Estimation of the human capital depreciation rate: An international comparison☆

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Abstract

This study estimates the degree to which the human capital accumulated through formal education is depreciated by internal factors and conducts an international comparison. Since intellectual stimulation or opportunities for skills use might differ depending on whether an individual is employed or unemployed, an estimation method where states of employment are distinguished from one another is used for the presented analysis. I find that the depreciation rates for the unemployed are higher than those for the employed in most OECD member countries. This finding supports the intellectual challenge and use-it-or-lose-it hypotheses. For depreciation rates for the employed, Korea is top with 1.90% and the United Kingdom is the lowest with -0.56%. For depreciation rates for the unemployed, Slovakia has the highest rate of 3.66%, whereas Japan has the lowest of 0.08%. Korea, Poland, and Estonia have high depreciation rates for both the employed and the unemployed. The United Kingdom and Ireland have low (high) depreciation rates for the employed (unemployed). Japan, Italy, and Spain have low depreciation rates for both the employed and unemployed. The results of this study suggest certain policy implications. For instance, employment policy that encourages the unemployed to find a job is important in the United Kingdom. On the contrary, for Korea, raising the level of skills used in the workplace should be promoted by the government.

Keywords: Human capital depreciation rate, International comparison

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I. Introduction

Not only does an individual's human capital determine his/her wage, living standard, and quality of life, it is also closely related to productivity, growth, and employment at the national level. It plays a significant role in integrating society as well. Despite the considerable effort and political interest in amassing and improving human capital, however, research on how accumulated human capital is maintained or depreciated remains scant. In particular, the importance of estimating a human capital depreciation rate as a starting point of research on human capital depreciation has generally been overlooked, except for the works by Mincer and Polacheck (1974), Mincer and Ofek (1982), Carliner (1982), Neuman and Weiss (1995), and Albrecht et al. (1999).

Although it is theoretically plausible to consider a human capital depreciation rate, the fact that the depreciation of human capital is affected by a variety of factors such as physical ageing, unemployment, and technological change has led to this scarcity of empirical studies. Neuman and Weiss (1995) distinguished the depreciation of human capital into internal and external depreciation. The former indicates depreciation caused by individual-related reasons including any loss of physical or mental ability. The latter occurs when the stock of knowledge obtained by schooling gradually becomes obsolete owing to environmental changes, corresponding to the so-called vintage effects suggested by Becker (1964). On the contrary, Rosen (1975) and Weiss and Lillard (1978) argued that it is impossible to distinguish between these two depreciation factors because they occur at the same time. The present study estimates only internal depreciation by using information on cognitive skills, rather than on individual wage information, derived from the Program for International Assessment of Adult Competencies (PIAAC). The PIAAC measures adults' proficiency in key information-processing skills, a kind of cognitive skill, by directly and individually testing literacy, numeracy, and computer-based problem solving[1].

Among previous studies, Groot (1998) and Arrazola and Hevia (2004) proposed models that estimate the human capital depreciation rate directly. Specifically, both estimated the depreciation rates of human capital accumulated through formal education by using data collected from the United Kingdom/Netherlands and Spain, respectively. This study proposes a more developed estimation model than their studies, which both estimated the depreciation rate of human capital by using wage data, thereby reflecting internal *and* external depreciation. On the contrary, this study uses data on cognitive skills to estimate human capital depreciation rates, thus reflecting only *internal* depreciation. As explained in detail later, since the depreciation of cognitive skills in adulthood is not significantly affected by ageing itself, the internal factors caused by physical ageing are not taken into account when the depreciation rate is estimated in this study.

Moreover, this study adopts the intellectual challenge and 'use-it-or-lose-it' hypotheses to explain the depreciation of human capital, which argue that cognitive skills dwindle when individuals are in an environment that provides low levels of intellectual stimulus or they have insufficient opportunities to use their cognitive skills in the workplace and in daily life. These hypotheses have been questioned by many researchers since they were suggested in the 1920s (Salthouse 2006, 2007; Schooler 2007). Pazy (2004) supported the use-it-or-lose-it hypothesis by suggesting that not using cognitive skills causes their depreciation. Mincer and Ofek (1982), Krahn and Lowe (1998), and De Grip and Van Loo (2002) similarly reported

1 The PIAAC began in 2008 with a preliminary survey in 2010 and a formal one conducted in 2011 and 2012. It was conducted as an initiative of the OECD among 157,000 adults aged from 16 to 65 years old in 24 countries: Australia, Austria, Flanders (Belgium), Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Poland, Russia, Slovakia, South Korea, Spain, Sweden, the United Kingdom, and the United States.

the depreciation of skills when they are not used[2].

Fratiglioni, Paillard-Borg, and Winblad (2004) and Staff et al. (2004) provided results favourable for these two hypotheses. In particular, Staff et al. (2004) showed that intellectual stimulation received during education and occupational activities increases cerebral reserves and maintains cognitive functioning in old age, thereby explaining the degree to which cognitive skills decrease as people age (Schaie 1994). Bosma et al. (2003a, 2003b) also found that mental workload at work negatively affects cognitive impairment as people age. Avolio and Waldman (1990), Finkel et al. (2009), Riberio et al. (2013), Kröger et al. (2008), and Ravaglia et al. (2002) examined the modifying effects of job complexity and/or occupational type on age-related cognitive decline. Marquié et al. (2010) showed that mental stimulation at work influences both the level of cognitive performance and the rate of cognitive change, providing empirical evidence for the use-it-or-lose-it hypothesis[3].

This study is the first attempt to estimate the degree to which human capital accumulated by formal education is depreciated by internal factors. Moreover, since the degree of internal human capital depreciation faced by employed individuals might differ from that faced by the unemployed, this study proposes a method of estimating depreciation rates by distinguishing both states in one estimation model, since the intellectual stimulation and skills-use opportunities individuals face might vary depending on whether they are in work. The employed after formal education may accumulate additional human capital by using their own human capital, whereas if individuals are unemployed, they are more likely to experience a significant depreciation of human capital. This study can also be distinguished from previous studies as it expands the scope of the analysis to an international comparison.

[2] While most studies have paid attention to the atrophy of skills caused by career discontinuity or career interruption, De Grip et al. (2008) focused on the underutilization of skills due to overeducation.

[3] Apart from the degree of mental stimulation at work, differences in occupational characteristics might influence a person's cognitive ability. For instance, Virtanen et al. (2008) suggested that long working hours may have a negative impact on cognitive functioning in midlife and facilitate cognitive deterioration.

For the analysis, literacy scores from the PIAAC are used to estimate the depreciation rates of human capital, and each country's estimation results are then compared.

The remainder of this paper is organized as follows. Section II presents the estimation model developed in this study. In Section III, an international comparison is conducted by using the estimates of human capital depreciation rates and the results derived from distinguishing the states of employment are suggested. Section IV concludes.

II. Estimation model for the depreciation rates of human capital

According to Groot (1998), based on the assumption that *t* years elapsed after an individual *i* had completed formal education, the current value of human capital (K_i) that an individual *i* had accumulated through formal education is shown in Eqn. (1). *t* is obtained by subtracting the number of schooling years (S_i) and 6 from one's age:

$$K_i = (1 - \delta_{ni})^t S_i \tag{1}$$

Contrary to previous studies(Groot 1998; Arrazola and Hevia 2004), in this work, depreciation rates are assumed to be affected by the various characteristics of individual *i*:

$$\delta_{ni} = \delta_n(Z_i) \tag{2}$$

The relation between individual *i*'s proficiency score (C_i) measured in the PIAAC and the current value of one's human capital is

$$C_i = e^{\beta_K \{1-\delta_n(Z_i)\}^t S_i + \beta_X X_i + u_i} \tag{3}$$

Eqn. (3) indicates that the current score of an individual's proficiency is determined by the current value of human capital accumulated through formal education and other factors (X). OECD (2015) defined proficiency measured in the PIAAC as 'the bundle of knowledge, attributes and capacities that can be learned'. Consequently, the cognitive skills measured by PIAAC scores are mostly explained by the current value of an individual's human capital.

Cognitive skills are influenced by an individual's family background and innate ability (Hanushek et al. 2013). The learning process, innate ability, and environment influence cognitive skills' formation through interactions with one another. Therefore, we must control for these related variables. Here, X includes gender, language in use, status of birth abroad, parents' immigration status, academic backgrounds of the parents, and number of books at home. And X also includes learning strategy and the social capital variable. Learning strategy significantly affects an individual's learning performance (Flavell, 1979; Zimmerman and Pons, 1986; Eccles and Midgley, 1989; Garcia and Pintrich, 1994; Blumenfeld, 1992; Britton and Tesser, 1991; Brown, Campione, and Day, 1981). The interaction between social capital and human capital has further been examined[4]. Responses to the question item on health status are also included as a control variable. Salthouse (2009a) reported that a substantial part of the cohort effect can be controlled for by using an individual's schooling year and health status. Table A1 describes the control variables and measured indicators in this study.

Taking the natural logarithm of Eqn. (3) leads to Eqn. (4), which is an estimation equation for the cross-sectional data. The key factor to the estimation is how effectively X can control for the endogeneity caused by the unobservable characteristics contained in u_i.

[4] Desjardins and Warnke (2012) summarized research on the effect of social capital on cognitive skills. Sharp et al. (2010) argued that social participation positively affects an individual's cognitive skills.

$$lnC_i = \beta_K\{1 - \delta_n(Z_i)\}^t S_i + \beta_X X_i + u_i \tag{4}$$

As noted in the Introduction, the depreciation rates addressed in this study are limited to the internal depreciation rates of human capital accumulated through formal education. Since developing and using the human capital accumulated through formal education can accumulate further human capital, even after formal schooling ends, these depreciation rates might be negative.

