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Education, Skills, and Technical Change

Implications for Future US GDP Growth

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Edited by
Charles R. Hulten
and Valerie A. Ramey

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National Bureau of Economic Research
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8. Unless otherwise determined by the Board or exempted by the terms of paragraphs 6 and 7, a copy of this resolution shall be printed in each NBER publication as described in paragraph 2 above.

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Prefatory Note

This volume contains revised versions of the papers presented at the Conference on Research in Income and Wealth titled "Education, Skills, and Technical Change: Implications for Future U.S. GDP Growth," held in Bethesda, Maryland, on October 16–17, 2015.

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Executive Committee, December 2016

9

Recent Flattening in the Higher Education Wage Premium
Polarization, Skill Downgrading, or Both?

Robert G. Valletta

9.1 Introduction

Holding a four-year college degree confers a distinct advantage to workers in the US labor market. The wage gaps between college-educated working adults and those with a high school degree—higher education wage premiums—are large and have grown substantially over the past thirty-five years. These gaps may have been bolstered by technological advances in the workplace, notably the growing reliance on computers and related technologies, because the skills that are needed to master and apply these technologies are often acquired through or associated with higher education (Krueger 1993; Autor, Katz, and Krueger 1998; Autor, Levy, and Murnane 2003; Acemoglu and Autor 2011).

The expansion of the higher education wage premium has not been completely uniform over time, however, with rapid growth in the 1980s followed by progressively slower growth ("flattening"). During the years 2000 through 2010, the wage premium for college-educated workers rose by only a small amount. Most recently, from 2010 to 2015, the wage premium for those with

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college and graduate degrees was largely unchanged, suggesting that the factors propelling its earlier rise have disappeared.

While the wage advantage associated with higher education remains large, the lack of growth in recent years represents a departure from the earlier pattern. This change may have important implications for the value of higher education as an individual and social investment, and consequences for economic growth as well. Despite the voluminous literature on returns to education, little attention has been paid to slower growth in the college wage premium and differences between these higher education groups (Lindley and Machin [2016] is an exception).

In this chapter, I assess and attempt to explain the stalling of the higher education wage premium and its variation across the college-only and graduate-degree groups. I focus on two primary, related explanations for changing returns to higher education.

The first potential explanation is labor market "polarization" (Acemoglu and Autor 2011). This theory emphasizes a shift away from medium-skill occupations driven largely by technological change. It provides a broad, cohesive explanation for changes in employment patterns in the United States and other advanced economies in recent decades. Polarization may account for the slowdown in the college wage premium through a shift in the occupational distribution of college graduates toward jobs that are being displaced by automation technologies and related factors (such as outsourcing and rising trade). At the same time, rising demand for the cognitive skills possessed by graduate-degree holders may help maintain and expand their wage advantage relative to those holding a four-year college degree only (Lindley and Machin 2016).

I will refer to the second broad potential explanation for the flattening of higher education wage premiums as "skill downgrading," based on the recent work of Beaudry, Green, and Sand (2016). They emphasize a general weakening since the year 2000 in the demand for cognitive tasks in the workplace, reflecting a maturation in the information technology (IT) revolution and consequent slowdown in workplace IT investments. Skill downgrading in their framework refers to the process by which weaker demand for advanced cognitive skills cascades down the skill distribution as highly skilled workers, such as those possessing advanced degrees, increasingly compete with and replace lower-skilled workers in occupations that rely less heavily on advanced cognitive skills.

I begin my empirical assessment in the next section by establishing the basic facts regarding changes in educational attainment and the higher education wage premiums, distinguishing between individuals with a four-year college degree and those with graduate degrees. The analyses throughout are based primarily on data from the Current Population Survey (CPS) monthly earnings files (monthly outgoing rotation groups, or MORG) spanning the period 1979–2015. I also conduct selected parallel analyses using the CPS Annual Social and Economic Supplement files (March CPS-ASEC), which at the time of this writing provide earnings data through 2014. Standard wage regressions that adjust for changing workforce composition highlight the flattening of the higher education wage premiums noted above.

To help interpret these empirical findings, I then discuss the polarization and skill-downgrading arguments in more detail. Observed occupational employment shifts indicate the potential importance of polarization for the flattening of the college wage premium. The Beaudry, Green, and Sand skill-downgrading narrative takes polarization as its starting point but emphasizes different dynamics over time, with weaker demand for cognitive skills arising as a consequence of a slowdown in technology investment.

To assess the effects of polarization and skill downgrading on higher education wage premiums, I examine changing premiums within and between the broad occupation categories that are used to identify the extent of polarization. The results of these analyses suggest that polarization and skill downgrading have both contributed to the flattening of the wage premium for individuals with a four-year college degree or postgraduate degree. Consistent with the polarization story, the flattening in the wage premium is partly explained by shifting employment and relative wages across broad occupation groups, mainly for those with a college degree but no graduate degree. However, a substantial contribution also comes from the slowdown in the wage premium within broad occupation categories, consistent with skill downgrading and heightened competition between educational groups for similar jobs. In the conclusion, I discuss the implications of these findings for future research on the returns to higher education and its role in economic growth.

9.2 Changes in the Higher Education Wage Premium

The wage premium earned by individuals with higher educational attainment is commonly attributed to the more extensive skills that they possess (Card 1999; Goldin and Katz 2008). To save space, I will not review the voluminous and well-known literature on estimating and interpreting the returns to education, but will instead turn directly to updated estimates of the returns to higher educational attainment (college degrees and above).

9.2.1 Data and Descriptive Statistics

Because the data and processing procedures I use are well known, I describe them only briefly here, with additional details relegated to appendix A. The primary data used are from the CPS MORG files, compiled by the National Bureau of Economic Research (NBER) and available for the years 1979–2015 when this chapter was written. These files contain data for the quarter sample of the monthly CPS that receives survey questions regarding earnings and related variables in currently held jobs. I also use the complete monthly CPS files for selected tabulations that do not involve wages.

The data handling and processing procedures largely follow those detailed in Lemieux (2006a, 2010). These include elimination of observations with imputed values of earnings or hours and adjustments for changing top-codes. I use hourly wages as my earnings measure, either reported directly by hourly workers or formed as usual weekly earnings divided by usual weekly hours worked for salaried workers. All wage and earnings variables are deflated by the annual average value of the gross domestic product (GDP) deflator for personal consumption expenditures (and expressed in 2015 terms for ease of interpretation). For all of the analyses in this chapter, the samples are restricted to wage and salary workers age twenty-five to sixty-four (with farming and resource occupations excluded).

The basis for the measurement of educational attainment in the CPS switched in 1992 from the highest grade attained and completed to the highest degree received. I formed educational categories that are largely consistent over time following the guidance of Jaeger (1997).[1] Individuals with a graduate degree, along with information about the type of degree, are directly identified beginning in 1992. Graduate-degree holders prior to 1992 are identified as those reporting at least eighteen years of completed education. I code individuals who report seventeen years of completed schooling in the pre-1992 period as possessing a four-year college degree, but not a graduate degree.[2]

For comparison purposes, I also use data from the March CPS files to estimate changes in the higher education earnings premium. Compared with the MORG data, which provides information on earnings in the current reference week, the March CPS data refer to earnings in the complete prior calendar year. Following standard practice, I restrict the March CPS sample to full-time, full-year workers and use weekly earnings (annual labor earnings divided by weeks worked) as the earnings measure, once again dropping observations with imputed earnings or hours and adjusting for changing top-codes (e.g., Autor, Katz, and Kearney 2008). These files are currently available through 2015. Since the data refer to the prior calendar year, the reference period for the March data ends one year earlier than the MORG data (2014 rather than 2015).

1. Relative to Jaeger (1997), in the 1992-forward data I include individuals who report twelve years of schooling but no diploma in the "no degree" group rather than the "high school degree" group, to be consistent with the emphasis on degree attainment beginning in 1992.

2. Lindley and Machin (2016) take a similar approach, which groups individuals who drop out of a graduate program after one year or complete a one-year master's degree program with those who complete a four-year college degree only. This approach generates a slight discontinuity in the relative college/graduate shares in 1992, but the discontinuity is larger if instead such individuals are treated as having a graduate degree.

Table 9.1 **Educational attainment shares and real hourly wages**

	1980 (1)	1990 (2)	1992 (3)	2000 (4)	2010 (5)	2015 (6)
			Panel A. Employment share			
No degree (< 12 yrs. education)	0.197	0.130	0.115	0.099	0.082	0.077
High school degree	0.371	0.368	0.358	0.314	0.280	0.256
Some college	0.205	0.238	0.259	0.280	0.280	0.278
College only (4-year)	0.158	0.183	0.177	0.205	0.232	0.247
Graduate degree	0.069	0.081	0.090	0.103	0.126	0.143
Graduate degree by type						
Master's			0.068	0.075	0.094	0.107
Professional			0.012	0.014	0.016	0.016
Doctoral			0.010	0.013	0.016	0.019
			Panel B. Real hourly wage (2015$) (averages by group)			
No degree (< 12 yrs. education)	14.19	12.84	12.47	13.03	13.22	13.56
High school degree	16.33	15.99	15.87	17.20	17.77	17.98
Some college	18.80	19.29	19.16	20.84	21.47	21.59
College only (4-year)	22.85	25.32	25.18	28.98	30.49	30.93
Graduate degree	27.27	31.43	31.66	36.40	39.70	39.48
Graduate degree by type						
Master's			29.94	33.99	36.85	36.83
Professional			38.32	45.01	50.75	50.51
Doctoral			35.83	41.44	46.43	45.70

Notes: Author's calculations from CPS monthly files (panel A) and MORG files (panel B); sample weights used. See table 9.2 note for MORG sample description and counts. Master's degrees include MBAs along with a wide set of other master's degrees; professional degrees are JD, MD, and related.

Table 9.1 displays descriptive statistics for employment shares (panel A) and average real wages (panel B) by educational attainment, calculated using the full monthly CPS files for the employment shares and the MORG files for the wage data. These are provided for ten-year intervals that largely span the sample frame. The table also lists statistics for selected other years, including the year that the education variables changed (1992) to bridge the gap in definitions, and a listing for the final data year (2015).

Panel A of table 9.1 illustrates the well-known, steady decline in the employment share of individuals whose educational attainment is a high school degree or less accompanied by a steady rise in the share of individuals possessing a four-year college degree or graduate degree. As of 2015, nearly 40 percent of employed individuals age twenty-five to sixty-four held at least a college degree, and one in seven held a graduate degree, accounting for slightly more than a third of employed college graduates. Master's degrees (which include MBAs) account for most of the level and change in the fraction holding graduate degrees, along with a large proportional increase for the small share of doctoral degrees.

Panel B of table 9.1 illustrates the large wage gaps between the educational attainment groups, with the spread in real wages between the graduate-degree group and those with less than a high school degree widening approximately from a factor of two to a factor of three over the sample frame. Average real wages changed little over the sample frame for those with a high school degree or less. For those with at least some college education, average real wages rose somewhat between 1980 and 2000, with larger increases evident for those with higher educational attainment. Between 2000 and 2010, only holders of graduate degrees saw any meaningful increase in real wages. Between 2010 and 2015, real wages were flat to down slightly for all groups. The gap in average real wages between individuals with a four-year college degree or graduate degree and high school graduates rose from 40 to 67 percent in 1980 to 72 to 120 percent as of 2015.

9.2.2 Composition-Adjusted Estimates of Wage Gaps

To assess the changing wage premium associated with higher educational attainment, I estimate standard log-wage equations of the following form (where *i* indexes individuals):

$$\text{Ln}(w_i) = X_i\beta + S_i\Gamma + \varepsilon_i, \quad (1)$$

where X_i represents a set of demographic controls and S_i represents educational attainment (measured in discrete categories). This equation is estimated separately for each year using the MORG and March CPS data as described above. The control variables in the vector X include dummy variables for seven age groups (e.g., thirty to thirty-four, etc., with twenty-five to twenty-nine omitted), three racial/ethnic groups, gender, marital status, gender * marital status, and geographic location (nine census divisions). These controls adjust for the changing composition of the estimation sample, so that the results for the education categories reflect the average wage premium associated with educational attainment for an individual with a fixed set of demographic characteristics (X).[3]

Our interest centers on the estimated vector of coefficients (Γ) on a set of dummy variables representing discrete categories of educational attainment (S). Table 9.2 lists the numerical results for selected years, while figure 9.1 displays the results for the complete sample period of 1979 through 2015 (2014 for the March CPS).[4] For both displays, panel A lists the results for the MORG data, while panel B lists the results for the March CPS. The results are expressed in natural log terms. These conditional wage gaps are displayed

3. The results reported below are very similar when this set of control variables is replaced by complete interactions between four decadal age categories, four race/ethnic categories, the two genders, and marital status (married spouse present or not), for a total of sixty-four demographic cells.

4. The estimated coefficients for college and postgraduate educational attainment are highly statistically significant in virtually all cases reported below, with the exception of a few group-specific estimates reported in table 9.3.

