

This article was published on-line on April 27, 2017

Essays in
**ECONOMIC &
BUSINESS
HISTORY**

The Journal of the Economic & Business History Society



Editor

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ISSN 0896-226X
LCC 79-91616
HC12.E2

ELECTRICITY AND THE TECHNOLOGY–SKILL COMPLEMENTARITY: EVIDENCE FROM THE SWEDISH INDUSTRIAL CENSUS OF 1931

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Notwithstanding the popularity among economists of attributing the surging inequality of recent decades to technology–skill complementarity, researchers with a keen eye on history have been reluctant to pick up this thread. This paper joins Claudia Goldin and Lawrence Katz’s attempt to examine the role of electrification as an example of a technology that is complementary to workers’ rising skill levels. Sweden electrified manufacturing processes rapidly in the first quarter of the twentieth century, while the supply of skills through secondary education only increased significantly in the 1950s. We use industry-specific information from the Swedish Industrial Census of 1931 to establish whether electricity and the use of white-collar workers correlated positively. The results indicate that the correlation was positive, but the estimated effect was rather small. Moreover, the available evidence for skill ratios does not suggest that inequality, thus measured, increased. We conclude that labor market institutions prevented—and also overturned—the inequality push emanating from technology.

Introduction

Physical capital embodies new technologies, and since an element in the sustainable rise of national income is increasing capital to labor ratios—what economists label capital deepening—new technologies essentially propel modern economic growth. New technologies also drive the demand for workers' skills. Two views on how technology has influenced demand for workers' skills have gained prominence: if new technology and unskilled labor have been substituted for skilled labor with growing mechanization, we would characterize technology as essentially deskilling, favoring demand for unskilled workers (Harry Braverman 1974; Martin Brown and Peter Philips 1986); if new technology has instead accompanied workers' skills, we would rather characterize technology as promoting higher skill levels, favoring demand for skilled workers (Zvi Griliches 1969; Jan Tinbergen 1975). This latter view is coined skill–technology complementarity.

Both these views on technology and workers' skills have implications for the development of inequality through their relative demand on workers' characteristics—the quantity effect—which affect the composition of the workforce. They also have implications for the return to education—the price effect—which is an important determinant of individual wages (Jacob Mincer 1974). Unless the supply of skills changes in response to technological change, wage inequality might follow (Claudia Goldin and Lawrence Katz 2008). The magnitude of inequality has undergone profound change since the late nineteenth century, and the history of technologies has witnessed several leaps in radically new technologies, such as the steam engine, electricity and the combustion engine. Nevertheless, almost all the literature attempting to connect the evolution of inequality with the appearance of new technologies treats the post-1970 period as self-contained. It concludes that information and communication technologies (ICT) have spurred inequality, though it remains mute as to whether this is particular to or indicative of how the

technology–skill association operates in general (Alan Krueger 1993; Lawrence Katz and Kevin Murphy 1992).¹

A rare exception to the one-sided emphasis of recent decades is the work of Goldin and Katz (1998), who have ventured into an historical application of the complementarity notion, through an American study of the diffusion of electricity as a source of inanimate power in the first quarter of the twentieth century.² They study the growing use of continuous operations, coined batch technologies, and the effect these have had on the relative demand for skilled workers. They conclude that this new technology grew in tandem with an increased relative demand for skills. As a corollary to the increased relative demand for skills during electrification, one would expect to come across evidence that the skilled to unskilled wage ratio increased in the first quarter of the twentieth century, but the American ratio did not. Goldin and Katz explain this seeming contradiction by the rise of secondary schooling. The US led the way towards making secondary education a matter of concern for a large portion of the population. Most other developed countries could not match the American enrolment rates until decades later. The increase in the US secondary enrolment rates hence acted as a check to an increase in the skilled–unskilled wage gap.

The confluence of electrification and educational revolutions makes the US special; in fact, Sweden may provide a neater case for studying the technology–skill complementarity in the historical context of electrification and the use of batch technologies. First, electrification proceeded rapidly in Sweden owing above all to abundant supplies of suitable sites for hydropower. Second, an increase in secondary

¹ Studies that apply the technology–skill complementarity hypothesis to Sweden also focus on the period after 1970 (Bob Anderton et al. 2002; Pär Hansson 2000; Matthew Lindquist 2005). For an early twentieth century investigation into the technology–skill complementarity in a handful of Swedish mechanical engineering firms, see Fay Lundh Nilsson (2007, 127-132).

² Two others are Jeremy Atack et al. (2004) and Lawrence Katz and Robert Margo (2014).

schooling did not take place until the 1950s, well after the electrification of manufacturing was a *fait accompli*. If the forces of the technology–skill complementarity were correctly identified, we would expect a rise in the skill to unskilled wage ratio.