If factors cause systematic differences in the cohort to which an individual belongs (e.g. disparate quality of schooling depending on birth year) or if the social and biological changes that individuals experience at a certain age affect their cognitive competencies, these factors may not be sufficiently controlled for by X. Hence, depreciation rates for different ages are suggested:

$$\delta_{ni} = \delta_n(Z_i) = \delta_0 + \delta_1 \times age_i \tag{5}$$

Plugging Eqn. (5) into Eqn. (4) leads to

$$lnC_i = \beta_K\{1 - (\delta_0 + \delta_1 age_i)\}^t S_i + \beta_X X_i + u_i \tag{6}$$

The observed age difference consists of cohort and age effects. For instance, people with different ages have different depreciation rates because of the difference in the quality of education across birth cohorts, difference in experience after formal education, or difference in degree of biological ageing at a certain age. In cross-sectional data, the cohort and age effects cannot therefore be completely distinguished.[5]

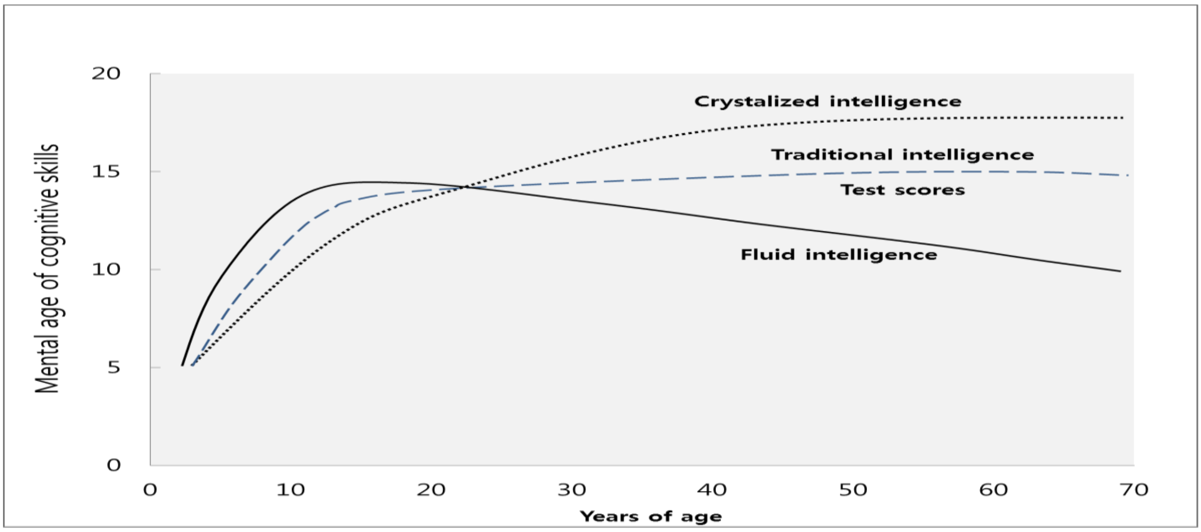
[5] Ban, Kim, and Kim (2015) summarized the advantages and disadvantages of using longitudinal and cross-

Basic cognitive skills comprise two components: cognitive mechanics and cognitive pragmatics. Cognitive mechanics includes concentration, processing speed, reasoning, working memory, and spatial perception. It is also called fluid intelligence (or Gf) as it is related to the ability to understand and learn independently of previous knowledge. All other cognitive functions such as knowledge, skills, and wisdom are categorized as cognitive pragmatics and these kinds of cognitive skills are often called crystallized intelligence (or Gc) as they are acquired or learned in advance. Crystallized intelligence is determined by the social and cultural learning environments.

In general, traditional intelligence test scores (G) associated with cognitive skills are stable throughout adulthood. A moderate decline may be expected if the nature of a test reflects the attributes of fluid intelligence more strongly, while a modest rise is plausible if a test is more closely related to crystallized intelligence. Desjardins and Warnke (2012) found that crystallized intelligence has a stable age profile in adulthood compared with fluid intelligence. While fluid intelligence dwindles in early adulthood, crystallized intelligence continues to rise slowly. As ageing progresses, fluid intelligence sharply wanes. Nonetheless, an individual's cognitive ability does not shrink greatly since a decrease in fluid intelligence is accompanied by a sufficient increase and maintenance of crystallized intelligence. In other words, overall cognitive ability can be preserved by continued learning and experiences, which lead to the augmentation of crystallized intelligence, even when fluid intelligence has already declined. Figure 1 illustrates the patterns of fluid and crystallized intelligence and their combination, G.

sectional data, stating that estimations obtained by using the former cause bias because of the retest effect. Salthouse (2009a) argued that retest effects from longitudinal data cause severer estimation bias compared with cohort effects from cross-sectional data and that cohort effects are unlikely to be significant if schooling years and health status are controlled for. The study also emphasized that estimation results from longitudinal data should not be considered to be more scientific. The refutations by Schaie (2009), Nilsson et al. (2009), and Abrams (2009) regarding the argument of Salthouse (2009a) and the subsequent rebuttal by Salthouse (2009b) are interesting.

Figure 1: Profiles of fluid intelligence and crystallized intelligence



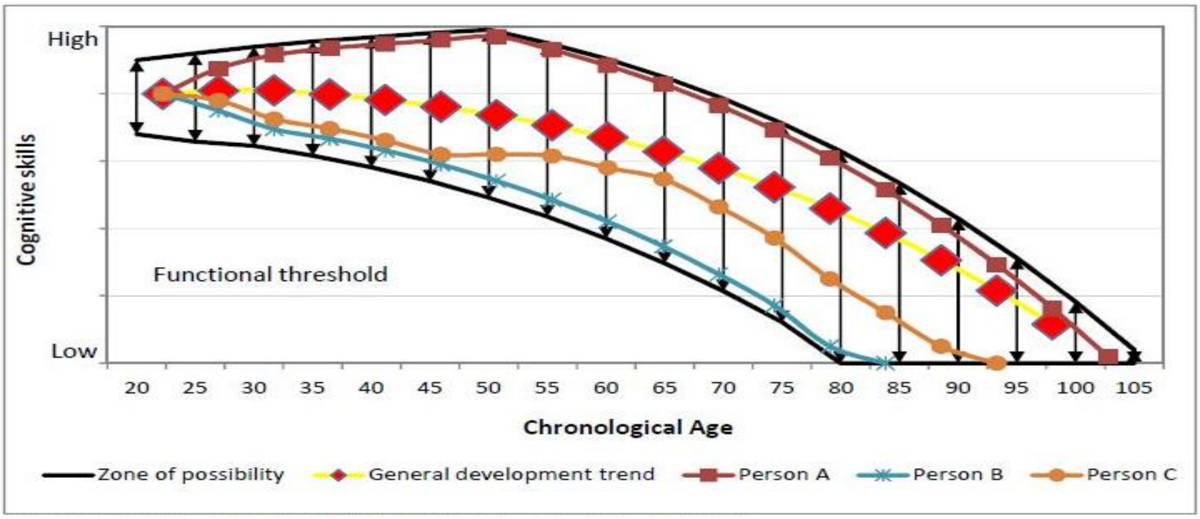
Source: Quoted and reconstructed from Cattell (1987), McArdle et al. (2002), and Desjardins and Warnke (2012).

The PIAAC measures foundation rather than basic cognitive skills, which in turn means that it assesses individuals' information-processing skills. Whether the measures of the PIAAC are closer to Gf or Gc is unclear. Further, these measures cannot show a decrease due to ageing, or the degree of decrease is insignificant even if it occurs. Therefore, the age effect on the depreciation rate is expected to be small.[6]

The decline in cognitive skills by ageing, however, differs significantly among individuals (Figure 2). Although G does not show a sharp decline before age 60, some individuals show sharp declines, or even rises. The intellectual stimulation and use-it-or-lose-it hypotheses of interest in this study may be good explanations of those cases. That is, individual differences in declining trends may be significant depending on the environments (e.g. the intellectual stimulation faced by individuals), even when no general decrease in cognitive skills due to ageing is observed.

[6] When Eqn. (6) is differentiated with respect to age, $\frac{\partial lnC}{\partial age} = \beta_K St(1-\delta_0-\delta_1 age)^{t-1}(-\delta_1)$ is derived. If the age difference is assumed to be biological ageing, this value must be 0, which requires $\delta_1 = 0$. In other words, there is no change in the depreciation rate due to the age effect if no biological age effect is assumed.

Figure 2: Individual differences in decrease in cognitive skills



Source: Quoted and reconstructed from Hertzog et al. (2008) and Desjardins and Warnke (2012).

Eqn. (4) shows that human capital accumulates during formal education (S) and cognitive skills consequently increase, whereas human capital depreciates and cognitive skills thereby deteriorate after its completion. This is equivalent to modelling the accumulation and depreciation of human capital by intellectual stimulation, regardless of the biological ageing process. The model used in this study assumes that intellectual stimulation and the frequency of skills use determine the depreciation rates of human capital rather than biological ageing, at least between the ages of 16 and 65[7]. Thus, birth cohorts are controlled for by using the age variable in Eqn. (6).

