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Changing educational profiles of detailed occupations, 1990-2001

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Abstract

The absence of repeated direct measures of job skill requirements, such as a fully updated edition of the *Dictionary of Occupational Titles* (DOT), creates problems for anyone interested in understanding whether, how much, and how fast the demand for cognitive skills in the workplace has grown over time. Many studies have merged cross-sectional skill scores for detailed occupations from the DOT or O*NET with time series of occupational employment shares, but this fails to capture any within-occupation changes in job requirements. This paper considers the utility of using workers' personal education as a time-varying measure of occupational skill requirements. Trends in educational composition within detailed occupations for 1990-2001 are examined using very large sample data. Shift-share analyses decompose the total change in workforce education into components attributable to changes in occupational employment shares and in education levels within occupations. Because occupations are often characterized in terms of modal education, the extent of educational heterogeneity within occupations is examined. Limitations of workers' personal education as a measure of job complexity, the need for repeated direct measures of job requirements, and implications for BLS data programs are discussed.

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Education is commonly understood to be a qualification or pathway for entry into many jobs. Probably the most commonly modeled relationship in social science is the association between earnings and personal education, either as a research question in itself or because

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education is a critical control variable for models focusing on other determinants of earnings. The guiding assumption in most cases is that different levels of education provide a large part of the cognitive skills, knowledge, and perhaps soft skills required by jobs. If one assumed effective matching between persons and jobs at the micro level, and effective adjustment of the aggregate supplies of different levels of education to employers' demand for education at the macro level, then it would seem that the education levels of workers could be used as a convenient proxy for the skill requirements of their jobs. Using worker education as a measure of job complexity has been criticized effectively by many (e.g., Spenner 1990), and these problems will be discussed extensively in the final section of this paper. Ideally, one would like an independent, direct measure of job demands, rather than relying on worker characteristics as proxies. However, there is one undeniable attraction in using workers' personal education as a measure of job skill requirements, which is their utility for trend studies.

The fact remains that after many years there are still few databases that measure job skill requirements directly, such as the Dictionary of Occupational Titles (DOT), and these data are available generally only for a cross-section. In the absence of repeated measures of job skill requirements, trends studies are limited to studying changes resulting from changing occupational employment shares over time. Everyone recognizes that the changing character of occupations themselves may also contribute to changing skill requirements, as jobs become more skill intensive or deskilled. However, by definition, a cross-sectional skills database cannot capture any change within occupations over time. Therefore, this component of change is absent from most trend studies, which effectively treat occupational skill requirements as constant over time. This is a well-known limitation of trend studies using the DOT (Cain and Treiman 1981; Spenner 1990). Indeed, the rate or magnitude of skill change within occupations remains

unknown and largely unaddressed several decades after this knowledge gap was identified because there are few or no repeated direct measures of job skill requirements.

The first section of this paper explains the value and uses of examining trends in the educational profiles of detailed occupations. The second section describes the data, covering the period 1990 to 2001. The third section presents descriptive information on trends in the educational composition of detailed occupations, which gives some sense of the magnitude of within-occupation changes over an eleven-year period. Shift-share analyses are used to assess the relative contributions of the between- and within-occupation components to the total change, which not only provide a fuller accounting than previous trend studies but also some indication of how much they might have missed by using cross-sectional skill scores.

The remainder of the paper reflects the fact that not all changes in educational composition are equally relevant. Many researchers and BLS databases classify occupations' education demands by category, so changes that are sufficient to alter an occupation's classification have particular relevance compared to changes that increase the concentration of a given education group within an occupation. Consideration of this issue underscores the significant educational diversity within occupations and raises questions about the complications that result from using a measure of central tendency to classify occupations into categories.

To address these issues the fourth section of the paper categorizes detailed occupations into five levels by modal education as a proxy for the occupation's required education. This closely approximates the idea of "typical entry path" used by the Occupational Outlook Handbook and is similar to the situation that will be faced by the Occupational Requirements Survey in classifying occupations into required education categories. Results show trends in the distribution of jobs and occupation by modal education, the degree to which the classification of

detailed occupations by modal education agrees with classification by one-digit occupation, the number and sizes of occupations that change education category over time, and other ways in which the heterogeneity of education within occupations complicates the use of concepts such as modal education and "typical" entry path.

A final section discusses the problems associated with using worker education as a proxy for job required education. Despite these problems, there are few alternatives to producing a historical series with available data, so understanding the recent record of educational change within occupations is a useful point of reference in the effort to understand changing job requirements within occupations over time.

I. Background

The absence of time series for direct measures of job skill requirements makes the use of readily available proxy measures, like workers' personal education, attractive despite their numerous limitations. Although it is possible and desirable to create repeated measures of job skill requirements going forward, and there is recent movement in this direction from several quarters (OECD 2013; Handel 2016b), there is no returning to the past to collect better historical data. There are small sample data sets with direct measures, such as the Quality of Employment Surveys in the 1970s, which can be used to study past trends for the overall economy and perhaps a subset of large occupations (Handel 2000, 2012, 2016a). The National Compensation Survey may be usable for studying more recent trends, as well. However, workers' personal education by detailed occupation is one of the few repeated measures that is available in abundance for understanding changes in job skill requirements both within and between occupations. This paper examines changes in education levels within occupations over time as

an exercise that provides a general perspective on how much and how rapidly skill requirements might change within occupations, rather than as an effort to produce conclusive answers.

Understanding the changing educational profiles of detailed occupations has value for several concerns. There is a gap in basic research regarding the rate of within-occupation skill change. Understanding precisely how educational attainment translates into occupational outcomes and how this may have changed over time are useful for researchers and policy makers. Issues of education and workforce policy, skills mismatch, and the growth of wage inequality typically involve assumptions regarding the changing nature of work that are difficult to test in the absence of time series data.

On a practical level, the U.S. Bureau of Labor Statistics (BLS) also has several occupation-level databases, whose data elements include education and skill. The Occupational Requirements Survey (ORS) uses a concept of occupational education requirements inherited from the DOT. However, in the absence of information on how rapidly occupations change there is limited basis for planning or understanding how frequently the occupation-level information must be updated.[2]

Information on the changing educational profiles of detailed occupations is also valuable for BLS' occupational projections program and the Occupational Outlook Handbook (OOH), which make prominent use of the concept of the "education typically needed for entry into an occupation." Unlike the DOT and ORS, the concept of "typical entry" path is focused more on how workers can best position themselves for career success than on the task requirements of occupations per se. This distinction between occupation- and worker-centered perspectives will reappear at several points in this paper below. One point that can be noted at the outset is that

[2] See Handel (2016a) for a review of available information on occupational dynamics.

BLS' interest in treating each occupation equally for databases such as ORS and OOH is in some tension with the practical need to use resources effectively, in which case occupations' relative size is a relevant consideration. A number of analyses below present unweighted results for occupations, treating all occupations as equally important, as well as results that weight occupations by their employment shares, which may produce significantly different conclusions.

II. Data

Analyses of trends in worker education by detailed occupation face a number of challenges. Because people work for several decades, there is substantial continuity in the composition of the workforce over time. The data analyzed must cover a sufficiently long time span that there is some turnover in the workforce, as well as time for changes in the nature of work to be large enough to be detected. Indeed, the very gradual nature of cohort succession means that measures of change in occupational characteristics are unlikely to be large when worker characteristics serve as proxies. Workforce turnover will be limited over a five-year period, for example. However, a wide observation window increases the likelihood that the data will not be comparable over time because both education and occupation codes change periodically in BLS and Census data. The ORS and OOH databases use detailed occupations, which limits the choice of data further to files with very large samples, such as the decennial Census or using pooled years of the CPS outgoing rotation groups. As will be apparent, even these large files have issues of small samples for some detailed occupations, which contribute to large swings in occupational education that are probably noise. Insofar as BLS treats all occupations as equally important for certain purposes, the analyses below that weight occupations equally indicate lower reliability may be a problem when occupational samples are small.

All analyses compare education by detailed occupation using the 1990 PUMS 5% sample (n=4,892,675) and three years of CPS merged outgoing rotation groups for 2000-2002 (n= 1,955,444). The CPS data can be interpreted as producing moving averages for 2001.[3] An advantage of these files is their large sample sizes, which permit more reliable estimates of educational attainment at the detailed occupation level than alternative sources. Nonetheless, even though the smaller file has nearly two million cases, averaging nearly 4,000 case per occupation, the uneven distribution of workers by detailed occupation mean that some occupations have small samples for one or more years.

The 1990 Census is the earliest survey using current education codes and the merged file for 2000-2002 is the last using the same occupation codes as the 1990 Census. Nevertheless, there is a potential question of comparability insofar as the Census occupation items were self-administered by households and the CPS items were administered by trained interviewers. A subsequent version of this paper may add CPS data for 2013-2015 which would not have this potential comparability problem. It is not possible to construct a single analysis for 1990-2015 because the occupation codes change after 2002.

However, the merged file for 2000-2002 is unusual for bridging the 1990 and 2000 Census occupational classification systems by double-coding all records in terms of both the 1990 and 2000 Census occupation categories. This means it is possible to cover the twenty-five years in two segments of similar length, with the 2000-2002 file serving as a link between the two period analyses. Nevertheless, the different occupation codes would limit the comparability

[3] The 5% extract of the 1990 Census was downloaded from IPUMS (www.ipums.org). Steven Ruggles, Katie Genadek, Ronald Goeken, Josiah Grover, and Matthew Sobek. *Integrated Public Use Microdata Series: Version 6.0* [dataset]. Minneapolis: University of Minnesota, 2015. I thank Peter Meyer of the U.S. Bureau of Labor Statistics for sharing his version of the 2000-2002 CPS Outgoing Rotation Group files, which are dual-coded in terms of both the 1990 and 2000 Census occupation classifications.

of results for the two periods. Likewise, it would be possible to extend the analysis further back in time to 1980, but in this case there would be a break in the comparability of the education codes.

All samples are restricted to wage and salary workers between 18 and 65 years old with a current job. Analyses collapse reported educational categories into five major levels (<HS, HS, some college, BA, post-graduate). Analyses using years of education impute values based on category midpoints and analyses of CPS data immediately preceding the shift from years of education to educational categories.

Both data files have 498 detailed 1990 Census occupations, but they each have three occupations not matched in the other file. These occupations account for less than 0.1% of the workforce in both years (see Appendix Table A1).

III. Trends in occupational education levels and employment shares

Any analysis using worker characteristics as a proxy for job characteristics constrains the results that are possible to some extent. Specifically, similar previous research used data from periods of rapidly increasing education levels (1940-1970) to examine the relative importance of within- and between-occupation changes in accounting for workforce education trends (Folger and Nam 1964; Rodriguez 1978). Naturally, there was a great deal of educational change that was available to be partitioned into between- and within-occupation components for those years. However, growth in educational attainment decelerated significantly after 1980, so any similar analysis will suggest much slower change in the nature of work more recently, contrary to conventional views. Of course, even if worker educational attainment did not change at all over time it is possible for occupational education levels to change significantly if the sorting of

workers into occupations by education grows stronger, i.e., the association between occupation and education may increase sharply.

Nevertheless, if all change represented a re-shuffling of existing worker education groups across occupations and the relative size of occupations remained fixed, then any growth in one occupation's level of "required skill" (worker education) would necessarily imply declining (measured) skill requirements for one or more other occupations. No group can receive a larger slice of a fixed pie (e.g., college graduates) without another receiving a smaller slice, at least in the limiting case that occupational employment shares remained unchanged. The apparent occupational downgrading that results mechanically in such situations, even if the task content of the job remained unchanged, might be considered an undesirable aspect of this approach to measuring job skill requirements. It is possible that some of these "zero-sum" dynamics might be at work even when workforce education levels are increasing and occupational shares are not completely fixed if both trends are small relative to changes in the strength of occupational sorting by education over time.