Our preliminary investigation into the existence of a skill–capital complementarity confirms the presence of a skill–capital complementarity. Yet, the measurement tools at our disposal do not lend themselves to a firm conclusion. The chapter also reviews what we know about the movement of the skill to unskilled wage ratio in the interwar years. The available evidence, if scarce, points to narrowing ratios in the 1930s and 1940s, which directs the spotlight to labor market institutions, a field of study on which Christer Lundh has left his imprint, above all through the influential “Spelets regler” (Lundh 2010).³ Could the institutional configurations that appeared during the first half of the twentieth century, forming the backbone of what is often referred to as the Swedish model in the labor market, have been a force sufficiently powerful to offset the push for inequality inherent in the skill–capital complementarity? The authors of this article gravitate towards a response in the affirmative.

Theoretical Framework

Our theoretical preamble begins with the relationship between technology and skills in the nineteenth century. A long-held view postulates that an important element in the early industrializations of today’s developed countries was the substitution of rather unskilled workers as machine operatives for skilled artisans—the so-called deskilling hypothesis (Brown and Philips 1986). The rise of the factory system rendered superfluous the skills possessed by numerous skilled handicraft workers. As the use of mechanized processes spread across different industries, artisans were relegated to the role of serving customers with minor repairs rather than producing new artifacts. Instead the new technology increased the relative demand for unskilled workers because of increased labor division within the factory system (in some cases the specialization was so high that the task could be learned

³ Published originally in 2002.

within a few hours). Technology was complementary to raw materials but not to skills. In the minds of those who favor this view of industrialization, technological development was deskilling (Atack et al. 2004). One may also view the *Luddite* movement in the early nineteenth century, the incarnation of technology resistance, as buttressing the deskilling hypothesis (Kevin O'Rourke et al. 2013).

However, by the turn of the century the relationship between technology and skill started to change. According to Goldin and Katz's (1998) influential interpretation, in the early decades of the twentieth century, capital deepening, technological change and the demand for skilled labor or white-collar workers were becoming complementary to one other. They conjecture that the switch from steam to electricity laid the foundation for a new technology–skill relationship. To understand how the new technology affected the demand for skill, let us digress briefly and consider how steam and electricity affected factory design (Harry Jerome 1934; Warren Devine 1983). The factory hall in the steam era was crisscrossed by belts and wires connected to the engine. This design implied a great need for unskilled labor that served the operation of the steam engine through hauling, conveying and assembling. The introduction of electricity, and in particular the use of small electric motors, did away with many of the belts and wires covering the factory hall. When each machine was run by a separate electric motor, the design of the factory changed. The operation of the factory now required fewer manual workers. A probable result of the transition from steam to electricity is a reduced demand for unskilled workers, whereas the demand for skilled workers and employees may have increased. We recapitulate briefly Goldin and Katz's (1998, 697) own words: “industries adopting advanced technologies in the first part of this century should have employed production workers with higher average skills and a larger share of nonproduction (white-collar) workers”.

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Because labor market institutions affect wage alignments, the nexus between technology, skill composition and rewards for skills is difficult to disentangle. O'Rourke et al. (2013) ponder on the role of institutions for the observed changes in skill rewards in the UK. Their theoretical proposition posits that the skilled-biased technical change, endogenous to the market, serves to increase wage inequality, whereas institutional factors, such as educational programs and the rising strength of labor unions, all of which are exogenous to the market, temper wage inequality. They suggest that the upward movement in the skill to unskilled wage ratio observed after the 1970s marks a distinct transition, expressed eloquently as “late nineteenth century chickens finally coming home to roost” (O'Rourke et al. 2013, 30). Thus, the existence of the technology–skill complementarity, boosting demand for skilled labor, would potentially be able to explain only partly the development of wage inequality between skilled and unskilled labor in Sweden, with institutional factors probably providing the rest of the explanation.

Christer Lundh (2010) has provided a very influential overview of the Swedish labor market since the mid-nineteenth century. He focuses largely on labor market institutions but some sections feature discussions concerning how technology affected the demand for workers in the manufacturing industry. However, these sections of his book are devoid of explicit references to the technology–skill complementarity hypothesis. Instead he appears to have joined those who view the development of production technologies during the first three quarters of the twentieth century as boosting demand for unskilled workers (Lundh, 2010, 160-166). The emergence of mass production technologies is a distinguishing feature of the late nineteenth and early twentieth century industrialization. The most prominent example of a mass production technology that appeared then is the moving assembly line, in particular the one that was used by the Ford Motor Company to produce cars. Each worker carried out a few simple operations, which made their work efforts efficient but repetitive and dull. The moving assembly line truly embodies the deskilling nature of new technology; the use of the moving assembly line lessened the requirements for manual dexterity since tasks could be learned in a matter of days or even hours, making workers' skills

superfluous. The moving assembly line furthermore implied an acceleration in the horizontal division of the work force into either blue-collar workers or white-collar workers. It also entailed a clearer distinction between workers doing manual work at the assembly line and engineers doing maintenance work.⁴

