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by

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The Evolution of the Human Capital of Women *

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Abstract

The labor market attachment of females has increased dramatically over the last half century, converging to a pattern similar to that of males. Human capital theory predicts an associated increase in human capital investment by females and a convergence in the life-cycle human capital investment profiles of males and females. This paper explores wage-based and job-skills-based approaches to measuring the increased supply of efficiency units of human capital by females over the last four decades. Results suggest that the magnitude of the contribution of the increased human capital of women to post-war economic growth is substantially under-estimated by conventional methods of measuring human capital and labor inputs. A complete picture of the evolution of the human capital of women requires new approaches to measuring their human capital.

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1 Introduction

The labor market attachment of females has increased dramatically over the last half century.[1] One implication of human capital theory is that, other things the same, the optimal life-cycle investment profiles of males and females will converge as life-cycle labor force participation patterns converge. In particular, the rise in female participation has increased the incentive for females to invest in human capital. One way the increased investment manifests itself is in a convergence in the share of successive female birth cohorts that are college graduates to that of males. However, an increase in the relative education level of females is only a partial indication of increased human capital; it does not measure the increase in human capital itself. In this paper the focus of interest is on providing evidence on the changes in human capital quantities for females relative to males over the period of increasing female participation.

A major problem for measuring human capital is that it is not directly observed. There is a large variety of approaches taken in the literature to measuring human capital. We argue that conventional "composition adjustment" approaches to measurement are likely to under-estimate the increase in female human capital in response to their increased incentive to invest because they ignore *within* education and experience cell changes in human capital. Composition adjustment based measures potentially capture the increases in female human capital due to changes in the composition of the female workforce with respect to their increased educational attainment and lifetime hours of work. However, an upward shift in female life-cycle human capital profiles for any given education group is not captured. In essence, the conventional methods do not measure cohort effects in observed education or experience cells. In this paper we explore two basic approaches to measuring human capital, with a focus on identifying these cohort effects. One is a wage-based approach in which the unobserved human capital is inferred from observed wages. The other is a job-skills-based approach in which the unobserved (multi-dimensional) human capital is inferred from observed occupations.

The wage-based approach was pioneered by Ben-Porath (1967) in his analysis of optimal life-cycle human capital accumulation in the post schooling period. It has since formed the basis of a

[1] This is well documented in the literature. Some examples include Blundell and Macurdy (1999), Goldin (2006), Blau and Khan (2013).

large literature on human capital, including Heckman, Lochner and Taber (1998), Kuruscu (2006) and Bowlus and Robinson (2012), hereafter BR. Heckman, Lochner and Taber (1998) extended the analysis in Ben-Porath (1967) to include the schooling period and to incorporate multiple types of human capital. Kuruscu (2006) relaxed the parametric assumption on the human capital production function. BR incorporated cohort effects by introducing technological change in human capital production functions and allowing for cohort effects induced by selection on ability in schooling choice.

The job-skills-based approach is a relatively recent development. In contrast to the wage-based literature, the job-skills based approach allows for a multi-dimensional skill portfolio of the same skill types for workers of all education groups. The primary sources of data for this literature are measures of skills or tasks rather than wages. Over the life-cycle, changes in this skill portfolio are inferred from occupational changes. Examples from this literature include Gathman and Schonberg (2010), Yamaguchi (2012) and Bowlus, Mori and Robinson (2016).

The structure of the paper is as follows. Section 2 first summarizes the Ben-Porath style framework incorporating cohort effects used in BR. The framework is then extended to add potential cohort effects through changes in the (expected) life-cycle hours and/or participation patterns. The extended framework contains three sources of cohort effects: (1) selection on ability in education choices, (2) technological change in human capital production functions, and (3) changes in the (expected) life-cycle hours and/or participation. Section 3 presents summary patterns of the distributions of education and life-cycle labor force participation by birth cohort that are relevant for cohort effects (1) and (3). It documents the increased participation of females across successive cohorts and a convergence of their life-cycle labor force participation profile to a shape very similar to that of males. The data on education levels strongly supports an increased incentive for females in the post-war to invest in human capital associated with their increased labor market attachment. The share of the female pre-war and immediate post-war birth cohorts with a BA degree (or higher) is much lower than for males. The subsequent cohorts show a rapid convergence to the male cohorts such that by the 1968 cohort the share of the cohort with a BA degree (or higher) for females is, in fact, marginally higher than for males.

Section 4 presents estimates of the life-cycle human capital profiles for males and females derived using the wage-based approach. First, the identification issue and the solution adopted in BR, is briefly reviewed. This takes the form of the construction of price series for four types of human capital, associated with four different education levels, based on wage observations for males. The estimates presented for both males and females use the price series obtained from the male wage observations. The underlying assumption is that human capital of any given type, in the sense of input in firms' production functions, is the same thing whether it is embodied in a male or a female. However, the quantities may vary across individuals, for example, because of different incentives to invest, and hence the average quantity for females in any group may differ from the average quantity for males.[2] The results presented in this section suggest that the human capital quantities for females increased substantially in ways that are not captured by standard methods. In particular, within education groups the female human capital quantity profiles show a substantial shift upward for the more recent cohorts that showed increased labor force participation. This is in sharp contrast to the pattern for males.

Section 5 measures the human capital of females using a job-based-skills portfolio approach. The literature on job skills typically constructs and uses a low dimension vector of job tasks for the analysis of the topic at hand. For these analyses the multi-dimensional aspect of the job skills play a key role.[3] For this paper, however, we construct a single dimension measure that can be compared with the single dimension measure of the wage-based approach. Identification of cohort (and life-cycle) effects from the occupation data is discussed. The results show qualitative patterns that are very similar to those obtained from the wage-based approach, especially for relative male-female differences.

Finally, Section 6 presents some conclusions and suggestions for future work.

[2]The situation is more complicated if the price paid for the same human capital embodied in females is lower than that paid for the same human capital in males. The large literature on discrimination is relevant for this issue. Section 4 discussed the potential bias and possible solutions when quantities for females are derived using the price series based on male wage data.

[3]See, for example, Autor, Levy and Murnane (2002) for an application to differential wage effects following the automation of "routine" skill jobs, Firpo, Fortin and Lemieux (2013) for an examination of the relation between occupational task bundles and wages, and Poletaev and Robinson (2008) and Robinson (forthcoming) for an application to occupation distance measures.

2 A Ben-Porath Wage-based Framework with Cohort Effects

Our basic framework is based on BR, which used a combination and extension of the discrete time Ben-Porath based models used in Heckman, Lochner and Taber (1998) and Kuruscu (2006). The model has heterogeneous human capital ("types"), associated with different schooling groups, that command different prices. In choosing a specific schooling level, individuals choose a specific human capital type and an associated production function for post-school investment. Individuals differ in their initial endowed ability. Higher ability level individuals choose a higher level of schooling, produce more human capital at each schooling level, and are more productive in post-school investment. As in Heckman, Lochner and Taber (1998), the individual's choice problem can be thought of in two stages: condition on a schooling level and optimize the post-schooling investment profile given the on-the-job production function (and type of human capital) associated with that schooling level; then select among schooling levels.

A key aspect of the analysis in BR, and the extension to a structural model in Agopsowicz, Bowlus and Robinson (2017) is the incorporation and measurement of cohort effects induced by technological change in the human capital production functions, and selection effects based on completed education levels by cohort. There are two sources of cohort effects in the original BR framework: (1) effects arising from heterogeneity in ability and (2) effects arising from technological change, broadly interpreted, in the production of the different types of human capital. A third source of cohort effects, particularly important for this paper, is the increased incentive for females to invest in human capital following the large secular increase in their participation rates.

2.1 Optimal Life-cycle Investment and Cohort Effects

Most males work full time and participation rates have not shown any major changes over the last three or four decades. Based on this, the optimal life-cycle investment problem for males in BR ignored labor supply issues. For females, however, a substantial fraction work part time and there have been dramatic changes in participation rates.[4] To account for these features, we amend the optimal life-cycle investment problem in BR to incorporate shifts over time in labor supply in a

[4]See, for example, Altonji and Blank (1999).

simple way. Apart from labor supply differences, males and females are assumed to be the same. They face the same production functions for human capital, and produce the same four types of human capital characterized by the four education levels as in BR.

Following the notation of BR, let the total length of the period be 1 and define $n_s = (1-l_s)$ as the fraction of the total period available for allocation between investment in human capital production and efficiency units supplied to the firm, for an s-year experienced worker, where i_s is the fraction of "hours at work" devoted to human capital production, and l_s is leisure or home production time. Total earnings in the period are given by $\lambda h_s n_s(1-i_s)$, and total efficiency units supplied to the firm are $E_s = h_s n_s(1-i_s)$, where λ is the price of human capital and h_s is the level of human capital of an s-year experienced worker.

