The Shelf Life of Incumbent Workers during Accelerating Technological Change: Evidence from Training Regulation Reform

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Preliminary version.

Extended abstract:

Changing technologies have a substantial impact on labor markets (e.g., Acemoglu, 2015; Acemoglu and Autor, 2011; Acemoglu and Restrepo, 2016; Acemoglu and Restrepo, 2017; Michaels *et al.*, 2014), because they change the demand for skills (e.g., Autor, 2013; Autor *et al.*, 2003; Goos and Manning, 2007; Goos *et al.*, 2014; Michaels *et al.*, 2014; Spitz-Oener, 2006).[1] As a result of new emerging technologies, such as cyber-physical systems and artificial intelligence, a public debate has evolved about the importance of life-long learning to ensure that employees can maintain and update their skills. For example, Randell Stephenson, CEO at AT&T, has argued that workers who do not spend five to ten hours a week in online learning will become technologically obsolete (NYT, Feb. 13, 2016).[2]

Yet incumbent workers incur high opportunity costs for continuously updating their skills—particularly those who work full-time and have a high earnings capacity.[3] In contrast, high school and college students have already learned how to handle new technologies and can undertake large human capital investments at low opportunity costs. Therefore, when

[1] See Akerman *et al.* (2015), Autor *et al.* (2002), Brynjolfsson and Hitt (2000), Brynjolfsson and Hitt (2003), Bresnahan *et al.* (2002), Doms *et al.* (1997) and Caroli and Van Reenen (2001) for evidence on the firm level. Chin *et al.* (2006) and Hynninen *et al.* (2013) provide historical evidence from the introduction of steam engines.

[2] A number of scientific studies have also shown that firms invest more in training their workers after they have adopted new technologies (Bresnahan *et al.*, 2002; Sieben *et al.*, 2009).

[3] This argument follows simple human capital theory (Becker, 1962). Indeed, Mincer (1974) argues that incumbent workers' opportunity costs increase to a point at which workers have no incentives to undertake human capital investments large enough to compensate for the depreciation of their existing human capital. Moreover, incumbent workers are more likely to have families, and therefore substitute time for home production.

technologies fundamentally change, are incumbent workers at a disadvantage relative to recent graduates? And, if so, does this disadvantage manifest in negative consequences for their careers?

Our paper investigates these empirical questions with a unique quasi-experimental setting. To do so, we exploit a large German training reform that led to a shock in the relative supply of graduates with modern IT skills complementing a fundamental technological innovation that substantially changed the demand for skills in the German manufacturing sector. To provide micro evidence about whether and, if so, how incumbent workers responded to the market entry of these IT-skilled graduates, we use highly precise register data that allows us to follow the careers of incumbent workers for more than 25 years.

As micro evidence on the long-term dynamics of workers' careers during periods of fundamental technological change is very scarce, our results provide important new insights of how technological change affects the labor market in the long-term. While the general relationship between the wage distribution, job tasks, and workers' skills is relatively well understood,[4] only two recent papers have analyzed the relationship between changing technologies and workers' careers. First, Cortes (2016) has studied how the careers of individual workers in routine and non-routine jobs have evolved over the last four decades. Second, El-Sahli and Upward (2017) have analyzed how the technology of containerization affected the employment patterns of UK dockworkers. We contribute to this literature by analyzing how incumbent workers' careers respond to the increasing supply of more technologically skilled recent graduates.

The labor supply shock of graduates with more technologically advanced skills may influence the careers of incumbent workers through at least three channels: First, incumbent workers, who incur high opportunity costs for training, may forgo promotions if they have to compete with these graduates in internal labor markets. Second, firms may become less likely to (financially) support the training of incumbent workers if the external supply of workers with more advanced technological skills rises enough that hiring young graduates becomes cheaper than training incumbent workers.[5] Third, the increasing supply of up-to-date skills may directly impact firms' decision to adopt newer technologies. As the theory of

[4] For example, Autor (2015), Acemoglu and Autor (2011), Autor *et al.* (2008), Autor *et al.* (1998), Acemoglu (2002), Acemoglu (1998), Dustmann *et al.* (2009).

[5] Some studies have shown that firms that adopt new technologies hire more skilled workers, while others show that they become more likely to train their incumbent workers (e.g., Akerman *et al.*, 2015; Bartel and Sicherman, 1998; Bresnahan *et al.*, 2002; Brynjolfsson and Hitt, 2000; Brynjolfsson and Hitt, 2003; Sieben *et al.*, 2009).

endogenous technological change argues, firms become more likely to adopt newer technologies if workers whose skills complement the new technology are cheap and available. As a result, the supply of more technologically advanced graduates may create its own demand at the expense of the demand for incumbent workers with outdated skills (e.g., Acemoglu, 1998; Beaudry *et al.*, 2010; Caselli and Coleman II, 2001; Lewis, 2011; Machin and Manning, 1997).

