DEMOGRAPHIC RESEARCH
A peer-reviewed, open-access journal of population sciences

DEMOGRAPHIC RESEARCH

VOLUME 30, ARTICLE 26, PAGES 753–794
PUBLISHED 13 MARCH 2014
http://www.demographic-research.org/Volumes/Vol30/26/
DOI: 10.4054/DemRes.2014.30.26

Research Article

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Abstract

BACKGROUND

Population aging proceeds with other socioeconomic developments, including educational expansion. Improvements in educational attainment lead to changes in demographic behaviors such as assortative mating, fertility, and the intergenerational transmission of education, which change the health of the elderly and the education of their offspring generation.

OBJECTIVE

We examine such a jointly-changing process in South Korea.

METHODS

We apply a recursive demographic model (Mare and Maralani 2006) by using the Korean Longitudinal Study of Ageing (KLoSA).

RESULTS

First, improvements in education lead to improvements in health among the elderly. Intermediate demographic factors make positive contributions to this improvement. Second, improvements in education lead to a decline in the ratios of offspring to the elderly because better-educated people have fewer children. However, this decrease is not substantial. Third, improvements in education increase the ratio of college-educated offspring to the unhealthy elderly because of improvements in both offspring's education and elderly health.

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CONCLUSION
The results suggest that improvements in education change configurations of the elderly and their offspring's generations, mitigating the negative consequences of population aging, such as increasing burdens of elderly support.

1. Introduction: Alternative ways to measure population aging

Population aging is a worldwide phenomenon, with the median age of the world population forecast to rise to 38.1 years in 2050 from 26.7 years in 2000 (Goldstein 2009). Population aging has important socioeconomic consequences because the age structure of a population determines the ratio of net producers to net consumers in a population. Hence, most industrialized countries are concerned about negative consequences of population aging and have attempted to develop pronatal policies that balance the population's age structure (Kalwij 2010; McDonald 2002). Population aging, however, also occurs in tandem with other socioeconomic changes such as educational expansion and improvements in health, which may mitigate the consequences of rising dependency ratios. Skirbekk, Loichinger, and Weber (2012) proposed a new measure of population aging—the cognition-adjusted dependency ratio (CADR)—and showed that the ranking for degree of population aging depends upon the measures: whereas India has fewer elderly people per working-aging individual than the U.S., the U.S. has fewer cognitively-limited elderly people per working-age individual than India. There is also evidence that increasing human capital per capita may offset the loss of total economic product due to fertility decline in a population level (Lee and Mason 2010) and the cost of supporting an elderly population may be reduced as the health of the elderly has continued to improve over decades (Martin, Schoeni, and Andreski 2010). In other words, "population aging is intrinsic to the processes that bring us a highly-educated population and comfortable standards of living" (Lee and Mason 2010: 179). In this study, we examine changing joint configuration of the elderly and their offspring in terms of health and educational attainment by applying a demographic model.

Accounting for the changing configurations of the elderly and the offspring generation is important in population aging. This has been largely overlooked, however, in previous research. Earlier studies found that the better-educated enjoy better health and survival chances in later life than do the less educated (e.g., Cutler and Lleras-Muney 2008; Elo and Preston 1996). Based on this positive educational gradient in health and survival chances, recent studies have used educational attainment in projecting the size of the elderly population in the future (Batljan, Lagergren, and

Thorslund 2009; Batljan and Thorslund 2009; Joung et al. 2000; Lutz 2009). These studies have examined how the expected change in the educational composition among the elderly may affect the size of the elderly population and the prevalence of serious illness among them. Although these studies provide better estimates of the size and the composition of the elderly population than do conventional projection models based on age and sex, they do not account for the fact that changes in the educational composition in one generation also lead to changes in educational attainment of the next generation, who will provide the elderly with the support. Extending Mare and Maralani's (2006) recursive demographic model, the current study proposes a new model that examines the implications of education for population aging by accounting for jointly-changing configurations of elderly health and educational attainment of the offspring generation.

2. Education and elderly health: Demographic pathways

Researchers have studied the relationship between education and health in a variety of ways. First, studies have documented the positive association between education on one hand and health and survival chances on the other (e.g., Elo and Preston 1996). Recent studies have found significant causal effects of education on health and mortality in the United States and Scandinavian countries by using natural experiments induced by institutional changes (Arendt 2005; Lleras-Muney 2005; Oreopoulos 2007; Spasojevic 2011). These studies commonly exploit the fact that compulsory schooling laws typically impose the restrictions on school-leaving ages. These laws were introduced in varying times and places. These differences create exogenous variations in school-leaving ages across birth cohorts and places, leading to differences in educational attainment across cohorts and places. These studies used such variations as an instrument to estimate causal effects of education on health and mortality. Second, another line of research studies mediating mechanisms such as health-related behaviors and social, psychological, and economic resources (Ben-Shlomo and Kuh 2002; Chandola et al. 2006; Ross and Wu 1995). These studies show that better-educated people enjoy better health and survival chances than the less-educated because the formers are less like to engage in risky behaviors and possess more socioeconomic resources the latter. Third, recent studies have used educational attainment to project the size of the elderly population in the future (Batljan, Lagergren, and Thorslund 2009; Batljan and Thorslund 2009; Joung et al. 2000; Lutz 2009). These projection studies show that improvements in education among the elderly would mitigate the problems of population aging because education improves elderly health. Despite their difference in methods and focuses, all of these studies suggest that improvements in education will lead to better health among the elderly, mitigating the socioeconomic pressure of population aging to some extent.

We should be cautious, however, in interpreting the implications of improvements in education on population aging. Whereas improvements in education lead to better health among the elderly, they also lead to changes in intervening demographic processes. First, educational expansion will lead to fertility decline, given the negative relationship between education and fertility (Bongaarts 2003; Jejeebhoy 1995; Skirbekk 2008).[5] Hence, educational expansion may accelerate population aging by further unbalancing the age structure of the population. However, improvements in education and the subsequent reduction in fertility are likely to lead to better educational outcomes among offspring. This positive intergenerational association in educational attainment has been found consistently (e.g., Mare 1981; Shavit and Blossfeld 1993). Recent studies have documented that the relationship between mother's education and children's education is indeed causal in the United States by using the variations in school-leaving ages as an instrument (Oreopoulos, Page, and Stevens 2006). The higher levels of education in the offspring's generation may also lessen the negative socioeconomic consequences of population aging. Second, studies on educational assortative mating consistently found a strong association between husband's and wife's education in the United States (Mare 1991; Schwartz and Mare 2005) and in other countries (Park and Smits 2005). This strong pattern of educational assortative mating suggests that improvements in educational attainment also lead to changes in spousal educational attainment, which, in turn, affect the level of fertility and offspring's educational outcomes.

These intervening demographic variables, such as spousal education, level of fertility, and children's education, are also associated with health and mortality. First, spouse's education is positively associated with an individual's self-reported health (Huijts, Monden, and Kraaykamp 2010; Monden et al. 2003) and survival chances (Bosma et al. 1995) in various European countries: having a better-educated spouse enhances one's own health. Second, children's education is positively associated with the health and survival chances of the elderly because better-educated children provide their parents with more support than do their less-educated counterparts (Friedman and Mare 2010; Zimmer, Hermalin, and Lin 2002).

[5] The causality of this relationship remains controversial. For example, Monstad, Propper, and Savanes (2008) showed no causal effect of education on the level of fertility by using the change in the legal age of compulsory education in Norway as an instrument. A recent study also suggests that reverse causation is more plausible because the level of fertility does not vary across educational levels if childbearing has no effect on educational progressions (Cohen, Kravdal, and Keilman 2011). The bulk of evidence, however, suggests that there is a negative relationship between education and fertility. See Skirbekk (2008) for a review of this literature.

Third, family size is also associated with health in later life, although this relationship is complicated. On one hand, evolutionary biology suggests a negative association between family size and health because of the trade-off between investment of resources in somatic maintenance and reproduction (Westendorp and Kirkwood 1998). In other words, if a woman produces too many children, this excessive reproduction may harm her health. Similarly, having and raising a child may lead to economic strain, role overload, and stress, leading to worse health (Hank 2010). On the other hand, parenthood can also improve health due to more involvement in community activities and support from children in later life (Hank 2010). In this sense, the association between family size and health depends on the relative importance of these competing biological and social factors. There is mixed empirical evidence. Among women born in the early twentieth century in England and Wales, childless women and women with more than five children had higher mortality rates than the others, suggesting a non-monotonic relationship (Grundy and Tomassini 2005). Engeleman et al. (2010) also found a positive association between family size and difficulty with activities of daily living (ADLs) in Egypt. Further, the relationship between family size and health also depends on the socio-economic context. There is positive association between family size and self-rated health among the West German women age 50+, but because of differences in labor market participation this relationship is reversed in East Germany (Hank 2010). In sum, multiple demographic factors, including assortative mating, differential fertility, and the intergenerational transmission of education contribute to the relationship between education and elderly health.