The unskilled character of manual work at the assembly line made it possible to hire workers with little or no skill requirements, and very little on-the-job training was required to prepare new workers before joining the work force. All of a sudden, employers could hire workers with no previous experience in industrial work, such as women, farm workers and immigrants. Lundh (2010) does not enter into a discussion of what effects the increased demand for unskilled workers had on their relative earnings. He argues that the kind of mass production technologies that would affect the demand for unskilled workers did not permeate Swedish manufacturing until the 1950s and 1960s, coinciding with the rise of labor immigration into Sweden. Most of the immigrants found employment in manufacturing at that time, owing largely to the great supply of industrial employment with little or no formal skill requirements. If the scale effect of mass production technologies speaks in favor of unskilled workers, so too would the price effect, unless counteracting forces, like labor immigration, functioned to undo it. Another question concerns to what extent mass production really permeated manufacturing other than the well-known instance of car manufacturing. Whereas electricity came to be adopted across the entire spectra of manufacturing processes, mass production technologies may only have concerned a narrow segment of mechanical engineering industries.

⁴ In Sweden, the deskilling notion in the spirit of Braverman (1974) has spurred numerous studies of either separate firms or specific industries that focus on how technological changes have affected work organizations and power relations between workers and employers (Bengt Berglund 1982; Christina Johansson 1988; Maths Isacson 1987).

Electrification and Demand for Skilled Labor

The Swedish transition from steam to electricity began in the 1880s and proceeded rapidly after the turn of the century.⁵ The ample supply of rivers suitable for harnessing waterpower spurred the development of electricity, whereas the lack of domestic sources of coal probably impeded the use of the steam engine. When steam peaked in the 1880s it accounted for no more than half of the installed capacity of horsepower used for motive and mechanical power in manufacturing establishments. The rest of the energy supply stemmed from waterpower providing direct mechanical power, wind and draught animals (Svante Prado 2014). To generate electricity implied merely a switch from waterwheels to turbines. Manufacturing establishments were hence located already at river sites fit for hydropower. Resource endowments and path dependence set Sweden on a rapid course towards the so-called Second Industrial Revolution, centered on electricity and the development of a new cluster of industries in electro-mechanical engineering. Groundbreaking innovations, such as the three-phase alternate current and new transmission techniques, triggered the emergence of small electric motors. The widespread use of them, instead of steam engines, would relax the constraints of the old energy regime, by then characterized by increasing energy prices and inefficient organization of production processes (Kerstin Enflo et al. 2008).

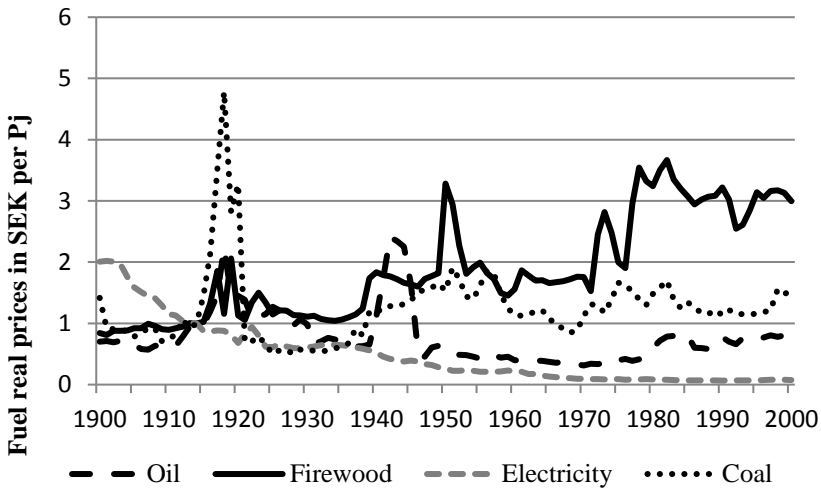
The manufacturing sector and urban households adopted electricity early. By the 1930s, electricity had also spread to the countryside. The Swedish state promoted the diffusion and adoption of electricity by establishing a national grid, which connected electricity production sites in the north of the country with consumers in the south. This had important implications for the role of electrification in also promoting the mechanization of the Swedish industrial production between rural and urban areas. By the 1920, electricity provided industry with almost 75 percent of all motive power, and by the 1950s, the electrification of mechanized production in rural areas had also been completed (Schön 2000).

⁵ See Filip Hjulström (1940) and Lennart Schön (1990; 2000) for overviews of Swedish electrification.

