the results. Column 1 shows the estimates when no control variables are included. Cognitive ability has a negative and significant effect on the risk of developing dementia. The relationship increases slightly when controlling for age and gender in Column 2, where age has a positive and significant effect on dementia. Column 3 presents the 2SLS estimate. Interestingly, this results in an increased effect of cognitive ability on dementia. The instrument for education is, however, insignificant. When I instead introduce the endogenous estimate for education in Column 4, the effect of cognitive ability on dementia is smaller and significant. The variable for years of education reveal a small but positive and significant effect on risk of developing dementia, which indicates that, when controlling for cognitive ability, the endogenous variable for years of education seem to have a positive effect on dementia.

Table 9: Incidence of dementia

	(1) OLS	(2) OLS	(3) 2SLS	(4) OLS
Cognitive ability	-0.015***	-0.016***	-0.030***	-0.017***
	(0.001)	(0.001)	(0.011)	(0.001)
Age		0.002***	0.002***	0.002***
		(0.000)	(0.000)	(0.000)
Gender		0.003	-0.005	0.002
		(0.002)	(0.006)	(0.002)
Years of education			0.013	0.001***
			(0.009)	(0.000)
First stage			0.169***	
			(0.053)	
F-statistic			10.05	
Observations	22,436	22,436	22,436	22,436
R-squared	0.065	0.067	-	0.068

Notes: The dependent variable is *dementia*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses. These are clustered in all regressions and clustered by country and birth cohort in the 2SLS estimates. The sample window is five years before and after each reform. *** p < 0.01, ** p < 0.05, * p < 0.1.

The results indicating that cognitive ability is negatively related to the incidence of dementia, while the instrument for education is not, point to that there exists reverse causality between education and cognitive ability. As the effect of cognitive ability on dementia changed as I add education in Table 9, the next step is to test the association between cognitive ability and education. Table 10 presents the results. When using the endogenous variable for years of education, there evidently seems to be a significant and positive relationship on cognitive ability. When instead including the instrument for education, the relationship is insignificant in both estimations. This strengthens the belief that there seems to be no causal effect of education on dementia, since this should be mediated through cognitive ability.

Table 10: Cognitive ability

	(1)		(2)	
	OLS	2SLS	OLS	2SLS
Years of education	0.115***	-0.142	0.115***	-0.158
	(0.002)	(0.124)	(0.002)	(0.132)
Age			0.026***	0.039***
			(0.003)	(0.008)
Gender			-0.043***	0.124
			(0.014)	(0.083)
First stage		0.235***		0.231***
		(0.054)		(0.054)
F-statistic:		19.02		18.89
Observations	22,441	22,441	22,441	22,441
R-squared	0.343	-	0.347	-

Notes: The dependent variable is *cognitive ability*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses. These are clustered in all regressions and clustered by country and birth cohort in the 2SLS estimates. The sample window is five years before and after each reform. *** p < 0.01, ** p < 0.05, * p < 0.1.

6.4 Alternative channels

An alternative explanation behind the profound relationship between education and dementia, is that people with higher education also have a higher socio-economic status. They are therefore also more likely to live a healthy lifestyle if, as noted by Galama et al. (2018), the possible income effect does not lead to them increasing their consumption of unhealthy goods. It is therefore interesting to see whether the instrument for education can predict factors, except from cognitive ability, that is related to dementia. In Table 11, the instrument for years of education is regressed on five different variables, all known risk factors of dementia. Education has no impact on either of the risk factors. Controls for age and gender are included in all regressions, although the results remain approximately the same when they are excluded. It therefore seems as if the studied compulsory schooling reforms did not have any effect on adult socioeconomic outcomes.

