Retirement and Cognitive Decline: Evidence from Global Aging Data

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Abstract

This study analyzes the effect of retirement on cognitive function. According to the human capital theory, we can hypothesize that workers invest in their cognitive ability more than retirees because cognitive investment increases a worker's wage. As a result, it is possible that the cognitive ability decreases after retirement, a hypothesis analyzed in this study. In health economics, this hypothesis has been examined especially after 2000. First, we show that an analysis method used in some related studies is not valid for estimating this effect. Furthermore, we analyze this effect by using our method. Our estimates indicate that the workers' numerical ability decreases after retirement in a wide range of analyzed countries and heterogeneous groups. However, retirement has a weak effect on cognitive ability. Additionally, we investigate the heterogeneity of this effect. For example, we find that the elderly with higher body mass indexs and fat intake experience a negative effect of retirement on cognitive function.

JEL Classification Numbers: I10, I12, J24, J26
Keywords: mental retirement, cognitive function, social security, pension eligibility age, cross-country instruments, global aging data

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1 Introduction

Many developed countries have been faced with the issue of an aging population. By 2015, there were almost 900 million individuals aged 60 years and over living worldwide. Rising life expectancy is contributing to rapid increases in these numbers and is associated with increased prevalence of chronic diseases such as dementia. According to the World Alzheimer Report 2015 [1] , the global costs of dementia have increased from USD 604 billion in 2010 to USD 818 billion in 2015, that is, an increase of 35.4 percent. Recently, some studies have investigated the relation between retirement and cognitive function. For example, according to Rohwedder and Willis (2010), there is a negative effect of retirement on cognitive function. The question is what is the mechanism behind this phenomenon. As Rohwedder and Willis (2010) point out, one of the hypotheses is explained by the human capital theory in economics. Ben-Porath (1967) introduced the concept of a human capital production function. This function relates inputs such as current stock of human capital and the investment such as schooling or on-the-job training to the skill output. On the possibility that retirement causes cognitive decline, one hypothesis is that workers engage in more cognitive investment behavior than retirees because cognitive investment increases a worker's wage.

Health problems after retirement have become one important public policy relevant topics. As such, retirement-related policies, such as a reform of the pension system, have become important for developed countries to sustain their social security systems. Numerous developed countries have been facing similar problems of a decreasing birthrate and an aging population. As population ages, the cost of social security and welfare increases, eroding the country's budget. As such, numerous developed countries have reformed the pension system to reduce the cost of social security and social welfare. Countries such as the United States, the United Kingdom, and Korea have already decided to increase the pension eligibility age in the subsequent decades, while Japan has already done so. Such pension reforms in developed countries are mostly expected to delay retirement. As Gruber and Wise (1998) discuss, the relationship between the social security system and retirement in developed countries has attracted a fair amount of attention in economics. When policy makers evaluate the effects of these reforms, health is a key factor. Since an active work life is beneficial for the health of the elderly, it would lead to a reduction of medical expenses, whereas their medical expenses would increases otherwise.

Along the growing interest on the effect of the policies that delay the retirement of the elderly, a number of studies have investigated the relation between retirement and health over the past two decades. [2] Since the controversy continues with respect to the estimated results

[1] See the website at https://www.alz.co.uk/research/world-report-2015 for further details.

[2] Using various health indexes, numerous researchers have examined this relationship. Kerkhofs and Lindeboom (1997) is one of the first studies that suggests endogenous decisions between retirement and health, and explains the effect of retirement on health. They find that the Hopkins Symptom Checklist, a health index, can be improved after early retirement in the Netherlands by applying fixed effect methods. Lindeboom et al. (2002) extend Kerkhofs and Lindeboom (1997)'s study to other indices, such as the Mini Mental State Examination test on cognitive ability, the CES-D test of depressing feelings, and applying fixed effect methods to Dutch data, which yields different results from those of Kerkhofs and Lindeboom (1997). Charles (2004) is also one of the first to analyze the causal effect of retirement on health in economic

of various health indexes, the discussion about the effects of retirement on cognitive function is no exception. For example, Adam et al. (2006) confirm the positive effect of occupational activities on the cognitive function of the elderly in Europe. On the other hand, Rohwedder and Willis (2010) discuss this hypothesis to explain why retirement decreases cognitive function, and show the negative relationship between these using elementary regression analysis. However, they do not control for basic elements such as age and education. Bingley and Martinello (2013) reexamine the estimated model of Rohwedder and Willis (2010), adding years of education and gender variables, and concluding that their estimated negative effect is weaker than the results of Rohwedder and Willis (2010). This implies that the results are sensitive to the controlled characteristics included in the model of Rohwedder and Willis (2010). Furthermore, Coe and Zamarro (2011) find no clear relationship between retirement and cognitive function in Europe. Coe et al. (2012) also find no clear general relationship between them, [3] while, on the other hand, Mazzonna and Peracchi (2012) find a negative relationship between the two in Europe. Bonsang et al. (2012) also find a negative relationship between the two, although they control only for age factors. Depending on specifications, the negative relationship might change. As such, Kajitani et al. (2014) suggest the existence of cognitive deterioration heterogeneity, depending on the characteristics of the occupation. Kajitani et al. (2016a) also suggest that the duration of retirement has a negative effect on cognitive function. [4]

Consequently, the goal of this study is to examine the controversial hypothesis that there exists a causal effect of retirement on cognitive function. To do so, we examine two items. First, we examine the validity of cross-sectional estimation and the influence of the set of analyzed countries on the effect of retirement on cognitive function. Second, we reexamine this effect in the U.S. and other countries. We also investigate the source of heterogeneity of the effect by using a simple economic model. To the best of our knowledge, this is the first analysis to interpret the effect of retirement on cognitive ability by using an economic model with endogenous retirement. Based on this discussion, we empirically evaluate the heterogeneity of individual characteristics and of the time spent on leisure activities. These points are either not covered or mentioned as a scope for further research in literature. Our estimates indicate that workers' numerical ability decreases after retirement in a wide range of analyzed countries and heterogeneous groups. This finding is related to the studies suggesting that mathematical scores are strongly related to the worker's wage. (Rose and Betts, 2004; Altonji, Blom, and Meghir, 2012; Rendall et al., 2014) Additionally, we analyze the effect of body mass index (BMI) and fat intake on the heterogeneity of the effect of retirement on cognitive function, a relationship discussed in medical literature. The remainder of

literature, focusing on subjective wellbeing and using instrumental variables (IV). Additionally, there are numerous studies that analyze the effect of retirement on various health indexes. For example, Bound and Waidmann (2007), Coe and Lindeboom (2008), Dave et al. (2008), Neuman (2008), Johnston and Lee (2009), Latif (2011), Coe and Zamarro (2011), Kajitani (2011), Behncke (2012), Bonsang et al. (2012), Mazzonna and Peracchi (2012), Hernaes et al. (2013), Bingley and Martinello (2013), Hashimoto (2013), Insler (2014), Kajitani et al. (2014), Hashimoto (2015), and Kajitani et al. (2016a) are among the representative studies.

[3] They find a positive relationship between retirement duration and cognitive function only for blue-collar workers.

[4] Kajitani et al. (2016b) suggest a non-linear effect of working hours on cognitive function.

this paper is organized as follows: section 2 describes the dataset used; section 3 discusses the heterogeneity of the effect of retirement on cognitive function; section 4 examines the validity of the cross-sectional cross-country analysis; section 5 performs dynamic analysis and discusses our main results; and section 6 concludes this paper and discusses the future scope for research.

2 Data

This paper uses the Health and Retirement Study (HRS)[5] and other similar datasets, such as the China Health and Retirement Longitudinal Study (CHARLS), the English Longitudinal Study of Ageing (ELSA), the Survey of Health, Ageing, and Retirement in Europe (SHARE), and the Japanese Study of Ageing and Retirement (JSTAR). They are panel surveys of individuals aged 50 or over. Moreover, the family datasets are constructed so that the questions in the HRS family studies are as similar as possible to the original questions in the HRS. They include a rich variety of variables to capture living aspects in terms of economic status, health status, family background, as well as social and work status.

We use the cognitive function score in the HRS and other related datasets. In the HRS, we use the test scores of immediate word recall (first half of word recall test), delayed word recall (second half of word recall test)[6], serial7's, backwards counting and word recall summary score (immediate word recall + delayed word recall). Word recall summary score is between 0 and 20. The immediate word recall and delayed word recall tests ask the respondent to recall as many words as possible from a list of 10 words. The score of Immediate Word Recall and Delayed Word Recall is the number of words from 10-word list that were recalled correctly. The serial7's test asks the respondent to subtract 7 from the prior number beginning with 100 for 5 trials. The score of the serial7's test is between 0 and 5. The backwards counting test asks the respondent to count backwards for 10 continuous numbers from 20. The original score of this test is 2 if successful on the first try, 1 if successful on the second, and 0 if not successful on either try. However, we make the indicator which is equal to one when the respondent is successful on the first try. We use only this indicator suggesting whether the respondent succeed on the first try.[7] In section 3, we use only word recall summary score, while sections 4 and 5, we use all types of scores.

We summarize the cognitive function scores in Tables 1 and 2. Table 1 shows the descriptive statistics of the age group from 60 to 69 in all countries, and the descriptive statistics for the U.S. are shown in Table 2. According to Table 1, cognition scores are not the same level in all countries.[8] All scores in China and European countries are comparatively low compared to the U.S., the U.K., Korea, and Japan. In Table 2, we can observe certain characteristics of

[5]See the website (http://hrsonline.isr.umich.edu) for details

[6]There are two rounds in the Word Recall tests. In the first round (immediate word recall), there is a test to recall the number of words as much as possible. In the second round (delayed word recall), a respondent is asked to recall the same words after a given period of time.

[7]We make the indicator suggesting whether the respondent succeed on the first try because we cannot interpret the estimated coefficient of the original score.

[8]In each test, the maximum test score in KLoSA is different from that of other studies.

cognitive function: females have higher score than males in the word recall summary score, and males have higher score than females in serial'7. Highly educated (Univ. Graduate) individuals have higher score than individuals with lower levels of education in all cognitive scores.

Table 1: Summary Statistics of Cognition Scores (Age 60 -69) around 2010

	Obs.	Mean	S.D.	Min	Max
HRS					
Word Recall Sum. Score	5057	10.33	3.23	0	20
Immediate Word Recall	5057	5.64	1.56	0	10
Delayed Word Recall	5057	4.68	1.89	0	10
Serial 7's	5057	3.53	1.65	0	5
ELSA^{*1}					
Word Recall Sum. Score	3593	11.17	3.32	0	20
Immediate Word Recall	3592	6.17	1.67	0	10
Delayed Word Recall	3593	5.01	1.93	0	10
SHARE^{*2}					
Word Recall Sum. Score	18998	9.31	3.40	0	20
Immediate Word Recall	19025	5.33	1.68	0	10
Delayed Word Recall	19019	3.97	2.03	0	10
Serial 7's	18576	3.76	1.74	0	5
JSTAR					
Word Recall Sum. Score	1463	10.10	3.00	0	20
Immediate Word Recall	1501	5.27	1.49	0	10
Delayed Word Recall	1471	4.80	1.85	0	10
Serial 7's	1508	4.10	1.20	0	5
CHARLS					
Word Recall Sum. Score	3838	6.89	3.16	0	18
Immediate Word Recall	3890	3.91	1.60	0	10
Delayed Word Recall	3856	2.95	1.87	0	10
Serial 7's	3880	3.11	1.88	0	5
KLoSA					
Word Recall Sum. Score^{*3}	2253	4.74	1.31	0	6
Immediate Word Recall^{*3}	2253	2.68	0.67	0	3
Delayed Word Recall^{*3}	2253	2.06	0.96	0	3
Serial 7's	2253	3.83	1.57	0	5

^{*1}: No Serial 7's Score in ELSA.
^{*2}: Calculated using weight.
^{*3}: KLoSA's Word Recall Scores are not comparable with other dataset.

We analyze the effect of retirement on cognitive function in two ways as explained in subsequent sections (sections 4 and 5). In the first analysis, we utilize cross-sectional cross-country variations of pension eligibility age. Subsequently, we use the cross sectional datasets of the HRS 2004 and 2010, ELSA 2004 and 2010, and SHARE 2004 and 2010, including CHARLS 2011 and JSTAR 2009. However, we cannot use the Korean Longitudinal Study of Ageing (KLoSA) because the questions with respect to the test scores in the first analysis are not

Table 2: Summary Statistics: The US (Age:60-69) at 2010

	Obs.	**Mean**	**S.D.**	**Min**	**Max**	**Obs.**	**Mean**	**S.D.**	**Min**	**Max**
			Male					**Female**		
Word Recall Sum. Score	2038	9.70	3.14	0	20	3019	10.76	3.21	0	20
Immediate Word Recall	2038	5.37	1.56	0	10	3019	5.82	1.54	0	10
Delayed Word Recall	2038	4.32	1.82	0	10	3019	4.92	1.90	0	10
Serial 7's	2038	3.76	1.55	0	5	3019	3.38	1.69	0	5
			Not Univ. Graduate					**Univ. Graduate**		
Word Recall Sum. Score	3819	9.86	3.14	0	20	1236	11.81	3.05	0	20
Immediate Word Recall	3819	5.42	1.53	0	10	1236	6.33	1.45	0	10
Delayed Word Recall	3819	4.43	1.84	0	10	1236	5.45	1.82	0	10
Serial 7's	3819	3.27	1.70	0	5	1236	4.33	1.12	0	5
			White					**Blue**		
Word Recall Sum. Score	2889	11.04	3.13	0	20	1027	9.36	3.05	1	19
Immediate Word Recall	2889	5.95	1.50	0	10	1027	5.17	1.50	1	10
Delayed Word Recall	2889	5.08	1.85	0	10	1027	4.17	1.76	0	10
Serial 7's	2889	3.80	1.51	0	5	1027	3.25	1.69	0	5

comparable with other datasets. We use JSTAR 2009 because the survey year is nearest to the other studies of 2010 and all respondents are the questions of the word recall summary score, while in JSTAR 2011 these questions are asked to only people above 65. In the second analysis, we perform a dynamic analysis of certain countries. We utilize both the pension eligibility age and the long-term variation of retirement behavior, and we choose the analyzed countries based on the availability of information on pension eligibility age. We mainly use the harmonized datasets. [9] However, when the variables are not available in the harmonized datasets, we use the variables of the original datasets. In Table 3, we explain which dataset we use in each section of this paper.

In this paper, we use the pensionable age for IV, and perform the cross-sectional cross-country analysis in section 4, using the pensionable age for all countries we analyze. Rohwedder and Willis (2010) and Bingley and Martinello (2013) also perform a cross-sectional cross-country analysis and use the pensionable age based on Pensions at a Glance (OECD) and Social Security Programs throughout the World: Europe, 2004. However, the pensionable ages in some countries are partly incorrect. We correct these and explain this point in the Appendix (A.1). In section 5, we use only the pensionable ages confirmed to be correct.

[9] The Gateway to Global Aging Data (http://gateway.usc.edu) provides harmonized versions of data from international aging and retirement studies (e.g., HRS, ELSA, SHARE, KLoSA, CHARLS). All variables of each dataset aim to have the same items and follow the same naming conventions. As such, the harmonized datasets enable researchers to conduct cross-national comparative studies. The program code to generate the harmonized datasets from the original datasets is provided by the Center for Global Ageing Research, USC Davis School of Gerontology and the Center for Economic and Social Research (CESR). Some variables, such as measures of assets and income, are imputed by this code.

Table 3: The datasets which we use in each section

	Wave	Year
Section 4 (Cross Sectional Analysis)		
The HRS	7,10	2004,2010
The SHARE	1,4	2004,2010
The ELSA	2,5	2004,2010
The JSTAR	2	2009
The CHARLS	1	2011
Section 5 (Dynamic Analysis)		
The HRS	3-10	1996-2010
The SHARE*1	1-5	2004-2012
The ELSA	1-6	2002-2014
The JSTAR	1-4	2007-2013
The KLoSA	1-4	2006-2012

*1: We analyze only Denmark, France and Germany.

3 Retirement and Cognitive Function Decline

3.1 Discussion

One of our targets is to analyze the heterogeneity of retirement on cognitive function effect. As such, we discuss in this section which characteristics correlate the difference in the cognitive scores between retirees and non-retirees, establishing that there are factors except basic individual characteristics, such as gender, job characteristics, etc., which correlate this difference.

First, we show the average scores of the serial 7's test and the word recall summary in Japan, the U.S., South Korea, China, Germany and France. In Figures 1 and 2, we show the difference in the average cognitive scores between retired and non-retired individuals in different countries. Generally, the difference in cognitive scores between retired and non-retired individuals is extremely small in all analyzed countries. This difference is based on two retirement definitions, as per related literature, that is, "self-reported retire" and "not work for pay". [10] "Not work for pay" is self-explanatory, meaning that a respondent is not working for wages or other type of payment. "Self-reported retire" means that a respondent reports his status to be retired: for this definition, we use the "r@lbrf" variable in each harmonized data (e.g., Harmonized SHARE, Harmonized ELSA), which is constructed based on the RAND HRS data. In the HRS, "r@lbrf" takes seven values, and we define a respondent as "self-reported retire" if "r@lbrf" indicates "partly retired," "retired," "disabled" or "not in labor force." In other words, the difference between "not work for pay" and "self-reported retire" is whether unemployed respondents are included or excludes. [11] Numerous related

[10] For example, the respondent retire if the respondent is "not work for pay" in Rohwedder and Willis (2010). In Bonsang et al. (2012), a respondent is ""Retired" if he/she reports not working" (self-reported status).

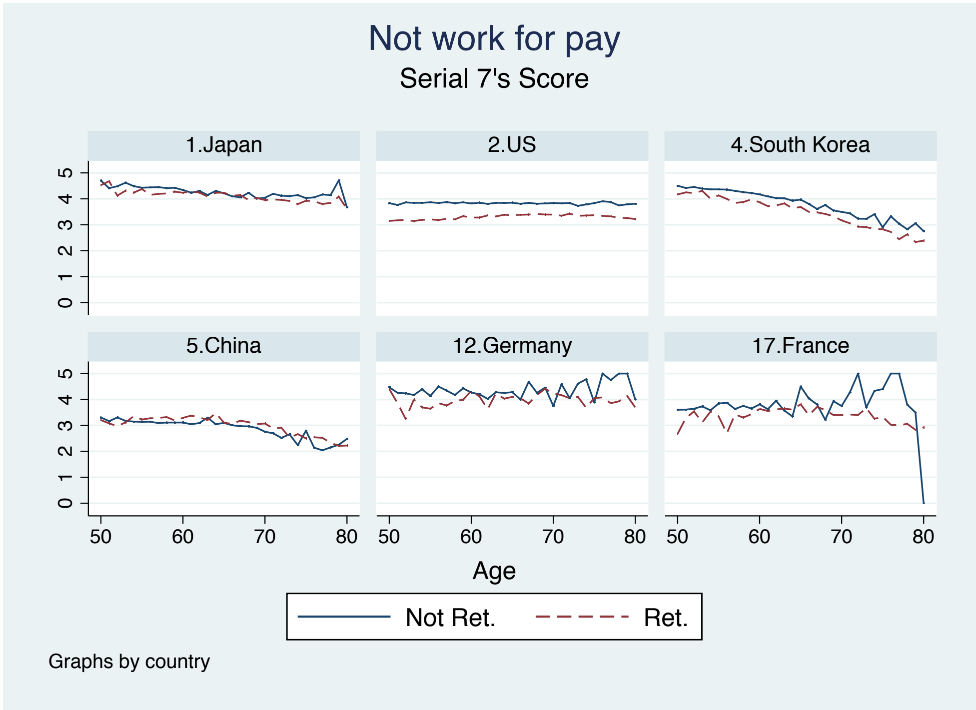
[11] See the codebook of the Rand HRS data if you want to know the detail about the variable "r@lbrf" which we use. http://hrsonline.isr.umich.edu/modules/meta/rand/randhrsm/randhrsM.pdf. They explain how they construct the variable "r@lbrf" in p.1033. We use the variable "r@lbrf" in all Harmonized Data

studies (e.g. Rohwedder and Willis (2010), Coe and Zamarro (2011), Bonsang et al. (2012), Bingley and Martinello (2013)) use two similar definitions of retirement.

The two different definitions of retirement are used in Figures 1 and 2, where we can observe the difference in the relationship of cognitive scores between retired and non-retired individuals in certain countries. However, the influence of the retirement definition used is weak. The relationship of cognitive scores between retired and non-retired individuals is similar across countries for both definitions. However, the relationship of cognitive scores between retirees and non-retirees is heterogeneous between different countries. For example, with respect to the serial 7s score in the U.S., the score for those retired is lower than for those not retired. On the other hand, in China, the retired have higher scores than not retired individuals. The cognitive function scores between retired and not retired people have a heterogeneous relationship, which depends on the analyzed countries. This relationship does not seem to change depending on the types of cognitive score. Additionally, in the word recall summary score, the score of retired individuals is lower than that of not retired ones in the U.S. On the other hand, in China, the opposite is true. Japan has the similar characteristics with China in serial 7's score. Since each country has different demographics, it is possible that this difference correlates the difference in the relationship of overall average cognitive scores between retirees and non-retirees.

Sets.