The determination of how much human capital to produce in each period is almost identical to BR and can be characterized in terms of comparing marginal cost, MC, and marginal revenue, MR_s, of producing human capital in each period. The only difference is that allowing for labor supplied to be less than the full period introduces a dependence of the marginal revenue on the labor supply. The MR_s depends on the interest rate, labor supply and the length of the working life, and declines with experience:

$$MR_s = \lambda[\frac{n_{s+1}}{1+r} + \frac{n_{s+2}}{(1+r)^2} + \ldots + \frac{n_T}{(1+r)^{T-s}}]. \tag{1}$$

MC depends on the production function, but is constant with respect to experience under the neutrality assumption. A declining path for human capital production is traced out by the intersection of the declining MR_s with the fixed MC. The life-cycle profile of E_s follows from the path of human capital production and hence depends on the properties of MR_s and MC.[5]

The simplifying assumption for males used in BR was $n_s = 1$. The model generates a peak in E_s for males in the later part of the working life. This is important for implementation of the flat-spot method for identifying human capital prices. For females, however, it is necessary to relax this assumption. For at least some periods for many females, $0 \leq n_s < 1$. This implies differences in the life-cycle paths of supplied efficiency units, E_s. In particular, for periods of non-participation, $n_s = 0$, so that MR_s is typically lower for females, implying lower investment and therefore lower

[5] See BR for more details.

production of human capital.

In BR, cohort effects are introduced into the framework via changes in education patterns and the human capital production functions for different cohorts. As in Heckman, Lochner and Taber (1998), an individual's ability affects the amount of human capital they produce in the schooling phase and hence their stock at the start of the post-school phase. In choosing a schooling level in the first stage of the life-cycle optimization problem, individuals with higher ability choose higher levels of education. This induces cohort effects due to selection on ability within a cohort into college. Assuming a common initial ability endowment distribution across cohorts, changes in the fraction of a birth cohort whose highest level of education is a college degree imply changes in the mean endowed ability of the college graduates from that cohort.[6] This effect is incorporated by allowing the human capital stock (for each human capital type) at the start of the post-school phase, $h_0(c)$, to vary by birth cohort, c.[7] For example, for college graduates, other things the same, a decrease in the fraction of the birth cohort with a college degree increases $h_0(c)$, and hence, increases $E_s(c)$ for any experience level.

Similarly, cohort effects due to secular technological changes in the production of human capital are incorporated by allowing the schooling phase production function for college graduates to improve over time with advancing knowledge, resulting in a higher $h_0(c)$ and hence, increased $E_s(c)$ for any experience level for more recent cohorts. In this paper, in addition to cohort effects from selection and technological improvements in human capital production that apply to both males and females, we allow for the optimal life-cycle $E_s(c)$ profile to shift up for female cohorts with greater (planned) participation.

3 Cohort Effects, Labor Force Participation Rates and Education Levels

The cohort effects in the framework of the previous section are of three types: (1) effects due to cohort specific selection effects in education choice, (2) effects, for females in particular, due to

[6] It should be noted that this is not an innocuous assumption. The initial endowment distribution is determined both by attributes at birth and the influence of early childhood factors in the household which may change over time.

[7] Effects through selection on the "ability to learn" in the post schooling phase could also be allowed.

cohort variation in participation, and (3) effects due to different cohorts facing different production functions. Observed education patterns by cohort are useful to assess the first type of cohort effect due to cohort specific selection effects in education choice, and observed participation patterns are relevant for the second type of cohort effect due to cohort variation in participation. It is more difficult to directly assess the third type. For the first two types we use data from the civilian population in the March Current Population Surveys (MCPS) of 1963 to 2009 are to document the evolution of labor force participation and education levels by sex for birth cohorts from 1925 to 1967.

3.1 Labor Force Participation

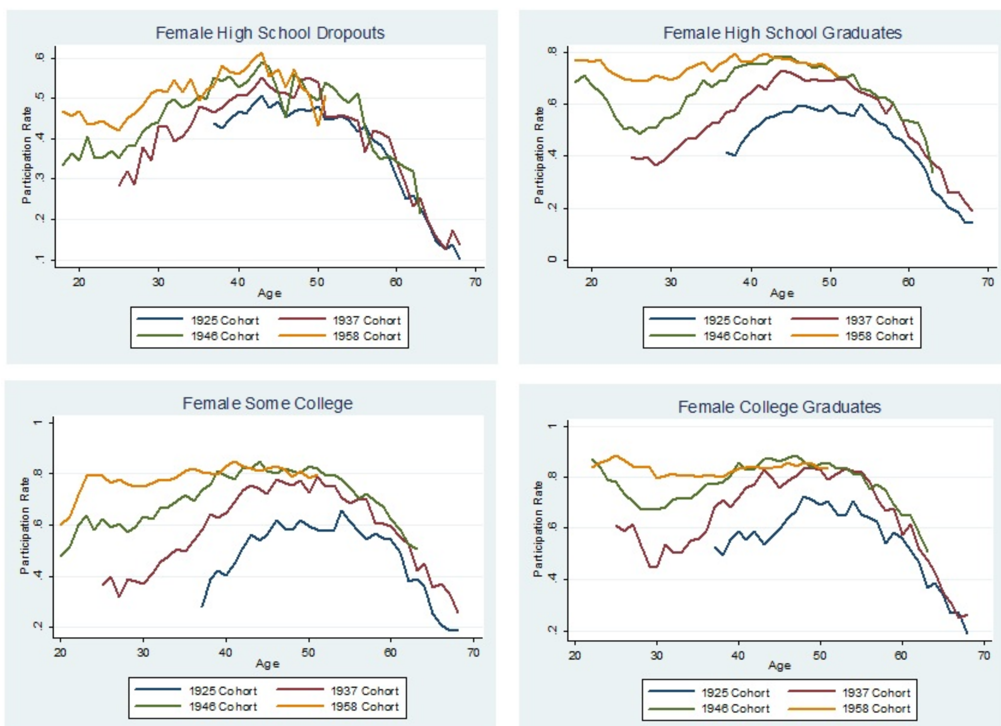

Figure 1: Life-cycle Labor Force Participation Rates for Females

There is a large literature documenting a strong secular increase in labor force participation for females.[8] In general participation rates are higher for more educated groups and the fraction

[8]See, for example, Blundell and Macurdy (1999), Blau and Khan (2013).

of female college graduates has increased strongly. However, participation rates for females have increased for all education levels. Figure 1 shows the participation rates in the MCPS for females for four education groups.[9] The more recent cohorts for all education groups show higher participation levels at all ages. There is an interesting change in the life-cycle pattern of participation. For the early cohorts the peak in participation rates for the cohort does not happen until relatively late in the life-cycle. The most dramatic difference in the shifts in profiles across the cohorts is that participation in the earlier part of the life-cycle increases. For all but the dropouts, by the 1958 cohort the rate is at its peak and relatively flat shortly after the formal education period.

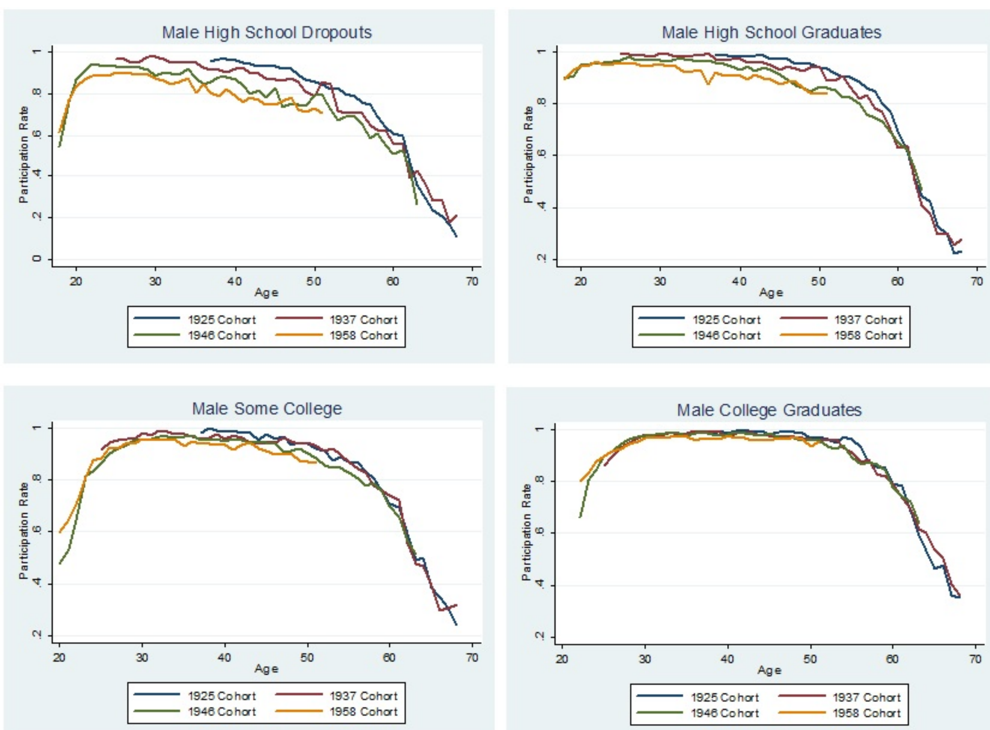

Figure 2: Life-cycle Labor Force Participation Rates for Males

By comparison, male participation rates show only minor changes across cohorts, with a tendency for participation rates to fall for more recent cohorts. Figure 2 plots the pattern for males for the same

[9] Figures 1 and 2 are reproduced from Figures 5 and 6 in Bowlus, Mori and Robinson (2016).

four education groups. Male college graduates for all of the birth cohorts show a flat participation rate at a very high level from their mid to late 20s until their mid-50s and still show participation rates of 80% or more until age 60. Some college males show the same pattern but begin to show a slow decline somewhat earlier, and start to fall below 80% by their late 50s. They also show a very slight drop for more recent cohorts. High school graduates are quite similar to the some college group except that they show a slightly larger drop for more recent cohorts. High school dropouts show the most cohort variation with lower participation for the most recent cohorts and generally lower participation at each age. Thus for males, cohort effects are likely to be minor relative to those for females, and in the opposite direction for the lower education groups.

