Does Education Improve Cognitive Performance Four Decades After School Completion?

A Replication Study of Nicole Schneeweis, Vegard Skirbekk and Rudolf Winter-Ebmer (*Demography*, 2014)

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Abstract

This paper replicates the analysis of Schneeweis et al. (2014) using their sample as well as an extended sample. Schneeweis et al. (2014) use the Survey of Health, Ageing and Retirement in Europe (SHARE) dataset and exploit compulsory schooling reforms implemented in six European countries to analyse the impact of education on cognitive functioning decades after leaving school. They find a positive effect of education on memory scores and some evidence of a protective effect of education on the decline in verbal fluency. Our results support their findings when we use the same waves as they do, but also when we extend the sample by including more countries and interview waves and use different variables for years of education.

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1 Introduction

The sustainability of national social security and health systems is likely to be challenged as a result of the ageing population in Europe (Schneeweis et al., 2014). The declining importance of state provided social security and healthcare systems around the world is an indicator for the importance of individual or household decision-making skills of older individuals (Banks & Mazzonna, 2012). Cognitive abilities are essential for decision making (Banks & Oldfield, 2007) and, therefore, important for labour market, pension and retirement policies (Banks & Oldfield, 2007; Schneeweis et al., 2014). Recent literature suggests that education may be an important determinant of cognitive abilities (Banks & Oldfield, 2007; Glymour et al., 2008; Brinch & Galloway, 2012; Schneeweis et al., 2014; Crespo et al., 2014; Kamhöfer & Schmitz, 2016; Kamhöfer et al., 2019), but causal evidence is still sparse. Being able to replicate studies that find an effect of education on cognitive abilities is of relevance. We, therefore, aim to replicate the findings of Schneeweis et al. (2014) and investigate the validity of the findings with more data.

Schneeweis et al. (2014) analyse the long-run effects of education on cognitive performance. To estimate the effects they implement a Two-Stage Least Square (2SLS) approach. For identification, this approach makes use of compulsory schooling reforms implemented in six European countries. Schneeweis et al. (2014) find a positive effect of education on memory performance and also find that education reduces the decline in verbal fluency. They find stronger effects for men and individuals who had many books at home when growing up.

We first replicate the results based on how Schneeweis et al. (2014) did their analysis. We use the same waves and determine the years of education in a similar manner. We then extend the sample by including more compulsory schooling reforms and more interview waves. Due to the availability of more information that comes with including more reforms and waves, we check how robust the first-stage results are when we use different variables for years of education. We also replicate the second stage results using more reforms, all available interview waves and our variable for years of education. Our results are not far-fetched from that of Schneeweis et al. (2014).

2 Data and sample selection

Schneeweis et al. (2014) use data from the Survey of Health, Ageing and Retirement in Europe (SHARE). SHARE is a micro panel database covering most of the European Union and Israel (Börsch-Supan et al., 2013). Schneeweis et al. (2014) consider only individuals from Austria, Czech Republic, Denmark, France, Germany and Italy, who participated in one or more waves. They use the first wave (2004/2005), second wave (2006/2007) and fourth wave (2011/2012) for their baseline analysis. In further analyses, they also use the third wave (2008/2009) known as the SHARELIFE, which has information on individuals' life histories. They only consider individuals aged 45 or older, who were born in the country of residence or migrated before age 5. This ensures that they attended school in the country of residence in the early stages, when they could possibly be affected by the compulsory schooling reforms. For the baseline sample, they select individuals born between 1939 and 1956. They also consider three sub-samples: individuals born up to *(i.)* 10 years (sample 10) *(ii.)* 7 years (sample 7), and *(iii.)* 5 years (sample 5) before and after the pivotal birth cohort of the respective reform.

The tests Schneeweis et al. (2014) used to measure cognitive functioning are *Immediate and Delayed Memory*, *Fluency*, *Numeracy* and *Orientation-to-date*. As explained by Schneeweis et al. (2014): *Immediate Memory* measures the number of words a respondent recalls out of ten words directly after they are read (range: 0 to 10); *Delayed Memory* measures the number of words a respondent recalls out of the same ten words 5 to 10 minutes later after other interview questions have been asked (range: 0 to 10); *Fluency* (verbal fluency score) measures the number of animal names a respondent is able to state in a minute (range: 0 to 100); *Numeracy* measures the ability of a respondent to answer basic and more advanced mathematical questions from daily life (range: 1 to 5); and *Orientation-to-date* measures a person's ability to remember the correct date comprising the day of the month, month, year, and day of the week (range: 0 to 4). They conduct a level analysis which uses the current test score and a slope analysis which uses the difference in current and previous test scores. For the level analysis, Schneeweis et al. (2014) generate binary variables for numeracy and orientation since "numeracy and orientation have larger densities at the upper tail of the distributions, with 55% achieving either the highest or the second-highest value of numeracy and 89% showing a perfect orientation-to-date", but treat the other test scores as continuous variables. They define *Good Numeracy* to be 1 for individuals who achieve numeracy scores of 4 and 5, and *Good Orientation* to be 1 for individuals scoring 4 on the orientation variable. They also define the change in test scores as "*cognitive decline*, which we calculate by subtracting the cognitive outcome from the cognitive outcome in a previous wave. Thus, a positive value implies a decline in cognitive performance, and a negative value represents a performance improvement." Only individuals who participated in more than one of the cognitive assessments are considered in the slope analysis, therefore, there are fewer observations.

There are certain things regarding *Numeracy* and *Orientation-to-date* in the SHARE data that need to be noted. From wave 4 onwards, the *Numeracy* test is only asked to baseline respondents, and in waves 4 and 5, *Orientation-to-date* was asked to baseline respondents. However, there are some panel respondents who have also performed these tests. In wave 7, these tests were only performed by respondents who had already taken part in the wave 3 SHARELIFE. This implies that respondents who joined the survey from wave 4 onwards did not take the *Orientation-to-date* test in wave 7. This explains why Schneeweis et al. (2014) do not include wave 4 data for the *Numeracy* and *Orientation-to-date* in their sample.[1] We do not include the wave 4 data for the *Numeracy* and *Orientation-to-date* in the slope analysis for the narrow replication, and in the wider replication, we do not perform the slope analysis for these tests. Although, these tests may not have been done by panel respondents in certain waves, there are imputed test scores available for them in those waves.[2] We do use the imputed scores for respondents who performed tests in specific waves but responded to some or all items of the test with "Don't know" or "Refusal".