Figure 1: The Serial 7's Score and The Word Recall Summary Score By Country (All waves)



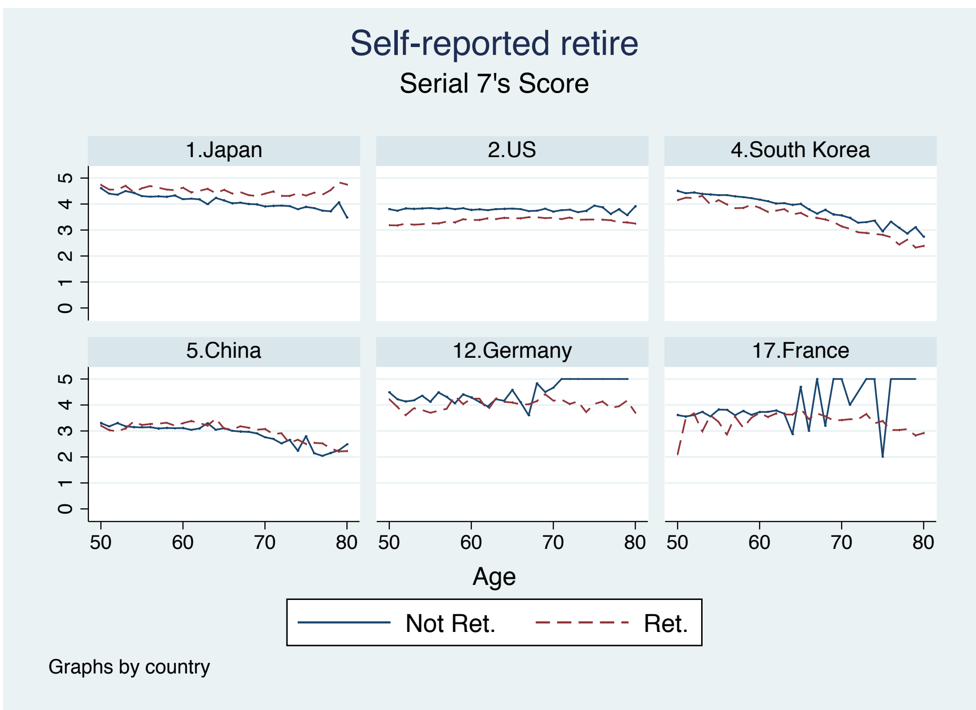
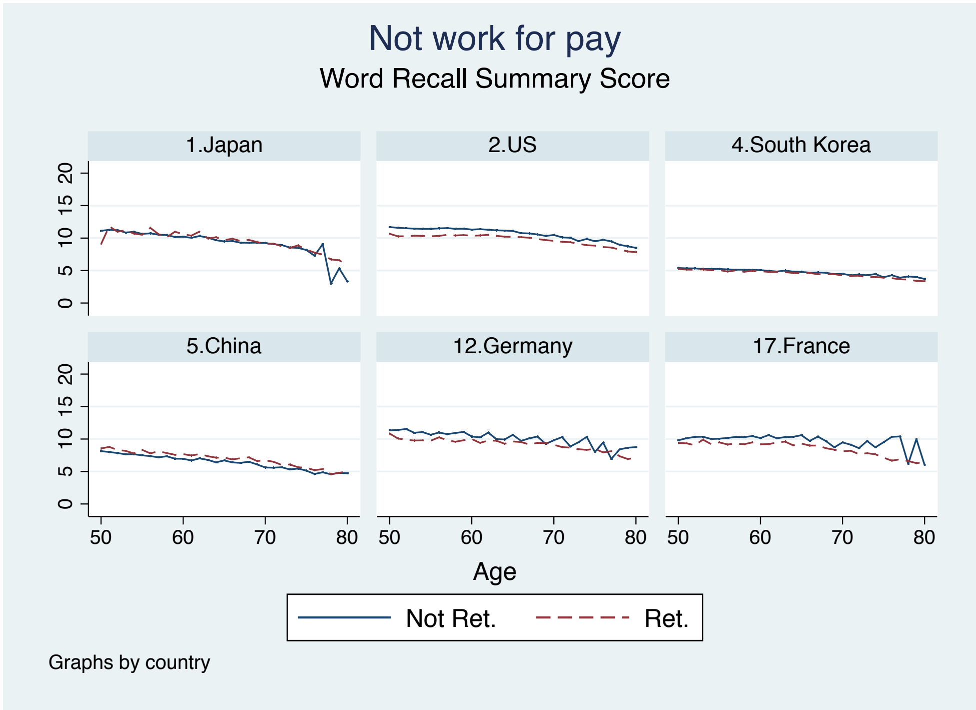
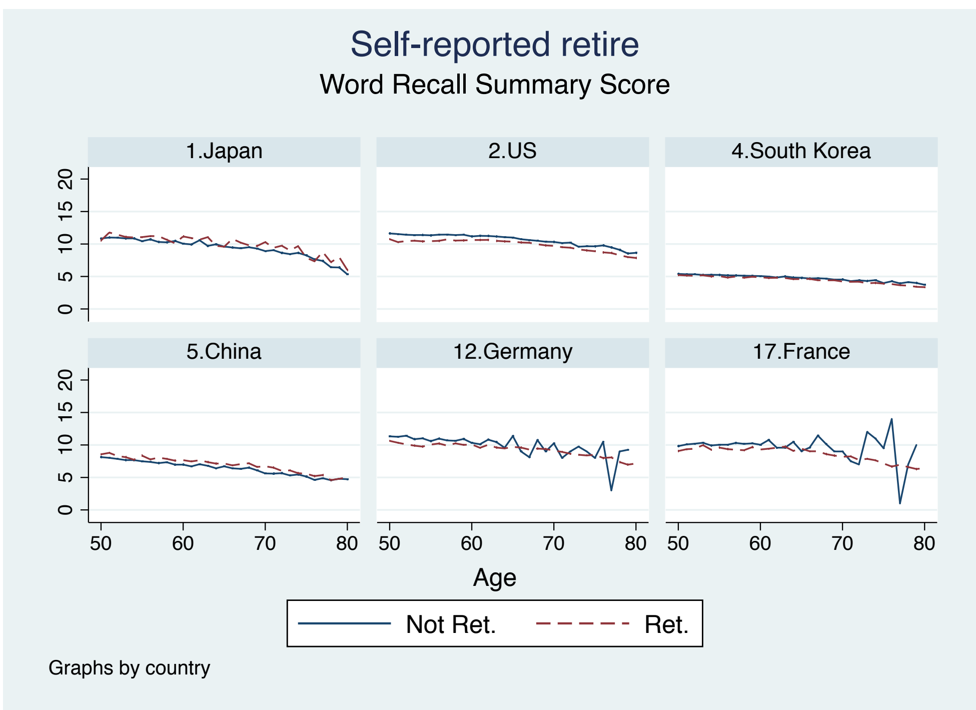


Figure 2: The Serial 7's Score and The Word Recall Summary Score By Country (All waves)





Subsequently, Figures 3, 4, 5 and 6 compare the cognitive levels of the U.S. and China for each characteristic. In related studies, heterogeneity such as gender differences and job types are important for explaining the retirement on cognitive function effect. In fact, Coe et al. (2012) estimate the effect of retirement on cognitive function depending on job types (white-collar and blue-collar). In Figures 3, 4, 5 and 6, when we separate respondents into two job categories, we use the information based on "occupation code for job with longest reported tenure" in the U.S. With respect to China, we cannot separate the job category into white-collar and blue-collar in the same way because the information on the job category of retirees is not available. As a result, we do not use the cognitive scores based on job types in China. As we observe in the above-mentioned figures, there are some characteristics for finding the heterogeneity between the U.S. and China in Figures 3, 4, 5 and 6. However, the difference in cognitive scores between retirees and non-retirees in these figures is not the effect of retirement on cognitive function since the former is endogenous. However, we can observe that unobserved heterogeneity influences the difference in cognitive score between retirees and non-retirees among different countries.

- In each country, the differences in characteristics, such as gender, educational, and asset level differences, explain the difference in cognitive function between retirees and non-retirees. In fact, the differences between their scores are heterogeneous, depending on gender, educational, and asset level differences. Moreover, the influence of retirement definition on the difference in the cognitive scores between retirees and non-retirees is weak.
- It is possible that there exist characteristics, except gender, educational, and asset level differences to cause the difference in the scores between retirees and non-retirees. As such, endogeneity of retirement causes a difference in cognitive scores between retirees and non-retirees. However, it is possible that these factors strongly correlate with the country of residence. In fact, in China, the cognitive function scores of retirees are larger than those of non-retirees for all characteristics, while the relationship is inverse in the U.S. for all characteristics. These relationships are similar for both scores of serial 7s and word recall summary score. The unobserved factors, except gender and educational differences, are important because it is possible these factors cause the inverse relationship between the scores of retirees and non-retirees.

As discussed in this section, factors, except gender, educational, and asset level differences, are important for explaining the difference in cognitive function scores between retirees and non-retirees. In other words, when we consider the effect of retirement on cognitive function, we have to consider the influence of the unobserved heterogeneity on the difference in cognitive function scores. In the next section, through a critical review of related literature, we consider this point further.

Figure 3: The Serial 7's Score in The U.S. and China (All waves) By Education Level, Gender, Occupational Type and Wealth Level: Univ = University, LTU = Lower Than University

Figure 4: The Serial 7's Score in The U.S. and China (All waves) By Education Level, Gender, Occupational Type and Wealth Level: Univ = University, LTU = Lower Than University

Figure 5: The Word Recall Summary Score in The U.S. and China (All waves) By Education Level, Gender, Occupational Type and Wealth Level

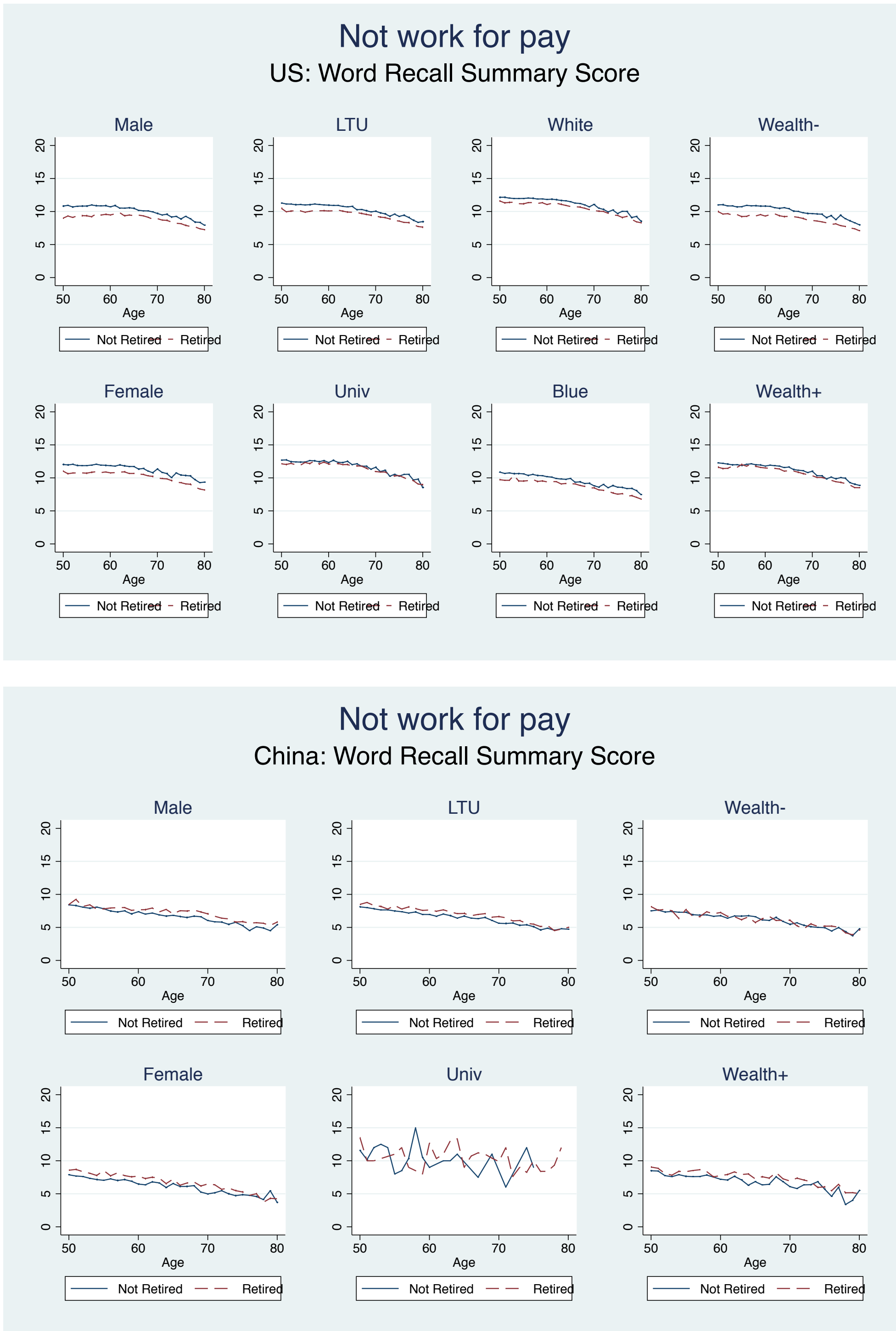
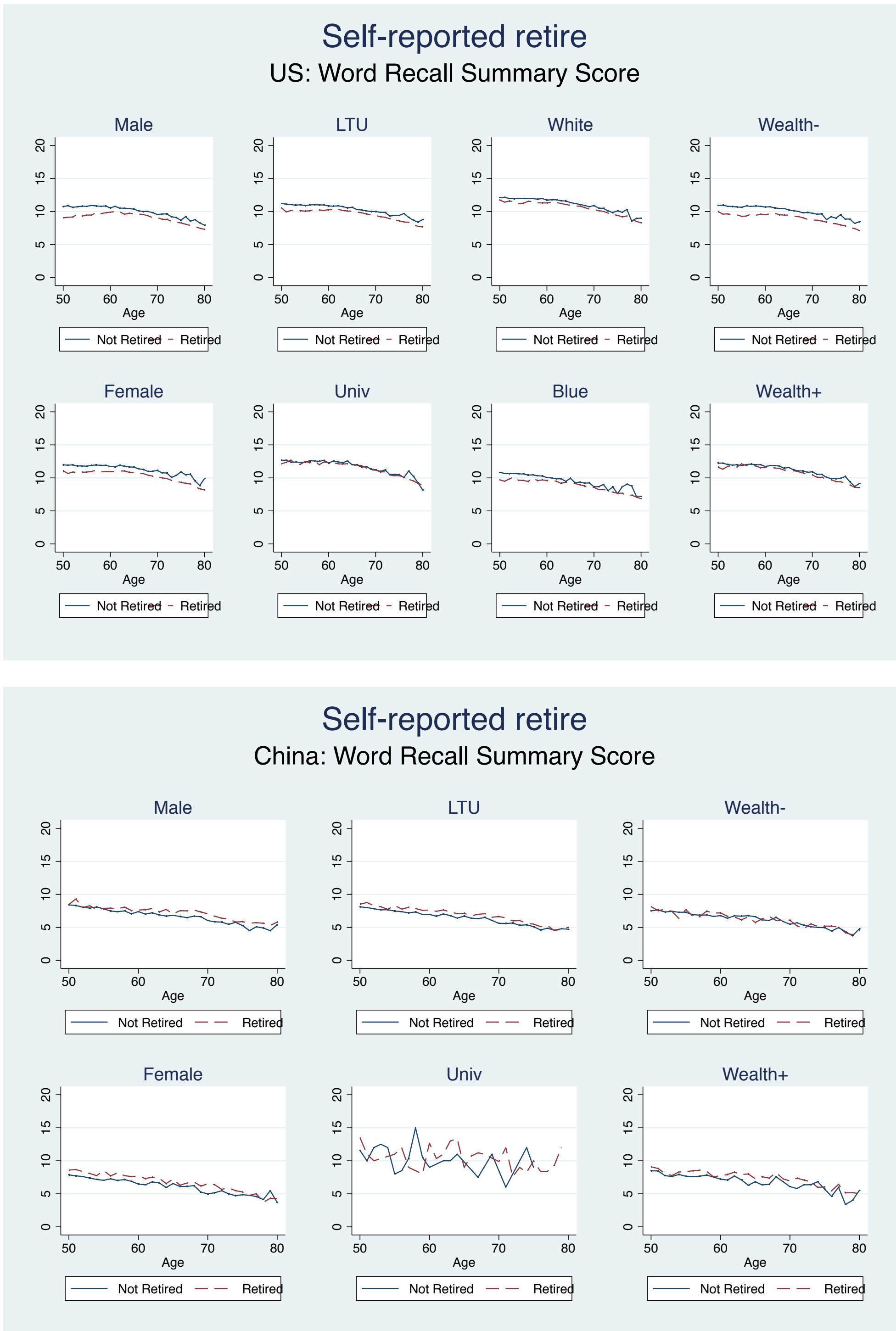


Figure 6: The Word Recall Summary Score in The U.S. and China (All waves) By Education Level, Gender, Occupational Type and Wealth Level



4 Validation Analysis on Cross-Sectional Cross-Country Analysis

In the previous section, we discussed the heterogeneity of the difference in cognitive scores between retirees and non-retirees among different countries. To further consider this point, determine the validity of cross-sectional analysis in previous literature through a critical review. As robustness is weak when using the estimation strategy based on cross-sectional analysis, we find that the estimated results are sensitive with respect to heterogeneity of the set of analyzed countries. We consider that the effect of only a part of the analyzed countries influences the final effect of retirement on cognitive function.

4.1 Identification Strategy of Cross-Sectional Cross-Country Analysis

In this section, we investigate the robustness of the estimation strategy using cross-country variations of pension eligibility age. Since the goal of this research is that we estimate the effect of retirement on cognitive function, the target of our identification strategy is to exclude the endogeneity bias of the retirement variable. Our analysis is carried out in two stages: first, we perform a cross-sectional cross-country analysis; and, second, a dynamic analysis using panel structure is carried out. In the first stage, the identification strategy is to use the variation of pension eligibility ages among different countries in a specific year, which varies by country. We can use this exogenous variation for controlling for retirement endogeneity by simultaneously analyzing different countries with different pension eligibility ages

Rohwedder and Willis (2010) analyze the effect of retirement on cognitive function Similarly, which we reexamine along with other related studies (Coe and Zamarro (2011), Bingley and Martinello (2013)) in this paper. When analyzing the effect of retirement on cognitive function, the problem of the cross-country cross-sectional analysis is that the results are not robust when we change the specifications or the set of analyzed countries. Considering the observed heterogeneity or changing the set of analyzed countries provides heterogeneous results. We consider that the effect of only a limited set of the analyzed countries influences the final effect of retirement on cognitive function by using this strategy. Rohwedder and Willis (2010) use pension eligibility ages based on external data sources. [12] Moreover, we investigate again whether the pension eligibility ages in the analyzed countries are correct and find that they are partly incorrect. Therefore we use a modified version of the pension eligibility ages in Rohwedder and Willis (2010). In the Appendix (A.1), we explain the pension eligibility ages used in this section.

According to our analysis, the effect of retirement on cognitive function is heterogeneous in different country sets. Therefore, it is important to analyze this effect in each country because it is possible that the unobserved heterogeneity cannot be controlled for using cross-sectional cross-country analysis. To omit individual unobserved heterogeneity, we estimate the effect

[12] They use the Pensions at a Glance (OECD) and Social Security Programs throughout the World: Europe, 2004.

of retirement on cognitive function by using the dynamic variation of individual retirement behavior in the second stage analysis.

4.2 Analysis Framework

Rohwedder and Willis (2010) estimate the following model. They use the HRS, the SHARE, and the ELSA for 2004, restricting the analyzed sample between ages of 60 and 64. Moreover, Rohwedder and Willis (2010) do not control for any variable. $notwork_i$ is an indicator which is equal to one when a respondent is in the not work for pay category in the survey year, $cognition\_score_i$ is the word recall summary score (minimum 0, maximum 20), and age_i is the respondent's age.

$$\begin{aligned} cognition\_score_i &= \beta_0 + \beta_1 notwork_i + \epsilon_{1i} \\ notwork_i &= \alpha_0 + \alpha_1 1\{age_i \geq A_i^{eb}\} + \alpha_2 1\{age_i \geq A_i^{fb}\} + \epsilon_{2i} \\ A_i^{eb}&\text{: the early retirement benefit eligibility age} \\ A_i^{fb}&\text{: the full retirement benefit eligibility age} \end{aligned} \tag{1}$$

Bingley and Martinello (2013) estimate the same model as in (1), additionally including the years of schooling variable. However, we control for other control variables except the educational level. As discussed in subsequent sections, according to medical literature, it is possible that other individual characteristics except the educational level influence cognitive function, which we implement in our analysis. However, we also check for the sensitivity of the effect of retirement on cognitive function in the various set of control variables. We estimate the following model considering observed respondent heterogeneity.

$$\begin{aligned} cognition\_score_i &= \beta_0 + \beta_1 notwork_i + \gamma' x_i + \epsilon_{1i} \\ notwork_i &= \alpha_0 + \alpha_1 1\{age_i \geq A_i^{eb}\} + \alpha_2 1\{age_i \geq A_i^{fb}\} + \eta' x_i + \epsilon_{2i} \\ A_i^{eb}&\text{: the early retirement benefit eligibility age} \\ A_i^{fb}&\text{: the full retirement benefit eligibility age} \end{aligned} \tag{2}$$

In model (1), the individual characteristics, x_i, of model (2) are unobserved. These produce the difference of cognitive function and also can correlate with the variable . They can also modify the final effect of retirement on health conclusion. Rohwedder and Willis (2010) and Bingley and Martinello (2013) do not use any estimation weights for cross-country analysis in their estimations and do not adjust the estimation according to population size, we produce an estimation weight based on the source of UN data: A World of Information, [13]. and explain the methodology of calculating an estimation weight in the Appendix (A.3).

With respect to the control variables included in the estimation model, it is rather difficult to assess which variables need to be included. For example, public health literature studies the

[13]See the website http://data.un.org/Default.aspx for more detail.

determinants of cognitive function, certain studies discuss the relationship between behavioral factors (physical activity, lifestyle habits and leisure time activity) and cognitive function (Dik et al. (2003), Scarmeas and Stern (2003), Wilson et al. (2003), Nyberg et al. (2012), Raji et al. (2016), Satizabal et al. (2016)). As such, McEwen and Sapolsky (1995) and Sindi et al. (2016) indicate the relationship between stress and cognitive function. Moreover, Nyberg et al. (2000) suggest that gender differences influence cognitive function. Satizabal et al. (2016) find that the incidence of dementia has declined over the last three decades, but cannot find a factor that explains this phenomenon. There are also numerous studies that discuss the relationship between social factors and cognitive function. In our study, we include demographic factors, such as gender, family structure, economic variables, and the country of residence, in the estimation model to control for fundamental social determinants of human behavior. In section 5, we also discuss how social factors influence cognitive function using a simple economic model.

In summary, the analysis of this section has the following conclusions.

- The effect of control variables for individual heterogeneity cannot be ignored. However, in this framework (cross-country cross-sectional analysis), the magnitude of the effect of retirement on cognitive function is similar to the magnitude estimated in some of related literature (Rohwedder and Willis (2010), Bingley and Martinello (2013)), even though we include control variables for individual heterogeneity.