The gradual change in recent workforce education levels is illustrated in **Table 1**, which shows workers' average years of education grew from 13.3 years in 1990 to 13.6 years in 2001, an increase of approximately 0.3 years of education over the 11 years covered by the data after rounding. The distribution of the workforce by educational category shifted mostly toward workers with a *bachelors' degree* (+3.6 percentage points), and away from *high school dropouts* (-2.4) and workers with *less than a bachelor's degree* (-1.5).

To account for the possibility that recent flows into the labor market are distributed differently than the overall stock of workers the second panel of Table 1 shows results for workers age 24-34. Indeed, the distribution of younger workers shifted somewhat more strongly

toward those with a *bachelor's degree* (+4.5), with larger declines among *high school graduates* (-3.2), as well as workers with *less than a bachelor's degree* (-3.3), and little change in the share of high school dropouts. For both all and younger workers, the share with a post-graduate degree increased somewhat, as well. These results suggest possible differences between younger cohorts and the overall workforce, where younger workers show the effects of recent changes most strongly, which are diluted among the overall workforce by effects of past trends that carry over to the present through inertia. Nevertheless, sample size constraints prevent sub-group analyses that examine this possibility more deeply.

The bottom two panels of Table 1 show the distribution of the workforce by the modal education level of their occupation for all workers and young workers. Clearly, the shift of more than ten percent of workers out of occupations classified as *some college* and the even greater increase in occupations classified as *BA level* are more dramatic than anything observed in the upper panels of the table. The divergence between distributions of workers by own education and modal occupational education reflects the fact that not all workers' education is equal to the occupational mode and the pattern of educational diversity within occupations can change over time, which are key aspects of the analyses in Section IV.

Because workers' own educational attainment rose somewhat between 1990 and 2001, it is possible for the education levels within all occupations to increase, rather than for an increase in one occupation necessarily coming at the expense of declining education levels in others. However, insofar as patterns of education by occupation differ greatly from the relatively small changes in workforce education without accommodating changes in occupational employment shares, there may be occupations whose skill requirements appear to be decreasing as well as occupations whose skill requirements appear to be increasing as a mechanical result of the

method of measuring change in occupational skill requirements based on workforce characteristics.

A. Trends in education within occupations

Trends in education within occupations can be measured in terms of (1) mean years of education or (2) the changing shares of different education groups within occupations.

To a significant extent changes in mean years of education within occupations mirror the growth in workers' attainment, which increased by 0.274 years between 1990 and 2001. This can be shown by using intervals to describe the distribution of changes in mean years of education within occupations, where the key interval of interest ranges from one-half to 1.5 times the overall change in mean education, or growth in mean education of 0.137 to 0.412 years. Occupations whose mean years of education grew by an amount within this range essentially mirrored general workforce trends. Other intervals are defined in relation to that range of values and the distribution of occupations and workers are shown in **Table 2**. Row 3, which is highlighted, shows that the average education rose by roughly the same amount as the workforce overall for more than 37% of all occupations accounting for nearly half of all workers (48.8%) when employment shares are averaged over both years. These occupations essentially mirrored the general trend and they account for nearly half the workforce; the mean years of education within these occupations rose in tandem with the general increase in attainment. In principle, all occupations could have fallen into this interval, all reflecting the general workforce trend more or less equally, but this was not the case empirically. A number of occupations experienced above-average gains, so others necessarily experienced below-average gains. Indeed, for a significant share of occupations this meant average education levels actually *declined*.

- Average education declined within nearly one-quarter of occupations accounting for roughly 15% of the workforce (row 1).

- About 16% of occupations accounting for 28% of the workforce experienced below-average gains in mean education (row 2).

- A larger number of occupations (24%) experienced above-average gains, but they employed a much smaller share of the workforce (8.5%) (rows 4 and 5).

Obviously, the caveats discussed earlier regarding use of workforce education to infer job characteristics would need to be considered before concluding that required skill demands actually fell in the occupations in which average education declined. Some of these occupations are related to farming, simple construction jobs, and manufacturing production jobs, so they may reflect increasing representation of immigrant workers. The task complexity or quality of performance within these occupations may have declined somewhat, but it is entirely possible that the only aspect that changed are the personal characteristics of the workers now holding these jobs. It is also the case that a number of the occupations with declining average education are skilled trades, technical, and professional jobs.

Table 3 provides more detail for occupations that experienced the greatest change, those within which mean education declined by at least 0.75 years or increased by at least 1.25 years. These cut points are approximately 1 year above or below the average (+0.274 years) for the workforce overall. These eighteen occupations represent the outer range of change over the eleven-year period. The nine occupations with the largest declines between 1990 and 2001 mostly began the period with low mean education, but mean education also declined for a number of occupations that began with high levels in 1990, complicating any explanation based on regression to the mean. The nine occupations with large gains mostly had means in the middle or upper range in 1990. However, across the entire sample of 495 occupations there is essentially no relationship between the initial *level* of mean education in 1990 and *changes* in the

mean over the next eleven years ($r = 0.03$). In general, it is not simple to describe the occupations that changed most in terms of their initial levels.

However, Table 3 also shows the samples sizes for each occupation experiencing a large change. Seven occupations had a sample size below 50 persons for at least one year, so estimated differences in means may reflect sampling variation rather than genuine change in the population. If an occupation's sample size is small for even a single year, there is potential for sampling flukes to produce sharp changes. Indeed, converting changes in means to absolute values, there is a relatively strong correlation across all occupations between the size of changes and the (ln) smallest sample size for an occupation across the two years (-0.43). When at least one year's sample is small, occupations tend to show larger changes in mean years of education, suggesting that some of the largest movements may be noise and should be ignored. The problem would be even greater if analyses were extended to recent years because the CPS is the only data compatible with the 2001 education and occupation codes and sample sizes would likely be smaller than the 5% 2010 Census extract even after pooling multiple years, as is the case here. The implications of these results for BLS programs would seem to be that most change in education levels within occupations over more than a decade are relatively modest, especially when the size of occupations is taken into account, but there are a few occupations with large samples that, rather unpredictably, experience greater change in their educational composition over roughly a decade.

Some of these results remain similar when categories of educational attainment are used to characterize occupational education levels, but others differ. **Table 4** shows the average percentage changes are relatively small (column 1), especially when occupations are weighted by employment (column 3), consistent with the preceding. Likewise, the standard deviation of the

change in education shares also drops by about 50% when occupations are weighted by employment (column 2 vs. column 4).

However, unlike the previous results for years of education, whether or not *changes* in the educational composition of occupations are related to the *initial shares* of different education groups is fairly sensitive to whether or not the correlations are weighted by employment. Unweighted correlations in Appendix Table A2 tend to be low except for occupations with high post-graduate shares tending to increase their share of post-graduates over time (0.44). However, the weighted correlations present a much more complex picture that is difficult to summarize, so it is not possible to conclude simply that changes in education shares are unrelated to initial levels. They show a tendency for occupations with high shares of high school graduates to increase their shares of both high school graduates and workers with some college, while decreasing their shares of all other education groups. Occupations with high initial shares of workers with a BA increase their shares of both workers with a BA and workers with less than high school, while their shares of high school graduates and workers with some college decline. This issue will be assessed more formally in a subsequent section by looking at changes in segregation indices, which show generally modest growth in the segregation of different education groups across detailed occupations.

However, the main difference when using education categories rather than mean years of education is shown in the right panel of Table 4. These figures are changes in education shares for the 5% of occupations with the most extreme negative and positive swings respectively (approximately fifty occupations per row).[4] These shifts are very large in an absolute sense and

[4] It is important to note that these occupations were selected without regard to their size in terms of employment shares. They are the 10% percent of *occupations* with the greatest decreases and increases in shares of different education groups. It is also important to note that the fifty occupations described in each row are not necessarily the same set of fifty occupations, e.g., the fifty occupations experiencing large swings in percentage of workers

compared to the average changes in education shares shown in the left panel. They also appear larger than the results in Table 3 using years of education even though they are based on the same underlying data. These changes are also far larger than the general workforce trends in workforce educational attainment shown in Table 1, so they likely reflect some degree of resorting rather than simply demographic trends in the relative sizes of education groups that are common to all occupations.

Again, however, there are moderate to large (negative) correlations between the absolute changes in education shares and the (ln) smallest sample size, ranging from -0.30 to -0.49. In other words, large changes are associated with small occupations. Reinforcing this point, the final column of Table 4 shows that the fifty occupations in each of the first three rows, showing changes in the shares of < HS, HS, and some college workers, accounted for less than 2% of the workforce in each case, even though they accounted for 10% of all occupations. Likewise, the fifty occupations with large changes in percentages with a BA or a post-graduate degree accounted for about 3.5% of the workforce in both cases, despite accounting for 10% of all occupations.

Whether these results imply frequent updating of an occupational requirements database is warranted depends partly on whether the shares of the workforce affected are judged to be a deciding factor or whether each occupation is to be treated as equally important. However, the importance of these changes also depends on whether they have the effect of changing the skill classification of occupations. If the percentage with a BA in an occupation rises from 55% to 80% the modal education remains the same and the occupation's classification as requiring a BA

with a high school education need not be the same as the fifty experiencing large swings in their percentage with a BA. This occupation focus is consistent with BLS' interest in treating each occupation on its own terms in building databases such as ORS and OOH. In practice, this impulse is balanced against the need to use resources effectively, in which case occupational size becomes relevant.

is unchanged. This points to the relevance of a categorical approach because both ORS and OOH classify occupations in terms of the dominant education group rather than in continuous terms using either mean years of education or percentage shares of different educational categories. The degree to which changes in the educational profiles of occupations have altered their classification by education level is considered in the following section, where required education is defined categorically using modal education level.

The remainder of the current section considers the relative importance of the kinds of trends considered in Tables 2 and 4 compared to trends in occupational employment shares. Shifts in occupational employment are the only aspect of skill change captured by most trend studies, which append cross-sectional data from the DOT or O*NET to time series data on occupational employment shares. The question to be answered is whether previous analyses restricted to the effects of between-occupation changes in employment shares captured most of the change in skill requirements or whether they have missed a large part of the change because they could not measure within-occupation shifts in skill requirements. Before the formal shift-share analysis, it is useful to consider how much occupational employment shares tend to change over time.

B. Trends in occupational employment shares

Just as the magnitude of the increase in workforce education levels has a limiting effect on the magnitude of changes on might expect in education levels within occupations, the potential impact of between-occupation shifts is affected by the extent to which occupational employment shares change over time. This is affected, in turn, by the relative fineness of the occupational classification. Using 495 occupational categories means that the average occupation employs only 0.2% of the workforce, suggesting most occupations do not have scope

for growing or shrinking very much. Although the standard deviation of occupational employment shares need not be small, empirically it is relatively low (~0.4%) in both years. Only 18 or 19 occupations in either year account for at least 1% of the workforce, which clearly limits the size of likely changes in employment shares for most occupations. Nevertheless, these few occupations—less than 4% of all occupations—accounted collectively for about a third of the workforce in 1990 (36%) and 2001 (32%).[5] Any trends driven by changes in occupational employment shares would have to have a consistent effect on either a large number of very small occupations or on these few relatively large occupations.

In fact, about 12.9% of the workforce was redistributed across detailed occupations between 1990 and 2001. Consistent with the cross-sectional distributions, losses were concentrated in fifteen occupations, whose total share of the workforce fell by 7.3 percentage points, and gains were concentrated in twelve occupations, whose total share grew by 5.4 percentage points.[6] These twenty-seven occupations, or 5.5% of all occupations, accounted for roughly half of the changing distribution of the workforce across occupations in this period.

The simple correlations between changes in occupational employment shares and the occupation's level of education in 1990 or 2001 are all low, whether education is measured in years or categories. The largest correlations are between change in employment share and the initial proportion of the occupation that were high school graduates (r = -0.11) or college graduates (r = 0.10) (not shown). When the occupations are weighted for average employment size the strength of both correlations increases modestly (±0.04) (not shown). Contrary to

[5] Not surprisingly, the skewness (5.1, 5.8) and kurtosis (36.7, 51.8) of the occupational size distributions are very high for both 1990 and 2001.