Table 9.2 **Composition-adjusted wage/earnings differentials (log points, relative to high school graduates)**

	1980 (1)	1990 (2)	1992 (3)	2000 (4)	2010 (5)	2015 (6)
Panel A. CPS MORG data						
Full sample						
College degree or higher	0.304	0.449	0.464	0.518	0.566	0.566
	(.003)	(.003)	(.003)	(.004)	(.004)	(.005)
College only (4-year)	0.270	0.402	0.403	0.451	0.475	0.477
	(.004)	(.004)	(.004)	(.005)	(.005)	(.005)
Graduate degree	0.383	0.553	0.581	0.648	0.727	0.712
	(.005)	(.005)	(.005)	(.006)	(.006)	(.006)
Observations	121,001	123,111	119,014	83,314	85,397	76,789
College degree or higher sample						
Graduate degree	0.111	0.149	0.170	0.194	0.245	0.226
	(.006)	(.006)	(.006)	(.007)	(.006)	(.006)
Observations	27,042	33,334	32,684	26,789	32,305	31,572
Panel B. CPS March data						
Full sample						
College degree or higher	0.293	0.449	0.477	0.538	0.579	0.576
	(.006)	(.006)	(.006)	(.006)	(.006)	(.007)
College only (4-year)	0.260	0.400	0.415	0.468	0.488	0.488
	(.007)	(.007)	(.007)	(.006)	(.007)	(.007)
Graduate degree	0.368	0.557	0.593	0.680	0.740	0.725
	(.009)	(.009)	(.009)	(.008)	(.008)	(.008)
Observations	34,258	38,123	37,143	52,489	45,575	43,435
College degree or higher sample						
Graduate degree	0.102	0.155	0.174	0.206	0.244	0.230
	(.011)	(.010)	(.010)	(.009)	(.008)	(.009)
Observations	8,184	10,630	10,709	16,350	17,608	17,540

Notes: Estimated coefficients from ln(wage or earnings) regressions for the years indicated in the column labels; horizontal lines identify coefficients obtained from separate regressions. Standard errors in parentheses. Samples are wage and salary workers age twenty-five to sixty-four for both data sources, restricted to full-time, year-round workers (annual hours ≥ 1,750) in the CPS March data. Dependent variable is ln(hourly earnings) for the MORG data and ln(weekly earnings) for the CPS March data, with allocated values dropped and top-code adjustments (see the text and appendix). Composition adjustment relies on the inclusion of the following control variables (all categorical): seven age, three race/ethnic, married, female, married × female, and eight geographic divisions.

for three educational groupings: the broad group of all workers with at least a four-year college degree, and the two subgroups consisting of those with a four-year degree only ("college only"), and those who hold a postgraduate degree as well. The results for the "college degree or higher" group are based on regressions that are estimated separately from the one used to estimate the returns for the two subgroups (as indicated by the horizontal lines in

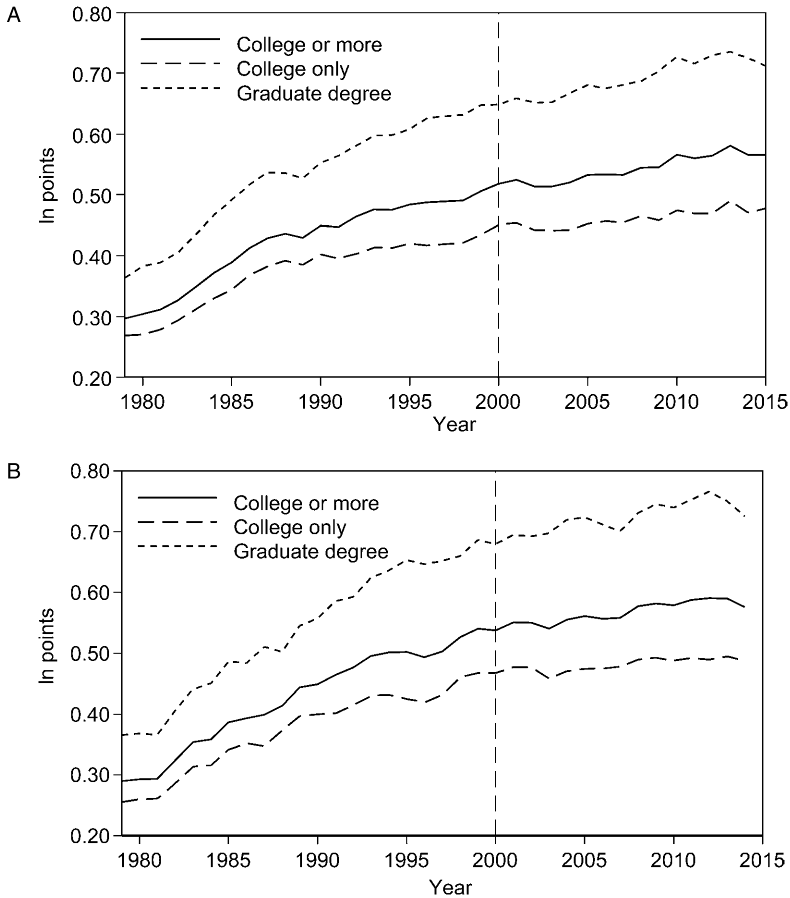

Fig. 9.1 Estimated higher education wage premium, 1979–2015. ***A*, CPS MORG data (1979–2015); *B*, March CPS data (1979–2014).**

Notes: Author's calculations using CPS MORG and March data (see table 9.2 note). Differentials expressed relative to high school graduates.

the table). The higher education wage premiums are first expressed relative to the wages of high school graduates. In addition, separate estimates are provided for those holding a graduate degree. These are based on the restricted sample of individuals who have at least a college degree, hence they represent the graduate wage premium relative to the wages of the college-only group.

The estimates in table 9.2 and figure 9.1 show that the wage premiums for higher education generally have been rising over time. However, both data sets show that the growth has slowed in recent decades, with the slowdown for the graduate group lagging behind that for the college-only group. The

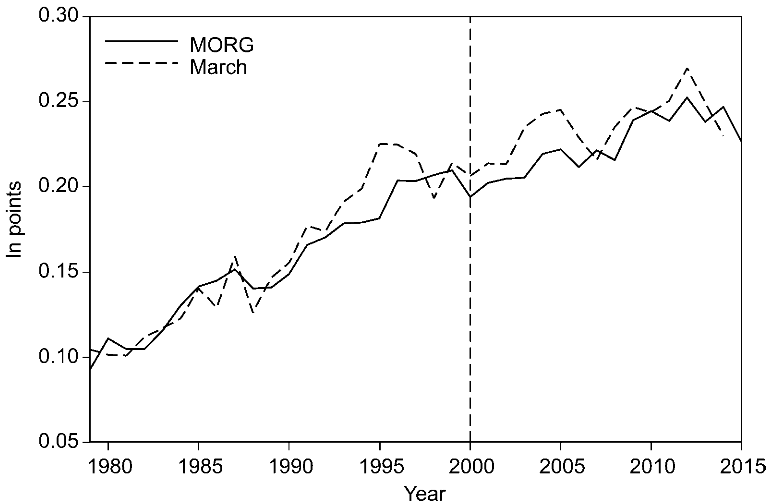

Fig. 9.2 Estimated graduate-degree wage premium

Notes: Author's calculations using CPS MORG and March data (see table 9.2 note). Differentials expressed relative to four-year college graduates.

rate of growth in the college-only wage premium was cut approximately in half between the 1980s and 1990s and then slowed virtually to a standstill after 2000. It rose about 2 to 2.5 log points through 2010 and then was unchanged between 2010 and 2015.

For the graduate-degree group, the slowdown over time is most evident based on the results for the college or higher sample. These are displayed at the bottom of both panels in table 9.2 and also in figure 9.2, where the results for the MORG and March data sets are directly compared. The estimated wage premiums are very similar in the two data sources, with somewhat greater annual volatility evident in the March data for the college-only sample in figure 9.2 due to its smaller sample. Relative to the college-only group, individuals with a graduate degree saw consistent wage premium gains of about 4 to 5 log points in each of the decades of the 1980s, 1990s, and first decade of the twenty-first century. During this time frame, their wage advantage over college-only workers grew steadily, reaching nearly 25 log points by 2010. However, since 2010, the graduate-degree premium is down slightly in both data sources (through 2015 in the MORG data and 2014 in the March data).

9.2.3 Robustness Checks and Disaggregation by Age and Gender

One potential concern with respect to these results is the possibility that they reflect underlying changes in employment conditions among narrow worker groups or industries. Such narrow changes may be independent of the broad occupational changes and shifting labor market competition related to polarization and skill downgrading (which are discussed and analyzed below, in sections 9.3 and 9.4). One such narrow group is teachers, who constitute a substantial but declining share of employed college graduates.[5] Excluding educator and librarian occupations from the regressions raises the estimated higher education wage premiums by 2–4 log points in general. However, the pattern over time is unchanged relative to the full sample results, with progressive flattening in the wage premiums and no change from 2010 forward.

It is also important to consider the potential influence of changing conditions in key industries that employ large numbers of college graduates. One such industry is the financial sector, for which the housing bust and financial crisis tied to the Great Recession of 2007–2009 destroyed a disproportionate number of jobs. Many finance-sector jobs are highly paid, and their disappearance may have affected the higher education wage premium. However, exclusion of workers employed in the financial, insurance, and real estate sectors from the regression analysis has virtually no impact on the estimated wage premiums and their pattern over time.[6] Similarly, Beaudry, Green, and Sand (2016) highlight the role of the business and management services industries for their findings, emphasizing substantial employment changes for young college graduates in this sector. Exclusion of individuals employed in these industries does not affect the estimated college-only wage premium. It does raise the level of the graduate school wage premium, suggesting a relatively low value for graduate degrees in this industry. Nonetheless, the pattern of the higher education wage premiums over time, as reflected in the results from table 9.2 and figure 9.1, is unaffected.

It is also instructive to examine the higher education wage premium decomposed by age group and gender. Analyses of employment and wage patterns for the college educated often highlight younger workers, who are likely to experience the most immediate effects of changing employment conditions across educational attainment groups (e.g., Beaudry, Green, and Sand 2014). Figure 9.3 parallels figure 9.1 (panel A, MORG), but displays wage premiums for the youngest decadal age group in my sample (age twenty-five to thirty-four) in panel A and an older group (age forty-five to fifty-four) in panel B.[7] For younger workers, movements in the wage premi-

5. Among workers with at least a four-year college degree in the MORG data, the fraction of educators and librarians declined by a third over my sample frame, from 24 percent in 1979 to about 16 percent in 2015.

6. Separate analyses by broad industry, also noted in section 9.4, show that the higher education wage premiums within the finance sector broadly track the patterns evident for the overall economy.

7. The underlying regressions used to produce the results in figure 9.3 are identical to those used for table 9.1 and figure 9.1, except the samples are restricted to the indicated age groups and the age category controls are adjusted accordingly. I use age forty-five to fifty-four rather than the oldest group in my sample, age fifty-five to sixty-four, to minimize the influence of partial retirement decisions on relative earnings over time.

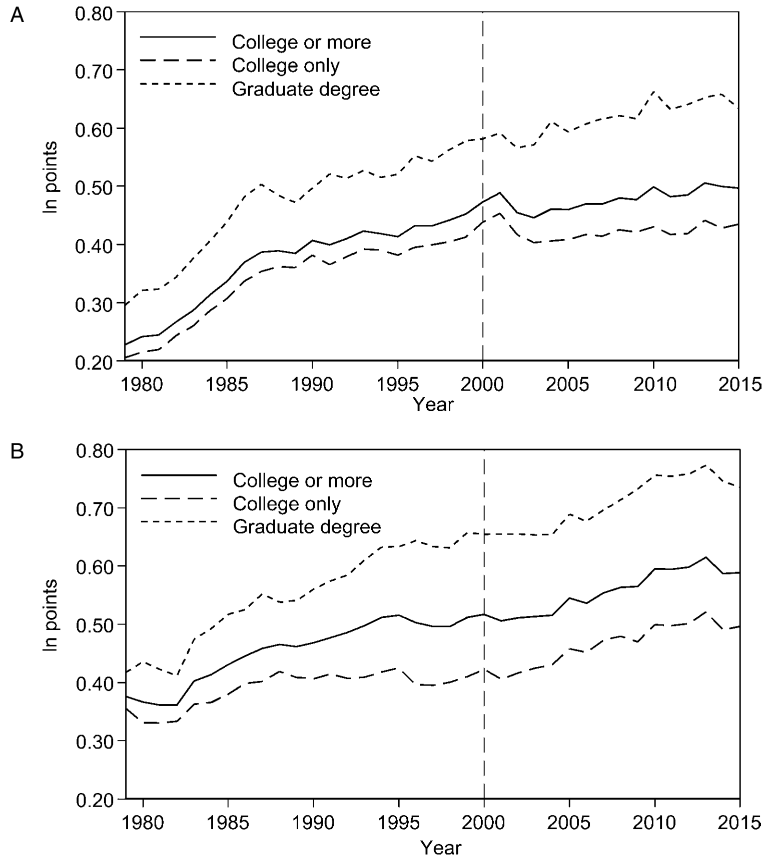

Fig. 9.3 Estimated higher education wage premium by age group, 1979–2015. *A*, age twenty-five to thirty-four; *B*, age forty-five to fifty-four.