- We also examine the effect of changing the set of the analyzed sample (e.g., changing the set of analyzed countries), which is significant. This suggests that the effects of retirement on cognitive function are also heterogeneous among different groups even if the analyzed groups have similar ages.

- The IV we correct largely influence the final results when we compare them to the results estimated by the instrumental variable which Rohwedder and Willis (2010) and Bingley and Martinello (2013) use. As such the correcting effect of the IV is not weak.

Finally, the figure of Rohwedder and Willis (2010) (Figure 6) using the 2010 dataset has certain drawbacks. [14] According to Figure 7, there is no intuitive relationship, discussed in Rohwedder and Willis (2010), between average cognitive score and percent eligible for early public pension benefits. In Rohwedder and Willis (2010), they show the negative relationship between average cognitive score and Percent eligible for early public pension benefits. This indicates that the intuitive relationship of Rohwedder and Willis (2010) is also not robust.

4.3 Results

First, we restrict the sample to those aged 60 to 64, following Rohwedder and Willis (2010) and Bingley and Martinello (2013). Subsequently, we examine the effect of including the other control variables and changing the IV (Table 4). The IV1 columns represents the analysis

[14] See Figure 6 in Rohwedder and Willis (2010), pp.134-135.

Figure 7: Similar Analysis in Figure 6 by Rohwedder and Willis (2010) (the dataset at 2010)

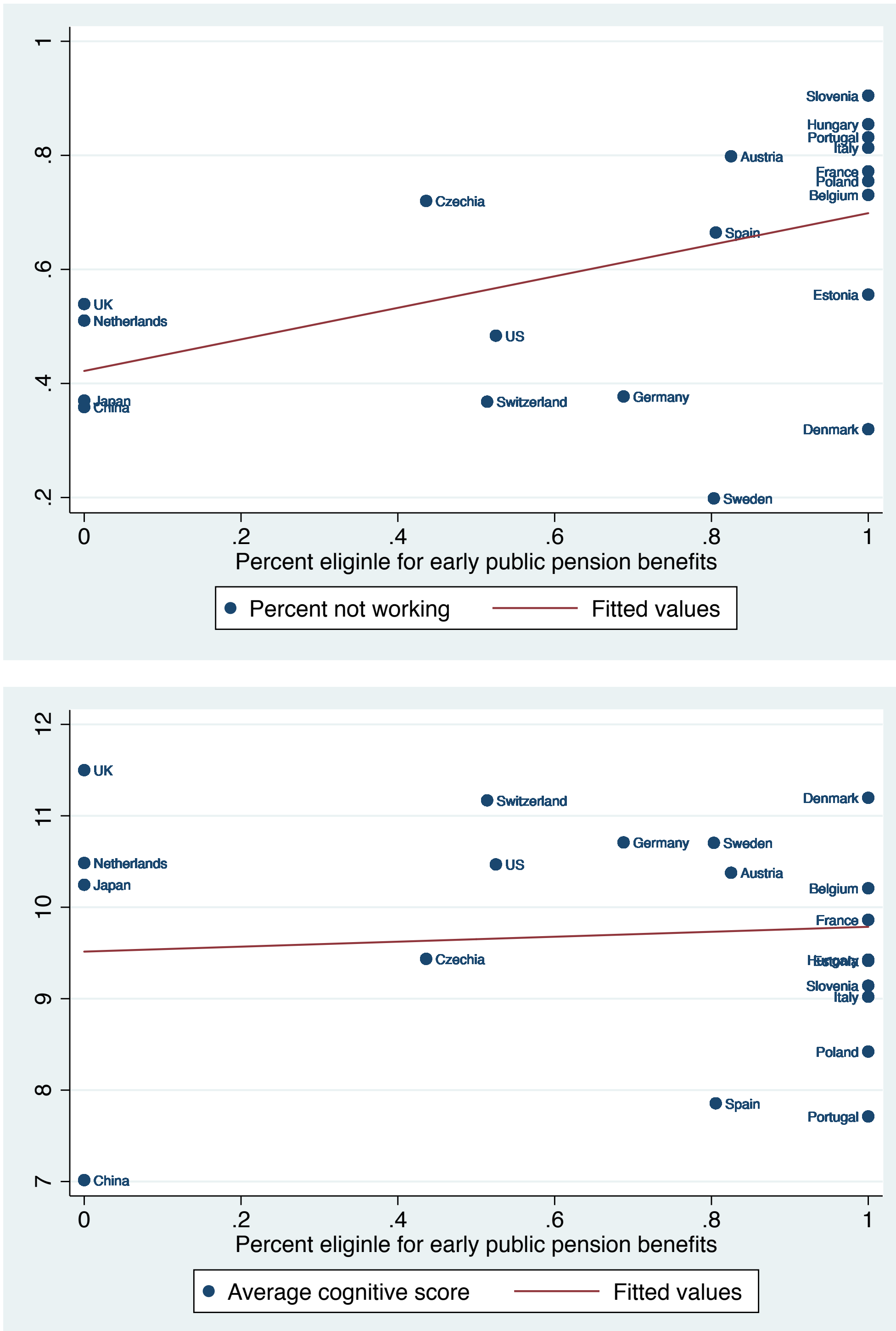
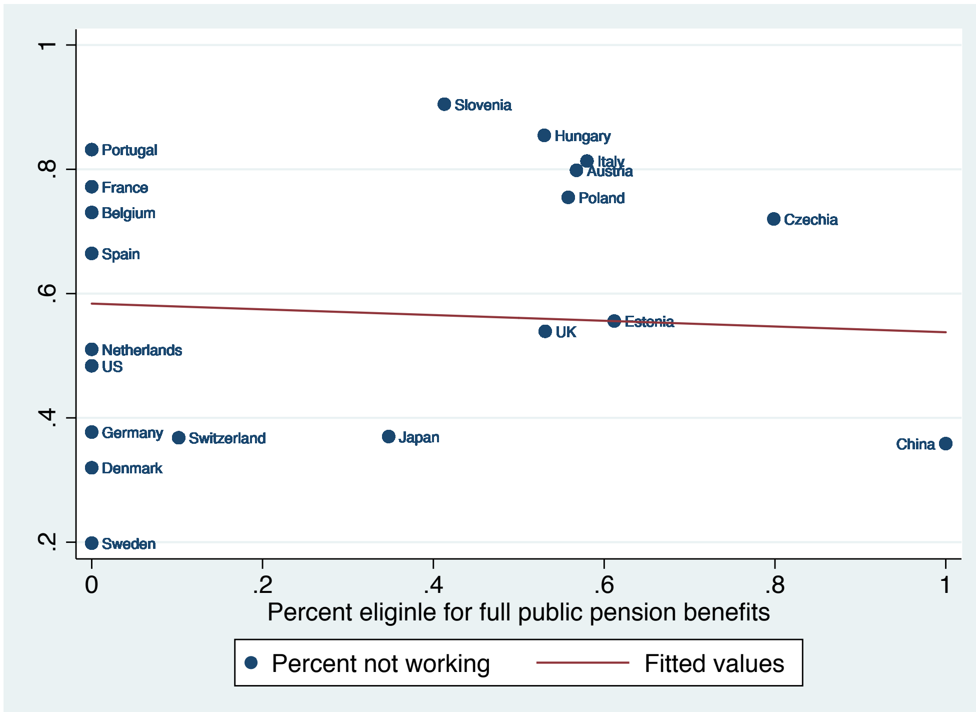
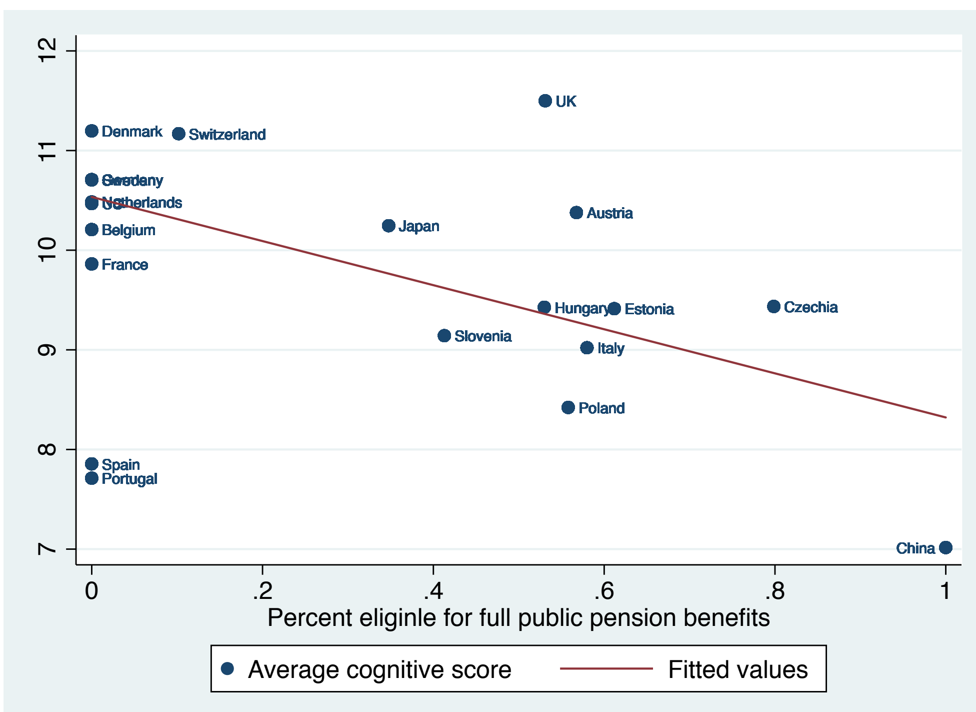


Figure 8: Similar Analysis in Figure 6 by Rohwedder and Willis (2010) (the dataset at 2010)





results when we use the same IV as Rohwedder and Willis (2010) and Bingley and Martinello (2013). The IV2 columns show the analysis results when we use our IV, which are confirmed to be correct. We estimate the results using the ordinary least squares (OLS) method when the Durbin-Wu-Hausman (DWH) test is not rejected in the specification using IV. When the DWH test is rejected, we support the result of the specification using IV. Column (1) in Table 4 presents the results of the specification in Rohwedder and Willis (2010); column (3) shows the results of the specification in Bingley and Martinello (2013); [15] and column (2) are the results of only changing the variable of university enrollment indicator in Bingley and Martinello (2013). We also verify the effect of the difference in the education level definition on the estimated coefficients in the columns (2) and (3). Form columns (4)-(7), we use basic individual characteristics variables, which Rohwedder and Willis (2010) and Bingley and Martinello (2013) do not include. As such, column (4) only controls for the age effect, column (5) adds country dummies into specification (2) and columns (6) and (7) add the other individual characteristics control variables into specification (5). The properties of Table 4 can be summarized as follows.

- The Difference in the IV: changing the IV1 and IV2 gradually influences the value of the coefficients when we add control variables for individual characteristics. The effect becomes gradually larger as the control variables for individual heterogeneity are included when we compare the specifications between IV1 and IV2. Specification (1), which is the same as in Rohwedder and Willis (2010), produces a small difference in the effect of retirement on cognitive function between IV1 and IV2. However, for specifications (6) and (7), the difference in the effect of retirement on cognitive function (between IV1 and IV2) is very large. Consequently,the estimated effect of retirement on cognitive function is influenced by the included control variables.

- The Difference in the Control Variables: when we include country dummies, the change in the magnitude of the coefficients is very large. When comparing the specifications (2) and (5), the magnitude of the coefficients of (2) is significantly larger compared to (5). Finally, the direction of the coefficient is negative in specification (6), while the absolute value of the coefficient is very small (the OLS result in specification (7): -0.455 (OLS)). The value of specification (2) coefficient of is -6.538 (IV2). As a result, the omitted variable bias is significant in specification (2). The results of Table 4 suggest that the country's effect of retirement on cognitive function heterogeneity is significant and not weak as per Table 4. In specification (7), the coefficients of Spain (OLS: -2.230) or Italy (OLS: -1.243) are negative, while the coefficient of the U.S. (OLS: 2.082) is positive.

- The Influence of Estimation Weight: we estimate the effect of retirement on cognitive function by using our estimation weight(calculation methodology is explained in the Appendix (A.3)). According to Table 6, the effect of using estimation weights is not insignificant. By using estimation weights, the influence of the U.S. and the

[15] Bingley and Martinello (2013) impute the value of the years of schooling in the ELSA. However, we do not impute this value and omit the sample of ELSA in column (3) in Table 4.

U.K. increase because the population size is comparatively large in the set of analyzed countries. When the influence of these two countries increases, the magnitude of the retirement on cognitive function effect increases as well. The effect of retirement on cognitive function is however negative.

Subsequently, we discuss the weighted estimation results in Table 6, and comment on the difference in the definition of education level. We estimate the same specification as Bingley and Martinello (2013)[16] in column (3) of Table 6. The effect of omitting the ELSA and the weighting estimation is significant. While Bingley and Martinello (2013) reports a result of -3.014 in the specification "All" in their Table 3, we obtain coefficients of -5.011 (IV1) and -5.138 (IV2). Please note that we do not impute years of schooling variable of ELSA. As a result, we omit the samples of the ELSA altogether. This point also suggests that the change in the set of analyzed countries is significant as well. we use only the dummy variable indicating people with education above college degree available in the harmonized data set created with the code that Global Aging Data provides.[17] We call the set of analyzed countries in Tables 4 and 6the "original" set.

Table 8 shows the results of the same specification (7) in Table 6. However, we show the results of the different cohorts. The columns "2004" present the estimated results using the sample aged 60 to 64 in 2004. and the columns "2010" present the results for 2010. The analyzed cohorts are different between the two columns, the analyzed countries are the same in both the columns "2004" and "2010." We analyze the same set of analyzed countries except Greece in Tables 4 and 6. In 2010, Greece is omitted from the SHARE, making it impossible to include it in the analysis. According to Table 8, the effect of the difference in the cohorts is weak. The DWH tests in both columns "2004" and "2010" are rejected (IV2). However, the OLS results are almost the same (-0.468 (2004) and -0.694 (2010)) after controlling for the heterogeneity of the analyzed countries, and the coefficients of the other control variables are also similar between the OLS result of "2004" and "2010." The effect of retirement on cognitive function is also strong in "2010."

[16]See the specification "All" in Table 3 of Bingley and Martinello (2013).
[17]See the website at http://gateway.usc.edu.

Table 4: The effect of instrumental variables and other control variables (without the coefficients of country)

	(1)		**(2)**		**(3)**		**(4)**		**(5)**			**(6)**			**(7)**		
	IV1	IV2	IV1	IV2	IV1	IV2	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2
1st Stage Result																	
IV-early	0.183***	0.122***	0.171***	0.109***	0.190***	0.070***	0.161***	0.098***		0.084***	0.088***		0.014	-0.003		0.019	0.001
	(0.013)	(0.010)	(0.014)	(0.011)	(0.016)	(0.013)	(0.015)	(0.011)		(0.015)	(0.016)		(0.017)	(0.019)		(0.017)	(0.018)
IV-normal	0.160***	0.212***	0.136***	0.171***	0.161***	0.170***	0.166***	0.208***		0.041**	0.082***		0.055***	0.068***		0.056***	0.070***
2nd Stage Result																	
Not work for pay	-3.346***	-3.047***	-5.216***	-6.538***	-4.433***	-4.708***	-3.302***	-2.588***	-0.570***	-0.771	-2.483***	-0.527***	-0.717	-3.502*	-0.455***	-0.581	-3.217
	(0.319)	(0.373)	(0.415)	(0.574)	(0.404)	(0.630)	(0.347)	(0.409)	(0.071)	(0.940)	(0.931)	(0.072)	(2.116)	(2.114)	(0.073)	(1.960)	(2.060)
Univ			1.140***	0.948***					1.669***	1.640***	1.397***	1.618***	1.592***	1.217***	1.484***	1.472***	1.222***
			(0.119)	(0.141)					(0.081)	(0.156)	(0.157)	(0.082)	(0.297)	(0.299)	(0.086)	(0.205)	(0.216)
Years of schooling					0.239***	0.232***											
					(0.014)	(0.018)											
Female			1.694***	1.857***	1.569***	1.598***			1.040***	1.067***	1.298***	1.120***	1.146***	1.534***	1.106***	1.123***	1.479***
			(0.096)	(0.117)	(0.093)	(0.109)			(0.066)	(0.141)	(0.142)	(0.067)	(0.300)	(0.303)	(0.067)	(0.272)	(0.287)
Age							4.112	4.107				1.762	1.801	2.379	2.172	2.191	2.587
							(2.729)	(2.660)				(2.401)	(2.442)	(2.661)	(2.406)	(2.421)	(2.611)
Age squared							-3.310	-3.325				-1.497	-1.523	-1.904	-1.827	-1.838	-2.079
							(2.201)	(2.145)				(1.936)	(1.958)	(2.136)	(1.941)	(1.946)	(2.099)
Mariage												0.591***	0.593***	0.620***	0.356***	0.363**	0.510***
												(0.083)	(0.086)	(0.091)	(0.089)	(0.144)	(0.151)
N of children												-0.099***	-0.099***	-0.095***	-0.085***	-0.085***	-0.086***
												(0.021)	(0.021)	(0.022)	(0.021)	(0.021)	(0.022)
Income															0.129**	-0.010	-0.021
															(0.056)	(0.016)	(0.015)
Own house															0.581***	0.576***	0.475***
															(0.093)	(0.120)	(0.126)
Total wealth															0.006	0.003*	0.002
															(0.006)	(0.002)	(0.002)
Observations	8838	8838	8509	8509	7352	7352	8838	8838	8509	8509	8509	8447	8447	8447	8355	8355	8355
R^2	-0.071	-0.046	-0.260	-0.521	-0.046	-0.085	-0.067	-0.014	0.189	0.189	0.122	0.199	0.198	0.038	0.210	0.209	0.076
DWHchi2	57.548	31.994	144.107	142.550	102.651	46.607	48.327	19.207		0.044	4.607		0.023	2.365		0.010	2.089
DWHpval	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.834	0.032		0.879	0.124		0.919	0.148

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

All economic variables (e.g. Total wealth, Income) are measured in dollars.
In the specification (7), (country dummy) × (economic variable)
(e.g. (Total wealth) × (the U.S. dummy)) variables are also included.
The estimated coefficients of these cross terms are not presented.
The Belgium dummy is omitted.

Table 5: The effect of instrumental variables and other control variables (only the coefficients of country)

	(1)		(2)		(3)		(4)		(5)			(6)			(7)		
	IV1	IV2	IV1	IV2	IV1	IV2	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2
Country dummy																	
2.US									1.958***	1.886***	1.274***	2.138***	2.066**	1.011	2.082***	2.035***	1.053
									(0.145)	(0.365)	(0.366)	(0.148)	(0.817)	(0.822)	(0.183)	(0.754)	(0.794)
3.UK									2.015***	1.960***	1.486***	1.992***	1.939***	1.157*	1.658***	1.630***	1.055**
									(0.158)	(0.308)	(0.309)	(0.157)	(0.623)	(0.627)	(0.207)	(0.482)	(0.513)
11.Austria									0.776***	0.787***	0.881***	0.799***	0.808***	0.936***	1.004***	1.008***	1.107***
									(0.232)	(0.237)	(0.242)	(0.232)	(0.250)	(0.260)	(0.324)	(0.332)	(0.348)
12.Germany									0.672***	0.647***	0.433*	0.617***	0.591*	0.212	0.562**	0.548*	0.257
									(0.184)	(0.219)	(0.226)	(0.183)	(0.344)	(0.354)	(0.235)	(0.319)	(0.337)
13.Sweden									1.185***	1.092**	0.303	1.158***	1.070	-0.224	1.177***	1.134	0.228
									(0.184)	(0.469)	(0.470)	(0.184)	(1.002)	(1.007)	(0.306)	(0.740)	(0.772)
14.Netherlands									0.731***	0.718***	0.603***	0.685***	0.671***	0.470*	0.917***	0.908***	0.714**
									(0.195)	(0.205)	(0.210)	(0.194)	(0.249)	(0.261)	(0.290)	(0.323)	(0.334)
15.Spain									-1.694***	-1.728***	-2.018***	-1.692***	-1.726***	-2.225***	-2.230***	-2.250***	-2.669***
									(0.213)	(0.266)	(0.275)	(0.213)	(0.436)	(0.449)	(0.284)	(0.422)	(0.453)
16.Italy									-1.109***	-1.120***	-1.211***	-1.174***	-1.186***	-1.361***	-1.243***	-1.245***	-1.297***
									(0.186)	(0.193)	(0.199)	(0.186)	(0.229)	(0.241)	(0.228)	(0.230)	(0.242)
17.France									-0.122	-0.125	-0.146	-0.112	-0.115	-0.162	0.239	0.235	0.146
									(0.203)	(0.203)	(0.213)	(0.201)	(0.205)	(0.224)	(0.260)	(0.268)	(0.287)
18.Denmark									1.332***	1.284***	0.870***	1.352***	1.306**	0.629	1.296***	1.280***	0.936**
									(0.234)	(0.326)	(0.336)	(0.232)	(0.566)	(0.579)	(0.306)	(0.399)	(0.438)
19.Greece									0.081	0.048	-0.235	0.083	0.052	-0.404	-0.527*	-0.542	-0.851**
									(0.192)	(0.248)	(0.253)	(0.193)	(0.398)	(0.404)	(0.275)	(0.356)	(0.383)
20.Switzerland									1.169***	1.091**	0.427	1.150***	1.076	-0.009	1.621***	1.581**	0.761
									(0.284)	(0.458)	(0.467)	(0.285)	(0.871)	(0.885)	(0.427)	(0.736)	(0.773)
Observations	8838	8838	8509	8509	7352	7352	8838	8838	8509	8509	8509	8447	8447	8447	8355	8355	8355
R^2	-0.071	-0.046	-0.260	-0.521	-0.046	-0.085	-0.067	-0.014	0.189	0.189	0.122	0.199	0.198	0.038	0.210	0.209	0.076
DWHchi2	57.548	31.994	144.107	142.550	102.651	46.607	48.327	19.207		0.044	4.607		0.023	2.365		0.010	2.089
DWHpval	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.834	0.032		0.879	0.124		0.919	0.148

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

All economic variables (e.g. Total wealth, Income) are measured in dollars.
In the specification (7), (country dummy) × (economic variable)
(e.g. (Total wealth) × (the U.S. dummy)) variables are also included.
The estimated coefficients of these cross terms are not presented.
The Belgium dummy is omitted.