Table 11: Risk factors for developing dementia

	Low income	Depression	Obesity	High alcohol consumption	Sedentary lifestyle	Smoking
Years of education	-0.009	-0.016	0.003	0.006	-0.015	-0.000
	(0.013)	(0.013)	(0.016)	(0.007)	(0.022)	(0.018)
Age	-0.001	0.006**	0.006***	0.001***	0.001	-0.010***
	(0.001)	(0.003)	(0.001)	(0.000)	(0.002)	(0.002)
Gender	-0.047***	-0.008	-0.001	0.021***	-0.060***	0.051***
	(0.009)	(0.009)	(0.011)	(0.004)	(0.014)	(0.012)
Observations	28,406	28,406	28,406	28,406	28,406	28,406

Notes: The dependent variables are *low income, depression, obesity, high alcohol consumption, sedentary lifestyle,* and *smoking*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses and are clustered by country and birth cohort. The sample window is five years before and after each reform. First stage estimate: 0.231*** (0.053), F-statistic: 18.89. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

6.5 Robustness

The choice of including five birth cohorts before and after each reform was made in accordance with previous studies applying the same method. Since some countries changed the length of compulsory schooling numerous times during the period of interest, it was also important that the window around the pivotal cohorts only was affected by the change in question, and not previous or subsequent ones. To investigate the robustness of the main results, I run the regressions using three other samples: one with a four-year bandwidth, one with a six-year bandwidth and one using the full sample. As before, the window around the affected birth cohorts that occurred close to each other are adjusted accordingly, so that they do not include years where another reform has been affective.

Table 12 presents the results from the robustness test. Using a four-year bandwidth, the strength of the first stage is reduced somewhat in comparison to the main results. It does, however, still meet the requirement of an F-statistic above 10. The effect of the instrument for education does not change much from the main results, and it is still insignificant. The same pattern can be seen when using the six-year bandwidth. Here, the first stage is only reduced marginally, when compared to the first stage when using five birth cohorts. When using the full sample, the results change somewhat. Education seems to have a positive and significant effect on the probability of developing dementia. This effect is, however, only significant on the 10-percent level. It should also be noted that the F-statistic is below the standard rule of thumb in both regressions wherefore the estimates should be interpreted with care. We can, however, draw the conclusion that none of the samples produces estimates indicating that education would have the expected negative effect on dementia.

Table 12: Robustness test – Incidence of dementia

	4-year bandwidth		6-year bandwidth		Full sample	
	(1)	(2)	(1)	(2)	(1)	(2)
Years of education	0.004	0.004	0.000	-0.000	0.021*	0.024*
	(0.008)	(0.008)	(0.006)	(0.006)	(0.013)	(0.014)
Age		0.001**		0.001***		0.002***
		(0.001)		(0.000)		(0.001)
Gender		-0.001		0.002		-0.015*
		(0.005)		(0.004)		(0.008)
First stage	0.191***	0.189***	0.219***	0.216***	0.110***	0.105***
	(0.055)	(0.054)	(0.051)	(0.051)	(0.036)	(0.036)
F-statistic	12.16	12.14	18.31	18.30	9.43	8.58
Observations	23,899	23,899	32,397	32,397	75,009	75,009
R-squared	-0.023	-0.018	-0.000	0.001	-0.266	-0.332

Notes: The dependent variable is *dementia*. All estimations include a constant and all regressions include country- and birth cohort-fixed effects. Standard errors are in parentheses and are clustered by country and birth cohort. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7. Concluding discussion

The aim of this research was to examine whether education causally relates to dementia. Given the prevalence of the disease, together a rapidly ageing population, it is of key importance to evaluate possible modifiable risk factors and increase our knowledge of how dementia can be prevented. From a large body of literature, it is well known that higher education associates with dementia. However, the question of whether the link between education and dementia is causal or not, remains unclear. Using compulsory school leaving ages across European countries as an instrument for years of education, this research attempts to address the problem of endogeneity.