The incentive to invest in human capital is higher when expected participation is higher. Thus human capital theory predicts greater relative investment by females over this period. The magnitudes of the increase in participation are large across all the female birth cohorts. In terms of the framework of the previous section, the increased participation for more recent cohorts implies a decrease in leisure, l_s, and therefore an increase in $n_s = (1 - l_s)$, the fraction of the period to be allocated between investment in human capital production, $n_s i_s$, and efficiency units supplied to the market, $n_s(1-i_s)$. Other things the same, female education levels should be higher relative to males for the more recent birth cohorts, and the female human capital profiles, $E_s(c)$, for any experience level for more recent cohorts should be increasing relative to males in all education groups, assuming that they expected to increase their participation in the labor market.

Goldin (2006) discusses four distinct phases that led to the current major role of females in the labor market. In the last of these phases, beginning with the cohorts born in the 1940s, there was a clear indication that as young women they expected to be in the labor market for much longer periods than their mothers. There is, of course, an issue of causality in the relationship between participation and education levels over this period that this paper largely abstracts from. However, for the purposes of measuring increased human capital for females associated with increased participation, the only requirement is that the increasing n_s for more recent cohorts increased the marginal benefit of producing human capital relative to the marginal cost.

Goldin (2006) also discusses a shift in the college majors for women: "Whereas in 1970 a standard dissimilarity index for college majors between men and women exceeded 0.5, it fell to about 0.3 in 1985 (Goldin (2005). Both men and women increased their majors in business administration, but women did to a greater extent and reduced their concentrations in the more traditional fields of education, literature, languages and home economics. Women's majors shifted from those that were "consumption" related to those that were "investment" related".[10] In the framework of Section 2 the amount of human capital produced during a conventional 4 year degree may have been smaller, and the amount of post college investment may have been smaller for the cohorts of females who expected to be in the labor market for a shorter period than males. An important issue not explicitly considered in our framework is that there may be two types of human capital: one type may be useful largely in market production (associated with Goldin's "investment" major); and another type may be less useful in market production and more useful in home production (associated with Goldin's "consumption" major). The large increase in female labor force participation and associated shift in production at the university level as seen in major choice towards more market oriented human capital would show up as technological improvement in producing (market oriented) human capital for females relative to males. Unlike a technological improvement through advancing knowledge, this "technological improvement" would be tied to the increase in participation.

3.2 Completed Education Levels

Figure 3 shows the completed education level shares of four education groups for successive birth cohorts of females from 1931 to 1967.[11] The two lowest education levels show declining shares, while the two highest education levels show increasing shares.

Figure 4 shows a comparison for the shares of the lower education levels between males and females. The share of high school dropouts shows a similar pattern for males and females. For both sexes the shares start about equally at one third of the birth cohorts at the start of the 1930s, followed by an almost identical and rapid decline in the share up to the immediate post-war cohorts, stabilizing around 10 percent by the 1967 cohort. The share of high school graduates for males is

[10] Goldin (2006), p.10.)

[11] The estimates are obtained from using observations on the same age group, 31-35, for each cohort to control for life-cycle effects in reporting.

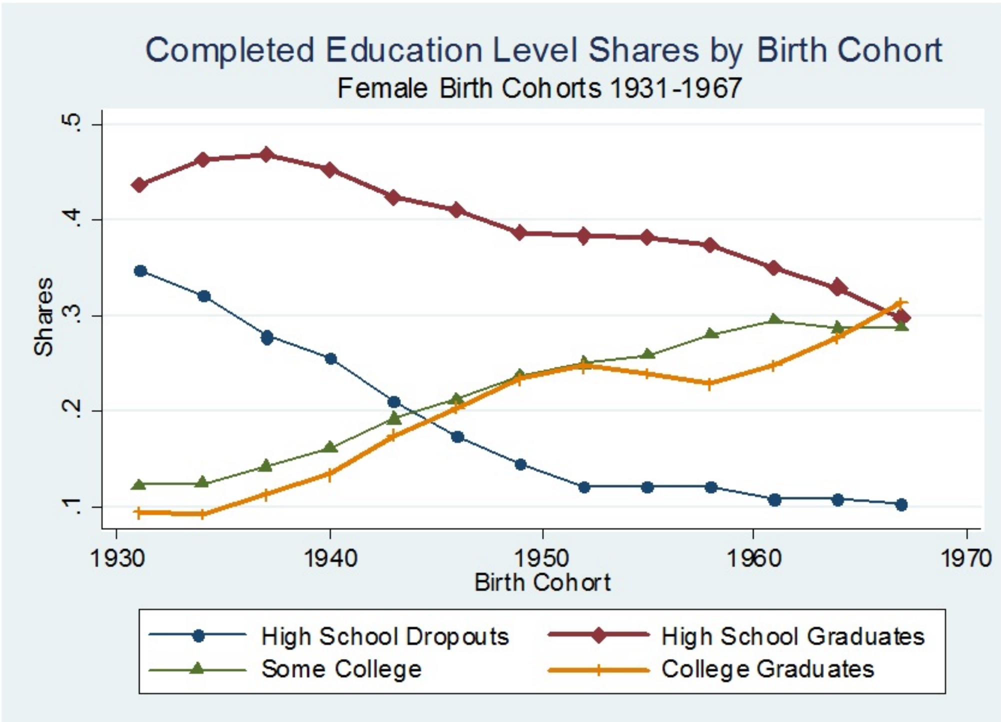

Figure 3: Increasing Educational Attainment for Females

relatively stable at just over 30 percent. In contrast, for females there is a secular decline from over 40 percent to just under than 30 percent.

Figure 5 shows the comparison for the upper education levels. For the some college level males and females start with roughly equal shares, at just under 15 percent of the 1931 birth cohort, and both increase rapidly until the 1950 birth cohort, reaching shares of over 25 percent. At this point the patterns diverge somewhat with the share continuing to increase for females, but staying constant for males. College graduates show a marked difference. Prior to the 1947 birth cohort, there is a rapid increase in the share of the cohort that are college graduates for both males and females. Females start much lower and do not close any of the gap by the 1947 birth cohort. For the post-war cohorts, however, the share of males who are college graduates falls from a peak of over 30 percent to around 25 percent for the early 1960s cohorts, during this period females close much of

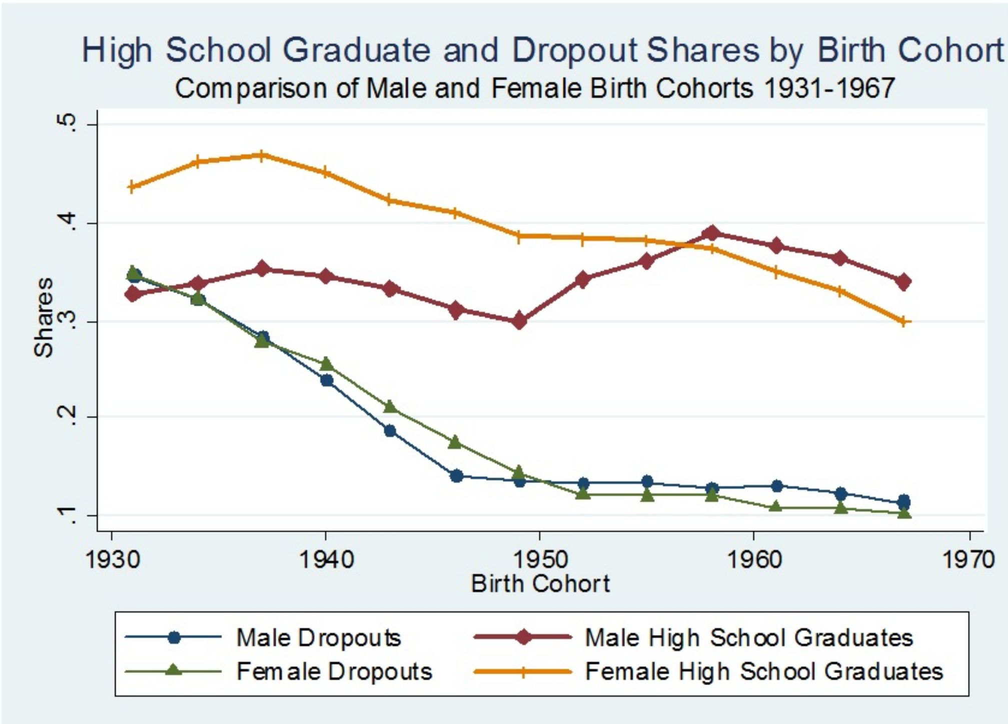

Figure 4: Lower Education Groups: Comparison of Males and Females

the gap. In fact, by the early 1960s cohorts, the share for females surpasses the share for the male cohorts.

