Graduate Labor Economics

Notes to Accompany Lecture 4: Skill-Biased Technical Change

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The rapid rise of the college wage premium—coinciding as it has with a rising relative supply of college-educated workers—suggests an increase in the relative demand for more-educated or more-"skilled" workers (Katz and Murphy, 1992). Many observers have attributed these demand shifts to *skill-biased technical change* (SBTC): technological improvements that complement more-educated workers relative to those with lower levels of education.

In this lecture we'll discuss some of the evidence for the SBTC hypothesis. My notes here will focus on a classic paper by Berman et al. (1994), which I'll also use as a springboard to talk about between/within decompositions—a useful tool for anyone's toolkit. In class, we'll start by discussing BBG, then turn to Akerman et al. (2015), who demonstrate the skill complementarity of one specific technology of more recent vintage: broadband internet.

1 Berman, Bound, and Griliches (1994)

Berman et al. (1994, BBG) offer two main pieces of evidence of skill-biased technical change occurring in the US manufacturing sector in the 1980s: (i) employment shifted towards higher-skill occupations, with the bulk of this shift occurring *within* narrowly defined industries rather than *between* them; and (ii) industry-level skill-upgrading is positively correlated with both computer investments and with R&D expenditures. We'll focus on the first of these facts, though the second is a crucial part of BBG's overall argument.

1.1 Skill-upgrading in US manufacturing

- BBG use industry-level data drawn from the Annual Survey of Manufacturers (ASM), a rotating panel sourced from the Census of Manufactures (CM).
    - The CM, conducted once every five years, collects a wealth of data about the full population of US manufacturing establishments. The ASM surveys a stratified random sample of CM plants to provide annual detail between Census years.
    - BBG work with data aggregated to the level of 450 manufacturing industries, identified by 4-digit SIC codes. Inspecting the codes can give you a sense of the level of granularity: `https://www.census.gov/prod/techdoc/cbp/cbp96/sic-code.pdf`. Examples include SIC 2011, "meat-packing plants"; SIC 2321, "men's and boy's shirts"; SIC 3724, "aircraft engines and engine parts"; and catch-all categories like SIC 3799, "transportation equipment n.e.c. (not elsewhere classified)".

 Email: brendan.m.price@frb.gov. These notes are adapted from UC Davis course ECN 250A, which I taught in Winter 2018 and Spring 2019. Any views or opinions expressed here are my own and do not necessarily represent the views or policies of the Board of Governors of the Federal Reserve System or its staff. This version: 2020/03/21.

- For each industry, BBG observe employment and hours worked subdivided into "production" and "non-production" workers; total payroll (or "wage bill"), again subdivided into production and non-production; the value of shipments (i.e., sales or revenues); and expenditures on capital investments, energy, and materials. From these data, one can compute value added, defined as the value of shipments minus expenditures on intermediate material inputs.
- BBG's data are known today as the NBER-CES Manufacturing Industry Database. The latest version, which spans 1958–2011, is available at http://www.nber.org/nberces.

- Central to BBG's analysis is the distinction between production and non-production workers. Quoting Census, BBG write: "Production workers are 'workers (up through the working foreman level) engaged in fabricating, processing, assembling, inspecting and other manufacturing.' Nonproduction workers are 'personnel, including those engaged in supervision (above the working foreman level), installation and servicing of own product, sales, delivery, professional, technological, administrative, etc."'

- BBG start by showing a secular increase in share of manufacturing workers employed in non-production occupations: excluding non-operating establishments like corporate headquarters (where all workers are coded as non-production), the non-production share rose from 22.7 percent in 1959 to 23.4 percent in 1973 to 24.8 percent in 1979 to 28.6 percent in 1989.
  - Why these particular years? The non-production share fluctuates over the business cycle because production employment is more cyclical, so BBG compare employment at business cycle peaks. Researchers make countless decisions about which numbers to report, and offering simple justifications for one's decisions (as BBG do here) helps avoid any appearance of cherrypicking.

- BBG interpret the rising non-production employment share as evidence of skill-upgrading. Why is it reasonable to interpret the non-production share as a proxy for skill intensity?
  - Non-production tasks like designing products and coordinating production appear likely (on prior grounds) to require higher levels of education.
  - Non-production workers are paid more than production workers on average, though there is heterogeneity: a skilled technician is likely paid more than a low-level clerical worker.
  - The production and non-production categories closely align with the "blue-collar" and "white-collar" designations used in the Current Population Survey (CPS). The non-production share in the ASM neatly matches the white-collar share in the CPS, both in levels and in changes, and CPS data show that white-collar workers are more educated on average than blue-collar workers.

- BBG note that the rising non-production share likely *understates* the shift in demand towards high-skill labor, both because a lot of skill-upgrading occurs within the production and non-production categories—a fact they substantiate using the more granular occupation codes present in the CPS—and because in the absence of demand shifts employers should be *reducing* their use of skilled labor in response to the rising costs of employing skilled workers.