The depreciation that occurs during t years may also vary considerably depending on whether an individual is employed. The intellectual challenge and use-it-or-lose-it hypotheses view that the degree of depreciation might differ from individual experiences. Taking into account this point, two distinct depreciation rates are assumed: a depreciation rate with being

[7] For instance, the additional accumulation of human capital in the graduate course after completing college education is regarded as having an overwhelming effect on cognitive skills' deterioration due to ageing. The estimation model in this study also reflects this point. Katzman (1993) suggested that education can stimulate synaptic growth and Jacobs et al. (1993) reported that increased levels of dendritic branching are more prevalent in more educated individuals. In other words, cognitive skills are developed by the intellectual stimulation received during formal education. Therefore, if an individual receives less intellectual stimulation after formal education than during it, human capital will depreciate. Otherwise, human capital will accumulate.

employed for t_0 years and a depreciation rate with being unemployed for t_1 years. That is, for t years after the end of formal education, an individual is assumed to face a depreciation rate of δ_{n0} for t_0 years and δ_{n1} for t_1 years, rather than the depreciation rate δ_n. The present value of human capital is now:

$$(1-\delta_n)^t S = (1-\delta_{n0})^{t_0}(1-\delta_{n1})^{t_1} S \tag{7}$$

Taking the logarithm into Eqn. (7), Eqn. (8) is derived as follows:

$$tln(1-\delta_n) = t_0 \ln(1-\delta_{n0}) + t_1 \ln(1-\delta_{n1}) \tag{8}$$

Since $t = t_0 + t_1$, defining $wer = \frac{t_0}{t}$ yields Eqn. (9):

$$\delta_n \cong \delta_{n0} wer + \delta_{n1}(1-wer) \tag{9}$$

The depreciation rate δ_n can now be seen as a weighted sum of δ_{n0} and δ_{n1}. The weight wer is the ratio of years of employment among t years. If one is employed for the entire t years, wer will become 1 and $\delta_n = \delta_{n0}$. On the contrary, if one is unemployed for the entire t years, wer will be 0 and $\delta_n = \delta_{n1}$. The calculation of wer with actual data was based on the number of years of working full-time or part-time for more than six months divided by t, so some values exceed 1. In that case, they are turned into 1[8]. Thus, the set of values taken as wer is expressed as follows: $wer = \{0,1\}$.

[8] The proportion of samples exceeding 1 (2) is approximately 18% (0.2%). The majority of samples with wer greater than 1 have a low t value, perhaps because t is calculated with a relation $t = age - S - 6$. Another reason is the possibility of studying and working in the same time. In this study, this period is regarded as the period of being employed.

Since the depreciation rates for the employed (δ_{n0}) and unemployed (δ_{n1}) are expressed by Eqn. (10) and Eqn. (11), respectively, the total depreciation rate (δ_n) is represented as Eqn. (12). As a result, the estimation equation becomes Eqn. (13) from which δ_{01}, δ_{11}, $\delta_{00} - \delta_{01}$, and $\delta_{10} - \delta_{11}$ can be estimated. By using these estimates, δ_{00}, δ_{01}, δ_{10}, and δ_{11} are calculated:

$$\delta_{n0} = \delta_{00} + \delta_{10} age \tag{10}$$

$$\delta_{n1} = \delta_{01} + \delta_{11} age \tag{11}$$

$$\begin{aligned} \delta_n &= \delta_{n0} wer + \delta_{n1}(1 - wer) \\ &= (\delta_{00} + \delta_{10} age) wer + (\delta_{01} + \delta_{11} age)(1 - wer) \\ &= \delta_{01} + \delta_{11} age + (\delta_{00} - \delta_{01}) wer + (\delta_{10} - \delta_{11}) wer \times age \end{aligned} \tag{12}$$

$$\begin{aligned} lnC_i = \beta_K \{1 - (\delta_{01} + \delta_{11} age_i + (\delta_{00} - \delta_{01}) wer_i + (\delta_{10} - \delta_{11}) age_i \times wer_i)\}^t S_i \\ + \beta_X X_i + u_i \end{aligned} \tag{13}$$

Eqn. (6) and Eqn. (13) are estimated by using the nonlinear least squares method. Meanwhile, in the PIAAC, an individual's proficiency is not represented by a measured value, but by plausible values (PVs), which are commonly used in large-scale surveys. Literacy, which is used as the variable for cognitive skills in this study, also has 10 PVs from $PV1$ to $PV10$. For this reason, the estimation of depreciation rates is shown in Eqn. (14). The arithmetic average of the estimated depreciation rates ($\hat{\delta}_{PV}$) derived by using each PV from $PV1$ to $PV10$ yields $\hat{\delta}$. P indicates the number of PVs (i.e., 10 in the PIAAC).

$$\hat{\delta} = \frac{1}{P}\sum_{PV=1}^{P}\hat{\delta}_{PV} \tag{14}$$

The standard error (se_{δ}) is represented in Eqn. (15). Two sampling methods were used for each country in the PIAAC survey. In the case of non-stratified sampling, $f = \frac{R-1}{R}$, and in the case of stratified sampling, $f = 1$. R is the number of repeated samplings (i.e., 80 in the PIAAC). $\hat{\delta}_{r,PV}$ is an estimate obtained from replicated sampling.

$$se_{\delta} = \sqrt{\left\{\sum_{PV=1}^{P} f \sum_{r=1}^{R}\left(\hat{\delta}_{r,PV} - \hat{\delta}\right)^2 \frac{1}{P}\right\} + \left\{(1 + \frac{1}{P})\frac{1}{P-1}\sum_{PV=1}^{P}\left(\hat{\delta}_{PV} - \hat{\delta}\right)^2\right\}} \tag{15}$$

The depreciation rates and standard errors are estimated by using the above method. The former are estimated by country and the mean value of the countries is also provided. The ‘average’ estimate presented below is the average depreciation rate of the OECD countries used in the analysis. The standard error is calculated by summing the square of each country’s standard errors, taking the square root of it, and dividing it by the number of countries.

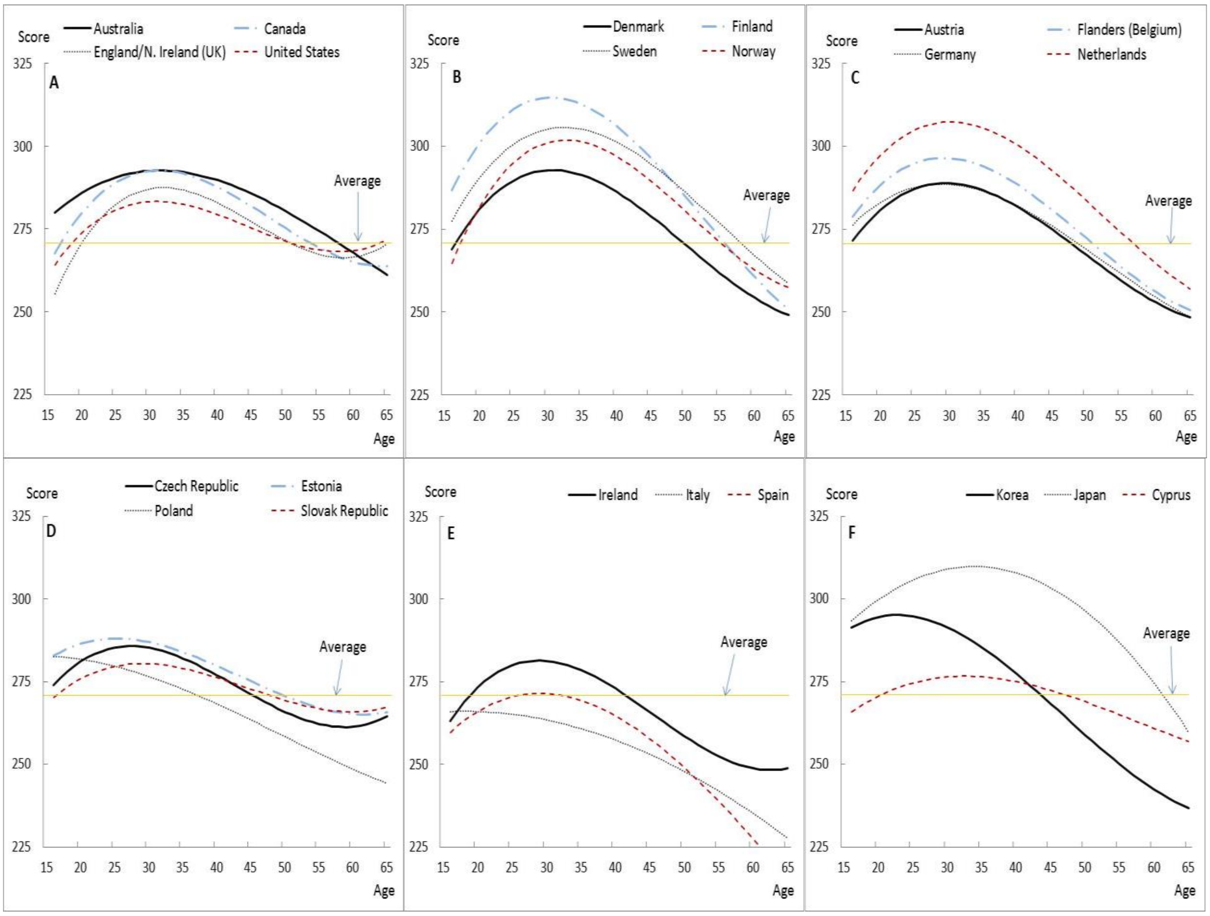
III. Estimation results of human capital depreciation rates

Figure 3 illustrates the age-skill profiles measured by literacy proficiency[9]. In most countries, this profile shows a convex shape with its peak in the 20s and 30s age range. Korea shows a significant gap in the level of skills depending on age. In Japan, skills are maintained after a considerable increase until the middle age and decline sharply in older people. No

[9] According to OECD (2013), literacy is defined as the ability to understand, evaluate, use, and engage with written texts to participate in society, achieve one’s goals, and develop one’s knowledge and potential. The literacy proficiencies in the PIAAC do not simply measure abilities and knowledge related to ‘reading’. Rather, they measure key information-processing skills.

substantial gap in the level of skills across ages is observed in English-speaking countries or former eastern communist countries. Italy, a group E country, has a lower skill level than the OECD average at all ages, but its gap across ages is small.