Thus, overall, the pattern of completed education levels for females relative to males shows the features expected from the increased incentive for females to invest in human capital implied by their increased labor force participation.

3.3 Technological Change in Human Capital Production Functions

It is difficult to directly assess the third type of effect due to different cohorts facing different production functions from simple data patterns since the production functions are not directly observable. BR assumed that there is secular technological improvement in the production function for college graduates that reflects advancing knowledge, and present some indirect evidence for this. For the other education groups there could be either positive or negative technological change,

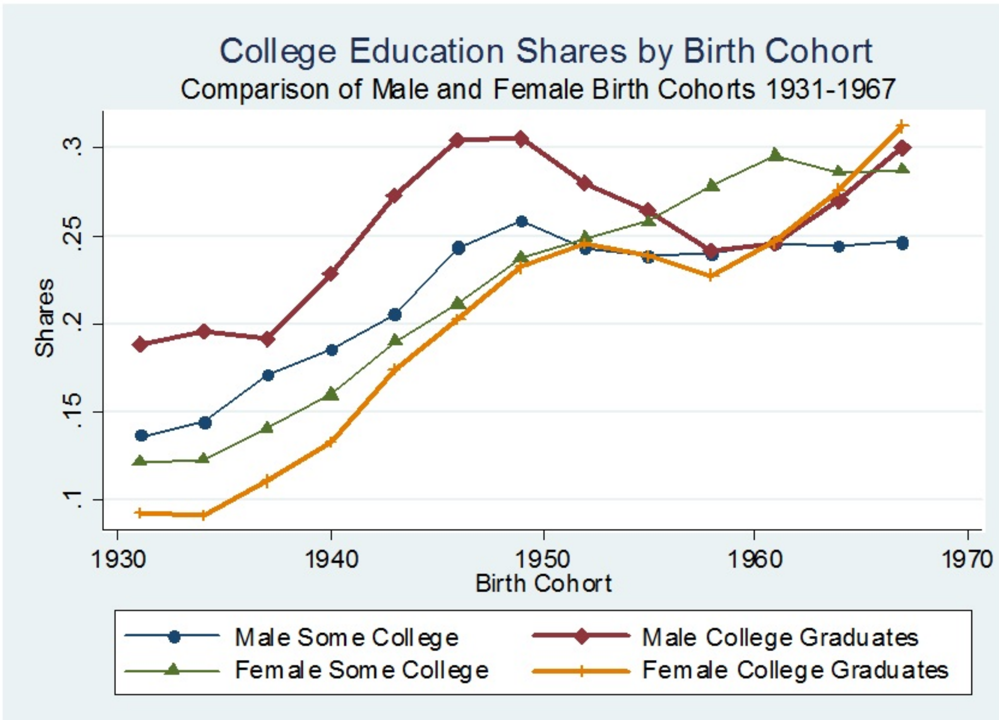

Figure 5: Higher Education Groups: Comparison of Males and Females

depending on a large range of family and schooling factors. Agopsowicz, Bowlus and Robinson (2017) estimate a structural model with parametric production functions for the four education groups and report periods of negative technological change for some lower education groups. Green and Riddell (2013) and Barrett and Riddell (2016) present evidence from international surveys on adult literacy that tries to separate cohort and age effects. The literacy measure in these data is a broad measure designed to capture prose literacy, document literacy, numeracy and problem solving. Green and Riddell (2013) and Barrett and Riddell (2016) show evidence of strong cohort effects for many OECD countries, including the United States. Importantly, they show that these cohort effects are negative for recent cohorts in a majority of OECD countries. The conclusion in Barrett and Riddell (2016) is that "in most of these OECD countries successive birth cohorts have poorer literacy outcomes - i.e.

begin their adult lives with lower levels of literacy."[12] These studies also try to assess the relative importance of parental background and formal schooling to the generation of literacy and find a very important role for the formal schooling system.[13] The conclusion from Green and Riddell (2013) is that "we are doing a poorer and poorer job of educating successive generations."[14] Overall the evidence suggests that the technological change in the production function, which captures in part how well the school system functions, may well have periods in which the change is negative.

4 Wage-based Approach to Measuring Male and Female Human Capital

Table 2 in BR reports summary estimates of the cohort effects on the life-cycle human capital profiles for United States male college graduates for birth cohorts 1937-1961. The profiles are obtained by dividing the observed annual earnings for male full time, full year workers in the MCPS by a price series estimated for college graduate type human capital using a "flat spot" method.[15] Price series for four human capital types, based on the four education groups used above, are reported in Figure 3 in BR. In this section these price series are used to estimate life-cycle human capital profiles for both males and females for all four education groups.

The assumption is that there is no specifically male or female human capital. So each of the four types of human capital, associated with the four education groups can be held by either males or females based solely on their education level. Thus, for example, female and male college graduates have the same "type" of college graduate human capital. This is the same as the assumption made in constructing college graduate human capital in the standard implementation of the canonical model using composition adjustment: males and females may have different amounts of the college graduate type human capital, but they do not have different types. In a standard competitive market both

[12] Barrett and Riddell (2016), p. 21.

[13] Sample selection is made to ensure that the individuals studied were primarily exposed to the education system in the country recorded in the data set at the time of the test.

[14] Green and Riddell (2013), p.17.

[15] See BR for details. A very similar price series is estimated in Hendricks and Schoellman (2014). The estimated price series corrects for important cohort effects reported in Carneiro and Lee (2011), BR, and Hendricks and Schoellman (2014), especially over the period of the rapidly rising skill premium. Carneiro and Lee (2011) and Hendricks and Schoellman (2014) attribute these effects primarily to variation in the quality of college graduate birth cohorts linked to enrolment rates. BR allow for both selection effects linked to enrolment rates, and for secular improvement in human capital production functions at the college level, corresponding to advancing knowledge.

males and females would face the same human capital prices for the four types of human capital. In that case, the price series derived in BR based on data for males can be used to compute efficiency units of human capital for females.

There is, of course, a large literature that studies discrimination against females. This discrimination can take many forms. If it results in a different (lower) price for females for the same type of human capital, the male price series would be an over-estimate of the price series for females resulting in an under-estimate of the female human capital quantity when the female wage is divided by this over-estimated price. Using the male price series is not a problem if the level of discrimination has been constant over time. In this case changes in the cohort pattern of efficiency units for females could still be identified and contrasted with changes in the cohort pattern for males. The primary concern is that there may have been a secular decrease in discrimination resulting in a secular decline in the amount of under-estimation of the human capital of females, imparting an upward bias on the estimated change in the quantity of their human capital.

It is possible that the main effect of discrimination is not to put a large wedge on the price but rather to prevent females from acquiring the levels of human capital acquired by males by reducing access to training and promotion opportunities or other barriers. It is also possible that a large part of the disappearance of the gender wage gap, at least on labor market entry for female college graduates is due to the shift in college major to produce the "investment" rather than "consumption" type human capital referred to by Goldin (2006) and that this shift could be in part a response to reduced barriers from discrimination. In this case use of the price series based on males would still permit the estimation of changes in the actual amount of efficiency units of human capital supplied by females across the different cohorts even in the presence of declining discrimination.[16]

It is difficult in the presence of discrimination to get a correct price series for females. Estimating a price series using wage data on females is highly problematic for a variety of reasons. The implementation of the flat-spot method for males in BR was based on evidence related to a number of assumptions required for the method to work. The identification of the separate price and quantity of human capital from the observed data on their product, the wage, is in general a difficult problem.

[16] Altonji and Blank (1999) discuss pre-market barriers that may have reduced women's human capital investment (section 3.1.3).

The “solution” in BR relies on a number of special features of the data that hold for males, but that do not hold for females. Very important was the continuing high participation rates for all cohorts over the flat spot range for males to avoid participation induced selection effects, which is not present for females. Further, given the continuing high participation for males, BR then exploited the strong decline in the fraction of the male birth cohorts with a college degree after the peak in 1946-49 to try and pin down the age range for the flat spot for college graduates. This decline implied a direction of bias imparted by cohort effects to the shape of the age-earnings profiles that could be signed for particular years of the cross section data and a pattern of age-earnings profile slope changes in successive cross sections. This evidence helped to avoid starting the flat spot too early in the life-cycle when the true human capital profile is still increasing. This strong decline in the fraction of birth cohorts with a college degree after the peak in 1946-49 does not happen for females (Figure 5). Therefore, it would be much more difficult to find the flat spot and it is much less likely to be stable for females. The combination of participation induced selection issues and flat spot identification problems present for females leads us to prefer the males series, albeit recognizing the potential for biases due to discrimination.

4.1 Comparison of Male and Female Life-Cycle Human Capital Profiles

The comparisons presented in this section are for estimates based on the evidence for full time and full year males and females. They are not designed to measure relative changes for females via changes in labor supply *per se*. They are designed to examine whether a “composition adjustment” approach to measuring female human capital is likely to under count the growth in female human capital following a participation increase. That is, we are looking for evidence of relative changes for females compared to males even within education group and full time and full year workers.