The results suggest that education do not significantly predict the risk of developing dementia when using an IV approach. This should be contrasted with the results from OLS regressions, where education significantly associates with a lower risk of dementia. This pattern is observed throughout the empirical analysis: the endogenous education variable generates estimates that indicate a negative relationship between years of schooling and incidence of dementia, while the exogenous education variable suggests no significant effects. The OLS estimates are, however, small in comparison to other studies and is possible that my variable for dementia is underestimated, which could be a potential source of the seemingly small effect.

A similar pattern is observed when investigating the relationship between education and cognitive ability. While the results from 2SLS regressions suggest that the effects of education are insignificant, OLS regressions produce significant and positive coefficients on cognitive ability. These are quite large in magnitude and more similar to results obtained in previous studies. Furthermore, cognitive ability significantly and negatively relates to the risk of developing dementia. This is in line with expectations since cognitive test scores often are used to imply whether individuals face the risk of developing dementia. The results are robust to including education into the model, indicating that cognitive ability significantly relates to dementia independently of educational attainment. These results strengthen the idea that education cannot causally predict dementia. Overall, I find no support for the hypothesis of cognitive reserve (Stern, 2002) and my findings suggest that previous papers using OLS, which have concluded that education has a protective role against dementia, might suffer from endogeneity.

Both Larsson et al. (2017) and Nguyen et al. (2016) apply the IV approach and find evidence of a significant, causal relationship between education and risk of developing dementia when using genetic variants as an instrument for education. The fact that my instrument differs from theirs, could be a possible explanation to the different results. As they conclude, genetic variants can be associated with different risk factors, which thus could violate the exclusion restriction. But Nguyen et al. (2016) also find evidence of a significant effect of education when using compulsory schooling reforms as an instrument and continuous cognitive test scores as a measure of dementia risk score. An alternative explanation to the diverging results is that they contrast differences in the studied populations. Nguyen et al. (2016) investigate individuals in the US, while I use a multi-country dataset of European countries.

When investigating other factors that are known to be associated with incidence of dementia, my results indicate that the compulsory schooling reforms did not have an effect on income, depression, or any of the investigated health behaviors. Seblova et al. (2020) conclude that the exogenous variation in years of schooling in Sweden only had minor impacts on adult socioeconomic outcomes. Their results also indicate that education seem to have very small effects on dementia, and state that, to maintain cognitive benefits throughout the lifespan, it is possible that changes in midlife conditions are required. It might be that the absence of other effects of the compulsory schooling reforms used in this paper, indicates that the reforms did not affect the lives of the respondents' enough to provide a protection against dementia.

If changes in socio-economic status are needed to obtain any real effects of education on dementia, this points to a pathway between education and dementia which not necessarily is explained by a cognitive reserve. As stated by the extension of the Grossman (1972) model by Galama et al. (2018), education should lead to increased lifetime assets, increased skill accumulation and an increased valuation of health in comparison to wealth. The net effect of education on health is thus positive, as long as the increased assets are not used to consume more of unhealthy goods. In earlier research, it is possible that the educational variance had a larger effect on other later-life outcomes, which thus reduced the risk of dementia. The results of my paper do not point us in any direction of whether this is true or not, since the instrument for education could not explain neither of the factors. In future research, it would be relevant to evaluate this mechanism more closely. If it is possible to deliver evidence of a significant relationship between early-life education and incidence of dementia, which is not mediated through health behaviors or income, this might provide more convincing evidence of the theory of cognitive reserve.

Testing for heterogenous effects separating the sample by gender, income and educational level produces estimates that confirm my main results. Education does not significantly predict the risk of developing dementia when using an IV approach. The heterogeneity tests also point to some interesting patterns in the instrument, where men, individuals with lower education and higher adult income, seem to have been more strongly affected by the compulsory schooling reforms in question. This is especially true when separating the sample by educational level. This is expected, given that compulsory education should have had the largest effect on students that otherwise would have dropped out of school as soon as possible. Lastly, as a robustness test, I ran the main regressions while changing the bandwidth of the samples. The results were uniform with the main findings, although resulted in a weak first stage when the whole sample was included. This is not surprising, given that some countries changed the length of compulsory schooling several times during the period of interest.