For the first part of the replication, we use the same waves as Schneeweis et al. (2014) but a current version from SHARE (release 8.0.0). There are some differences between this release and the one used by Schneeweis et al. (2014) (release 2.3.0 for waves 1 and 2, and release 1.1.1 for wave 4). The major difference in the data has to do with the variable for years of education. There were two variables for years of education in wave 2, the raw years of education as provided by the respon-

[1] Schneeweis et al. (2014) write that data on the test scores for numeracy and orientation are not available in wave 4. However, the release we use (but also earlier releases currently available at the SHARE website: `http://www.share-project.org/data-access.html`) includes these test scores in wave 4.

[2] Results based on the imputed data can be found in our working paper Tawiah & Schiele (2023).

dents and the corrected years of education which are raw years of education corrected by SHARE. Subsequent waves and the current releases of wave 2 only have the corrected years of education. Comparing the two variables, we do not find much difference between them for most countries except for Denmark, where there are vast differences. Schneeweis et al. (2014) use the raw years of education for Denmark in wave 2, however, we use the corrected years education for consistency and as advised by the SHARE team. This creates some differences in the results which will be shown and discussed in the following sections. We also try as much as possible to adjust the years of education similar to that of Schneeweis et al. (2014). They use information on years of education from waves 2 or 4 for those who participated in those waves, since educational degrees but not years of education were asked in wave 1. The years of education of those who only participated in wave 1 are calculated using country-specific conversion tables provided by SHARE. Additional corrections are made to the years of education based on educational qualifications for missing, zero or implausibly low values.

Table 1: Replication of Table 2 from Schneeweis et al. (2014) - Descriptive Statistics of Baseline Sample: Level Analysis

	Female		Age		Years of Education: Individuals		Years of Education: Compulsory		Immediate Memory		Delayed Memory	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
Austria	0.57	0.57	62.24	61.98	10.26	11.24	8.28	8.27	5.67	5.64	4.37	4.36
Czech Republic	0.57	0.57	61.76	61.28	12.16	12.12	8.58	8.58	5.48	5.49	3.78	3.79
Denmark	0.52	0.52	59.37	58.91	12.09	13.62	5.77	5.77	5.96	5.96	4.85	4.84
France	0.55	0.55	60.13	59.64	11.99	12.16	8.46	8.46	5.39	5.41	4.07	4.08
Germany	0.54	0.54	59.76	59.27	13.33	13.31	8.26	8.27	5.96	5.95	4.45	4.43
Italy	0.56	0.56	60.88	60.44	8.71	9.04	6.11	6.11	4.94	4.94	3.46	3.45
Total	0.55	0.55	60.81	60.33	11.26	11.73	7.63	7.59	5.51	5.51	4.09	4.09

	Fluency		Good Numeracy		Good Orientation		Observations		Individuals	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
Austria	23.56	23.57	0.72	0.74	0.91	0.92	4,724	4,212	3,624	3,182
Czech Republic	22.11	22.21	0.60	0.62	0.88	0.89	5,448	4,984	4,571	4,126
Denmark	23.92	23.93	0.58	0.60	0.90	0.90	3,755	3,767	1,901	1,903
France	21.01	21.16	0.51	0.54	0.87	0.89	5,683	5,534	3,644	3,496
Germany	23.27	23.23	0.74	0.74	0.92	0.93	2,860	2,919	1,590	1,595
Italy	15.93	15.88	0.33	0.33	0.90	0.91	5,229	5,207	2,928	2,895
Total	21.33	21.32	0.57	0.58	0.90	0.90	27,699	26,623	18,258	17,197

Notes: Orig. presents the original values from Schneeweis et al. (2014) and *Repl.* presents the values from our replication sample.

Table 1 shows the descriptive statistics of the sample for the level analysis from Schneeweis et al. (2014) and for our sample. The proportion of females is exactly the same for both samples and the difference in average ages is marginal. With individual years of education, there is a year difference in the average for Austria and 1.5 years difference in the average for Denmark. The difference for

Denmark is not surprising since the variable for wave 2 used for Denmark by Schneeweis et al. (2014) (raw years of education) is different from what we use (corrected years of education). The difference found in Austria could be a result of the reduction in the number of individuals and hence, the number of observations in our sample. The corrected years of education could have also undergone further corrections in the current versions. The average years of education for the rest of the countries are similar. The averages of the test scores are quite similar. Our sample size is slightly smaller than that of Schneeweis et al. (2014). For the slope analysis, the descriptive statistics are shown in Table 2. The average change in tests scores is similar for most tests. The direction of the changes is very similar. As mentioned above, the number of observations for the slope analysis is smaller than that of the level analysis. Czech Republic was included in the SHARE from wave 2. Schneeweis et al. (2014) do not include wave 4 data for the *Numeracy* and *Orientation* tests in their sample, and we exclude them in our slope analysis hence, the missing values for these tests for Czech Republic.

Table 2: Replication of Table 3 from Schneeweis et al. (2014) - Descriptive Statistics of Baseline sample: Slope Analysis

	Immediate Memory		Delayed Memory		Fluency		Numeracy	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
Austria	−0.01	−0.00	−0.24	−0.21	0.36	0.32	−0.06	−0.09
Czech Republic	−0.08	−0.05	−0.07	−0.04	−2.23	−2.00	–	–
Denmark	0.02	0.01	−0.15	−0.15	−0.25	−0.25	−0.14	−0.13
France	−0.29	−0.30	−0.49	−0.49	0.99	1.01	−0.08	−0.08
Germany	0.05	0.06	−0.21	−0.21	0.22	0.16	−0.03	−0.06
Italy	−0.22	−0.23	−0.22	−0.22	−0.12	−0.12	−0.05	−0.04
Total	−0.11	−0.11	−0.25	−0.24	0.00	0.01	−0.07	−0.08

	Orientation		Duration		Observations		Individuals	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
Austria	−0.06	−0.05	39.50	39.94	1,100	1,030	741	668
Czech Republic	–	–	49.50	49.45	877	858	877	858
Denmark	0.01	0.01	42.35	42.29	1,854	1,864	1,326	1,331
France	0.03	0.02	40.18	40.07	2,031	2,030	1,379	1,375
Germany	0.00	−0.01	43.01	42.95	1,268	1,322	893	927
Italy	0.00	−0.00	42.34	42.34	2,301	2,312	1,521	1,527
Total	0.00	−0.00	42.30	42.31	9,431	9,416	6,737	6,686

Notes: Orig. presents the original values from Schneeweis et al. (2014) and *Repl.* presents the values from our replication sample.

