The Political Economy of Innovation in the Industrial Revolution: Labor Market Conflict and Technical Change*

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Abstract

We study conflict in the labor market as a factor driving technical change. Strike activity was associated with significant increases in patented invention during the Industrial Revolution in England. The positive relationship between strikes and invention was strongest in textiles, the most dynamic industry, and holds controlling for industry-specific wages and output. The legalization of labor unions in 1824 delivered a shock that shifted how invention responded to strikes and the direction and bias of technical change. After the legalization of unions the positive relationship between strikes and invention increased differentially within textiles, patenting within textiles shifted towards job tasks in which workers were previously less organized, and the relative pay of lower skilled, less organized, and female factory workers rose.

JEL Codes: O33, O31, N34, N63, J50, J31, P10

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I Introduction

Economic study of induced innovation focuses on the influence of factor prices, endowments, and demand (Acemoglu 2002a;b; 2007; Hicks 1932; Schmookler 1966). However, theory and history indicate that bargaining conflict in the labor market is a distinct and important driver of innovation (Rosenberg 1976; Bowles and Gintis 1993). Indeed, classical economics suggests that conflict in the labor market was a core determinant of technological change in the Industrial Revolution, and specifically that new inventions enabled employers to replace skilled and organized workers with unskilled and less organized labor (Marx 1867 [1976]). Despite these indications of importance, quantitative evidence on the role of bargaining conflict in induced technical change is remarkably limited.

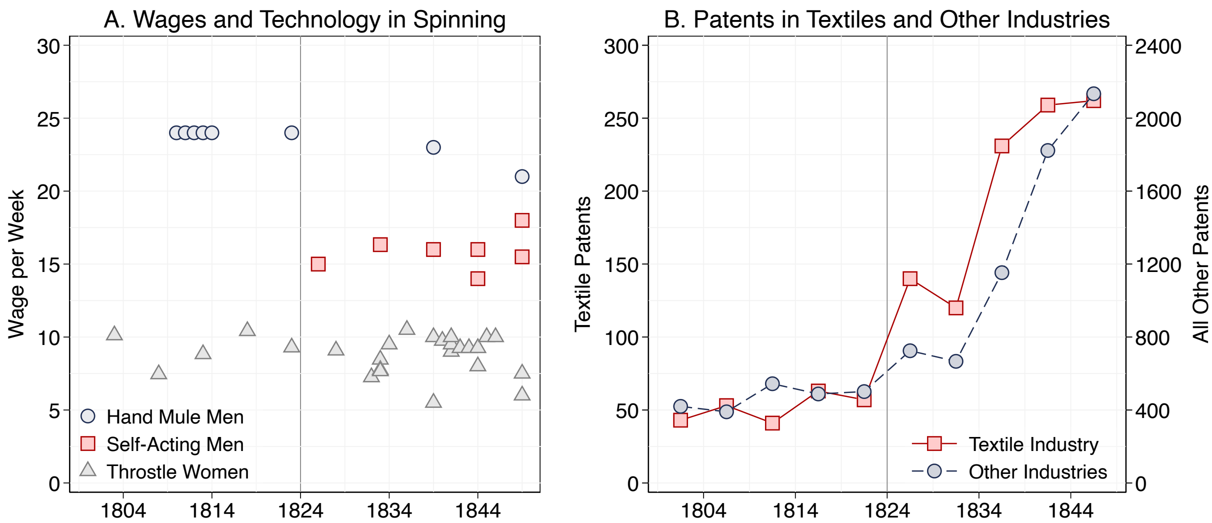
We study how conflict in the labor market drove invention and shaped labor market outcomes in the Industrial Revolution. We investigate the relationships between strikes, technical change, and labor market outcomes before and after the legalization of labor unions in England in 1824. In economic terms, the legalization of unions exogenously lowered the price of collective action for workers and increased transaction costs for firms. Policy makers had expected that legalization would reduce union activity; instead, legalization had the *unintended effect* of increasing union activity and the costs of enforcing transactions for employers (Hammond and Hammond 1968; Page 1919; Smart 1917; Dicey 1904).