Previous studies, however, did not examine this joint process as a whole. The model proposed in this study complements previous research by providing a framework that integrates demographic elements into research on elderly health disparity and population aging. This demographic approach first appeared in Mare and Maralani (2006), which examined the intergenerational effect of education in Indonesia. Subsequent research applied this approach to different societal contexts (e.g., Choi and Mare 2010; Kye and Mare 2012; Maralani 2013). The current study extends this approach to studying implications of educational differentials in elderly health on population aging. Such an extension has crucial implications. Scholarly and policy discussions about support for the elderly have focused on the age structure of the population because it is an important element to consider in developing the elderly support system (Lee and Tuljarpurkar 1997). Yet health differences among the elderly population and educational differences among the offspring generation should also be taken into account because these differences will determine how much the elderly generation will need to maintain an adequate quality of life and how much the offspring generation can contribute to supporting their parental generation.

3. Research questions

We examine how changes in educational attainment lead to changes in the distribution of elderly health and the distribution of the offspring generation's educational attainment in South Korea by focusing on demographic processes. Specifically, we examine the following research questions:

1. How do changes in the distribution of educational attainment lead to changes in the distribution of health among the elderly in South Korea?
2. How do assortative mating, differential fertility, and the intergenerational transmission of education mediate the relationship between education and elderly health in South Korea?
3. How do changes in the distribution of educational attainment affect the joint distribution of the elderly health and the offspring generation's education in South Korea?

4. Population aging and socioeconomic development in South Korea

South Korea is one of the most rapidly aging countries in the world (Organisation for Economic Co-operation and Development [OECD] 2011). The elderly support ratio in South Korea—defined as the number of people of working age (20-64) per person 65 and older—was 6.3 in 2009, above the OECD average of 4.2. South Korea's elderly support ratio, however, is projected to be 1.5 in 2050, lower than the OECD average of 2.1. Rapid increases in life expectancy and decreases in the fertility rate are responsible for this rapid population aging. In South Korea, life expectancy at birth was 77.9 years in 2008, a 12.5 year increase from 1983 (OECD 2011), and the total fertility rate decreased from 6.0 to 1.2 in less than 50 years since 1960 (Jun 2004). South Korea has not yet developed old-age pension programs to cope with this rapidly aging population. For example, the percentage of gross domestic product (GDP) spent on publicly funded old-age survivor benefits in South Korea is the lowest among the OECD countries (Kapteyn 2010). This lack of public support for the elderly, combined with the increasing prevalence of the nuclear family that may reduce the total amount of familial support for the elderly on average (De Vos and Lee 1993), raises concerns about the deterioration of quality of life in old age.

South Korea also experienced rapid educational expansion in tandem with demographic changes. In South Korea, less than five percent of women born in the 1920s had ever attended college, but more than 50 percent of women born in the 1970s did so (Korea National Statistical Office 2010). Average years of schooling increased from 6.4 years in 1970 to 11.7 years in 2010. The level and the rate of change are higher than most other rapidly developing Asian countries (Lee and Francisco 2012). Strong parental educational investment and export-driven economic development fostered the exceptional educational expansion, and was conducive to rapid economic development in turn (Lee 2008; Lee and Francisco 2012). Such a dramatic increase in educational attainment leads to rapid accumulation of human capital, which has important implications for population aging. Rapid educational expansion should contribute to improvements in elderly health given strong educational gradients in health. Khang et al. (2004) showed persistent educational differentials in elderly health and mortality in South Korea. At the same time, educational expansion also makes the population older due to subsequent reductions in fertility and improved survival chances, as noted above.

The rapid socioeconomic and demographic changes make South Korea well-suited to examine the implications of improvement of education for population aging. Population aging and educational expansion are worldwide phenomena, but the pace of changes in South Korea is exceptionally fast. Chang (2010) characterized this rapid socioeconomic and demographic transformation as “compressed modernization”. While industrialization and demographic transition took more than a century in Western countries, South Korea have completed both in less than a half century. This compressed process accompanied unexpected and undesirable consequences, including overly rapid population aging. The policies that promoted development, ironically, also contributed to furthering population aging in South Korea. Strong implementations of family planning program contributed to fertility decline (Choe and Park 2006).[6] The rapid educational expansion also would have been impossible if there had been no policy effort to promote more schooling. The very family and education policies, which promoted economic development, accelerated population aging in turn. These policy interventions succeeded in achieving the intended goals, but furthered population aging. These policies, however, affected the composition of educational attainment and health as well as age structure of population. Therefore, it is interesting to examine the implications of changing educational attainment on population aging in South Korea.

5. Data

We use the Korean Longitudinal Study of Ageing (KLoSA), a biannual longitudinal survey of the non-institutionalized Korean population, age 45 and older. The KLoSA collected data on socio-demographic characteristics, income, assets, family

[6] Reduction in family size was claimed to help invest more resources on individuals, which is conducive to economic development in the 1970s. See Hodgson (1988) for a critical review on this topic.

composition, health, employment, and life satisfaction. The household and individual response rates at the baseline year survey are 81.5 and 75.4 percent respectively, which is comparable with panel surveys in the U.S., such as the Health and Retirement Survey 1992 (Korea Labor Institute 2007). The KLoSA is a stratified multi-stage probability sample. First, it stratified 15 cities and provinces. Each city and province is first stratified by type of area (urban and rural), and then by type of housing (apartment complex and single family homes). There are 60 possible strata (15×2×2). Eight of the cities do not have rural areas, however, resulting in 52 strata. Out of 52 strata, 1000 enumeration districts were selected, and between 1 and 12 households were interviewed in each enumeration district. We take this sampling design into account in our analysis.

The analytic samples are based on currently or previously married women who were 60 years or older in 2006, the baseline survey year. For each selected woman, we assemble information on her education, husband's education, number of children, the schooling level of each living child (aged 20+), self-reported health, and two measures of functional limitations in everyday life. We classify educational attainment of women and their husbands into four categories: no schooling, elementary education (one to six years of schooling), secondary and some high school (seven to 11 years), and high school graduates and above (12+ years). The educational attainment of their offspring also has four categories, but captures a possible higher educational attainment for the offspring's generation: no schooling or elementary school (zero to six years), junior high school (seven to nine years), high school (10 to 12 years) and some college and above (13+ years). The survey collected information on the total number of surviving children only rather than the number of total births. Because child mortality is negatively associated with maternal education in South Korea (Choe 1987; Kim 1988), using the number of surviving children would underestimate the educational differentials in fertility and sibship size. However, mortality rates among children and young adults are fairly low in South Korea (Kim 2004), suggesting that this data limitation will not seriously bias our results.

We use three different measures of health outcomes: self-reported health, difficulty with activities of daily living (ADLs), and difficulty with instrumental activities of daily living (IADLs). Data for self-reported health was originally collected in five categories: "very good", "good", "fair", "poor", and "very poor". In this study, we use a dichotomized variable: good health ("good" and "very good") and other ("fair", "poor", and "very poor"). We also use two measures of functional limitations: difficulty with ADLs and IADLs. The ADLs items include dressing, washing, bathing, eating, getting out of bed, using toilets, and urinating. We classify respondents as "functionally limited in ADLs" if they report a limitation in any of these seven items. The IADLs items include brushing hair, cleaning, preparing meals, washing clothing, traveling a short distance without using transportation, traveling with transportation, shopping, managing money, making a telephone call, and taking medicine. We classify respondents as "functionally limited in IADLs" if they report a limitation in any of these ten items. These two measures of functional limitations complement self-reported health in that they measure different aspects of independent living among the elderly (Wiener et al. 1990).[7]

We construct two analytic samples: a marriage/fertility/health sample and a transmission sample. The marriage/fertility/health sample is used to estimate the equations for assortative mating, fertility, and health outcomes. The unit of analysis in this sample is an elderly woman age 60 and older. The transmission sample is used to estimate the equation for children's education. The unit of analysis in this sample is offspring of the marriage/fertility/health sample aged 20 and older.

6. Methods: A recursive demographic model for education and elderly health

6.1 Basic model

We extend Mare and Maralani's (2006) model to examine health disparity by education. In this model, the elderly women's health is jointly determined by educational attainment, assortative mating, differential fertility, and children's education. Formally, we can express the demographic processes that generate health disparity by education as follows:

$$h_{kl|i} = p_{k|i}^{M} \times r_{ik} \times p_{j|iks}^{O} \times p_{l|ikrP^{O}}^{H} \quad (1)$$

where *i*: woman's education (*i*=1…4), *k*: husband's education (*k*=1…4), *j*: children's education (*j*=1…4), *s*: the number of sibling, and *l*: health outcomes (*l*=0,1).