Table 6: The effect of instrumental variables and other control variables using weight (without the coefficients of country)

	(1)		(2)		(3)		(4)			(5)			(6)			(7)	
	IV1	IV2	IV1	IV2	IV1	IV2	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2
1st Stage Result																	
IV-early	0.210***	0.167***	0.197***	0.147***	0.203***	0.126***	0.185***	0.144***		0.085***	0.081***		0.010	-0.001		0.020	0.004
	(0.016)	(0.013)	(0.016)	(0.013)	(0.018)	(0.015)	(0.017)	(0.014)		(0.017)	(0.017)		(0.020)	(0.022)		(0.020)	(0.021)
IV-normal	0.186***	0.218***	0.160***	0.173***	0.160***	0.135***	0.190***	0.215***		0.052**	0.090***		0.068***	0.075***		0.066***	0.076***
2nd Stage Result																	
Not work for pay	-5.397***	-5.338***	-6.192***	-7.612***	-5.011***	-5.138***	-5.623***	-5.602***	-0.571***	-0.979	-2.903***	-0.532***	-3.826	-5.318**	-0.461***	-2.485	-5.056**
	(0.357)	(0.433)	(0.432)	(0.634)	(0.451)	(0.674)	(0.391)	(0.482)	(0.083)	(0.998)	(1.118)	(0.084)	(2.422)	(2.618)	(0.085)	(2.136)	(2.578)
Univ			1.149***	0.928***					1.724***	1.665***	1.386***	1.656***	1.205***	1.001***	1.538***	1.332***	1.069***
			(0.156)	(0.184)					(0.101)	(0.178)	(0.194)	(0.101)	(0.354)	(0.383)	(0.106)	(0.247)	(0.295)
Years of schooling					0.256***	0.253***											
					(0.016)	(0.020)											
Female			1.675***	1.851***	1.573***	1.587***			0.909***	0.963***	1.219***	0.989***	1.438***	1.641***	0.985***	1.249***	1.583***
			(0.120)	(0.143)	(0.111)	(0.124)			(0.080)	(0.159)	(0.168)	(0.081)	(0.354)	(0.386)	(0.081)	(0.301)	(0.363)
Age							5.954	5.956				6.526**	6.936**	7.122**	7.086**	7.260**	7.481**
							(3.749)	(3.744)				(2.871)	(3.234)	(3.574)	(2.882)	(3.016)	(3.509)
Age squared							-4.746	-4.748				-5.330**	-5.566**	-5.673**	-5.785**	-5.868**	-5.973**
							(3.023)	(3.019)				(2.316)	(2.602)	(2.876)	(2.324)	(2.430)	(2.826)
Mariage												0.551***	0.625***	0.659***	0.334***	0.461***	0.622***
												(0.097)	(0.120)	(0.131)	(0.106)	(0.172)	(0.204)
N of children												-0.133***	-0.128***	-0.126***	-0.121***	-0.122***	-0.124***
												(0.024)	(0.026)	(0.028)	(0.024)	(0.024)	(0.028)
Income															0.162*	-0.018	-0.030*
															(0.084)	(0.016)	(0.018)
Own house															0.549***	0.509***	0.457***
															(0.113)	(0.125)	(0.146)
Total wealth															0.006	0.002	0.001
															(0.006)	(0.002)	(0.002)
Observations	8838	8838	8509	8509	7352	7352	8838	8838	8509	8509	8509	8447	8447	8447	8355	8355	8355
R^2	-0.281	-0.272	-0.394	-0.715	-0.074	-0.093	-0.316	-0.313	0.222	0.219	0.124	0.232	0.041	-0.171	0.242	0.172	-0.116
DWHchi2	171.812	96.053	207.155	177.266	115.794	56.994	168.328	88.990		0.366	5.966		1.294	4.719		0.504	4.356
DWHpval	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.545	0.015		0.255	0.030		0.478	0.037

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

All economic variables (e.g. Total wealth, Income) are measured in dollars.
In the specification (7), (country dummy) × (economic variable)
(e.g. (Total wealth) × (the U.S. dummy)) variables are also included.
The estimated coefficients of these cross terms are not presented.
The Belgium dummy is omitted.

Table 7: The effect of instrumental variables and other control variables using weight (only the coefficients of country)

	(1)		(2)		(3)		(4)		(5)			(6)			(7)		
	IV1	IV2	IV1	IV2	IV1	IV2	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2	OLS	IV1	IV2
Country dummy																	
2.US									1.952***	1.798***	1.068**	2.104***	0.858	0.294	2.064***	1.305	0.342
									(0.150)	(0.395)	(0.442)	(0.152)	(0.934)	(1.012)	(0.188)	(0.821)	(0.991)
3.UK									1.977***	1.860***	1.307***	1.932***	0.994	0.569	1.614***	1.161**	0.586
									(0.160)	(0.329)	(0.362)	(0.160)	(0.713)	(0.770)	(0.209)	(0.527)	(0.634)
11.Austria									0.746***	0.767***	0.864***	0.751***	0.904***	0.974***	1.000***	1.093***	1.212***
									(0.235)	(0.241)	(0.251)	(0.236)	(0.276)	(0.292)	(0.325)	(0.348)	(0.378)
12.Germany									0.642***	0.589***	0.340	0.566***	0.115	-0.090	0.527**	0.310	0.034
									(0.186)	(0.226)	(0.245)	(0.186)	(0.389)	(0.423)	(0.235)	(0.326)	(0.381)
13.Sweden									1.142***	0.951*	0.051	1.114***	-0.424	-1.120	1.128***	0.432	-0.452
									(0.187)	(0.502)	(0.558)	(0.187)	(1.150)	(1.244)	(0.305)	(0.793)	(0.946)
14.Netherlands									0.701***	0.671***	0.531**	0.654***	0.412	0.302	0.915***	0.773**	0.592
									(0.195)	(0.209)	(0.219)	(0.195)	(0.277)	(0.299)	(0.291)	(0.329)	(0.364)
15.Spain									-1.671***	-1.746***	-2.102***	-1.686***	-2.288***	-2.561***	-2.253***	-2.605***	-3.052***
									(0.215)	(0.284)	(0.309)	(0.215)	(0.506)	(0.551)	(0.286)	(0.479)	(0.570)
16.Italy									-1.096***	-1.122***	-1.243***	-1.182***	-1.404***	-1.505***	-1.257***	-1.313***	-1.386***
									(0.188)	(0.198)	(0.207)	(0.188)	(0.253)	(0.271)	(0.225)	(0.233)	(0.256)
17.France									-0.139	-0.144	-0.168	-0.134	-0.171	-0.188	0.196	0.152	0.097
									(0.207)	(0.208)	(0.219)	(0.206)	(0.228)	(0.246)	(0.267)	(0.276)	(0.308)
18.Denmark									1.303***	1.205***	0.743**	1.320***	0.540	0.186	1.251***	1.003**	0.688
									(0.240)	(0.340)	(0.373)	(0.238)	(0.635)	(0.689)	(0.316)	(0.428)	(0.507)
19.Greece									0.026	-0.042	-0.364	0.012	-0.540	-0.789	-0.493*	-0.751*	-1.078**
									(0.198)	(0.260)	(0.282)	(0.199)	(0.466)	(0.501)	(0.286)	(0.401)	(0.471)
20.Switzerland									1.226***	1.066**	0.310	1.172***	-0.107	-0.685	1.665***	1.033	0.229
									(0.293)	(0.487)	(0.540)	(0.294)	(0.998)	(1.084)	(0.432)	(0.792)	(0.943)
Observations	8838	8838	8509	8509	7352	7352	8838	8838	8509	8509	8509	8447	8447	8447	8355	8355	8355
R^2	-0.281	-0.272	-0.394	-0.715	-0.074	-0.093	-0.316	-0.313	0.222	0.219	0.124	0.232	0.041	-0.171	0.242	0.172	-0.116
DWHchi2	171.812	96.053	207.155	177.266	115.794	56.994	168.328	88.990		0.366	5.966		1.294	4.719		0.504	4.356
DWHpval	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.545	0.015		0.255	0.030		0.478	0.037

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

All economic variables (e.g. Total wealth, Income) are measured in dollars.
In the specification (7), (country dummy) × (economic variable)
(e.g. (Total wealth) × (the U.S. dummy)) variables are also included.
The estimated coefficients of these cross terms are not presented.
The Belgium dummy is omitted.

Table 8: The effect of the difference in the cohort groups using weight (Sample aged from 60 to 64)(Original without Greece)

	2004			2010	
	OLS	IV1	IV2	OLS	IV2
1st Stage Result					
IV-early		0.021	0.005		0.002
		(0.020)	(0.022)		(0.023)
IV-normal		0.061**	0.070***		0.088***
		(0.026)	(0.024)		(0.025)
2nd Stage Result					
Not work for pay	-0.468***	-2.064	-5.131*	-0.694***	-6.379**
	(0.086)	(2.222)	(2.916)	(0.091)	(2.574)
Univ	1.534***	1.369***	1.051***	1.360***	0.670*
	(0.107)	(0.258)	(0.331)	(0.107)	(0.342)
Female	0.996***	1.200***	1.590***	1.173***	1.800***
	(0.082)	(0.306)	(0.397)	(0.082)	(0.325)
Age	7.714***	7.897***	8.247**	-0.345	2.480
	(2.929)	(3.019)	(3.593)	(2.954)	(4.189)
Age squared	-6.292***	-6.394***	-6.592**	0.298	-1.759
	(2.362)	(2.431)	(2.890)	(2.384)	(3.350)
Mariage	0.345***	0.443**	0.631***	0.383***	0.647***
	(0.108)	(0.174)	(0.219)	(0.110)	(0.187)
N of children	-0.123***	-0.125***	-0.127***	-0.071***	-0.080**
	(0.024)	(0.024)	(0.028)	(0.026)	(0.033)
Income	-0.006	-0.016	-0.030	0.055	-0.002
	(0.033)	(0.017)	(0.019)	(0.071)	(0.018)
Own house	0.550***	0.517***	0.454***	0.489***	0.327**
	(0.115)	(0.126)	(0.152)	(0.112)	(0.160)
Total wealth	0.004*	0.002	0.001	-0.001	-0.004
	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)
Observations	7987	7987	7987	9195	9195
R^2	0.243	0.200	-0.124	0.173	-0.438
DWHchi2		0.197	3.507		7.515
DWHpval		0.657	0.061		0.006

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

	2004			2010	
	OLS	IV1	IV2	OLS	IV2
Country dummy					
2.US	2.062***	1.464*	0.315	-0.080	-1.262**
	(0.188)	(0.851)	(1.115)	(0.210)	(0.600)
3.UK	1.612***	1.254**	0.567	1.248***	0.690*
	(0.209)	(0.544)	(0.706)	(0.236)	(0.392)
11.Austria	1.002***	1.075***	1.214***	0.282	0.885*
	(0.325)	(0.346)	(0.383)	(0.293)	(0.453)
12.Germany	0.525**	0.353	0.024	-0.323	-1.493*
	(0.235)	(0.331)	(0.409)	(0.455)	(0.775)
13.Sweden	1.124***	0.575	-0.481	0.322	-1.720
	(0.305)	(0.821)	(1.057)	(0.442)	(1.087)
14.Netherlands	0.914***	0.802**	0.586	0.083	-1.044
	(0.291)	(0.330)	(0.377)	(0.289)	(0.637)
15.Spain	-2.256***	-2.534***	-3.067***	-2.654***	-2.752***
	(0.286)	(0.487)	(0.618)	(0.292)	(0.389)
16.Italy	-1.260***	-1.305***	-1.391***	-1.515***	-1.301***
	(0.225)	(0.232)	(0.259)	(0.310)	(0.400)
17.France	0.197	0.161	0.094	-0.583**	0.028
	(0.267)	(0.274)	(0.311)	(0.271)	(0.438)
18.Denmark	1.249***	1.054**	0.677	0.826**	-0.476
	(0.316)	(0.429)	(0.536)	(0.365)	(0.801)
20.Switzerland	1.661***	1.161	0.202	0.884***	-1.399
	(0.432)	(0.813)	(1.037)	(0.287)	(1.094)
Observations	7987	7987	7987	9195	9195
R^2	0.243	0.200	-0.124	0.173	-0.438
DWHchi2		0.197	3.507		7.515
DWHpval		0.657	0.061		0.006

Standard errors in parentheses
* $p < .1$, ** $p < .05$, *** $p < .01$

Table 9 reports the result when we change the set of analyzed countries. The age range is from 60 to 69 because we can use the variation of pension eligibility age as much as possible in numerous countries. The specification numbers of each column in Table 9 indicate the same specification number of each column in Tables 4 and 6. All results are estimated by using only the dataset of 2010. However, many countries have joined the sister survey of the HRS since 2004. [18] We change the set of the analyzed countries in each result, and separate it for 2010 into four regions based on linguistic areas. "Italic" shows the estimated results including countries such as France, Spain Portugal, and Italy. Table 9 omits the estimated results of the coefficients of the country dummies and other control variables in each specification. "Slavic" includes only European countries: Estonia, Slovenia, Portland, Hungary, and Czech Republic. "Germanic" includes European countries as well: the U.K., the Netherlands, Germany, Denmark, Belgium, Sweden, Austria, and Switzerland. "New SHARE and East Asia" includes Japan, China, Czech Republic, Poland, Hungary, Portugal, Slovenia, and Estonia. "Original without Greece" includes the countries in the "original" set(the set of analyzed countries used by Rohwedder and Willis (2010)) without Greece. As such, the degree of the heterogeneity of the estimated results is large as per Table 9. When we analyze "original without Greece," the coefficients are significantly negative ("original without Greece": -0.608 (OLS), "Germanic": -0.333 (OLS), "Italic": -0.362 (OLS)) while the coefficients of "new SHARE and East Asia" or "Slavic" are significantly positive or not significant ("New SHARE and East Asia": 0.413 (OLS), "Slavic": -0.138 (OLS)(not significant)).

Finally, Table 10 shows the effect of changing the surveyed age-group and the definition of retirement, with similar results to specification (7) in Table 6. The columns of "not work" are the analysis for retirement defined as "not work for pay," and the columns of "SR retire" for retirement defined as "a respondent reports a retired status" (the same definition as "self-reported retire" in the section 3 as in footnote 11). The "complete retire" is the retirement defined as both "not work for pay" and "a respondent reports a retired status." According to Table 10, the effect of changing the age group and the retirement definition is not significant.

In summary, this section emphasized the following findings:

- Unobserved heterogeneity largely influences the estimated result when we omit the important control variables(Tables 4 and 6).

- The heterogeneity of the set of the analyzed countries largely influences the estimated result. When we change the set of analyzed countries, we obtain a different conclusion. As a result, we should pay attention to the heterogeneity of each country when we analyze the effect of retirement on cognitive function(Table 9).

- The definition of retirement does not largely influence the estimated results. Occasionally, the results derive different conclusions depending on the definition of retirement(Table 10). [19]

[18] The JSTAR is the data for 2009, the CHARLS is the data for 2011.

[19] Kajitani et al. (2013) also report that the sensitivity of the retirement definiton is weak.

- Other factors, which are the difference in age groups or the difference in cohorts, are not important(Table 8, 10).

According to our analysis, the country heterogeneity largely influences the estimated results although the difference in cohorts or age groups is not important. When we use the identification strategy in this section (cross-sectional cross-country analysis), we cannot omit the unobserved heterogeneity that can correlate the other control variables and can be the source of bias for the coefficient of the retirement variable. We consider we should analyze the effect of retirement on cognitive function in only one country and omit unobserved individual heterogeneity when we estimate this effect. In the subsequent section, we analyze countries whose pension eligibility ages are confirmed to be correct. [20] We also analyze the influence of heterogeneity of transition behavior (leisure activity) before and after retirement and the influence of individual heterogeneity.

[20]In the Appendix (A.1), we discuss how to confirm pension eligibility age in each country.

Table 9: The effect of the difference in the set of analyzed countries (Sample aged from 60 to 69)

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2
Italic														
1st Stage Result														
IV-early		0.230***		0.248***		0.240***		0.128**		0.216***		0.087		0.079
		(0.053)		(0.055)		(0.052)		(0.055)		(0.057)		(0.061)		(0.063)
IV-normal		0.173***		0.147***		0.145***		0.090***		0.164***		0.048**		0.037*
		(0.012)		(0.013)		(0.012)		(0.016)		(0.014)		(0.019)		(0.020)
2nd Stage Result														
Not work for pay	-0.854***	-2.360***	-0.653***	-2.445***	-0.446***	-1.417***	-0.591***	3.034**	-0.774***	-3.524***	-0.559***	-0.736	-0.362**	-1.613
	(0.140)	(0.534)	(0.143)	(0.629)	(0.133)	(0.550)	(0.145)	(1.475)	(0.140)	(0.624)	(0.148)	(2.760)	(0.159)	(3.594)
Observations	4620	4620	4239	4239	4534	4534	4620	4620	4239	4239	4080	4080	3620	3620
R^2	0.009	-0.020	0.063	0.023	0.186	0.174	0.022	-0.133	0.121	0.027	0.135	0.135	0.156	0.139
DWHchi2		9.859		10.931		3.337		6.108		24.089		0.003		0.100
DWHpval		0.002		0.001		0.068		0.013		0.000		0.953		0.752
Slavic														
1st Stage Result														
IV-early		0.053***		0.074***		0.043**		0.039***		-0.049*		-0.030		-0.020
		(0.014)		(0.016)		(0.017)		(0.014)		(0.027)		(0.026)		(0.026)
IV-normal		0.265***		0.210***		0.209***		0.197***		0.228***		0.113***		0.108***
		(0.027)		(0.025)		(0.025)		(0.032)		(0.024)		(0.031)		(0.031)
2nd Stage Result														
Not work for pay	-0.584***	-0.018	-0.624***	-1.470*	-0.315	-0.714	-0.414*	2.692**	-0.620***	-1.377*	-0.426**	2.836	-0.138	2.917
	(0.209)	(0.708)	(0.222)	(0.889)	(0.214)	(0.848)	(0.212)	(1.278)	(0.221)	(0.826)	(0.216)	(2.312)	(0.231)	(2.513)
Observations	6789	6789	6664	6664	6688	6688	6789	6789	6664	6664	6662	6662	6086	6086
R^2	0.005	0.000	0.037	0.028	0.122	0.120	0.018	-0.103	0.059	0.052	0.092	-0.028	0.093	-0.004
DWHchi2		2.661		1.420		0.205		9.102		0.919		2.110		1.614
DWHpval		0.103		0.233		0.651		0.003		0.338		0.146		0.204
Germanic														
1st Stage Result														
IV-early		0.035**		0.043**		0.014		-0.021		0.101**		0.014		0.013
		(0.016)		(0.017)		(0.024)		(0.016)		(0.043)		(0.046)		(0.048)
IV-normal		0.339***		0.324***		0.343***		0.172***		0.312***		0.088***		0.091***
		(0.017)		(0.019)		(0.024)		(0.022)		(0.020)		(0.029)		(0.028)
2nd Stage Result														
Not work for pay	-0.610***	-1.037***	-0.672***	-1.885***	-0.736***	-1.893***	-0.340***	3.751***	-0.659***	-2.094***	-0.374***	-2.404	-0.333**	-0.867
	(0.122)	(0.362)	(0.129)	(0.414)	(0.161)	(0.465)	(0.124)	(0.901)	(0.133)	(0.429)	(0.141)	(2.216)	(0.151)	(2.147)
Observations	11172	11172	10166	10166	7441	7441	11172	11172	10166	10166	9788	9788	8802	8802
R^2	0.008	0.004	0.065	0.033	0.085	0.055	0.020	-0.303	0.090	0.047	0.096	0.021	0.108	0.104
DWHchi2		0.620		6.444		7.912		25.934		14.978		0.927		0.064
DWHpval		0.431		0.011		0.005		0.000		0.000		0.336		0.801
New SHARE and East Asia														
1st Stage Result														
IV-early		0.463***		0.443***		0.043***		0.447***		0.050**		0.051**		0.096***
		(0.011)		(0.011)		(0.016)		(0.011)		(0.023)		(0.023)		(0.023)
IV-normal		0.117***		0.100***		0.170***		0.057***		0.220***		0.140***		0.123***
		(0.018)		(0.019)		(0.019)		(0.020)		(0.021)		(0.024)		(0.026)
2nd Stage Result														
Not work for pay	0.823***	0.814***	0.792***	0.454**	-0.246	-1.144	0.871***	1.589***	0.592***	0.222	0.621***	2.359**	0.413***	1.774
	(0.090)	(0.212)	(0.090)	(0.224)	(0.187)	(0.856)	(0.090)	(0.207)	(0.092)	(0.625)	(0.093)	(1.203)	(0.105)	(1.399)
Observations	12807	12807	12629	12629	7413	7413	12807	12807	12629	12629	12606	12606	10705	10705
R^2	0.015	0.015	0.038	0.035	0.134	0.124	0.018	0.007	0.129	0.127	0.137	0.078	0.174	0.140
DWHchi2		15.085		2.579		1.012		25.809		0.841		0.304		1.066
DWHpval		0.000		0.108		0.314		0.000		0.359		0.581		0.302
Original														
1st Stage Result														
IV-early		0.128***		0.128***		0.140***		0.091***		0.116***		0.001		0.002
		(0.009)		(0.010)		(0.013)		(0.010)		(0.016)		(0.020)		(0.020)
IV-normal		0.231***		0.212***		0.186***		0.176***		0.194***		0.055***		0.052***
		(0.009)		(0.009)		(0.010)		(0.012)		(0.010)		(0.015)		(0.015)
2nd Stage Result														
Not work for pay	-1.164***	-2.499***	-0.994***	-2.750***	-0.792***	-1.626***	-1.083***	-2.717***	-0.813***	-2.010***	-0.698***	-4.853**	-0.608***	-3.940*
	(0.065)	(0.231)	(0.065)	(0.248)	(0.068)	(0.259)	(0.066)	(0.467)	(0.067)	(0.284)	(0.070)	(2.281)	(0.072)	(2.336)
Observations	20087	20087	18746	18746	16260	16260	20087	20087	18746	18746	18108	18108	16746	16746
R^2	0.028	-0.009	0.103	0.041	0.177	0.164	0.032	-0.019	0.145	0.118	0.157	-0.147	0.173	-0.016
DWHchi2		42.834		62.764		9.962		17.998		19.996		3.923		2.110
DWHpval		0.000		0.000		0.002		0.000		0.000		0.048		0.146
All countries														
1st Stage Result														
IV-early		0.332***		0.331***		0.134***		0.292***		0.107***		0.058***		0.052***
		(0.007)		(0.008)		(0.012)		(0.009)		(0.015)		(0.017)		(0.017)
IV-normal		0.121***		0.097***		0.196***		0.053***		0.198***		0.108***		0.092***
		(0.008)		(0.008)		(0.009)		(0.010)		(0.009)		(0.013)		(0.014)
2nd Stage Result														
Not work for pay	0.607***	3.684***	0.576***	3.186***	-0.797***	-1.853***	0.688***	6.092***	0.069	-1.410***	0.153**	0.073	-0.017	-0.226
	(0.063)	(0.189)	(0.063)	(0.182)	(0.065)	(0.241)	(0.065)	(0.269)	(0.065)	(0.264)	(0.066)	(0.753)	(0.070)	(0.948)
Observations	32894	32894	31375	31375	23673	23673	32894	32894	31375	31375	30714	30714	27451	27451
R^2	0.007	-0.178	0.090	-0.041	0.181	0.160	0.011	-0.542	0.229	0.191	0.239	0.239	0.262	0.261
DWHchi2		81.425		87.093		19.604		462.480		30.384		0.006		0.038
DWHpval		0.000		0.000		0.000		0.000		0.000		0.940		0.846