Notes: Author's calculations using CPS MORG data (see table 9.2 note). Differentials expressed relative to high school graduates.

ums over time largely parallel those for the complete sample in figure 9.1, with large gains in the 1980s followed by slower gains in the 1990s and the first decade of the twenty-first century, and no change since 2010. By contrast, for older workers the college-only premium was largely flat in the 1990s, perhaps because this group did not readily adapt to the new information technologies introduced during that decade. The college-only premium for older workers picked up in the early twenty-first century, although like the graduate-degree premium, it has been flat since 2010. Comparison across the two panels in figure 9.3 also indicates that the higher education wage premiums are larger for older than for younger workers, by about 5 to 10 log points, on average. This likely arises due to important interaction or

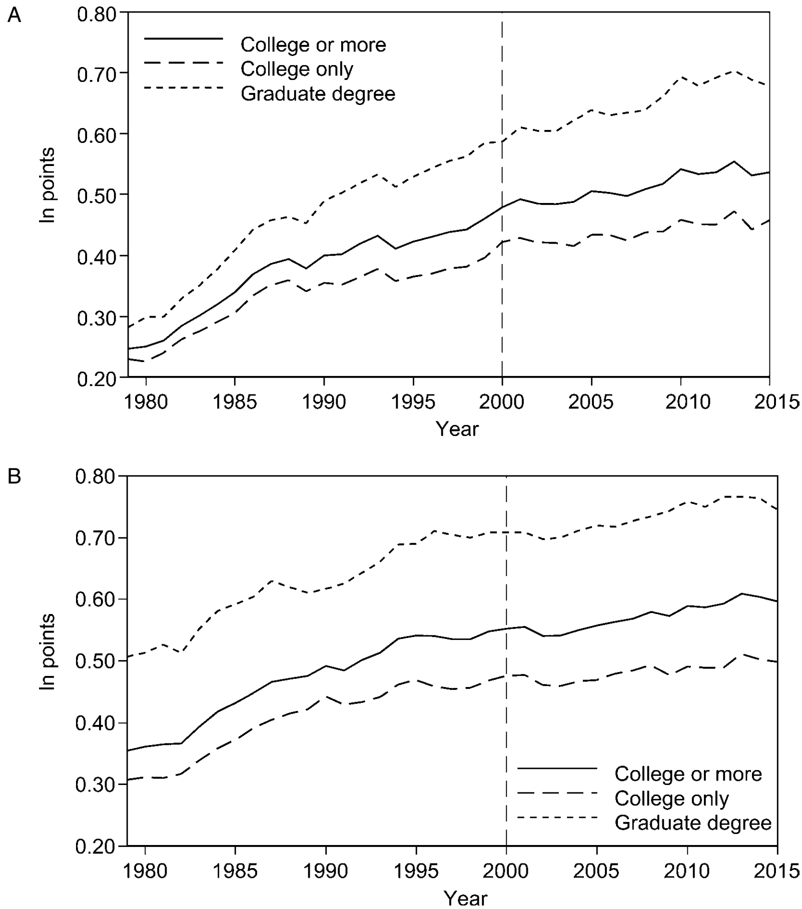

Fig. 9.4 Estimated higher education wage premium by gender, 1979–2015. *A*, men; *B*, women.

Notes: Author's calculations using CPS MORG data (see table 9.2 note). Differentials expressed relative to high school graduates.

reinforcing effects between higher education and the subsequent acquisition of on-the-job skills that raise wages as workers age.

Given the well-known increase in the attainment of higher education for women relative to men, it is also informative to examine the wage premiums by gender. These are displayed in figure 9.4 (panel A for men, panel B for women). The series represent the composition-adjusted higher education wage premiums by gender; as such, they reflect relative wages within gender group and hence should not be interpreted as capturing wage differences between men and women. The higher education wage premiums are larger for women than for men, although the gap has closed over time, especially for graduate degrees. The pattern over time for both genders is similar to that for the overall sample in figure 9.1 (panel A), with a flattening of the wage premiums over time and essentially no change since 2010.

9.2.4 Summing Up: Higher Education Wage Premiums over Time

The results presented in this section indicate general flattening in the wage premiums associated with four-year college and graduate degrees. The sharp increases observed in the 1980s have been followed by much slower gains. Since the year 2000, the wage premium associated with a four-year college degree has changed little. By contrast, from 2000 to 2010, the wage premium for holders of graduate degrees relative to those with four-year college degrees continued to grow at its previous pace, contributing to increasing "convexification" in the returns to higher education (Lemieux 2006b; Lindley and Machin 2016). Since 2010, however, wage premiums for both groups have sputtered. They remain large but were essentially unchanged for the college-only group and down slightly for holders of graduate degrees. These patterns indicate that the factors propelling earlier increases in the returns to higher education have dissipated.

Because of the significant time required for individual investments in higher education—four years or more—the flatter wage premiums may reflect a delayed response of the supply of college-educated individuals to earlier increases in demand (Acemoglu and Autor 2011; Autor 2014). However, given the relatively consistent increase over time in the college-educated employment share listed in table 9.1 (panel A), factors on the demand side that affect relative productivity and employers' preference for workers with higher education merit further consideration.

9.3 Potential Explanations: Polarization and Skill Downgrading

The slower growth and eventual flattening in the wage premium for higher education documented in the preceding section raises the possibility that the factors propelling rising wage premiums for highly skilled workers have dissipated. Past accounts of rising wage premiums for skilled workers generally revolved around the skill-biased technological change (SBTC) explanation of labor market developments. Under SBTC, rising reliance on sophisticated workplace technologies boosts the employment and wages of workers, mainly the highly educated, whose skills enable them to apply those technologies (e.g., Bound and Johnson 1992; Autor, Katz, and Krueger 1998). Recent research has pointed to factors that may alter or offset this process. I focus on two broad explanations: labor market polarization and skill downgrading.

9.3.1 Polarization and Skill Downgrading: The Basics

The "polarization" hypothesis is a leading explanation for recent employment developments in the United States and other advanced countries (Goos and Manning 2007; Acemoglu and Autor 2011; Autor 2015; Goos, Manning, and Salomons 2014). This is a refinement of the SBTC story that accounts for excess employment growth in the top and bottom portions of the wage distribution, with erosion in the middle.

In the polarization framework, evolving workplace technologies undermine demand for "routine" jobs, in which workers and the tasks they perform are readily substituted by computer-intensive capital equipment and processes. They include white-collar office jobs (e.g., bookkeeping and clerical work), termed "routine cognitive" jobs, and blue-collar occupations that involve repetitive production or monitoring activities, termed "routine manual" jobs. These routine jobs are concentrated toward the middle of the wage and skill distribution. By contrast, workers in high-wage "nonroutine cognitive" (or "abstract") jobs tend to have skills that are complementary with computer-based technologies, while low-wage service workers in "nonroutine manual" jobs are neither substitutes nor complements with computer-based technologies. Polarization arising from changes in domestic production technologies may be reinforced by related changes in overseas production technologies through the impact of offshoring and import competition (see, e.g., Autor, Dorn, and Hanson 2013).

Beaudry, Green, and Sand (2016) provide a related but alternative framework for understanding changing occupational employment patterns over the past few decades. They rely on a basic variant of the polarization hypothesis as their starting point, but they emphasize a slowdown in IT investments that has undermined the demand for cognitive skills since the year 2000. In their narrative, weaker demand for cognitive skills and the consequent impact on highly skilled workers has cascaded down the skill distribution, undermining the demand for lesser skilled workers as well. They refer to this process as "skill downgrading," which contrasts with the opposite pattern of "skill upgrading" that occurs during the initial period of accelerating IT investments.

The similarities and contrasts between the polarization and Beaudry, Green, and Sand skill-downgrading scenarios can be readily summarized with reference to the production functions and associated objective functions that underlie the two models. In a basic model of polarization, firms rely on cognitive and routine task inputs supplied by workers for production, combined with inputs of computer capital (see, e.g., Autor, Levy, and Murnane 2003).[8] The firm aims to maximize profits π by choosing appropriate input combinations given its production function F:

$$(2) \qquad \max_{\Omega, L_c, L_r} = p * F(\Omega, L_c, L_r, \theta) - r\Omega - w_c L_c - w_r L_r$$

where p is the price of the firm's output, Ω is a form of technological (computer) capital with per-unit rental rate r, L_c and L_r are inputs of cognitive

8. This representation is adapted from Autor, Levy, and Murnane (2003), modified to be broadly consistent with the notation and framework in Beaudry, Green, and Sand (2016). Nonroutine manual jobs are largely ignored here for simplicity and because they have limited relevance for college-educated workers.

and routine labor with wage rates w_c and w_r, and θ is a technology parameter that shifts the level of output for a given set of inputs (assumed constant in this basic version of the model, but allowed to change in the Beaudry, Green, and Sand variant below). The production function $F(\cdot)$ is assumed to reflect constant returns to scale and hence diminishing marginal productivity for individual inputs.

Production efficiency requires hiring labor inputs up to the point where each input's marginal product equals its market wage or rental rate. Importantly, Autor, Levy, and Murnane (2003) assume that computer capital is perfectly substitutable with routine labor inputs, implying complementarity between computers and cognitive (nonroutine) labor in their setting. In this framework, as the price of computer capital falls, production techniques shift toward greater reliance on cognitive labor inputs and less on routine labor inputs, with corresponding reductions in the relative wage paid for routine labor inputs. Because routine tasks are common among many jobs toward the middle of the wage distribution, polarization will tend to erode or "hollow out" middle-class jobs and wages.

Beaudry, Green, and Sand extend the basic polarization model by incorporating the key feature that cognitive labor inputs create a stock of organizational capital for firms, which enables them to develop and utilize new technologies. This is captured in the following modification of equation (2), which is a discrete-time version of the objective function from equation (1) in Beaudry, Green, and Sand (2016):

(3)
$$\max_{L_c, L_r} \pi = p * F(\Omega, L_r, \theta) - w_c L_c - w_r L_r$$
$$s.t.\ \Delta\Omega = L_c - \delta\Omega_{-1}.$$

Relative to the production function in equation (2), Ω in equation (3) represents intangible "organizational capital" rather than tangible computer capital. In this modified framework, cognitive labor inputs do not directly affect current production but instead contribute to output through the accumulation of organizational capital (which depreciates at the rate δ). The first-order conditions for production efficiency are similar to the basic polarization model from equation (2).

This modified model is distinguished by its dynamic properties in response to a technological shift, or change in θ. Beaudry, Green, and Sand assume that an increase or improvement in the technology factor θ raises the productivity of the organizational capital accumulated through the use of cognitive labor inputs but has no direct effect on the productivity of routine labor inputs. These model features generate a "boom-bust cycle" in the demand for cognitive tasks and overall labor demand in response to technological improvement. In particular, the dynamics of the model predict that the stock of cognitive tasks/skills grows during the boom, as the economy adjusts to the need for additional organizational capital to manage the new technology.

Once the level of organizational capital becomes sufficiently large for appropriate use of the new technology, the demand for cognitive tasks declines as their use is shifted from expanding organizational capital to maintaining it by offsetting depreciation (similar to the pattern in existing models of technology diffusion and capital investment).

The Beaudry, Green, and Sand model can predict the strong growth in demand and wages for workers in jobs that rely heavily on cognitive tasks/skills up to the year 2000—the boom phase—followed by a decline thereafter—the bust phase. The demand reversal during the bust phase causes high-skilled workers to move down the occupational ladder and replace lower-skilled workers, pushing the latter group further down the occupational ladder ("skill downgrading") and perhaps out of the labor market entirely.[9]

9.3.2 Descriptive Evidence

Broad empirical evidence suggests that polarization and skill downgrading are both contributing to changing employment patterns and hence may be affecting higher education wage premiums.

Patterns of occupational job growth in recent decades confirm the relevance of the polarization narrative. Labor demand and job growth have been relatively rapid in the high-wage nonroutine cognitive and low-wage nonroutine manual categories, with the middle-wage routine jobs experiencing downward pressure. This pattern can be seen in figure 9.5, which displays annual rates of job growth for the four broad polarization categories over four subperiods (classified using the broad occupational scheme from Acemoglu and Autor [2011]; see appendix B for the correspondence).[10] The figure shows substantial growth in the 1980s, followed by a slowdown in the 1990s for all groups (reflecting in part the impact of the early 1990s recession).[11] Polarization is evident in the 1990s, reflected in a sharper slowdown for the routine versus the nonroutine categories. This process appeared to accelerate after the year 2000, with substantial gains for nonroutine jobs and substantial net losses for routine jobs, particularly during the Great Recession of 2007–2009 and the subsequent recovery.[12]

9. As Beaudry, Green, and Sand note in their introduction: "In this maturity stage, having a college degree is only partly about obtaining access to high-paying managerial and technology jobs—it is also about beating out less educated workers for barista and clerical-type jobs."

10. Autor (2015) relabeled the nonroutine categories and collapsed the two routine categories into a single one. I maintain the original four-group categorization based on the cognitive/manual and routine/nonroutine distinctions due to the preponderance of college graduates in each of the cognitive categories.

11. The start year of 1983 was dictated by the availability of official BLS occupational employment data beginning in that year, and the change between 1999 and 2000 is omitted to eliminate the influence of a discontinuity in occupation category definitions.

12. The differential growth rates across the broad occupation categories have generated significant changes in their employment shares over time. Nonroutine cognitive jobs are the largest category: their share rose from about 30 percent to slightly over 40 percent of all jobs during the sample frame. The share of routine jobs declined from nearly 60 percent to about 45 percent. The share of nonroutine manual jobs rose from about 12 to about 15 percent, mostly since the year 2000.