We also do the analyses using all available waves of the SHARE dataset i.e. waves 1, 2, 4-8 for the main analysis, and some information from wave 3 and wave 7 (SHARELIFE) for other analyses.[3] Including more waves enriches the sample and analyses, especially for the slope analysis. The increase in the sample size should reduce the standard errors, thereby making the estimates more precise ceteris paribus. Using three waves for the slope analyses allows for a maximum of two possible estimates of cognitive decline per individual. With the additional four waves, a maximum of seven observations per individual is possible. This enables us to analyse the effect of education on cognitive decline over a longer period. Finally, the inclusion of multiple waves also allows us to use a single measure of years of education, namely self-reported years of education, so that we do not have to approximate years of education based on information on the highest educational attainment and conversion tables, which is also a difficult task.[4]. Table A2 in the Appendix gives details on the different variables for years of education. We, therefore, do a complete analysis with all the countries used in Schneeweis et al. (2014). Summary statistics for the all waves sample are given in Tables A3 and A4 in the Appendix.

3 *Main Results*

3.1 *Narrow replication*

Schneeweis et al. (2014) estimate the causal effect of education on the level of cognitive performance (level analysis, *l*) and on cognitive decline (slope analysis, *s*). For the level and slope analyses, they use the following models (presented differently) respectively:

$$Y_{ickt} = X'_{ickt}\beta_l + \rho_l E_{ickt} + \gamma_c + \lambda_k + \mu_c T + \varepsilon_{ickt} \quad (1)$$

$$Y_{ickt} - Y_{ickt+r} = X'_{ickt}\beta_s + \rho_s E_{ickt} + \gamma_c + \lambda_k + \mu_c T + \varepsilon_{ickt} - \varepsilon_{ickt+r} \quad (2)$$

where Y_{ickt} is the cognitive achievement of individual i in country c of birth cohort k in survey year t. $Y_{ickt} - Y_{ickt+r}$ is the change in cognitive performance in survey year t compared with survey year $t + r$. E_{ickt} is the number of years that the individual spent in education, and X_{ickt} is a vector of control variables. X_{ickt} includes a female dummy variable and an indicator variable for whether a person was born abroad and migrated before age 5. In Eq. (1), it also contains indicators for the interview year and control variables for the quality of the interview session (the interviewer's perception of whether something may have impaired the respondent's performance on the tests and whether another person was present during the interview). In Eq. (2), it also contains an indicator for the first interview year, control variables for the quality of both interview sessions, and the number of months between the two interviews (*Duration*). γ_c and λ_k refer to country and cohort fixed effects, and $\mu_c T$ captures country-specific linear trends in birth cohorts.

They use Two-Stage Least Squares (2SLS) to estimate Eqs. (1) and (2), because ε_{ickt} and ε_{ickt+r} might be correlated with years of education. They instrument years of education with the compulsory years of schooling ($Comp_{ck}$) in the respective country and birth cohort. The first-stage which shows the impact of compulsory schooling on years of education is modelled as:

$$E_{ickt} = X'_{ickt}\alpha + \pi Comp_{ck} + \gamma_c + \lambda_k + \mu_c T + \nu_{ickt} \quad (3)$$

[3] See Börsch-Supan (2022a,b,c,d,e,f,g,h); Börsch-Supan et al. (2013). In wave 7, those who did not participate in wave 3, the SHARELIFE wave, were requested to do the SHARELIFE interview along with a condensed set of questions from the regular questionnaire. Those who already participated in wave 3 received a regular panel questionnaire.

[4] For example, some of the compulsory schooling reforms are not visible in SHARE's conversion tables

The compulsory years of schooling are assigned as Schneeweis et al. (2014) did using the information provided in Table 1 from Schneeweis et al. (2014).The information is also available in Table A1 in the Appendix. For more details on the reforms, check the Appendix of Schneeweis et al. (2014).

We replicate Fig. 1 in Schneeweis et al. (2014) shown in Figure A1 in the Appendix, which depicts the effect of compulsory schooling on actual years of schooling. Compared with the original figure, our graph shifts upward. The upward shift can be attributed to the increased number of years of education found in Denmark and Austria. In spite of this, we also find a jump in the mean years of education at the time of the various reforms indicating an impact of the reforms on years of education.

Replicating Table 4 from Schneeweis et al. (2014) based on Eq. (3), our results in Table 3 also show an increase in years of education of about one-third of a year on average due to the increase in compulsory schooling years. They also estimate this effect using smaller windows around the pivotal cohort (see Section 2). "Smaller windows have the advantage that persons and circumstances before and after the changes in the law are similar but also the disadvantage of producing smaller sample sizes" (Schneeweis et al., 2014). However, it should be noted that a too small estimation window can lead to the situation in which the fixed effects for / trends in birth cohorts can no longer be cleanly distinguished from the effects of the reform due to insufficient overlap of cohorts across countries. We also replicate these in Table 3. Our results are not so different from the original results.

The replication results of Table 5 in Schneeweis et al. (2014) are presented in two tables, level analysis in Table 4 and slope analysis in Table 5. OLS and 2SLS results are based on Eq. (1) for the level analysis and Eq. (2) for the slope analysis.

Table 3: Replication of Table 4 from Schneeweis et al. (2014) - First Stage Regressions

	Baseline		Sample 10		Sample 7		Sample 5	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
Compulsory schooling	0.315**	0.301**	0.317**	0.303**	0.314**	0.299**	0.331**	0.311**
	(0.062)	(0.056)	(0.063)	(0.057)	(0.073)	(0.063)	(0.090)	(0.077)
F Statistics	25.82	28.81	24.98	28.06	18.41	22.53	13.40	16.43
Observations	27,699	26,506	25,378	24,289	20,126	19,973	15,509	15,626

*Notes: S*tandard errors clustered at individual level in parenthesis. The sample includes all observations with non-missing immediate memory scores. * $p < 0.05$, ** $p < 0.01$
Orig. presents the original results from Schneeweis et al. (2014) and *Repl.* presents the results from our replication sample.