In summary, this study contributes to the field of research on risk factors for developing dementia, by using compulsory schooling reforms in an IV setting on a multi-country European dataset, which, to my knowledge, has not been done before. The results contradict most of the earlier OLS findings and is not able to support the cognitive reserve hypothesis. It is worth mentioning that this paper does not examine the relationship between education and cognitive decline. In future research, it would be interesting to investigate whether exogenous variation in education can explain differences in performance on cognitive tests among individuals that has experienced similar cognitive decline across time. This would ultimately test the full chain of cognitive reserve.

References

Alzheimer's Association. (2021). Types of dementia, Alzheimer's Association, Available online: https://www.alz.org/alzheimers-dementia/what-is-dementia/types-of-dementia [Accessed 4 May 2021]

Angrist, J. D., & Imbens, G. W. (1995). Two-Stage Least Squares Estimation of Average Causal Effects in Models with Variable Treatment Intensity, *Journal of the American Statistical Association*, 90(430), 431-442

Angrist, J. D., & Pischke, J. (2008). Mostly Harmless Econometrics: An Empiricist's Companion, Princeton: Princeton University Press

Bolzern, B., & Huber, M. (2017). Testing the validity of the compulsory schooling law instrument, *Economic Letters*, 159, 23-27

Brent, R. J. (2018). The value of a year's general education for reducing the symptoms of dementia, *Applied Economics*, 50(25), 2812-2823

Brunello, G., Fort, M., Schneeweis, N., & Winter-Ebmer, R. (2015). The Causal Effect of Education on Health: What is the Role of Health Behaviours?, *Health Economics*, 25, 314-336

Brunello, G., Fort, M., Weber, G., & Weiss, C. T. (2013). Testing the internal validity of compulsory school reforms as instrument for years of schooling, *IZA Discussion Paper*, (No. 7533), Available online: https://www.econstor.eu/bitstream/10419/80644/1/766626660.pdf [Accessed 21 May 2021]

Brunello, G., Weber, G., & Weiss, C. T. (2017). Books are Forever: Early Life Conditions, Education and Lifetime Earnings in Europe, The Economic Journal, 127(600), 271-296

Börsch-Supan, A., M. Brandt, C. Hunkler, T. Kneip, J. Korbmacher, F. Malter, B. Schaan, S. Stuck, S. Zuber. (2013). Data Resource Profile: The Survey of Health, Ageing and Retirement in Europe (SHARE). International Journal of Epidemiology. DOI: 10.1093/ije/dyt088

Börsch-Supan, A. (2020). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 2. Release version: 7.1.0. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w2.710

Börsch-Supan, A. (2020). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 4. Release version: 7.1.0. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w4.710

Börsch-Supan, A. (2020). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 5. Release version: 7.1.0. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w5.710

Börsch-Supan, A. (2020). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 6. Release version: 7.1.0. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w6.710

Börsch-Supan, A. (2020). Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 7. Release version: 7.1.1. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w7.711

Cawley, J., Heckman, J., & Vytlacil, E. (2001). Three observations on wages and measured cognitive ability, *Labour Economics*, 8(9), 419-442

Cook, C. J., & Fletcher, J. M. (2015). Can education rescue genetic liability for cognitive decline?, *Social Science & Medicine*, 127, 159-170

Foverskov, E., Glymour, M. M., Mortensen, E. L., Osler, M., Okholm, G. T., & Lund, R. (2020). Education and adolescent cognitive ability as predictors of dementia in a cohort of Danish men, *PLOS ONE*, 15(8)

Galama, T. J., Lleras-Muney, A., & van Kippersluis, H. (2018). The Effect of Education on Health and Mortality: A Review of Experimental and Quasi-Experimental Evidence, NBER Working Papers, (No. 24225), Available online: https://www.nber.org/system/files/working_papers/w24225/w24225.pdf [Accessed 5 April 2021]