[6] These occupations are singled out because they lost or gained at least 0.2 percentage points of the workforce. The shares of only two occupations shrank by more than one percentage point of the workforce and only one gained close to one percentage point, which is not unexpected given the size distribution of the workforce by detailed occupation.

common impression, there was no strong tendency for occupations with higher levels of education to expand their share of employment over time. Reflecting the general continuity in the occupational distribution, the unweighted correlation of occupational employment shares between 1990 and 2001 is very high ($r = 0.94$).

In general, these results might suggest modest scope for between-occupation shifts to account for a large share of the changing educational distribution. However, it is also possible that these changes in occupational employment shares account for a large proportion of what were relatively slight changes in education over this period. Clearly, there was some change in the educational level within occupations between 1990 and 2001, reflecting both the slight general growth in workers' educational attainment and some resorting of workers by education across occupations. There were also some change in the relative sizes of occupations. The question then becomes the relative contributions of each component to overall changes in mean years of education and changes in the overall shares of different education groups.

C. Shift-share analyses

The central question addressed by the shift-share analysis performed here is how much of the change in workforce education levels could be predicted based on changes in (1) the educational profiles within occupations holding their relative sizes constant vs. (2) the relative sizes of occupations holding their educational composition constant. Almost all previous analyses have used cross-sectional measures of job requirements, meaning the first component is unmeasured and its relative importance remains unknown.

Table 5 presents the results of shift-share analyses for the changes in mean years of education and education group shares given in Table 1. The first row shows that changes in the relative size of detailed occupations predict nearly 40% of the observed increase in mean

education, while changes in education within occupations explain a bit more than 60%. Likewise, within-occupation changes account for roughly 70-85% of the total change in workforce shares for three education groups (<HS, <BA, BA), while between-occupation shifts are more important in explaining total change for two other (HS, post-graduate). It should be recognized that these proportions refer to a situation in which the absolute changes in workforce education are relatively modest.

Nevertheless, although there are problems in using workforce education as a measure of job requirements, and the overall changes in education means and proportions are modest, these results suggest understanding skill changes within detailed occupations may require more attention. One cannot assume that analyzing the effects of changing occupational employment shares will capture most decadal skill change. Partly arguing against this interpretation, however, is the fact that nearly half of all workers were in occupations that increased their average level of education more or less in direct proportion to the changes in the overall workforce. It is possible, then, that half of the within-occupation effect on line 1 of Table 5 is simply a reflection of trend growth in educational attainment. Whether or not this kind of trend growth is actually accompanied by employer responses that raise the complexity of job tasks cannot be answered in the absence of repeated, direct measures of occupational skill demands, whose absence was the motivation for the present exercise.

IV. Modal education as an occupational descriptor

The previous section examined the changing educational composition of occupations using mean years and multiple group proportions, but this is not necessarily most consistent with the approaches taken by BLS, some researchers, and, indeed, the public. For example, the DOT and ORS classify occupations in terms of a single required education level and the OOH

identifies the "most common" education required for entry in an occupation. While the bases for classification are not entirely clear and may vary, the fact that few occupations are internally homogeneous means that some decision rule is required if occupations are characterized in terms of a single education category. Indeed, the average standard deviation of years of education within occupations was 2 years in 1990, ranging from 1.5 years to 3.0 years at the 5th and 95th percentiles, respectively. Values for 2001 were only marginally lower.

To examine skill change when occupations are characterized in terms of a single education level, this paper classify occupations according to their modal education category using five levels: < HS, HS, some college, BA, and post-graduate education. In addition to examining trends, this section will also consider the adequacy of classifying occupations into a single education category, including the information loss when the internal heterogeneity of occupations is omitted.

The lower panels of Table 1 show levels and trends differ significantly when workers are classified by the modal education group within their occupation rather than according to their own education. Among the key differences:

- There are almost no workers in occupations in which less than high school is the modal education level (~1%), in contrast to their share of the workforce shown in the upper panel (~10%).

- Somewhat more workers are in occupations in which post-graduate degrees are modal (3-4%), but the percentage also falls short of their share of the workforce in both years (8%-9%).

- Workers are over-represented in occupations in which high school is the modal education level (~45%) relative to their share of the workforce (~33%), reflecting the relative integration of high school dropouts into occupations in which high school graduates predominate, discussed below.

- The shares of workers and jobs classified as *some college* and BA are more similar to one another.

- However, there was a sharp decline in the share of jobs in which "some college" was the modal education (-10 percentage points) and a corresponding rise in the share of workers in occupations in which a BA was modal (+12 percentage points).

The shifts out of *some college* jobs and into BA-level jobs are far larger than the corresponding changes in the distribution of workers' own education shown in the upper panel of Table 1 for both the overall workforce and younger workers, so changes in the workforce composition cannot be their only explanation. Either occupations recruiting those with a BA have grown at the expense of occupations filled by those with less than college, or some occupations have changed their educational composition sufficiently that the modal education has shifted from some college to BA level. Although the exact mechanism is not obvious from Table 1, clearly, there have been dramatic changes in the shares9 of workers in occupations at those two levels.

Presenting a more occupation-centered perspective, **Table 6** gives the unweighted count and percentages of occupations by modal education for 1990 and 2001 (columns 1 and 2), as well as carrying over the weighted percentages from the lower panel of Table 1 for comparison (column 3). Occupations whose modes are high school and some college levels together account for about three-quarters of all occupations in both years, though their combined share of the workforce declined from about 82% to 69% between 1990 and 2001. This gives some sense of the distribution of occupations that ORS is likely to encounter, though the breakdowns will differ to the extent that the direct measures of job educational requirements used by ORS differ from this classification.

The right panel of Table 6 shows that classifying detailed occupations by workers' modal education is generally consistent with classifying them by broad occupational categories. All post-graduate occupations and almost all BA occupations are in the managerial, professional, and

technical group. Likewise, all of the few occupations whose modal education is less than high school are in craft, operative/laborer, service, and farm broad occupations. Weighting for occupational size accentuates these differences somewhat (not shown).

There is more diversity within the two large, intermediate groupings, but the high school occupations are found more commonly among the blue collar, service and farm broad occupations compared to the some college occupations, which lean more toward clerical/sales and upper white collar occupations. Further, when occupations are weighted by employment shares, the *some college* occupations concentrate much more strongly in the clerical category (not shown). Taking these broad occupation results as a robustness check, they suggest classifying occupations by modal education produces generally sensible results.

The remainder of this section examines the diverse implications of cross-classifying workers' personal education and their occupation's modal education, and tries to account for the shift from occupations in which some college is the mode to those in which a BA is the most common level of education.

A. Cross-classification of the workforce by personal education and occupational modal education

Characterizing occupations in terms of a single level of education, such as the mode, is an idealization to the extent that occupations are internally diverse with respect to worker education. However, if the diversity is relatively low then this simplification has practical value and only minor drawbacks. The strengths and limitations of this approach, as well as general understanding regarding labor market patterns, can be illuminated by cross-classifying the workforce according to both their own education and their occupation's modal education level.

Any cross-classification of frequencies can be described in terms of the variables' joint distribution, which gives the best overall view of the most populous combinations of categories, and the two conditional distributions, which each speak to different concerns. **Table 7** shows the joint distributions for 1990 and 2001, as well as the difference in the bottom panel. The twenty-five values in each of the first two panels sum to one hundred percent. The most common combinations are highlighted in pink and these seven cells account for about 80% of the workforce in each year. Cells with the lowest density shaded in grey. Larger values in the bottom panel, showing the biggest changes, are highlighted in pink.

Given the classification of occupations in terms of the modal education, it is not surprising that most of the workforce is on or close to the diagonal, indicating congruence between workers' own education and the largest education group of their co-workers. Nevertheless, nearly 55% of workers are in off-diagonal cells in both years. This kind of internal diversity would present problems of occupational classification even if the row variable was a direct measure of job education requirements, such as the DOT's GED variable, rather than a measure of worker attainment. There would still be a certain number of individuals reporting a level of education required for their *job* that differed from the level of education assigned to their *occupation* on the basis of all respondents in the occupation. If some measure of central tendency, such as the mode, is used to classify occupations, then there will be some proportion of cases within the occupation that will be mischaracterized by that classification.

If there were perfect or near-perfect sorting such that the mode were a perfect occupational descriptor, then all cases would be on the diagonal in both years, but this is clearly not the case. This points to an interesting tension. If workers were always completely segregated by education into different occupations there would be no need to investigate within-

occupation change because the latter presupposes transitional periods in which occupations have a diverse educational composition. Therefore, insofar as one admits occupations are susceptible to internal change one must concede that modal education is an imperfect descriptor, and insofar as one seeks to use modal education serves as a highly accurate occupational descriptor one is implicitly discounting the possibility of within-occupation change and the use of changes in educational composition as an indicator of skill change. Too much educational variation within occupations means a measure of central tendency like the mode masks diversity within occupations, but too little variation already settles the question as to how much change there can be within occupations over time because the process of change invariably means periods of substantial heterogeneity.

The bottom panel of Table 7 shows that almost all of the large changes between 1990 and 2001 reflect movement of workers with HS, some college, and a BA out of occupations classified as "some college" and into BA-level occupations. In fact, *all* groups of workers, including those with less than high school and with post-graduate degrees, were less likely to be found in occupations in which some college was the most common and more likely to be found in occupations in which a bachelor's degree was the modal level of education. The 12 percentage point growth in the size of college occupations noted in Table 1 reflects substantial growth in the numbers of workers without a BA who worked in occupations in which college graduates predominated, as well as increased sorting of workers with a BA into those occupations.

In contrast to the joint distribution showing the overall density, the conditional distributions control for either the type of worker or the type of occupation. Converting Table 7 into a table of row percentages shows the kinds of occupations where workers with different

educations tend to concentrate. A table of column percentages shows the various worker education groups from which occupations with different modal educations tend to draw.

Adopting a worker-centered perspective, the row percentages in **Table 8** show the different kinds of jobs obtained by workers controlling for their own level of education. This is known as an "outflow table" in sociological studies of occupational mobility, where rows typically indicate father's occupation (social origin) and columns indicate son's occupation (destination). Each row sums to one hundred percent, showing the outcome distribution or outflow pattern for each group defined by origins. In Table 8 worker education is the origin variable and occupation type is the destination variable. Information on the probability of entering different kinds of occupations controlling for worker education is relevant for job counseling and employment services, including career exploration tools like OOH. For example, the vast majority (>80%) of workers with less than high school work in occupations in which high school is the modal education in both years. In other words, most high school dropouts are not segregated into occupations in which dropouts predominate. This does not necessarily imply that occupations in which dropouts do predominate are also relatively mixed, though the next table with column percentages shows that this is in fact the case. Outflow patterns for the other worker education groups are as follows:

- About two-thirds of high school graduates are in occupations in which high school is the modal education in both years.
    - Most other high school workers were in *some college* occupations, but the small share of high school graduates in BA occupations also grew significantly over time (~6 percentage points) (see bottom panel).

- Workers with some college tended to be spread more evenly across occupation levels than other workers in both years
    - In trend terms, the share of some college workers with jobs in BA-level occupations grew by a remarkable 11.6 percentage points between 1990 and

2001, matched by a similar decline in occupations in which their own education was modal.

- Workers with a BA were nearly evenly divided in 1990 between occupations in which some college was the modal education and a BA was modal. Nearly 13% of workers with a BA worked in occupations in which high school graduates predominated in 1990.
    - Over time the share of college graduates in high school occupations actually increased slightly to 15% (2001).
    - However, the most dramatic trend among college graduates was the increased share working in BA-level occupations, which grew from 40.2% to 59.6%. This was due mostly to a decline in the share working in some college occupations, which dropped 22 percentage points from 1990 to 2001.

- In both years only a minority of workers with a post-graduate degree worked in occupations in which post-graduates were the modal education group (~31%).
    - Although the percentage of post-graduates working in post-graduate occupations increased slightly over time, the percentage remained below one-third in 2001.
    - The largest share of post-graduates worked in occupations in which a BA was the modal education, rising sharply from 41% in 1990 to 54% in 2001.
    - The growing proportion of post-graduates in BA and post-graduate jobs reflected a very sharp drop of more than 16 percentage points in the share of post-graduates in occupations in which some college was the mode.