The notion of “development blocks” has gained ground in Swedish economic history writing since Erik Dahmén (1989). So has the idea, sprung from the international literature, that electricity embodies the qualities of a so-called general-purpose technology (GPT): one that has great scope for improvement, broad externalities and many technological complementarities (Timothy Bresnahan and Manuel Trajtenberg 1995; Richard Lipsey et. al 1998). The Swedish literature has cross-fertilized these two strands of thought and created an analytical narrative of industrial transformation (Karolin Sjöo 2014, 85-121). This narrative identifies two development blocks after 1900 that excelled in the use of electricity, a true GPT (Enflo et al. 2008). The first of these development blocks hosted mutually reinforcing relationships (complementarities) between the metal industries and mechanical engineering industries on the one hand and the railways on the other. The second block boosted development through mutually reinforcing relationships in the pulp and paper industries, the chemical industry and, anew, the mechanical engineering industry. Enflo et al. (2008) show how the importance of electricity for chemistry, metal, railways and machinery increased almost uninterruptedly, and the metal industries had the highest share of electricity use in the early 1930s.

The role of inexpensive energy sources was of utmost importance for the capital accumulation and increase of capital intensity in Sweden during the twentieth century. Figure 1, which plots energy prices relative to consumer prices, shows divergence across different energy carriers’ prices. It is only in the case of electricity that a clear downward trend is observed throughout the entire period. This real electricity drop provides support for the hypothesis that the greater availability of electricity spurred capital accumulation in the country’s manufacturing industry during the early twentieth century since most of the real price reduction occurred before 1930. Schön (2000, 180-182) furthermore shows that electricity prices developed counter to the prices of other fuels; when fuel prices increased, electricity prices decreased.

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Source: Own calculations based on fuel prices from Ruta Gentvilaite et al. (2015) and the consumer price index (CPI) from Rodney Edvinsson and Johan Söderberg (2010).

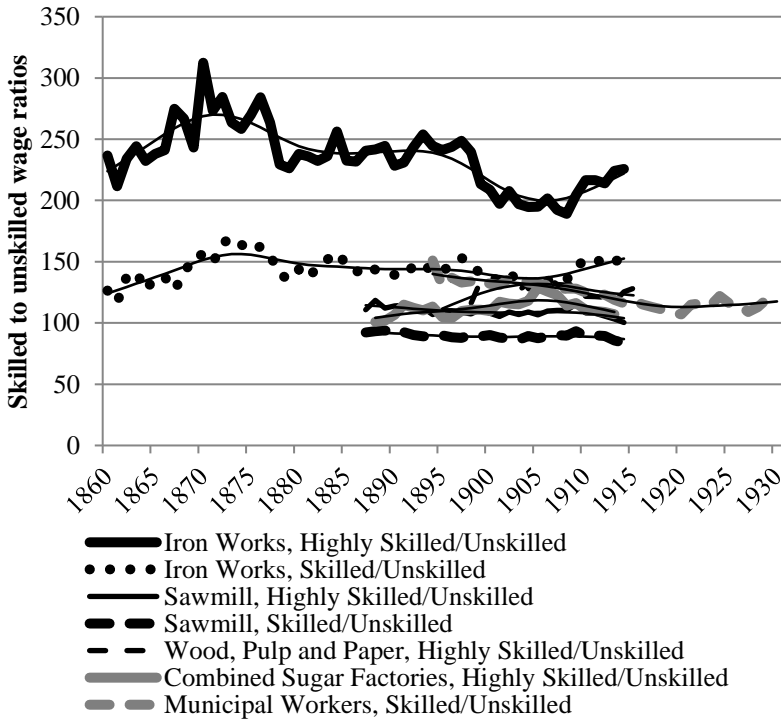
Note: The reference year (=1) is 1914.

Figure 1

The Price of Coal, Electricity, Fuel, Firewood and Oil Divided by CPI in Sweden, 1900-2000

How did the rapid adoption of electricity affect production processes and thereby demand for workers' skill levels? Prado (2014) employs Arnold Harberger's (1998) yeast versus mushrooms dichotomy for 1869 to 1912 to examine the diffusion pattern of productivity growth rates across Swedish manufacturing industries. He finds mostly a mushroom-like pattern and dismisses the idea that the steam engine had the potential to foster unified growth rates across industries. After 1900, a yeast-like pattern asserts itself, thus implying a coincidence of homogeneous diffusion of productivity improvements and emergence of electricity. This coincidence entertains the possibility that electricity, through its quality as a GPT, fostered cost reductions across the entire

spectrum of production processes. If this were true, we would expect an even stronger effect by 1930, when electricity propelled almost all production processes in Swedish manufacturing. Electricity would by then be the prime factor affecting the technology–skill interplay that this book chapter attempts to uncover.