Grossman, M. (1972). On the Concept of Health Capital and the Demand for Health, *Journal of Political Economy*, 80(2), 223-255

Hofmarcher, T. (2021). The Effect of Education on Poverty: A European Perspective, *Economics of Education Review,* 83(2)

Irwin, K., Sexton, C., Daniel, T., Lawlor, B., & Naci, L. (2018). Healthy Aging and Dementia: Two Roads Diverging in Midlife?, *Frontiers in Aging Neuroscience,* 10(275)

Jolliffe, I., & Cadima, J. (2017). Principal component analysis: a review and recent developments, *Philosophical Transactions of The Royal Society A: Mathematical Physical and Engineering Sciences,* 374(2065)

Larsson, S. C., Traylor, M., Malik, R., Dichgans, M., Burgess, S., & Markus, H. S. (2017). Modifiable pathways in Alzheimer's disease: Mendelian randomisation analysis, *The BMJ,* 359

Lochner, L. (2011). Nonproduction benefits of education: Crime, health, and good citizenship, in E. A. Hanushek, S. Machin, & L. Woessmann (eds), *Handbook of the Economics of Education,* Amsterdam: Elsevier, 4, 183-282

Mazzonna, F., & Peracchi, F. (2017). Unhealthy Retirement?, *Journal of Human Resources,* 52(1), 128-151

Meng, X., & D'Arcy, C. (2012). Education and Dementia in the Context of the Cognitive Reserve Hypothesis: A Systematic Review with Meta-Analyses and Qualitative Analyses, *PLOS ONE*, 7(6)

National Association for Biomedical Research. (2020). Five most expensive diseases, National Association for Biomedical Research, 3 March, Available online: https://www.nabr.org/biomedical-research/importance-biomedical-research/five-most-expensive-diseases [Accessed 16 April 2021]

Nguyen, T. T., Tchetgen Tchetgen, E. J., Kawachi, I., Gilman, S. E., Walter, S., Liu, S. Y., Manly, J. J., Glymour, M. M. (2016). Instrumental variable approach to identify the causal effect of educational attainment on dementia risk, *Annals of Epidemiology,* 26(1), 71-76

Prince, M., Albanese, E., Guerchet, M., & Prina, M. (2014). World Alzheimer Report 2014: Dementia and Risk Reduction. An analysis of protective and modifiable factors, Alzheimer's Disease International, Available online: https://www.alzint.org/u/WorldAlzheimerReport2014.pdf [Accessed 13 April 2021]

Seblova, D., Fischer, M., Fors, S., Johnell, K., Karlsson, M., Nilsson, T., Svensson, A. C., Lövdén, M., & Lager, A. (2020). Does Prolonged Education Causally Affect Dementia Risk When Adult Socioeconomic Status Is not Altered? A Swedish Natural Experiment in 1.3 Million Individuals, *American Journal of Epidemiology*

Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept, *Journal of the International Neuropsychological Society*, 8(3), 448-460

Stern, Y. (2012). Cognitive reserve in ageing and Alzheimer's disease. *The Lancet Neurology,* 11(11), 1006-2012

Wooldridge, J. M. (2012). Introductory Econometrics. A Modern Approach. 5th edn, Mason: South Western

World Health Organization. (2013). Social determinants of health: Key concepts, 7 May, Available online: https://www.who.int/news-room/q-a-detail/social-determinants-of-health-key-concepts [Accessed 6 May 2021]

World Health Organization. (2020). Dementia, World Health Organization, 21 September, Available online: https://www.who.int/news-room/fact-sheets/detail/dementia [Accessed 13 April 2021]

Zweifel, P., Breyer, F., & Kifmann, M. (2009). Health Economics, 2nd edn, Springer: Dordrecht Heidelberg London New York