The $h_{kl|i}$ represents the rates at which women at given level of education *i* marry men with education level *k*, and have elderly health status *l*. Right-hand terms in equation (1) also account for the number and educational attainment of children. The term $p_{k|i}^{M}$ represents the probability that a woman in education category *i* marries a husband with educational attainment *k*. The r_{ik} is the expected number of children born to couples with woman's education *i* and husband's education *k*. The $p_{j|iks}^{O}$ is the

[7] ADLs and IADLs are also subject to respondents' subjective evaluation of their conditions. Because the definition of "limitation" may differ by individual, this is not an objective health measure. There are studies to examine validity and reliability of these measures (e.g., Hartigan 2007). The current study does not focus on the measurement issues. Instead, we use three different outcomes of elderly health to see if the patterns are robust to different measures of outcome.

probability that an offspring has educational attainment *j*, conditional on the woman's education *i*, husband's education *k*, and the number of siblings *s* for children of these couples. Here, the number of sibling (*s*) is the number of children of couple (*r*) minus 1. Finally, the $p^{H}_{l|ikrP^{O}}$ is the probability that a woman with education category *i*, who married a husband with education category *k*, has the number children *r* and distribution of children's education p^{0}, has health outcome *l*. We estimate the four equations separately: ordinal logistic regression models for husband's education ($p^{M}_{k|i}$) and offspring's education ($p^{O}_{j|iks}$), Poisson regression for the number of children (r_{ik}), and binary logistic regression for the health outcomes ($p^{H}_{l|ikrP^{O}}$). This model is recursive. We assume the followings; woman's education determines husband's education; woman's and husband's education determines the number of children; woman's education, husband's education, and the number of siblings determines children's education; and woman's health is determined by all forgoing variables. We use the transmission sample for offspring's education ($p^{O}_{j|iks}$), and the marriage/fertility/health sample for other equations.

Using estimated parameters in each regression model, we estimate conditional probability of each component ($p^{M}_{k|i}$, r_{ik}, $p^{O}_{j|iks}$, and $p^{H}_{l|ikrP^{O}}$) in equation (1), which yields estimated $h_{kl|i}$. Using the estimated $h_{kl|i}$ and observed marginal distribution of women's educational attainment (W_i), the marginal distribution of elderly women's health outcomes is estimated in the following way:

$$H_l = \sum_{i=1}^{4} \sum_{k=1}^{4} h_{kl|i} \times W_i \qquad (2)$$

where H_l is the distribution of expected elderly health and W_i denotes women's educational attainment respectively.

In the model of health ($p^{H}_{l|ikrP^{O}}$) in equation (1), children's education is used as a covariate to predict elderly health. Each individual has a different number of children, and there should be multiple ways to include this measure in the model, such as the highest, mean, or lowest level attained by the children. In this study, we use the percentage of children in each education category to capture the level of children's education. Because this model also includes the number of children as another covariate, we can distinguish the impact of the number of children on women's elderly health from the level of children's education. Childless women have missing data for children's education. In this study, we set childless women's value for children's education category to zero. This specification is equivalent to a "dummy variable adjustment" method in handling missing data.[8] This choice does not affect the coefficients of children's educational attainment, and assumes a linear relationship between the number of children and the logit of being healthy.

6.2 Simulation

Using the parameters estimated from the equation (1), we simulate how the distribution of elderly health responds to changes in distribution of education. We present the results from two different simulations: a five percent change in women's schooling 1) from zero to 12+ years and 2) from 7-11 to 12+ years.[9] The purpose of simulation is to illustrate how demographic variables intermediate the relationship between education and elderly health, leading to changes in joint configuration of elderly health and offspring's education.[10] Changes in educational attainment will change health outcomes in later life in multiple ways as described in a previous section (2. Education and elderly health: Demographic pathways). First, improvements in education will enhance health independently of subsequent changes in demographic behaviors because education improves economic conditions, provides more social-psychological resources, and encourages a healthier lifestyle (e.g., Ross and Wu 1995). But demographic elements also affect changes in elderly health. Increases in education will affect the choice of spouse[11], as well as the quantity of children and their education level. By conducting simulations in which each element changes or is held constant according to changes in education, we can quantify the contribution of each element to the health in later life. In Appendix A1, we present how simulations work in detail.

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[8] Suppose that some data are missing on a variable X. Then, we create a dummy indicator for missing (D) and a new variable (X*) that equals values of X if data are not missing and that equals to any constant (c) if data are missing. Then, the coefficients of X* capture the expected changes in an outcome variable associated with one unit change in X when data are not missing regardless of the choice of c and the coefficient of D captures the expected difference in outcome between the missing cases and the non-missing cases that have value of c in X (Allison 2001: 9-11).

[9] We examined six different scenarios: five percent of women change their education; from zero to 12+ years, from zero to 1-6 years, from zero to 7-11 years, from 1-6 to 12+ years, from 1-6 to 7-11 years, and from 7-11 to 12+ years. Among them, we presented two extreme scenarios.

[10] A five percent change is chosen to illustrate how the model works instead of predicting realistic trends. This choice is somewhat arbitrary, and magnitude of changes might be larger or smaller. To complement this weakness, we present projection results using expected changes in Korean women's educational attainment.

[11] This study assumes that husband's education is determined by wife's education. Hence, upgrading of women's education leads to the equivalent amount of upgrading of husband's education. However, this may not reflect the historical reality because women's education increased more rapidly than men's education in South Korea, similar to most other industrialized countries. In this sense, this study may overstate to some extent the influences of assortative marriage on children's education and health of the elderly.

After simulations, we compute two different ratios. First, we compute the ratios of the simulated proportion healthy (or functionally not limited) to the baseline (observed) proportion healthy. If the ratios are greater than one, this means that improvements in educational attainment lead to improvements of health among the elderly. These ratios, computed in various conditions in which intervening demographic mechanisms are present or absent, show the proportional changes in the share of the healthy elderly and the contribution of demographic elements to such changes.

Second, we compute the generational support ratios. The measure proposed here is the ratio of the number of offspring to the number of the female elderly over age 60. This measure captures how many people in the offspring's generation will be available to support an elderly woman in the parental generation.[12] By computing the ratios of simulated generational support ratios to baseline generational support ratios, we can assess the relationship between education and generational support ratios. We also compute this measure by elderly health status and offspring's educational attainment. By comparing the joint distributions of elderly health and children's education before and after the simulations, we can see how changes in educational attainment in one generation lead to changes in the generational support structure in the population by accounting for heterogeneity in elderly health and the offspring generation's education. Here, we focus on the ratios of college-educated offspring to the unhealthy elderly. This can be an alternative measure of population aging similar to cognition-adjusted dependency ratio (CADR) (Skirbekk, Loichinger, and Weber 2012). An advantage of our measure is to account for changing configuration of offspring's generation as well as elderly health.

Because our sample only includes female respondents, the results may not be generalized to the entire population including males. First, improvements in elderly health among men due to upgrading education may differ from women. Second, the simulated changes in women's education may lead to changes in the sex ratios among the elderly. For these reasons, our results may not be able to be generalized for the entire population. Nonetheless, we restrict our analyses to women for simplicity. In the final section, we discuss the implications for this simplification.

Because key measures in our simulation analyses are based on the parameter estimates from four different regression analyses, it is difficult to assess sampling variability analytically. Hence, we use a bootstrapping method to compute standard errors (Efron and Tibshirani 1993). We account for the KLoSA's stratified multi-stage sample design in computing bootstrap standard errors (Lee and Forthofer 2006). First, we resample 1,000 bootstrap samples with replacements from the original data set

[12] This generational support ratio is different from the typical support ratio, which refers to the ratio of the number of working age people (age 20-64) to the number of pension-age people (age 65+). These two measures deviate from each other primarily due to variations in fertility timing and different age ranges.

because 1,000 replications are sufficient to compute a reliable confidence interval (Efron and Tibshirani 1993). Each bootstrap sample is composed of strata that include the same number of primary sampling units as the original data. Second, we compute 1) the ratios of simulated-proportion healthy to baseline-proportion healthy and 2) measures of generational support ratios described above for each bootstrap sample. Finally, we estimate standard errors of estimates by computing the standard deviations of these ratios.