In general, these results indicate that many people work in occupations in which the most common education level is a somewhat lower or higher than their own. The bottom panel of Table 8 shows there has been a general upgrading tendency for all kinds of workers except those with less than high school, who were more polarized in 2001 than 1990. The most dramatic change has been the increased share of all education groups working in occupations in which a BA is the modal education and a corresponding decline in the concentration of workers in *some college* occupations. The shift was most pronounced for workers with BA degrees, but occurred among workers in all other education to a greater or lesser degree, as well. Accounting for this pattern presents a bit of a puzzle. It is possible that occupations that were BA level in 1990 grew much faster than those in which some college was the modal education. It is also possible that the relatively small increase in the percentage of workers with a BA shown in Table 1 was

enough to tip the composition of many occupations (or certain populous occupations) just enough to change the modes from some college to a bachelor's degree. These alternatives are investigated below.

In contrast to the worker-centered perspective of row percentages, **Table 9** presents the data from an occupation-centered perspective using column percentages. This conditional distribution gives a breakdown of worker education conditioning on occupation type and is relevant for programs like ORS, which needs to be concerned with the implications of internal diversity for occupational classification. Mobility analyses refer to this as an "inflow table" because it shows the percentage breakdown of workers entering each occupational destination. By construction, occupations are characterized by the modal education of their workers, so the values in diagonal cells are guaranteed to be the largest in each column.[7]

Nevertheless, despite the fact that an occupation must draw *more* of its workers from the modal education group than from any of the others, the *share* of the modal education group is otherwise free to vary. At the limit, it is possible for modal education groups to account for as much as 100% of an occupation's workers. However, given five categories, it is also possible for the modal education group to account for as little as 21% of workers in an occupation. This requires that the remaining 79% of the occupation's workers are divided relatively evenly among the other four education categories, averaging 19.75% each, representing a very slight departure from a uniform distribution. Roughly midway between these upper and lower bounds is a 60% share. Therefore, the size of modal group shares can be evaluated depending on their proximity to the values 20%, 60%, and 100%. If the modal group's share is close to 20%, for example,

[7] This contrasts with the outflow Table 8, in which there is no necessity for the largest occupation to be on the diagonal, where occupational education matches workers' education. Indeed, Table 8 shows workers with less than HS, college graduates (in 1990), and post-graduates were most commonly found in occupations in which HS, some college, and BA degrees were the modal education, respectively.

then it might be more accurate to characterize the occupation as mixed, and modal shares close to 60% might be considered moderately large.

In fact, **Table 9** shows the shares of modal education groups tend to be highly similar within and across years, clustering within a few percentage points of 46% in almost all cases. The exception is post-graduate occupations which draw an average of 68% of their workforce from individuals with a post-graduate education. Thus, it appears most detailed occupations are not highly concentrated with respect to the education levels of their workers. Indeed, except for post-graduate occupations, modal education groups typically account for less than 50% of workers in their occupation.

Whereas the bottom panel of Table 8 showed strong movement of workers out of *some college* occupations and into BA-level occupations, the bottom panel of Table 9 showing trends in occupational recruitment between 1990 and 2001 has a more diffuse pattern. *Some college* occupations were less likely to draw workers with a BA or higher in 2001 compared to 1990 (-5.5 percentage points), but more likely to draw workers having only high school (4.2 percentage points), dampening any trend toward more consistent sorting into occupations by education. Likewise, BA-level occupations were less likely to employ workers with a post-graduate degree in 2001 (-4.5 percentage points), but more likely to employ workers with less than a BA (5.9 percentage points).

B. Concentration of education groups within detailed occupations

Table 9 seems to show that modal education groups account for only a moderate share of workers within most occupations and that most occupations are relatively unconcentrated in terms of worker education. Nevertheless, trends are somewhat ambiguous. Workers with BA

and post-graduate degrees are more likely to work in occupations in which their education is the mode, but less educated workers are more likely to work in BA-level.

Table 10 investigates levels and trends in educational concentration within occupations more formally using segregation indices. The first and second panels show the index of dissimilarity (D) for all pairs of worker education groups across detailed occupations and multigroup summary indices for 1990 and 2001.[8] The third panel shows trends, which are generally in the direction of slightly greater segregation. Occupations are not classified by modal education in this analysis; they enter as 498 nominal units and the index measures the degree to which any two education groups are integrated with or segregated from one another within occupational units.

In general, the index of dissimilarity is a measure of the difference between two distributions of proportions, indicating the extent to which groups are evenly or unevenly distributed across units relative to their population proportions. In this case, the dissimilarity index measures the evenness with which different worker education groups are spread across detailed occupations, with zero segregation indicating the proportion of each education group in every occupation equals their proportion in the overall workforce (complete integration) and unity indicating the two education groups being compared are never in any occupation with one another (complete segregation). The index is a measure of the disproportionate representation of two education groups across occupations, or "disproportionality in group proportions" (Reardon and Firebough 2002, p.55). The pairwise indices are calculated as half the sum of the absolute

[8] Pairwise indices of dissimilarity were calculated in Stata using the -duncan- command written by Ben Jann. Multigroup indices were calculated in Stata using the -seg- command written by Sean F. Reardon, described in Reardon and Firebough (2002).

differences in percentages between two education groups within each occupation.[9] The index of dissimilarity is not affected by changes in the relative sizes of education groups in the overall workforce, such as those shown in the top panel of Table 1 (Jones 1992). Summary indices of multigroup dissimilarity have also been developed, including weighted averages of the pairwise indices, but they are not insensitive to changes in the relative sizes of education groups (Reardon and Firebough 2002, pp.38, 52).

Both pairwise and multigroup indices of dissimilarity are ratios of the percentage of current workers who would have to change occupations to achieve full integration relative to the percentage who would have to do so under conditions of complete segregation, i.e., the ratio of observed segregation to maximum segregation. As a point of comparison, gender segregation in the Census and CPS data used here was 0.53 in 1990 and 0.52 in 2001 as measured by the index of dissimilarity.

As one would expect, reading down columns in Table 10, segregation increases as the distance between pairs of education groups increases. Likewise, reading across rows, segregation decreases as the educational distance between groups declines. Occupational segregation is lowest for adjacent education groups, which are shown on the diagonal. The bottom section of the table reorders this information from lowest to highest values of D and by educational distance for convenience; the ordering of relationships is identical across years. Segregation indices for workers separated by one level of education range from 0.25 to 0.43.

[9] For example, the dissimilarity index for high school and college graduates across three occupations is 0.40 (0.80÷2) for these hypothetical data:

Occupation	HS	BA	Abs. diff.
A	0.50	0.20	0.30
B	0.40	0.30	0.10
C	0.10	0.50	0.40
Total	1.00	1.00	0.80

The workers who are least segregated from one another are high school graduates and workers with some college (D = 0.25), suggesting they are the two groups that are most interchangeable. They are followed closely by high school graduates and dropouts in 1990 (D = 0.29). The neighboring groups that are most segregated from one another in both years are workers with some college and a BA (~0.42).

Indices for workers separated by two education levels range from 0.52 to 0.67, which is somewhat higher than occupational segregation by gender. By contrast, segregation between high school dropouts and post-graduates, separated by the maximum four levels, was 0.85 (1990) and 0.88 (2001), or well over 80% of the maximum possible in both years.

Although there is a common impression that skilled jobs are becoming more restricted to those with higher education, the third panel of Table 10 showing the differences between 1990 and 2001 indicates (a) workers with a BA have not become more segregated from workers with some college or only a high school education, and (b) workers with some college have not become more segregated from high school graduates. The two polar categories, high school dropouts and post-graduates, have become somewhat more segregated from other groups over time. However, the general impression is a modest increase in sorting of workers across occupations, which is confirmed by the small change in the multigroup index of dissimilarity, which increased by 0.021 or 5.6%.[10] This is also consistent with simple regressions of years of education on detailed occupation. The 498 occupation dummies explain 35% of the variance in 1990 and 40%, in 2000. Occupations are often rather heterogeneous in terms of workforce education and there is only a modest tendency for this heterogeneity to decline over time.

[10] Reardon and Firebough's (2002) preferred index of multigroup segregation, the Information Theory Segregation Index based on Theil's H, also increased modestly from 0.190 to 0.209 or 10%.

The natural complement to analyses of educational concentration within occupations is analyses of educational diversity. Insofar as occupations draw from a very wide range of education groups, it is less valid to characterize them in terms of modal education. **Table A3** shows the education distributions for the most diverse fifty occupations in each year. Educational diversity within occupations is measured using Simpson's Index of Diversity, which is 1 minus the Herfindahl-Hirschman index of concentration. For convenience, panels group occupations according to whether they have high representation of less educated workers (>15% with less than HS), disproportionate numbers of highly educated workers (>15% with a post-graduate education), or mostly draw from the populous middle of the educational distribution (<15% below HS and <15% with postgraduate education). Within panels occupations are separated by year and ordered according to the percentage of workers with less than high school, more than a BA, and exactly high school, respectively. Occupation groups appearing in both years are shown in bold. Also shown are sample sizes, which are usually but not always relatively large.

The wide dispersion in educational attainment illustrates the difficulty of characterizing these occupations in terms of a single education category. Some occupations are close to mirroring the distribution of the overall workforce in one or both years, such as managers of properties and real estate (18), managers in food and lodging (17), farm managers (475), welfare service aides (465), and supervisors of sales workers (243).[11] The modest representation of clerical and administrative support workers (303-389) is unexpected, given their frequently ambiguous bundling of significant literacy and interpersonal demands with relatively low levels of professional discretion and autonomy. A number of occupations are those for which

[11] Numbers in parentheses are 1990 Census occupation codes.

education might be expected to play a limited role in transmitting necessary job skills (e.g., dancers, athletes). Others are residual (n.e.c. or *not elsewhere classified*) occupations, whose well-known heterogeneity is reflected in these figures. *Managers and administrators, n.e.c.* (22) is a particularly large and heterogeneous group. This suggests the need for particular caution in characterizing this occupation and the desirability of working to reduce the size of this category in the future.

There is significant overlap in the occupations listed across years, but also numerous occupations that are unique to a given year. Therefore, it is not necessarily easy to anticipate or predict most of the occupations for which modal education has limited reliability and validity as a proxy for occupational skill demands, though some occupations may not change much in moving into and out of the top 10% most diverse occupations. More critically, because the distribution of educational attainment in many of these occupations is bimodal, small shifts in composition would be sufficient to alter their categorization over time based on the one education group that accounts for (marginally) more workers than other group(s).

C. Changes in the modal education of detailed occupations over time

The bottom half of Table 1 showed a larger decrease in the share of workers in *some college* occupations and a larger increase in the share working in BA-level occupations between 1990 and 2001 than might be expected based on the small changes in the educational composition of the workforce shown in the upper panels. Tables 7-9 showed these aggregate occupational trends by worker education level and Table 10 showed changes in worker sorting across occupations. However, it remains unclear exactly how small increases in worker educational attainment combined with small increases in educational sorting across occupations

produced large changes in the percentage of the workforce classified as holding jobs in BA-level occupations.

Table 11 cross-classifies occupations by their modal education in 1990 and 2001 in terms of raw frequencies (upper panel), unweighted percentages (middle panel), and weighted percentages or employment shares (lower panel). Weights are average employment shares for 1990 and 2001 so figures will not correspond exactly to those in previous tables. Cells on the diagonal are shaded blue and cells off the diagonal with high density are shaded orange. Eighty-five percent of occupations accounting for 77% of the workforce are on the diagonal, meaning they did not change occupational categories over time. However, 75 occupations, 15% of all occupations, accounting for 23% of the workforce, did change classification between 1990 and 2001. There are some offsetting movements of occupations and workforce shares into and out of the *high school* and *some college* categories. However, the major change is a small group of thirteen occupations that switched classifications from *some college* to BA-level, which altered the classification of 10.1% of the workforce. All except one had sample sizes above 1,000 cases in 2001. About 8.2% of the workers were in four occupations that changed from *some college* to BA-level: *Managers NEC*, *Registered nurses*, *Sales representatives—mining, manufacturing, wholesale*, and *Sales occupations—other business services*.[12] The share of workers with some college averaged 37.2% in 1990 and fell by an average of 6.4 percentage points in the thirteen occupations changing classification. Likewise, the initial the share of workers with a BA was 29.3% and rose by an average of 8.6 percentage points. The swings were towards the extremes in terms of magnitudes (see rows 3 and 4, Table 4) and larger than one might expect given the size of the changes in workforce educational attainment and segregation across occupations.