Appendix A

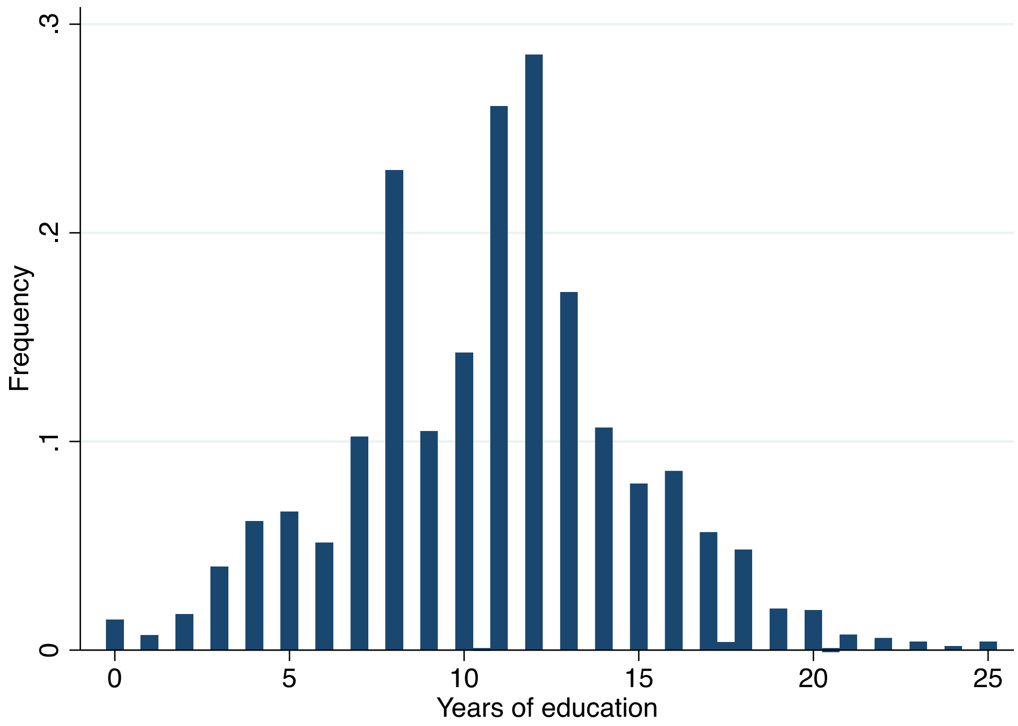

Figure A1: Histogram over years of education.