6.3 Exogeneity of education and age structure of population

On the individual level, we assume that education is exogenous to all other variables in the model. In other words, husband's education, the number of children, offspring's educational attainment, and women's health status are assumed to be determined endogenously. This strong assumption may not reflect the reality for several reasons. First, the relationship between women's and their husbands' education is reciprocal rather than causal (Logan et al. 2008). Second, the statistical association between women's education and level of fertility may not be causal, either. Studies relying on natural experiments also suggest that unobserved confounders could seriously bias the estimate of effect (Monstad, Propper, and Salvanes 2008; Skirbekk, Kohler, and Prskawetz 2004). Finally, there is evidence that education is causally linked to children's education (Oreopoulos, Page, and Stevens 2006) and a person's own health and mortality (Arendt 2005; Lleras-Muney 2005; Oreopoulos 2007; Spasojevic 2011). Such causal effects apply to sub-populations who comply with policy interventions or institutional changes. However, they may not be generalized to the entire population (Angrist and Pischke 2009). Not everybody changes educational attainment by responding to such institutional changes. For example, most college-educated individuals may not be affected by changes in compulsory schooling because they would progress further than compulsory schooling in any case. Due to the lack of causal estimates in the population level, we cannot determine whether or not each relationship is causal. Nevertheless, our analysis proceeds as if education is exogenous to all other variables to illustrate demographic pathways through which education differentials are accrued throughout the life course while avoiding overly complicated data analysis.

On the population level, we assume that educational expansion accelerates population aging, improves elderly health, and provides better-educated offspring. However, the relationship between education, on one hand, and age structure and health, on the other, is complex. The life cycle wealth model for population aging, for example, shows that countries with lower fertility are spending more on human capital per child (Lee and Mason 2010: 178).[13] Life cycle wealth, which affects investment on children's education, is assumed to respond to population aging. In this sense, changes in age structure of population may affect the distribution of educational attainment in population level. Nevertheless, the simulation analysis in this study assumes the exogeneity of education in the population level. In other words, we examine how changes in the distribution of educational attainment lead to changes in (education- and health status-specific) support ratios in population. The purpose of this paper is not to establish causality between education and the age structure of a population. Instead, we aim to describe how differential demographic behaviors intersect educational expansion and population aging.

6.4 Differential mortality

There are substantial educational differentials in survival chances (Elo and Preston 1996; Lleras-Muney 2005). We also have evidence for educational differentials in adult mortality and maternal educational differentials in child mortality in South Korea (Choe 1987; Kim 1988; Kim 2004). Hence, improvements in educational attainment should increase the number of survivors in old age and the number of surviving offspring. Because child mortality in South Korea is fairly low, we expect that educational differentials in adult mortality will matter more than maternal educational differentials in child mortality. In other words, educational upgrading makes the population older as well as healthier. Increasing longevity eventually increases the number of less healthy or vulnerable people in the population. To fully account for the implications of changing survival chances, we need information on the joint distribution of survival probability, health status, own and spousal education, and the number and educational attainment of offspring. Unfortunately, such data do not exist for South Korea. Instead, we address the implications of differential mortality by using information available from period life tables by education. In Appendix A2, we present a supplementary analysis to assess the implications of differential mortality by using bivariate relationships between education and mortality on the aggregate level. Based on this analysis, we assume that the simulated changes in women's education lead to a 1 percent increase in elderly population. Please see Appendix A2 for more detailed discussion.

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[13] Life cycle wealth is defined as "a desire for claims on future output to support consumption in old age" (Lee, Mason, and Miller 2000: 194). This form of wealth increases, following rising longevity and decreasing fertility. This suggests that saving behaviors respond to the changing age structure of the population.

7. Results

7.1 Descriptive results

Table 1 shows summary statistics for variables of interest. In addition to health outcomes and key covariates, we present the distribution of two control variables: age and rural residence. Age is an important confounder given the educational expansion, fertility decline, improvements in health conditions over time, and the deterioration of health conditions as individuals age. If we do not control for age, we might mistakenly attribute changes due to age and birth cohort to education. Rural residence is also an important confounder due to the long-standing rural-urban inequality in various socioeconomic outcomes in South Korea.[14] Of course, there would be more confounding variables that we cannot control for because of data limitations. Subsequent results are subject to biases due to this omission.

Several patterns are noteworthy. First, husbands' educational attainment is higher than their wives, reflecting a gender gap in educational opportunity in the past. Second, whereas only 17.6 percent of elderly women report that their health conditions are "good" or "very good", a majority of women report no functional limitations in ADLs and IADLs. In particular, more than 90 percent of women have no problem in ADLs. Compared with studies in Canada and the United States (Menec, Shooshtari, and Lambert 2007; Glymour et al. 2010), the discrepancy between the self-reported and more objective measures of health is more substantial in South Korea. This discrepancy may reflect cross-national differences in reporting health-related measures, a subject for future research. Finally, offspring's educational attainment is much higher than their parents. In addition, Table 1 shows that the distributions of variables for mothers of the transmission sample (which consists of the elderly women's offspring) are different than those in the marriage/fertility/health sample (which consists of the elderly women). The elderly women with more surviving children are represented in greater numbers in the transmission sample, making the distributions different. The mothers of the transmission sample on average are slightly older, more likely to live in rural areas, less educated, more likely to have less-educated husbands, and less healthy than those in the marriage/fertility/health sample.

[14] Previous studies have documented rural-urban differences in sex ratios among individuals in their 20s (Kim 1996), fertility (Kim, Lee, and Kim 2006), chance of transitioning to upper levels of school (Phang and Kim 2002), and longevity (Yoon 2010).

Table 1: Descriptive statistics

	Marriage/Fertility/ Health Sample	Transmission Sample
Age (%)		
60-64	32.1	27.0
65-69	23.5	23.6
70-74	17.8	19.7
75-79	14.5	16.4
80+	12.2	13.2
Total	100.0	100.0
Rural (%)	31.2	36.0
Own education (%)		
0	41.8	46.4
1-6	38.7	37.4
7-11	10.7	9.5
12+	8.8	6.7
Total	100.0	100.0
Husband's education (%)		
0	29.2	31.8
1-6	30.3	31.8
7-11	15.3	14.1
12+	25.2	22.3
Total	100.0	100.0
# of children (s.d.)	3.71(1.68)	-
# of siblings (s.d.)	-	5.48 (1.62)
Children's education (%)		
0-6	-	10.9
7-11	-	11.5
12	-	42.8
13+	-	34.9
Total	-	100.0
Health (%)		
SRH=good	17.6	16.3
No ADLs	92.1	91.7
No IADLs	80.3	78.9
Observations (n)	3,006	11,286

Table 2 presents the bivariate relationships between women's education and other variables. First, educational homogamy is strong, particularly for highly educated women. Ninety-three percent of women with high school diplomas married husbands in the same category. Second, women tend to marry "up". This is particularly the case for women with some secondary schooling: 63 percent of women in this category married husbands with a high school diploma. Third, women's education is negatively associated with the level of fertility: whereas women with no formal schooling have 4.1 surviving children on average, this number is 2.9 among women with a high school diploma. Fourth, we can see strong upward intergenerational mobility. Sixty percent of offspring whose mothers had no schooling completed at least high school, and almost all offspring of women with a junior high school education or above earned a high school diploma. Finally, the last panel of Table 2 shows the relationship between education and health outcomes. We can see educational gradients in self-reported health and IADLs. Whereas twelve percent of women with no schooling reported "good" health conditions and 69 percent of such women reported no functional limitations in IADLs, the corresponding figures are 33 percent and 94 percent among women with a high school diploma. By contrast, there is no such association between education and ADLs.

Table 2: Distribution of outcomes by women's educational attainment

	Husband's education (%)				
Women's Education	**0**	**1-6**	**7-11**	**12+**	**Total**
0	61.6	25.9	7.4	5.0	100.0
1-6	8.0	48.0	22.8	21.2	100.0
7-11	2.0	6.2	28.6	63.2	100.0
12+	1.3	1.9	3.7	93.1	100.0
Total	29.2	30.3	15.3	25.2	100.0
Observations (n)			3,006		

	# of children	
Women's Education	**Mean**	**S.D.**
0	4.12	1.87
1-6	3.59	1.53
7-11	3.30	1.37
12+	2.85	1.12
Total	3.71	1.68
Observations (n)	3,006	

Table 2: (Continued)

	Offspring's education (%)				
Women's Education	**0-6**	**7-11**	**12**	**13+**	**Total**
0	20.3	17.9	44.9	16.8	100.0
1-6	3.7	8.0	47.5	40.8	100.0
7-11	0.5	1.4	33.3	64.8	100.0
12+	0.3	0.5	14.9	84.3	100.0
Total	10.9	11.5	42.8	34.9	100.0
Observations (n)			11,286		

	Health outcomes		
	% Good health	*% No ADLs*	*% No IADLs*
0	12.1	87.1	68.6
1-6	17.1	95.0	87.0
7-11	29.0	96.4	90.9
12+	32.7	97.7	93.9
Total	17.6	92.1	80.3
Observations (n)		3,006	

7.2 Regression analyses

Table 3 presents the estimates of regression analyses for husband's education, fertility, offspring's education, and three health outcomes. Coefficients along with *t*-ratios are reported. These estimates are obtained using STATA 11's survey estimation commands that account for the complex survey design of the KLoSA. We interpret that the coefficients are significantly different from zero if the *t*-ratios are greater than 2.