Sources: Own calculations based on data from Bagge et al. (1933; 1935)

Notes: Data for municipal workers correspond to hourly wages while the rest to annual earnings. Combined sugar factories comprise of raw-sugar mills and refineries. Sawmill workers are from the Härnösand area.

Figure 2
Wage Differentials Between Skilled and Unskilled Labor, Annual Figures and HP Trend

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We close this preamble to our empirical investigation by reviewing the evidence of wage differentials and summing up what the literature has conjectured on the technology–skill duality in Swedish manufacturing. Figure 2 sums up the few available series of skilled to unskilled wage ratios most of which originate from Gösta Bagge et al. (1933; 1935) and end before World War I. The only series reaching across the 1920s is the one concerning municipal workers’ relative wages. These series can serve as indication of long-running tendencies in spite of heterogeneity in time, space and economic activity (for instance, sawmill workers refer only to the Härnösand district). Having said as much, Figure 2 conveys the message that the skilled to unskilled wage ratio remained quite stable in most industries. The sole exceptions are the relative gains made by unskilled workers in the iron industry and the public sector (municipal workers). Additional information on skill ratios are reported by Jonas Ljungberg (2004), and are measured as rewards to schooling. The ratios do not constitute unambiguous support for a rise in educational premiums in the 1930s and 1940s: on the one hand, wage rates for workers outperformed those of graduate engineers, and on the other, wage rates of graduate engineers outperformed those of college engineers.

Table 1
Unskilled–Skilled Wage Ratio and Proportion of Unskilled Workers
in the Manufacturing Industry, 1914-1985

Period	Centre year	Unskilled-skilled wage ratio	Proportion of unskilled workers
1914-1924	1920	0.87	0.44
1925-1934	1930	0.88	0.49
1935-1944	1940	0.87	0.54
1945-1954	1950	0.89	0.55
1955-1964	1960	0.89	0.58
1965-1974	1970	0.90	0.59
1975-1985	1980	0.94	0.60

Source: Lundh and Prado (2015, online appendix, p. 6)

Information on skill ratios after 1914, pertaining to the mechanical engineering industry, and based on the internal wage statistics of the Swedish Metal Trade Employers' Association (Sveriges Verkstadsförening), also appears in Christer Lundh and Svante Prado (2015), and Table 1 reproduces their results. For 1914-1985, the archive of the Association contains statistics on the hourly earnings of skilled workers ("yrkesarbetare") and unskilled workers ("tempoarbetare"; "grovarbetare") in the cities of Stockholm (1925-1947), Göteborg, Malmö and Eskilstuna (1925-1983). If these pay ratios were indicative of economy-wide rewards to skills, they would suggest that across the 1920s, in the heyday of Swedish electrification, the rewards to skills in fact declined. This interpretation supports the view, contrary to the one of complementarity between technology and skill, that manufacturing favored demand for unskilled workers.

Data and Methodology

Statistics Sweden conducted three complete industrial censuses during the twentieth century. The first of these pertains to 1931 and forms the empirical foundation of our investigation (Företagsräkningen 1931). This industrial census has a more complete coverage than the annual industrial statistics (SOS, Industri). It includes all firms and the published version of it lists, with the exception of agriculture, all economic activities including public and quasi-public firms (run by the state or municipalities). For the purpose of this paper, it lists 168 different industries within the mining and manufacturing sector, which exceeds the range of the annual industrial statistics by a wide margin. This large sample of industries is as close as it gets to establishment-level information, and one may notice that Goldin and Katz's (1998) influential study relies on similar information taken from the US manufacturing census.⁶

The census has aggregated the different industries into 10 branches: 1) ores, iron and metal work, machinery, etc.; 2) extraction industries

⁶ The use of firm-specific data and census data exceeds by far the scope of this study. It instead belongs to a research endeavour that one of the present authors intends to undertake in the near future.

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and quarrying; 3) manufacture of wood products, carpentry, etc.; 4) manufacture of wood pulp, paper, paper products, printing and publishing; 5) food manufacturing industries; 6) manufacture of textiles and clothing; 7) manufacture of leather, horsehair and rubber goods; 8) manufacture of chemicals and chemical products; 9) constructions, repairs and installations; and 10) electricity, gas and water services. The last category of industries, which refers to utilities, is excluded from the sample in order to maintain the focus on the manufacturing sector.

As in the annual publications of the pre-1952 versions of the Swedish industrial statistics, output in the census is sales values, hence gross output. Ideally the census would have provided data for intermediate consumption, thereby making it possible to compute net output, or value added as it is referred to in national accounts. On the issue of data constraints, the census does not offer information on capital investments. This neglect forces us to use horsepower per worker as a proxy for capital intensity. The census provides a detailed classification of the kinds of energy sources used to generate motive power. It distinguishes among steam, water, oil and gas engines on the one hand and electric motors on the other. Thus it allows us to separate the role of electricity in total motive power.