Figure 3: Age-literacy proficiency profiles in OECD countries

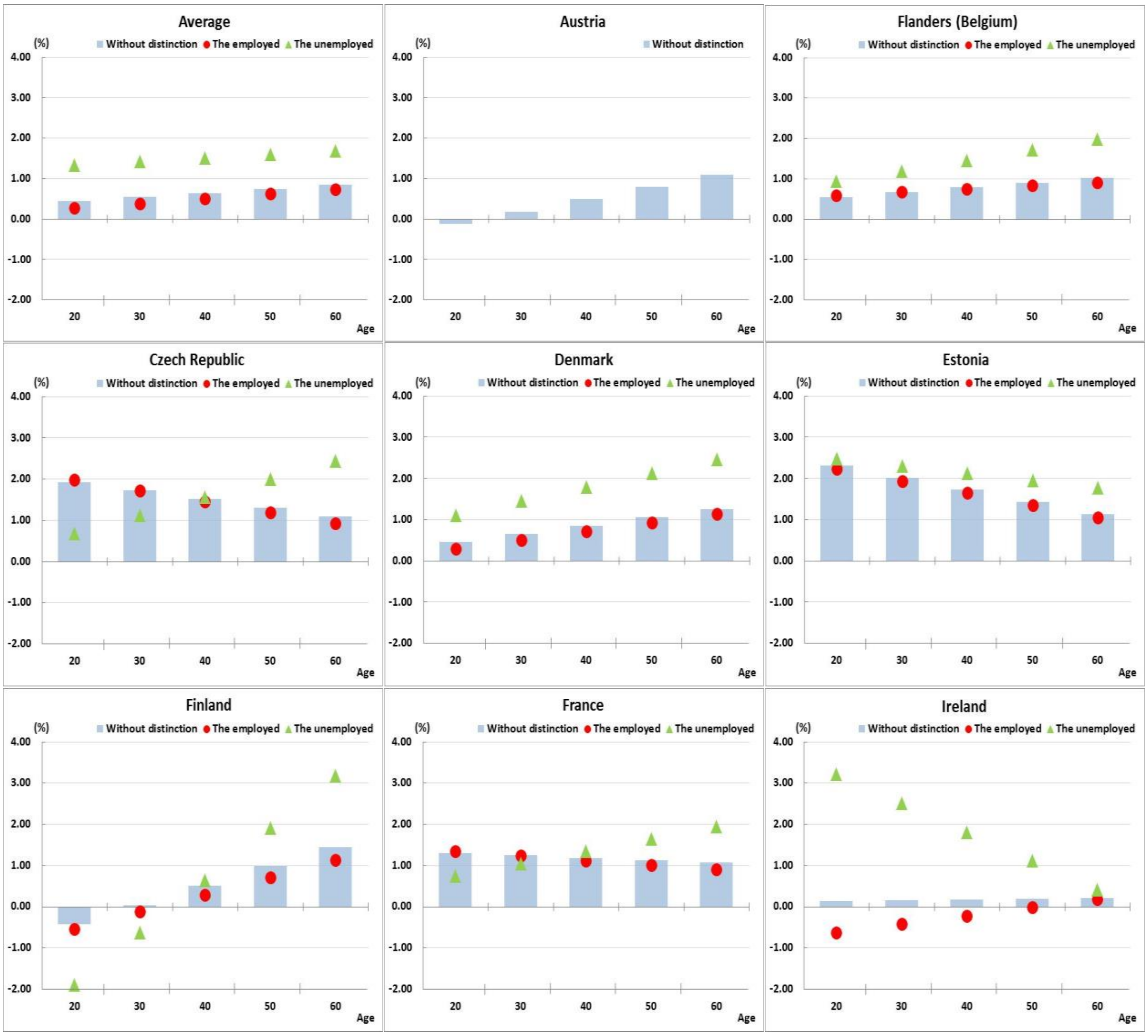


Note: The A–D countries are grouped according to regional or language considerations, with the remainder grouped in E and F. A cubic specification of the trend curves is found to be most accurate in reflecting the distribution of scores by age in most countries. Foreign-born adults are excluded from the analysis.

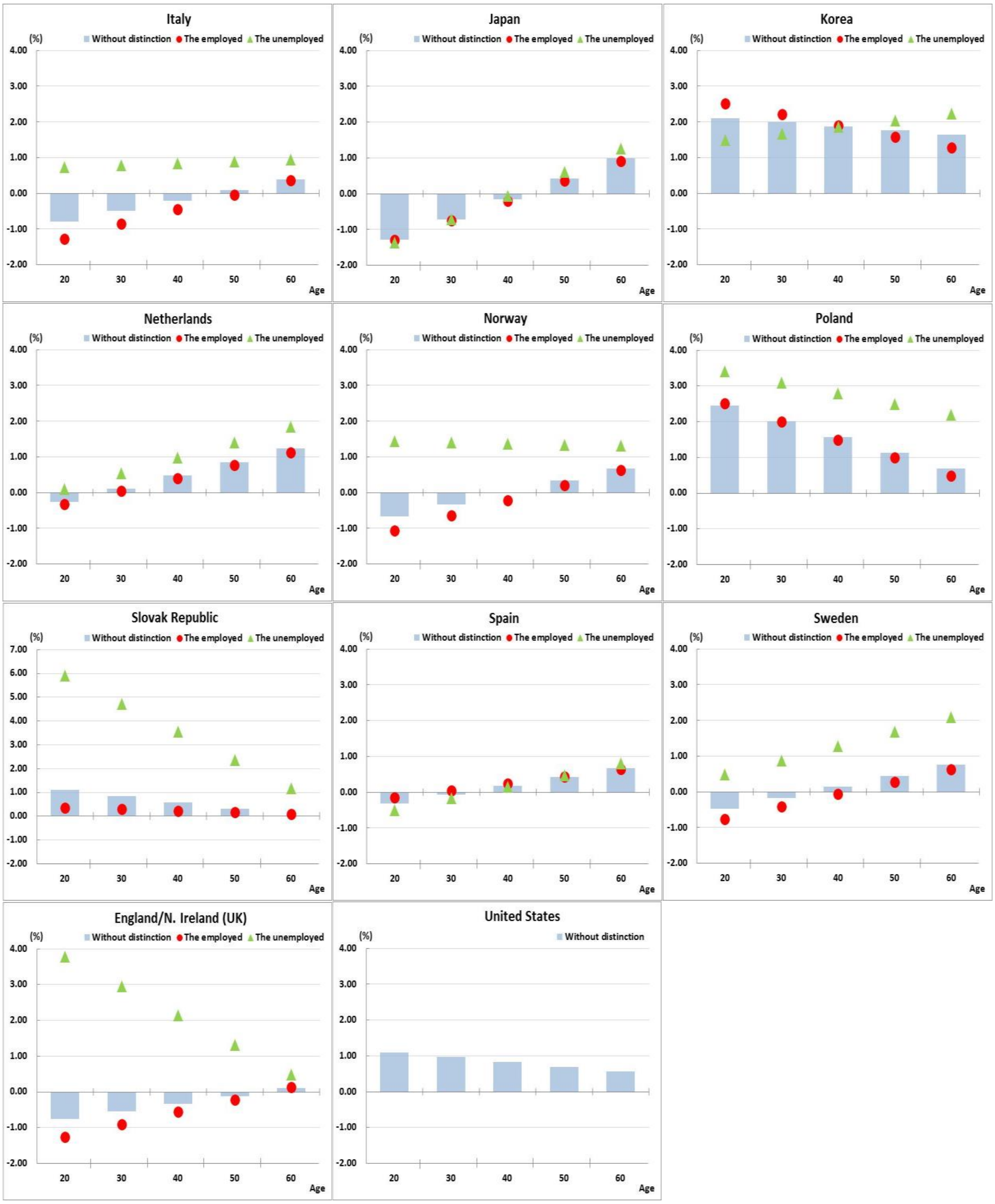
Source: OECD (2013).

Figure 4 and Table A2 show the estimation results of the human capital depreciation rates from Eqn. (6), which do not distinguish between states of employment. The results of estimating the depreciation rates by distinguishing between the employed and unemployed from Eqn. (13) are also shown in Figure 4 and Table A3[10]. All the estimates are obtained by using the literacy proficiency of the PIAAC as a proxy for cognitive skills. As mentioned above, age does not mean one's biological age but rather birth year.

Figure 4: Depreciation rates by age in OECD countries



[10] Since the length of employment after formal education is longer than the length of unemployment, the depreciation rate of human capital after formal education is more influenced by the depreciation rate for the employed. Thus, the depreciation rate by age without distinction between states of employment is similar to the depreciation rate by age for the employed.



Source: OECD (2012).