This paper analyzes how the careers of incumbent workers respond to the increasing supply of graduates with modern IT skills. We exploit a reform of a mandatory apprenticeship training regulation in a large manufacturing occupation in Germany, a reform that led to a substantial shock in the relative supply of graduates with modern IT skills. We analyze the response of incumbent workers' careers to this supply shock by using a difference-in-differences approach with a comparison group of incumbent manufacturing workers from an unaffected occupation. As workers of both occupations had a similar level of general education, were trained in the same firms, and were exposed to the same institutions, we can isolate the causal effect from influences of unrelated institutional changes and macroeconomic developments.

In contrast to other countries, apprenticeship training is the main school-to-work route in Germany, with about two thirds of the German workforce participating. Apprenticeship graduates are skilled workers who are comparable to U.S. workers with a medium level of college education, because apprenticeship-training programs last between three and three and a half years. Apprenticeship training is regulated at the federal level, and mandatory training curricula define the requisite skills for more than 350 training occupations. Independent institutions monitor apprenticeship training programs and carry out occupation-specific final exams to enforce these curricula (Acemoglu and Pischke, 1998; Dustmann and Meghir, 2005; Dustmann and Schönberg, 2009; Harhoff and Kane, 1997; Ryan, 2001). Thus all apprentices who successfully graduate from their training program have, at the least, the skills required by their current training regulation.

As a result, we can use reforms of training curricula to infer when entire cohorts of graduates enter the labor market with fundamentally new skills. We exploit this unique feature to analyze how the careers of incumbent workers, who have been trained *before* the

reform, respond to the reform-induced supply shock of workers who possess technological advanced IT-skills, because they were trained after the reform.[6]

We analyze a particular reform in the occupation of machining metal operators, who produce metal parts such as precision parts for cars and heavy machinery. Given the occupation's technological content, the relatively good pay, and the long-term employment prospects in Germany, many young men with a medium level of general education chose to become machining metal operators. They performed processes such as drilling, turning, and milling on several specific manual machines until the mid-1980s. At that point, computer numerical control machines (CNC), a groundbreaking new technology, spread across the industry (see Figure 1). CNC technology integrated most manual machining processes into one machine that workers could control via a computer system. Therefore, CNC machines substantially changed both the nature of work and the necessary skills in the occupation (Bartel *et al.*, 2007; Lewis, 2011).

In the late 1980s, German policy makers reformed the training curriculum of machining metal operators in response to the invention of CNC technology. Until then, machining metal operators had to learn how to use one of several traditional manual machines during apprenticeship training. After the reform, all machining metal operators throughout Germany had to learn in-depth CNC skills in a structured and elaborated training program, which often took place in specialized training centers. The training program provided very sophisticated CNC skills, such as coding and debugging CNC programs. Although CNC technology was available before the reform, the reform accelerated the supply of workers with sophisticated CNC skills within a very narrow window of time. In contrast, apprentices who had graduated (and later became workers) before the reform did not receive extensive CNC training as mandatory element of their apprenticeship training. Therefore, these incumbent workers were, on average, less proficient in the use of CNC technology than post-reform apprenticeship graduates.

Using a difference-in-differences approach to identify the effect of the reform-induced supply shock, we analyze how the careers of incumbent machining metal operators[7] *without* modern CNC skills responded to the increasing supply of CNC-trained graduates. The reform-induced supply shock of CNC-skilled apprenticeship graduates is the treatment. The

[6] We emphasize here that we do *not* compare those who have been trained before the reform with those who have been trained thereafter. Instead, our interest is to understand how incumbent workers respond to the increasing competition of technological advanced skilled workers.

[7] The term „incumbent workers" refers to those who graduated before the apprenticeship training reform and thus did not receive CNC training as a mandatory part of their apprenticeship training.

treatment group consists of incumbent machining metal operators who graduated shortly before the reform and therefore did not receive CNC training as mandatory part of their apprenticeship training.

The comparison group consists of incumbent workers from a similar occupation that was not exposed to a groundbreaking technological innovation leading to a reform-induced supply shock of graduates with modern IT-skills. This group consists of incumbent *non-machining* metal mechanics from the same graduation cohorts as our treatment group. In contrast to machining metal operators, non-machining metal mechanics assemble parts but do not use CNC technology. Otherwise, non-machining metal mechanics are very similar to machining metal operators, because both groups have studied and worked in the same vocational schools and firms, produced similar final goods, and have representation by the same unions. As a result, both groups were exposed to exactly the same labor market institutions and macroeconomic conditions, and their employers applied similar selection criteria when hiring.

Our analysis relies on register data from the Federal Employment Agency of Germany. This data allows us to follow our treatment and comparison groups for more than 25 years, i.e., both before and after the supply shock. The data contains highly accurate information about workers' wages, employment status, and common demographic characteristics (e.g., age, nationality, and education). Moreover, the data allows us to link the worker to the firm, so that we can account for the unobserved heterogeneity in training quality by matching workers from the two groups who have been trained in the same firms at the same time.