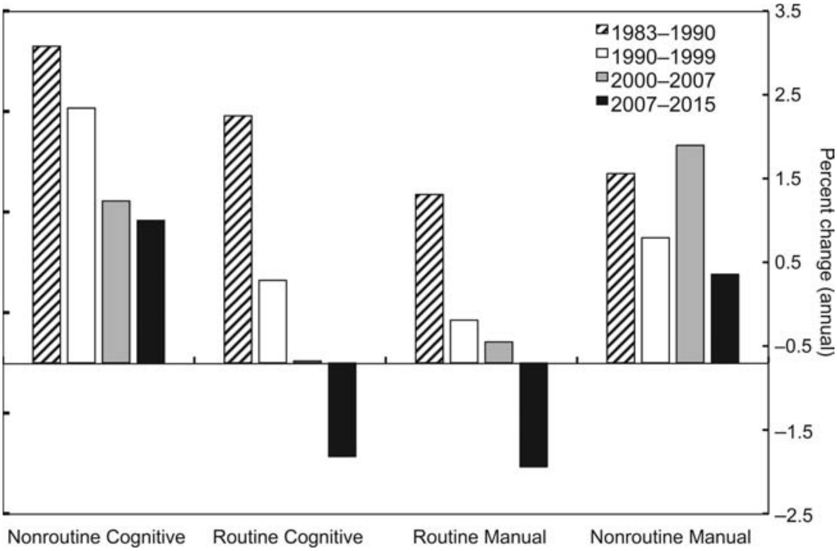

Fig. 9.5 Employment growth by broad occupation category, subperiods from 1983 to 2015

Notes: Author's calculations from Bureau of Labor Statistics data. See text and appendix table 9B.1 for occupation category definitions.

Polarization will differentially affect highly educated and less educated groups due to their very different occupational distributions. Figure 9.6 shows the shares of the college-only and graduate-degree groups in the nonroutine cognitive (panel A) and routine cognitive (panel B) categories. Workers with at least a college degree account for a large and rising share of nonroutine cognitive jobs, reaching nearly 70 percent by 2014 (panel A). Underlying this pattern is a significant rise in the share of nonroutine cognitive jobs held by individuals possessing a graduate degree, with little change in the share from the college-only group. This pattern is consistent with rising demand for the most highly educated individuals in jobs that require extensive nonroutine cognitive skills. The college-only group share also has grown in the routine cognitive category (panel B), commensurate with their rising share of the overall workforce.

Figure 9.7 reverses the figure 9.6 calculations by displaying the share of nonroutine cognitive jobs within the college-only and graduate-degree groups. Among the college-only group, the fraction employed in nonroutine cognitive jobs declined between 2000 and 2015, from about 68 to 64 percent. By contrast, the share of graduate-degree holders employed in nonroutine cognitive jobs has been largely stable at about 90 percent in recent years, while their overall workforce share has grown.

These tabulations suggest that polarization may be an important factor underlying the rising relative return to postgraduate education. As discussed

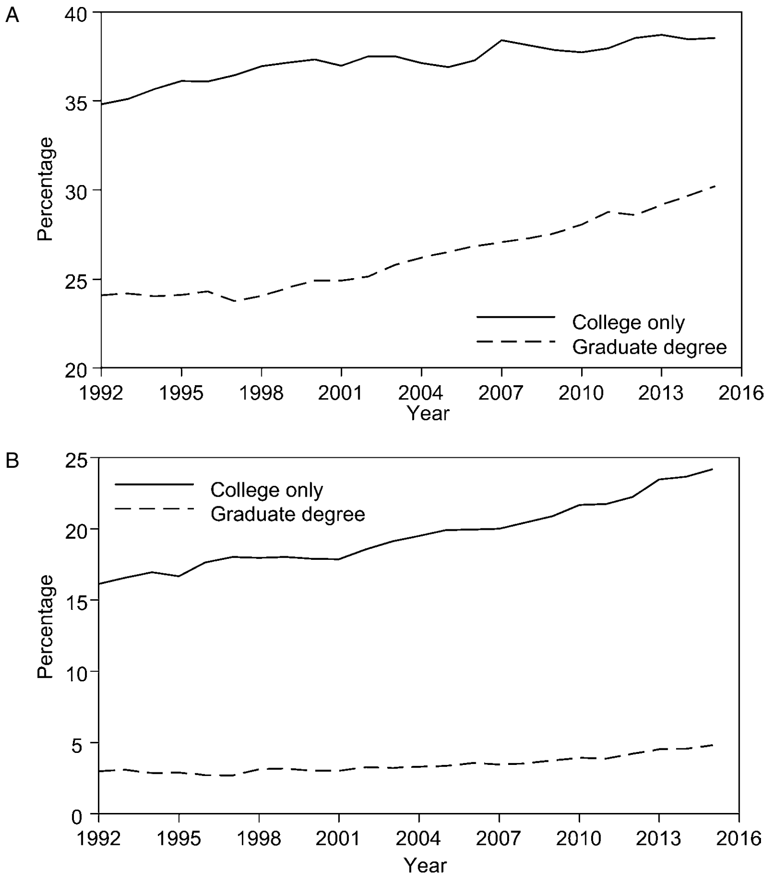

Fig. 9.6 Higher educational attainment shares by occupation category (selected), 1992–2015. ***A*****, nonroutine cognitive;** ***B*****, routine cognitive.**

Notes: Author's calculations using monthly CPS files. See text and appendix table 9B.1 for occupation category definitions. Series are shares of educational attainment groups in the broad occupation categories.

by Autor (2015), the wage impacts of polarization depend not only on skill/technology complementarity, but also on (a) the demand elasticity for products and services that rely heavily on the different skill/task groups, and (b) labor supply elasticities for the different skill/task groups. In regard to nonroutine cognitive jobs, both factors imply that workers in these jobs are likely to see their wages rise in response to rising reliance on computer and automation technologies (assuming that their skills are complementary with computers). Demand for their output is relatively elastic, and an inelastic supply response due to the time required for acquiring additional education implies that the supply of such workers does not respond quickly to rising

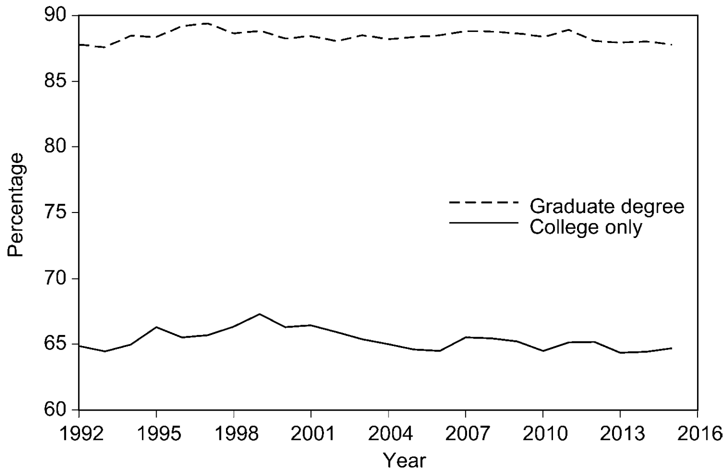

Fig. 9.7 Share of nonroutine cognitive employment by educational attainment, 1992–2015

Notes: Author's calculations using monthly CPS files. See text and appendix table 9B.1 for occupation category definitions. Series are nonroutine cognitive jobs as a share of employment within each educational attainment group.

demand. As such, ongoing polarization should put upward pressures on the relative wages of individuals employed in nonroutine cognitive jobs, most of whom have college or graduate degrees.[13]

As discussed above, the Beaudry, Green, and Sand "skill downgrading" alternative takes polarization as its starting point, but emphasizes a more general decline in demand for cognitive skills, which may affect all educational attainment groups. Beaudry, Green, and Sand present evidence to support the claim that the demand for cognitive and technological skills in the US labor market has weakened since the year 2000. They focus on broad patterns in employment across occupational and educational attainment groups, distinguishing between jobs that are intensive in cognitive versus routine or manual skills. The patterns in employment growth that they document are consistent with a reversal in the demand for cognitive skills, notably a slowdown in the relative rate of employment growth for occupations that are toward the top end of the wage distribution. They also use a more detailed identification scheme for cognitive-task-intensive jobs and confirm the shift out of such jobs by college graduates implied by my figure 9.7 (see their figure 10).

13. Based on these considerations, Autor (2014) notes that while polarization is likely to lower wages of workers in routine skill/task occupations, wages for workers in nonroutine manual jobs are likely to be relatively unaffected by polarization, despite the favorable polarization effects on employment for that group.

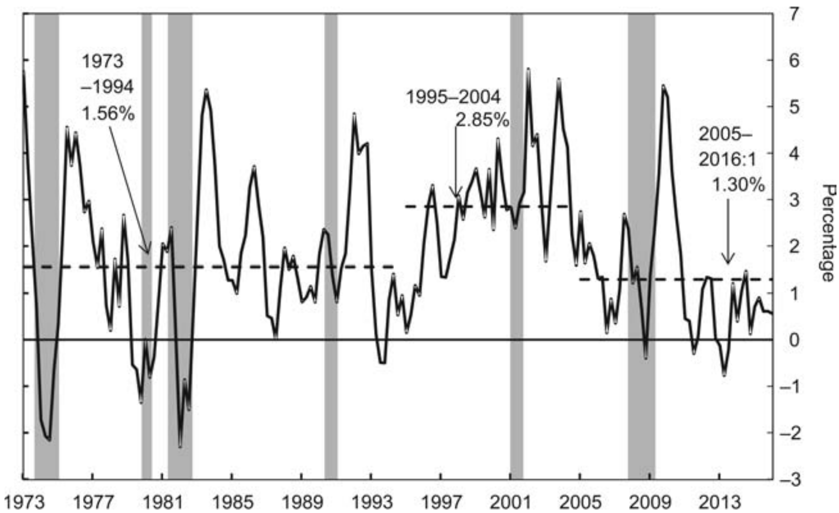

Fig. 9.8 US productivity growth, 1973–2016:Q1 (with period averages)

Notes: Author's calculations from US Bureau of Labor Statistics data. Series displayed is labor productivity in the nonfarm business sector, percentage change from four quarters earlier. Gray areas denote NBER recession dates.

One key element of the Beaudry, Green, and Sand framework and predictions is a pickup followed by a decline in technological advance, which generates the boom-bust cycle for cognitive employment and eventual skill downgrading in their model. This assumption is supported by patterns in US productivity growth in recent decades, depicted in figure 9.8.[14] The growth in output per worker measured by productivity gains generally reflects improvements in production technologies. Figure 9.8 shows a sharp productivity acceleration from 1995 to 2004, which corresponds roughly to the period of diffusion for new IT technologies that motivated the Beaudry, Green, and Sand model.[15] This was followed by an even more pronounced downshift in productivity growth. Productivity gains were especially slow from 2010 forward, the period during which the wage premium for higher education was flat or down (as discussed earlier in section 9.2). This correspondence suggests that the Beaudry, Green, and Sand narrative of a technology slowdown is relevant for understanding the recent pattern in the higher education wage premium.

Beaudry, Green, and Sand note that their model has limited implications for relative wages across skill groups. They also note, however, that a simple

14. I thank my colleague John Fernald for his advice with this display; see also Fernald (2015).

15. Beaudry, Green, and Sand focus on the year 2000 as a dividing line for the slowdown in demand for cognitive skills. However, it is likely that firms' ability to utilize new organizational capital associated with the IT revolution, and hence increase measured productivity, continued for a time after investment in that capital and corresponding rapid expansion of cognitive jobs largely came to an end.

parametrization of their model generates the slowdown in wage growth across the skill spectrum observed during the "bust" phase, consistent with the observed slowdown in real wages beginning in the year 2000 (see my table 9.1, panel A).[16] The skill-downgrading narrative also can explain the recent elevated level of "underemployment" of young college graduates, defined as the tendency for them to work in jobs that do not strictly require a college degree (see Abel and Deitz, chapter 4, this volume).

9.4 Wage Effects of Polarization and Skill Downgrading

The confluence of polarization and skill-downgrading influences on the labor market in recent years has been noted by others. Autor (2015), Lindley and Machin (2016), and Beaudry, Green, and Sand (2016) all provide a balanced, informed discussion and interpretation of labor market developments from 2000 forward and acknowledge the possibility that polarization and skill downgrading may both be playing a role. Each may have contributed to the flattening of the higher education wage premiums documented in section 9.2.

No sharp dividing lines between the two explanations are readily apparent. However, some insight can be gleaned by examining the wage premium patterns within and across the four broad occupation groups used in the polarization typology. The descriptive evidence presented in section 9.3.2 showed complex changes in the employment and wage patterns of highly educated individuals across the broad polarization occupation grouping in recent years. A within-between analysis is a relatively straightforward means for combining these changes into a single set of summary results.

This analysis begins with the same wage regressions as reported in section 9.2, but with separate regressions run for each of the four broad occupation groups from the polarization typology. Let γ represent a higher education wage premium (college or more, college only, or graduate degree) estimated for a specific year based on equation (1) and reported in table 9.2. The overall premium estimate can be decomposed as follows:

$$(4) \qquad \gamma = (\text{within effect}) + (\text{between effect})$$

$$= \sum_{j=1}^{4} w_j * \gamma_j + (\text{between effect})$$

where j subscripts the four broad occupation groups in the polarization typology, the γ_j's are occupation-specific estimates of the higher education premium, and the weights w_j are set equal to the share of each occupation group in total employment.