First, a general picture is presented using plots of the raw data for selected cohorts to show evidence that the (presumed) increase in expected working life time in the post war cohorts of females relative to males has the expected effect. Figure 6 presents the profile plots of efficiency units supplied by full time, full year males for the four education groups for three selected, evenly spaced, three year birth cohorts, 1937 (1938-1938), 1949 (1948-1950) and 1961 (1960-1962), that surround the peak in the fraction of male birth cohorts with a college degree. The figure reflects the pattern for college graduates shown in more detail in Table 2 in BR. This pattern is consistent with a combination of cohort effects due to secular technological improvement in the production of human capital (broadly interpreted) for college graduates, and selection effects associated with the fraction of the cohort with a college degree. After 1949 the positive effect of secular technological improvement is reinforced by a positive selection effect, as the fraction of the cohort with a college degree declines. Before 1946 the two effects oppose one another.

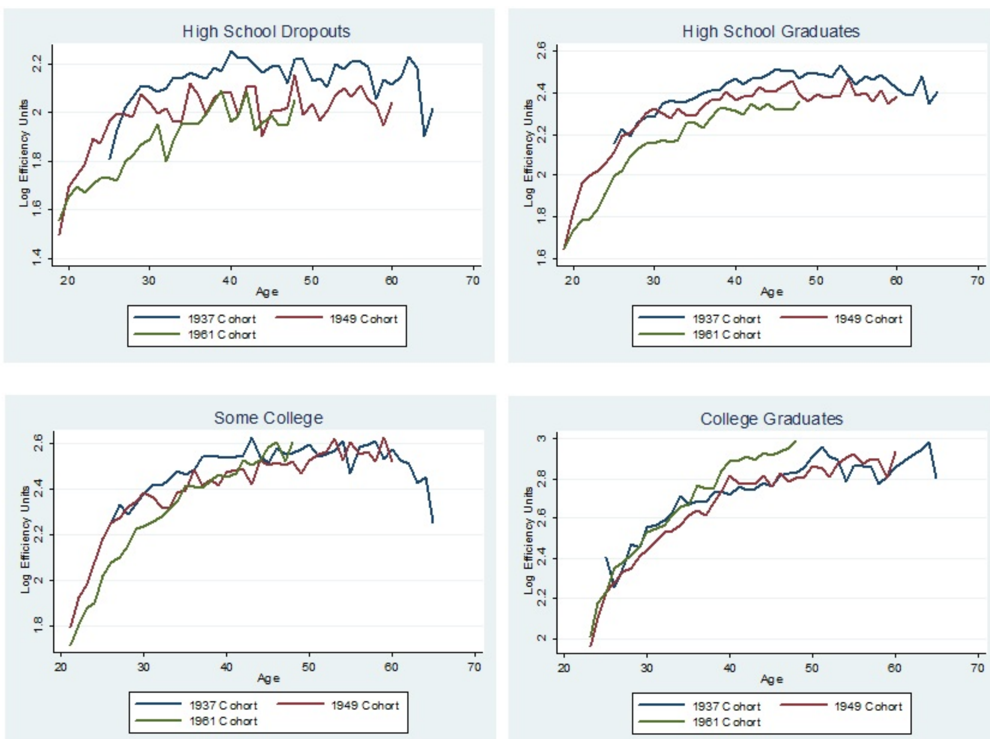

Figure 6: Life-cycle Human Capital Profiles: Males

The patterns for the education groups below college graduates are different. The early cohorts have a large fraction of dropouts. This fraction decreases over cohorts producing a negative selection effect for this group for the more recent cohorts. There is no strong presumption on the cohort effects due to technological change for this group. On the one hand, there could be a "trickle down" from the advance in knowledge to all the lower education groups. On the other hand, there are also likely to be other changes in the production functions for these groups, many of which may be negative, as discussed earlier. In any case Figure 6 shows that the more recent cohorts of dropouts have lower profiles. The same is true for the other education groups below college graduate. The high school graduates and some college samples are larger than the dropouts for most of the period and the profiles are smoother. There is a clear pattern for high school graduates for lower profiles for the more recent cohorts. Selection into the high school group is assumed to be from the dropouts, and selection out is assumed to be to the higher some college group. Both effects are negative. The some college group is more complicated after the 1949 cohort as it can have selection in from both the higher college graduate group and the lower high school group. In any case there is a clear decline from the earliest cohort.

As shown in Figures 1 and 2, there is a very different pattern of participation for females. The framework of Section 2 suggests that participation induced cohort effects should increase not only the fraction of females with higher education levels in more recent cohorts relative to males, but also the amount of human capital within education and experience groups. That is, the life-cycle human capital profiles of females for all four education groups could be shifted upward by this cohort effect. Of course, this is not the only cohort effect. For the technology effects it may be a reasonable first approximation to assume that these are the same for males and females. For the selection effects due to changing fractions of the cohort in the different education levels, Figure 5 suggests that there may be some differences between males and females.

Figure 7 presents the profile plots of efficiency units supplied by full time, full year females. Given the different participation pattern for females, these profiles should be interpreted as the efficiency units supplied by the females in the cohort that were participating and working full time and full year. For the males with more continuous participation this also approximates the profile of a representative male, but for most of the period this is not true for females.

Figure 7 shows a clear contrast with the pattern for males. Apart from the dropout group, which for much of the period can be expected to have a negative selection effect based on the change in the fraction of the cohort that are dropouts, there is clear evidence of an upward shift in the profiles,

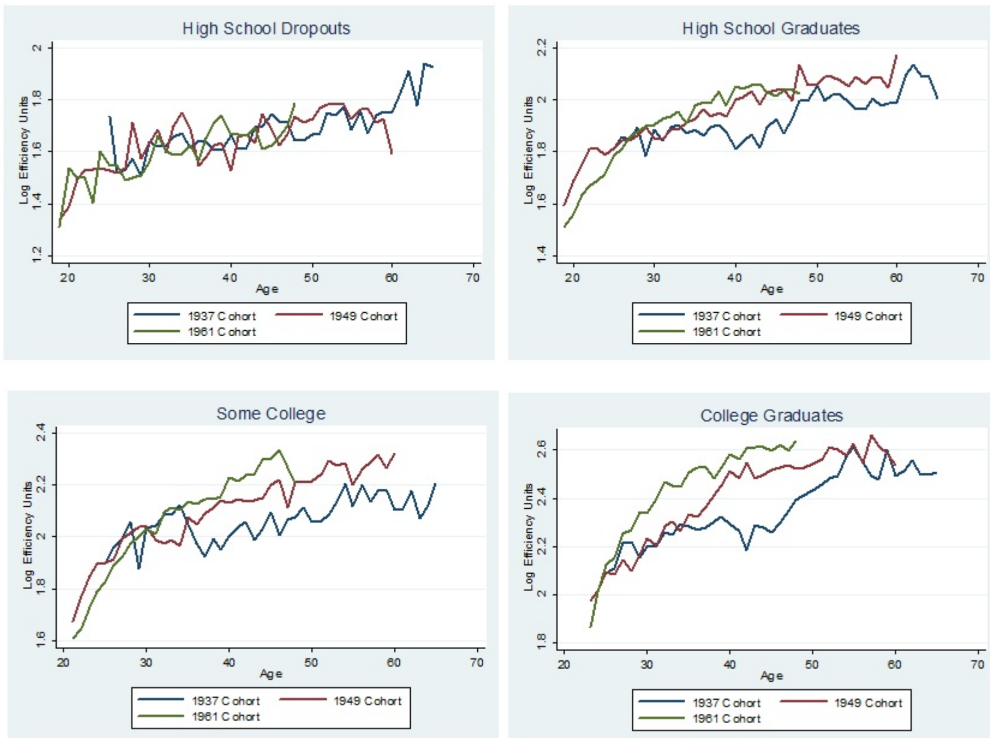

Figure 7: Life-cycle Human Capital Profiles: Females

consistent with the increased participation. Male dropouts, high school graduates, and to a lesser extent the some college group show a decline in the recent cohorts. Females show roughly constant patterns across cohorts for dropouts but increases for the other groups. For college graduates, as discussed above, only the post 1949 cohorts show an increase in the profile for males. For females, however, there are clear increases across all three cohorts.