We find strike activity led to significant increases in patenting in the industrial revolution. Strike activity in a given industry led to increases in the patenting of inventions in that industry. This positive relationship was strongest within the most dynamic industry, textiles, and increased significantly after the legalization of labor unions in 1824.[1] The positive relationships that we find between strikes and invention hold controlling for variation in wages and output at the industry-level and when we study the arrival of high quality patents.

To study labor market outcomes, we gather disaggregated data on jobs and wages in the textile industry, which pioneered mechanization. The data reveal the bias of technical change shifting to unskilled and less organized labor after unions were legalized. We find invention shifting toward jobs in which workers were not organized, especially during strikes; relative pay for low skilled workers rising; new jobs differentially promoting the employment of low

[1] On the leading role of the textiles industry in technical change and productivity growth in the industrial revolution see Crafts (2021), Allen (2009a), Harley (1999), Berg (1994a), and Berg and Hudson (1992).

Figure 1: Wages in Spinning and Patented Inventions



Panel A plots weekly wages in factory spinning for adult men using the hand mule and self-acting mule and women using the throstle, in shillings, from Wood (1910a). Panel B plots the number of patented inventions in textiles and other industries in 5-year periods indexed to 1824, when labor unions were legalized via the repeal of the Combination Acts, in data from Woodcroft (1854) and Nuvolari, Tartari, and Tranchero (2021).

wage and less organized workers; and large firms paying relatively high wages to female child laborers but not paying a premium to workers in other demographic groups.

Figure 1 motivates our study. Panel A graphs wages for factory spinners before and after the invention of the *self-acting spinning mule*, which was developed in response to a strike by spinners after labor unions were legalized in 1824. We observe no increase in wages before the self-acting technology was invented. Factory owners facing the strike hired the inventor Richard Roberts to develop this machine, which was patented in 1825 and led to the introduction of lower paying jobs and a fall in wages for work using the hand mule technology. Contemporaries viewed this process as emblematic. Marx (1867 [1976], p. 563; 1885 [1955], p. 161) argued that self-acting spinning "opened up a new epoch in the automatic system" but that, "strikes have regularly given rise to the invention and application of new machines. . . employed by the capitalists to quell the revolt of specialized labour." More generally, historians observe that the costs of labor conflict were economically important and shifted with the legalization of unions, which was particularly salient in the textile industry (Rule 1986; Bruland 1982; Gatrell 1977; Rosenberg 1976; Webb and Webb 1894). Panel B shows that the number of patented inventions in textiles increased sharply and differentially after unions were legalized by the 1824 repeal of the Combination Acts.

Economic theory and history together generate hypotheses that we test in novel data. First, we expect to find that invention responds positively to strike activity within an industry. Second, we expect to find a positive differential in the relationship between strikes and invention within the textiles industry, especially after the legalization of unions. Third, if strike activity had a direct effect on invention, we would expect to find this controlling for variation in wages and output in an industry. Fourth, we expect to find strike activity promoted high quality invention, given historical evidence tying strikes to important textiles inventions. Fifth, we expect to find strikes and the legalization of unions promote invention that shifts demand away from skilled and towards less organized unskilled labor, leading to declines in the relative wages of skilled workers in the dynamic textiles industry. Sixth, we expect to find larger firms in textiles hiring relatively more female workers and, potentially, paying higher wages to workers who were unskilled and posed lower enforcement costs.

We focus on the relationships between reports of strike activity, patents, and jobs in England. We measure news of strike activity using reports in *The Times*, which was the leading national newspaper in England, provided business news to the commercial middle classes, and offers unique, consistent evidence of the media market signal on strikes from 1790 to 1850.[2] Our baseline measure records the number of strike reports in an industry-year. We measure invention using Patent Office data and measures of patent quality from the economic history literature. We assemble disaggregated data on wages and union activity at the job (occupational task) level in the textiles industry to document how conflict and invention related to the structure of work and labor market outcomes.

First, we test and confirm the hypothesis that strike activity reports are positively associated with inventive activity within industries. We focus our main analysis on the pattern of strike reports and patents at the industry-by-year level.[3] We find a positive relationship between strike reports and inventions when we study all the variation within

[2] We discuss how *The Times* provides a market signal, how *The Times* aggregated news from other papers, newspaper and non-newspaper sources of evidence on strikes, and the signal in newspaper coverage below.