The within component in equation (4) is defined as the employment-

16. The slowdown in real wage growth for all educational groups displayed in table 9.1 is maintained when the data are adjusted for the same individual characteristics as used for the regression analyses in tables 9.2 and 9.3 (using a reweighting methodology).

weighted sum of the estimated occupation-specific wage premiums. It represents the higher education wage premium conditional on occupational skill/task group. It can be interpreted as the competitive advantage enjoyed by individuals with higher educational attainment when competing directly with less educated individuals for similar jobs (within the broad polarization occupation groupings). As such, a decline in the within component likely reflects a Beaudry, Green, and Sand skill-downgrading effect, which causes enhanced competition across educational groups for similar jobs. The between component is obtained as the difference between the total estimate and the within component.[17] It does not have a precise interpretation in the context of the polarization and skill-downgrading narratives: a relative increase in the shares of college-educated workers in routine jobs could reflect ongoing polarization in the distribution of jobs or the process of skill downgrading. However, it is informative nonetheless to assess whether the changes in the wage premium are associated with shifts in the occupational distribution of employment by education group.

I conduct this analysis by first estimating higher education wage premiums within each of the four broad polarization occupation groups, which provide the inputs into equation (4) above. The regressions are otherwise identical to those reported in table 9.2. Table 9.3 lists the regression results, focusing on the college-only premium (measured relative to high school graduates) and the graduate-degree premium (measured relative to the college-only group), with results for the same set of years as table 9.2 listed. The panel immediately below the regressions lists the decomposition of the "total" effect into "within" and "between" components.

The regression results in table 9.3 indicate that the higher education wage premiums are widely dispersed and their changes over time have been relatively consistent across the occupation groups. The exception is routine manual jobs, in which the higher education wage premium is relatively small for both education groups: the college-only premium is about half its size relative to the estimates for the other three groups, and the graduate premium is not statistically different from zero.

These patterns imply that increases in the total effect over the complete sample frame have been primarily driven by changes in the within component, with limited movement in the between component. This is confirmed by the decomposition results listed in table 9.3 for selected years and displayed in figure 9.9 for the complete sample frame. The within component, representing a competitive advantage to higher education within broad occupation groups, accounts for virtually all of the increase in the higher education wage premiums over time. However, the between component con-

17. Note that the total effect corresponds to the full-sample estimates from table 9.2. For example, the first total effect listed in column (1) of table 9.3, 0.270, corresponds to the college-only estimate from column (1) of panel A in table 9.2.

Table 9.3 **Within-between analysis of higher education wage premiums (CPS MORG data, regressions by broad occupation groups)**

	1980 (1)	1990 (2)	1992 (3)	2000 (4)	2010 (5)	2015 (6)
College only versus high school degree (full sample)						
Regressions						
Nonroutine cognitive	0.215	0.303	0.305	0.350	0.378	0.392
	(.007)	(.007)	(.007)	(.009)	(.009)	(.011)
Routine cognitive	0.134	0.255	0.265	0.309	0.346	0.327
	(.007)	(.007)	(.007)	(.009)	(.009)	(.010)
Routine manual	0.056	0.142	0.134	0.131	0.163	0.160
	(.010)	(.011)	(.011)	(.014)	(.014)	(.014)
Nonroutine manual	0.166	0.246	0.256	0.286	0.297	0.325
	(.014)	(.014)	(.014)	(.017)	(.013)	(.014)
Decomposition						
Within component share of total	0.135	0.237	0.241	0.278	0.314	0.322
	0.501	0.590	0.598	0.616	0.662	0.674
Between component share of total	0.135	0.165	0.162	0.173	0.160	0.155
	0.499	0.410	0.402	0.384	0.338	0.326
Total	0.270	0.402	0.403	0.451	0.475	0.477
Graduate degree (college degree or higher sample)						
Regressions						
Nonroutine cognitive	0.068	0.096	0.109	0.128	0.170	0.154
	(.006)	(.006)	(.006)	(.007)	(.007)	(.007)
Routine cognitive	0.101	0.085	0.112	0.157	0.147	0.135
	(.021)	(.018)	(.018)	(.025)	(.022)	(.022)
Routine manual	0.034	0.032	0.033	0.072	0.041	0.017
	(.031)	(.033)	(.037)	(.040)	(.042)	(.042)
Nonroutine manual	−0.032	−0.008	0.015	0.151	0.194	0.130
	(.048)	(.046)	(.044)	(.050)	(.035)	(.036)
Decomposition						
Within component share of total	0.068	0.087	0.103	0.131	0.163	0.144
	0.612	0.587	0.605	0.674	0.667	0.637
Between component share of total	0.043	0.061	0.067	0.063	0.081	0.082
	0.388	0.413	0.395	0.326	0.333	0.363
Total	0.111	0.149	0.170	0.194	0.245	0.226

Notes: See note to table 9.2 for basic data and specifications. Coefficients listed with standard errors in parentheses; regressions run separately for each of the broad occupation groups listed, by year. See the text for a description of the decomposition.

tributed to a slight increase in the wage premiums for both higher education groups up to the year 2000, indicating an ongoing shift toward higher-paid cognitive jobs for college-educated workers.

Our primary goal is to understand and interpret the changes in the within and between components since the year 2000. For the college-only group, the within component continued to grow after the year 2000 at

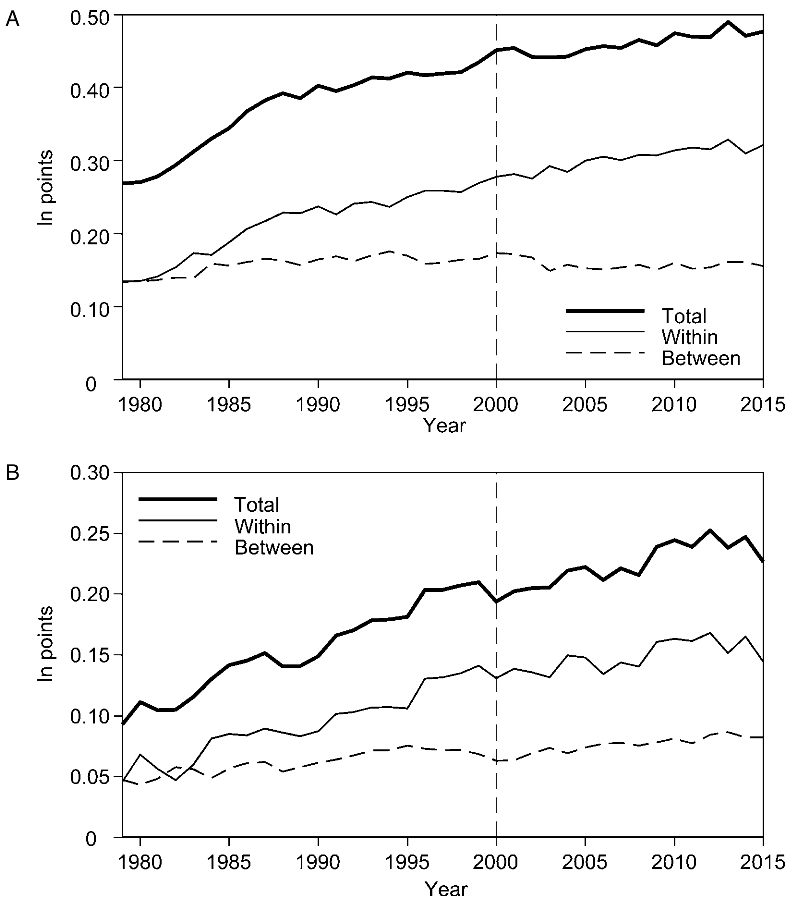

Fig. 9.9 Total and within/between wage premiums, 1979–2015. *A*, college only (relative to high school graduates); *B*, graduate degree (relative to college graduates).

Notes: See text and table 9.3 for data and methods. Based on broad polarization occupation grouping (nonroutine cognitive, routine cognitive, routine manual, nonroutine manual).

nearly the same rate as in the 1990s, rising by about 3.5 log points through 2010 and another 1.0 points through 2015. However, this was offset by a decline in the between component of about 2 log points from 2000 through 2015. This suggests that despite the increase in the college-only group's competitive advantage over lesser educated individuals within broad occupation groups, their overall wage advantage has been eroded slightly by a shift toward routine jobs. This is consistent with polarization or skill downgrading.

For the graduate-degree group, the between effect did not decline after 2000, indicating that their occupational distribution has not shifted away from highly paid cognitive jobs. However, between 2010 and 2015, the wage gap between graduate-degree holders and the college-only group within the same broad occupations fell by about 2 log points, suggesting that the direct competitive edge afforded by graduate training may be eroding. This erosion of the within effect for the graduate group suggests that skill downgrading may be playing an increasingly important role at the top of the skill distribution.

These results are robust to alternative definitions for the four broad occupations groups, including reorganization of the routine and nonroutine manual categories and separate treatment of selected services industries.[18] I also investigated alternative decompositions based on industry rather than occupation categories. These analyses indicated that the level and changes in higher education wage premiums are almost entirely determined within industries, with virtually no contribution coming from differences or changes over time in the wage premium and higher education shares across industries.

Overall, the results suggest rising competition between education groups for increasingly scarce well-paid jobs. Some of this is reflected in the movement of individuals holding only a college degree into routine jobs, consistent with polarization or skill downgrading, and some is reflected in the wage advantage of those with graduate degrees over the college-only group within broad occupations, suggesting skill downgrading.

9.5 Discussion and Conclusions

I have documented a flattening in the US higher education wage premium over the last few decades. In particular, after rising substantially in the 1980s, growth in the wage gap between individuals with a four-year college or graduate degree and those with a high school degree slowed progressively. The gaps have changed little since the year 2000, and they were flat to down during the period 2010–2015. These patterns suggest that the previously growing complementarity between highly educated labor and new production technologies, especially those that rely on computers and related organizational capital, may be leveling off.

I investigated these patterns with reference to two related explanations for changing US employment patterns: (a) a shift away from medium-skill occupations driven largely by technological change (“polarization”; e.g., Acemoglu and Autor 2011), and (b) a general weakening in the demand for advanced cognitive skills that cascades down the skill distribution (“skill downgrading”; Beaudry, Green, and Sand 2016). Descriptive evidence and comparison of the higher education wage premiums within and between

18. I thank my discussant David Autor for emphasizing the importance of investigating alternative occupational groupings, based on his recent research (e.g., Autor and Dorn 2013).

broad occupation groups suggests that both factors have played a role in the flattening of the overall premiums. Occupational employment shifts have held down the college-only premium somewhat since the year 2000, suggesting that college-educated workers are increasingly sliding down into routine jobs. This is consistent with polarization or skill downgrading. More recently, since 2010, the wage gap between graduate-degree holders and the college-only group within the same broad occupations has declined somewhat, suggesting that graduate training may be providing less of a competitive edge than it has in the past. This suggests that skill downgrading may be playing an increasingly important role at the top of the skill distribution. Overall, the results suggest rising competition between education groups for increasingly scarce well-paid jobs.

These findings should not be interpreted as suggesting that college and graduate training are no longer sound financial investments, from an individual or social perspective. Recent analyses indicate that relative to financing costs, higher education yields positive net returns for most individuals who complete college (Abel and Deitz 2014; Autor 2014; Daly and Cao 2015). On the other hand, it is important to note that the wage premiums to higher education are likely to vary substantially across individuals. Although higher education may be financially advantageous on average, the flattening of returns as costs have continued to rise suggests that college may be an unfavorable financial investment for rising numbers of individuals. In these circumstances, individual variation in returns looms as an increasingly important issue for future research.

I have focused on demand-side factors propelling the relative wages of college graduates, but supply-side factors may be important as well (Acemoglu and Autor 2011; Autor 2014). Sorting out the relative contributions of a demand slowdown and supply speed-up may be a worthwhile endeavor for future research. Related to overall supply trends, the composition of the college-educated workforce may have shifted in important ways. Enrollment at for-profit colleges has expanded rapidly since the year 2000, and subsequent wage increases appear limited, even for those who complete four-year undergraduate and graduate degrees at for-profit institutions (Cellini and Turner 2016). This may be holding down the returns to college estimated from the population of employed college graduates.

With these caveats in mind, I will conclude by noting that my findings raise the possibility of an eroding relationship between technological advance and the returns to investment in higher education. If this interpretation proves to be correct and durable, it has potentially important implications for this volume's primary themes. Human capital has been a key engine of growth in developing and advanced economies alike. Slower growth in the returns to higher education suggest that this connection may be fraying, raising the possibility of continued slow growth ahead.

Appendix A
MORG and March CPS Data

The data handling and definitions for the CPS MORG and March data generally follow Lemieux (2006a, 2010) and Autor, Katz, and Kearney (2008; see also Buchmueller, DiNardo, and Valletta 2011). All analyses are limited to wage and salary workers age twenty-five to sixty-four (with farming and resource occupations excluded), and appropriate survey weights are used for all tabulated results.