4.2 Estimates of the Wage-based Cohort Effects

Table 2 in BR, presents summary measures of the cohort effects over a wide range of birth cohorts obtained from a simple regression framework. A variation on this approach is followed here to compare males and females. The individual level data used to construct the means by cohort plotted in Figures 6 and 7 are used to estimate cohort dummy variable coefficients in a set of regressions using the log human capital (efficiency units supplied) quantity, lnE_s, on a set of cohort dummies, representing all three year cohorts, 1937 (1936-1938), 1940 (1939-1941), etc., from 1937 to 1964. The data are restricted to these cohorts and to the age range, 30-45, that is represented in all the cohorts. The regressions are run for each education group with and without a quadratic in age and produce essentially the same results for the cohort effects. When the quadratic in age is included the cohort dummy variable differences represent intercept differences in (parallel) cohort profiles; when it is excluded they represent differences using an unweighted average over all ages of profiles that are not required to be parallel over the 30-45 age range.[17]

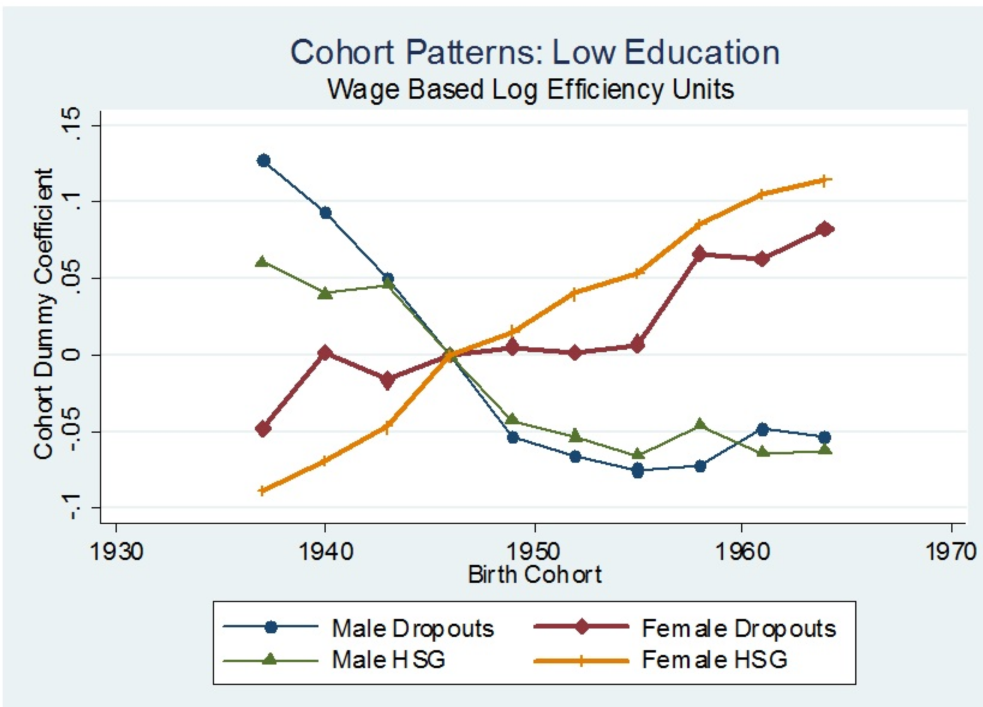

Figure 8: Wage-based Cohort Patterns: Lower Education Groups

Figure 8 plots the estimated coefficients on the cohort dummy variables for males and females

[17]Table 2 in BR, report results for regressions using the same mean data that are plotted in the equivalent of Figures 6 and 7, rather than the individual level data, but the estimates are essentially the same. They note that use of their price series resulted in life-cycle profiles for males all lining up with similar Ben-Porath shapes, in contrast to the profiles constructed under the assumption of the standard Ben-Porath assumption of a constant price. (See Figure 7 in BR.)

for the two lowest education groups. It shows a very different pattern for males and females in the expected direction. The males show a large drop up to the 1949 cohort and then a plateau. Females, in contrast, show a persistent improvement over cohorts. Dropouts provide a particularly clear case. Both males and females are subject to similar declining fraction of dropouts in the cohorts before the war, implying the same negative direction for the selection effects due to education choice. If production function changes were roughly the same for males and females for this group, the increased human capital for females suggests that the negative direction for the selection effects due to education choice was outweighed by the positive cohort effect due to their participation increase.

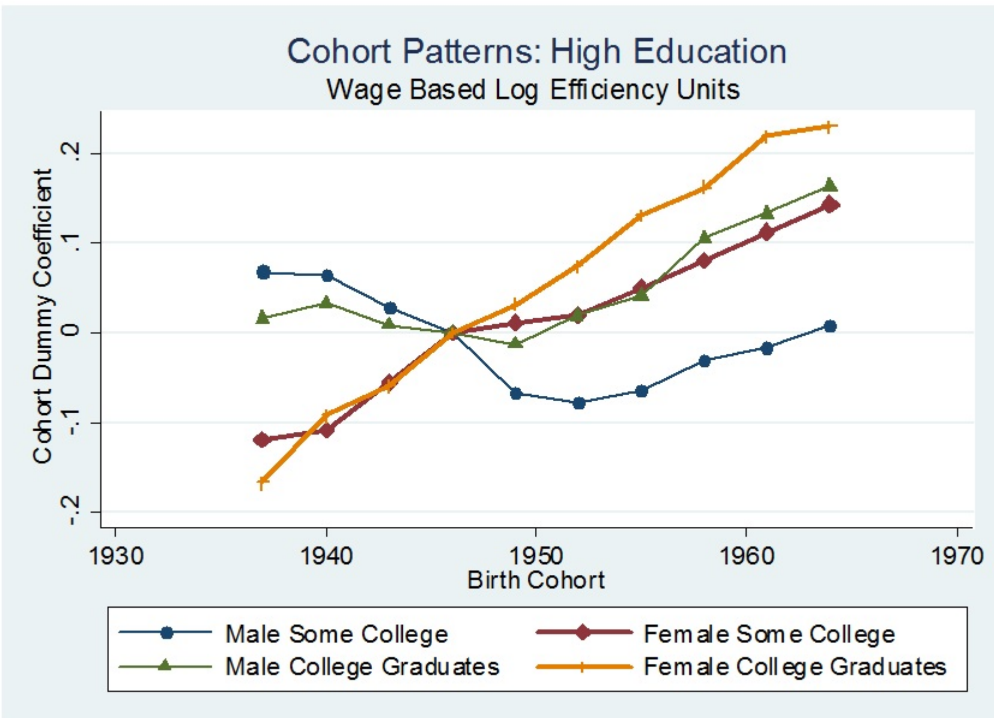

Figure 9: Wage-based Cohort Patterns: Higher Education Groups

Figure 9 plots the estimated coefficients on the cohort dummy variables for males and females for the two highest education groups. The pattern for male college graduates is the same as in BR. After the 1949 cohort the technological change effect and the selection effect are both positive for males and the cohorts improve. Before 1949 the technology and selection effects oppose one another. Females, as with the lower education groups, show a strong secular improvement with a much larger overall gain than males. This is, again, consistent with a much stronger incentive for more recent cohorts of female college graduates, who expect to be in the market longer, to invest more than female college graduates from earlier cohorts. The magnitudes are large: a full time, full year female college graduate from the 1961 cohort supplied, on average, over 20% more than the average female full time, full year college graduate from the 1946 birth cohort. This strong cohort pattern within education and experience cells suggests that conventional labor input measures likely significantly underestimate the contribution of females to post-war economic growth.

5 Job-skills-based Approach to Measuring Male and Female Human Capital

The wage-based approach provides evidence consistent with upward shifts in the life-cycle profiles of the amount of efficiency units supplied by more recent cohorts of females for all education groups. This implies increased female human capital within education/experience cells that cannot be picked up by standard composition adjustment approaches to measuring human capital. However, the wage-based approach may have over-estimated the upward shift if declining discrimination resulted in a declining wedge between the prices males and females received for the same human capital. In this section we explore an alternative "job-skills" approach. This approach infers the amount of human capital from occupation data instead of from wage data thus avoiding the problems associated with declining discrimination.

Different occupations represent different bundles of skills. In order to compare human capital from a multi-dimensional bundle of skills to the single dimension measure from the wage-based approach we need to "scale" the bundles along a single dimension. We do this in a way that is analogous to the composition adjustment approach to scaling the different age and education cells to compute a single total for a given type of human capital. The composition adjustment approach used in the standard implementation of the canonical model computes efficiency units for a single skill held by different education and experience cells by "pricing" the cells using the average wage of the cell averaged over the entire period. Our job-skills-based approach can be implemented in the same way by "pricing" the occupations to scale them and produce quantities on a single dimension. Our preferred approach modifies this by doing the scaling on the basis of the previously estimated efficiency units from the wage-based approach for males. The argument is that the male efficiency units are correctly estimated and can therefore provide a direct baseline quantity scaling for the occupations. There are obvious complications for either form of scaling, for example, due to differences in compensating differentials for males and females, but we abstract from these in this paper.

5.1 Capturing Life-Cycle and Cohort Effects with Job-Skills-Based Methods

Within the framework of Section 2, it is straightforward to capture both life-cycle and cohort effects on quantities of human capital supplied by workers through the wage-based method. Given the price series, the quantities across the life-cycle or across cohorts can be calculated simply by dividing the observed wages across the life-cycle or across cohorts by the appropriate price. The issue is more complicated with job-skills-based methods due to the form of occupational coding done in the available data sets.

The observed data across the life-cycle or across cohorts are occupations. If there was a very fine grid of occupations in which all workers had identical skills within occupations it would be possible to capture both changes in skills across the life-cycle and changes across cohorts by observing these occupations. Moreover, the price wedge between males and females for the same type of human capital could be estimated from wage differences within this fine grid of occupations. Unfortunately, in practice the occupation codes do not conform to this ideal situation.

Consider first the following simple example. Let the occupations represent multi-dimensional skill bundles. Let individuals start in an occupation that corresponds to their initial bundle and then make investments in these skills that simply scale them up. The ideal fine occupation grid would represent sequences on job ladders such that each higher level bundle of any type corresponded to a different occupation. In that case, with enough occupation codes the growth in skills over the life-cycle could be inferred from occupation data. Suppose, however, that the actual occupation coding is such that many “careers” in which the bundle does evolve through human capital investment are represented by a single occupation code rather than a sequence of codes on a job ladder. This is the case, for example, with many professions such as lawyer, doctor, and professor. In that case neither growth in skills over the life-cycle, nor differences in the human capital across cohorts of lawyers, can be identified from the occupation data.