[12] The 1990 Census codes for these occupations are 22, 95, 259, and 257, respectively.

However, with modal shares so close to the theoretical minimum, even smaller swings can shift the categorical classification of occupations.

IV. Summary

This paper considers the use of worker education as a proxy for job skill requirements in order to understand the extent of change within occupations over time. Results from the preceding analyses may be summarized as follows:

- The average education of the workforce increased 0.274 years between 1990 and 2001, mostly reflecting
  - slight declines in the shares of workers with less than high school (-2.4%) and some college (-1.5%), and
  - slight growth in the shares of workers with a BA (3.4%) and post-graduate degrees (1.2%) (Table 1)

- Occupations whose mean years of education essentially mirrored the workforce trend, increasing by 0.14-0.41 years, accounted for over one-third of all occupations and nearly half of the workforce.
  - Average years of education fell in nearly one-quarter of occupations (15% of the workforce)
  - Average education rose much more than average in nearly one-quarter of occupations (8.5% of the workforce) (Table 2).
  - There is no relationship overall between an occupation's average education in 1990 and the change in average education over the decade.
  - There is a substantial correlation (r = -0.43) between the absolute size of the change in mean education within an occupation and its (ln) sample size, arguing for caution in interpreting large swings in occupational characteristics observed in the data. However, some occupations with very large sample sizes also experienced large changes in their education levels.

- When the shares of different education groups are used instead of average years of education, there are a number of extreme outliers among the ten percent of occupations with the largest changes in education group composition.
  - However, each set of fifty occupations accounts for only 1.2% to 3.6% of the workforce depending on the education group in question (Table 4).
  - Likewise, for all occupations, larger changes tend to be associated with smaller occupational sample sizes.

- About 13% of the workforce was redistributed across detailed occupations between 1990 and 2001.

    - About one-half of the compositional shifts was concentrated in 27 occupations or 5.5% of all occupations.
    - Change in occupational employment shares is not strongly related to occupations' initial education level.
    - The overall correlation of occupational employment shares between 1990 and 2001 is 0.94.

- Shift-share analyses indicate that changes in the composition of employment *between* occupations can account for 40% of the small change in average years of education between 1990 and 2001, while changes in education levels *within* occupations account for the remaining 60%.
    - However, the conclusions that can be drawn from this decomposition need to be tempered by the fact that occupations whose internal changes simply mirrored the workforce trend accounted for nearly half of total employment. Until the relationship of this movement to actual changes in job task content can be established, the significance of a major portion of within-occupation education change is unclear.
    - Within-occupation effects account for 70-85% of changes in the proportions of the workforce with less than high school, some college, and a BA degree.
    - Between-occupation effects account for similarly large proportions of the changes in the shares of high school graduates and post-graduates, i.e., observed changes in occupational employment shares are sufficient to account for most of the decline and growth of these two education groups (Table 5).

- The large changes in education observed within some large occupations and the large proportion of total educational change attributable to the within-occupation component in shift-share analyses suggests BLS might need to monitor trends within certain detailed occupations relatively closely.
    - This conclusion is subject to the qualifications involved in using worker education as a measure of job characteristics (discussed in Section V) and would need to be cross-checked against trends in direct measures of job requirements in the future when they are more available.

- Many BLS programs classify occupations into categories based on the dominant educational level associated with them. Using modal education or some similar classifier is much simpler than using the entire percentage breakdown across five education groups. When modal education is used to analyze change the most notable trend is a large decline in the share of workers in occupations classified as *some college* (-10.3%), and a similar increase in the share in occupations classified as BA-level (12.0%). These shifts are much larger than changes in the underlying distribution of workers' own education (Table 1).

- Sensitivity analyses show classification of detailed occupations based on their modal education is reasonably consistent with a classification based on collapsing

one-digit occupation into six broad groups (upper white-collar, lower white-collar, craft, production, service, and farm) (Table 6).

- Nevertheless, 55% of workers are in occupations whose modal education differs from their own, usually by one level (Table 7).
    - This raises the intellectual problem that any investigation of within-occupation change presumes some internal diversity, but too much diversity casts doubt on the value of an occupational descriptor based on a measure of central tendency alone.

- The significant shift from *some college* occupations to BA-level occupations was not simply due to more systematic sorting of workers with a BA into occupations in which a BA was the modal education level. The joint distribution of workers' own education and the modal education of their occupation shows workers with all levels of education were less likely to be in *some college* occupations and more likely to be in BA-level occupations (Table 7).

- Outflow tables show large proportions of workers at all levels of education end up in occupations in which other education groups are more common than their own. OOH and other career exploration or job counselling tools need to recognize that a given level of education can be a pathway to occupations in which other levels of education are typical.
    - These tables also show the occupational distributions of workers at all levels of education shifted away from *some college* occupations in favor of BA-level occupations between 1990 and 2001 (Table 8).

- Inflow tables show the modal education group accounts for only about 46% of the workforce in most occupations, reinforcing the impression that most detailed occupations are quite diverse internally. In other words, most modes' shares of occupational workforces are relatively small, about one-third of the distance between their theoretical minimum (~21%) and maximum (100%). Most workers who do not have the modal education level within occupations are drawn from adjacent educational levels rather than more distant levels (Table 9).

- Total change can be driven by changes in the distributions of education and occupation, and by changes in their association. The fact that the size of certain occupation-level trends seem large relative to workforce trends raised the possibility that increased worker sorting by education across occupations may be important. However, trends in segregation indices, which measure the association between education and occupation, also seem modest (Table 10). Education groups do not sort much more strongly into detailed occupations in 2001 compared to 1990.

- Finally, the possibility that changes in the educational composition of occupations were large enough to alter their classification was investigated. Results showed a small number of sufficiently large occupations changed modes from *some college*

to BA-level (Table 11), producing the changes observed in the bottom panels of Table 1.

An additional point worth noting is that the OOH and many research studies classify occupations according to their dominant education or typical entry path but there does not seem to be any systematic study of how typical the typical entry path is for different occupations or how large a share of an occupation belongs to the largest education group. For most detailed occupations it turns out that the percentage of workers with the modal education level is surprisingly small. There is substantial educational heterogeneity within most occupations, which obviously complicates efforts to assign a single "required" level of education to occupational data. This reinforces the advisability of obtaining direct measures of job requirements to reduce the uncertainty generated by within-occupation educational diversity.

V. Limitations in using worker education as a proxy for job required education

Using a personal characteristic of workers such as education as a proxy for the requirements of their jobs has long been recognized as problematic for various reasons. The most common objection is the possibility that credentialism may distort the relationship between personal and job characteristics. In addition, much of the knowledge required for certain jobs is acquired on the job, not in school (e.g., auto sales workers). There is wide variation across countries, broad occupations, and education groups in the percentage of workers saying either school or workplace experience were important in developing the skills used in their current jobs (Handel 2012, pp.56ff.). If credentialism inflates education requirements or the dominance of on-the-job learning renders education largely irrelevant in the hiring process, then there may be limited validity in treating trends in workers' education as an indicator of job requirements. Indeed, there is recent evidence for the long-held suspicion that job educational requirements are

themselves somewhat flexible in response to the tightness or looseness of labor markets (Modestino, Shoag, Balance 2016). Economists also increasingly recognize that education levels reflect social skills, work attitudes, social networks, and cultural capital in addition to technical skills or human capital, which complicate simple equations of education, cognitive skills, and job requirements (Heckman and Rubinstein 2001). A number of other, less-recognized issues deserve discussion, as well.

Education levels have been rising broadly over a long period for many reasons other than changing job demands (*e.g.*, restrictions on child labor, changing conceptions of length of childhood and socialization requirements, conceptions of citizenship and national unity, democratized access to education). One result of the preceding analyses is that education levels within many occupations appear to simply follow the overall trend in workforce education. Previous research shows that even within demonstrably less-skilled and slowly changing occupations, such as taxi driver, mean education levels have risen in tandem with general education levels (Handel 2000). This reflect a kind of creeping credentialism or simply changes in the relative size of different worker education groups over time. Regardless of the exact interpretation, because the rate of educational expansion has waxed and waned over time, using worker education as a proxy for job requirements will capture effects of forces unrelated to job requirements that affect attainment and ascribe them to trends in job requirements.

While changes in average levels of education may reflect changes in job demands, they reflect other forces relatively independent of the job market, as well. Students' knowledge of the job market and their foresight in making career decisions is varies greatly and is often limited. Many young people have only vague ideas or plans regarding job they would like to pursue in the future, despite resources designed to close this gap like OOH. To a significant extent,

individuals' decisions to stop or continue their education reflect non-economic motivations and preferences (e.g., "grit," self-direction), levels of economic resources and social support, immigrant status, and other diverse cultural, family, peer, and neighborhood influences. Parents' level of education tends to set a floor on the education of their children (Mare 1995, pp.177ff.). In addition, the promotion and overall growth of education at the primary, secondary, and post-secondary levels in different periods have reflected various subsidies, legal requirements[13], public policies, institution-building initiatives[14], public campaigns, cultural beliefs, and popular movements.[15] These processes do not simply mirror the state of the current or near-term job market but they influence the changing levels of education within occupations.

If educational attainment is not synchronized precisely with the job market, it is possible for there to be more workers with a given level of education than jobs requiring that level of education. Likewise, individuals who failed to complete their degree or majored in a field of study for which job demand is weak may find their options are limited and may take jobs in which most workers have less education. This raises the level of education within those occupations and may set off a cascade effect that bumps previously common kinds of workers from these positions into jobs typically filled by even less educated workers (Thurow 1975). When using workers' attainment rather than direct indicators to measure job demands, it may be difficult to distinguish this kind of downward mobility from trends toward skill upgrading within occupations over time. Independent, direct measures of job tasks or job requirements would help

[13] For example, increases in age of compulsory schooling during the 1930s, Vietnam-era draft deferments, and more recent changes in high school graduation requirements and policies regarding proprietary schools and online education.

[14] Examples include post-war expansion of two- and four-year colleges and universities.

[15] Examples of the latter three include the early twentieth-century "high school movement," the postwar GI Bill, public campaigns to eliminate dropping out of high school since the 1960s, widespread general beliefs in the value of education, waxing and waning student loan programs, recent efforts to promote "college for all," and reductions in funding for public higher education that shift a larger share of tuition costs to students.

reveal whether the jobs themselves are actually becoming more cognitively complex or remaining relatively stable. In general, the meaning of educational diversity within occupations is highly ambiguous when direct measures of job content are unavailable.

Similar issues may arise from imperfections in the matching process even if the aggregate distributions workers' education and job educational requirements were identical. Invariably, there will be individuals mismatched to jobs due to imperfect information, geographic immobility, network-based hiring, and statistical discrimination, among other reasons. To the extent that workers are not well-matched to jobs, personal education is not a valid or clean measure of job requirements. Indeed, over 30% of U.S. workers report a level of education required for their job that is lower than their own level of education (Handel 2016b, pp.185ff.).

If job requirements change over time within occupations, there is also likely to be some discrepancy between the education of workers and the current requirements of their jobs. Even if matching were perfect in prior years, rising hiring demands would not be reflected in the education levels of older workers, who may have obtained the newly required skills on the job and are unlikely to raise their level of formal education by returning to school. The education histories of different cohorts may exert a persistent influence on educational composition of different occupations over many decades. One can expect some resorting of older workers and forced exit from the labor market, but the occupation- and firm-specific skills of experienced workers and the disruptive effects of turnover will offset those forces in part. Therefore, the matching of workers to jobs based on education likely involves some degree of lag. At any point in time the mix of job incumbents will include different cohorts that may have been hired according to different standards. If sample sizes were larger, one could compare education levels by birth cohort within occupations to shed light on this possibility.