MORG Data (Definitions, Top-Coding, and Imputation)

As noted in the text, I use hourly wages as my earnings measure, either reported directly by hourly workers or formed as usual weekly earnings divided by usual weekly hours worked for salaried workers. Wage levels are expressed in real terms using the GDP deflator for personal consumption expenditures.

Following Lemieux (2006a), the wage analyses are limited to individuals whose hourly wage is greater than $1 and less than $100 (in 1979 dollars); only a small number of observations are dropped due to this restriction. Recorded earnings are subject to maximum limits ("top-codes") in the public-use data files, which change over time. I multiplied the value of top-coded earnings observations by 1.4. This largely follows Lemieux (2006a), with the exception that for the sake of consistency over time, I did not rely on the higher top-code enabled by the use of unedited earnings values for the years 1989–1993.

As noted in past research, nonresponse to the earnings and hours questions in the CPS data and the consequent need to impute their values is substantial and has grown over time, potentially distorting analyses of wage differentials. Following common practice, I dropped observations with imputed values of earnings or hours worked from all wage analyses. I followed the procedures outlined in Lemieux (2006a) for identifying imputed earnings observations. This includes the comparison of unedited and edited earnings values during the years 1989–1993, when the earnings imputation flags are incorrect. Imputation flags are missing for 1994 and most of 1995, which precludes dropping observations with imputed values during this period.

CPS March Annual Demographic Supplement Data (Definitions, Top-Coding, and Imputation)

I supplement the CPS MORG analyses using data from the CPS March Annual Demographic Supplement files. These files are currently available through 2015. Income data from the annual March supplement refer to the prior calendar year, so the reference period for the March data that I use ends one year earlier than the MORG data (2014 rather than 2015).

As noted in the text, following standard practice, I restrict the March CPS sample to full-time, full-year workers and use weekly earnings (annual labor earnings divided by weeks worked) as the earnings measure. The sample restriction with respect to real hourly wages (in 1979 dollars), the treatment of top-coded values, and the elimination of imputed earnings values are the same as described for the MORG data.

Appendix B

Polarization Occupational Coding (Excluding Agriculture/Resources)

Table 9B.1 Polarization occupational coding

Broad polarization category	Standard Occupational Classification (SOC) major occupation groupings
Nonroutine cognitive	Management, business, and financial operations (SOC 11, 13) Professional/technical (SOC 15–29)
Routine cognitive	Sales and related (SOC 41) Office and administrative support (SOC 34)
Routine manual	Construction and extraction (SOC 47) Installation/maintenance/repair (SOC 49) Production (SOC 51) Transportation and material moving (SOC 53)
Nonroutine manual	Health care support (SOC 31) Protective services (SOC 33) Food preparation and serving (SOC 35) Building and grounds (SOC 37) Personal care and service (SOC 39)

Note: 2010 SOC codes listed; earlier period codes harmonized.

References

Abel, Jaison R., and Richard Deitz. 2014. "Do the Benefits of College Still Outweigh the Costs?" Federal Reserve Bank of New York *Current Issues in Economics and Finance* 20 (3). https://www.newyorkfed.org/medialibrary/media/research/current_issues/ci20-3.pdf.

Acemoglu, Daron, and David Autor. 2011. "Skills, Tasks and Technologies: Implications for Employment and Earnings." In *Handbook of Labor Economics*, vol. 4b, edited by Orley Ashenfelter and David Card, 1043–171. Amsterdam: Elsevier-North Holland.

Autor, David H. 2014. "Skills, Education, and the Rise of Earnings Inequality among the 'Other 99 Percent.'" *Science* 344 (6186): 843–51.

———. 2015. "Polanyi's Paradox and the Shape of Employment Growth." Federal Reserve Bank of St. Louis: Economic Policy Proceedings, *Reevaluating Labor Market Dynamics*, 129–77. http://economics.mit.edu/files/9835.

Autor, David H., and David Dorn. 2013. "The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market." *American Economic Review* 103 (5): 1553–97.

Autor, David H., David Dorn, and Gordon H. Hanson. 2013. "The China Syndrome: Local Labor Market Effects of Import Competition in the United States." *American Economic Review* 103 (6): 2121–68.

Autor, David H., Lawrence F. Katz, and Melissa S. Kearney. 2008. "Trends in U.S. Wage Inequality: Revising the Revisionists." *Review of Economics and Statistics* 90 (2): 300–323.

Autor, David H., Lawrence F. Katz, and Alan B. Krueger. 1998. "Computing Inequality: Have Computers Changed the Labor Market?" *Quarterly Journal of Economics* 113 (4): 1169–214.

Autor, David H., Frank Levy, and Richard J. Murnane. 2003. "The Skill Content of Recent Technological Change: An Empirical Exploration." *Quarterly Journal of Economics* 118 (4): 1279–333.

Beaudry, Paul, David A. Green, and Benjamin M. Sand. 2014. "The Declining Fortunes of the Young Since 2000." *American Economic Review* 104 (5): 381–86.

———. 2016. "The Great Reversal in the Demand for Skill and Cognitive Tasks." *Journal of Labor Economics* 34 (S1, pt. 2): S199–247.

Bound, John, and George Johnson. 1992. "Changes in the Structure of Wages in the 1980s: An Evaluation of Alternative Explanations." *American Economic Review* 83:371–92.

Buchmueller, Thomas C., John DiNardo, and Robert G. Valletta. 2011. "The Effect of an Employer Health Insurance Mandate on Health Insurance Coverage and the Demand for Labor: Evidence from Hawaii." *American Economic Journal: Economic Policy* 3:25–51.

Card, David. 1999. "The Causal Effect of Education on Earnings." In *Handbook of Labor Economics*, vol. 3, edited by Orley Ashenfelter and David Card. Amsterdam: Elsevier.

Cellini, Stephanie Riegg, and Nicholas Turner. 2016. "Gainfully Employed? Assessing the Employment and Earnings of For-Profit College Students Using Administrative Data." NBER Working Paper no. 22287, Cambridge, MA.

Daly, Mary C., and Yifan Cao. 2015. "Does College Pay?" In *Does College Matter?* Federal Reserve Bank of San Francisco 2014 Annual Report. http://sffed-education.org/annualreport2014/#college-essays/does-college-pay.

Fernald, John. 2015. "Productivity and Potential Output before, during, and after the Great Recession." *NBER Macroeconomics Annual 2014*, vol. 29, edited by Jonathan Parker and Michael Woodford, 1–51. Chicago: University of Chicago Press.

Goldin, Claudia, and Lawrence F. Katz. 2008. *The Race between Education and Technology*. Cambridge, MA: Harvard University Press.

Goos, Maarten, and Alan Manning. 2007. "Lousy and Lovely Jobs: The Rising Polarization of Work in Britain." *Review of Economics and Statistics* 89 (1): 118–33.

Goos, Maarten, Alan Manning, and Anna Salomons. 2014. "Explaining Job Polarization: Routine-Biased Technological Change and Offshoring." *American Economic Review* 104 (8): 2509–26.

Jaeger, David. 1997. "Reconciling the Old and New Census Bureau Education Questions: Recommendations for Researchers." *Journal of Business and Economic Statistics* 15 (3): 300–309.

Krueger, Alan. 1993. "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989." *Quarterly Journal of Economics* 108 (1): 33–60.

Lemieux, Thomas. 2006a. "Increasing Residual Wage Inequality: Composition Effects, Noisy Data, or Rising Demand for Skill?" *American Economic Review* 96 (3): 461–98.

———. 2006b. "Postsecondary Education and Increasing Wage Inequality." *American Economic Review* 96 (2): 195–99.

———. 2010. "What Do We Really Know About Changes in Wage Inequality?" In *Labor in the New Economy*, edited by Katharine G. Abraham, James R. Spletzer, and Michael Harper. Chicago: University of Chicago Press.

Lindley, Joanne, and Stephen Machin. 2016. "The Rising Postgraduate Wage Premium." *Economica* 83:281–306.

Comment David Autor

Robert Valletta's chapter illuminates one of the leading puzzles for contemporary US labor economics: the unexpected "flattening" of the premium to higher education in the United States in the first decade of the twenty-first century. This single metric—the college/high school wage premium—has been the North Star guiding neoclassical analysis of the evolution of wage inequality during a period of rapidly shifting wage structures. Two impactful papers by Beaudry, Green, and Sand (2014, 2016,) argue that since approximately the year 2000, this North Star has become an increasingly dubious point of navigation. Specifically, Beaudry, Green, and Sand highlight the failure of the college premium to rise in the first decade of the twenty-first century following two decades of steep increases. They interpret this deceleration as reflecting the maturation of the information technology revolution, which in turn has spurred a slackening in the pace of workplace IT investments and a consequent slowdown in the trend of rising demand for highly educated labor. A key piece of evidence favoring Beaudry, Green, and Sand's narrative is the precipitous fall in US investment in information-processing equipment and software in the United States after 1999 (figure 9C.1), which seems to have precisely the right timing to explain a falloff in IT augmentation of skilled labor demand.

Valletta's careful analysis extends and probes the Beaudry, Green, and Sand findings, verifies their robustness, and considers their interpretation

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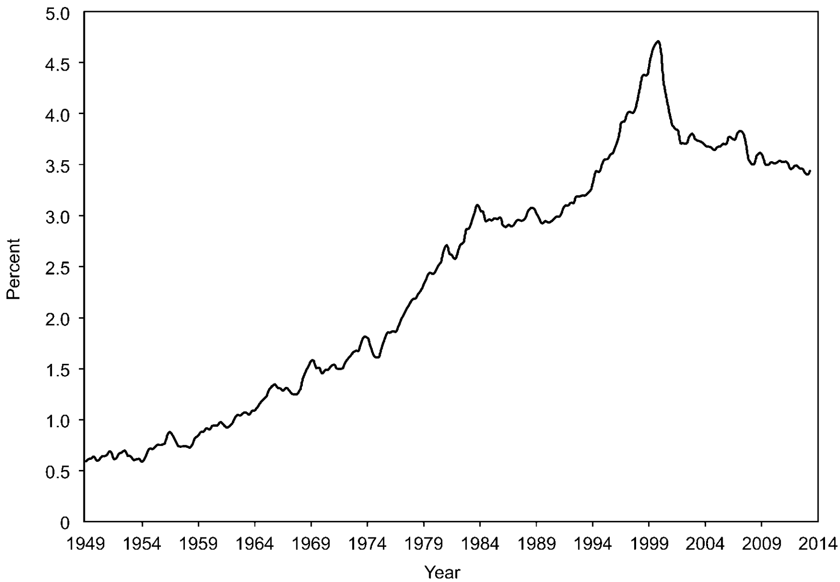

Fig. 9C.1 Private fixed investment in information-processing equipment and software as a percentage of gross domestic product, 1949–2014

Source: FRED, Federal Bank of St. Louis (http://research.stlouisfed.org/fred2/graph/?g=GXc; accessed 8/3/2014). This graphic originally appeared in Autor (2015).

in the light of both their conceptual framework and an alternative framing offered by Acemoglu and Autor (2011). There are many things to admire about Valletta's chapter: it is empirically rigorous, intellectually ecumenical, and commendably ambitious in synthesizing and adjudicating between two conceptual models that are not, to a first approximation, speaking the same language. My remarks focus exclusively on one question that is core to both Valletta's and Beaudry, Green, and Sand's work: When did rising demand for college-educated labor decelerate? I argue below that (a) the recent flattening of the skill premium in the first decade of the twenty-first century is *not* surprising in light of the canonical supply-demand model, and (b) what *is* surprising is that the underlying demand for college labor decelerated sharply and (to date) inexplicably almost a decade beforehand. These observations render the phenomenon that Valletta tackles no less consequential, but they may suggest a different set of explanations for the slowdown than those focusing on discontinuous changes in economic trends in the first decade of the twenty-first century.

Modeling School

Following an extraordinarily influential series of papers that includes Goldin and Margo (1992), Katz and Murphy (1992), Murphy and Welch

(1992), Card and Lemieux (2001), and Goldin and Katz's magisterial 2008 volume *The Race between Education and Technology*, labor economists have applied a remarkably simple and surprisingly powerful calibrated supply-demand model (the "canonical model") to rationalize the fluctuations over time in the skill premium and the accompanying evolution of wage inequality. This so-called canonical model takes its inspiration from the observation by Nobel Laureate Jan Tinbergen in 1974 that there appears to be an ongoing "race" between technology and schooling, with technological advancements progressively raising the demand for educated labor and the school system simultaneously secularly raising its supply. When technological advancement surges faster than educational production, the relative scarcity of educated labor rises, and the skill premium rises with it—that is, technology pulls ahead of education in this two-person race. Conversely, when educational production surges ahead of technologically induced demand shifts, the skill premium falls.

While many elements of this description seem far too simple (e.g., history provides many examples of technologies that replace rather than complement skills), this framework provides a surprisingly good high-level description of what we see in the data. The canonical model provides a benchmark for interpreting the evolution of the skill premium. I apply this model here to address the question of whether we should be surprised—and if so, how much—by the slowdown in the skill premium after 2000. Before applying the model, I review its rudiments, and I refer readers to Acemoglu and Autor (2011) for a fuller development.