The results show that older women are more likely to marry less-educated husbands, have more children, have less-educated children, and be less healthy. Rural residents tend to marry less-educated husbands, have more children, and have less-educated children. Rural residence, however, is not significantly associated with subjective and objective health conditions.

The results point to several other conclusions about the relationship between women's education and outcome variables. First, there is a strong association between women's education and husbands' education: better-educated women married better-educated husbands. This strong assortative mating pattern suggests that marriage may contribute to widening health disparity by education.

Table 3: Parameter estimates for regression analyses

	Husband Education (Ologit)		Fertility (Poission)		Offspring Education (Ologit)		Self-reported health (Logit)		ADLs (Logit)		IADLs (Logit)	
	β	t	β	t	β	t	β	t	β	t	β	t
Age												
60-64												
65-59	-0.097	-0.900	0.145	7.190	-0.161	-1.880	-0.324	-2.330	-0.355	-1.040	-0.360	-1.750
70-74	-0.504	-4.120	0.230	10.240	-0.319	-3.400	-0.407	-2.580	-0.832	-2.480	-1.043	-5.190
75-79	-0.806	-6.600	0.241	8.380	-0.595	-5.550	-0.703	-3.750	-1.371	-4.190	-1.606	-7.710
80+	-1.402	10.400	0.190	5.630	-0.812	-6.560	-0.288	-1.440	-2.326	-7.410	-2.509	-11.810
Rural	-0.461	-5.070	0.171	9.140	-0.238	-3.120	0.132	0.950	0.313	1.680	-0.232	-1.600
Women's education												
0												
1-6	2.012	18.110	-0.088	-4.190	0.623	8.100	0.079	0.500	0.236	1.070	0.396	2.710
7-11	3.804	23.570	-0.101	-2.930	1.078	8.760	0.531	2.540	0.364	0.950	0.383	1.570
12+	5.778	19.970	-0.245	-6.680	1.803	10.360	0.626	2.290	0.875	1.670	0.779	2.420
Husband's education												
0												
1-6			0.074	3.130	0.700	8.180	-0.080	-0.460	0.459	2.120	0.208	1.410
7-11			0.003	0.090	0.927	8.450	0.021	0.110	0.015	0.050	0.145	0.710
12+			0.044	1.440	1.695	14.560	-0.109	-0.490	0.269	0.890	0.405	1.810
# of Siblings					-0.137	-6.180						
# of kids							-0.047	-1.160	0.020	0.500	0.027	0.860
Offspring's education												
% 0-6												
% 7-11							0.002	0.360	-0.002	-0.660	-0.004	-1.330
% 12							0.006	2.010	0.004	1.270	0.000	-0.120
% 13+							0.012	3.930	0.003	0.990	0.000	0.140
Constant			1.145	42.460			-2.032	-7.060	2.767	6.760	2.097	7.220
Cut points												
cut point 1	-0.402	-3.200			-2.313	-19.810						
cut point 2	1.714	11.850			-1.291	-11.740						
cut point 3	2.902	18.880			1.158	10.680						
Observations	3,006				11,286				3,006			

* Standard errors are adjusted for strata and cluster in survey design.

Second, there is a negative relationship between education and the level of fertility. Husbands' education has a non-monotonic relationship with the level of fertility. Men with some secondary schooling have the same indistinguishable level of fertility as those with no schooling. Men with a high school diploma have higher level of fertility than men with no schooling, but this difference is not statistically significant.

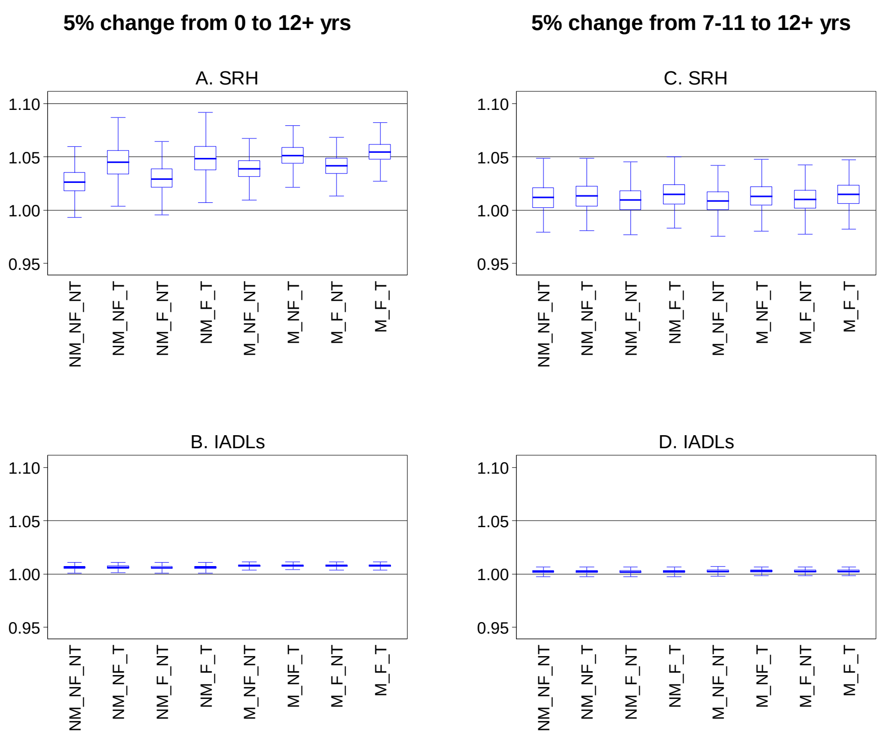
Third, offspring's educational attainment is strongly associated with parental education. The influence of mother's education on offspring's education is about the same as father's education. The number of siblings is negatively associated with children's educational attainment. Finally, the relationship between health and other covariates depends on the measures of health outcomes. Women's education is significantly associated with self-reported health and IADLs but not with ADLs. Offspring's education is significantly associated with only self-reported health. This relationship, however, between children's education and health of the elderly depends on the measures of health outcomes. The current study shows no association between offspring's education and ADLs and IADLs. Other covariates have no significant association with any of the health outcomes used in the current study.

7.3 Simulation: Changes in the proportion of healthy elderly

As discussed above, we adjust for educational differentials in mortality in the following simulation analyses. In other words, we assume that simulated changes in educational attainment that lead to the one percent increase in the elderly population and health status of these "additional survivors" is the same as the original sample. Because women's education is not significantly associated with the ADLs, we conduct simulation analyses for self-reported health and the IADLs. In simulation analyses, the distributions of age and rural residence are fixed to mirror the sample distributions shown in Table 1.

Figure 1 shows the ratios of the simulated proportions healthy to the baseline proportion healthy when we change 5 percent of women's educational attainment from lower categories to higher ones according to a couple of scenarios. As indicated at the bottom of Figure 1, *M* represents assortative marriage, *F* is differential fertility, and *T* is intergenerational transmission. *N* indicates the absence of respective elements. For example, *M_F_T* simulation assumes that changes in women's education lead to subsequent changes in husband's education, number of children, and children's education. By contrast, in *NM_NF_NT* simulation, none of these changes occur. In all simulations, the relationships between health outcomes and all covariates, presented in Table 3, are assumed to be present as estimated. If the ratios are greater than 1, it indicates that the simulated changes in educational attainment lead to an increase in the proportion of healthy individuals in terms of self-reported health or IADLs. Box plots are presented to show the point estimates along with sampling variability, which is estimated by a bootstrap method. The box plots show the medians (lines in the middle), the lower quartile (25th percentiles) and the upper quartile (75th percentiles) (boxes), and adjacent values (outer lines). Adjacent values are equal to 1.5 times the interquartile range above the upper quartile or below the lower quartile if there are values greater than these (outliers). Otherwise, they are equal to maximum or minimum. In the following discussion, we define the proportional changes as statistically significant if the ranges between two adjacent values do not include one.