Because changing reward to investment in education is an empirical implication of Goldin and Katz's (1998) model, it is essential to clarify the meaning of workers' skill levels in our empirical investigation. The evidence at our disposal, output and other variables by industry, does not distinguish among either workers' formal education or practical skills, which makes it necessary to resort to a cruder proxy for human capital. Our approach to distinguishing among industries' use of human capital uses shares of occupational status. This solution finds support in Goldin and Katz (1998, 719) who argue that the relative size of white-collar workers "provides an alternative proxy for skill levels" because, on average, white-collar jobs correlate positively with higher levels of education. Although it is more to the point to say that our investigation differentiates between demand for white-collar and blue-collar workers in response to changes in technology, the skill metaphor applies throughout in order to convey the flavor of Goldin and Katz's argument.

Moreover, Anderton et al. (2002) argue that the wage bill of white-collar and blue-collar workers mirrors the relative demand for skills. The employment shares of white-collar and blue-collar workers that we use probably track these cost shares.

The census splits each industry's employment into seven categories: owners and managers; administrative and commercial staff; technical and science trained personnel; shop, catering and kitchen staff; workers at production; machinists, electricians, transport, warehouse and trade workers; and homeworkers. Our approach to examining skill intensity begins by collapsing the administrative and commercial staff and technical and science-trained personnel into a white-collar heading. We completely exclude the categories of owners and managers, shop, catering and kitchen staff and homeworkers in an effort to have a narrower definition of white-collar and blue-collar workers; the higher the share of white-collar employment, the more skill-intensive the industry. The econometric exercise also includes a specification that narrows the white-collar category by including only the technical and science-trained personnel. Our approach is consistent with Goldin and Katz's (1998) who use the relative size of a "nonproduction" group of workers as a proxy for skill level, and for a specification of white-collar workers. As regards the empirical model, we have run a straightforward linear regression model (OLS), as

$$W = \beta_0 + \beta_1 \left(\frac{Y}{L}\right) + \beta_2 \left(\frac{Hp_{El}}{Hp_{Tot}}\right) + \beta_3 \left(\frac{Hp_{Tot}}{L}\right) + \varepsilon_i$$

in which the dependent variable W is the share of white-collar workers in total employment, thus capturing skill intensity. The variable is composed either by adding administrative and commercial staff to technical and science-trained personnel (extended version) or by including only technical and science-trained personnel (narrow version). The first independent variable $\frac{Y}{L}$ is gross output per worker, where gross output is measured through sales values. The next variable $\frac{Hp_{El}}{Hp_{Tot}}$ is the share of horsepower generated by electricity out of the total horsepower used in the industry, while the variable $\frac{Hp_{Tot}}{L}$ captures the share of horsepower per worker and is

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used as a proxy for the level of capital investment or capital deepening, a variable also included in Goldin and Katz's (1998) specification. The independent variable of interest is the share of electric motors in total horsepower. To verify the technology–skill complementary hypothesis requires us to establish a positive association between these two variables. The regression exercise moreover holds constant the effects of output per worker and horsepower per worker.

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Table 2 sets out the results of the different regression specifications. Overall, the results provide support for the technology–skill complementarity hypothesis for Sweden. The coefficients measuring the effect of electricity on the demand for white-collar workers have the expected positive sign and are statistically significant in all regression specifications. The size of the effect, though—the Oomph to speak with Stephen Ziliak and Deirdre McCloskey (2008)—is rather inconsequential. Based on the results of both specifications in Table 2, a one percentage point increase in the share of electric motors' horsepower brings a rather modest increase of approximately 0.1-0.04 percentage points increase in the share of white-collar workers. Also, a standard deviation increase in the share of electricity adoption (i.e., approximately 17.5 percentage points) is associated with an increase of approximately 0.7-1.5 percentage points in the employment share of white-collar workers.⁷

⁷ An increase of 0.7 percentage points refers to the specification where the dependent variable—share of white collar workers is narrowly defined only by the number of technical and science trained personnel. Accordingly, the figure of 1.5 percentage points increase is estimated by the specification which extends the white-collar workers category by including the administrative and commercial staff.