Just as Schneeweis et al. (2014), our OLS results also show a positive association between education and levels of cognitive functioning. Our results are slightly larger. For 2SLS results in the level analysis, the direction of the results is almost the same for all the cognitive tests except in sample 7 and sample 5 of good orientation. We also do not find statistically significant results for fluency, good Numeracy and good Orientation. For immediate memory and delayed memory, the standard errors are quite similar but the effects are smaller than the original hence, most of them lose some strength in statistical significance. For instance in the baseline results, Schneeweis et al. (2014) find that an additional year of schooling increases immediate memory by 0.14 words at 5% significance level but we find an increase of 0.11 words at 10% significance level. Just as Schneeweis et al. (2014), the size of the effects is larger the smaller the sample around the pivotal cohorts with sample 5 having the largest effect. For those in sample 5, the effects for immediate memory and delayed memory remain strong. This indicates that the effect of an additional year of schooling on memory is more evident amongst those closer to the reform.

Table 4: Replication of Table 5 (Level Analysis) from Schneeweis et al. (2014) - Baseline Results

dep. var:	Immediate Memory		Delayed Memory		Fluency		Good Numeracy		Good Orientation	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
A. OLS										
Baseline	0.112**	0.126**	0.125**	0.139**	0.504**	0.568**	0.032**	0.038**	0.004**	0.005**
	(0.003)	(0.004)	(0.004)	(0.004)	(0.015)	(0.017)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	27,699	26,506	27,693	26,497	27,555	26,402	22,368	26,506	22,467	26,506
B. 2SLS										
Baseline	0.144*	0.112	0.171*	0.128	−0.260	−0.335	−0.013	−0.026	−0.007	−0.019
	(0.066)	(0.069)	(0.078)	(0.083)	(0.322)	(0.347)	(0.023)	(0.027)	(0.013)	(0.015)
Observations	27,699	26,506	27,693	26,497	27,555	26,402	22,368	26,506	22,467	26,506
Sample 10	0.155*	0.121+	0.184*	0.138+	−0.020	−0.111	−0.012	−0.024	−0.006	−0.019
	(0.067)	(0.070)	(0.080)	(0.084)	(0.308)	(0.333)	(0.023)	(0.027)	(0.013)	(0.015)
Observations	25,378	24,289	25,375	24,281	25,245	24,193	20,450	24,289	20,540	24,289
Sample 7	0.205**	0.139+	0.217*	0.141	−0.161	−0.059	−0.023	−0.031	0.002	−0.019
	(0.079)	(0.077)	(0.093)	(0.093)	(0.366)	(0.370)	(0.026)	(0.030)	(0.015)	(0.016)
Observations	20,126	19,973	20,124	19,967	20,021	19,897	16,257	19,973	16,333	19,973
Sample 5	0.233*	0.197*	0.324**	0.270*	−0.361	−0.384	−0.032	−0.042	0.001	−0.024
	(0.093)	(0.091)	(0.118)	(0.113)	(0.445)	(0.451)	(0.032)	(0.036)	(0.017)	(0.019)
Observations	15,509	15,626	15,422	15,622	15,507	15,562	12,559	15,626	12,618	15,626

Notes: Standard errors clustered at individual level in parenthesis. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$
Orig. presents the original results from Schneeweis et al. (2014) and *Repl.* presents the results from our replication sample.

Similar to Schneeweis et al. (2014), we only find a statistically significant association between schooling and cognitive decline in delayed memory. We also do not find statistically significant effects for decline in immediate memory, delayed memory and numeracy. We find larger effects than the original for fluency but they are only statistically significant at 10% significance level. For decline in orientation, we find a larger and significant effects compared to Schneeweis et al. (2014) even though our sample sizes are smaller and our estimates less precise.

Importantly and other than one would expect, the estimates suggest that education accelerates the decline in orientation. A possible explanation for positive effects of education on decline in orientation is that more education leads to higher orientation, which than leads to a faster decline in orientation in older ages. This explanation is not supported by the results for the level analysis though.

Table 5: Replication of Table 5 (Slope Analysis) from Schneeweis et al. (2014) - Baseline Results

dep. var: Δ in ...	Immediate Memory		Delayed Memory		Fluency		Numeracy		Orientation	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
A. OLS										
Baseline	−0.002	−0.002	−0.016**	−0.015**	−0.011	0.001	−0.003	0.001	0.000	−0.000
	(0.004)	(0.005)	(0.005)	(0.005)	(0.016)	(0.018)	(0.005)	(0.004)	(0.002)	(0.002)
Observations	9,431	9,370	9,435	9,368	9,378	9,326	6,737	4,202	6,768	4,202
B. 2SLS										
Baseline	−0.080	−0.123	−0.083	−0.090	−0.755*	−0.756+	−0.041	−0.049	0.061	0.118*
	(0.085)	(0.101)	(0.093)	(0.107)	(0.367)	(0.416)	(0.082)	(0.092)	(0.045)	(0.056)
Observations	9,431	9,370	9,435	9,368	9,378	9,326	6,737	4,202	6,768	4,202
Sample 10	−0.079	−0.133	−0.101	−0.109	−0.780*	−0.819+	−0.025	−0.029	0.062	0.123*
	(0.084)	(0.102)	(0.093)	(0.109)	(0.366)	(0.425)	(0.080)	(0.094)	(0.044)	(0.059)
Observations	8,561	8,513	8,567	8,512	8,513	8,473	5,973	3,714	6,002	3,714
Sample 7	−0.045	−0.100	−0.010	−0.049	−0.606	−0.617	0.081	0.067	0.077	0.134*
	(0.095)	(0.115)	(0.103)	(0.123)	(0.391)	(0.459)	(0.086)	(0.105)	(0.048)	(0.068)
Observations	6,757	6,966	6,762	6,965	6,717	6,933	4,729	3,019	4,752	3,019
Sample 5	0.062	0.042	0.073	0.001	−0.616	−0.791	0.078	0.119	0.050	0.142+
	(0.104)	(0.124)	(0.116)	(0.135)	(0.422)	(0.520)	(0.095)	(0.122)	(0.049)	(0.079)
Observations	5,154	5,364	5,157	5,363	5,117	5,334	3,605	2,348	3,627	2,348

*Notes: S*tandard errors clustered at individual level in parenthesis. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$
Orig. presents the original results from Schneeweis et al. (2014) and *Repl.* presents the results from our replication sample.