In short, the validity of worker education as a proxy for job requirements is limited to the extent that (1) strict economic rationality does not account fully for individuals' educational and occupational choices or employer hiring practices, (2) skills for some occupations are acquired primarily through job experience rather than education, (3) the broader institutional context influences aggregate supplies of education independent of job market requirements, (4) imperfect matching produces mismatch even when the aggregate supplies of and demand for different levels of education are balanced, and (5) cohort dynamics induce educational heterogeneity within occupations even if matches of new workers to jobs is perfect at each point in time. Measuring job task content directly, independent of the characteristics of job holders, is the only way to know what people actually do at work (Handel 2016b).

Arguing in favor of the validity of worker education as a measure of job requirements is the possibility that employers only create jobs that match existing supplies or are able to customize job requirements upward or downward to match the education levels of workers effectively. According to this reasoning, the task content of the jobs employers offer is perfectly responsive to supply conditions. If one can assume a one-to-one correspondence between worker education and job requirements, then using the former to proxy for the latter is valid. Needless to say, this is a strong assumption as it may imply that workers in the same job in the same establishment, such as retail or fast food, perform varying tasks with significantly different skill demands. With respect to time series, this position implies every increase in workforce education, whatever the reason, is reflected in rising job educational requirements as tasks demands are fine-tuned to match the characteristics of new entrants.

Finally, there are a number of practical issues that affect the study of education by occupation. Large swings are in the composition of occupations are observed even for some

occupations with large sample sizes; the issue is exacerbated when occupational samples are small. Both education and occupation are measured with error. This will produce misclassifications and anomalies when the two variables are cross-tabulated, including questionable cases of workers with very low and very high educations apparently in occupations usually filled by those with the polar opposite levels of education. It is likely that measurement error leads to downward bias in estimates of educational segregation by occupation. In addition, surveys typically ask respondents their highest level of education. In some cases individuals with a less marketable university concentration return to one- or two-year technical schools for more occupationally-specific credentials that lead to employment. To the extent that this is relatively common in some occupations, using respondents' measured education would impart an upward bias to estimates of the occupations' required education.[16] BLS researchers compiling the Occupational Outlook Handbook have found secondary schools have tended to drop vocational education programs over time and post-secondary institutions have moved into these vacant niches. This will give the appearance that the task requirements of these occupations have increased when it appears that it is mostly the education provider that has changed (Michael Wolf, personal communication).

VI. Conclusion

There are many reasons to be cautious when using workers' education as a direct measure of their jobs' required education, though the magnitudes of these problems are not well understood. Clearly, worker education is a second-best alternative to direct measures of job requirements. However, there are very few other options available for analyzing historical

[16] For example, even a bachelor's degree in biology from a competitive four-year institution may be less marketable if it is a terminal degree than an associate's degree in medical technology from a community college (Ducey 2009, pp.141f.).

patterns of change within occupations and their relative contributions to overall changes in job skill requirements. There appears to be no research since Rodriguez (1978) that has examined changes in the educational profiles of occupations to decompose trends in workforce education into within- and between-occupation components.

The implications of the preceding for BLS and ORS are ambiguous because the magnitude of educational change within occupations is bound to be influenced significantly by the rate of educational change in the overall population of adults. The well-known flattening of growth in educational attainment for cohorts born after 1960 means that any investigation of trends in job demands based on a direct correspondence with workers' own education was bound from the start to find very modest change in recent years. If one assumes workers and job are relatively well-matched then occupational trends in overall job requirements can be inferred simply from well-known trends in overall worker education levels, except insofar as there is resorting of workers across occupations. However, resorting in the context of generally stable education levels means some occupations will also appear to be undergoing deskilling by virtue of the fact that less educated workers are increasingly concentrated within them.

Nevertheless, shift-share analyses indicate that within-occupation shifts account for a majority of the (small) changes in educational level and composition. Using mean years of education, about 40% of growth in workforce education could be predicted based on changes in the employment shares of detailed occupations, but 60% reflected changes in average education within occupations. Nevertheless, the fact that nearly half of the workforce were in occupations that simply reflected the general upward growth of workforce attainment argues for discounting some part of the within-occupation component when drawing substantive conclusions. In the absence of direct measures one cannot know whether employers responded by increasing job

task complexity or whether fully half of the within-occupation component is just trend-following.

Future studies are needed that use direct measures of job skill requirements to determine the within- and between-occupation components, as well as to answer more basic questions regarding the magnitude and rates of change in job skill requirements. Analyses using modal education to classify occupations also illustrate the sensitivity of such categorical schemes to relatively moderate-sized changes in composition. When modes account for relatively small shares of the occupational workforce, shifts may lead to occupational reclassifications that appear large relative to the underlying changes in group proportions within the occupation. This problem will be exacerbated by sample size limitations, which will increases the noisiness and reduce the reliability of estimates of change within occupations.

By way of conclusion, one can note that the rising levels of education in most occupations documented in this study are open to widely diverging interpretations depending on whether or not one assumes these changes reflect more skilled job tasks. If all educational upgrading reflects changes in tasks then it appears studies using cross-sectional skill scores and varying occupational employment weights will underestimate a significant fraction of total skill upgrading. However, if almost all change reflects simply a general upward drift in the education of job-holders then conclusions using cross-sectional occupational skill measures remain largely valid and educational upgrading within occupations is a kind of credentialism or normative shift. The only way to settle this issue is by measuring job tasks directly in the spirit of replicating the Dictionary of Occupational Titles. A number of examples indicate it is possible to collect such data easily in sample surveys on a periodic basis (e.g., Handel 2016b; OECD 2013). This kind

of data would permit more conclusive analyses regarding the magnitude and rate of skill change than is possible with available data on worker education and occupational employment.

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Table 1. Distribution of workers by own education and occupation's modal education, 1990 and 2001

	Mean (sd)	<HS	HS	<BA	BA	Post-BA
	years			*percent*		
Own education						
All ages						
1990	13.3 (2.7)	12.0	33.7	31.0	15.6	7.8
2001	13.6 (2.6)	9.6	32.8	29.5	19.0	9.0
change	0.3 (-0.1)	-2.4	-0.9	-1.5	3.4	1.2
Age 24-34						
1990	13.5 (2.5)	9.1	33.0	32.0	19.7	6.2
2001	13.7 (2.6)	9.2	29.8	28.7	24.2	8.1
change	0.2 (0.1)	0.1	-3.2	-3.3	4.5	1.9
Occupation's modal education						
All ages						
1990		1.0	46.3	35.4	13.9	3.4
2001		1.2	43.6	25.1	25.9	4.3
change		0.2	-2.7	-10.3	12.0	0.9
Age 24-34						
1990		0.9	45.1	36.4	14.6	3.0
2001		1.3	42.7	24.0	28.0	4.0
change		0.4	-2.4	-12.4	13.4	1.0

Note: Upper panel shows means and percentage distributions of workers according to their personal level of education. Lower panel shows percentage distributions of workers by the modal education level of their occupation. All figures are weighted. Data are from 5% 1990 Census extract and merged outgoing rotation group files of the CPS for 2000-2002.

Table 2. Changes in average years of education within detailed occupations, 1990-2001

	Change in mean years	Occupations Number	Occupations Percent	Workforce Percent
1	Decline (change <0 years)	113	22.8	14.7
2	Below avg. gain (0 < change ≤ 0.137)	78	15.8	28.0
3	Avg. gain (0.137 < change ≤ 0.412)	184	37.2	48.8
4	Above avg. gain (0.412 < change ≤ 1.25)	111	22.4	8.5
5	Very high gain (change > 1.25)	9	1.8	0.0
	Total	495	100.0	100.0

Note: Values are number and percentage of occupations and the percentage of the workforce in occupations whose mean years of worker education changed by amounts given in each row. Workforce percentages were calculated using average employment shares for both years. The highlighted row represents an interval centered on the overall change in mean years of worker education between 1990 and 2001 (0.274 years). The nine occupations whose mean education grew more than 1.25 years accounted for less than four-hundredths of one percent of the workforce, rounding to zero.

Table 3. Education by occupation for occupations with greatest change, 1990-2001

Code	Occupation	Mean 1990	Change 1990-2001	Sample size 1990	Sample size 2001
786	Hand cutting and trimming occupations	10.78	-1.21	746	155
477	Supervisors, farm workers	11.14	-1.06	2151	526
214	Industrial engineering technicians	14.36	-1.01	726	107
659	Miscellaneous precision woodworkers	11.86	-1.00	75	19
87	Optometrists	17.66	-0.86	399	245
215	Mechanical engineering technicians	14.58	-0.83	1314	302
743	Textile cutting machine operators	10.90	-0.78	350	82
584	Plasterers	10.91	-0.77	1392	711
168	Sociologists	16.62	-0.75	91	31
129	Computer science teachers	15.68	1.27	172	452
564	Brickmason and stonemason apprentices	10.98	1.44	36	48
149	Home economics teachers	16.41	1.59	20	4
404	Cooks, private household	10.81	1.74	373	95
148	Trade and industrial teachers	15.65	1.83	58	47
483	Marine life cultivation workers	11.09	2.01	44	16
284	Auctioneers	12.67	2.04	139	53
89	Health diagnosing practitioners, n.e.c.	15.25	2.21	704	192
403	Launderers and ironers	9.26	2.29	41	8

Note: Occupation in top panel saw their mean education decline by at least 0.75 years and occupations in the lower panel saw mean education rise by at least 1.25 years. Codes are 1990 Census occupation codes. Means for 1990 and changes for 1990-2001 are in years of education.

Table 4. Changes in percentage shares of educational groups within occupations, 1990-2001

	Unweighted		Weighted		Minima, percentiles, maxima						
	Mean	SD	Mean	SD	Min	Pct 1	Pct 5	Pct 95	Pct 99	Max	Share
< HS	-2.6	(5.7)	-2.0	(2.9)	-47.0	-20.5	-11.4	4.6	12.8	25.8	1.6
HS	1.3	(7.0)	0.5	(3.2)	-19.7	-14.2	-7.9	11.2	28.0	64.4	1.4
< BA	-1.4	(6.9)	-1.3	(3.6)	-34.3	-22.7	-12.7	8.6	20.0	38.6	1.2
BA	1.2	(5.8)	2.4	(3.2)	-36.4	-18.5	-7.4	9.6	17.4	29.7	3.6
Post-BA	1.5	(6.2)	0.3	(2.3)	-14.7	-8.7	-2.9	12.8	30.7	54.1	3.3

Note: Values refer to the changes in the shares of different education groups within 495 detailed occupations in percentage points, except for right column. Weights are average of occupational employment shares for 1990 and 2001. Percent point changes in education shares in the right panel are for percentiles of occupations, not percentiles of the workforce, e.g. Pct 1 for refers to change in shares for the occupation with the fifth greatest negative change for a given education group, Pct 5 refers to the occupation with the twenty-fifth largest negative swing. The right column ("Share") shows the combined share of workforce in the fifty occupations with the greatest negative and positive change in education shares, where workforce shares are averages for 1990 and 2001.

Table 5. Shift-share decompositions of changing education, 1990-2001

	Raw value			Percentage contribution		
Education	Between	Within	Interact	Between	Within	Interact
Years	0.111	0.172	-0.001	39.4	61.0	-0.4
< HS	-0.41	-2.03	0.09	17.5	86.2	-3.8
HS	-1.31	0.54	-0.04	160.9	-66.2	5.3
< BA	-0.11	-1.21	-0.11	7.6	84.9	7.5
BA	1.04	2.43	-0.03	30.2	70.7	-0.8
Post-grad	0.84	0.27	0.09	69.9	22.6	7.5

Note: Left panel shows raw values of between-occupation, within-occupation, and interaction components of total changes in years of education and shares of the workforce with different levels of education. Right panel shows each component's contribution as a percentage of the total change.