Table 2
 Relationship between Demand for Skilled Labor and Industry
 Characteristics in Swedish Manufacturing in 1931

	Dependent variable			
	Share of white-collar workers (extended) ¹		Share of white-collar workers (narrow) ²	
	(1)	(2)	(3)	(4)
Output per worker (Y/L)	0.189*** (0.0308)	0.192*** (0.0568)	0.02 (0.012)	0.021* (0.012)
Share of electric motors' HP	0.085*** (0.026)		0.0374** (0.01)	
Categories				
1. Share of electric motors' HP (0-60%) (reference category)				
2. Share of electric motors' HP (61-84%)		2.724* (1.567)		1.378** (0.608)
3. Share of electric motors' HP (85-100%)		4.017*** (1.402)		1.75*** (0.544)
Total HP per worker	0.0437 (0.0784)	0.0042 (0.956)	0.106*** (0.03)	0.0861*** (0.029)
Constant	-0.745 (2.396)	3.364** (1.394)	-0.854 (0.926)	0.936* (0.541)
Observations	161	161	161	161
R-squared	0.246	0.237	0.128	0.102
Standard error of regression	5.267	5.317	2.037	2.084

Notes: Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

¹ The “extended” white-collar workers’ category includes the administrative and commercial staff and technical and science-trained personnel.

² The “narrow” white-collar workers’ category includes only the technical and science-trained personnel.

Goldin and Katz’s (1998, 722 Table VI) somewhat differently specified model also predicts that a unit change in the fraction of total horsepower run by purchased electricity brings an increase in the share of nonproduction (white-collar) workers. But the predicted effect of their model is larger: a unit increase in the electricity horsepower brings an increase of 0.05 units in the white-collar workers’ share of total labor costs.

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The small effect of electricity on demand for white-collar workers may stem from threshold levels in the share of electric motors. Once industries have exceeded a certain share of electricity, the additional boost to white-collar demand decreases. The aggregate nature of the data may also mask the impact of electricity on demand for white-collar workers. To deal with the potential presence of threshold levels, an alternative specification treats the share of electric motors as a categorical variable: #1 (0-60 percent); #2 (61-84 percent); and #3 (85-100 percent). This specification shows that the relative effect of electrification on the demand for skilled labor (accounting for all white-collar workers) increases significantly as industries employ more electric motors in their production. The relative effect of employing 61-84 percent of horsepower by electric motors is associated with a significant increase in the relative demand for skilled labor by almost 1.5 to 3 percentage points, while the relative effect of employing 85-100 percent (as opposed to 0-60 percent) is associated with an even higher relative demand for skilled labor by almost 2 to 4 percentage points. This is consistent with Schön's (2000) proposition that the forerunner in electricity use tended to employ relatively higher shares of white-collar workers.

The regression results suggest that electricity had an impact on the workforce composition, even when controlling for capital deepening. We may coin this a volume effect. This is a cross-section though, and whether this effect would also hold in a more dynamic regression analysis remains to be seen in future work. In addition, note that although our results suggest that there is a positive and statistically significant association between the level of electricity adoption and the demand for skilled workers, this does not suggest much about the causal relationship between the two variables. This would arguably require establishment-level data for several benchmark years.

As our scant evidence of pay ratios indicated, nothing suggests that the small volume effect borne out by our econometric exercise had an impact on the relative price of skilled and unskilled workers. The skilled to unskilled pay wage ratios remained relatively stable during the years of

electrification up until the First World War and tended to decrease in the 1920s (such as in the case of iron works, municipal workers and the engineering industry). If anything, the available evidence tilts the interpretation towards declining pay ratios, hence contrary to what we would expect. In this respect, our study is reminiscent of the American one because, there too, the quantity effect was not accompanied by changing pay ratios. In the American case though, the increasing supply of skilled workers through the expansion of secondary education provides a clue to the absence of a price effect.

In sum, the problem haunting the technology-skill complementary conjecture is the following: the era in which we would expect the inequality effect intrinsic to the technology-skill complementarity to realize its full potential coincides with the great leveling of the twentieth century. Besides Thomas Piketty (2014) and his associates, who have documented a sharp fall in top income shares, a range of evidence on labor market outcomes, speaking more directly to the effects of technology on skill rewards, also testifies to a reduction in inequality during the first half of the twentieth century (Svenja Gärtner and Svante Prado 2016; Peter Lindert and Jeffrey Williamson 2016, 194-218). In addition to the small volume effect, what else could have tempered, or even overturned, the push for greater inequality in Sweden?

Perhaps the answer rests with the impact labor market institutions had on income distribution, which is in line with what O'Rourke et al. (2013) proposed. Such an emphasis would provide a recognizable agenda for Swedish economic historians, one that Lundh (2010) in particular, through his general coverage of the subject, has made so much easier to pursue. In recent research, conducted jointly with others, he has argued that the acts of labor market institutions contributed significantly to compress the wage structure in the second and third quarters of the twentieth century in Sweden and, in particular, contributed to the rapid decline in inter-county wage differentials and the urban to rural wage ratio in the latter half of the 1930s and 1940s (Lundh and Prado 2015; Kristoffer Collin et al. 2016).