Schneeweis et al. (2014) also check for whether the effects vary by gender and family background using sample 10. 2SLS regressions are estimated for males and females separately. The measure Schneeweis et al. (2014) wanted to use for family background was education of parents. This is, unfortunately, not available hence they use the number of books an individual had available at home at age 10 as a proxy. Based on the variable for the number of books, they split the sample into two: individuals with few books (0 - 10 or 11-25 books) and individuals with many books (26 - 100, 101 - 200 or more than 200 books).

Looking at the level analysis for gender in panel A of Table 6, we only find a significant effect on immediate memory for males at 10% significance level. Just as Schneeweis et al. (2014) , we do not find significant effects for females. The size of the effects is a bit larger in our replication results for men, in general the results are quite similar. The results for the gender gradient in the slope analysis (panel A of Table 7) are also rather similar, although we do not find significant effects on the decline in delayed memory and fluency for males like Schneeweis et al. (2014) did, but instead a marginally significant effect on change in orientation for females.

Table 6: Replication of Table 6 (Level Analysis) from Schneeweis et al. (2014) - Heterogeneity Analysis

dep. var: Δ in ...	Immediate Memory		Delayed Memory		Fluency		Numeracy		Orientation	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
A. OLS										
Baseline	−0.002	−0.002	−0.016**	−0.015**	−0.011	0.001	−0.003	0.001	0.000	−0.000
	(0.004)	(0.005)	(0.005)	(0.005)	(0.016)	(0.018)	(0.005)	(0.004)	(0.002)	(0.002)
Observations	9,431	9,370	9,435	9,368	9,378	9,326	6,737	4,202	6,768	4,202
B. 2SLS										
Baseline	−0.080	−0.123	−0.083	−0.090	−0.755*	−0.756+	−0.041	−0.049	0.061	0.118*
	(0.085)	(0.101)	(0.093)	(0.107)	(0.367)	(0.416)	(0.082)	(0.092)	(0.045)	(0.056)
Observations	9,431	9,370	9,435	9,368	9,378	9,326	6,737	4,202	6,768	4,202
Sample 10	−0.079	−0.133	−0.101	−0.109	−0.780*	−0.819+	−0.025	−0.029	0.062	0.123*
	(0.084)	(0.102)	(0.093)	(0.109)	(0.366)	(0.425)	(0.080)	(0.094)	(0.044)	(0.059)
Observations	8,561	8,513	8,567	8,512	8,513	8,473	5,973	3,714	6,002	3,714
Sample 7	−0.045	−0.100	−0.010	−0.049	−0.606	−0.617	0.081	0.067	0.077	0.134*
	(0.095)	(0.115)	(0.103)	(0.123)	(0.391)	(0.459)	(0.086)	(0.105)	(0.048)	(0.068)
Observations	6,757	6,966	6,762	6,965	6,717	6,933	4,729	3,019	4,752	3,019
Sample 5	0.062	0.042	0.073	0.001	−0.616	−0.791	0.078	0.119	0.050	0.142+
	(0.104)	(0.124)	(0.116)	(0.135)	(0.422)	(0.520)	(0.095)	(0.122)	(0.049)	(0.079)
Observations	5,154	5,364	5,157	5,363	5,117	5,334	3,605	2,348	3,627	2,348

*Notes: S*tandard errors clustered at individual level in parenthesis. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$
Orig. presents the original results from Schneeweis et al. (2014) and *Repl.* presents the results from our replication sample.

With respect to the role of number of books, we do not find any significant effects in either groups in the level analysis as show in panel B of Table 6. Results of the slope analysis in panel B of Table 7 show a positive and significant effect on orientation at 10% significance level for those who had few books. Although insignificant, we find extremely large effects on immediate memory, delayed memory and fluency for those who had many books, especially fluency. In general, the effects by family background are estimated very imprecisely and thus do not seem to be too trustworthy.

Table 7: Replication of Table 6 (Slope Analysis) from Schneeweis et al. (2014) - Heterogeneity Analysis

dep. var:	Immediate Memory		Delayed Memory		Fluency		Numeracy		Orientation	
	Orig.	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*	*Orig.*	*Repl.*
A. By Gender										
Male	−0.123	−0.180	-0.227^{+}	−0.289	-0.826^{+}	−0.978	−0.022	0.015	0.073	0.084
	(0.113)	(0.199)	(0.135)	(0.235)	(0.486)	(0.859)	(0.090)	(0.115)	(0.055)	(0.072)
Observations	3,768	3,731	3,774	3,732	3,738	3,708	2,645	1,649	2,654	1,649
Female	−0.031	−0.092	0.032	−0.003	−0.787	−0.718	−0.042	−0.091	0.040	0.147^{+}
	(0.135)	(0.111)	(0.152)	(0.121)	(0.604)	(0.452)	(0.148)	(0.142)	(0.075)	(0.086)
Observations	4,793	4,782	4,793	4,782	4,775	4,771	3,328	2,076	3,348	2,076
B. By Family Background										
Few books	−0.014	−0.047	0.140	0.122	−0.959	−0.639	−0.072	−0.058	0.119	0.167^{+}
	(0.146)	(0.103)	(0.167)	(0.115)	(0.699)	(0.421)	(0.181)	(0.128)	(0.105)	(0.088)
Observations	4,428	4,527	4,432	4,529	4,406	4,509	3,205	1,899	3,218	1,899
Many books	−0.253	−1.375	−0.511	−2.498	−1.539	−8.393	−0.156	−0.202	−0.103	−0.099
	(0.201)	(3.015)	(0.318)	(5.686)	(1.080)	(24.570)	(0.174)	(1.030)	(0.088)	(0.406)
Observations	2,840	2,910	2,844	2,909	2,834	2,906	1,714	1,028	1,726	1,028

*Notes: S*tandard errors clustered at individual level in parenthesis. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$
Orig. presents the original results from Schneeweis et al. (2014) and *Repl.* presents the results from our replication sample.