Table 10: The effect of the difference in the definition of retirement and the surveyed age-group using weight

	SR retire				**Not Work**				**Complete retire**			
	2004		**2010**		**2004**		**2010**		**2004**		**2010**	
	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2	OLS	IV2
Age group: 60-64												
1st Stage Result												
IV-Early-bi		0.037		0.062**		0.003		0.022		0.010		0.032
		(0.023)		(0.025)		(0.023)		(0.025)		(0.023)		(0.025)
IV-Normal-bi		0.107***		0.098***		0.044**		-0.003		0.073***		0.033
		(0.021)		(0.022)		(0.021)		(0.023)		(0.022)		(0.024)
2nd Stage Result												
retirement	-0.274***	-0.216	-0.393***	1.239	-0.439***	-1.415	-0.583***	14.847	-0.398***	-0.702	-0.530***	3.577
	(0.092)	(1.401)	(0.107)	(1.547)	(0.088)	(3.615)	(0.110)	(19.854)	(0.089)	(2.147)	(0.108)	(4.303)
Observations	8078	8078	9239	9239	8095	8095	9299	9299	8076	8076	9213	9213
R^2	0.171	0.171	0.104	0.064	0.172	0.155	0.105	-3.669	0.172	0.171	0.106	-0.170
DWHchi2		0.008		1.051		0.077		2.926		0.018		1.106
DWHpval		0.930		0.305		0.781		0.087		0.892		0.293
Age group: 60-69												
1st Stage Result												
IV-Early-bi		0.070***		0.082***		0.029		0.022		0.027		0.028
		(0.021)		(0.021)		(0.021)		(0.021)		(0.021)		(0.021)
IV-Normal-bi		0.123***		0.139***		0.069***		0.058***		0.089***		0.084***
		(0.012)		(0.011)		(0.012)		(0.013)		(0.013)		(0.013)
2nd Stage Result												
retirement	-0.275***	0.777	-0.319***	0.411	-0.451***	1.527	-0.480***	1.241	-0.422***	1.167	-0.443***	0.490
	(0.074)	(0.704)	(0.087)	(0.720)	(0.067)	(1.328)	(0.081)	(1.849)	(0.067)	(1.033)	(0.081)	(1.263)
Observations	15830	15830	16858	16858	15852	15852	16945	16945	15827	15827	16823	16823
R^2	0.168	0.155	0.111	0.105	0.170	0.113	0.112	0.070	0.170	0.132	0.113	0.100
DWHchi2		2.264		0.890		2.383		0.631		2.477		0.390
DWHpval		0.132		0.345		0.123		0.427		0.116		0.532

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

5 Dynamic Analysis

According to the study of cross-country and cross-sectional analysis validity in section 4, the estimation strategy such as the strategy used by Rohwedder and Willis (2010), Coe and Zamarro (2011), and Bingley and Martinello (2013) is not appropriate for estimating the effect of retirement on cognitive function. According to the results of the section 4, in "original without Greece" countries, the effect of retirement on cognitive function is negative, while the effect of retirement on cognitive function is positive in "new SHARE and East Asia" countries. The effect of only a part of the analyzed countries influences the final conclusion on the effect of retirement on cognitive function. As such, we use another identification strategy in this section to omit the unobserved heterogeneity of individual characteristics. Before we proceed to the estimation, we discuss the source of the effect of retirement on cognitive function heterogeneity. In related literatures, Rohwedder and Willis (2010) suggest that it is possible that the difference in the activity during leisure time influences cognitive function after retirement. They raise the analysis on this point as a future work. Bonsang et al. (2012) also suggest that increased social interaction is increased may be an important factor for the cognitive reserve. We would like to consider these points in a simple framework.

5.1 What Is The Source of The Effect of Retirement on Cognitive Function Heterogeneity?: A Simple Theoretical Analysis

In this section, we investigate the hypothetical mechanism causing the heterogeneity of the difference in cognitive function scores between retirees and non-retirees, based on a simple economic model. This simplified model has a similar structure to Grossman (1972). Rohwedder and Willis (2010) present a similar idea about the mechanism of a cognitive function decreases after retirement. Although Mazzonna and Peracchi (2012) present a model as well, retirement is exogenous and there is no asset accumulation. They formulate the utility function with a cognitive investment itself. As such, we formalize the utility function with cognitive ability because the latter is a health asset and the cognitive investment increases this asset. This is the first analysis to present the model with endogenous retirement. (3) is a simple dynamic model with two cognitive abilities. The following is an elderly's maximization problem.

$$
\begin{aligned}
\max_{\{c_t, l_t, i^f_{Wt}, i^j_{Wt}, i^f_{Lt}, i^j_{Lt}\}_{t=50}^{T}} \sum_{t=50}^{T} \beta^{t-50} u(c_t, \tilde{l}_t, a^f_t, a^j_t) \\
(50 \leq t \leq T) \\
s.t.\ A_{t+1} = (1+r)A_t + P(l_t, R, Pension_t) + y_t - c_t - G(i^f_{Wt}, i^j_{Wt}, i^f_{Lt}, i^j_{Lt}) \\
a^f_t = A_f(t, i^f_{Wt}, i^f_{Lt}, X_{ft}) \\
a^j_t = A_j(t, i^j_{Wt}, i^j_{Lt}, X_{jt}) \\
\tilde{l}_t = l_t - L(i^f_{Lt}, i^j_{Lt}) \\
y_t = y(a^f_t, a^j_t, t, l_t)
\end{aligned}
\tag{3}
$$

$$
\begin{aligned}
l_t &\in \{0, 0.5, 1\} \\
(1 - l_t) \cdot i_{Wt}^{mMax} \geq i_{Wt}^{m} &\geq 0 \;\; (m = f, j) \\
c_t \geq 0, \tilde{l}_t \geq 0, i_{nt}^{m} \geq 0 (m = f, j)(n = W, L), A_{t+1} &\geq 0
\end{aligned} \tag{4}
$$

We would like to define the following notations.

- c_t: consumption, $\tilde{l}_t$: finally consumed leisure time, a_t^f: fundamental cognitive ability, a_t^j: job specific cognitive ability.
- l_t: leisure time, A_t: asset, R: pensionable age, $Pension_t$: pension payment.
- i_{Wt}^f: fundamental cognitive investment at workplace, i_{Lt}^f: fundamental cognitive investment during leisure time, i_{Wt}^j: job specific cognitive investment at workplace, i_{Lt}^j: job specific cognitive investment during leisure time.
- X_{ft}: technological factors of fundamental cognitive ability, X_{jt}: technological factors of job specific cognitive ability.
- $A_f(\cdot)$: the production function of fundamental cognitive ability, $A_j(\cdot)$: the production function of job specific cognitive ability.
- $P(\cdot)$: the function of pension payment, $G(\cdot)$: the cost function of cognitive investment, $L(\cdot)$: the function of reduced time by cognitive investment, $y(\cdot)$: the function of income, $i_{Wt}^{mMax}(m = f, j)$: maximum values of cognitive investment during work time.

We assume that "fundamental cognitive ability" is a basic cognitive ability, such as calculation, reading, and memory ability. This ability is the target of our analysis. We also assume that "job specific cognitive ability" is the cognitive ability for a specific job, such as a computing skill. We would like to explain the important structures of model (3) when we consider the hypothetical mechanism of retirement heterogeneously influencing cognitive function.

- The elderly can input cognitive investment at the workplace only when they work. The maximum amount of investment changes according to the amount of leisure($(1 - l_t) \cdot i_{Wt}^{mMax} \geq i_{Wt}^{m} \geq 0 (m = f, j)$). When the elderly enjoy their leisure time, they can invest in the cognitive ability. However, these investments reduce leisure($\tilde{l}_t = l_t - L(i_{Lt}^f, i_{Lt}^j)$). The elderly finally consumes $\tilde{l}_t$ as leisure.
- We assume that $y(a_{t+1}^f = \alpha_1, a_{t+1}^j = \alpha_2, t + 1, l_{t+1} = \alpha_3) - y(a_t^f = \alpha_1, a_t^j = \alpha_2, t, l_t = \alpha_3) < 0$. In other words, age increase lowers their income. Although the elderly continue to input the same level of leisure time and have the same level of cognitive ability, the income continues to decrease as age increases. This is an effect of health on income: aging reduces the incentive to work progressively.

- We assume that $P(l_t, R, Pension_t) = 0$ if $t \leq R$. When we consider the liquidity constraint ($A_t \geq 0$), the incentive to work increases when R increases.

- We assume that it is possible that the elderly have a preference for fundamental cognitive ability and job specify ability. As such, it is possible that $\frac{\partial u(c_t, \tilde{l}_t, a_t^f, a_t^j)}{\partial a_t^m} > 0 (m = f, j)$. This structure produces the incentive to invest in the cognitive ability which is an important property. This structure also gives the working status two benefits; income and the opportunity to invest in cognitive abilities at the workplace; this is because the model has the structure that elderly input cognitive investment at the workplace only when they work. Additionally, the elderly who have a preference as regards cognitive abilities have the incentive to invest cognitive abilities during leisure time. This preference provides an incentive to invest in cognitive abilities after retirement.

- The marginal utility of cognitive ability investment is the value of $\frac{\partial u(c_t, \tilde{l}_t, a_t^f, a_t^j)}{\partial a_t^m} \frac{\partial a_t^m}{\partial i_{nt}^m} (m = f, j)(n = W, L)$. In other words, the factors of the cognitive ability production function are important for deciding the amount of investment when they influence the marginal productivity of the production function($\frac{\partial a_t^m}{\partial i_{nt}^m} (m = f, j)$).

We parameterize model (3) to discuss the hypothetical mechanism, the specification presented here being an example. We only present the hypothesis of why the effect of retirement on cognitive ability is different. The hypotheses should be investigated empirically section. The details of the parameterization are explained in the Appendix (A.2). We parameterize the utility function, pension payment function, and cognitive ability functions as follows.

- $u(c_t, \tilde{l}_t, a_{ft}, a_{jt}) = c_t^{\gamma_1} \tilde{l}_t^{\gamma_2} a_{ft}^{\gamma_3} a_{jt}^{1-\gamma_1-\gamma_2-\gamma_3}$
- $P(l_t, R, Pension_t) = 1\{l_t \geq 0.5\} 1\{t \geq R\} Pension_t$
- $A_m(t, i_{Wt}^m, i_{Lt}^m, X_{mt}) = \alpha_1 i_{Wt}^m + \alpha_2 i_{Lt}^m + \alpha_3 Hetro_1 + \alpha_4 Hetro_2 + A_{m0} \exp(-\alpha_5 t)(m = f, j)$

In our "benchmark" model, we set the parameters: $\gamma_3 = 0.0, 1 - \gamma_1 - \gamma_2 - \gamma_3 = 0, R = 70, \alpha_5 = 0.05$. We simulate the economic behavior of 5,000 agents after solving the dynamic programming. Subsequently, initial asset (A_0) and initial cognitive abilities ($A_{m0}(m = f, j)$) are taken from a distribution. We observe the influence of the average value of A_{m0} of the initial distribution. The vertical line of all figures indicates the average value of each variable for all agents. The start of the value of the horizontal line in each figure means "age 50." In other words, age 1 means age 51.

- The influence of the difference in preference of cognitive ability: in Figure 9, we analyze the effect of the change in the parameter of fundamental cognitive ability in the utility function. We only change parameter $\gamma_3 = 0.0$ ("benchmark" model) into $\gamma_3 = 0.2$ in the "without preference" case. In the "with preference" case, the elderly start to retire around age 70 (horizontal line = 20). Then, the fundamental cognitive investment during leisure time also increases simultaneously in the "with preference" case.

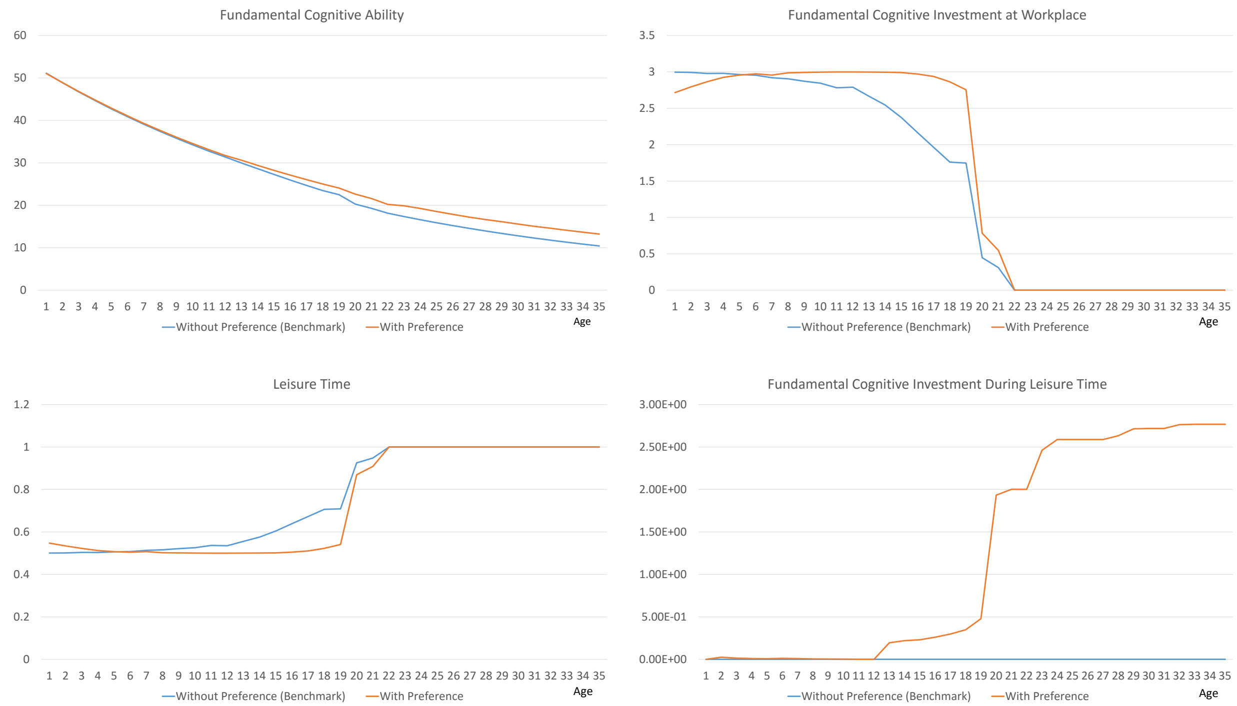
On the other hand, in the "without preference" case, the fundamental cognitive investment during leisure time does not increase simultaneously in the "without preference" case. This is the effect of preference change on cognitive investment behavior. In the "without preference" case, the incentive to increase leisure is large. As a result, the elderly without fundamental cognitive ability preference retire earlier in the "without preference" case. Additionally, fundamental cognitive investment at workplace also decreases earlier in the "without preference" case. Consequently, the effect of retirement on cognitive function is considered to be the difference in cognitive investment behaviors (both during leisure time and at the workplace) before and after retirement. The mechanism to change cognitive ability by retirement is that the elderly change investment behavior after retirement. As a result, the effect of retirement on the cognitive function becomes heterogeneous in both cases through the change in cognitive investment behaviors before and after retirement.

- The influence of the difference in initial cognitive ability level: in Figure 10, we analyze the effect of the average value of A_{m0} of the initial distribution. We only change the average value of A_{m0} into a lower average value in "high initial ability." In this case, the heterogeneity of the effect of retirement on cognitive function is unclear (the difference in cognitive investment behaviors before and after retirement). In all behaviors, there is no difference between the two types. As such, the effect of retirement on cognitive function may be weak because the effect of retirement on cognitive investment behaviors is considered to be the difference in investment behaviors before and after retirement.
- The influence of the difference in technological factor of cognitive ability production function: in Figure 11, we only change the parameter $\alpha_5 = 0.05$ ("benchmark" model) into $\alpha_5 = 0.025$ in the "high tech" case. In this case, there is a difference in cognitive investment behaviors between the two cases("high tech" case vs "low tech" case). However, the heterogeneity of the effect of retirement on cognitive function is clear because cognitive investment behaviors heterogeneity is large.
- The influence of the pension eligibility age on investment activity: In Figure 12, when we change the pensionable age 70 into age 65, the average leisure time increases at the same age "Pension Eligibility Age 70" and "Pension Eligibility Age 65" in both cases. Cognitive investment behavior at the workplace also sharply decreases at the pensionable age. The retirement behavior is strongly influenced by whether an elderly arrives at their pensionable age. In other words, we can use the pensionable age as an IV to control for the endogeneity of cognitive investment behaviors, which we include in our empirical estimation.

We have discussed the source of the effect of retirement on cognitive abilities heterogeneity as the heterogeneity of cognitive investment behaviors before and after retirement (both during leisure time and at the workplace). As such, we perform an empirical analysis based on the discussion in this section.

Finally, we discuss the relationship between model analysis in this section and public health literature. In public health literature, numerous studies focus on the determinants of

Figure 9: The Influence of the Difference in Preference to Cognitive Ability (Without Preference to Fundamental Cognitive Ability vs Without Preference to Fundamental Cognitive Ability)



cognitive function, as in the relationship between cognitive function and lifestyle habits or between cognitive ability and human behaviors (physical activity and lifestyle habits such as leisure time activity)(Dik et al. (2003), Scarmeas and Stern (2003), Wilson et al. (2003), Nyberg et al. (2012), Raji et al. (2016), Satizabal et al. (2016)). The effect of these activities on cognitive function is the cognitive investment behaviors during leisure time heterogeneity. We consider the heterogeneity of activities during leisure time in the empirical section.