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Before World War I the level of union density was still quite low (c. 15 percent) but collective agreements covered about half of the working force in industry because the agreements were valid also for non-union members employed by firms that directly, or through the employer's association, accepted the agreement. Unionism increased rapidly during the interwar period and around 1930, half of blue-collar workers in industry were union members. Collective agreement coverage reached 60-80 percent, depending on the industrial branch (Lundh 2010, 105). Meanwhile, unlike Britain, in which unions were organized by occupation, trade unions and employers in Sweden were largely organized by industry. Therefore, collective agreements were in general industry specific. This organizing principle provides a possible explanation as to why intra-industry wage variation was rather minor throughout. Collective agreements covered both skilled and unskilled workers' wages and working conditions within a particular industry. This alignment prevented frictions from appearing across worker categories within the same industry. Skilled and unskilled workers' wages increased in tandem within similar industries, whereas inter-industry differences remained. The introduction of centralized wage bargaining between the Swedish Employers' Confederation (Svenska Arbetsgivareföreningen, SAF) and the Swedish Confederation of Trade Unions (Landsorganisationen i Sverige, LO) in the late 1930s also paved the way for wage compression across different industries.

Centralized agreements, designed to stem soaring inflation during the initial phases of the war, were instrumental in the rapid compression of inter-industry wage differentials during World War II (Svante Prado and Joacim Waara 2015). These agreements stipulated that only low-wage industries would be fully compensated for the rising cost of living. As a corollary to this particular stance on wage policy, low-wage industries outgrew high-wage industries. One may view this stance of wage alignment during the war as a predecessor of the so-called solidaristic wage policy that would be put into practice in the 1950s. The actual wage policy known as solidaristic aimed to compress the industrial wage structure in collective bargaining by allowing a

larger raise in payments to the low-wage groups. To achieve this aim required coordinated collective bargaining for the entire industrial labor market. As both main parties in the industrial labor market, if for different reasons, intended to keep wage dispersion within a certain range, coordinated collective bargaining ending with a nationwide collective agreement at the industry level took place in 1952, and continuously from 1956 to 1982 (Jörgen Ullenhag 1971; Lundh 2010).

With the Swedish economy armed with this much resistance to the inequality forces embedded in the technology–skill complementarity, it should perhaps come as no surprise that the available, if scarce, evidence of skill–unskilled wage ratios fails to convey an upward trend despite the rapid electrification of manufacturing processes.

Conclusion

This article addresses the role of technology–skill complementarity in Sweden during the interwar years. In particular, it discusses the role of the rapid electrification of Swedish manufacturing and how it affected the demand for skilled and unskilled workers. According to the idea of Goldin and Katz, which is firmly set in an American context, the gradual substitution of the electric motor drive for the steam engine rendered redundant the use of cadres of unskilled workers. Electrification instead spurred the demand for skilled workers through an increasing use of continuous batch methods. The early American expansion in secondary schooling increased the supply of skilled workers, which tempered a rise in the skilled to unskilled wage ratio that otherwise would have followed in the wake of electrification. In Sweden, electrification proceeded just as fast, or even faster, than in the US, and no expansion of secondary education occurred until the 1950s.

We test for the presence of a technology–skill complementarity by using cross-sectional branch level data from the Swedish industrial census of 1931, focusing on mining and manufacturing. The share of electric motors in total horsepower denotes technologies, in this case electrification, and each industry’s share of engineers and administrative and commercial personnel (non-production workers) denotes the use of

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human capital. Admittedly, our measures of technologies and workers' skills are merely crude proxies; nevertheless, they allow a preliminary operationalization of the notion of technology–skill complementarity.

The test confirms the skill–capital complementarity—the higher the degree of electrification the higher the share of white-collar workers—which provides support to the hypothesis that the rapid electrification of Swedish manufacturing brought about consequences for the demand for different worker characteristics. The estimated effect, meanwhile, is rather small. Moreover, the scant evidence concerning skilled to unskilled wage ratios does not bear out that skill-biased technological change impinged on the relative rewards to skilled and unskilled workers in the manner the model posits. If anything, the historical evidence shows that the skilled–unskilled ratio declined. Other evidence also shows that the 1930s and 1940s witnessed marked reductions in inequality.

If we were to take the evidence of wage ratios at face value, the increasing relative rewards to unskilled workers would suggest that labor market institutions, in the form of unionization and centralized collective agreements, favored unskilled workers' wages and prevented the pro-inequality forces to exercise their raw clout on the rewards to skills.

ACKNOWLEDGEMENTS

We would like to acknowledge the useful suggestions from two anonymous referees. Svante Prado would like to acknowledge financial support from the Riksbankens Jubileumsfond and the Jan Wallander and Tom Hedelius Foundation (research project “Weights and Currencies”).

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