The canonical model posits two skill groups, high and low. It draws no distinction between skills and occupations (tasks), so that high-skilled workers effectively work in separate occupations (perform different tasks) from low-skilled workers. In most empirical applications of the canonical model, it is natural to identify high-skilled workers with college graduates (or in different eras, with other high-education groups), and low-skilled workers with high school graduates (or in different eras, those with less than high school). Critical to the two-factor model is that high- and low-skilled workers are imperfect substitutes in production. The elasticity of substitution between these two skill types is central to understanding how changes in relative supplies affect skill premiums.

Suppose that the total supply of low-skilled labor is L and the total supply of high-skilled labor is H. Naturally not all low- (or high-) skilled workers are alike in terms of their marketable skills. As a simple way of introducing this into the canonical model, suppose that each worker is endowed with either high or low skill, but there is a distribution across workers in terms of efficiency units of these skill types. In particular, let $\mathcal{L}$ denote the set of low-skilled workers and $\mathcal{H}$ denote the set of high-skilled workers. Each low-skilled worker $i \in \mathcal{L}$ has l_i efficiency units of low-skilled labor and each high-skilled worker $i \in \mathcal{H}$ has h_i units of high-skilled labor. All workers supply their efficiency units inelastically. Thus the total supply of high-skilled and low-skilled labor in the economy can be written as

$$L = \int_{i \in \mathcal{L}} l_i di \text{ and } H = \int_{i \in \mathcal{H}} h_i di.$$

The production function for the aggregate economy takes the following constant elasticity of substitution form

$$(1) \qquad Y = [(A_L L)^{(\sigma-1)/\sigma} + (A_H H)^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)},$$

where ($\sigma \in 0, \infty$) is the elasticity of substitution between high-skilled and low-skilled labor, and A_L and A_H are factor-augmenting technology terms.[1] The elasticity of substitution between high- and low-skilled workers plays a pivotal role in interpreting the effects of different types of technological changes in this canonical model. We refer to high- and low-skilled workers as *gross substitutes* when the elasticity of substitution $\sigma > 1$, and gross complements when $\sigma < 1$.

In this framework, technologies are *factor augmenting*, meaning that technological change serves to increase the productivity of either high- or low-skilled workers (or both). This implies that there are no explicitly skill-replacing technologies. Depending on the value of the elasticity of substitution, however, an increase in A_H or A_L can act either to complement or (effectively) substitute for high- or low-skilled workers (see below).

Assuming that the labor market is competitive, the low-skill unit wage is simply given by the value of the marginal product of low-skilled labor, which is obtained by differentiating equation (1) as

$$(2) \qquad w_L = \frac{\partial Y}{\partial L} = A_L^{(\sigma-1)/\sigma}[A_L^{(\sigma-1)/\sigma} + A_H^{(\sigma-1)/\sigma}(H/L)^{(\sigma-1)/\sigma}]^{1/(\sigma-1)}.$$

Similarly, the high-skill unit wage is

$$(3) \qquad w_H = \frac{\partial Y}{\partial H} = A_H^{(\sigma-1)/\sigma}[A_L^{(\sigma-1)/\sigma}(H/L)^{-[(\sigma-1)/\sigma]} + A_H^{(\sigma-1)/\sigma}]^{1/(\sigma-1)}.$$

Combining equations (2) and (3), the skill premium—the high-skill unit wage divided by the low-skill unit wage—is

$$(4) \qquad \omega = \frac{w_H}{w_L} = \left(\frac{A_H}{A_L}\right)^{(\sigma-1)/\sigma}\left(\frac{H}{L}\right)^{-(1/\sigma)}.$$

Equation (4) can be rewritten in a more convenient form by taking logs

$$(5) \qquad \ln \omega = \frac{\sigma - 1}{\sigma}\ln\left(\frac{A_H}{A_L}\right) - \frac{1}{\sigma}\ln\left(\frac{H}{L}\right).$$

1. This production function is typically written as $Y = [\gamma(A_L L)^{(\sigma-1)/\sigma} + (1-\gamma)(A_H H)^{(\sigma-1)/\sigma}]^{\sigma/(\sigma-1)}$, where A_L and A_H are factor-augmenting technology terms and γ is the distribution parameter. I suppress γ (i.e., set it equal to 1/2) to simplify notation.

The log skill premium, $\ln \omega$, has been a central object of study in the empirical literature on the changes in the earnings distribution. Equation (5) shows that there is a simple log-linear relationship between the skill premium and the relative supply of skills as measured by H/L. Equivalently, equation (5) implies

$$\frac{\partial \ln \omega}{\partial \ln H/L} = -\frac{1}{\sigma} < 0. \tag{6}$$

This relationship corresponds to the second of the two forces in Tinbergen's race (the first being technology, the second being the supply of skills): for a *given skill bias of technology*, captured here by A_H/A_L, an increase in the relative supply of skills reduces the skill premium with an elasticity of $1/\sigma$. Intuitively, when high- and low-skilled workers are producing the same good but performing different functions, an increase in the number of high-skilled workers will necessitate a substitution of high-skilled workers for the functions previously performed by low-skilled workers.[2] The downward-sloping relationship between relative supply and the skill premium implies that if technology, in particular A_H/A_L, had remained roughly constant over recent decades, the remarkable increase in the supply of skills (seen, e.g., in table 9.1 of Valletta's chapter) would have led to a significant decline in the skill premium. The lack of such a decline is a key reason why economists believe that the first force in Tinbergen's race—changes in technology increasing the demand for skills—must have also been important throughout the twentieth century (cf. Goldin and Katz 2008).

More formally, differentiating equation (5) with respect to A_H/A_L yields

$$\frac{\partial \ln \omega}{\partial \ln (A_H/A_L)} = \frac{\sigma - 1}{\sigma}. \tag{7}$$

Equation (7) implies that if $\sigma > 1$, then relative improvements in the high-skill-augmenting technology (i.e., in A_H/A_L) increase the skill premium. This can be seen as a shift out of the relative demand curve for skills. The converse is obtained when $\sigma < 1$: that is, when $\sigma < 1$, an improvement in the productivity of high-skilled workers, A_H, relative to the productivity of low-skilled workers, A_L, shifts the relative demand curve inward and reduces the skill premium. Nevertheless, the conventional wisdom is that the skill premium increases when high-skilled workers become relatively more—not relatively less—productive, which is consistent with $\sigma > 1$. Most estimates put σ in this

2. In this interpretation, we can think of some of the "tasks" previously performed by high-skilled workers now being performed by low-skilled workers. Nevertheless, this is simply an interpretation, since in this model there are no tasks and no endogenous assignment of tasks to workers. One could alternatively say that the H and L tasks are imperfect substitutes, and hence an increase in the relative supply of H labor means that the H task is used more intensively but less productively at the margin.

context to be somewhere between 1.4 and 2 (Johnson 1970; Freeman 1986; Heckman, Lochner, and Taber 1998).

The key equation of the canonical model links the skill premium to the relative supply of skills, H/L, and to the relative technology term, A_H/A_L. This last term is not directly observed. Nevertheless, the literature has made considerable empirical progress by taking a specific form of Tinbergen's hypothesis, and assuming that there is a log-linear increase in the demand for skills over time coming from technology, captured in the following equation:

$$\ln\left(\frac{A_{H,t}}{A_{L,t}}\right) = \gamma_0 + \gamma_1 t, \quad (8)$$

where t is calendar time and variables written with t subscripts refer to these variables at time t. Substituting this equation into equation (8), we obtain

$$\ln \omega_t = \frac{\sigma - 1}{\sigma}\gamma_0 + \frac{\sigma - 1}{\sigma}\gamma_1 t - \frac{1}{\sigma}\ln\left(\frac{H_t}{L_t}\right). \quad (9)$$

Equation (9) implies that "technological developments" take place at a constant rate, while the supply of skilled workers may grow at varying rates at different points in times. Therefore, changes in the skill premium will occur when the growth rate of the supply of skills differs from the pace of technological progress. In particular, when H/L grows faster than the rate of skill-biased technical change, $(\sigma - 1)\gamma_1$, the skill premium will fall. And when the supply growth falls short of this rate, the skill premium will increase. Surprisingly, this simple equation provides considerable explanatory power for the evolution of the skill premium—though its limitations are also immediately evident.

Doing the Katz-Murphy

Using data from Autor (2014), I fit this simple model to fifty years of US data for 1963–2012. Figure 9C.1 provides the key input into this estimation: the observed log relative supply of US college versus noncollege labor for years 1963–2012, measured in efficiency units and normalized to zero in the base year.[3] Figure 9C.2 highlights the steep rise in production of college-educated labor in the United States in the postwar period—specifically until the late 1970s—followed by a sharp deceleration after 1980. This deceleration is frequently interpreted as the key driver of the rapid rise in the skill premium after 1980 (Katz and Murphy 1992). Notably, there is also a steep *acceleration* of supply after 2004. All else equal, one would except this supply acceleration to depress the skill premium absent any slowdown of the secular

3. Extensive details on the calculation of these series are provided in Acemoglu and Autor (2011).

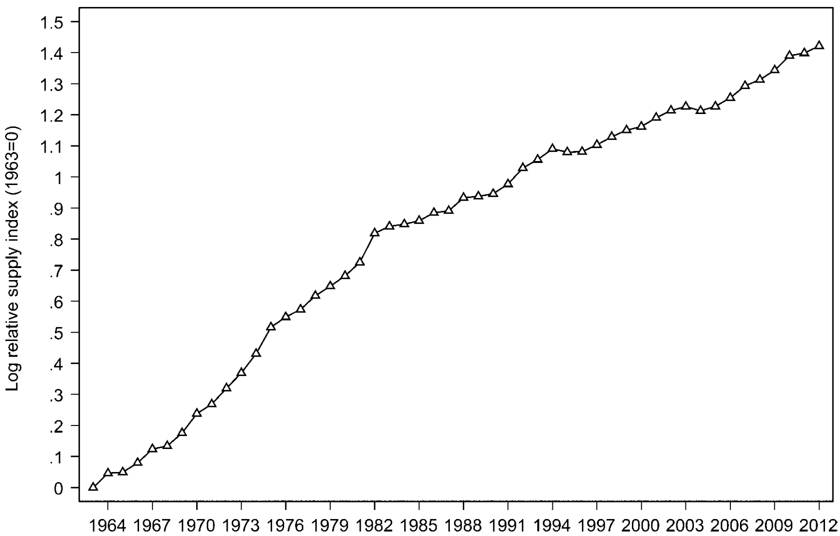

Fig. 9C.2 Efficiency units of college versus noncollege labor supply, 1963–2012
Source: Data from Autor (2014).

trend rise in relative demand after 2004. This observation highlights that the evolution of the skill premium is *not* a sufficient statistic for fluctuations in demand for skilled labor; one must also account for supply.

Using the data series in figure 9C.2, I fit equation (9) to obtain the following estimate:

$$\ln \omega_t = \text{constant} + \underset{(0.0013)}{.0151} \times t - \underset{(0.0429)}{0.302} \cdot \ln\left(\frac{H_t}{L_t}\right). \tag{10}$$

This simple ordinary least squares (OLS) model implies that (a) the relative demand curve for college versus noncollege labor is shifting outward by approximately 1.5 log points per year, and (b) that increases in the relative supply of skilled labor buffer the impact of shifting demand on wage inequality. Specifically, the point estimate of −0.30 on the relative supply term implies an elasticity of substitution of $\hat{\sigma} = 1/3.31$. While the explanatory power of this time-series model is high ($R^2 = 0.94$), the point estimate for the elasticity of substitution is more than *twice* as high as Katz-Murphy's 1992 estimate of 1.41. This implies that either the elasticity of substitution is changing over time or that the linear time trend is not doing an adequate job of capturing trends in relative demand.

Figure 9C.3 explores these possibilities. The series plotted with circular markers corresponds to the measured (i.e., observed) skill premium in each year. This series depicts the now familiar rise in the skill premium from the

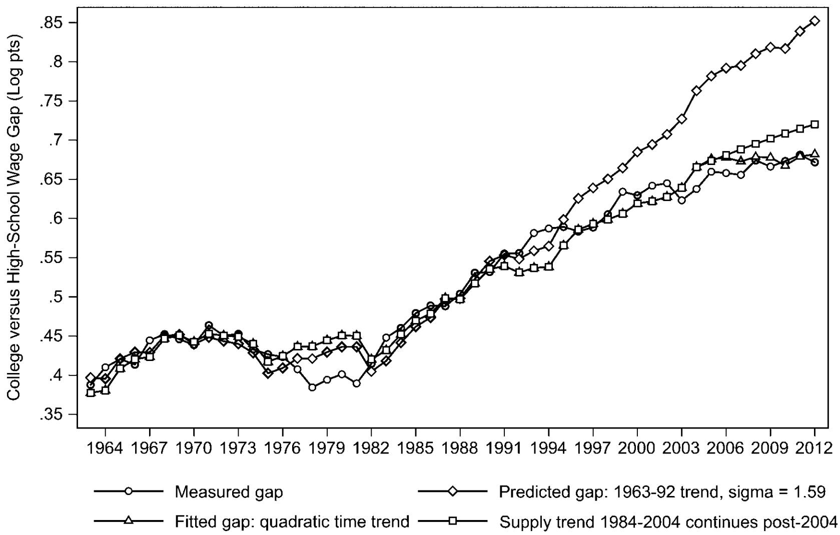

Fig. 9C.3 Observed, predicted, and fitted evolution of the log college/noncollege hourly earnings gap, 1963–2012

Source: Data from Autor (2014).

early 1960s (start of the series) to the early 1970s, the sharp fall between 1971 and 1981, the steep and continuous rise from 1982 to 1999, and then the much shallower rise from 2000 to 2012 (end of the series). The series with diamond markers performs a within-series extrapolation by reestimating equation (10) using only data from 1962 to 1992 (the period of best fit), and recovering estimates of the time trend and the elasticity of substitution ($\hat{\gamma} = 0.028$, $\hat{\sigma} = 1/{-0.631} = -1.59$). The plotted series then projects this estimate forward to 2012 using the estimated parameters from the 1962 to 1992 fit in combination with the *observed* evolution of aggregate skill supplies (ln H_t/L_t). Notably, the time trend and elasticity recovered from this procedure are extremely similar to those obtained by Katz-Murphy's in 1992, and using data for 1963 through 1987. The similarity of the current estimates implies that Katz-Murphy's within-sample point estimates continue to closely track the observed data for an additional five years *out of sample*.