This single code career problem has to be addressed in order to capture accumulation of human capital over the life-cycle from observations on occupations only rather than wages. In the extreme case, if individuals are in a “career” occupation and do not change their observed occupation code over the life-cycle, then there are no occupation changes to capture skill growth. More generally, within occupation code investments that increase supplied efficiency units with age or tenure cannot be directly captured. A recent literature using occupation data in conjunction with job skills measures from the Dictionary of Occupation Titles (DOT) and the UK Skills Surveys discusses these issues.[18] In this paper we go someway to address the problem for males by “experience scaling” the bundles. This again, has some similarities to the computation of efficiency units within skill type using composition adjustment methods where part of a composition change is in the age or experience distribution.

The main interest in this paper is to capture cohort effects rather than life-cycle effects and, unfortunately, job-skills-based methods face a similar problem in capturing cohort effects as they do in capturing life-cycle effects. Figure 2 shows that life-cycle participation profiles did not change much for males across cohorts. If males don’t change their life-cycle occupation sequence much over cohorts, then it will be difficult to pick up any cohort effects when we use the scaled bundles. Female participation changed markedly over cohorts and females changed their life-cycle occupation sequence more than males over cohorts so it may be possible to capture some of these effects for females.

One of the cohort effects emphasized for the college graduate group in BR comes from secular technological improvement in the production of human capital, broadly interpreted. A more recently trained physicist or doctor is exposed to production functions that incorporate advances in

[18]See, for example, Yamaguchi (2012) and Bowlus, Mori and Robinson (2016).

knowledge. The value added at the university stage is higher. In the absence of selection effects this increases the human capital of more recent cohorts. The wage-based methods are able to capture cohort effects from any source, including this technological improvement in human capital production for college graduates. It is more difficult to do so using occupation based data. This is a weakness of the job-based-skills approach and further research is needed to fully capture these effects with this approach.

5.2 Data for the Job-Skills-Based Measures

The basic data set for the wage-based analysis uses the MCPS for the period 1964-2009. This provides a source of annual data for a large age range covering a wide range of pre- and post-war cohorts. For comparison of the wage-based and the job-skills-based analyses we use the same data set, but drop the years of the data set before the start of the three digit 1970 occupation coding. Three digit coding was not available in the MCPS until 1968, and 1970 coding began in 1971. In implementing the job-skills-based approach we emphasize consistency over time as much as possible in the data source for occupations. There are four different census occupation coding periods in the data covering 1970, 1980, 1990 and 2000 census coding. There is a very strong similarity between the 1980 and 1990 codes, but more major differences between 1970 and 1980 and between 1990 and 2000. The Integrated Public Use Microdata Series (IPUMS) project conducted by the Minnesota Population Center at the University of Minnesota constructed a set of three digit occupation codes, based on 1990 census coding, that aims for consistency across the 1970 through 2000 census coding. To maximize consistency the project used previous research based on dual coded files and documentation on the coding schemes themselves and reduced the the number of codes. The final number of codes is less than the close to 500 in the later period original coding schemes, but still provides for a lot of variation with close to 400 codes.

The literature that uses job skills data typically takes two steps to assign job skills to workers in the main data sets such as the monthly CPS, the MCPS or the NLSY79. First job skill ratings are taken from sources such as the DOT or ONET and average skill ratings for a low dimension vector of skills for each occupation is constructed. Second, the skill ratings are assigned to individuals in the main data sets on the basis of their 3-digit occupation code.[19]

For this paper, where we wish to scale the multi-dimensional skill portfolios or bundles on a single dimension measure, we treat each of the approximately 380 IPUMS consistent codes used in the period of our data as unique bundles of skills. We do not use external data sources on ratings of the skills. Instead we form a grid made up of all the unique consistent IPUMS codes and discrete experience points and then scale these experience-skill bundles, according to the average efficiency units of the workers in that cell or grid point, taking the average over all the data periods.

An alternative method for constructing the single dimension measure is to follow the usual procedure, as for example in Bowlus, Mori and Robinson (2016), and first construct a low dimension vector of skills for each occupation based on a source such as DOT. Next, construct a grid of discrete bundles of the skills and then expand the grid to include discrete experience categories. Finally scale these experience-skill bundles using the average efficiency units of the workers at each grid point, averaging over all the periods. In practice, discretizing each skill in a vector of three skills, like the one specified in Bowlus, Mori and Robinson (2016), and allowing for even a modest number of discrete categories for each skill soon results in a grid where there are as many points as unique occupations. For the purposes of our analysis which requires a single dimension measure, there does not appear to be anything to gain by introducing outside data sources on the skills in this way.

5.3 Estimates of the Job-Skills-based Cohort Effects

In this section we present summary measures of the cohort effects obtained from the job-skills-based approach. The results are obtained using the same regression analysis used in the wage based approach, with the same sample, but the dependent variable now represents the log of efficiency units where the efficiency units are obtained from the single dimension job-skills-based measure described above. Each individual in the data set is assigned a value of efficiency units based on their 3 digit IPUMS consistent 1990 code.

Figure 10 plots the estimated coefficients on the cohort dummy variables for males and females for the two lowest education groups. Comparing this with the same figure (Figure 8) from the

[19]See, for example, Poletaev and Robinson (2008), Yamaguchi (2012), Gathman and Schonberg (2010), and Bowlus, Mori and Robinson (2016).

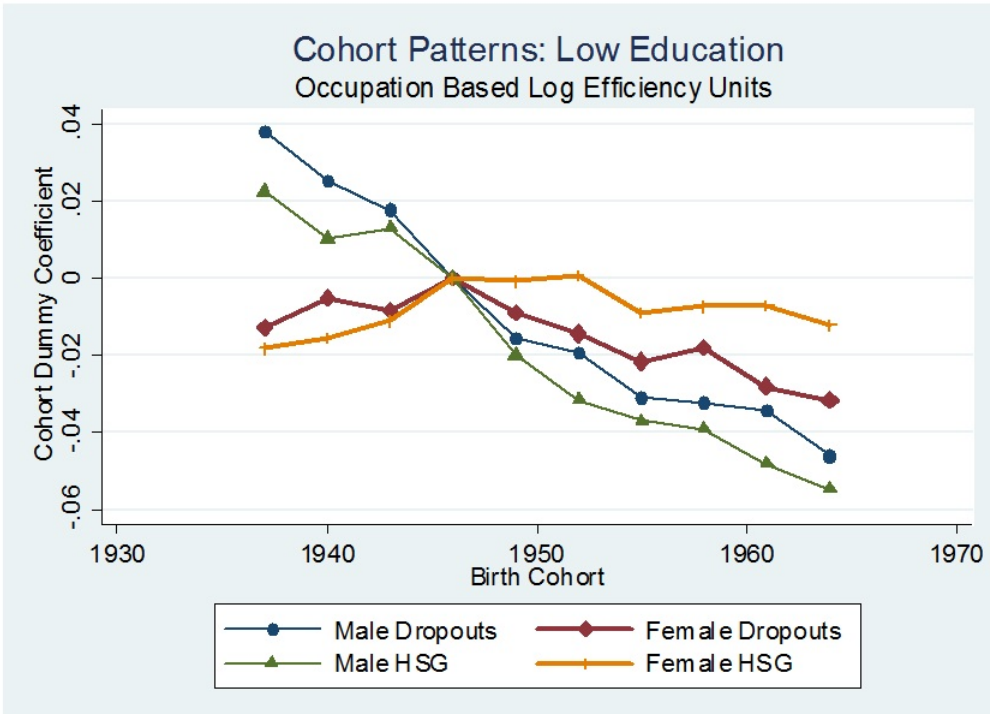

Figure 10: Skill-based Cohort Patterns: Lower Education Groups

wage-based approach, the male-female difference is still apparent, though there are some significant differences. The earlier cohorts for females again show improvement while for males their human capital declines. However the later cohorts decline for both males and females, albeit the rate of decline is slower for females. As noted earlier, the job-skills-based approach can only capture the cohort effects to the extent that the cohorts change occupation patterns. They cannot capture within occupation changes. The magnitudes are, therefore, likely to be different and the pattern may be affected by differential changes in the amount of occupational change across cohorts (within education) for males and females.