[3] Our focus on the industry-year as a unit of analysis reflects the spatial concentration of invention and the temporal manner in which invention responded to strikes. Spatially, invention was concentrated: almost 50% of patents were granted to applicants using London addresses. Temporally, strikes had the potential to shape invention over different time horizons, but the relationship between past strikes and subsequent invention is ambiguous, contingent on both strike outcomes and later organizing, and empirically hazy. In addition, while workers certainly sometimes struck in response to technical change, they did so in response to technology adoption rather than invention *per se* and there were typically long and variable lags between the dates at which patents were granted and the dates at which technologies were adopted in practice.

an industry and when we focus the analysis on narrow windows of time in an industry. We thus find that invention in an industry rises with strike activity in that industry when we compare years within a given decade, and that invention shifts with and not before strikes.

Second, we test for differences in the relationship between strikes and invention across industries and over time. We find that the positive relationship between strikes and invention was strongest, and increased most following the legalization of unions, in the textile industry, the most dynamic industry of the industrial revolution. We find that an additional strike report is associated with a 1.2% increase in invention for all industries, and a 2.3% increase in textiles across all years in our data. These relationships shift after the legalization of unions in 1824, when an additional strike report in textiles is associated with a differential 7.6% increase in the number of textile patents, and are not explained by underlying trends.

Third, we address questions relating to causal inference and identification. A natural question is whether confounders, which shift at the industry-by-year level, could explain the relationship we observe between strikes and invention. The main candidates are industry-year changes in factor prices or in demand. To assess the role of these factors, we incorporate data on wages and industrial activity at the industry-year level in our analysis. We find the strong positive relationship between strikes and invention holds virtually unchanged, conditional on current and lagged wages and current and lagged output in a given industry.

A related question concerns the potential endogeneity of the legalization of unions. In point of fact, policy makers explicitly intended and expected that this legal change would *reduce* labor market conflict and union activity (Hammond and Hammond 1968, pp. 118-120; Page 1919, p. 76; Dicey 1904, p. 522). Legalization thus led to *unintended* increases in union activity and enforcement costs for employers. The legislation was taken to parliament by MPs committed to *laissez-faire* economics, and passed with minimal review and almost no prior news media coverage, in a period when the working classes were disenfranchised.

Finally, exogenous shifts in labor supply cannot plausibly explain the relationship between strikes and technical change. The industry-year variation in strikes and invention that we study plays out at a frequency at which exogenous shifts in labor supply due to demographic changes are not plausible confounders, as demographic trends were relatively stable. Further, extensive evidence shows that labor supply was itself endogenous, with migration and entrance into industrial employment induced by relative wages, as shown below. That said, the relationship between labor market conflict and technical change reflects a setting shaped by demographic trends, including population growth, as we also discuss below.

Fourth, we clarify the economic process by investigating the quality of patents and the role of supply-side factors. Historical research suggests strikes led to technical progress, but the relationship between strikes and patent quality is theoretically ambiguous. We study patent quality using a measure that captures historical citations and references, from Nuvolari, Tartari, and Tranchero (2021). We find strikes were associated with differentially larger increases in the number of high quality textiles patents, defined as patents above median quality, after the decriminalization of unions. We find an even larger positive relationship between strikes and textile patents in the top 25% of the distribution, but no relationship in the top 5% of the distribution. When we study the supply-side, we find that the share of textiles patents by independent machine makers increased sharply following the legalization of unions. We also find that the response to strikes was largest for inventors who were firm owners, former apprentices, and machine makers; other factors such as inventors' university training, religion, and cultural networks are not associated with a response to strikes.

Fifth, we provide evidence on the direction and bias of technical change within textiles. We study technical change and wages across the job and task structure. We distinguish jobs in which workers did and did not organize unions in the period before unions were in fact legalized. We test and confirm that patents for invention shifted towards non-union jobs, and that strikes led to larger increases in patents for invention targeting non-union jobs, after union bargaining was legalized. We also show that, after the legalization of unions, low-paying jobs enjoyed relatively fast wage growth and that new jobs were also lower-paying, consistent with technological change biased towards unskilled and less organized labor.