Figure 10: The Influence of the Difference in Initial Cognitive Ability Level (High Initial Fundamental Cognitive Ability vs Low Initial Fundamental Cognitive Ability)

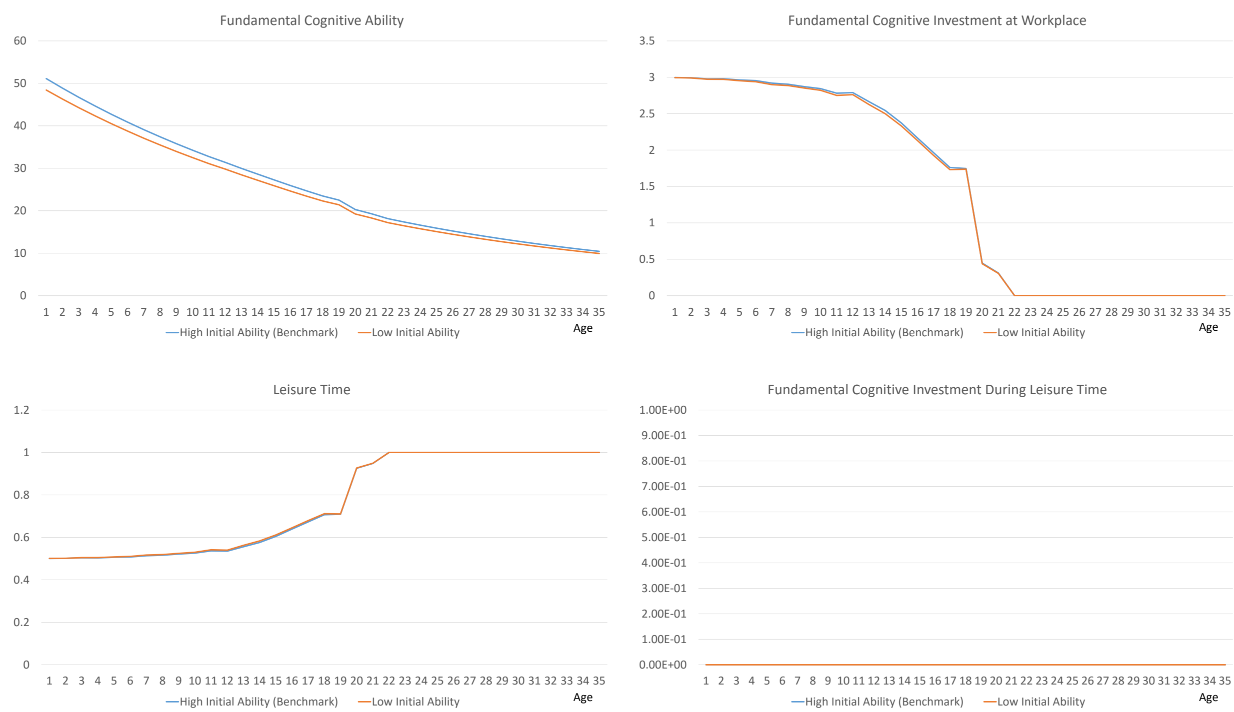


Figure 11: The Influence of the Difference in Technological Factor of Cognitive Ability Production Function (High Technology vs Low Technology)

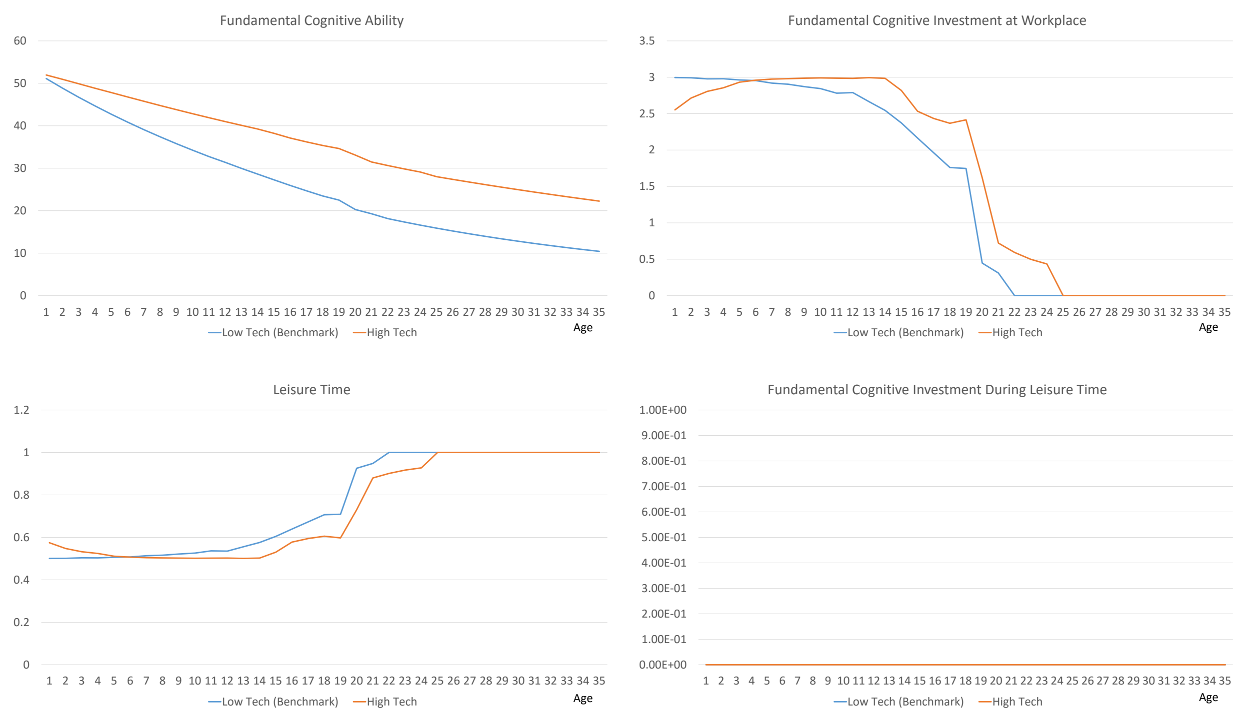
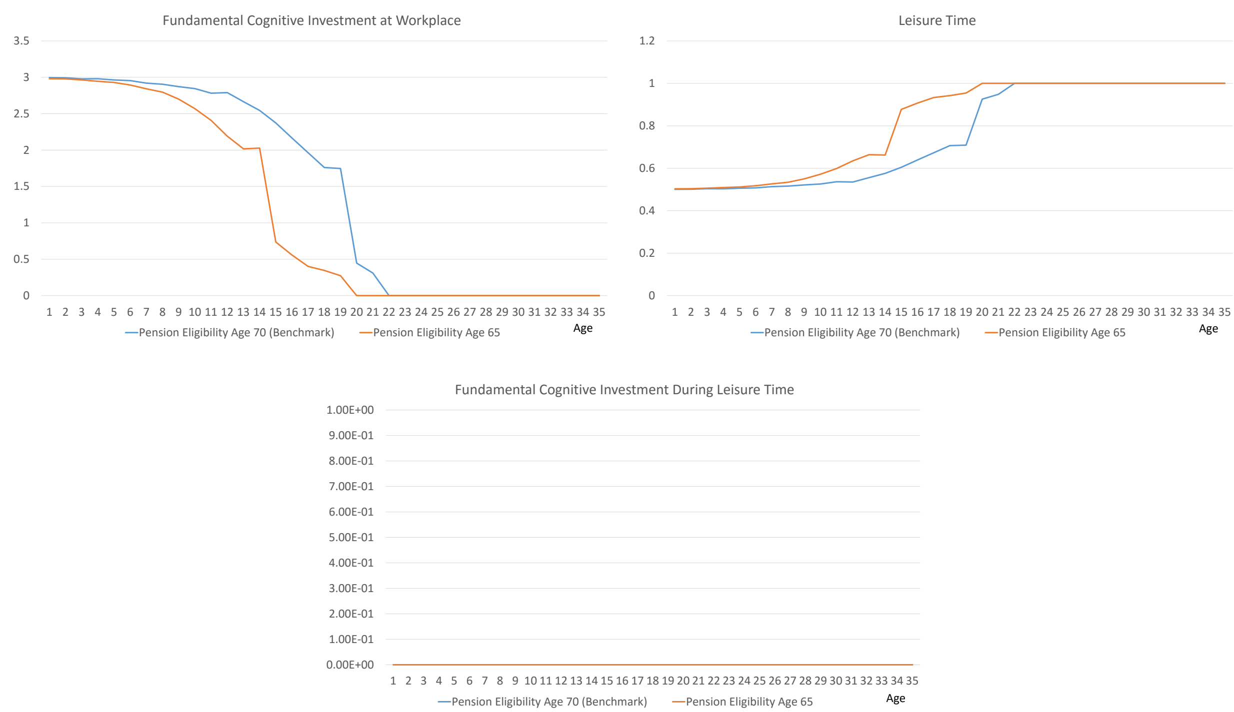


Figure 12: The Influence of the Pension Eligibility Age (Pensionable Age 70 vs Pensionable Age 65)

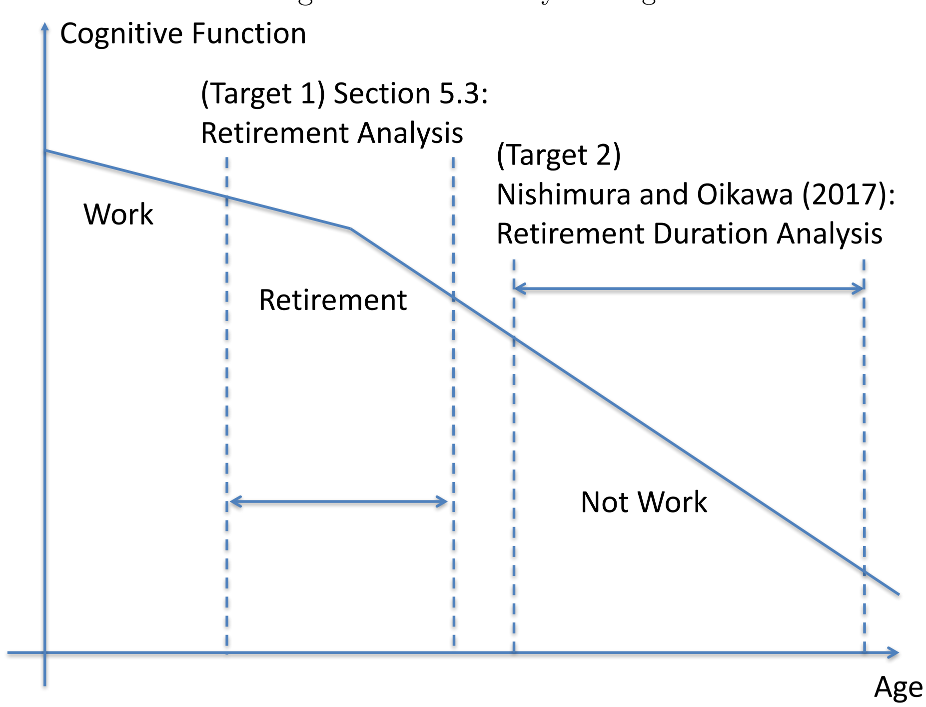


5.2 Estimation Strategy

In this section, we use the dynamic variation of retirement behavior on cognitive function while, in section 5.3, we analyze the effect of retirement on cognitive functions in the U.S., England, France, Germany, Denmark, Korea, and Japan, as the information on the correct pension eligibility age in these countries is available. We also use the exogenous variation of whether a respondent arrives at his/her pension eligibility age to control for retirement endogeneity. We analyze the effect of **whether a respondent retires** on cognitive function in the same section.

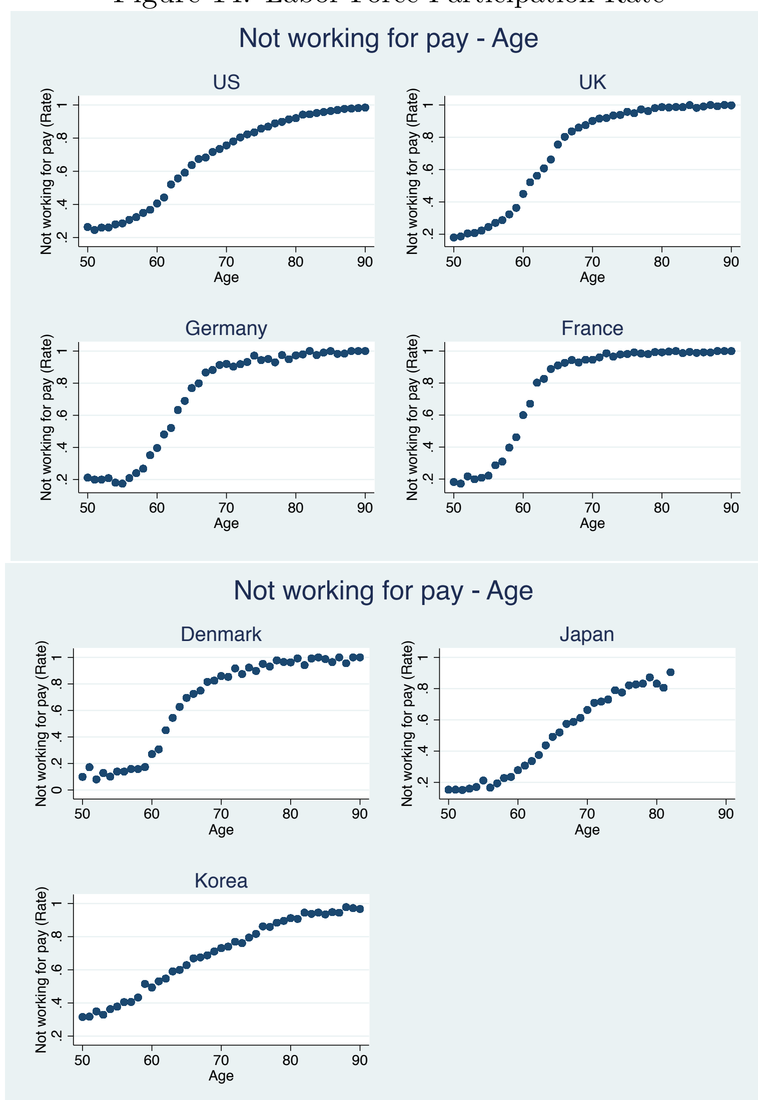
In Nishimura and Oikawa (2017), we analyze the effect of **the difference in the retirement duration** on cognitive function only in the U.S. In this analysis, we use the exogenous variation of the difference in the pension eligibility age among different cohorts, which determines retirement timing. We use this variation for retirement duration in our analysis. In this section, we analyze only the U.S. To analyze the effect of retirement duration on cognitive function, we have to use the exogenous variation of the difference in the pension eligibility age among different cohorts which can be obtained solely for the U.S. Figure 13 shows the targets of our analysis and describes the goal of each section. We split our analysis into two parts after this section: first, we analyze the effect of the transition from working to retirement status on cognitive function; second, we analyze the effect of retirement duration on cognitive function scores (with respect to retirees only).

Figure 13: The Analysis Targets



As per Figure 14, there are two retirement stages in all countries. From 50 to 70, the elderly start to retire having a comparatively short retirement duration. From 70 to 80, almost all elderly retire. The elderly aged more than 70 have a long retirement duration. As such, we analyze the effect of retirement on cognitive ability separately in these two stages. However, related studies do not analyze the elderly over 80 (Table 11), and only the first stage of retirement (comparatively short retirement duration). We add the analysis of the second stage of retirement. However, in the second stage, there are few elderly who do not retire. We focus on the effect of the difference in the retirement duration on cognitive ability only among retirees.

Figure 14: Labor Force Participation Rate



In the section 5.1., we discussed the following heterogeneity aspects on which base our empirical analysis:

Table 11: Age Range in The Related Literatures

The Literatures Using Panel Structure	Age Range
Bonsang et al. (2012)	51-75
Coe et al. (2012)	Less than 80
Mazzonna and Peracchi (2012)	50-70

- The influence of the difference in preference to cognitive ability;
- The influence of the difference in initial cognitive ability level;
- The influence of the difference in technological factors of cognitive ability production function.

We find that the above heterogeneities can influence the heterogeneities of investment behaviors during leisure time. In the empirical analysis, we consider the heterogeneity of the initial cognitive score (initial cognitive ability), of activities during leisure time, and of individual characteristics (e.g., gender, which is a technological factor of the cognitive ability production function). However, we do not observe the preference for cognitive ability but we consider the transition of leisure time activity before and after retirement. However, the initial cognitive ability level and some technological factors are observed. Subsequently, we separate the sample depending on the heterogeneity of observable characteristics, which allows us to control for the direct effect by controlled heterogeneity of cognitive investment behaviors. However, some characteristics we consider for the separation of the sample (e.g., BMI) are difficult to interpret. For example, we could not determine which factor (preference, initial cognitive ability, technology) BMI describes. This is a limitation of the analysis.

The HRS collects the Consumption and Activities Mail Survey (CAMS). Section A of the CAMS explains that "The activities component of the CAMS allows for describing activity patterns and permits the investigation of different types of activities and how specific types of activities are affected by health, family, and economic transitions in later life and, in turn, how activities affect health and well-being." [21] We use the CAMS data of the time consumed in leisure activities of a respondent before and after retirement.

The importance of the effect of retirement on cognitive function heterogeneity is significant. We only analyze the effect of retirement on cognitive function for individual countries. Therefore, we cannot derive a general conclusion with respect to the effect of retirement on cognitive function, as results may vary according to the analyzed country. However, this effect can be analyzed for other countries if data variation to identify the effect of retirement on cognitive function is employed and a panel dataset with enough waves for long-term analysis is used. If we can obtain the variation of the change in pension eligibility age among different cohorts, we can analyze the effect of retirement on cognitive function in both frameworks of this paper (retirement analysis and retirement duration analysis). When we use panel data with enough waves, including respondents who have different pension eligibility ages in some countries, we can analyze the effect of retirement on cognitive function in these countries.

[21] Refer to the website at https://ssl.isr.umich.edu/hrs/filedownload2.php?d=522 for further details.

We expect future research to consider the importance of the heterogeneity of the effect of retirement on cognitive function in countries other than those analyzed in this paper.

5.3 Retirement Analysis

5.3.1 Analysis Framework

As discussed in section 4, the country heterogeneity cannot be ignored. As a result, we analyze each country, while omitting the unobserved heterogeneity. Our analysis includes the U.S., England, France, Germany, Denmark, Korea, and Japan because the correct information on the pension eligibility age and the number of waves of datasets for dynamic analysis are available. The identification strategy in this section is to use the variation of whether a respondent arrives at the pension eligibility age: we analyze the effect of **whether a respondent retires** on cognitive function. We use the fundamental cognitive ability equation in the model (3) and derive the following equation from the fundamental cognitive ability equation.

$$a_t^f = A_f(t, i_{Wt}^f, i_{Lt}^f, X_{ft}) = \alpha_0 + \alpha_1 i_{Wt}^f + \alpha_2 i_{Lt}^f + \gamma' X_{ft} + \epsilon_{ft} \tag{5}$$

Let $a_t^f = cognition\_score_{it} + \tilde{\epsilon}_{1t}$ and $\alpha_1 i_{Wt} + \alpha_2 i_{Lt} = \beta retire_{it} + \tilde{\epsilon}_{2t}$. $cognition\_score_{it}$ is cognitive test scores. $retire_{it}$ is an indicator of whether a respondent retires. In other words, a cognitive score is a proxy of cognitive ability, and retirement status is a proxy of a cognitive ability investment activity. Finally, we derive the following equation from equation (5).

$$cognition\_score_{it} = \alpha_0 + \beta retire_{it} + \gamma' X_{ft} + \epsilon_{ft} - \tilde{\epsilon}_{1t} + \tilde{\epsilon}_{2t}$$

We estimate the following equation.

$$\begin{aligned} cognition\_score_{it} &= \beta_0 + \beta_1 retire_{it} + \gamma' x_{it} + a_{1i} + \lambda_{1t} + \epsilon_{1it} & (6) \\ retire_{it} &= \alpha_0 + \alpha_1 1\{age_{it} \geq A_i^{eb}\} + \alpha_2 1\{age_{it} \geq A_i^{fb}\} \\ +\alpha_1 1\{age_{it} \geq A_i^{eb}\} age_{it} &+ \alpha_2 1\{age_{it} \geq A_i^{fb}\} age_{it} + \eta' x_{it} + a_{2i} + \lambda_{2t} + \epsilon_{2i} & (7) \\ A_i^{eb}&: \text{the early retirement benefit eligibility age} \\ A_i^{fb}&: \text{the full retirement benefit eligibility age} \end{aligned}$$

$retire_{it}$ is an indicator equal to one when a respondent retires at period t. λ_{1t} and λ_{2t} are time fixed effects. a_{1i} and a_{2i} are individual fixed effects. x_{it} are control variables at period t.

As discussed in section 4.2., with respect to the control variables included in the estimation model, what should be included is difficult to determine. As in section 4, we include demographic factors, such as gender, family structure, and economic variables, in the estimation model to control for the fundamental social factors that influence human behavior.

There are two ways to we define whether "a respondent retires." The first definition of retirement is based on the self-reported retirement status. In the first definition, we define that "a respondent retire" when "self-reported retire" variable is equal to the value of one. This is the same definition of retirement "self-reported retire" in the section 3.1 (the definition based on the variable "r@lbrf"). See the detail of the footnote 11. Some studies use the self-reported information. (Coe et al. (2012) and Mazzonna and Peracchi (2012)) The second definition is that "a respondent retire" when a respondent does not work for pay. This definition is the most popular in the previous studies.[22] We do not follow any definition used in the literatures. We define that "a respondent retire" when a respondent do "not work for pay" and "self-reported retire." We call this retirement definition "complete retire." We use the definition of complete retire, since using "self-reported retirement" could include samples working for payment although retired who invest in cognitive abilities, sample which we omit. On the other hand, if we use the definition of not work for pay, the sample looking for jobs may also invest more than retirees. We also omit these samples.

The analyzed age range for each country is shown in Table 12. We choose these age ranges of each country based on Figure 14, based on whether a respondent retires, among same age respondents. For example, in France, most people do not work for pay at 70, thus showing no variation in whether a respondent retires among respondents above 70. However, some Japanese people still work at 80. Finally, we analyze only the samples who do not conform to complete retire at least once in this analysis, because we want to omit the respondents who both have not worked for pay and retired at an early age.

Table 12: Age Range for Retirement Analysis

Country	Age range
US	50-79
England	50-69
Germany	50-69
France	50-69
Denmark	50-69
Japan	50+
Korea	50-79

As in section 5.1, the heterogeneity of the model produces the heterogeneous transition pattern of cognitive investment during leisure time before and after retirement. We consider the heterogeneity of the transition pattern of cognitive investment during leisure time. In all analyzed countries, there is a question on social attendance in the surveys. We use this variable to obtain information about transition before and after retirement. Especially in the U.S., we can obtain detailed information on the amount of time spent in each activity from the Consumption and Activities Mail Survey (CAMS). We show the transition of time spent in each activity before and after retirement in Table 13. In almost all activities, there

[22]Many studies use this definition. For example, Rohwedder and Willis (2010), Coe and Zamarro (2011), Bonsang et al. (2012), Bingley and Martinello (2013), Hashimoto (2013) and Hashimoto (2015).

is a difference before and after retirement, with the hours of watching TV showing the most significant change. The time spent using computer decreases after retirement as a direct result of it, as the elderly use computers in their offices otherwise. We pay attention to the heterogeneity of time spent watching TV and time spent for social attendance before and after retirement in the U.S. Certain studies (Eskelinen et al. (2008), Devore et al. (2009)) report that there is a relationship between fat intake and cognitive function. As such, we consider the heterogeneity of BMI and the amount of fat intake, using the 2013 dataset of the Health Care and Nutrition Study, although the year of the survey is not consistent with our analysis years. However, we consider that the amount of fat intake in 2013 is a proxy of the amount of fat intake in other years. However, it is possible that the amount of fat intake during the lifetime of the respondents forms a technological factor of a cognitive decline, while BMI is also a proxy of a cognitive decline technological factor. These heterogeneities are not analyzed in extant studies.

Table 13: The Amount of Time Spent in Each Activity Before and After Retirement (Hours)

Activities	**(1) Not retired**	**(2) Retired**	**(3) (2)-(1)**
Working for pay	3.9	0.1	-3.8
Using the computer	1.7	0.6	-1.1
Wacthing TV	2.5	3.4	0.9
Walking	1.1	0.8	-0.3
Attending social activities	2	2.2	0.2
Reading newspapers	0.6	0.8	0.2
Listening to music	1.1	0.9	-0.2
House cleaning	0.6	0.8	0.2
Preparing meals and cleaning-up afterwards	0.8	1	0.2
Sleeping and napping	6.7	6.6	-0.1
Visiting in-person with friends	1	1.1	0.1
Washing, ironing, or mending clothes	0.3	0.4	0.1
Yard work or gardening	0.3	0.4	0.1
Playing cards or games, or solving puzzles	0.1	0.2	0.1
Reading books	0.5	0.6	0.1
Praying or meditating	0.5	0.6	0.1
Shopping or running errands	0.5	0.6	0.1
Physically showing affection	0.5	0.4	-0.1
Treating or managing an existing medical condition	0.2	0.3	0.1
Participating sports	0.3	0.3	0
Communicating by phone,letters, e-mail	0.8	0.8	0
Personal grooming	1	1	0
Caring for pets	0.4	0.4	0
Helping friends	0.2	0.2	0
Doing volunteer work	0.1	0.1	0
Attending religious services	0.1	0.1	0
Attending meetings of clubs or religious groups	0.1	0.1	0
Taking care of finances or investments	0.1	0.1	0
Attending concerts, movies	0	0	0
Singing or playing a musical instrument	0	0	0
Doing arts and crafts projects	0.1	0.1	0
Doing home improvements	0.1	0.1	0

5.3.2 Results

We discuss the estimated results only when the coefficients of IV in the first stage are significant, and analyze only male elderly in Japan because we cannot obtain the significant results in the first stage estimation when we include female elderly. We also test the endogeneity of retirement with the DWH test. When we do not reject the null hypothesis, we support the results of fixed effects (FE) model. "IV-bi-E(N)" is dummy that indicates whether a respondent reaches pensionable age. "IV-bi-E(N)-Age" is a cross term of the variable "IV-bi-E(N)" and age.