Table 6. Distribution of occupations by modal education

Modal education	Occupation Number	Occupation Percent	Workforce share	Broad occupation Mgr/Prof	Cler	Craft	Prod	Serv	Farm
1990									
<HS	10	2.0	1.0			2		4	4
HS	247	49.6	46.3	2	28	84	99	23	11
<BA	131	26.3	35.4	47	47	16	2	17	2
BA	57	11.5	13.9	54	3				
Post-BA	53	10.6	3.4	53					
Total	498	100	100	156	78	102	101	44	17
2001									
<HS	12	2.4	1.2			3	4	1	4
HS	245	49.2	43.6	4	26	82	93	28	12
<BA	119	23.9	25.1	34	45	17	4	16	3
BA	67	13.5	25.9	60	7				
Post-BA	55	11.0	4.3	55					
Total	498	100	100	153	78	102	101	45	19

Note: Figures under "Number" are counts of the number of occupations, "Percent" is unweighted percent of occupations, and "Workforce" represents the share of the workforce (weighted percent). Figures under broad occupation headings are the number of detailed occupations in each cell, which sum to 498 in each panel. The Mgr/Prof group includes technical workers and the Cler group includes sales workers.

Table 7. Joint distribution of workforce by workers' education and modal education of occupation
(cell values sum to 100% within years for upper and middle panels)

Worker Education	Modal education within occupation					
	<HS	HS	<BA	BA	Post-BA	Total
1990						
<HS	0.5	10.0	1.4	0.1	0.0	
HS	0.4	21.6	10.3	1.3	0.2	
<BA	0.1	12.4	15.0	3.0	0.4	
BA	0.0	2.0	6.7	6.3	0.6	
Post-BA	0.0	0.4	1.9	3.2	2.3	
						100
2001						
<HS	0.6	7.9	0.9	0.3	0.0	
HS	0.4	20.8	8.4	3.2	0.1	
<BA	0.1	11.7	11.1	6.3	0.3	
BA	0.0	2.8	4.0	11.3	0.9	
Post-BA	0.0	0.5	0.8	4.8	2.9	
						100
change						
<HS	0.1	-2.1	-0.5	0.2	0.0	
HS	0.1	-0.8	-2.0	1.9	0.0	
<BA	0.0	-0.8	-3.9	3.3	0.0	
BA	0.0	0.8	-2.7	5.1	0.2	
Post-BA	0.0	0.1	-1.2	1.6	0.7	
						0.0

Note: Upper and middle panels show percentage distribution of workers by education across occupations with different modal education levels; figures sum to 100% within panels. Bottom panel shows difference in cell percentages between 2001 and 1990, and figures sum to zero. Cells with very low density are shaded grey, cells with high density shaded pink, and cells with densities close to expectation from a uniform distribution are unshaded. Pink cells account for 82% of workforce in 1990 and 78% in 2001.

Table 8. Distribution of occupational modal education conditional on workers' education
(rows sum to 100)

Worker Education	Modal education within occupation <HS	HS	<BA	BA	Post-BA	Total
1990						
<HS	4.1	83.2	11.6	0.9	0.2	**100**
HS	1.0	64.0	30.7	3.8	0.4	**100**
<BA	0.4	40.0	48.6	9.8	1.2	**100**
BA	0.2	12.8	43.0	40.2	3.9	**100**
Post-BA	0.1	5.3	24.6	41.1	28.9	**100**
2001						
<HS	6.4	81.7	9.0	2.8	0.1	**100**
HS	1.3	63.3	25.4	9.6	0.4	**100**
<BA	0.4	39.4	37.6	21.4	1.1	**100**
BA	0.2	14.9	20.9	59.6	4.5	**100**
Post-BA	0.1	5.2	8.3	53.6	32.8	**100**
change						
<HS	2.3	-1.5	-2.6	1.9	-0.1	**0.0**
HS	0.3	-0.7	-5.3	5.8	-0.1	**0.0**
<BA	0.0	-0.6	-11.0	11.6	-0.1	**0.0**
BA	0.0	2.1	-22.1	19.4	0.6	**0.0**
Post-BA	0.0	-0.1	-16.3	12.5	3.9	**0.0**

Note: Rows of upper and middle panels show percentage distribution of workers across occupations with different modal education levels; figures sum to 100% by row within rounding error. Bottom panel shows difference in cell percentages between 2001 and 1990 (e.g., 6.4 - 4.1=2.3 for $cell_{11}$). Rows in lower panel sum to zero within rounding error. Row percentages greater than 20% in upper and middle panels are bordered in color, values greater than ±5% in lower panel shaded blue, and very low values shaded grey in all panels.

Table 9. Distribution of workers' education conditional on occupational modal education
(columns sum to 100%)

Worker Education	Modal education within occupation				
	<HS	HS	<BA	BA	Post-BA
1990					
<HS	48.7	21.5	3.9	0.8	0.8
HS	34.3	46.5	29.2	9.2	4.3
<BA	13.5	26.8	42.5	21.9	10.7
BA	2.9	4.3	19.0	45.2	18.0
Post-BA	0.7	0.9	5.4	23.0	66.2
Total	**100**	**100**	**100**	**100**	**100**
2001					
<HS	50.6	18.0	3.5	1.1	0.3
HS	35.0	47.7	33.3	12.2	2.9
<BA	10.9	26.7	44.3	24.4	7.5
BA	3.1	6.5	15.9	43.8	20.1
Post-BA	0.5	1.1	3.0	18.6	69.3
Total	**100**	**100**	**100**	**100**	**100**
change					
<HS	1.9	-3.5	-0.5	0.3	-0.5
HS	0.7	1.1	4.2	3.0	-1.5
<BA	-2.6	-0.1	1.8	2.6	-3.2
BA	0.2	2.2	-3.1	-1.4	2.1
Post-BA	-0.2	0.2	-2.4	-4.5	3.1
Total	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Note: Columns of upper and middle panels show percentage composition of occupations by worker education levels; figures sum to 100% by column within rounding error. Bottom panel shows difference in cell percentages between 2001 and 1990. Columns in lower panel sum to zero within rounding error. Column percentages greater than 20% in upper and middle panels are bordered in color, relatively large cell values in lower panel shaded blue, and very low values shaded grey in all panels.

Table 10. Segregation of education groups across detailed occupations

	Pairwise indices of dissimilarity				Multigroup
	< HS	HS	< BA	BA	index
1990					
HS	0.288				
< BA	0.521	0.250			
BA	0.753	0.596	0.419		
post-grad	0.845	0.759	0.627	0.354	0.372
2001					
HS	0.328				
< BA	0.547	0.252			
BA	0.779	0.593	0.428		
post-grad	0.878	0.783	0.666	0.370	0.393
change					
HS	0.040				
< BA	0.026	0.002			
BA	0.026	-0.004	0.009		
post-grad	0.033	0.024	0.038	0.016	0.021

	Indices ordered by level and size		
One level	**1990**	**2001**	**change**
HS, <BA	0.250	0.252	0.002
<HS, HS	0.288	0.328	0.040
BA, post-grad	0.354	0.370	0.016
< BA, BA	0.419	0.428	0.009
Two levels			
< HS, < BA	0.521	0.547	0.026
HS, BA	0.596	0.593	-0.004
< BA, post-grad	0.627	0.666	0.038
Three levels			
< HS, BA	0.753	0.779	0.026
HS, post-grad	0.759	0.783	0.024
Four levels			
< HS, post-grad	0.845	0.878	0.033

Note: Pairwise indices of dissimilarity for 1990 and 2001 in first two main panels, and difference in third panel. Multigroup index of dissimilarity from Reardon and Firebough (2002). Bottom panel reorders values by magnitudes, which also corresponds to the distance between education groups, e.g., HS and < BA are one level apart, whereas < HS and post-graduate groups are four education levels apart.

Table 11. Transition table of detailed occupations by modal education in 1990 and 2001

	2001 mode					
	< HS	HS	< BA	BA	post-grad	total
1990 mode						
Occupation counts						
< HS	4	5	1			10
HS	8	217	20	2		247
< BA		19	96	13	2	130
BA		1	1	52	2	56
post-grad			1		51	52
Total	12	242	119	67	55	495
Occupation percentages						
< HS	0.8	1.0	0.2			2.0
HS	1.6	43.8	4.0	0.4		49.9
< BA		3.8	19.4	2.6	0.4	26.3
BA		0.2	0.2	10.5	0.4	11.3
post-grad			0.2		10.3	10.5
Total	2.4	48.9	24.0	13.5	11.1	100.0
Workforce percentages						
< HS	0.6	0.4	0.0			1.0
HS	0.8	38.2	6.1	0.0		45.1
< BA		5.2	20.2	10.1	0.0	35.6
BA		0.0	0.0	14.4	0.1	14.6
post-grad					3.74	3.8
Total	1.4	43.8	26.3	24.6	3.9	100.0

Note: Top panel is cross-tabulation of occupations (n=495) by modal education in both years. Cell values in middle panel are unweighted percentages and values in bottom panel are percentages weighted by average occupational employment shares across years. Diagonal cells shaded blue and other cells with high density shaded orange. Shaded cells account for 93% of occupations (upper and middle panels) and 98% of the workforce (bottom panel).

Appendix

Table A1. Occupations unique to each file

Code	Occupation title	Share (%)
Occupations in 1990 only		
3	Legislators	0.011
16	Postmasters, mail superintendents	0.038
179	Judges	0.026
	Total share of 1990 sample (%)	0.076
Occupations in 2001 only		
466	Family child care providers	0.021
473	Farmers, except horticultural	0.011
474	Horticultural specialty farmers	0.001
	Total share of 2001 sample (%)	0.032

Note: Codes are 1990 Census occupation codes. "Share" is the occupation's share of the workforce in 1990 or 2001 in percent (e.g., 0.011 is eleven thousandths of 1%).

Table A2. Correlations between initial education share and change in share within occupations

Change in share	Share in 1990 < HS	HS	< BA	BA	Post-BA
Unweighted					
< HS	-0.26	-0.23	0.04	0.20	0.18
HS	0.25	0.18	-0.04	-0.16	-0.16
< BA	0.18	0.26	-0.02	-0.24	-0.15
BA	0.01	0.11	0.29	-0.01	-0.28
Post-BA	-0.24	-0.39	-0.24	0.26	0.44
Weighted					
< HS	-0.28	-0.39	0.05	0.34	0.24
HS	0.32	0.35	-0.07	-0.32	-0.24
< BA	0.33	0.50	-0.03	-0.54	-0.23
BA	-0.33	-0.39	0.22	0.40	0.09
Post-BA	-0.13	-0.23	-0.23	0.28	0.25

Note: Correlations shows relationships between initial share of a given education group within occupations (column label) and the growth in share of a given education level within occupations (row label). Correlations with absolute values greater than 0.30 are highlighted.