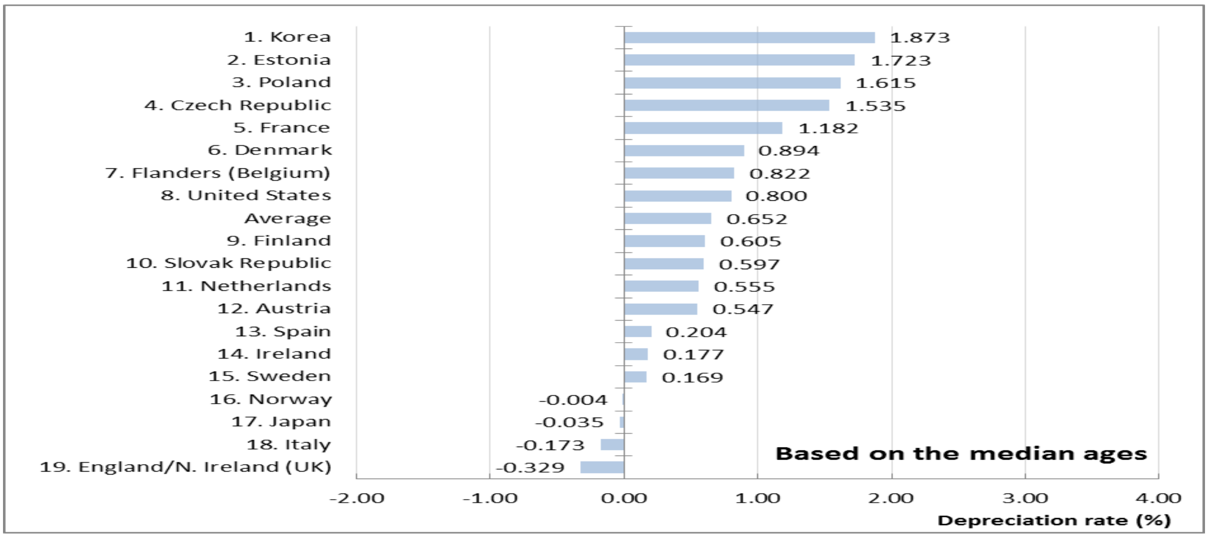
The OECD average depreciation rate obtained by not distinguishing between states of employment increases as age rises, suggesting that the younger generation experiences a better quality of education and enjoys an environment more favourable for the accumulation of human capital, even after formal education, compared with the older generation. However, depreciation is greater in young generations in the former eastern communist countries, the United States, France, and Korea. However, the trends in Korea and France are not statistically significant (see Table A2).

The depreciation rate for the unemployed for the OECD average as well as for most countries is higher than that for the employed. According to the intellectual challenge and use-it-or-lose-it hypotheses, individuals receive different amounts of intellectual stimulation depending on their states of employment, which lead to distinct depreciation rates. The results of this study thus support these two hypotheses. However, the positive depreciation rates for the young employed in Korea, Czech Republic, and France have larger estimates than those for their young unemployed counterparts.

Figure 5 shows the depreciation rates obtained by using median ages but without distinguishing between states of employment[11]. The OECD average depreciation rate is 0.65%. Arrazola and Hevia (2004) estimated the human capital depreciation rates of Spanish wage earners aged 16–64 in 1994 by using data from the European Household Panel as 1–1.5%. On the contrary, the depreciation rate for Spain estimated in this study is only 0.20%. Recall that the estimate from Arrazola and Hevia (2004) reflects both internal and external depreciation. Figure A1 shows an international comparison of the human capital depreciation rates by age.

Figure 5: International comparison of the human capital depreciation rates without a distinction between states of employment

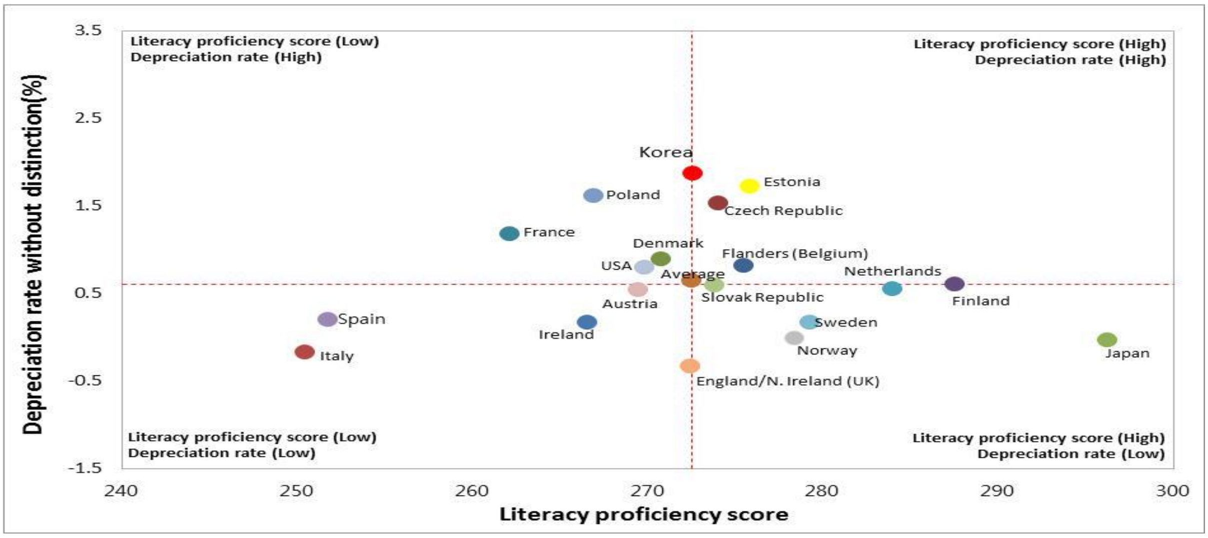
[11] In the PIAAC data, each OECD member country's median age is as follows: 42 years in Austria, 43 in Flanders (Belgium), 39 in Czech Republic, 42 in Denmark, 40 in Estonia, 42 in Finland, 41 in France, 38 in Ireland, 41 in Italy, 42 in Japan, 40 in Korea, 42 in the Netherlands, 40 in Norway, 39 in Poland, 39 in Slovakia, 41 in Spain, 41 in Sweden, 40 in the United Kingdom, and 42 in the United States. The median age of all OECD member countries is 41.



Source: OECD (2012).

Figure 6 shows the literacy proficiency scores and depreciation rates together. Korea's level of skills is around the OECD average, whereas its depreciation rate is the highest of all members. The United Kingdom has a level of skills similar to that of Korea, but its depreciation rate is the lowest.

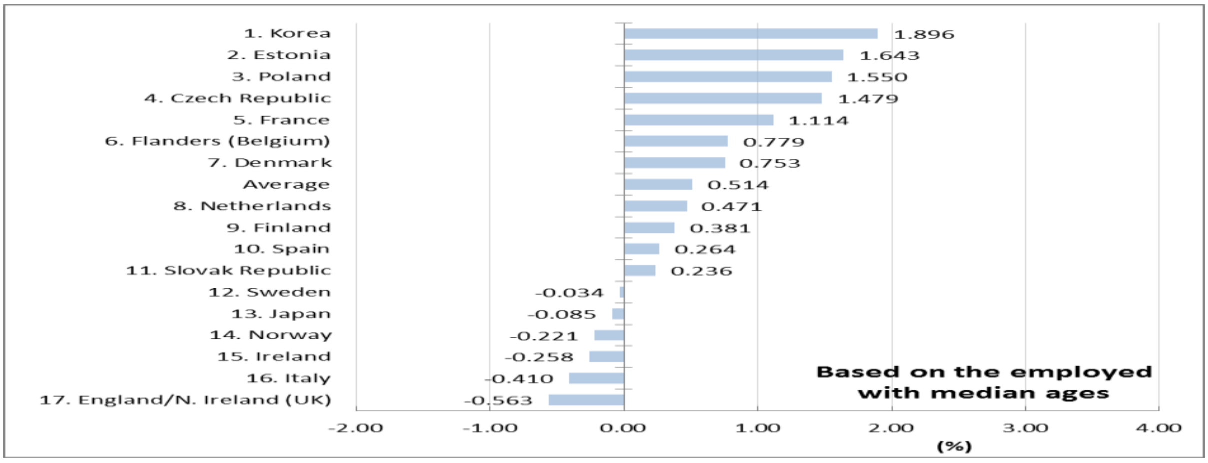
Figure 6: International comparisons of the literacy proficiency scores and depreciation rates



Source: OECD (2012).

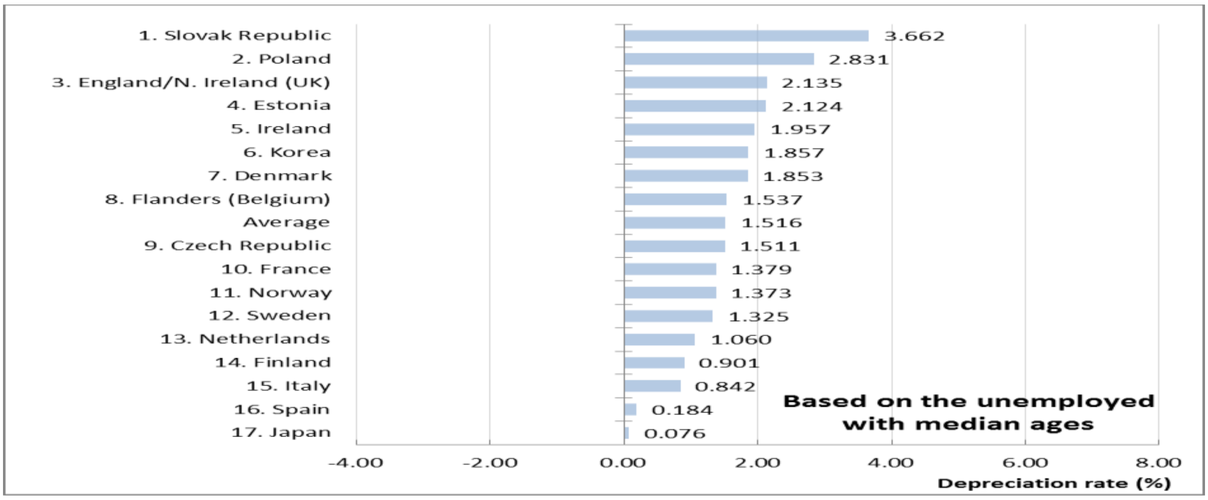
Figures 7 and 8 compare the depreciation rates depending on the states of employment based on the median ages of each country. For the depreciation rates for the employed, Korea is top with 1.90% and the United Kingdom is the lowest with -0.56%. Some countries have negative depreciation rates; this can be interpreted as accumulation, which occurs by developing the human capital accumulated from formal education. The depreciation rates for the unemployed have positive estimates in all countries. Slovakia is the highest with 3.66% and Japan is the lowest with 0.08%.