Sixth, we study how employment and pay varied with firm size within textiles. We find that larger firms, which used more advanced technology and were more capital intensive, employed relatively more female workers by the 1830s. We also find that larger firms paid significantly higher wages to female child laborers, but not to more skilled or less "obedient" demographic groups. These patterns are consistent with technology directed towards both unskilled labor and reductions in enforcement costs associated with contested exchange.

Our study contributes to the economics of induced innovation and labor markets. Where Hicks (1932) proposed that shifts in factor prices induce technical change, recent research focuses on autonomous shifts in labor supply due to education and demography (Acemoglu 2002a; 2007; Acemoglu and Autor 2010). In contrast, we document how labor market conflict induced technological change during the industrial revolution, when factor prices, endowments, and demand were not confounders. However, in a deeper sense our investigation extends a logic in Hicks' argument, as we study the relationship between technical change and strikes, which raise the salience of *future* factor prices for invention.[4] We thus test and find support for the "contested exchange" perspective on labor markets and political economy (Bowles and Gintis 1988; 1993). Consistent with this framework, our investigation shows how distributional conflict in the labor market may induce the development of technologies that shape the future path of factor prices and thus secure longer-run profitability. In this we confirm Rosenberg's (1976) argument that strikes are key "focusing devices" which direct technical change, alongside shifts in material input prices, whose impact is documented by Hanlon's (2015) related study of innovation in cotton processing during the US Civil War.

Our findings also clarify the economics of directed and biased technical change. Technical change has been skill-biased in recent decades, but existing evidence on the bias of technology during the industrial revolution is ambiguous. Economists reviewing the same narrative sources variously suggest technical change was directed towards *unskilled* labor (Acemoglu 2002b) or *skilled* labor (Caselli 1999). Economic history research broadly finds stable skill premia, but has focused on skill premia within the construction industry or restricted comparisons of adult male wages across industries (Allen 2009a; Jackson 1987; Feinstein 1988). We examine variation in invention and pay across job tasks within the key textiles sector. We find a shift in the direction and bias of technical change towards unskilled, less organized labor and routine jobs within textiles after the legalization of unions.[5] Our findings confirm Acemoglu's (2002b) hypothesis, but indicate a different causal process, shaped by labor market conflict, with less of a role for other autonomous shifts in labor supply.

Our study also contributes the larger literature on the Industrial Revolution, and contrasts with the leading demand and supply side explanations. On the demand side, Allen (2009a;b) argues that high wages drove technical change, by comparing wages in England and France and by studying changes in spinners' wages in England before the mechanization of

[4]Fellner (1961) suggests *expectations* on factor prices may direct invention in his critical review of Hicks.

[5]The pattern we document, in which automation promotes routine labor process tasks, contrasts with the pattern since 1980 in which automation has eliminated routine tasks (Acemoglu and Restrepo 2019).

spinning in the 1760s.[6] On the supply side, Mokyr (2009) argues that culturally-driven shifts in knowledge and skill formation were causal. In contrast, we find that workers' collective action drove technical change at the industry-level, when and at frequencies over which factor prices and cultural shifts were not confounders, particularly after the legalization of unions. However, we study the interplay between innovation and the labor market *during* the industrial revolution, and thus in a context shaped by the initial mechanization of spinning and prior knowledge processes that Allen (2009a) and Mokyr (2009) emphasize.

We also contribute to research on the political economy of labor markets. A rich literature examines political responses to historical technical changes that shifted labor market outcomes (Mokyr 1990; 1998; Frey 2019). In the period we study, Caprettini and Voth (2020) document how the adoption of labor-saving technology in British agriculture shaped the "Swing Riots" of 1830, focusing on variation in technology induced by geography. In contrast, we study how collective action by industrial workers and the legalization of unions shaped the development of technology and labor market outcomes. In this, we quantitatively test and confirm hypotheses on the role of strikes in directing technological change derived from Marxian economics (Bruland 1982; Rosenberg 1976; Marx 1867 [1976]; 1885 [1955]).