Table A3. Most educationally diverse fifty occupations by education level, 1990 and 2001

Occupations with over 15% of workers with less than high school

Code	N	Occupation	Simpson	<HS	HS	<BA	BA	post-BA
			1990					
477	2,151	Supervisors, farm workers	0.713	32.4	35.8	21.3	8.9	1.6
489	**202**	**Inspectors, agricultural products**	**0.725**	**28.7**	**32.6**	**27.7**	**10.2**	**0.9**
495	**866**	**Forestry workers except logging**	**0.753**	**26.1**	**29.4**	**27.1**	**13.3**	**4.1**
475	**6,873**	**Managers, farms, except horticultural**	**0.733**	**24.9**	**36.5**	**23.3**	**12.7**	**2.5**
499	79	Hunters and trappers	0.748	23.7	21.8	34.3	17.4	2.8
828	1,394	Ship captains and mates, except fishing	0.736	23.3	37.0	23.0	13.9	2.9
494	477	Supervisors, forestry and logging	0.710	21.7	43.1	21.6	9.2	4.4
485	**2,485**	**Supervisors, related agricultural occs**	**0.722**	**19.8**	**34.5**	**32.4**	**12.2**	**1.2**
476	479	Managers, horticultural specialty farms	0.751	18.8	28.3	31.1	19.1	2.7
193	691	Dancers	0.728	15.6	36.2	30.8	14.4	2.9
465	2,087	Welfare service aides	0.741	15.2	34.9	30.6	12.6	6.6
			2001					
666	688	Dressmakers	0.714	29.6	37.2	22.3	10.1	0.8
489	**71**	**Inspectors, agricultural products**	**0.731**	**28.0**	**37.7**	**18.5**	**10.9**	**4.9**
495	**365**	**Forestry workers except logging**	**0.728**	**22.7**	**27.9**	**35.7**	**12.1**	**1.6**
406	3,191	Child care workers, private household	0.700	21.2	37.9	32.5	7.6	0.9
773	122	Motion picture projectionists	0.705	20.4	28.0	40.3	11.3	0.0
693	127	Adjusters and calibrators	0.728	19.4	35.1	31.2	11.2	3.1
485	**1,440**	**Supervisors, related agricultural occs**	**0.735**	**18.9**	**36.5**	**24.1**	**19.3**	**1.1**
674	116	Misc. precision apparel/fabric workers	0.739	18.7	32.1	30.8	16.6	1.8
462	347	Ushers	0.716	17.4	24.3	42.4	11.3	4.6
475	**1,198**	**Managers, farms, except horticultural**	**0.733**	**17.2**	**36.8**	**28.6**	**13.5**	**3.9**
833	59	Marine engineers	0.709	16.7	38.2	31.8	12.8	0.6
473	252	Farmers, except horticultural	0.706	15.8	43.2	24.3	15.2	1.5
404	95	Cooks, private household	0.704	15.7	31.2	39.7	12.9	0.5

Note: Occupations in this panel are ordered by percentage of workers in occupation with less than high school education. "Codes" in all panels are 1990 Census occupation codes. Simpson index of diversity is 1 minus Herfindahl-Hirschman index of concentration. Figures in last five columns in all panels are education breakdowns in percent. Occupations appearing in both years shown in bold in all panels. n.e.c. = not elsewhere classified

Occupations with more than 15% of workers with a post-graduate degree

Code	N	Occupation	Simpson	<HS	HS	<BA	BA	post-BA
			1990					
89	704	Health diagnosing practitioners, n.e.c.	0.709	4.0	21.2	22.8	9.1	42.9
165	1,111	Archivists and curators	0.714	1.9	11.2	19.8	27.2	39.9
158	2,979	Teachers, special education	0.715	1.9	11.8	16.6	34.7	35.0
67	1,350	Statisticians	0.710	0.1	10.0	21.7	33.3	34.9
105	**2,971**	**Therapists, n.e.c.**	**0.712**	**1.9**	**9.2**	**19.8**	**36.0**	**33.2**
77	**1,350**	**Agricultural and food scientists**	**0.715**	**0.6**	**12.7**	**18.8**	**37.5**	**30.4**
3	551	Legislators	0.727	2.4	10.7	22.3	35.9	28.6
177	**4,196**	**Religious workers, n.e.c.**	**0.747**	**3.6**	**12.5**	**25.6**	**31.2**	**27.1**
26	6,953	Management analysts	0.713	1.1	9.2	24.6	38.1	26.9
174	29,351	Social workers	0.718	2.3	11.0	20.7	39.4	26.7
159	**20,503**	**Teachers, n.e.c.**	**0.743**	**2.4**	**13.7**	**29.8**	**30.9**	**23.2**
15	**10,296**	**Managers, medicine and health**	**0.747**	**2.6**	**17.8**	**33.8**	**25.6**	**20.2**
186	**3,612**	**Musicians and composers**	**0.756**	**5.1**	**15.2**	**30.8**	**29.2**	**19.7**
97	**3,955**	**Dietitians**	**0.771**	**7.9**	**22.7**	**18.5**	**31.6**	**19.3**
5	**24,216**	**Administrators/officials, public admin**	**0.740**	**1.7**	**17.3**	**31.2**	**31.3**	**18.5**
21	**16,956**	**Managers, service organizatns, n.e.c.**	**0.746**	**3.4**	**17.1**	**30.8**	**31.5**	**17.2**
235	**22,997**	**Technician, n.e.c.**	**0.732**	**3.5**	**23.5**	**39.3**	**17.6**	**16.0**
7	**28,202**	**Financial managers**	**0.712**	**0.9**	**14.5**	**29.3**	**39.6**	**15.7**
225	3,343	Science technicians n.e.c.	0.730	4.8	21.4	41.0	17.7	15.2
			2001					
105	**1,542**	**Therapists, n.e.c.**	**0.700**	**1.2**	**7.3**	**20.6**	**33.7**	**37.2**
77	**779**	**Agricultural and food scientists**	**0.702**	**2.4**	**16.4**	**11.7**	**43.4**	**26.1**
58	194	Marine and naval architects	0.762	5.7	14.8	27.2	28.8	23.5
186	**1,239**	**Musicians and composers**	**0.752**	**3.7**	**16.2**	**24.8**	**33.1**	**22.3**
5	**12,882**	**Administrators/officials, public admin**	**0.734**	**0.7**	**15.5**	**27.8**	**34.1**	**21.9**
177	**2,801**	**Religious workers, n.e.c.**	**0.739**	**0.8**	**17.1**	**28.0**	**32.7**	**21.3**
65	3,715	Operations and systems researchers	0.711	0.2	13.0	26.0	40.2	20.6
8	3,811	Personnel/labor relations managers	0.713	0.8	13.2	24.9	40.8	20.3
21	**11,115**	**Managers, service organizatns, n.e.c.**	**0.735**	**1.6**	**16.7**	**25.4**	**36.3**	**19.9**
15	**12,945**	**Managers, medicine and health**	**0.734**	**1.0**	**16.4**	**34.0**	**29.3**	**19.2**
97	**1,403**	**Dietitians**	**0.774**	**10.9**	**24.0**	**15.5**	**31.6**	**18.0**
199	1,348	Athletes	0.735	3.4	15.9	26.2	37.6	16.9
235	**1,824**	**Technician, n.e.c.**	**0.718**	**1.3**	**16.4**	**40.6**	**25.0**	**16.7**
7	**12,560**	**Financial managers**	**0.698**	**0.4**	**13.6**	**26.1**	**43.4**	**16.5**
4	349	Chief execs/genrl admin, public admin	0.739	1.4	34.6	25.6	22.1	16.4
159	**11,942**	**Teachers, n.e.c.**	**0.732**	**2.1**	**16.2**	**31.8**	**33.8**	**16.0**
34	362	Business and promotion agents	0.706	0.0	18.3	23.2	42.5	15.9

Note: Occupations are ordered by percentage of workers in occupation with more than a BA.

Occupations with few workers with less than high school (<15%) or a post-graduate degree (<15%)

Code	N	Occupation	Simpson	<HS	HS	<BA	BA	post-BA
			1990					
28	**643**	**Purchasing agents/buyers, farm**	**0.730**	**14.3**	**38.0**	**27.0**	**17.7**	**3.0**
277	**6,906**	**Street/door-to-door sales workers**	**0.736**	**8.4**	**31.2**	**34.4**	**19.3**	**6.7**
384	**1,191**	**Proofreaders**	**0.722**	**3.3**	**28.9**	**33.9**	**27.1**	**6.9**
4	896	Chief execs/genrl admin, pub admin	0.758	7.0	28.4	31.8	19.3	13.5
18	**13,304**	**Managers, properties/real estate**	**0.737**	**7.5**	**26.9**	**36.0**	**22.6**	**7.1**
223	2,567	Biological technicians	0.749	10.5	26.4	33.6	23.0	6.5
259	58,895	Sales reps, mining, manuf, whole.	0.711	4.4	24.2	35.6	31.5	4.2
6	**2,498**	**Administrators, protective services**	**0.718**	**2.5**	**24.1**	**40.9**	**20.3**	**12.2**
36	**7,392**	**Inspectors/compliance, ex. constr.**	**0.725**	**3.4**	**22.3**	**33.4**	**32.5**	**8.4**
155	**11,797**	**Teachers, pre-k and kindergarten**	**0.710**	**3.2**	**21.9**	**38.6**	**29.4**	**6.8**
22	**202,572**	**Managers and administrators, nec**	**0.740**	**3.4**	**21.3**	**34.3**	**28.1**	**12.8**
254	**21,091**	**Real estate sales occupations**	**0.709**	**2.4**	**20.5**	**39.6**	**29.1**	**8.4**
194	**2,708**	**Artists, performers, related, n.e.c.**	**0.743**	**5.5**	**20.3**	**37.6**	**22.7**	**13.9**
34	1,168	Business and promotion agents	0.731	5.4	19.7	30.5	35.6	8.8
27	**22,017**	**Personnel, training, and labor relations specialists**	**0.729**	**2.8**	**19.6**	**34.4**	**31.6**	**11.6**
8	11,519	Personnel/labor relations managers	0.742	3.5	19.5	32.6	30.5	13.8
25	28,435	Other financial officers	0.714	1.1	17.5	33.7	35.6	12.1
214	726	Industrial engineering technicians	0.718	7.0	17.3	30.0	39.2	6.5
215	1,314	Mechanical engineering technicians	0.731	5.9	17.3	27.8	38.4	10.8
199	2,938	Athletes	0.734	3.8	15.6	36.5	29.2	14.9

Note: Occupations are ordered by percentage of workers in occupation with a high school education.

Occupations with few workers with less than high school (<15%) or a post-graduate degree (<15%)

Code	N	Occupation	Simpson	<HS	HS	<BA	BA	post-BA
			2001					
343	787	Cost and rate clerks	0.724	9.4	38.8	29.0	17.0	5.7
17	17,968	Managers, food and lodging	0.704	7.4	37.4	34.0	18.6	2.7
283	659	Demonstrators, promoters and models, sales	0.715	14.2	36.6	31.8	17.3	0.2
494	193	Supervisors, forestry, and logging	0.757	10.4	36.1	22.0	20.5	11.1
243	60,023	Supervisors/proprietors, sales occs	0.703	4.0	35.2	34.9	21.8	4.0
224	1,146	Chemical technicians	0.699	1.7	32.7	37.7	22.0	5.9
28	**172**	**Purchasing agents/buyers, farm**	**0.701**	**2.8**	**30.9**	**29.4**	**34.1**	**2.8**
18	**6,448**	**Managers, properties/real estate**	**0.729**	**6.7**	**30.3**	**34.5**	**22.9**	**5.6**
277	**2,638**	**Street/door-to-door sales workers**	**0.749**	**7.8**	**29.6**	**30.4**	**24.3**	**8.0**
384	**271**	**Proofreaders**	**0.721**	**3.6**	**27.3**	**35.0**	**27.7**	**6.4**
194	**1,428**	**Artists, performers, related, n.e.c.**	**0.725**	**3.0**	**25.1**	**34.4**	**29.3**	**8.2**
257	11,000	Sales occs, other business services	0.716	3.7	24.5	32.5	33.7	5.5
189	1,362	Photographers	0.726	6.2	23.3	31.1	34	5.4
22	**98,298**	**Managers and administrators, nec**	**0.736**	**1.8**	**21.2**	**29.2**	**33.8**	**14.1**
254	**6,999**	**Real estate sales occupations**	**0.700**	**1.3**	**20.8**	**38.7**	**31.7**	**7.4**
188	1,852	Painters, sculptors, craft-artists	0.701	2.8	19.3	35.9	35.8	6.3
155	**10,123**	**Teachers, pre-k and kindergarten**	**0.732**	**2.2**	**18.6**	**30.8**	**34.5**	**14.0**
27	**10,122**	**Personnel, training, and labor relations specialists**	**0.707**	**0.9**	**17.3**	**31.0**	**39.2**	**11.6**
36	**4,113**	**Inspectors/compliance, ex. constr.**	**0.707**	**1.0**	**16.4**	**31.1**	**39.4**	**12.2**
6	**1,113**	**Administrators, protective services**	**0.705**	**0.7**	**15.5**	**42.1**	**26.8**	**14.8**

Note: Occupations are ordered by percentage of workers in occupation with a high school education.