Figure 1: Ratios of the simulated proportion of healthy individuals to baseline proportion healthy



* N: No effect, M: Assortative Marriage, F: Differential Fertility, T: Intergenerational Transmission

Not surprisingly, more drastic changes in the distribution of women's educational attainment lead to greater improvements in elderly health. For example, in the *M_F_T* simulation, the proportion reporting good health increases by 5.4 percent in Figure 1-A (where the five percent change occurs from zero to 12 + years), but the increase is just 1.4 percent in Figure 1-C (where change occurs from 7-11 to 12 + years). The adjacent values in Figure 1-C include one. This means that five percent change of women from 7-11 to 12 + years of schooling does not significantly improve elderly health.

The results also show that the intermediating demographic variables contribute to the improvement of self-reported health. For simplicity, let us focus on the first scenario for self-reported health, where five percent of women are moved from zero to 12+ years of schooling. The difference between *M_F_T* and *NM_NF_NT* is 2.7 percentage points. Given that a 5.4 percent increase in proportion reporting good health is expected in *M_F_T* simulation, this means that about a half of such improvement comes from changes in subsequent demographic behaviors. In other words, changes in the proportion reporting good health would be halved without subsequent changes in demographic behaviors. Children's education appears to be the most important factor. If changes in women's education do not lead to changes in offspring's education, then improvement in elderly health would be substantially reduced (See *M_F_NT*). Assortative marriage and differential fertility also make some positive contributions, but the magnitude appears much smaller than intergenerational transmission of education (See *NM_F_T* and *M_NF_T*).

For the IADLs, there is little contribution of the demographic elements. In both scenarios, changes in the proportion not functionally limited in the IADLs are almost identical for all simulations. In other words, the absence or presence of the relationship between women's education and demographic behaviors does not make any difference in the proportion healthy in terms of IADLs. This is the case because intermediate demographic variables are not significantly associated with the IADLs, as shown in Table 3. The magnitudes of changes driven by changes in education are also much smaller than those in the self-reported health. For example, a change of five percent of women from no schooling to 12 + years leads to a less than one percent change in the percentage not functionally limited in the IADLs for all simulations, although these are statistically significant.

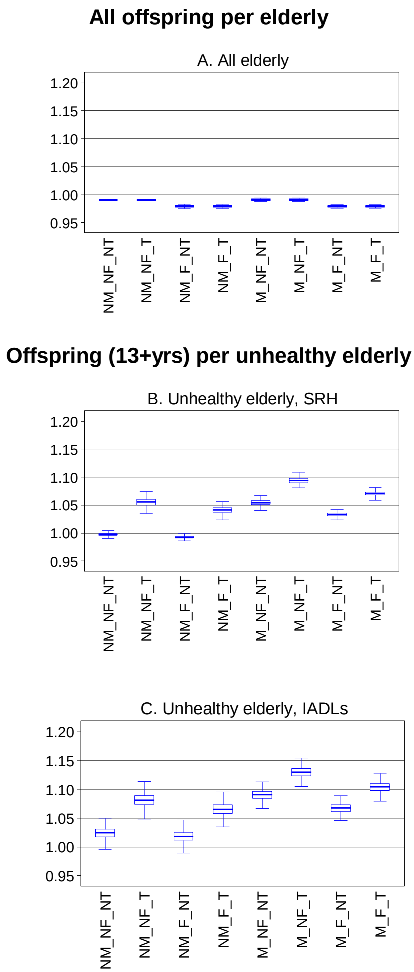
7.4 Simulation: Changes in the generational support ratios

Figure 2 presents two different ratios from one scenario: five percent change in women's schooling, from zero to 12+ years.

a) $$\frac{\text{simulated all offspring/all elderly}}{\text{baseline all offspring/all elderly}}$$

b) $$\frac{\text{simulated college-educated offspring/unhealthy elderly}}{\text{baseline college-educated offspring/unhealthy elderly}}$$

Figure 2: Ratios of simulated generational support ratios to baseline generational support ratios (5% change from 0 to 12+ yrs)



*N: No effect, M: Assortative Marriage, F: Differential Fertility, T: Intergenerational Transmission

These ratios represent the proportional changes in generational support ratios induced by educational upgrading. If the ratios are greater than 1, it indicates that the simulated changes in the distribution of educational attainment lead to an improvement in support ratios (i.e., more offspring per elderly). The graphs in Figure 2 show the proportional changes in overall generational support ratios (A) and the proportional changes in the support ratios for college-educated offspring to the unhealthy elderly (B and C).[15]

First, upgrading women's education slightly worsens the overall generational support ratios when education affects fertility (Figure 2-A). When fertility does not respond to changes in educational attainment, the overall support ratios change slightly. Even when this relationship exists, the magnitude of change is not great. The simulated change in the *M_F_T* simulation reduces the number of offspring per elderly by 1.2 percent. This analysis shows that the influences of educational differentials in fertility are not large enough to worsen the generational support ratios substantially.

Second, upgrading women's education leads to a substantial increase in the number of college-educated offspring per unhealthy elderly. This is the case for both health outcomes. We can expect an eight percent increase in the number of college-educated offspring per unhealthy elderly in terms of self-reported health in the *M_F_T* simulation (Figure 2-B). Interestingly, we can see that demographic elements are important in such a substantial change. Without subsequent changes in demographic behaviors, the increase of this support ratio is just 0.7 percent (*NM_NF_NT* simulation). Assortative mating and intergenerational transmission help boost the support ratio, whereas differential fertility works in the opposite direction. The absence of an intergenerational transmission of education (*M_F_NT*) leads to a 3.8 percentage point reduction in the improvement of this support ratio. This is the case because women's education is positively associated with children's education and children's education is in turn positively associated with women's self-reported health. The simulation with no assortative mating (*NM_F_T*) yields a slightly smaller reduction (3.0 percentage points). Because husband's education is not significantly associated with women's self-reported health, this positive contribution is due to the positive relationship between father's education and children's education. Differential fertility negatively affects this support ratio. Without differential fertility, the improvement of the support ratio would be substantially larger, 10.4 percent (*M_NF_T* simulation). This is the case because differential fertility reduces the size of the offspring's generation; the reduced family size, however, does not improve self-reported healthy. This also implies that benefits

[15] In supplementary analyses (not shown), we also examined the ratios of all offspring to unhealthy elderly. This shows that upgrading women's education leads to an increase in the number of offspring per unhealthy elderly in terms of IADLs, but no change in terms of self-reported health. To illustrate the changing joint configuration of elderly health and offspring's education, we focus our discussion on the ratios of the unhealthy elderly to college-educated offspring.

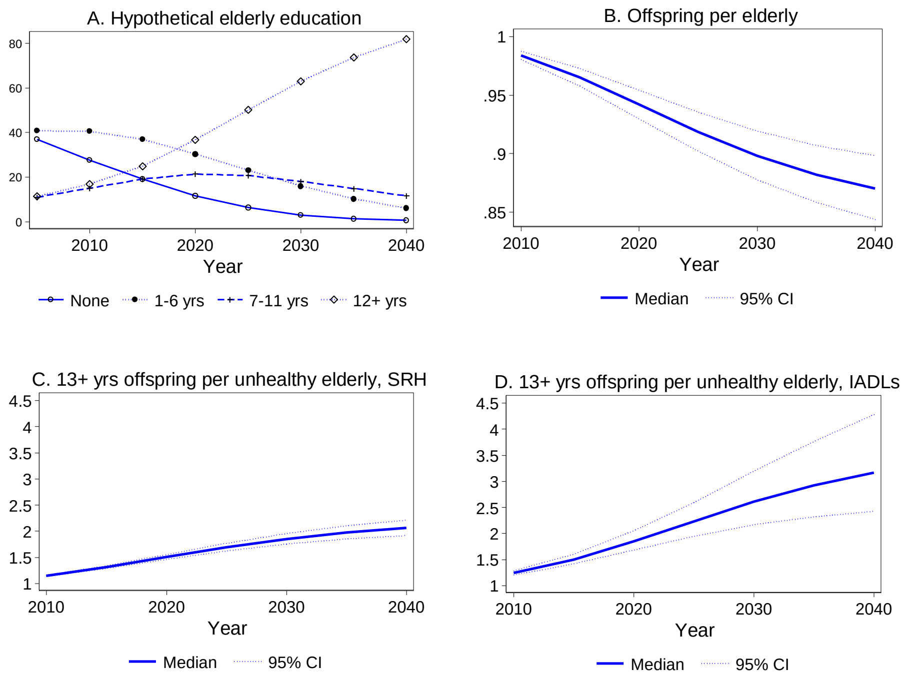
from reduced family size for children's education are not large enough to fully offset the impact of an overall reduction in the size of the offspring's generation. For the IADLs, we can see similar but larger changes (Figure 2-C). In the *M_F_ T* simulation, an 11.4 percent change in the support ratio is expected when we use the IADLs as a health outcome. Such a substantial improvement is also largely driven by changes in demographic behaviors, without which the improvement is just 3.3 percent (e.g., *NM_NF_NT* simulation). Because the IADLs are not significantly associated with any intermediate demographic variables, such findings exemplify the importance of accounting for changes in the configuration of the offspring's generation as well as the elderly. Assortative mating, differential fertility, and intergenerational transmission of education do matter for the elderly support structure even if they are not associated with elderly health because they influence the configurations of the offspring's generation.