- While we often think of education as our go-to measure of worker skill, occupational classifications like production/non-production have a nice feature that educational codings lack: the number of non-production jobs in a particular industry is chosen directly by employers. So, whereas we might observe rising levels of educational attainment in manufacturing stemming from rising education levels in the workforce at large, rising education won't *mechanically* result in more workers performing white-collar tasks. In this sense, one might argue that shifts in the occupational content of work are prima facie more directly informative about changes in labor demand than are shifts in the educational composition of the workforce.

1.2 Within or between?

- BBG advance two explanations for why US manufacturing shifted towards skilled labor in the 1980s.
  - One explanation is that there may have been shifts in product demand towards high-skill industries. The US experienced rising trade volumes throughout BBG's sample period. Because the US is endowed with a more-skilled workforce than those of our trading partners, classic results in Heckscher-Ohlin trade theory suggest that rising openness to trade should cause US manufacturing to shift towards high-skill-intensive industries (e.g., aircraft manufacturing) and away from low-skill-intensive industries (e.g., textile production).[1] Furthermore, the Reagan defense buildup of the 1980s led to growth in high-tech defense industries (e.g., aerospace) that employ lots of skilled workers.
  - A second explanation is SBTC: holding product demand constant, labor demand shifted towards skilled workers because the technological advances occurring during this period—for example, computer-automated design and numerically controlled machines—tended to complement high-skill labor.
- To distinguish between these stories, BBG posit that product demand shifts will manifest as skill-upgrading *between industries*, as skill-intensive sectors expand relative to less-skilled sectors, whereas SBTC will induce skill-upgrading *within industries*. BBG thus decompose the overall rise in the non-production share into between- and within-industry components.
- Between/within decompositions come up in many contexts, so it's worth understanding how they work. Using my own notation (as I find BBG's a bit confusing):
  - Let E_{jt} denote employment in industry j. Let $E_t \equiv \sum_j E_{jt}$ denote total manufacturing employment. Likewise, let N_{jt} denote non-production employment in industry j, and let $N_t \equiv \sum_j N_{jt}$ denote total non-production employment within the manufacturing sector.
  - Define $\lambda_{jt} \equiv \frac{E_{jt}}{E_t}$ as j's share of manufacturing employment, let $s_{jt} \equiv \frac{N_{jt}}{E_{jt}}$ denote the non-production share within industry j, and let $s_t \equiv \frac{N_t}{E_t}$ denote the same share within manufacturing.
  - The aggregate skill share is a weighted average of industry skill shares:

$$s_t = \frac{N_t}{E_t} = \frac{\sum_j N_{jt}}{E_t} = \sum_j \frac{E_{jt}}{E_t}\frac{N_{jt}}{E_{jt}} = \sum_j \lambda_{jt} s_{jt} \tag{1}$$

    so the change in non-production share from $t = 0$ to $t = 1$ is

$$\Delta s = \sum_j \lambda_{j1} s_{j1} - \sum_j \lambda_{j0} s_{j0} \tag{2}$$

[1] The trade explanation also implies an increase in the US skill premium—a consequence of factor price equalization—as trade increases the effective supply of low-skill labor in the United States. Absent shifts in production technology, the rising skill premium in turn implies that—within industries—employers should substitute *away from* skilled workers, who have suddenly become more expensive to employ. This prediction is at odds with BBG's evidence.

- There are many ways to decompose expressions like this into between and within components. Such decompositions are really just Oaxaca-Blinder decompositions, and they inherit the annoying property that the choice of base period affects the breakdown of an overall change into its constituent parts. Here are some of the options.

  - Add and subtract $\sum_j \lambda_{j0} s_{j1}$. By rearranging terms, we get

$$\Delta s = \underbrace{\sum_j \Delta\lambda_j s_{j1}}_{\text{between}} + \underbrace{\sum_j \lambda_{j0} \Delta s_j}_{\text{within}} \tag{3}$$

    But notice that we're using $t = 1$ industry skill shares to evaluate the between component, and $t = 0$ industry shares of employment to evaluate the within component. This feels pretty arbitrary.

  - We could instead add and subtract $\sum_j \lambda_{j1} s_{j0}$, in which case we get

$$\Delta s = \sum_j \Delta\lambda_j s_{j0} + \sum_j \lambda_{j1} \Delta s_j \tag{4}$$

    This is equally arbitrary!

  - Yet another decomposition is

$$\Delta s = \underbrace{\sum_j \Delta\lambda_j s_{j0}}_{\text{between}} + \underbrace{\sum_j \lambda_{j0} \Delta s_j}_{\text{within}} + \underbrace{\sum_j \Delta\lambda_j \Delta s_j}_{\text{covariance}} \tag{5}$$

    which uses base-period values to quantify both the between and within effects. This has the virtue of symmetry, but now we have an extra second-order "covariance" term, so we've lost some of the simplicity present in the earlier decompositions.