Our results show that incumbent workers experienced long-lasting earnings losses in response to the market entry of graduates with CNC skills. Over the observation period of more than 25 years, total earnings losses amounted to about 70% of an average workers' annual pre-treatment earnings. Earnings losses were largely related to reduced real daily wage growth. In contrast, we found only small effects on the extensive margin. On average, incumbent workers experienced only transitory unemployment during a short period immediately after the first market entry of CNC-skilled graduates and resumed a stable employment path in the long run.

A detailed analysis of the mechanisms suggests that incumbent workers forwent crucial promotions that went instead to CNC-skilled graduates, i.e., the incumbents' lower wage growth appears to be partly the consequence of a less favorable career path within firms. Moreover, incumbent workers have adjusted to the competition of CNC-skilled graduates by switching to other occupations, even within firms. In line with existing evidence on job

polarization, we find that, on average, incumbent machining metal operators became significantly less likely to remain in the metal working sector and significantly more likely to enter the service sector, particularly low-wage service jobs. Nonetheless, our results suggest that most incumbent workers remained in the metal working industry. One possible reason is that employment in German manufacturing has evolved in a more stable way than, for example, that of U.S. manufacturing after the East-European trade integration (Dauth *et al.*, 2014). Thus affected workers in Germany potentially had many opportunities for remaining in the metal working industry.

In the most general sense, we provide causal micro-evidence for a long-term adjustment process of labor markets to the consequences of technological change. Consequently, our results contribute to at least four strands of the literature. First, previous studies showed that the adverse consequences of routine-biased technological change were most substantial for medium-educated workers, particularly, for medium-educated production workers (Goos *et al.*, 2014). While our paper supports these findings—and shows that wage losses persist over workers' entire careers—our evidence also shows that workers adjust to the consequences of technological change by, for example, switching to other occupations and sectors. This result is consistent with recent studies suggesting that occupational mobility contributes to changes in the wage structure (e.g., Kambourov and Manovskii, 2009) and with empirical finding suggesting that the decline of employment in technology-intensive sectors is offset by an increase of employment in other sectors, such as the service sector (e.g., Gregory *et al.*, 2016).

Second, quasi-experiments are hard to find with only few data sources providing micro-level information about workers' careers and skills, and the changing nature of individual jobs. Therefore, most studies had to rely on aggregate measures that only allow them to infer time trends of descriptive associations between changes in the content of job tasks, computer usage, employment, and wage rates. However, as these descriptive associations often do not allow the inference of precise mechanisms, a number of researchers have criticized the results for merely reflecting other institutional and macroeconomic changes that cannot necessarily be interpreted as evidence for skill-biased technological change (Card and DiNardo (2002); DiNardo and Pischke (1997)). Our design allows us to identify a change in the supply of technological advanced IT skills for a narrowly defined treatment occupation in response to a fundamental technological innovation. Thus we are able to provide micro-level evidence on a specific mechanism that explains how technological changes influence the wage and employment structure.

Third, we complement a number of studies that have argued that human capital depreciates with technological change. For example, a number of older studies have associated U-shaped wage profiles with depreciating human capital (Ben-Porath (1967); Neuman and Weiss, 1995). Others have analyzed whether older workers decide to take early retirement, after their firms implemented modern computer technology (Aubert *et al.*, 2006). Yet others have argued that workers of different age groups are imperfect substitutes, because their human capital is specific to different vintages of technology[8], for explaining occupational mobility, college wage premiums, or changes in the wage structure (Bowlus and Robinson, 2012; Card and Lemieux, 2001; Violante, 2002). Our results contribute to that literature, because we identify such vintage effects in a clean setting. Moreover, we show that human capital depreciation may even affect relatively young workers with substantial long-term consequences for their careers.

Fourth, while most studies have analyzed the effects of labor market programs, training, and schooling reforms for those who benefit from them (Harmon and Walker, 1995; Heckman *et al.*, 1999; Pischke and von Wachter, 2008), some recent papers have highlighted important displacement effects for those who did not benefit from those labor market programs (Crépon *et al.*, 2013). Our study shows the long-term consequences from such a displacement effect.

The remainder of the paper is organized as follows. Section II describes the CNC technology and the institutional details of the apprenticeship system in Germany. Section III describes the training reform and the identification strategy. Section IV presents the data and descriptive statistics. Section V gives our empirical approach. Sections VI presents the main results, and section VII gives the mechanisms underlying incumbent workers' wage losses. Section VIII contains the robustness checks and that section IX concludes.

[8] Neuman and Weiss (1995) and Weiss and Lillard (1978) have used the term vintage human capital to explain cross-sectional wage patterns as a consequence of technological change.