Finally, our analysis speaks to classic questions concerning the timing and nature of the Industrial Revolution. The period between the late 1700s and early 1800s, when spinning was first mechanized, is emphasized in many studies (Mokyr 1990). However, Schumpeter (1939, p. 221) argued somewhat iconoclastically that, from a labor market perspective, "if one wishes to refer the industrial revolution to a definite historical epoch it can be located more justifiably in the second quarter of the nineteenth than in the end of the eighteenth century."[7] Our analysis uncovers shifts in technology and labor markets that echo this periodization, and documents how labor market conflict and institutions drive creative economic processes that are sometimes attributed more purely to technologists and entrepreneurs.

[6] These analyses are subject to debate. Kelly, Mokyr, and Gráda (2014) argue product wages were not high in England because British workers were more productive than their French counterparts. Stephenson (2018) questions whether Allen's (2009a) data accurately capture the real wage. Humphries (2013b) and Humphries and Schneider (2019) gather novel evidence and find spinners' wages were low and not rising before the spinning jenny was invented. See also Allen's (2019, 2020) extended responses to these critics.

[7] Schumpeter explicitly derived this view from Tougan-Baranowsky, who observed in his pioneering study that, "from the point of view of the working masses, the most 'revolutionary' era was not the last decades of the 18th century and the first of the 19th... ordinarily considered as the 'industrial revolution' – but rather the period between 1825 and 1850" (Tougan-Baranowsky 1913; p. 4 – our translation).

II Historical Evidence on the Economic Setting

II.1 The Process of Technical Change

The *direction* of technical change in the industrial revolution is subject to debate.

A leading view is that technical change was directed toward cheaper, unskilled labor. Thus, in *The Philosophy of Manufactures*, Andrew Ure (1835; p. 23) wrote that it is the,

> "aim and tendency of every improvement in machinery to supersede human labour altogether, or to diminish its cost, by substituting the industry of women and children for that of men; or that of ordinary labourers, for trained artisans."

Skill in manufacturing was historically "a male 'property' " (Rule 1987; p. 108). In the industrial revolution, women and child workers were often paired with advanced technology, especially in the textile industry which pioneered mechanization and factory production (Habakkuk 1967, p. 139; Berg 1994a).[8] Technical change in textiles led to an "extreme division of labour" in which workers were "engaged to perform specific tasks" and women and children were employed to an extent "unparalleled in non-textile industries" (Winstanley 1996, p. 123; Tuttle 1999). Technical change shifted the set of tasks different types workers performed and thus relative wages (Factories Inquiry Commission 1834).[9] Allen (2009a;b; 2018) argues technical change was broadly labor-saving and induced by high wages.[10]

Narrative evidence strongly suggests that conflict in the labor market also shaped the direction of technical change. Skilled male labor was "not only relatively expensive but potentially threatening" (von Tunzelmann 1994; p. 290); female and child workers were more "obedient" (Pinchbeck 1930; Tuttle 1999). Thus Gaskell (1833; pp. 185, 187) observed that because, "the child or woman was a more obedient servant…and an equally efficient slave to the machinery," and was substituted for "difficult to manage" men.[11] Critically, skilled adult male workers were differentially able to engage in collective action, strike, and

[8]The *Reports of the Factory Inspectors* thus observe, "the smaller amount of wages paid to women acts as a strong inducement to…employ them instead of men, and in power-loom shops this has been the case to a great extent" (Horner 1843; p. 20).

[9]The Factories Inquiry Commission (1834; I, p. 119) explicitly notes that the male-female wage premium reflects how adult male workers are suitable for all tasks while adult women are only suitable for some, and that future developments in machinery are likely to shift the allocation of tasks and thus relative wages.

[10]This "high wage" interpretation of the industrial revolution is challenged by Kelly, Mokyr, and Gráda (2014) and Humphries and Schneider (2019), who find that *product wages* were not high in England and that British spinners' wages were not rising before key technological break-throughs, as described above.