  - A final approach, and the one BBG use, is to employ *average* values when quantifying each component. Let $\overline{x}_j \equiv \frac{1}{2}(x_{j0} + x_{j1})$. By adding and subtracting $\frac{1}{2}(\sum_j \lambda_{j0} s_{j1} + \sum_j \lambda_{j1} s_{j0})$ and rearranging terms, we derive

$$\Delta s = \underbrace{\sum_j \Delta\lambda_j \overline{s}_j}_{\text{between}} + \underbrace{\sum_j \overline{\lambda}_j \Delta s_j}_{\text{within}} \tag{6}$$

    This is a nice compromise: we're back to just two terms, and we aren't arbitrarily using base-period shares for one part of the decomposition but not the other.

- Employing this formula, BBG show (in their Table 4) that most of the increase in non-production share occurs within industries, militating in favor of the SBTC hypothesis and against explanations rooted in rising trade volumes or the Reagan-era defense buildup.

  - Another detail worth mentioning: between/within decompositions are sensitive to the level of aggregation at which the decomposition is performed. For example, if BBG had performed their decomposition using 3-digit industries, then their "within" component would be inclusive of any changes in skill-intensity arising from shifts in the relative sizes of the 4-digit industries comprising each 3-digit nest, to the extent that these constituent

4-digit industries differ in their baseline skill intensities.[2] When interpreting these decomposition exercises, one should bear in mind that their informativeness depends on the granularity of the underlying classification.

- But wait! Rising trade volumes and the defense boom could increase skill demands *within industries* as well!
  - While import substitution (hurting low-skill domestic US industries) and export opportunities (favoring high-skill industries) relate to employment shifts between industries, openness to trade also creates opportunities for US firms to offshore production tasks to low-wage foreign suppliers while continuing to perform non-production tasks (design, engineering, marketing) in the United States. Such offshoring will lead to skill-upgrading within US manufacturing industries.
  - If rising defense procurements simply led to a proportional increase in the size of the aerospace industry (with relative factor usage held constant), this would show up in the between-industry component. But if the defense sector substitutes towards higher-skilled workers (so as to design new high-tech weaponry), that would show up in the within-industry term.
- To assess this possibility, BBG further decompose the between- and within-industry components into sub-components related to imports, exports, defense, and a residual category. I won't go into the details here, but the punchline is that trade and defense explain a substantial fraction of the between-industry component, but only a very small share of the within-industry component. That leaves SBTC as the "diagnosis of exclusion" for the skill-upgrading observed within detailed industries.

2 Skill-upgrading, technology adoption, and organizational change

- BBG's second main result is that industry-level changes in the non-production share are positively correlated with computer investments and R&D spending, pointing more directly to a role for technological change. This is really correlational evidence, not necessarily causal, but it's consistent with the SBTC story; indeed, SBTC would be hard to believe if this correlation did *not* hold.
- Since BBG, many subsequent papers have explored the nexus of technology adoption, skill-upgrading, and organizational change within and beyond manufacturing. Here are a few:
  - Krueger (1993) shows that, as of the 1980s, workers who used computers on the job earned 10–15 percent more than observationally similar workers who did not. If causal, these estimates suggest rising computer use could explain a large fraction of the rising return to education, since computer use is strongly correlated with educational attainment. Krueger's selection-on-observables empirical strategy is, however, open to critique.
  - DiNardo and Pischke (1997) reassess Krueger's findings using German survey data that record, alongside computer use, the use of other tools like calculators, telephones, and (famously) pencils. After replicating Krueger's results for Germany, they document similar "returns" to calculators and pencils, suggesting that all of these measures are

[2] By the same token, BBG can't rule out the possibility that skill shifts within 4-digit industries actually reflect subtle changes in product mix transpiring at even finer levels of aggregation—though 4-digit industries are pretty detailed.

proxying for some broader measure of skill or white-collar job content to which the returns have changed over time.

- Berman et al. (1998) show that *the same* manufacturing industries have exhibited skill-upgrading in the US and in other developed countries, consistent with the idea that recent skill shifts reflect worldwide changes in production technology, rather than idiosyncratic factors related to US institutions or product demand.
- Doms et al. (1997) explore the relationship between plant-level wages, occupational structure, skill intensity, productivity, and the adoption of 17 specific technologies that appear in the 1988 and 1993 Surveys of Manufacturing Technology.
- Bartel et al. (2007) conduct a detailed case study of one very specific industry (valve manufacturing), enabling them to paint a rich picture of the complementarities between technology adoption, skill-upgrading, organizational change, and product customization. This paper is chock-full of fascinating insights and a highly recommended read.

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