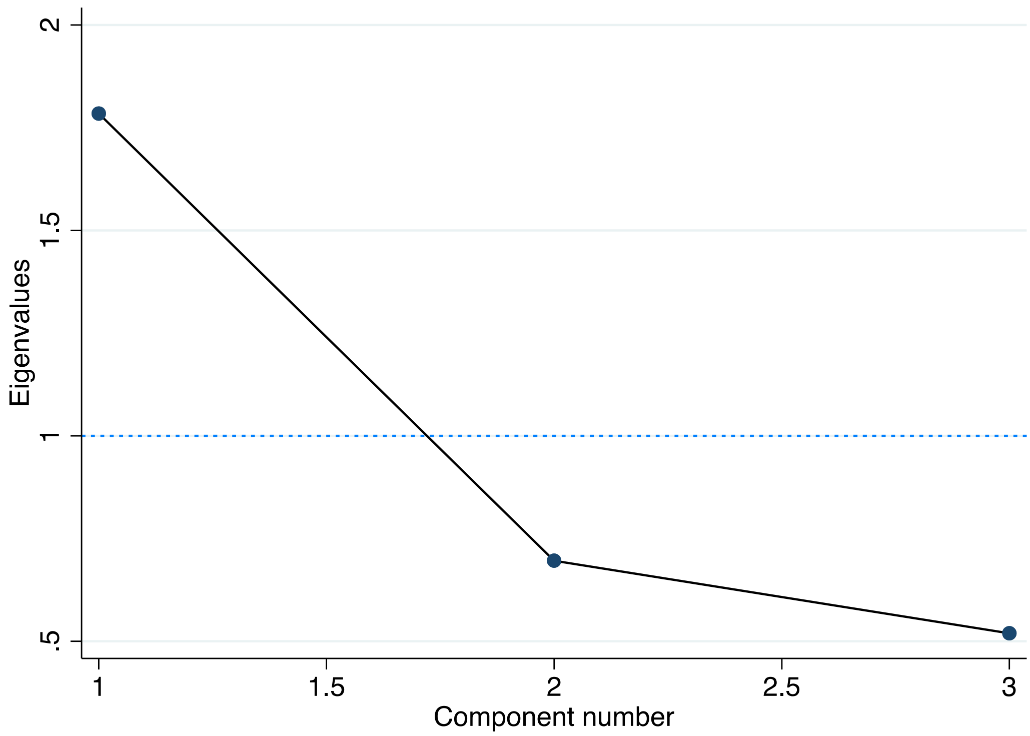

Figure A2: Scree plot over the eigenvalues for each component.

Appendix B

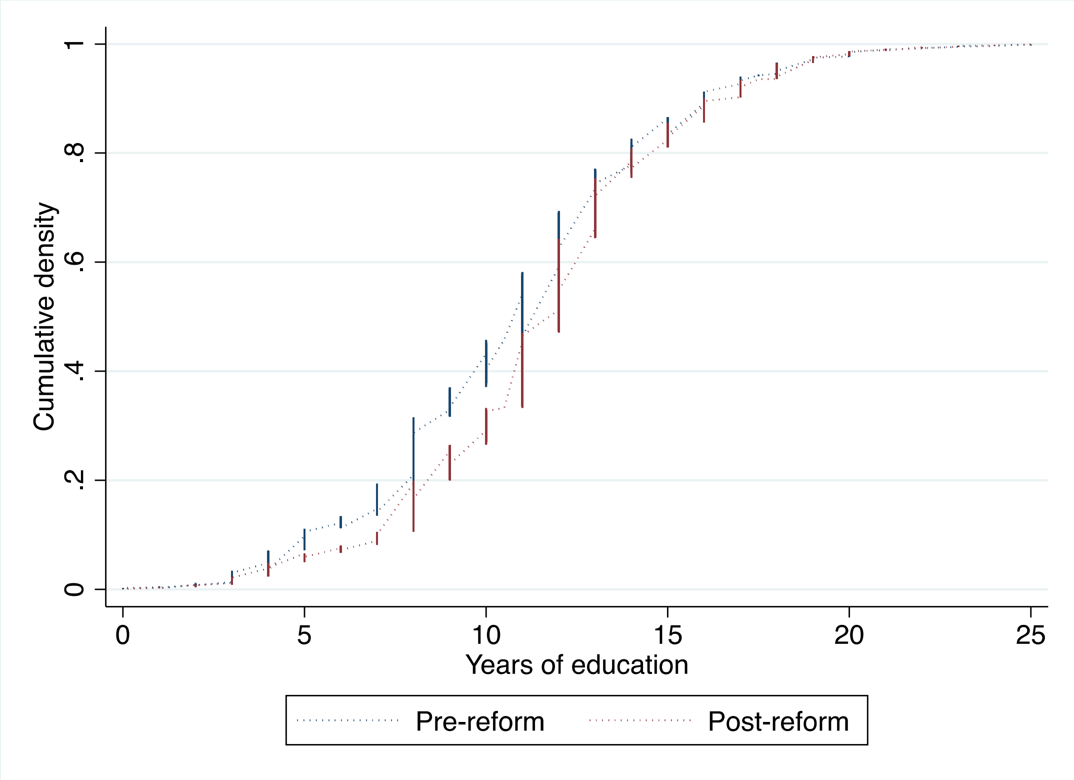

Figure B1: Cumulative density function of years of education before and after the compulsory schooling reforms.