[11]This is subject to debate. Nardinelli (1980) suggests technical change reduced demand for child labor. Tuttle (1999) and Humphries (2013a) argue that mechanization increased the productivity of children.

impose enforcement costs on firms, as we discuss below (Marx 1867 [1976]; Thompson 1963; Habakkuk 1967; Rosenberg 1976). Gatrell (1977; pp. 112-3) suggests that these costs varied with firm size in textiles and that, "large firms were *obliged* to save on labour, in view of their greater sensitivity to unionist bargaining power." This observation invites the hypothesis that larger firms hired more, or paid a premium to, unskilled and more obedient workers.

Human capital also shaped the development of technology from the supply side. Technical change reflected the activities of talented, highly trained machine makers, mechanics, and engineers (Kelly, Mokyr, and Ó Gráda 2023; Hanlon 2022; Cookson 2018; Mokyr 2009; MacLeod 1992). Some scholars propose an "entirely supply-based" interpretation in which a cultural "*zeitgeist*" directed these activities and technical change (Meisenzahl and Mokyr 2012; pp. 451, 474), however contemporaries observe these activities were in part endogenous, as economic development, "created a new demand for artificers... useful in the construction of machinery" (Kennedy 1819; p. 214). Indeed, while manufacturers developed technologies in-house, textiles firms were distinctive in "relying heavily on independent machine makers" (Cookson 1994; p. 751). Our quantitative analysis takes initial human capital endowments as given and studies how the occupations of inventors shifted when unions were legalized. But our analysis also reflects the fact that valuable inventions in textile machinery required limited scientific knowledge and were relatively "easy" (Meisenzahl and Mokyr 2012; p. 459).

While shifts in labor supply can also direct technical change, historical evidence indicates that labor supply responded to technology in the period we study.[12] As industrial production developed, "the great demand for labour was met by newcomers to the town... attracted by the prospects offered by the new industry," which offered relatively high wages to workers across the skill, age, and sex distributions (Collier 1964; pp. 15-16). Witness testimony before the Factories Inquiry Commission (1834; II, p. 169) confirms that, "People left other occupations and came to spinning for the sake of the high wages" and that, "whole families were sent for" by firm owners.[13] Urban population growth thus responded to technical change in the late 1700s and early 1800s.[14] However, demographic trends also shaped labor supply, with population growth accelerating and the British population becoming younger

[12] As a heuristic, we distinguish between labor market conflict and labor supply shifts not associated with such conflict. Clearly, however, strikes involve workers collectively refusing to supply labor.

[13] Advertisements posting employment vacancies in newspapers were frequent (Pinchbeck 1930; p. 185).

[14] This went beyond spinning in Manchester. Thus Felkin (1831; p. 1) observed that the, "large increase in population" in early 1800s Nottingham, "may be fairly attributed to [mechanical] bobbin net manufacture."

across the 1700s and first decades of the 1800s (Wrigley and Schofield 1989).

The overall *direction* of technical change in the Industrial Revolution remains ambiguous, given the complexity of the narrative record and evidence on innovation. The pattern of change varied across and within industries, including branches of textiles (Hudson 1986). Few patents indicate whether a given invention is labor-, skill-, or capital-saving (Nuvolari, Tartari, and Tranchero 2021). There was also variation in the direction of technical change at the level of individual techniques. Spinning was a female occupation before mechanization, became a skilled male occupation after mechanization began in the late 1700s, before the self-acting mule promoted the use of less skilled labor while still not eliminating skilled men in spinning (Pinchbeck 1930, p. 184; Lazonick 1979). The factor-saving implications of hiring a given type of worker also varied: child workers were cheap, but firms employed children as machine cleaners to realize capital savings from compact factory layouts that dominated any reduction in the wage bill (Factories Inquiry Commission 1834; I, p. 119). Reflecting this complexity, economists have suggested that the technical changes of the early 1800s were directed toward *skilled* labor (Caselli 1999) or *unskilled* labor (Acemoglu 2002b).