3.2 *Extension: Wider replication*

In the replications so far, we used the years of education variable adjusted in a similar manner as Schneeweis et al. (2014). Given the availability of more information from subsequent waves, we are able to use years of education as provided by the respondents also for wave 1 instead of using the conversion table.[5] The main adjustment we make is using the years of compulsory schooling as the minimum number of years of education. We then check how robust the results are using our adjusted years of education variable. Before we do so in the next section, we check whether we can replicate a first-stage effect using only reported years of education instead of also relying on the conversion tables. Comparing the two education variables for the Schneeweis et al. (2014) sample, we find only small differences between the means per cohort as depicted in Figure 1. Our adjustments are slightly below that of Schneeweis et al. (2014). This implies that the provided information on years of education does not deviate too much from the years of education calculated from the conversion tables. We use our adjusted years of education for the analyses using the all waves sample.

[5]For each individual we use the maximum number of (reported) years of education for all available observations.

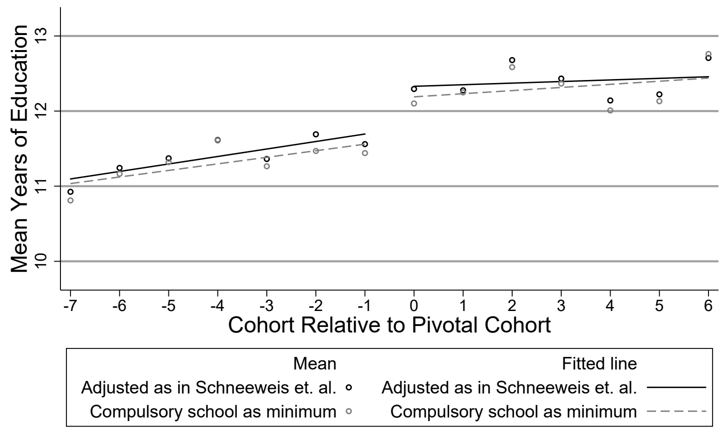

Figure 1: Comparing the two education variables - First stage

Now we do a wide replication analysis using all the available waves till date and our adjusted years of education, adding more countries and more reforms, and expanding the range of birth years. We include observations from Belgium [6], Netherlands and Sweden. The reforms we now use are presented in Table 8. They include reforms used by Schneeweis et al. (2014) as well as additional reforms from some countries they used and the new countries we consider. Individuals born from 1920 to 1959 are selected for the baseline analysis. Instead of looking at all three sub-samples as Schneeweis et al. (2014), we only look at the sample 10. From the baseline data, we consider individuals born up to 10 years before and after the pivotal birth cohort. For countries with multiple reforms, we consider individuals born up to 10 years before the pivotal cohorts of the first reform and 10 years after the pivotal cohorts of the last reform presented in Table 8. We only consider the sample 10 sub-sample to allow for enough overlapping of birth cohorts across the different countries. As stated above, the inclusion of the additional data should improve the results especially with respect to precision. Since the panel has been extended with more waves, we include survey year fixed effects in the slope analysis. From the descriptive analysis in Tables A3 and A4, we gain more than 100,000 observations for the level analysis and over 70,000 observations for the slope analysis.

[6]Only individuals who went to school in Flanders are considered since the reform only took place in this region.

Table 8: Compulsory Schooling Reforms

Country	Reform	Increase in Mandatory Years of Schooling	School-Leaving Age	Pivotal Cohort
Austria	1962	8 to 9	14 to 15	1951
Belgium (Flanders)	1953	8 to 9	14 to 15	1939
Czech Republic	1948	8 to 9	14 to 15	1934
	1953	9 to 8	15 to 14	1939
	1960	8 to 9	14 to 15	1947
Denmark	1958	4 to 7	11 to 14	1947
France	1936	7 to 8	13 to 14	1923
	1959	8 to 10	14 to 16	1953
Germany				
Hamburg	1949	8 to 9	14 to 15	1934
Schleswig-Holstein	1956	8 to 9	14 to 15	1941
Bremen	1958	8 to 9	14 to 15	1943
Lower Saxony	1962	8 to 9	14 to 15	1947
Saarland	1964	8 to 9	14 to 15	1949
Northrhine-Westphalia	1967	8 to 9	14 to 15	1953
Hesse	1967	8 to 9	14 to 15	1953
Rhineland-Palatinate	1967	8 to 9	14 to 15	1953
Baden-Wuerttemberg	1967	8 to 9	14 to 15	1953
Bavaria	1969	8 to 9	14 to 15	1955
Italy	1963	5 to 8	11 to 14	1949
Netherlands	1942	7 to 8	13 to 14	1951
	1947	8 to 7	14 to 13	1951
	1950	7 to 9	13 to 15	1951
Sweden	1949	6 to 7	13 to 14	1936
	1962	8 to 9	14 to 16	1950

Notes: Source: Brunello et al. (2016)

Figure 2 shows that there is still a jump in years of education as a result of the school reforms even with the inclusion of more waves and reforms.[7] The results in Table 9 are slightly smaller and the standard errors are relatively smaller. The first-stage F-statistics are also larger. We find that an additional year of compulsory schooling increases years of schooling on average between one-fourth and one-third of a year.

[7] The last reform of countries with multiple reforms, i.e. Czech Republic, France, Netherlands and Sweden, are used for the graph.