Figure 7: International comparison of the depreciation rates for the employed



Source: OECD (2012).

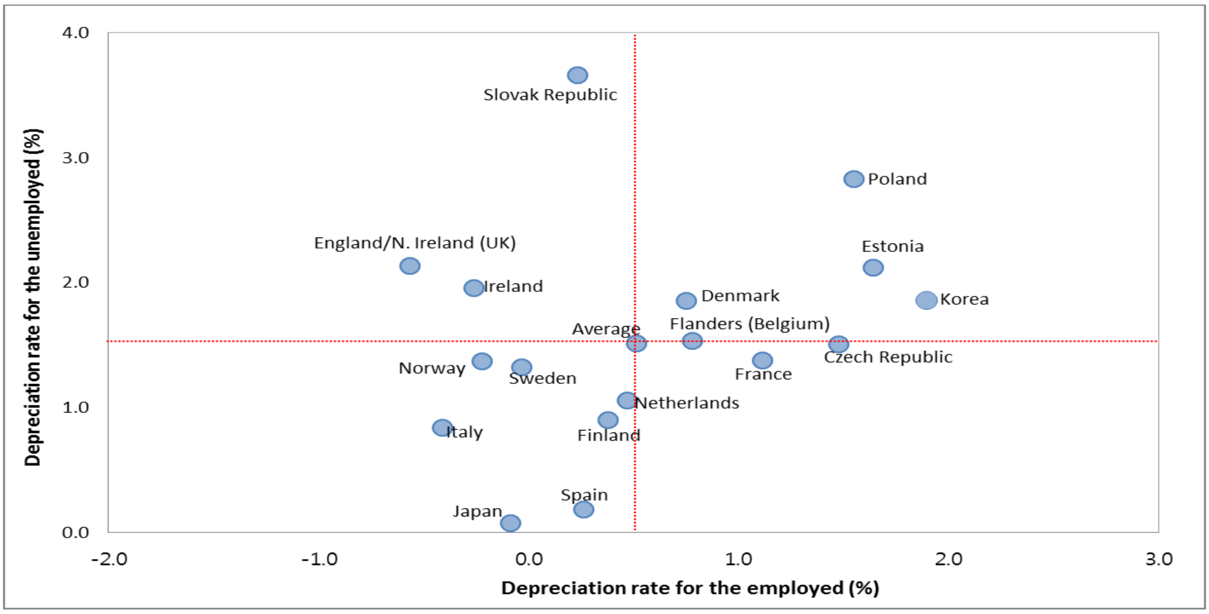
Figure 8: International comparison of the depreciation rates for the unemployed



Source: OECD (2012).

As shown in Figure 9, the depreciation rates of Korea, Poland, and Estonia are high for both the employed and the unemployed. The United Kingdom and Ireland exhibit low (high) depreciation rates for the employed (unemployed). Japan, Italy, and Spain have low depreciation rates for the employed and unemployed. However, as shown in Figure 6, Italy and Spain have the lowest levels of human capital, while Japan has the highest. Figures A2 and A3 compare the human capital depreciation rates for the employed and unemployed by age.

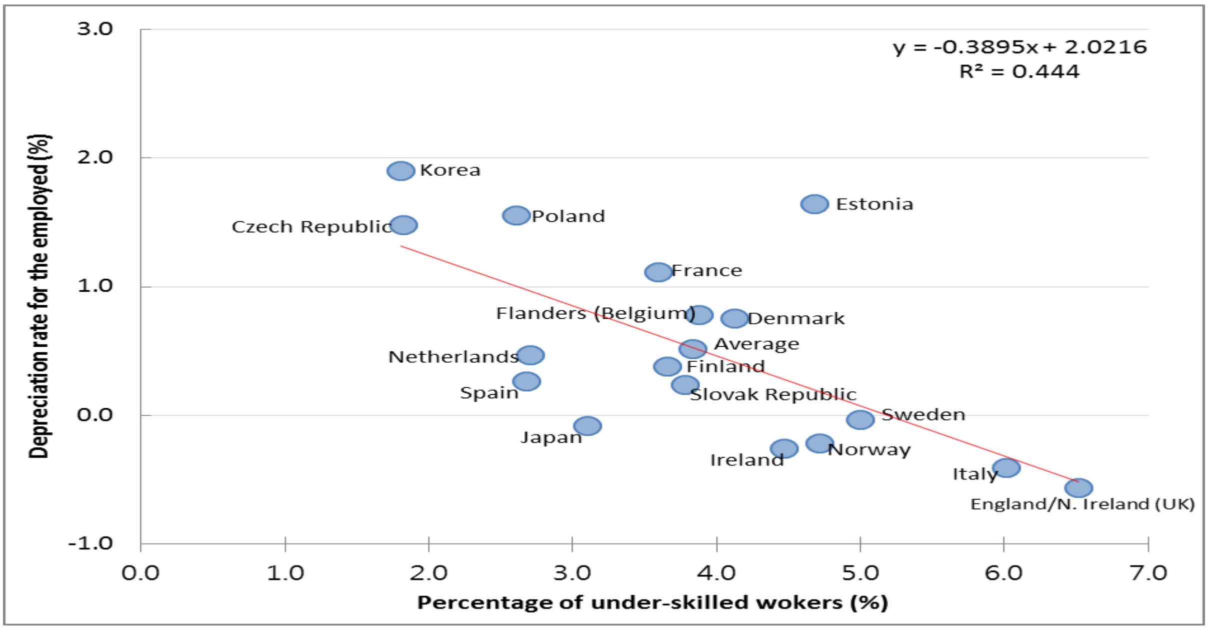
Figure 9: International comparison of the depreciation rates depending on the states of employment



Source: OECD (2012).

The degree of intellectual stimulation or skills use in the workplace and the amount of depreciation are affected by the gap between demand for skills and individuals' skills. No matter how high demand for skills at work is, if the level of skills an individual possesses is above that, the individual will not be intellectually stimulated and this will lead to depreciation. On the contrary, even if demand for skills in the workplace is low, if it is higher than the level of the individual's skills, s/he can accumulate human capital. Figure 10 depicts the relationship between the proportion of underskilled workers[12] and depreciation rates for the employed. The higher the proportion of underskilled workers, the lower are the depreciation rates for employees.

Figure 10: Relationship between underskilling and the depreciation rates for the employed



Source: OECD (2012).

IV. Discussion

This study estimated the internal depreciation rates of human capital accumulated through formal education and conducted an international comparison. The analysis found that most countries have positive depreciation rates, implying that policy for maintaining human capital after formal education ends is as important as that for accumulating and improving human capital during formal schooling. The diverse depreciation rates across countries are likely to result from differences in the quality of formal education, degree to which skills are used at work, and environment for lifelong learning. Further, this study found that the depreciation

[12] Underskilling was calculated by combining actual literacy scores and the self-reported skill mismatch information according to the method suggested by Pellizzari and Fichen (2013).

rates for the unemployed are higher than those for the employed in most OECD countries. This finding supports the intellectual challenge and use-it-or-lose-it hypotheses with respect to the internal depreciation of human capital.

Meanwhile, the results from this study suggest certain policy implications. For instance, while the levels of human capital in Korea and the United Kingdom are similar, Korea's depreciation rates are the largest and the United Kingdom's depreciation rates are the smallest among OECD countries. Moreover, Korea has the highest depreciation rate for the employed, whereas the United Kingdom has a substantially high depreciation rate for the unemployed. These findings infer that Korea has an issue of human capital depreciation for the employed, whereas the United Kingdom's issue is human capital depreciation for unemployed people. In this sense, employment policy that encourages the unemployed to find a job is important in the United Kingdom. On the contrary, for Korea, raising the level of skills used in the workplace should be promoted by the government to prevent the massive loss of human capital caused by low-skilled jobs.

This study has the following limitations. First, unobserved individual factors may not be fully controlled for, possibly leading to some bias. However, applying the same estimation model to several countries and comparing the results may offset that disadvantage to some extent. Second, the depreciation rates are estimated under the assumption that cognitive skills deterioration due to biological ageing is negligible. The estimation model includes an age variable to control for the birth year. If the cohort effect is insignificant, but the biological ageing effect is substantial, the age variable should be changed to biological age. In this case, age varies as *t* changes and an estimation model can be used, where individuals face different depreciation rates during the *t* period due to ageing[13]. Since it is impossible to control for both cohort and biological age with cross-sectional data, one of two models, the model used

[13] Then, the estimation equation becomes $lnC_i = lnA + \beta_K S_i \exp\left\{-(\delta_0 + \delta_1 age)t + \delta_1 \frac{t(t-1)}{2}\right\} + \beta_X X_i + u_i$.

in this study or the model suggested in footnote 13, needs to be chosen. Finally, this study adopted a model in which age is interpreted as the birth year. However, if the degree to which cognitive skills depreciate significantly depends on changes in biological ageing itself as opposed to intellectual stimulation or how skills are used, this estimation model would be biased. These issues should be addressed in future research.