The results for the higher education groups are plotted in Figure 11. These are qualitatively quite similar to the results from the wage-based approach (Figure 9), though again the magnitudes are different. The male college graduates show a very similar pattern to the wage-based estimates

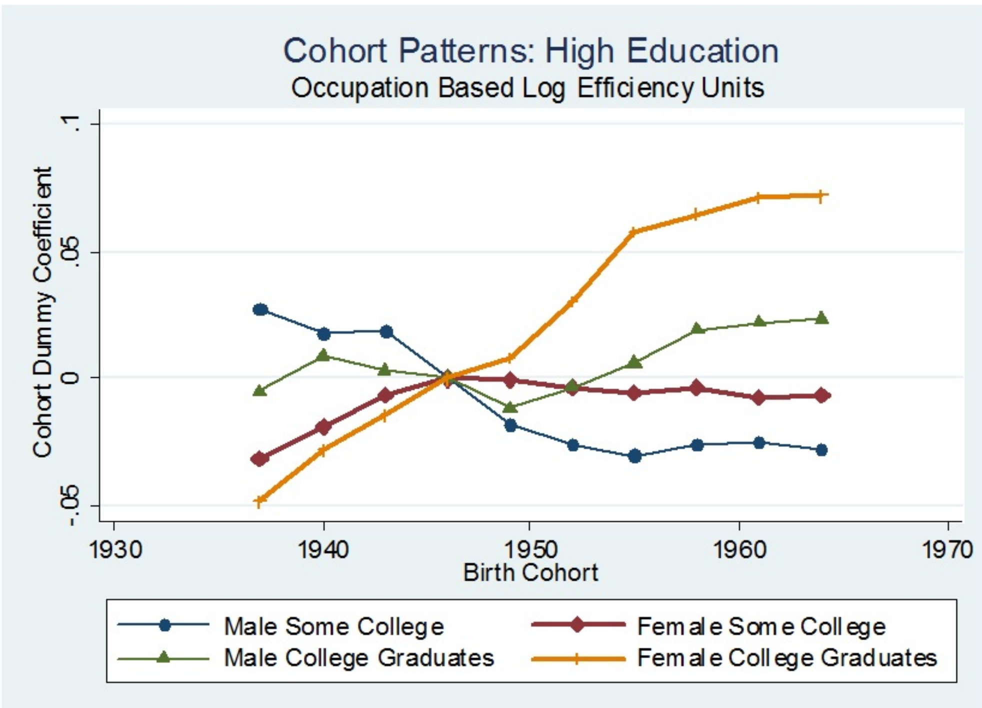

Figure 11: Skill-based Cohort Patterns: Higher Education Groups

and the females show a similar continuous growth over cohorts. The male some college group also show a similar pattern to the wage-based estimates and their decline in the pre-war cohorts again contrasts with the increase for females. Unlike the wage-based estimates, however, the some college group for females shows no growth after the 1949 cohort.

The relative patterns for males and females are similar in both the wage-based and the job-skills-based approach. For the higher education groups there is consistent evidence from both approaches of increased human capital in the more recent female cohorts. This suggests that there is enough change in occupation patterns, especially for female college graduates, for the job-skills-based approach to capture some cohort effects. The wage-based approach suggests that there is also substantial within occupation increases in the human capital for females, but the potential bias induced by declining discrimination makes it difficult to assess the true magnitude.

6 Cohort Effects and the Contribution of the Human Capital of Females to Growth

The evidence in the previous sections suggests that there have been substantial cohort effects in the human capital profiles for females associated with the large post-war increase in their life-cycle labor force participation. Conventional measures of human capital capture both the large increase in hours for females and their higher level of education, but they cannot capture the cohort effects which show increased human capital levels for females within detailed education and experience levels. This results in an underestimation of the true increase in the labor input of females and therefore of their true contribution to growth. Instead, conventional measures assign part of the female labour input contribution to multi-factor productivity (MFP).

In general, cohort effects result in a time varying deviation of the true labor input from the measured input using standard composition adjustment methods. The form of the deviation is discussed in detail in Bowlus, Bozkurt, Lochner and Robinson (2017) in the context of common fixed weight composition adjustment methods used most notably in the canonical model of wages and employment. Composition adjustment methods for aggregate analysis and the calculation of MFP, such as the Bureau of Labor Statistics (BLS) Tornqvist chained index, use time varying weights for the composition adjustment. The form of the analogous deviation in this case is discussed in BR. An illustration of the potential magnitude of the underestimation of the contribution of females for the period 1977-2000 using wage-based methods is provided in Section VI in BR. For the United States the BLS type measure for paid private workers underestimates the true input by 36.46 percentage points, which implies an overestimate of MFP of about 24 percentage points, assuming a labor share of two thirds. The results in the lower half of Table 4 in BR show that an important part of the overestimation of MFP for this period is due to an undercount of the increased contribution of females.

Comparison of Sections 4 and 5 show similar qualitative patterns for the cohort effects for females compared to males, but the issue of precise magnitudes remains open. Occupation based methods are likely to undercount the cohort effects since they cannot pick up within occupation changes. Wage-based methods are more generally applicable, but face a number of problems. The issue of discrimination is an important one in that declining discrimination could lead to an overestimate of the true female labor input. BR note that the overestimate of MFP would be reduced by 4 percentage points if discrimination against females over the period declined in the range of 10-12 percentage points. This is a difficult issue, but recent evidence that wage discrimination against females has been relatively constant at a historically low level for the last two or three decades suggests that it may not be a problem after the 1980s.[20]

A broader issue in the comparison of males and females is the potential for complications when workers have multiple skills, even within education groups, where the "endowments" may be different for males and females. The maintained assumption in this paper is that human capital of any given type, in the sense of an input in firms' production functions, is the same thing whether it is embodied in a male or a female. The wage-based approach uses a homogeneous (within education) human capital model which has a single price and single quantity and, in the absence of discrimination, the maintained assumption implies that the price series for males also applies to females. A simple

[20]For example, Blau and Kahn (2016) present results using data from the Michigan Panel Study of Income Dynamics (PSID) which has information on actual labor market experience. Their sample is full time, non-farm, wage and salary workers age 25-64 who worked at least 26 weeks during the preceding year. They report a "human capital adjusted" and "fully adjusted" female to male log wage ratio for 1980, 1989, 1998 and 2010, where the full adjustment includes industry and occupation dummy variables (Blau and Kahn (2016), Figure 2) For both measures there is an increase from 1980 to 1989, but no change thereafter.

extension to multiple skills within education that preserves the homogeneous model property of a single price and quantity is to allow for a fixed ratio “bundle” of multiple skills that is priced as a bundle, where the single quantity is the size of the bundle. As in the homogeneous model, males and females may differ in the quantity at any point in the life cycle, but they supply the same thing. The flat spot price series used in Section 4 is then simply the bundle price and the quantity is the bundle size.

The job-skills-based approach explicitly recognizes multiple skills, and given an interpretation of the maintained assumption that males and females in the same occupation supply the same thing, a difference in the occupational distributions by sex presents no special problems. Indeed, in this approach, changes in these distributions is the source of the relative quantity changes for females compared to males. The assumption in this approach is that within an occupation, the quantity of the “occupation input” for given a experience level does not change over time, and there is only one set of skills associated with the occupation - i.e. everyone “does” the occupation the same way. Since the occupations represent different inputs, this approach does not have the simplicity of an obvious single quantity, as in the wage-based approach. Instead, as a simple first step with this approach, weights based on wages or efficiency units from the wage-based approach were used to compute a total.

7 Conclusions

The labor market attachment of females has increased dramatically over the last half century, converging to a pattern similar to that of males. Human capital theory predicts an associated increase in human capital investment by females and a convergence in the life-cycle human capital investment profiles of males and females. This paper presents evidence from both wage-based and job-skills-based approaches to support this prediction. The evidence shows that conventional “composition adjustment” approaches to the measurement of human capital undercount the increased supply of efficiency units of human capital by females over the last four decades and that the magnitude of the contribution of the increased human capital of women to post-war economic growth thereby is substantially underestimated. A complete picture of the evolution of the human capital of women will require new approaches to measuring their human capital. The two approaches used in this paper complement each other and provide the same qualitative results. However, as currently implemented both approaches have some limitations. The exploration of ways of refining the two approaches is left for future work.

For the wage-based approach refinements would need to relax the single price and quantity property. In comparing the human capital of males and females, the single price and quantity property within education group of the wage-based approach is an attractive feature. The property can easily be extended to multiple skills by using a fixed bundle of the skills. However, if within education more than one bundle "type", i.e. ratio of multiple skills, is allowed, the attractive homogeneous model property of a single price and quantity no longer holds. Within a bundle type it would still be possible to maintain the assumption that males and females supply the same thing. However, a flat spot "price" series would no longer estimate a single price, and dividing wage payments by this price would no longer estimate a single quantity. If males and females differ in their distribution of bundle types, and if there was an increase in the relative price of the bundle type held more by females, use of the male "price" would over estimate the "quantity" for females in way similar to the effect of declining discrimination. In future work it would be worthwhile to explore ways of estimating a low dimension price vector from wages for each education group by subdividing the education groups into more than one type of human capital on the basis of a fixed characteristic such as college major.

For the job-skills-based approach refinements should take into account the recent literature that has documented large differences by sex in skill endowments and substantial within occupation variation in skills.[21] If, on average, females do an occupation differently, and if over time their way of doing the occupation produces more occupation output, none of this increase would be captured by the current job-skills-based approach. In future work it would be interesting to allow for variation within occupation and for technological change in producing occupation output that may affect

[21] See, for example, Baker and Cornelson (2016) for evidence on differences by sex in skill endowments. Several authors have noted important within occupation variation in skills. Bowlus, Mori and Robinson (2016) use the UK Skill Surveys to show how workers may use different skill combinations within the same occupation over time as they age. Autor and Handel (2013) use Princeton Data Initiative data to show the importance of within occupation variation in skills in explaining wage variation. Cassidy (2017) documents within occupation variation in tasks using the German Qualification and Career Survey.

males and females differently. In addition, alternative forms of aggregation in the job-skills-based approach, both within and across occupations, to obtain a single total quantity should be explored.

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