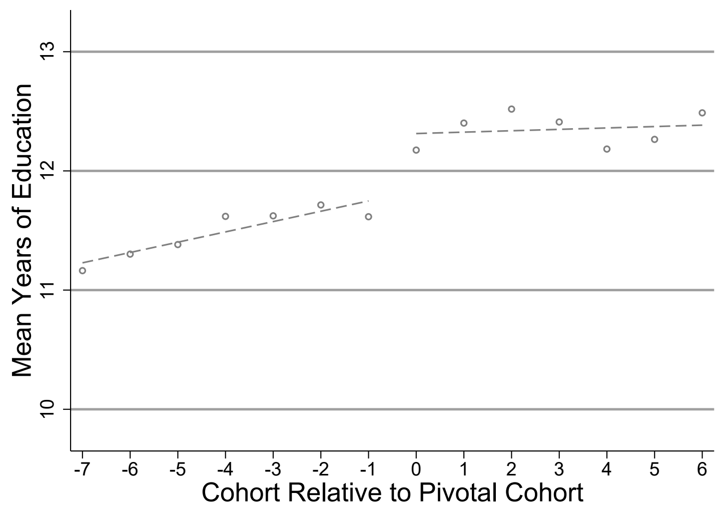

Figure 2: Replication of Fig 1 from Schneeweis et al. (2014) - First Stage, All Waves Sample

Note: The last reform of countries with multiple reforms, i.e. Czech Republic, France, Netherlands and Sweden, are used for this graph.

Table 9: First stage Regressions Using All Waves

	Baseline	Sample 10
Compulsory schooling	0.258**	0.297**
	(0.037)	(0.045)
F Statistics	48.80	44.32
Observations	122,888	97,616

*Notes: T*he sample includes all observations with non-missing immediate memory scores. Standard errors clustered at individual level in parenthesis. * $p < 0.05$, ** $p < 0.01$

Table 10 shows the OLS and 2SLS results for both the level and slope analyses. The positive association between education and levels of cognitive functioning still holds. We also find evidence for a positive effect of education on memory. The estimates suggest that an additional year of education as a result of an additional year of compulsory schooling improves immediate memory by 0.03-0.11 and delayed memory by 0.11-0.15 words on average and are thus in line with the results presented so far. In the slope analysis we find negative associations between education and cognitive decline, indicating that higher education is associated with a slower decline in cognitive abilities. The 2SLS estimates, however, provide no clear evidence that education causally slows down cognitive decline. Compared to the results from the narrow replication presented in Table 5, the size of the 2SLS estimates for the change in fluency have reduced considerably and lost their statistical significance.

Table 10: Baseline Results, All Waves

	Level					Slope (Δ in ..)		
dep. var:	Immediate Memory	Delayed Memory	Fluency	Good Numeracy	Good Orientation	Immediate Memory	Delayed Memory	Fluency
A. OLS								
Baseline	0.115**	0.132**	0.494**	0.037**	0.005**	−0.000	−0.005**	−0.010*
	(0.002)	(0.003)	(0.009)	(0.001)	(0.000)	(0.001)	(0.001)	(0.005)
Observations	122,888	122,772	122,534	52,363	92,480	81,365	81,256	81,082
B. 2SLS								
Baseline	0.027	0.107+	−0.151	−0.003	−0.008	−0.027	−0.012	−0.159
	(0.047)	(0.057)	(0.228)	(0.018)	(0.009)	(0.031)	(0.036)	(0.120)
Observations	122,888	122,772	122,534	52,363	92,480	81,365	81,256	81,082
Sample 10	0.107*	0.152*	0.322	0.013	0.003	−0.043	−0.034	−0.115
	(0.047)	(0.061)	(0.230)	(0.018)	(0.009)	(0.032)	(0.036)	(0.121)
Observations	97,616	97,532	97,391	40,122	73,649	65,272	65,191	65,083

Notes: Standard errors clustered at individual level in parenthesis. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

When we estimate the effects of education in the all waves sample by sex and family background, we find only little evidence for gradients between men and women or between individuals who had few books during childhood and individuals who had many books. Only in the level analysis and with respect to fluency we find larger differences between men and women indicating that education has lasting positive effects on cognitive abilities for women but not for men.

Table 11: Heterogeneity Analysis, All Waves

dep. var:	Level Immediate Memory	Delayed Memory	Fluency	Good Numeracy	Good Orientation	Slope (Δ in ..) Immediate Memory	Delayed Memory	Fluency
A. By Gender								
Males	0.133	0.153	−0.121	0.001	0.003	−0.013	0.013	−0.020
	(0.100)	(0.125)	(0.531)	(0.038)	(0.018)	(0.064)	(0.072)	(0.260)
Observations	43,891	43,847	43,763	18,445	33,241	28,907	28,900	28,880
Females	0.083	0.140*	0.474+	0.017	0.002	−0.052	−0.048	−0.133
	(0.053)	(0.069)	(0.249)	(0.020)	(0.009)	(0.035)	(0.041)	(0.127)
Observations	53,725	53,685	53,628	21,677	40,408	36,365	36,359	36,370
B. By Family Background								
Few Books	0.048	0.039	0.180	0.003	−0.012	−0.008	0.018	−0.170
	(0.056)	(0.072)	(0.254)	(0.022)	(0.011)	(0.030)	(0.036)	(0.120)
Observations	44,077	44,040	43,980	15,886	32,103	32,137	32,135	32,120
Many Books	0.565	1.179	2.402	−0.109	0.037	−0.236	−0.099	0.201
	(0.683)	(1.382)	(3.189)	(0.345)	(0.059)	(0.421)	(0.310)	(1.052)
Observations	34,756	34,737	34,710	11,646	25,878	25,475	25,470	25,484

Notes: Standard errors clustered at individual level in parenthesis. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

4 *Conclusion*

This paper replicates and extends the main results of Schneeweis et al. (2014). We do find similar results in the replication of the main results, although there are some differences in statistical significance. We also replicate the heterogeneity analysis from Schneeweis et al. (2014). The replication shows a gender gradient in the outcome variable recall, as in the original study. Other parts of the replication of the heterogeneity analysis are less conclusive, mainly due to rather noisy estimates in the replication. We then extend the sample used by Schneeweis et al. (2014) by including more reforms as well as subsequent interview waves and re-adjusting the years of education based on the information gained. Here, we also find evidence for positive effects of education on memory. Taken together, this can be considered a successful replication. Nevertheless, there is still room for further replications attempts. One interesting question that could be addressed in a wider replication is, for example, whether the problem of negative weighting in two-way fixed effects designs (De Chaisemartin & d'Haultfoeuille, 2020) is a relevant issue in this setting. Given that the research design employed here can also be seen as a (fuzzy) staggered difference-in-difference design, it seems appropriate to at least consider that negative weighting might affect the estimates presented in the original work and in this replication. Further research into how big the problem actually is in this and comparable settings, however, requires a greater departure from the original paper and goes beyond the scope of this work.