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Appendix

Table A1: Control variables used to measure the depreciation rates of human capital

<table>
<tr><th>Variable</th><th>Description</th><th>Note</th></tr>
<tr><td rowspan="6">Gender, Family background, Health status</td><td>Gender</td><td>0. Female
1. Male
* Dummy coding with female as the reference group</td></tr>
<tr><td>Highest level of the education of parents</td><td>1. None of them achieved secondary education or higher
2. At least one of them achieved secondary education or higher (excluding tertiary education)
3. At least one of them achieved tertiary education
* Dummy coding with ‘none of them achieved secondary education or higher’ as the reference group</td></tr>
<tr><td>Number of books in home at age 16</td><td>1. 10 books or less
2. 11 to 25 books
3. 26 to 100 books
4. 101 to 200 books
5. 201 to 500 books
6. More than 500 books
* Dummy coding with ‘10 books or less’ as the reference group</td></tr>
<tr><td>Country of birth and language background</td><td>0. Local birth or use of local language
1. Birth abroad and use of foreign language
* Dummy coding with ‘Birth abroad and use of foreign language’ as the reference group</td></tr>
<tr><td>Country of the birth of parents</td><td>1. Both of them were born abroad
2. One of them was born abroad
3. Both of them were born in the homeland
* Dummy coding with ‘Both of them were born abroad’ as the reference group</td></tr>
<tr><td>Health status</td><td>1. Excellent 2. Very good
3. Good 4. Fair
5. Poor
* Dummy coding with ‘Poor’ as the reference group</td></tr>
<tr><td rowspan="6">Learning strategies</td><td>When I hear or read about new ideas, I try to relate them to real life situations to which they might apply</td><td rowspan="6">1. Not at all
2. Very little
3. To some extent
4. To a high extent
5. To a very high extent
* Details are averaged</td></tr>
<tr><td>I like learning new things</td></tr>
<tr><td>When I come across something new, I try to relate it to what I already know</td></tr>
<tr><td>I like to get to the bottom of difficult things</td></tr>
<tr><td>I like to figure out how different ideas fit together</td></tr>
<tr><td>If I don't understand something, I look for additional information to make it clearer</td></tr>
<tr><td rowspan="4">Social capital</td><td>In the last 12 months, how often, if at all, did you do voluntary work, including unpaid work for a charity, political party, trade union, or other non-profit organization?</td><td>1. Never
2. Less than once a month
3. Less than once a week but at least once a month
4. At least once a week but not every day
5. Everyday
* Dummy coding with ‘Never’ as the reference group</td></tr>
<tr><td>People like me don't have any say about what the government does</td><td rowspan="3">1. Strongly agree
2. Agree
3. Neither agree nor disagree
4. Disagree
5. Strongly disagree
* Dummy coding with ‘Strongly agree’ as the reference group</td></tr>
<tr><td>There are only a few people you can trust completely</td></tr>
<tr><td>If you are not careful, other people will take advantage of you</td></tr>
</table>

Table A2: Estimation results of the depreciation rates without distinction between states of employment

		Average	Austria	Flanders (Belgium)	Czech Republic	Denmark	Estonia	Finland
β_k		0.018***	0.016***	0.022***	0.017***	0.021***	0.016***	0.020***
Depreciation rate (%)	δ_0	0.236*	-0.739	0.325	2.346***	0.075	2.903***	-1.372***
	age	0.010***	0.031***	0.012*	-0.021	0.020***	-0.029***	0.047***
Observations		102,767	4,732	4,528	5,625	7,044	6,945	5,102
Proficiency scores		272.51	269.50	275.48	274.01	270.79	275.88	287.55
		France	Ireland	Italy	Japan	Korea	Netherlands	Norway
β_k		0.021***	0.020***	0.013***	0.017***	0.019***	0.018***	0.018***
Depreciation rate (%)	δ_0	1.419***	0.105	-1.381	-2.442***	2.333***	-1.018*	-1.343**
	age	-0.006	0.002	0.029*	0.057***	-0.012	0.037***	0.033***
Observations		5,088	5,124	4,454	4,762	6,464	4,704	4,520
Proficiency scores		262.14	266.54	250.48	296.24	272.56	284.01	278.43
		Poland	Slovak Republic	Spain	Sweden	United Kingdom	United States	
β_k		0.016***	0.011***	0.021***	0.021***	0.016***	0.024***	
Depreciation rate (%)	δ_0	3.344***	1.646**	-0.802	-1.095**	-1.184*	1.369***	
	age	-0.044***	-0.027**	0.025***	0.031***	0.021**	-0.014*	
Observations		8,857	5,444	5,431	4,087	5,994	3,862	
Proficiency scores		266.90	273.85	251.79	279.23	272.46	269.81	

Note 1): Dependent variables are the natural log of the literacy scores, and the result of the control variables in <Table A1> is omitted because of a lack of space.

2): * p<.1, ** p<.05, and *** p<.01 significance levels

Source: OECD (2012).

Table A3: Estimation results of the depreciation rates for the employed and unemployed

			Average	Austria	Flanders (Belgium)	Czech Republic	Denmark	Estonia	Finland
β_k			0.017***	-	0.022***	0.017***	0.020***	0.016***	0.019***
Depreciation rate (%)	Estimation	δ_{01}	1.169***	-	0.421	-0.209	0.433	2.833*	-4.429***
		age	0.008	-	0.026	0.044	0.034	-0.018	0.127***
		wer	-1.136***	-	0.017	2.729	-0.574	-0.009	3.058**
		$age \times wer$	0.003	-	-0.018	-0.071	-0.013	-0.012	-0.085***
	Calculation	δ_{00}	0.033	-	0.437	2.520	-0.141	2.824	-1.371
		δ_{10}	0.012	-	0.008	-0.027	0.021	-0.030	0.042
		δ_{01}	1.169	-	0.421	-0.209	0.433	2.833	-4.429
		δ_{11}	0.008	-	0.026	0.044	0.034	-0.018	0.127
Observations			93,872	-	4,523	5,599	7,037	6,925	5,093

			France	Ireland	Italy	Japan	Korea	Netherlands	Norway
β_k			0.020***	0.018***	0.013***	0.016***	0.019***	0.018***	0.017***
Depreciation rate (%)	Estimation	δ_{01}	0.164	4.631***	0.618	-2.681***	1.113	-0.779	1.503
		age	0.030*	-0.070***	0.005	0.066***	0.019	0.044*	-0.003
		wer	1.409	-5.656***	-2.708*	0.287	2.023**	-0.270	-3.418**
		$age \times wer$	-0.041**	0.091***	0.036	-0.011	-0.050**	-0.008	0.046*
	Calculation	δ_{00}	1.573	-1.025	-2.090	-2.395	3.136	-1.049	-1.915
		δ_{10}	-0.011	0.020	0.041	0.055	-0.031	0.036	0.042
		δ_{01}	0.164	4.631	0.618	-2.681	1.113	-0.779	1.503
		δ_{11}	0.030	-0.070	0.005	0.066	0.019	0.044	-0.003
Observations			5,061	5,118	4,439	4,743	6,454	4,699	4,514

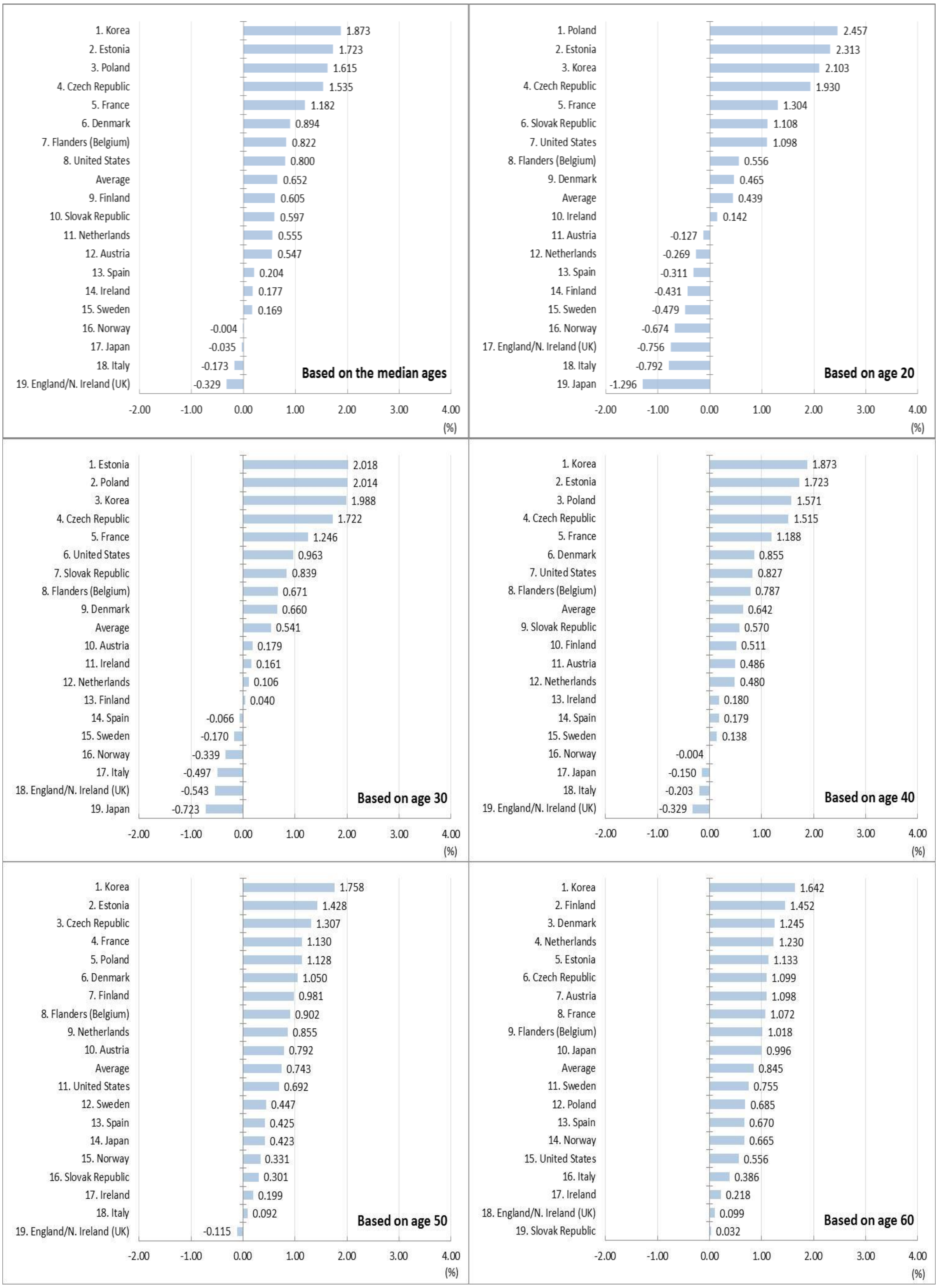
			Poland	Slovak Republic	Spain	Sweden	United Kingdom	United States	
β_k			0.015***	0.010***	0.021***	0.020***	0.015***	-	
Depreciation rate (%)	Estimation	δ_{01}	4.011**	8.291***	-1.148	-0.331	5.440**	-	
		age	-0.030	-0.119***	0.032*	0.040	-0.083**	-	
		wer	-0.479	-7.796***	0.606	-1.135	-7.401***	-	
		$age \times wer$	-0.021	0.112**	-0.013	-0.005	0.118	-	
	Calculation	δ_{00}	3.532	0.495	-0.542	-1.466	-1.961	-	
		δ_{10}	-0.051	-0.007	0.020	0.035	0.035	-	
		δ_{01}	4.011	8.291	-1.148	-0.331	5.440	-	
		δ_{11}	-0.030	-0.119	0.032	0.040	-0.083	-	
Observations			8,759	5,438	5,402	4,082	5,986	-	