7.5 Projections of generational support ratios

The analyses presented so far examined the implications of hypothetical changes in educational attainment for the joint distribution of elderly health and offspring's education. The magnitude of redistribution, five percent change, is chosen to illustrate how this model works. It represents an arbitrary unit, analogous to focusing on the effect of a "one unit" change in a typical regression model. The simulations show the implications of differential demographic behaviors for joint configuration of elderly health and offspring's education. These simulations, however, do not provide information about what the joint configurations look like in the future. In this section, we present such projections.

Projections require two types of information: educational attainment in the future and the relationships among the variables of interest. First, we use the 2005 Korean census data to generate projections of educational attainment of elderly women (age 60+) in the future. We group women into 5-year age intervals; those older than age 85 are grouped as age 85+. For 2010, we assume that the elderly women's educational attainment is the same as the educational attainment of women aged 55-80 in 2005. We project the elderly women's educational attainment in the same way up to 2040. This assumption is not perfect because not all women over age 85 die in five years, and someone aged 55-80 could die within the next five years. Nevertheless, this should be quite close to the true educational attainment of the elderly because 1) those aged over 85 are relatively small, 2) their mortality rate is high, and 3) educational differentials in mortality in old age are relatively small in South Korea (Kim 2004). The hypothetical educational attainment among the elderly women is presented in Figure 3-A. We can see that educational attainment among the Korean elderly women is likely to increase rapidly over time.

Figure 3: Projected GSRs under M_F_T model



Next, we assume that the relationships among the variables of interest, shown in Table 3, remain constant in the future. Obviously, this assumption is not realistic either. For example, the intergenerational association of education became weaker in South Korea as educational opportunity expanded (e.g., Park 2003, 2007). Nonetheless, this assumption is useful to see the implications of distributional changes in educational attainment holding constant the relationship among the variables. In projections, we also assume that changes in women's education lead to subsequent changes in husband's education, number of children, children's education, and health. This is equivalent to the *M_F_T* simulation presented previously. Hence, the projection predicts the joint configurations of elderly health and offspring's education in the future perfectly if these two assumptions are true. This is very unlikely to be the case. While imperfect, this projection provides useful information about the joint configurations, particularly as compared to model-based abstract simulations presented in the previous sections.

Figures 3-B, 3-C, and 3-D show the projected generational support ratios relative to those of 2005. If the ratio is greater than one, there is improvement in the generational support ratios; a ratio smaller than 1 means the opposite. As before, we rely on the bootstrap method to assess sampling variability. The solid lines are medians, and the dotted lines represent 95 percent confidence intervals. First, Figure 3-B shows changes in the ratio of all offspring to all elderly if we change elderly women's educational attainment according to Figure 3-A using the relationships among the variables shown in Table 3. This graph clearly shows that the overall generational support structure will become worse. For example, there would be a 13.0 percent decrease of the number of offspring per elderly in 2040 as compared with 2005. This is a substantial decrease that would be cause for concern. However, as we emphasized before, such changes come along with improvements in elderly health and offspring's education. This is illustrated well in Figure 3-C and Figure 3-D. From these graphs, we can clearly see that the ratios of college-educated offspring to the unhealthy elderly would improve in terms of both self-reported health and IADLs. These ratios would more than double in terms of self-reported health and more than triple in terms of IADLs. Hence, such joint changes should substantially mitigate the burden of population aging.

8. Summary and discussion

This study examines how changes in educational attainment in one generation lead to changes in the joint distribution of elderly health and education of the offspring generation, which has important implications for population aging. The elderly population's health, which is heterogeneous, determines the amount of support they need to maintain an adequate quality of life. The offspring generation is also heterogeneous in their capacity to support the parental generation. Educational attainment is strongly associated with both elderly health and offspring's education, so it is important to examine the implications of changes in education for the support of the elderly. Because education is also closely related with intermediate demographic variables such as marriage, fertility, and the intergenerational transmission of education, we applied a demographic model to account for these demographic elements. The primary findings are as follows.

First, educational upgrading leads to improvements in health among the elderly. Intermediate demographic factors such as assortative mating, differential fertility, and intergenerational transmission of education make positive contributions to this improvement. If the relationship between education and demographic variables were completely spurious, then improvements of health associated with educational upgrading would be substantially reduced. Second, educational upgrading leads to declines in the ratios of offspring to the elderly due to the negative association between education and fertility. This decrease, however, is small. For example, a five percent change of women's education from no schooling to high school graduate and above would lead to a 1.2 percent decrease in the ratio of offspring to the elderly when all intermediate demographic variables change according to changes in educational attainment (*M_F_T* simulation in Figure 2-A). In other words, educational upgrading may make the population only slightly older. Third, educational upgrading increases the ratio of the college-educated offspring to all elderly and unhealthy elderly because of improvements in both offspring's education and elderly health. This may mitigate the negative consequences of population aging to some extent.

There are several limitations in the current study. First, we restrict our sample to women for the sake of simplicity. There has been a persistent gender difference in life expectancy and healthy life expectancy in South Korea (Salomon et al. 2012), and a decreasing gender wage gap in emerging economic sectors (e.g., knowledge-intensive industry) may reinforce this trend because earnings are strongly correlated with health and mortality (Ural, Horrace, and Jung 2009). This suggests that the patterns reported here may not be able to be generalized to the entire population. However, huge gender differences in the improvement of health and survival chances due to education are not likely either. Hence, our results may not substantially deviate from the patterns that would be observed in the entire population.

Second, we may have exaggerated the role of education on population aging. First, there will be little variation in educational attainment in the near future, and consequently educational differentials in demographic behaviors and health may not be important as most people will be highly educated. Projection results shown in Figure 3, in particular, may overestimate the implications of educational expansion on population aging. Second, our analyses assume that education is exogenous to demographic behaviors and elderly health although we do not use estimates of causal effects of education on them. Hence, our results are a stylized description of the implication of education on population aging instead of predicting the future trends or evaluating causal effect of education on differential population aging. In addition, there will be factors improving elderly health other than education including medical technology and (possibly) decreasing population density due to population aging.[16]. Hence, we should be cautious in interpreting our results.

[16] Whereas implications of medical technology are straightforward, evidence is mixed with regard to the relationship between population density and elderly health. While earlier studies argued that population

Despite these limitations, these findings advance research in population aging by accounting for population heterogeneity by education and health. On one hand, improvements in education lead to fertility decline, unbalancing the age structure of the population. Such an impact, however, is just modest in South Korea. On the other hand, educational upgrading leads to changes in joint configuration of elderly health and offspring's education: improvements in elderly health and offspring's education. These changes may mitigate the problem of population aging because they should improve socioeconomic capacity of the offspring's generation and reduce the cost for supporting the elderly. In this sense, projection models based solely on gender and age are likely to exaggerate the negative consequences of population aging because population aging progresses in tandem with other socioeconomic development such as educational upgrading (Lee and Mason 2010). Previous projection models that account for educational upgrading in the population (Batljan, Lagergren, and Thorslund 2009; Batljan and Thorslund 2009; Joung et al. 2000; Lutz 2009) may not fix such problems completely because these models do not account for changes in configurations of the offspring's generation. The present study suggests that educational upgrading may mitigate the problems of population aging more than previous studies have suggested. More importantly, population aging proceeds in tandem with socioeconomic development including educational expansion. Consequently, bleak description about population aging may be misleading, and we need to be more cautious in discussing the implications of population aging for society.

Family size is another important issue, with different implications for the population as a whole and as an individual family. A smaller family size, on average, makes the population older. It is well-known that this population aging leads to reduced productivity and increased burden to support the elderly in population level. Many policies have been proposed and implemented to handle this issue (Uhlenberg 1992; van de Kaa 2006; Gauthier 2007). However, smaller family size is beneficial for individual families because it allows for more investment in the children. The negative association between family size and children's socioeconomic outcomes, shown in the current and previous studies (e.g., Guo and VanWey 1999), suggests strong incentives on the individual level to having a small family. Because of strong parental interest in children's success, boosting fertility should be very difficult without changing the relationship between family size and children's educational outcomes. The current study, however, also shows that the reduction in fertility following educational upgrading worsens all generational support ratios considered. For example, absence of differential fertility (*M_NF_T* simulation) leads to a 10.4 percent increase in college-

density is negatively associated with population health mainly due to crowding (Calhoun 1962; Levy and Herzog 1974), recent studies found the opposite because population density is positively associated with access to medical facilities (DeGuzman, Merwin, and Bourguignon 2013; Hanlon et al. 2012).

educated offspring per unhealthy elderly (with self-reported health as the outcome). This is 2.3 percentage points larger than the expected change in the *M_F_T* simulation. This difference shows the benefits on the population level of maintaining a large family. However, given the strong incentive to reduce family size on the individual level, it should be very challenging to effectively encourage individual families to increase family size. This challenge also emphasizes the importance of accounting for population heterogeneity by education and health in coping with population aging.