- Full sample: in Table 14, we show the results of full sample. First, in many countries, we do not find a negative effect of retirement on cognitive function. However, in the U.S., there is a negative effect of retirement on cognitive function in both scores (word recall summary and serial 7s). In Korea, only in serial 7s there is a negative effect of retirement on cognitive function. As such, it is possible that the effect of retirement on cognitive function is heterogeneous depending on the analyzed countries. Although the effect of retirement on cognitive function is negative, the magnitude is very small.

- Heterogeneity of characteristics: in Tables 15, 16, and 17, we show the results of heterogeneous groups by types of cognitive function scores:

  - Word recall summary scores: are presented in in Tables 15 and 16. In the U.S., there is a negative effect of retirement on word recall summary scores in almost all groups. However, in other countries, the effect is heterogeneous among different groups. In the U.S., the magnitude is very similar among heterogeneous groups. This suggests that the difference in the characteristics considered in Tables 15 and 16 is not important for explaining the effect of retirement on the score in the U.S. The magnitude is also limited in all groups. In Korea, we can find that the effect of retirement on the score is negative only in female and male groups. However, the effect is weak. Except for the U.S. and Korea, we do not find that there is a heterogeneous effect of retirement on the score when controlling for retirement endogeneity and omitting the unobserved heterogeneity. In England, there is a positive effect of retirement on the score in some groups (WR: England LTC, WR: England Initial score-, Initial score+). In France, Germany and Denmark, in almost all groups, there is no effect of retirement on the score except for the blue-collar group (WR: France Blue, WR: Germany Blue).
  - Serial 7 and backward counting: in Table 17, we show the results of serial 7s score and backward counting, although not available in the SHARE and the ELSA. We only show the results for the U.S, Korea, and Japan. In the serial 7s score, there is a negative effect of retirement on the score among almost all groups in all countries. However, there is no effect of retirement on the score in the elderly with college degree in all countries. In backward counting, there is no effect of retirement on the score in the U.S. among all groups.

- Heterogeneity of leisure time, fat intake, and BMI: in Tables 18, 19, and 20, we show the results of the word recall summary score, serial 7s score, and backward counting, considering the heterogeneity of activities during leisure time, BMI, and fat intake. "SAInc" ("SANInc") means that the elderly increase (do not increase) their social attendance immediately after retirement. We can define both "TVNInc" and "TVInc" similarly. "TVInc_SANinc" describes that the elderly increase the amount of time spent watching TV and do not increase social attendance. This is prepared for separating the sample based on the heterogeneity of leisure time in more detail. Watching TV is one of the fluctuating factors in the category of time spent before and after retirement. With respect to social attendance, it seems that there is not a systematic difference in the effect of retirement on the score among different groups, considering the heterogeneity of leisure time activity. In Table 18, the elderly who increase social attendance decrease Word Recall Summary Score after retirement. In Table 19, there is also not a systematic difference in the effect of retirement on the score. It is possible that social attendance does not cause effect of retirement on the cognitive score heterogeneity. It may be difficult to interpret social attendance as an investment behavior on cognitive function. In Table 18, the elderly with "BMI25-" identifies the elderly who have a BMI value lower than 25 at the first response, and "BMI25+" represents the elderly who have a BMI value above 25 at the first response. "Fat-" identifies the elderly whose fat intake is less than the 2013 median, while "Fat+" is for the elderly whose fat intake is above the 2013 median. According to Table 20, it is possible that BMI and fat intake are sources of heterogeneity of the effect of retirement on cognitive function. In the word recall summary score, both "BMI25+" and "BMI25-" indicate a negative effect of retirement on cognitive function. However, the magnitude of "BMI25+" is larger than that of "BMI25-"(WR: US, BMI25-, BMI25+). In the serial 7's score, only "BMI25+" and "Fat+" indicate the negative effect of retirement on cognitive function(S7: US, BMI25+, Fat+).

Finally, we interpret the estimated results based on the analysis in section 5.1. We have considered the effect of retirement on cognitive scores from the following points:

- (1) The Influence of the Difference in Preference to Cognitive Ability
- (2) The Influence of the Difference in Initial Cognitive Ability Level
- (3) The Influence of the Difference in Technological Factor of Cognitive Ability Production Function

With respect to (2), an initial cognitive ability is not a systematic factor for deciding the heterogeneity of the effect of retirement on cognitive ability according to our analysis, because the heterogeneity of initial cognitive ability is important only in the U.S. With respect to (3), gender difference, as an example of technological factors does not seem to be a systematic factor that produces the heterogeneity of the effect of retirement on cognitive ability. According to our analysis, the heterogeneity of the analyzed country seems more important than the heterogeneity of the analyzed group. In the U.S., almost all groups indicate an negative effect of retirement on cognitive score in word recall summary score and serial 7's. Based on the results of BMI and fat intake, eating habits may be an important factor in explaining the heterogeneity of the effect of retirement on cognitive function. Eating habits are heterogeneous in each country.

Finally, we consider what fat intake and BMI describe. The first possibility is a proxy of preference. Based on model (3), the investment behaviors after retirement depend on the preference of cognitive ability. The second possibility is a technological factor that influences the effect of cognitive investment behaviors on cognitive function. The following is an example:

$$A_m(t, i_{Wt}^m, i_{Lt}^m, X_{mt}) = (\alpha_1 i_{Wt}^m + \alpha_2 i_{Lt}^m) \cdot BMI + \alpha_3 Hetro_1 + \alpha_4 Hetro_2 + A_{m0} \exp(-t)$$
$$(\alpha_1 > 0, \alpha_2 > 0)$$

Table 14: Retirement Analysis (Full Sample): Word Recall Summary Score, Serial7's Backward Counting

	WR: US		WR: England		WR: France		WR: Germany		WR: Denmark		WR: Korea	
	Full		Full		Full		Full		Full		Full	
1st stage												
IV-bi-E		0.074***				0.172***		0.119***		-0.016		-0.974**
		(0.008)				(0.038)		(0.043)		(0.028)		(0.443)
IV-bi-N		1.192***		0.171***		5.091***		0.354		3.725***		-0.039**
		(0.232)		(0.011)		(1.934)		(1.691)		(1.361)		(0.020)
IV-bi-E - Age												0.017**
												(0.008)
IV-bi-N - Age		-0.018***		0.000		-0.078***		-0.005		-0.057***		
		(0.004)		(0.000)		(0.030)		(0.026)		(0.021)		
2nd stage												
Complete retire	-0.149***	0.099	0.067	0.467	0.018	-0.477	-0.144	0.612	-0.200	2.053	-0.098***	2.326**
	(0.029)	(0.318)	(0.056)	(0.397)	(0.167)	(0.817)	(0.201)	(1.903)	(0.195)	(2.004)	(0.029)	(1.036)
Observations	70542	70542	23923	23923	3998	3998	2365	2365	3497	3497	14127	14127
DWHpval		0.402		0.305		0.549		0.693		0.224		0.019

	S7: US		BWC: US		S7: Korea	
	Full		Full		Full	
1st stage						
IV-bi-E		0.074***		0.074***		-0.974**
		(0.008)		(0.008)		(0.443)
IV-bi-N		1.192***		1.192***		-0.039**
		(0.232)		(0.232)		(0.020)
IV-bi-E - Age						0.017**
						(0.008)
IV-bi-N - Age		-0.018***		-0.018***		
		(0.004)		(0.004)		
2nd stage						
Complete retire	-0.028**	-0.305**	-0.001	0.017	-0.122***	0.614
	(0.013)	(0.137)	(0.002)	(0.023)	(0.032)	(1.140)
Observations	70542	70542	70542	70542	14129	14129
DWHpval		0.042		0.480		0.518

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 15: Retirement Analysis (By Group): Word Recall Summary Score

	WR: US		WR: England		WR: France						WR: Korea	
	Male		Male		Male						Male	
1st stage												
IV-bi-E		0.091***				0.183***						-1.613***
		(0.011)				(0.049)						(0.511)
IV-bi-N		1.160***		0.174***		-0.142*						-0.030
		(0.342)		(0.019)		(0.085)						(0.024)
IV-bi-E - Age												0.029***
												(0.009)
IV-bi-N - Age		-0.017***		-0.000								
		(0.005)		(0.000)								
2nd stage												
Complete retire	-0.121***	-0.727	-0.022	-0.415	-0.217	-0.935					-0.130***	0.538
	(0.044)	(0.458)	(0.083)	(0.663)	(0.251)	(1.296)					(0.043)	(0.862)
Observations	31551	31551	11645	11645	1877	1877					8149	8149
DWHpval		0.186		0.557		0.562						0.436

	WR: US		WR: England		WR: France		WR: Germany		WR: Denmark		WR: Korea	
	Female		Female		Female		Female		Female		Female	
1st stage												
IV-bi-E		0.060***				0.205***		0.161**		-0.030		-0.049*
		(0.010)				(0.052)		(0.065)		(0.043)		(0.029)
IV-bi-N		1.251***		0.163***		4.847*		0.887		5.589***		-0.049*
		(0.317)		(0.014)		(2.667)		(2.835)		(2.104)		(0.028)
IV-bi-N - Age		-0.018***		0.000		-0.073*		-0.014		-0.085***		
		(0.005)		(0.000)		(0.041)		(0.044)		(0.032)		
2nd stage												
Complete retire	-0.168***	0.661	0.124*	0.679	0.174	-0.478	0.085	1.144	-0.257	0.498	-0.069*	-0.008
	(0.040)	(0.450)	(0.075)	(0.551)	(0.223)	(1.080)	(0.249)	(1.640)	(0.280)	(1.865)	(0.041)	(1.104)
Observations	38991	38991	12278	12278	2121	2121	1265	1265	1735	1735	5978	5978
DWHpval		0.050		0.293		0.535		0.464		0.701		0.956

	WR: US		WR: England		WR: France		WR: Germany		WR: Denmark		WR: Korea	
	LTC		LTC		LTC		LTC		LTC		LTC	
1st stage												
IV-bi-E		0.081***				0.221***		0.167***		0.036		-0.807*
		(0.009)				(0.050)		(0.059)		(0.040)		(0.471)
IV-bi-N		1.288***		0.203***		3.584		0.409		3.608*		-0.034
		(0.271)		(0.013)		(2.699)		(2.159)		(2.026)		(0.021)
IV-bi-E - Age												0.014*
												(0.008)
IV-bi-N - Age		-0.019***		0.000		-0.055		-0.007		-0.054*		
		(0.004)		(0.000)		(0.041)		(0.033)		(0.031)		
2nd stage												
Complete retire	-0.138***	0.180	0.092	0.547	-0.001	-0.448	-0.091	0.890	-0.115	1.895	-0.103***	2.792**
	(0.033)	(0.339)	(0.066)	(0.396)	(0.214)	(1.002)	(0.220)	(1.561)	(0.263)	(1.949)	(0.031)	(1.283)
Observations	53319	53319	16079	16079	2500	2500	1541	1541	1710	1710	12683	12683
DWHpval		0.335		0.250		0.634		0.517		0.276		0.024

	WR: US		WR: England		WR: France				WR: Denmark		WR: Korea	
	College		College		College				College		College	
1st stage												
IV-bi-E		0.050***				0.081				-0.063*		-2.797**
		(0.015)				(0.066)				(0.038)		(1.346)
IV-bi-N		0.922**		0.080***		8.519***				3.828**		-0.080
		(0.448)		(0.025)		(3.115)				(1.818)		(0.060)
IV-bi-E - Age												0.050**
												(0.024)
IV-bi-N - Age		-0.014**		-0.000		-0.132***				-0.059**		
		(0.007)		(0.000)		(0.048)				(0.028)		
2nd stage												
Complete retire	-0.179***	-0.306	-0.001	-0.538	0.163	0.288			-0.238	1.624	-0.061	-0.011
	(0.064)	(0.882)	(0.128)	(2.158)	(0.304)	(1.408)			(0.283)	(3.088)	(0.091)	(1.080)
Observations	17209	17209	5075	5075	1213	1213			1779	1779	1439	1439
DWHpval		0.926		0.903		0.906				0.542		0.964

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 16: Retirement Analysis (By Group): Word Recall Summary Score

	WR: US		WR: England		WR: France		WR: Germany		WR: Denmark		WR: Korea	
	White		White		White		White		White		White	
1st stage												
IV-bi-E		0.058***				0.149***		0.143***		-0.069**		-2.250***
		(0.009)				(0.044)		(0.049)		(0.029)		(0.754)
IV-bi-N		1.023***		0.144***		7.105***		0.226		3.459**		-0.075**
		(0.278)		(0.015)		(2.651)		(2.080)		(1.542)		(0.033)
IV-bi-E - Age												0.040***
												(0.013)
IV-bi-N - Age		-0.015***		0.000		-0.110***		-0.002		-0.053**		
		(0.004)		(0.000)		(0.041)		(0.032)		(0.024)		
2nd stage												
Complete retire	-0.170***	-0.446	0.034	0.029	0.186	-1.284	-0.053	0.764	-0.023	-0.831	-0.049	0.036
	(0.037)	(0.432)	(0.078)	(0.666)	(0.247)	(1.138)	(0.287)	(1.808)	(0.260)	(2.556)	(0.050)	(0.805)
Observations	47517	47517	12435	12435	2517	2517	1445	1445	2649	2649	4794	4794
DWHpval		0.560		0.930		0.162		0.750		0.790		0.917

	WR: US		WR: England		WR: France		WR: Germany	
	Blue		Blue		Blue		Blue	
1st stage								
IV-bi-E		0.108***				0.107		0.142*
		(0.016)				(0.072)		(0.082)
IV-bi-N		1.757***		0.196***		7.235*		-7.600**
		(0.473)		(0.016)		(3.814)		(3.214)
IV-bi-N - Age		-0.027***		0.000		-0.108*		0.119**
		(0.007)		(0.000)		(0.058)		(0.049)
2nd stage								
Complete retire	-0.061	0.264	0.111	0.771	-0.772*	-2.721	-1.148**	0.287
	(0.059)	(0.481)	(0.079)	(0.493)	(0.407)	(2.019)	(0.540)	(2.856)
Observations	17315	17315	11407	11407	906	906	521	521
DWHpval		0.504		0.174		0.352		0.574

	WR: US		WR: England		WR: Germany	
	Initial score-		Initial score-		Initial score-	
1st stage						
IV-bi-E		0.069***				0.210**
		(0.017)				(0.085)
IV-bi-N		1.847***		0.156***		-0.042
		(0.560)		(0.019)		(4.851)
IV-bi-N - Age		-0.028***		0.000		0.004
		(0.009)		(0.000)		(0.074)
2nd stage						
Complete retire	-0.244***	-0.998	0.091	1.838**	0.297	3.636
	(0.059)	(0.660)	(0.099)	(0.803)	(0.501)	(2.622)
Observations	15733	15733	7342	7342	501	501
DWHpval		0.227		0.031		0.119

	WR: US		WR: England		WR: France		WR: Germany	
	Initial score+		Initial score+		Initial score+		Initial score+	
1st stage								
IV-bi-E		0.057***				0.260***		0.239**
		(0.012)				(0.083)		(0.093)
IV-bi-N		1.319***		0.180***		1.079		15.366**
		(0.396)		(0.016)		(5.167)		(7.445)
IV-bi-N - Age		-0.020***		0.000		-0.017		-0.236**
		(0.006)		(0.000)		(0.079)		(0.114)
2nd stage								
Complete retire	-0.170***	-0.370	0.060	1.129**	-0.325	-1.664	-0.182	-0.899
	(0.047)	(0.636)	(0.077)	(0.542)	(0.342)	(1.753)	(0.490)	(1.236)
Observations	28451	28451	11868	11868	1024	1024	512	512
DWHpval		0.831		0.042		0.428		0.323

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 17: Retirement Analysis (By Group): Serial7's and Backward Counting

	S7: US Male		S7: US Female		S7: Japan Male		S7: Korea Male		S7: Korea Female		BWC: US Male		BWC: US Female	
1st stage														
IV-bi-E		0.091***		0.060***				-1.614***		0.008		0.091***		0.060***
		(0.011)		(0.010)				(0.511)		(0.775)		(0.011)		(0.010)
IV-bi-N		1.160***		1.251***		-1.786**		-0.030		-0.047		1.160***		1.251***
		(0.342)		(0.317)		(0.905)		(0.024)		(0.033)		(0.342)		(0.317)
IV-bi-E - Age								0.029***		-0.001				
								(0.009)		(0.014)				
IV-bi-N - Age		-0.017***		-0.018***		0.029**		-0.017***		-0.018***				
		(0.005)		(0.005)		(0.014)		(0.005)		(0.005)				
2nd stage														
Complete retire	-0.014	-0.027	-0.037**	-0.443**	-0.169*	-0.118	-0.133***	1.161	-0.101**	0.578	-0.000	0.049	-0.001	-0.015
	(0.018)	(0.184)	(0.017)	(0.201)	(0.089)	(0.927)	(0.046)	(0.908)	(0.046)	(1.200)	(0.003)	(0.034)	(0.003)	(0.033)
Observations	31551	31551	38991	38991	2299	2299	8151	8151	5978	5978	31551	31551	38991	38991
DWHpval		0.941		0.041		0.919		0.154		0.571		0.159		0.661

	S7: US LTC		S7: US College		S7: Japan College		S7: Korea LTC		S7: Korea College		BWC: US LTC		BWC: US College	
1st stage														
IV-bi-E		0.081***		0.050***				-0.807*		-2.797**		0.081***		0.050***
		(0.009)		(0.015)				(0.471)		(1.346)		(0.009)		(0.015)
IV-bi-N		1.288***		0.922**		-3.403**		-0.034		-0.080		1.288***		0.922**
		(0.271)		(0.448)		(1.682)		(0.021)		(0.060)		(0.271)		(0.448)
IV-bi-E - Age								0.014*		0.050**				
								(0.008)		(0.024)				
IV-bi-N - Age		-0.019***		-0.014**		0.054**		-0.019***		-0.014**				
		(0.004)		(0.007)		(0.027)		(0.004)		(0.007)				
2nd stage														
Complete retire	-0.026*	-0.342**	-0.028	-0.032	0.007	0.269	-0.134***	0.717	0.002	0.701	0.000	-0.003	-0.004	0.116**
	(0.014)	(0.153)	(0.025)	(0.313)	(0.207)	(1.084)	(0.035)	(1.422)	(0.076)	(1.058)	(0.003)	(0.026)	(0.004)	(0.055)
Observations	53319	53319	17209	17209	505	505	12685	12685	1439	1439	53319	53319	17209	17209
DWHpval		0.038		0.969		0.815		0.549		0.507		0.881		0.026

	S7: US White		S7: US Blue		S7: Japan Blue		S7: Korea White		S7: Korea Blue		BWC: US White		BWC: US Blue	
1st stage														
IV-bi-E		0.058***		0.108***				-2.250***		0.229		0.058***		0.108***
		(0.009)		(0.016)				(0.754)		(0.564)		(0.009)		(0.016)
IV-bi-N		1.023***		1.757***		-2.917**		-0.075**		-0.006		1.023***		1.757***
		(0.278)		(0.473)		(1.344)		(0.033)		(0.025)		(0.278)		(0.473)
IV-bi-E - Age								0.040***		-0.004				
								(0.013)		(0.010)				
IV-bi-N - Age		-0.015***		-0.027***		0.048**		-0.015***		-0.027***				
		(0.004)		(0.007)		(0.021)		(0.004)		(0.007)				
2nd stage														
Complete retire	-0.025	-0.338*	-0.054**	-0.054	-0.280**	0.497	-0.086*	0.730	-0.115***	-2.392	0.000	0.027	-0.002	-0.001
	(0.015)	(0.181)	(0.026)	(0.225)	(0.139)	(0.992)	(0.049)	(0.847)	(0.044)	(3.753)	(0.003)	(0.030)	(0.005)	(0.041)
Observations	47517	47517	17315	17315	1021	1021	4794	4794	8544	8544	47517	47517	17315	17315
DWHpval		0.080		0.990		0.423		0.333		0.543		0.405		0.985

	S7: US Initial score-		S7: US Initial score+	
1st stage				
IV-bi-E		0.076***		0.054***
		(0.018)		(0.012)
IV-bi-N		2.694***		0.953**
		(0.594)		(0.384)
IV-bi-N - Age		-0.041***		-0.014**
		(0.009)		(0.006)
2nd stage				
Complete retire	-0.095***	-0.100	-0.009	-0.435
	(0.031)	(0.286)	(0.018)	(0.279)
Observations	14192	14192	29992	29992
DWHpval		0.974		0.101

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 18: Retirement Analysis (Leisure Time): Word Recall Summary, Serial7's and Backward Counting

	WR: US		WR: US		WR: England		WR: England	
	SAInc		SANInc		SAInc		SANInc	
1st stage								
IV-bi-E		0.051^{**}		0.083^{***}				
		(0.021)		(0.022)				
IV-bi-N		0.041^{*}		0.035		0.158^{***}		0.159^{***}
		(0.023)		(0.023)		(0.033)		(0.017)
IV-bi-N - Age						0.000		-0.000
						(0.001)		(0.000)
2nd stage								
Complete retire	-0.277^{**}	0.217	0.062	2.040	-0.097	-2.898^{**}	0.081	0.793
	(0.124)	(2.129)	(0.131)	(1.588)	(0.195)	(1.364)	(0.107)	(0.732)
Observations	3935	3935	3842	3842	1640	1640	5732	5732
DWHpval		0.821		0.198		0.021		0.339