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Appendix: Additional tables and figures

Table A1: Compulsory Schooling Reforms from Schneeweis et al. (2014)

Country	Reform	Increase in Mandatory Years of Schooling	School-Leaving Age	Pivotal Cohort
Austria	1962/1966	8 to 9	14 to 15	1951
Czech Republic	1960	8 to 9	14 to 15	1947
Denmark	1958	4 to 7	11 to 14	1947
France	1959/1967	8 to 10	14 to 16	1953
Germany				
Hamburg	1949	8 to 9	14 to 15	1934
Schleswig-Holstein	1956	8 to 9	14 to 15	1941
Bremen	1958	8 to 9	14 to 15	1943
Lower Saxony	1962	8 to 9	14 to 15	1947
Saarland	1964	8 to 9	14 to 15	1949
Northrhine-Westphalia	1967	8 to 9	14 to 15	1953
Hesse	1967	8 to 9	14 to 15	1953
Rhineland-Palatinate	1967	8 to 9	14 to 15	1953
Baden-Wuerttemberg	1967	8 to 9	14 to 15	1953
Bavaria	1969	8 to 9	14 to 15	1955
Italy	1963	5 to 8	11 to 14	1949

Notes: 1966 is used for calculating the compulsory years of schooling in Austria. The 1967 reform in France is used for calculating the compulsory years of schooling.

Table A2: The Determinants for the Varying Years of Education Variable

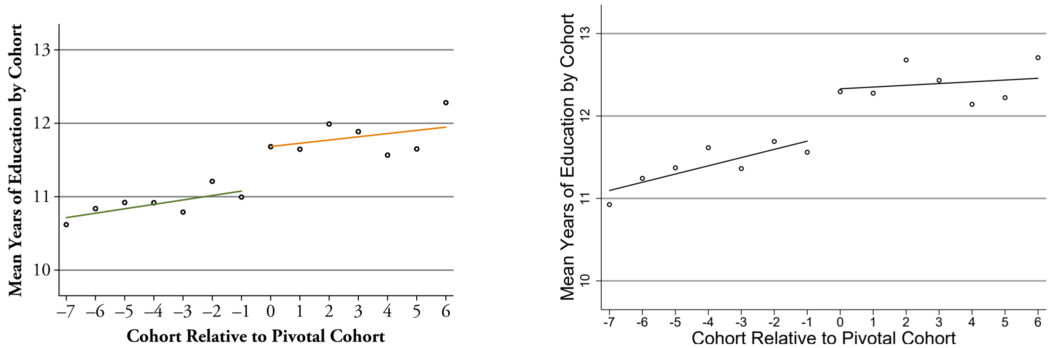
Country	Schneeweis et al. (2014)	Replicated based on Schneeweis et al. (2014)	New variable
Variables used from SHARE			
Austria, Czech, France, Germany and Italy	Corrected reported years of education (dn041_)	Corrected reported years of education (dn041_)	Corrected reported years of education (dn041_)
Denmark	Raw reported years of education (dn041_raw)	Corrected reported years of education (dn041_)	Corrected reported years of education (dn041_)
Adjustments			
Years of education for Wave 1 based on:	Highest educational attainment and conversion tables	Highest educational attainment and conversion tables	Reported years of education from subsequent waves
Further adjustments	Compulsory schooling as the minimum number of years of schooling for wave 1. Computed years of education based on conversion tables as the minimum years if reported years of schooling are less than the compulsory years of schooling	Same as Schneeweis et al. (2014)	Compulsory schooling as the minimum number of years of schooling

Table A3: Replication of Table 2 from Schneeweis et al. (2014) - Descriptive Statistics of Baseline Sample: Level Analysis, All waves sample

	Female	Age	Years of Education		Immediate Memory	Delayed Memory	Fluency	Good Numeracy	Good Orientation	Observations	Individuals
			Individual	Compulsory							
Austria	0.58	68.94	10.31	8.21	5.51	4.19	22.52	0.68	0.89	13,377	4,746
Belgium	0.53	67.91	12.33	8.68	5.15	3.71	20.15	0.46	0.84	12,202	3,664
Czech Republic	0.58	68.33	12.27	8.56	5.35	3.73	21.90	0.56	0.87	18,290	6,997
Denmark	0.53	67.71	13.19	5.36	5.56	4.36	23.05	0.53	0.86	13,814	4,187
France	0.57	68.56	11.69	8.31	5.01	3.68	19.08	0.45	0.85	17,819	5,843
Germany	0.52	67.72	12.83	8.23	5.50	4.02	21.80	0.65	0.88	11,414	4,689
Italy	0.54	68.49	8.55	5.85	4.47	2.96	14.92	0.28	0.87	18,645	6,549
Netherlands	0.54	66.35	11.65	8.67	5.39	4.10	20.56	0.59	0.85	11,917	5,114
Sweden	0.53	69.27	11.56	7.21	5.33	4.18	23.17	0.56	0.89	16,394	5,363
Total	0.55	68.23	11.50	7.61	5.22	3.84	20.61	0.52	0.87	133,872	47,152

Table A4: Replication of Table 3 from Schneeweis et al. (2014) - Descriptive Statistics of Baseline Sample: Slope Analysis, All waves sample

	Immediate Memory	Delayed Memory	Fluency	Duration	Observations	Individuals
Austria	0.02	0.02	0.71	31.81	8,573	3,758
Belgium	0.06	-0.01	0.22	30.97	8,481	2,784
Czech Republic	0.05	-0.02	0.10	32.23	11,198	4,637
Denmark	0.14	0.13	0.42	33.66	9,594	3,241
France	0.04	0.01	0.44	33.95	11,903	4,383
Germany	0.10	0.04	0.48	35.29	6,709	2,961
Italy	0.09	0.08	0.06	34.26	11,983	4,299
Netherlands	0.13	0.13	0.37	47.14	6,792	3,260
Sweden	0.14	0.10	0.66	35.71	10,973	4,172
Total	0.08	0.05	0.37	34.60	86,206	33,495



(a) Original (b) Replication

Figure A1: Replication of Fig 1 from Schneeweis et al. (2014) - First Stage