As the figure reveals, however, this projection badly misses the mark after 1992. Adjusting for the evolution of aggregate skill supplies, the growth in the skill premium is far more modest after 1992 than the extrapolation projects. Between 1992 and 2012, the observed college/noncollege log earnings gap rises by 11.6 log points. But the projection based on data to 1992—applying the observed evolution of skill supplies to 2012—predicts an increase of 30.4 log points, nearly three times as large as what occurred. A summary judgment is that the evolution of the skill premium has been *surprising* since 1992.

The Element of Surprise

Economic literature noted this surprise some time ago. Card and DiNardo (2002) first pointed out this discrepancy in their broad critique of the skill-biased technical change literature. Autor, Katz, and Kearney (2008) proposed an ad hoc workaround, which was to allow for a trend deceleration in the evolution of skill demands after 1992. Goldin and Katz (2008) and Autor (2014) pursue a related approach by applying a quadratic time trend in the time-series model, thereby allowing a smooth deceleration of the trend demand shift. The series in figure 9C.3 labeled "Fitted gap: quadratic trend" (triangular marker) shows just how well this works. Conditional on the quadratic trend the fit is impressively close. But of course, this is simple reverse engineering. This flexibility was added to the model because the data demanded it, not because the theory suggested it.

These various exercises raise an urgent question: After accounting for fluctuations in the supply of skilled labor, when did the "flattening" of demand for skill commence? Here, I draw a distinction between flattening in the *skill premium* and flattening (or deceleration) in the movement of the underlying demand schedule. As noted above, it would be entirely possible for the skill premium to decline even as demand was accelerating—if skill supplies rose fast enough. Figure 9C.1 makes clear that skill supplies *accelerated* after 2004. Was this *supply-side* change an important contributor to the observed flattening of the skill premium?

The series plotted in square markers in figure 9C.3 addresses this question. The log relative supply of college workers (figure 9C.2) rose at an annual rate of 4.31 log points between 1963 and 1982, by 1.79 log points between 1982 and 2004, and by 2.61 log points between 2004 and 2012 (i.e., a 45 percent *increase* after 2004). The series with square markers in figure 9C.3 (labeled "Supply trend 1984–2004 continues post-2004") replaces the observed values of $\ln(H_t/L_t)$ with a counterfactual series in which log relative supply rises at the 1963–1982 of 1.79 log points per annum. Surprisingly (at least to me), this substitution makes a *substantial* difference for inference. The estimated college premium rose by only 1.65 log points between 2004 and 2012. This exercise implies that had the relative supply of college-educated labor *not* accelerated after 2004, the skill premium would have risen by 5.47 log points rather than a measly 1.65 log points. I submit based on this evidence that had there been no *supply acceleration* after 2004, Beaudry, Green, and Sand would have had a more difficult time making the argument that there was a *demand deceleration* in the first decade of the twenty-first century.

How Long Has This Been Going On?

The evidence in figure 9C.3 in no way obviates the claim that demand for college workers flattened according to the canonical model. It instead under-

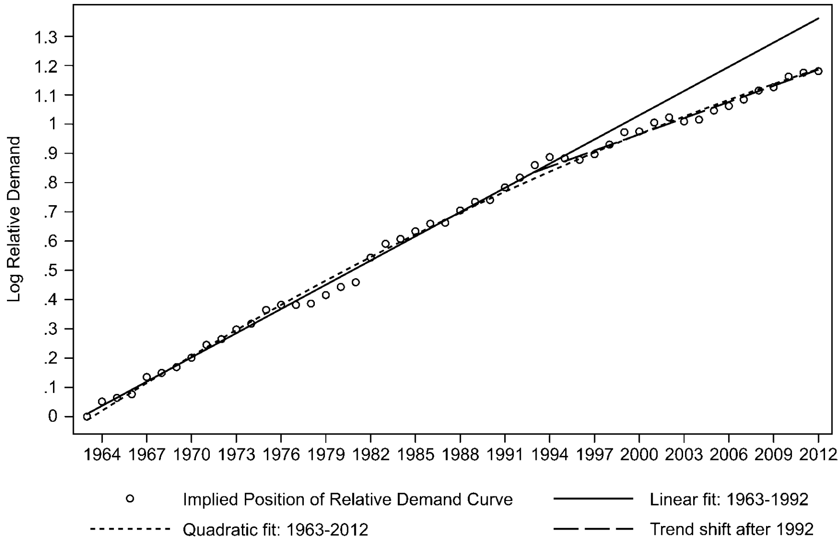

Fig. 9C.4 Implied evolution of the demand for college versus noncollege labor using σ = 1.59, 1963–2012

Source: Data from Autor (2014).

scores that the raw skill premium, not purged of the impact of supply forces, could generate misleading inferences about the trajectory of the demand for skilled labor.

To address this shortcoming, figure 9C.4 plots the implied log relative demand shift favoring college versus noncollege labor for 1962–2012, again using the estimated value of $\sigma = 1.59$ based on fitting equation (9) to data for 1962–1992. The plotted (scatter) points in figure 9C.4 are not regression estimates. They correspond instead to the calculated values of $\gamma_t = \omega_t - (1/\hat{\sigma})\ln(H_t/L_t)$ in each year, where we treat σ as known.[4] To guide interpretation of these data points, the figure also contains three regression lines. The solid line depicts a pure linear extrapolation, fitted and projected using data for 1962–1992. This corresponds to the implied path of relative demand from 1992 through 2012 had there been no deviation after 1992. The short-dashed series is the quadratic fit to this set of scatter points. The long-dashed series is a linear spline that allows for a discrete slope shift in 1992 (and otherwise fully overlays the initial trend from 1963 to 1992).

This plot highlights three key patterns. A first is that the trajectory of (implied) relative demand for educated labor is astonishingly linear for the initial thirty years of the series, 1963–1992. This linearity is in no sense

4. Equivalently, they are the time dummies from a saturated regression (no error term) of $\omega_t - (1/\hat{\sigma})\ln(H_t/L_t)$ on a full set of year indicators.

mechanical: the relative demand shift estimates plotted in figure 9C.4 are extracted from a college wage premium series that fluctuates dramatically over three decades, rising for the first ten years of the time interval, falling for the next nine, and then increasing with remarkable rapidity thereafter. The linearity of the (implied) underlying demand trend therefore reflects the uncanny success of the relative supply term $\ln H_t/L_t$ in explaining the fluctuations in the premium, leaving little behind but a smooth secular underlying demand shift favoring college-educated labor.

The second pattern immediately visible in figure 9C.4 is that the steady secular demand shift favoring college-educated labor *decelerates* after 1992, and does so abruptly. Estimates of equation (9), fit using a linear spline (long-dashed series), imply that the relative demand for college labor rose by 2.80 log points per year between 1963 and 1992 and then *decelerated* to 1.84 points thereafter (a fall of one-third). This pattern, while occasionally noted in the literature (cf. Acemoglu and Autor 2011), has not been rigorously explained by any formal model—though of course there are many informal explanations.

The third takeaway from figure 9C.4 is that it is hard to see any evidence of a discontinuous deceleration in the demand for educated labor in the first decade of the twenty-first century. Whether fit using the linear spline, allowing all the post-1992 points to cluster along one axis, or a quadratic trend, allowing the deceleration to cumulate over the full sample, there is almost nothing in this figure that suggests a trend break in demand in the first decade of the twenty-first century.[5] Rather, this evidence suggests that the trend movements in relative demand early in the twenty-first century were a continuation of those commencing circa 1992.

Conclusion: Timing Is Everything

These fact patterns lead me to draw a distinct inference from Beaudry, Green, and Sand: we *should not* be surprised by the evolution of the skill premium—or even the weaker job prospects of college-educated workers—in the early twenty-first century. These outcomes are consistent with steadily rising demand for college-educated labor and a surprising surge in new college entrants in the US labor market after 2003, which depressed the skill premium as it would be predicted to do. We *should* however be deeply puzzled by the sudden trend shift in demand after 1992, which ushered in (at least) twenty years of slower (though still nonnegligible) growth in demand for skilled labor.

5. If one squints, it is possible to see that some of the points immediately after 2000 fall slightly below the regression line, whereas those immediately before fall slightly above it—implying a possible further deceleration after 2000. But then the last three points in the series (2010–2012) again lie slightly above the regression line, suggesting a tiny reacceleration. This is pretty thin evidence.

This development is not altogether bad news, however. Had demand for skilled labor continued to rise after 1992 at its pre-1992 pace, the estimates in figure 9C.3 suggest that the United States would have seen *substantially* more growth of between-group inequality—specifically, a meteoric 30 log point rise in the college premium between 1992 and 2012, nearly three times as large as the economically significant rise of 11 log points that actually occurred. This "good news" is at best partial, however. In the canonical model, relative demand shifts intrinsically convey good economic news because they imply ongoing factor-augmenting technological progress.[6] Thus, this slowdown may be read to support Beaudry, Green, and Sand's view that as information technology has matured, the pace of accompanying labor augmentation has slackened. If so, however, we would want to caveat their conclusion to note that this slowdown started about ten years prior to the date that Beaudry, Green, and Sands pinpoint, and that it occurred during a period in which aggregate productivity growth was robust and US IT investment was rising extraordinarily rapidly (figure 9C.1).

References

Acemoglu, Daron, and David H. Autor. 2011. "Skills, Tasks and Technologies: Implications for Employment and Earnings." *Handbook of Labor Economics* 4:1043–171.

Autor, David H. 2014. "Skills, Education, and the Rise of Earnings Inequality among the 'Other 99 Percent.'" *Science* 344 (6186): 843–51.

———. 2015. "Why Are There Still So Many Jobs? The History and Future of Workplace Automation." *Journal of Economic Perspectives* 29 (3): 3–30.

Autor, David H., Lawrence F. Katz, and Melissa S. Kearney. 2008. "Trends in U.S. Wage Inequality: Revising the Revisionists." *Review of Economics and Statistics* 90 (2): 300–323.

Beaudry, Paul, David A. Green, and Benjamin M. Sand. 2014. "The Declining Fortunes of the Young Since 2000." *American Economic Review* 104 (5): 381–86.

———. 2016. "The Great Reversal in the Demand for Skill and Cognitive Tasks." *Journal of Labor Economics* 34 (S1, pt. 2): S199–247.

Card, David, and John E. DiNardo. 2002. "Skill-Biased Technological Change and Rising Wage Inequality: Some Problems and Puzzles." *Journal of Labor Economics* 20 (4): 733–83.

Card, David, and Thomas Lemieux. 2001. "Can Falling Supply Explain the Rising Return to College for Younger Men? A Cohort-Based Analysis." *Quarterly Journal of Economics* 116 (2): 705–46.

Freeman, Richard B. 1986. "Chapter 6 Demand for Education." *Handbook of Labor Economics* 1:357–86.

Goldin, Claudia, and Lawrence F. Katz. 2008. *The Race between Education and Technology*. Cambridge, MA: Harvard University Press.

Goldin, Claudia, and Robert A. Margo. 1992. "The Great Compression: The Wage

6. This is also true for technological progress that raises A_L or both A_H and A_L. Presuming as the model does that technological progress is always factor augmenting—there are no factor-retarding technological regresses—any movement of A_H or A_L must correspond to an *increase* of either or both terms and hence rising productivity.

Structure in the United States at Mid-Century." *Quarterly Journal of Economics* 107 (1): 1–34.

Heckman, James J., Lance Lochner, and Christopher Taber. 1998. "Explaining Rising Wage Inequality: Explorations with a Dynamic General Equilibrium Model of Labor Earnings with Heterogeneous Agents." *Review of Economic Dynamics* 1 (1): 1–58.

Johnson, George E. 1970. "The Demand for Labor by Educational Category." *Southern Economic Journal* 37 (2): 190–204.

Katz, Lawrence F., and Kevin M. Murphy. 1992. "Changes in Relative Wages, 1963–1987: Supply and Demand Factors." *Quarterly Journal of Economics* 107 (1): 35–78.

Murphy, Kevin M., and Finis Welch. 1992. "The Structure of Wages." *Quarterly Journal of Economics Structure* 107 (1): 285–326.

Tinbergen, Jan. 1974. "Substitution of Graduate Labor by Other." *Kyklos* 27 (2): 217–26.

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