	S7: US		S7: US	
	SAInc		SANInc	
1st stage				
IV-bi-E		0.051^{**}		0.083^{***}
		(0.021)		(0.022)
IV-bi-N		0.041^{*}		0.035
		(0.023)		(0.023)
2nd stage				
Complete retire	-0.001	-0.756	-0.021	0.209
	(0.052)	(0.961)	(0.057)	(0.673)
Observations	3935	3935	3842	3842
DWHpval		0.438		0.760

	BWC: US		BWC: US	
	SAInc		SANInc	
1st stage				
IV-bi-E		0.051^{**}		0.083^{***}
		(0.021)		(0.022)
IV-bi-N		0.041^{*}		0.035
		(0.023)		(0.023)
2nd stage				
Complete retire	-0.009	-0.229	-0.002	-0.159
	(0.009)	(0.177)	(0.011)	(0.119)
Observations	3935	3935	3842	3842
DWHpval		0.145		0.173

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 19: Retirement Analysis (Leisure Time): Word Recall Summary, Serial7's and Backward Counting

	WR: US		WR: US		WR: US		WR: US	
	TVInc		TVInc_SANInc		TVNInc		TVNInc_SAInc	
1st stage								
IV-bi-E		0.076***		0.077*		0.047**		0.064**
		(0.020)		(0.040)		(0.022)		(0.031)
IV-bi-N		0.051**		1.260		0.014		0.039
		(0.022)		(1.258)		(0.023)		(0.033)
IV-bi-N - Age				-0.019				
				(0.019)				
2nd stage								
Complete retire	0.070	0.857	0.295*	1.965	-0.383***	2.101	-0.455**	-1.388
	(0.121)	(1.430)	(0.172)	(1.575)	(0.130)	(3.122)	(0.180)	(2.718)
Observations	4291	4291	2095	2095	3801	3801	1844	1844
DWHpval		0.591		0.258		0.403		0.701
	S7: US		S7: US		S7: US		S7: US	
	TVInc		TVInc_SANInc		TVNInc		TVNInc_SAInc	
1st stage								
IV-bi-E		0.076***		0.077*		0.047**		0.064**
		(0.020)		(0.040)		(0.022)		(0.031)
IV-bi-N		0.051**		1.260		0.014		0.039
		(0.022)		(1.258)		(0.023)		(0.033)
IV-bi-N - Age				-0.019				
				(0.019)				
2nd stage								
Complete retire	-0.084	-0.724	-0.156**	-0.761	0.059	1.477	0.037	-0.358
	(0.051)	(0.641)	(0.074)	(0.707)	(0.056)	(1.421)	(0.075)	(1.181)
Observations	4291	4291	2095	2095	3801	3801	1844	1844
DWHpval		0.338		0.376		0.267		0.735
	BWC: US		BWC: US		BWC: US		BWC: US	
	TVInc		TVInc_SANInc		TVNInc		TVNInc_SAInc	
1st stage								
IV-bi-E		0.076***		0.077*		0.047**		0.064**
		(0.020)		(0.040)		(0.022)		(0.031)
IV-bi-N		0.051**		1.260		0.014		0.039
		(0.022)		(1.258)		(0.023)		(0.033)
IV-bi-N - Age				-0.019				
				(0.019)				
2nd stage								
Complete retire	-0.001	-0.198*	0.003	-0.125	-0.011	-0.109	-0.016	-0.158
	(0.009)	(0.110)	(0.014)	(0.115)	(0.011)	(0.237)	(0.014)	(0.226)
Observations	4291	4291	2095	2095	3801	3801	1844	1844
DWHpval		0.027		0.212		0.672		0.476

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

Table 20: Retirement Analysis (BMI and Fat intake): Word Recall Summary, Serial7's and Backward Counting

	WR: US		WR: US		WR: US		WR: US	
	BMI25-		BMI25+		Fat-		Fat+	
1st stage								
IV-bi-E		0.075***		0.074***		0.041**		0.119***
		(0.013)		(0.009)		(0.018)		(0.018)
IV-bi-N		0.630		1.466***		1.641***		-0.225
		(0.399)		(0.286)		(0.544)		(0.553)
IV-bi-N - Age		-0.009		-0.022***		-0.024***		0.004
		(0.006)		(0.004)		(0.008)		(0.009)
2nd stage								
Complete retire	-0.102*	0.006	-0.168***	0.105	-0.113	0.154	-0.048	0.196
	(0.053)	(0.577)	(0.035)	(0.379)	(0.071)	(0.765)	(0.072)	(0.667)
Observations	22572	22572	47578	47578	12030	12030	12004	12004
DWHpval		0.799		0.453		0.692		0.714

	S7: US		S7: US		S7: US		S7: US	
	BMI25-		BMI25+		Fat-		Fat+	
1st stage								
IV-bi-E		0.075***		0.074***		0.041**		0.119***
		(0.013)		(0.009)		(0.018)		(0.018)
IV-bi-N		0.630		1.466***		1.641***		-0.225
		(0.399)		(0.286)		(0.544)		(0.553)
IV-bi-N - Age		-0.009		-0.022***		-0.024***		0.004
		(0.006)		(0.004)		(0.008)		(0.009)
2nd stage								
Complete retire	-0.025	-0.351	-0.028*	-0.224	-0.016	-0.525	0.034	-0.849***
	(0.023)	(0.249)	(0.015)	(0.164)	(0.030)	(0.331)	(0.030)	(0.293)
Observations	22572	22572	47578	47578	12030	12030	12004	12004
DWHpval		0.180		0.231		0.118		0.002

	BWC: US		BWC: US		BWC: US		BWC: US	
	BMI25-		BMI25+		Fat-		Fat+	
1st stage								
IV-bi-E		0.075***		0.074***		0.041**		0.119***
		(0.013)		(0.009)		(0.018)		(0.018)
IV-bi-N		0.630		1.466***		1.641***		-0.225
		(0.399)		(0.286)		(0.544)		(0.553)
IV-bi-N - Age		-0.009		-0.022***		-0.024***		0.004
		(0.006)		(0.004)		(0.008)		(0.009)
2nd stage								
Complete retire	-0.001	0.068	-0.001	-0.006	0.007	0.057	0.010*	-0.050
	(0.004)	(0.042)	(0.003)	(0.029)	(0.005)	(0.054)	(0.005)	(0.046)
Observations	22572	22572	47578	47578	12030	12030	12004	12004
DWHpval		0.098		0.824		0.321		0.163

Standard errors in parentheses

* $p < .1$, ** $p < .05$, *** $p < .01$

6 Conclusion

In summary, the main findings of this paper are:

- Validation analysis on cross-sectional cross-country analysis: we show that the robustness is weak if we use the estimation strategy based on the cross-sectional analysis. We find that the estimated results are sensitive with respect to the heterogeneity of the set of analyzed countries. The effect of a part of the analyzed countries influences the final conclusion on the effect of retirement on cognitive function.
- Retirement analysis:

- Word recall summary score: in the U.S., there is a negative effect of retirement on word recall summary scores in almost all groups. However, in other countries, the effect is heterogeneous among different groups, and we cannot find that the effect is negative in many groups.
- Serial 7's: there is a negative effect of retirement on the score among almost all groups in all countries.
- Heterogeneity: the elderly with higher BMI and higher fat intake show negative effect of retirement on cognitive function.

Finally, we compare our results with the results of related literature in Table 21. Our results are based on "retirement analysis" (full sample).

Table 21: The Estimation Results in the Related Literatures

	Lindeboom et al.	Rohwedder and Willis	Coe and Zamarro	Behncke	Bonsang et al.	Mazzonna and Peracchi	Coe, Gaudecker, Lindeboom and Maurer	Bingley and Martinello	Motegi, Nishimura and Oikawa
	2002, Health Economics	2010, J Econ Perspectives	2011, J Health Economics	2012, Health Economics	2012, J Health Economics	2012, European Economic Review	2012, Health Economics	2013, European Economic Review	2016
cognitive functioning	negative(MMSE (tests cognitive abilities))	negative	no	negative	negative	negative	positive (blue collor) no (white collor)	negative	negative (Word Recall, US), no (Word Recall, England, Germany, France, Denmark), positive (Word Recall, Korea), negative (Serial 7, US, Korea)
Method	FE method	IV method	IV method	Nonparametric matching	FE-IV method	IV method	Generalization of 2SLS	IV method	FE-IV method
Method (details)		IVs: pension eligibility age for early and full	IVs: eligibility age for early and full retirement	Using state pension eligibility age as IV	IVs: pension eligibility age	IVs: pension eligibility age for early and full	IVs: pension eligibility age (nonparametric regression of first stage regression)	IVs: pension eligibility age for early and full	IVs: pension eligibility age for early and full
Def. of Retirement		not having worked for pay in the last 4 weeks	someone who is not in the paid labor force	retired describes her current situation best and not in paid work was her activity in the last month	not having worked for pay in the last 1 year	max {0, current age-age as retirement} including unemployment elderly as retirement	interview year-retirement year (calculating by units of month and convert to the unit of year)	not having worked for pay in the last 4 weeks	not working for pay and self-reported retire
Controls(Demog.)	age, residential area, marital status, children' health		education, marital status, children	children, birth place, residential area	age	age and education	education, race, religion and age	age, sex, and education	age, sex, family strcture and education
Controls(Economic)			income	income					income, asset
Controls(Working.)	employment status		self employment	working hours, employment status					
Controls(Health)	health								
Data	Longitudinal Aging Study Amsterdam panel 92, 95, 98	HRS ELSA SHARE at 2004	SHARE 1st-2nd wave	ELSA 1st-3rd wave	HRS 1998~2008 6 waves	SHARE 2004, 06	HRS, only male elderly born after 1931	HRS ELSA SHARE 2004	HRS 1996-2010, SHARE 2004-2012, ELSA 2002-2014, JSTAR 2007-2013, KLoSA 2006-2012
Country	Netherlands	The U.S.The U.K.EU	EU	The U.K.	The U.S.	EU	The U.S.	The U.S.The U.K.EU	The US, The UK, France, Germany, Denmark, Korea, Japan

In this paper, we show that social attendance may not be a proxy of cognitive investment behaviors, and that elderly do not change their leisure activities before and after retirement. As such, an important question is what kind of activity might be a cognitive investment behavior. Additionally, we only analyze the group and the countries where we can use the pensionable age as IV. Another instrumental variable would expand our analysis. Finally, we find that BMI and fat intake are important determinants of the effect of retirement on cognitive function heterogeneity. Consequently, this analysis should be expanded to more countries.

A Appendix

A.1 Pension Eligibility Age

Rohwedder and Willis (2010) use the pensionable age, which is based on the source from Pensions at a Glance (OECD) and Social Security Programs throughout the World: Europe, 2004. [23] We correct these pensionable ages and also add the pensionable age in 2010 for our analysis. For establishing the correct pensionable age, we use the information from the Bureau of Labor Statistics in each country, although not all are available. Subsequently, we contact with the Bureau of Labor Statistics or Bureau of Statistics directly, and obtain the information. If not, we use the OECD's Pensions at a Glance, Social Security Programs Throughout The World (Europe, Asia and the Pacific, and the Americas) and the EUs Mutual Information System in Social Protection as data sources, although detailed pension eligibility ages are still not available for many countries. Finally, the correct pension eligibility ages are obtained for the U.S., England, Germany, France, Denmark, Switzerland, Czech Republic, Estonia, Japan, China, and Korea. We do not analyze the countries where the detail information about the pension eligibility age cannot be available. We do not analyze the countries where the pension eligibility age is not available. The following tables show the eligibility ages for the countries analyzed.

[23] See the online Appendix by Rohwedder and Willis (2010) for details.

Table 22: Pensionable Age in Section 4

	2004								2010			
	R & W (2010)				MNO(2015)				MNO(2015)			
	Early		Full		Early		Full		Early		Full	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
R & W original countries												
US	62	62	65	65	62	62	65	65	62	62	66	66
UK	65	60	65	60	*1	*1	65	60	*1	*1	65	60
Austria	61	56	65	60	61+6m	56+6m	65	60	62	57+6m	65	60
Germany	60	60	65	65	60	60	65	65	63	60	65	65
Sweden	61	61	65	65	61	61	65	65	61	61	65	65
Netherlands	60	60	65	65	*1	*1	65	65	*1	*1	65	65
Spain	60	60	65	65	61	61	65	65	61	61	65	65
Italy	57	57	65	60	57	57	65	60	59	57	65	60
France	60	60	60	60	60	60	65	65	60	60	65	65
Denmark	60	60	65	65	60	60	65	65	60	60	65+6m	65+6m
Greece	60	55	62	57	55	55	65	60	60	60	65	65
Switzerland	63	62	65	63	63	61	65	63	63	62	65	64
Belgium	60	60	65	63	60	60	65	63	60	60	65	65
Other Western countries												
Czechia									60	*1	62+2m	*2
Poland									60	55	65	60
Ireland									*1	*1	65	65
Hungary									60	60	62	62
Portugal									55	55	65	65
Slovenia									58	58	61	63
Estonia									60	58	63	61
Luxemberg									60	60	65	65
East Asian countries												
Japan									60	60	64	62
China									*3	*3	60 *3	55 *3

*1: No early retirement.

*2: Different among the number of children. 61(No child), 59y8m(1 child) 58+4m(2 children) , 57(3 or 4 children) , 55+8m(more than 5 children)

Table 23: Pension eligibility age in Section 5

Table 24: PEA: US

Birth cohort	PEA
Early PEA	
	62y0m
Normal PEA	
~ 1937.12	65y0m
1938.1 ~ 1938.12	65y2m
1939.1 ~ 1939.12	65y4m
1940.1 ~ 1940.12	65y6m
1941.1 ~ 1941.12	65y8m
1942.1 ~ 1942.12	65y10m
1943.1 ~ 1943.12	66y0m
1944.1 ~ 1944.12	66y0m
1945.1 ~ 1945.12	66y0m
1946.1 ~ 1946.12	66y0m
1947.1 ~ 1947.12	66y0m
1948.1 ~ 1948.12	66y0m
1949.1 ~ 1949.12	66y0m
1950.1 ~ 1950.12	66y0m
1951.1 ~ 1951.12	66y0m
1952.1 ~ 1952.12	66y0m
1953.1 ~ 1953.12	66y0m
1954.1 ~ 1954.12	66y0m
1955.1 ~ 1955.12	66y2m
1956.1 ~ 1956.12	66y4m
1957.1 ~ 1957.12	66y6m
1958.1 ~ 1958.12	66y8m
1959.1 ~ 1959.12	66y10m
1960.1 ~ 1960.12	67y0m

Table 25: PEA: UK

Birth cohort	PEA
Normal PEA: Male	
~ 1953.12	65y0m
1954.1 ~ 1954.12	66y0m
1955.1 ~ 1959.12	66y0m
1960.1 ~ 1960.12	67y0m
1961.1 ~	67y0m
Normal PEA: Female	
~ 1949.12	60y0m
1950.1 ~ 1950.12	61y0m
1951.1 ~ 1951.12	62y0m
1952.1 ~ 1952.12	63y0m
1953.1 ~	65y0m

Table 26: PEA: Germany

Birth cohort	PEA
Early PEA: Male	
~ 1952.12	63y0m
1953.1 ~ 1953.12	63y2m
1954.1 ~ 1954.12	63y4m
1955.1 ~ 1955.12	63y6m
1956.1 ~ 1956.12	63y8m
1957.1 ~ 1957.12	63y10m
1958.1 ~ 1958.12	64y0m
1959.1 ~ 1959.12	64y2m
1960.1 ~ 1960.12	64y4m
1961.1 ~ 1961.12	64y6m
1962.1 ~ 1962.12	64y8m
1963.1 ~ 1963.12	64y10m
1964.1 ~ 1964.12	65y0m
Early PEA: Female	
~ 1951.12	60y0m
Normal PEA	
~ 1946.12	65y0m
1947.1 ~ 1947.12	65y1m
1948.1 ~ 1948.12	65y2m
1949.1 ~ 1949.12	65y3m
1950.1 ~ 1950.12	65y4m
1951.1 ~ 1951.12	65y5m
1952.1 ~ 1952.12	65y6m
1953.1 ~ 1953.12	65y7m
1954.1 ~ 1954.12	65y8m
1955.1 ~ 1955.12	65y9m
1956.1 ~ 1956.12	65y10m
1957.1 ~ 1957.12	65y11m
1958.1 ~ 1958.12	66y0m
1959.1 ~ 1959.12	66y2m
1960.1 ~ 1960.12	66y4m
1961.1 ~ 1961.12	66y6m
1962.1 ~ 1962.12	66y8m
1963.1 ~ 1963.12	66y10m
1964.1 ~ 1964.12	67y0m

Table 27: PEA: France

Birth cohort	PEA
Early PEA	
~ 1951.6	60y0m
1951.7 ~ 1951.12	60y4m
1952.1 ~ 1952.12	60y9m
1953.1 ~ 1953.12	61y2m
1954.1 ~ 1954.12	61y7m
1955.1 ~ 1955.12	62y0m
1956.1 ~ .	62y0m
Normal PEA	
~ 1951.6	65y0m
1951.7 ~ 1951.12	65y4m
1952.1 ~ 1952.12	65y9m
1953.1 ~ 1953.12	66y2m
1954.1 ~ 1954.12	66y7m
1955.1 ~ 1955.12	67y0m
1956.1 ~ .	67y0m

Table 28: Pension eligibility age in Section 5

Table 29: PEA: Denmark

Birth cohort	PEA
Early PEA	
~ 1953.12	60y0m
1954.1 ~ 1954.6	60y6m
1954.7 ~ 1954.12	61y0m
1955.1 ~ 1955.6	61y6m
1955.7 ~ 1955.12	62y0m
1956.1 ~ 1956.6	62y6m
1956.7 ~ 1958.12	63y0m
1959.1 ~ 1959.6	63y6m
1959.7 ~ 1964.6	64y0m
1964.7 ~	64y0m
Normal PEA	
~ 1953.12	65y0m
1954.1 ~ 1954.6	65y6m
1954.7 ~ 1954.12	66y0m
1955.1 ~ 1955.6	66y6m
1955.7 ~ 1955.12	67y0m
1956.1 ~ 1956.6	67y0m
1956.7 ~ 1958.12	67y0m
1959.1 ~ 1959.6	67y0m
1959.7 ~ 1964.6	67y0m
1964.7 ~	67y0m

Table 30: PEA: Japan

Birth cohort	PEA
Normal PEA: Male	
~1941.4.1	60y0m
1941.4.2~1943.4.1	61y0m
1943.4.2~1945.4.1	62y0m
1945.4.2~1947.4.1	63y0m
1947.4.2~1949.4.1	64y0m
1949.4.2~1953.4.1	65y0m
1953.4.2~1955.4.1	65y0m
1955.4.2~1957.4.1	65y0m
1957.4.2~1959.4.1	65y0m
1959.4.2~1961.4.1	65y0m
1961.4.2~	65y0m
Normal PEA: Female	
~1932.4.1	55y0m
1932.4.2~1934.4.1	56y0m
1934.4.2~1936.4.1	57y0m
1936.4.2~1937.4.1	58y0m
1937.4.2~1938.4.1	58y0m
1938.4.2~1940.4.1	59y0m
1940.4.2~1946.4.1	60y0m
1946.4.2~1948.4.1	61y0m
1948.4.2~1950.4.1	62y0m
1950.4.2~1952.4.1	63y0m
1952.4.2~1954.4.1	64y0m
1954.4.2~1958.4.1	65y0m
1958.4.2~1960.4.1	65y0m
1960.4.2~1962.4.1	65y0m
1962.4.2~1964.4.1	65y0m
1964.4.2~1965.4.1	65y0m
1965.4.2~	65y0m

Table 31: PEA: Korea

Birth cohort	PEA
Early PEA	
~ 1952.12	55y0m
1953.1 ~ 1956.12	56y0m
1957.1 ~ 1960.12	57y0m
1961.1 ~ 1964.12	58y0m
1965.1 ~ 1968.12	59y0m
1969.1 ~ .	60y0m
Normal PEA	
~ 1952.12	60y0m
1953.1 ~ 1956.12	61y0m
1957.1 ~ 1960.12	62y0m
1961.1 ~ 1964.12	63y0m
1965.1 ~ 1968.12	64y0m
1969.1 ~ .	65y0m

A.2 Parameterization: Model of Retirement and Cognitive Function Decline

We explain the details of model (3) parameterization in this section. We have explained the utility function, pension payments, and cognitive production functions in section 5. The cost function of cognitive investment, the function of reduced time by cognitive investment, and the function of income are parameterizes as follows:

- $G(i^f_{Wt}, i^j_{Wt}, i^j_{Lt}, i^j_{Lt}) = \beta_{Wf} i^f_{Wt} + \beta_{Wj} i^j_{Wt} + \beta_{Lf} i^f_{Lt} + \beta_{Lj} i^j_{Lt}$
- $L(i^f_{Lt}, i^j_{Lt}) = \alpha_f i^f_{Lt} + \alpha_j i^j_{Lt}$
- $y(a_{ft}, a_{jt}, t, l_t) = Y \cdot (a^{\eta_1}_{ft} a^{\eta_2}_{jt})(T-t)^{\eta_3}(1-l_t)$

A.3 Weight

The following procedure is used to calculate the estimation weights in section 4:

- We create the cells considering individual characteristics: age × gender × country of residence. The total number of cells is (The Number of Age (5)(From 60 to 64)) × (The Number of Gender (2)(Male, Female)) × (The Number of Country of Residence).

- In each cell, we calculate the population based on the source of UN data: A World Information. [24] All respondents can be assigned to a cell number depending on his/her characteristics.

- Finally, we make the following estimation weight. The following is the weight value of a respondent i. Let i be assigned to the characteristic number k. Then, the following value is assigned to respondent i for the estimation weight. B is the number of the set of the characteristics. T_k is the number of respondents in the (merged) dataset (for cross-country analysis) assigned to characteristics number k.

$$W_{ik} = \frac{1}{T_k} \frac{\Pr(\text{Cell Number} = k)}{\sum_{l \in B} \Pr(\text{Cell Number} = l)} \tag{8}$$

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[24] Please refer to the website at: http://data.un.org/Default.aspx.

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