Note 1): Dependent variables are the natural log of the literacy scores, and the result of the control variables in <Table A1> is omitted because of a lack of space.

2): * p<.1, ** p<.05, and *** p<.01 significance levels

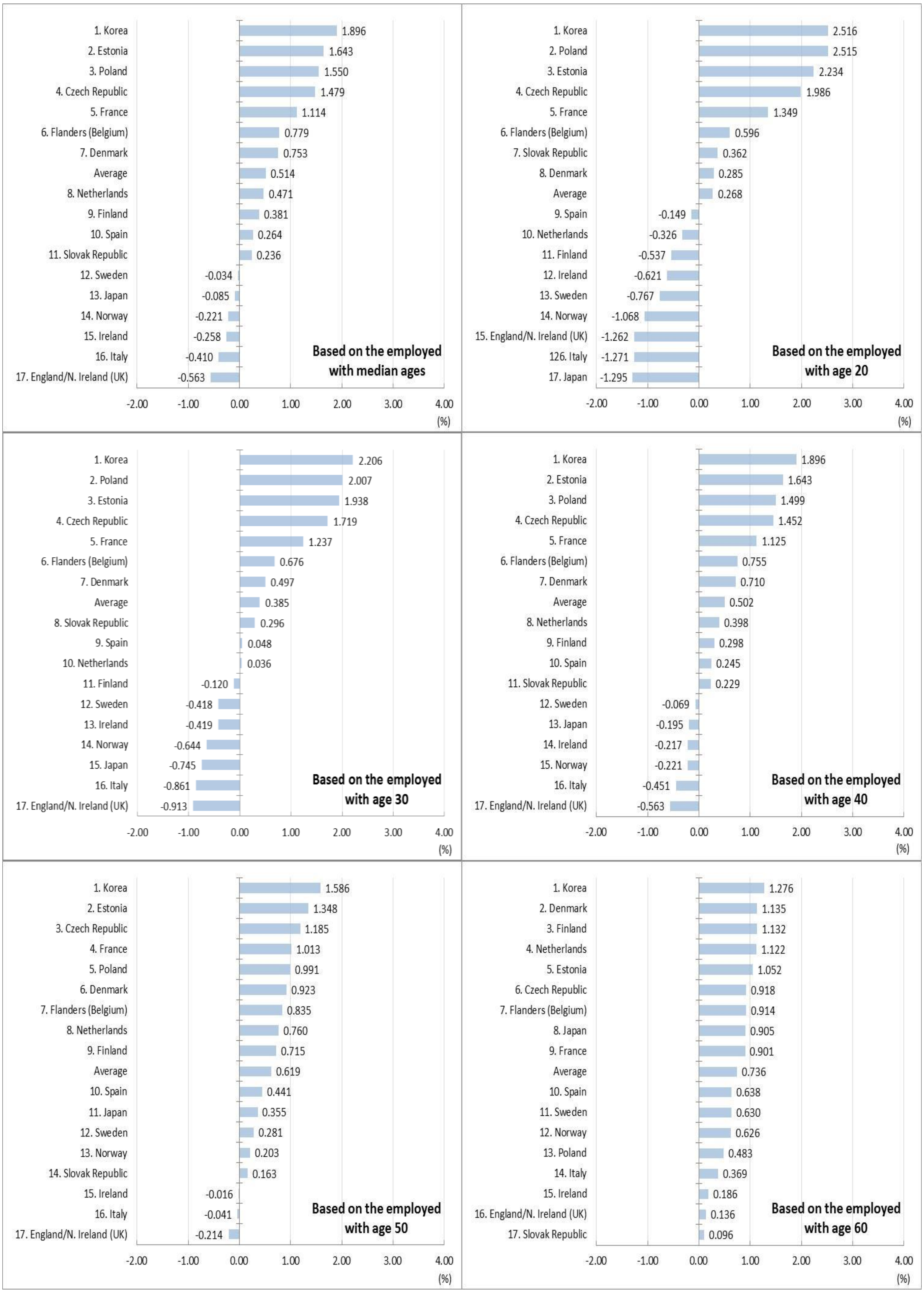
Source: OECD (2012).

Figure A1: International comparison of the depreciation rates without distinction between states of employment by age



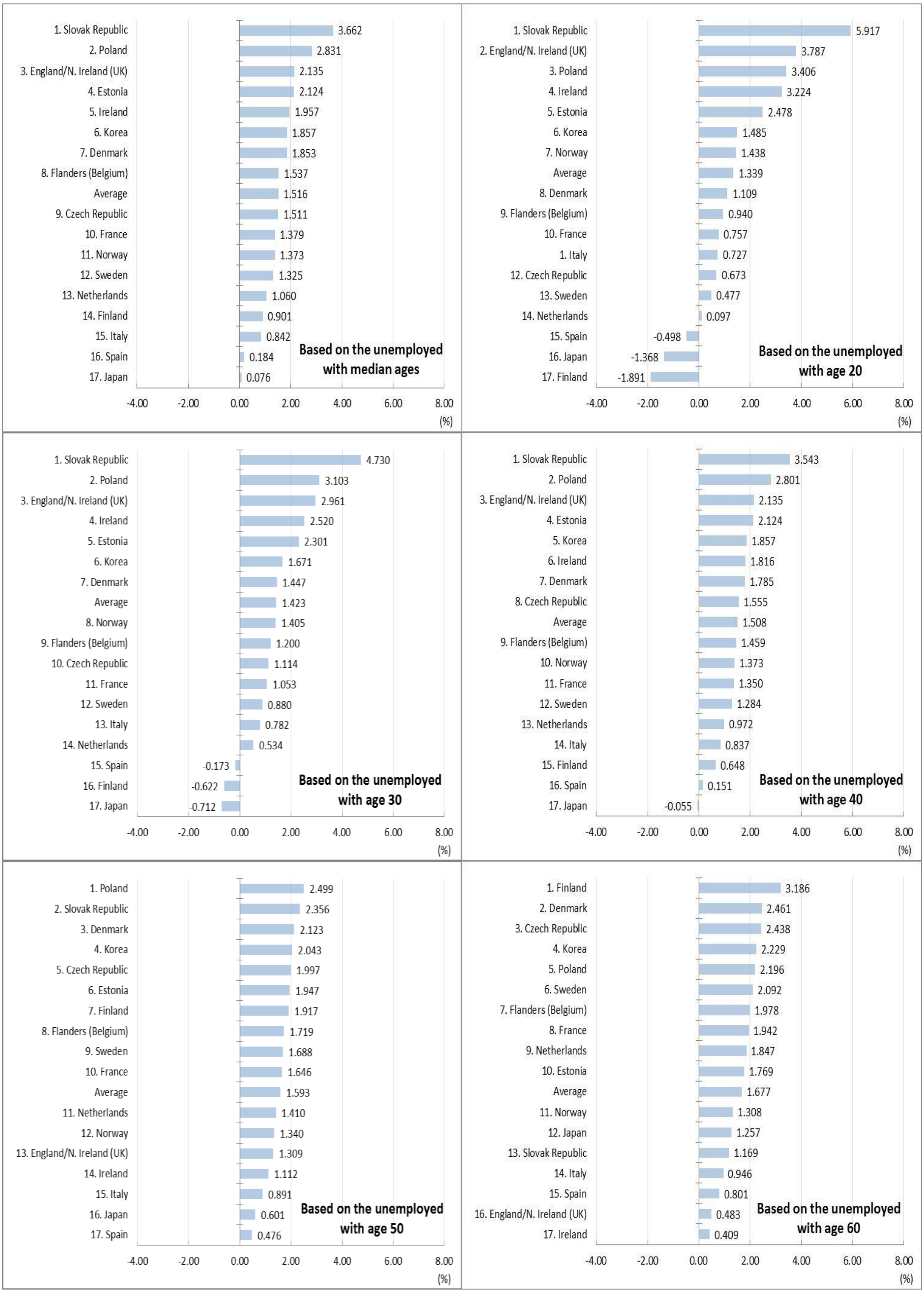
Source: OECD (2012).

Figure A2: International comparison of the depreciation rates for the employed by age



Source: OECD (2012).

Figure A3: International comparison of the depreciation rates for the unemployed by age



Source: OECD (2012).