9. Acknowledgements

Earlier versions of this paper were presented to the RC 28 2011 summer meeting at the University of Iowa, IA and the PAA 2012 annual meeting in San Francisco, CA. The first author greatly appreciates Esther M. Friedman for providing inspiring ideas for the approach taken in this study. Robert D. Mare, Kelly Musick, Charles Q. Strohm, and two anonymous reviewers provided valuable suggestions. We also thank Tom Rushmer for editorial help. The authors are also grateful for financial support from the Korea Foundation.

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Appendix

A1 Simulation method

Because our model has three intervening demographic mechanisms (assortative marriage, differential fertility, intergenerational transmission), there can be eight possible scenarios: (1) no assortative marriage, no differential fertility, and no intergenerational transmission (NM_NF_NT), (2) no assortative marriage, no differential fertility, and intergenerational transmission (NM_NF_T), (3) no assortative marriage, differential fertility, and no intergenerational transmission (NM_F_NT), (4) no assortative marriage, differential fertility, and intergenerational transmission (NM_F_T), (5) assortative marriage, no differential fertility, no intergenerational transmission (M_NF_NT), (6) assortative marriage, no differential fertility, and intergenerational transmission (M_NF_T), (7) assortative marriage, differential fertility, and no intergenerational transmission (M_F_NT), and (8) assortative marriage, differential fertility, and intergenerational transmission (M_F_T). In the first model (NM_NF_NT), changes in women's education are assumed to lead to no change in all subsequent demographic behaviors. By contrast, in the final model (M_F_T), changes in women's education are assumed to lead to changes in all intervening demographic variables. Formally, we modify $p^{M}_{k|i}$, r_{ik}, and $p^{O}_{j|iks}$ in the equation (1) in Section 6.1 to capture different assumptions (see Kye and Mare 2012: 1499). To illustrate how the different simulations work, let us think of the first scenario, redistribution of five percent women from the lowest (zero) to the highest (12+ years) education category. This change will not affect husband education, the number of children, and children's education except for women with the highest education (12+ years). For the women with 12+ years of schooling (W_4), their $p^{M}_{k|i}$, r_{ik}, and $p^{O}_{j|iks}$ will change depending on hypothetical conditions in the following way:

$$p^{H\_NM}_{k|4} = W_4 \times p^{H}_{k|4} + .05 \times p^{H}_{k|1} \quad \text{(A1)}$$

$$r^{NF}_{k4} = W_4 \times r_{4k} + .05 \times r_{1k} \quad \text{(A2)}$$

$$p^{O\_NT}_{j|4ks} = W_4 \times p^{O}_{j|4ks} + .05 \times p^{O}_{j|1ks} \quad \text{(A3)}$$

First, $p^{H\_NM}_{k|4}$ (equation A1) denotes the probability that a woman with 12+ years of schooling marries a husband with educational attainment k after simulation if the change in women's education does not lead to the corresponding change in husband's education. Second, r^{NF}_{k4} (equation A2) is the expected number of children born to couples with woman with 12+ years of schooling and husband education k after simulation if the change in her education does not affect fertility. Finally, $p^{O\_NT}_{j|4ks}$ (equation A3) is the post-simulation probability that an offspring has educational attainment *j*, conditional on woman's education being equal to 12+ years, husband's education *k*, and the number of siblings *s* for children of these couples if the change in women's education does not affect offspring's education. Then, we can modify the equation (1) in Section 6.1. to reflect the hypothetical changes in the distribution of women's education and redefined $h_{kl|i}$ according to hypothetical relationships defined above. Below, we present such modifications for selected scenarios. The $h_{kl|i}$s for other scenarios are obtained in similar ways. Using these modified rates and simulated distribution of women's education, we can compute expected distribution of elderly women's health and compare them with baseline distribution.

$$NM\_NF\_NT\text{: } h_{kl|i} = p^{M\_NM}_{k|i} \times r^{NF}_{ki} \times p^{O\_NT}_{j|iks} \times p^{H}_{l|ikrj} \quad \text{(A4)}$$

$$NM\_NF\_T\text{: } h_{kl|i} = p^{M\_NM}_{k|i} \times r^{NF}_{ki} \times p^{O}_{j|iks} \times p^{H}_{l|ikrj} \quad \text{(A5)}$$

$$M\_NF\_T\text{: } h_{kl|i} = p^{M}_{k|i} \times r^{NF}_{ki} \times p^{O}_{j|iks} \times p^{H}_{l|ikrj} \quad \text{(A6)}$$

$$M\_F\_T\text{: } h_{kl|i} = p^{M}_{k|i} \times r_{ik} \times p^{O}_{j|iks} \times p^{H}_{l|ikrj} \quad \text{(A7)}$$

A2 Implications of differential mortality by education

Here, we present a supplementary analysis to assess the implications of differential mortality by using bivariate relationships between education and mortality on the aggregate level. The Korea National Statistical Office provides period life table estimates, including five-year interval age-specific mortality rates, *m(x)*, between 1970 and 2009. Kim (2004) provides mortality ratios by education for men and women age 25-64 for 1970, 1980, 1990, and 2000. Combing these two sources of data, we compute hypothetical survival probabilities by education. To do this we make two assumptions. First, we assume that differential mortality by education only exists between age 25 and 64 and not in other parts of the age distribution. Our second assumption is that individuals in the sample are subject to average differential mortality available in the data. Our analytic sample includes Korean women born before 1962, and these two data provide partial information on *m(x)* by education for this group. On the one hand, *m(25)* in 1970 refers to *m(25)* of women born 1955. We do not have information on *m(25)* for women born before 1955. On the other hand, *m(80*) in 2000 refers to *m(80)* for women born in 1920. We do not have information on *m(80)* for women born after 1920. Consequently, while estimates for m(x) in the young age group (e.g., age 25-34), are available for relatively young cohorts of women, these in the old age group (e.g., age 70-79) are available for old cohorts. Because we do not have full information, we simply averaged available *m(x)* for each age-education group to compute *m(x)* for each education group. Whereas *m(x)*s for young ages reflect younger cohorts' mortality experiences, *m(x)*s for old ages reflect older cohorts 'mortality experiences. Although imperfect, the estimated *m(x)*s approximate education-specific mortality experiences of cohorts considered and provide information on the increase in the size of elderly women due to hypothetical improvement in educational attainment considered in simulation analyses. We compute the average *m(x)* by education based upon these assumptions and available data, and use them to construct separate life tables by education.

Table A1 shows life table estimates of survival probabilities where the radix is set to one at age 25 (l_{25}=1). We can see a clear educational gradient in survival chances. Whereas 75 percent of women with college education at age 25 would survive up to age 75, this figure is only 60 percent for women with no schooling. However, this computation also shows that the differential survival chance would not seriously distort the analyses. For example, let us consider the following change in women's education: five percent of women change from no schooling to 13+ years of schooling. This is a more drastic change than those considered in the simulation analyses presented above. The assumed change in this scenario would lead to 0.75 percent increase (.05 x .15) in female survivors at age 75. We made the same computation for other ages (see the last column of Table 1), which shows a less than one percent increase in the size of surviving women due to a five percent change from no schooling to 13+ years.

Table A1: Survival probabilities by education, women*

Age	1) No schooling	2) 1-6 years	3) 7-12 years	4) 13+ years	.05*(4-1)
25	1.00	1.00	1.00	1.00	-
30	0.97	0.98	0.99	1.00	0.001
35	0.90	0.97	0.99	0.99	0.005
40	0.87	0.95	0.98	0.99	0.005
45	0.83	0.93	0.97	0.98	0.007
50	0.81	0.91	0.96	0.97	0.007
55	0.79	0.88	0.95	0.95	0.008
60	0.76	0.85	0.93	0.94	0.008
65	0.73	0.80	0.89	0.91	0.008
70	0.68	0.75	0.83	0.85	0.008
75	0.60	0.66	0.74	0.75	0.007
80	0.48	0.53	0.59	0.60	0.006

* Sources: Korean National Statistical Office (2010b) and Kim (2004)