Existing evidence on the *bias* of technical change in the Industrial Revolution is also ambiguous. The bias of technical change is typically reflected in relative factor returns. A large body of research documents stable skill premia across the 1800s by comparing wages for skilled and unskilled workers in the construction industry (Allen 2010; Clark 2005; Bowley 1901), however technology, labor processes, and productivity were relatively stagnant in construction during the industrial revolution (Cooney 1993; p. 73). Studies examining differences in wages across more or less skilled industries also find broadly stable skill premia, but focus on select jobs and adult men (Feinstein 1988; Jackson 1987).[15] Relatively little research has examined the dynamics of wages by more finely disaggregated types of jobs or by skill and demographic groups *within* the textiles industry, despite textiles' leading role in the development of mechanized technologies, new factory jobs, and productivity growth.[16]

[15] An exception is Williamson (1985), which suggests technical change was *skill* biased in the early 1800. Three observations are important here. First, the increase in skill premia in Williamson's (1985) data is driven by the incomes of lawyers and doctors, and Feinstein (1988) and Jackson (1987) have shown the result reflects selective and unrepresentative data on incomes for these groups. Second, Williamson (1985) does not examine the wages of female and child workers. Third, the only wages in textiles that Williamson (1985) studies are composite wages for skilled spinners, which do not capture the job-level variation in wages within spinning (shown in Figure 1 above) or within textiles more broadly (examined in Section V below).

[16] A notable exception is Tuttle (1999), who collects evidence on wages of child workers in textiles starting

II.2 Strikes and Invention

Narrative evidence indicates that strikes drove invention in the industrial revolution (Bruland 1982; Smiles 1863).[17] Rosenberg (1976; p. 120) observes, "The preoccupation with substituting capital for labor (especially skilled labor) was more than just a matter of wage rates. Perhaps even more important was the great nuisance value of strikes." Mokyr (1994, p. 15) notes that, "inventions in the industrial revolution were stimulated by workers' strikes, not because machines were necessarily cheaper, but because they were more reliable and obedient." Table 1 provides examples of how strikes led quickly and directly to patented inventions, which contemporaries viewed as an underlying regularity. Thus Marx (1885 [1955]; p. 161) observes that "strikes have regularly given rise to the invention and application of new machines" designed to "to quell the revolt of specialized labour," and that machinery is "the most powerful weapon for suppressing strikes" (Marx 1867 [1976]; p. 562).

Table 1: Examples of Strikes Leading to Patented Inventions

Mule spinners strike of 1824-5 and the self-acting spinning mule: Inventor Richard Roberts worked, "on behalf of the employers to develop the self-acting cotton mule for the immediate objective of disrupting possible strikes of skilled workers" (von Tunzelmann 1994; p. 277).
Wool carders strike of 1833 and wool-combing machine: "This strike was the cause of the invention of the wool-combing machine, which wholly superseded the labour of that class of men, who were the chief ringleaders" (Tufnell 1834; p. 61)
Boilermakers strike of 1837 and riveting machine: "nothing could have been more injurious than the stoppage of the works at such a time. I remonstrated with the men, but without effect…I determined to do without them, and effect by machinery what we had heretofore been in the habit of executing by manual labour" (Fairbairn 1877; p. 163)

Strikes tended to shift incentives sharply, whereas factor prices and labor supply were typically slower moving. Thus a contemporary observed that while mechanization, "has occupied the attention of ingenious men, more or less earnestly, for the last four and twenty years…it has been most eagerly pursued when the manufacturers were labouring under the inconvenience of an actual or threatened turn-out [i.e. strike]" (Wheeler 1836; p. 538).

However, strikes and reports in newspapers could be correlated with economic factors that induced innovation through other channels. Historical evidence suggests strikes may

after the legalization of unions, and suggests that relative wages for children rose in this post-1824 period.

[17] While we focus on invention, labor market conflict also shaped technology adoption, including from abroad. Habakkuk (1967; p. 157) observes, "The adoption of the Fourdrinier machine after 1800 by English paper manufacturers was due largely to their desire to break the power of skilled labour in the industry."

have been procyclical (Gayer, Rostow, and Schwartz 1953; Cole 1948; Smart 1917). Our quantitative analysis thus examines how strikes were related to invention controlling for time-varying macroeconomic factors and current and lagged output and wages within industries.

II.3 The Political and Legal Environment

II.3.1 Historical Overview

The political and legal environment shaped the implications of labor market conflict. Historical evidence suggests changes in legal restrictions on unions and collective bargaining were particularly important, alongside shifts in contract law and labor market regulation. The disenfranchisement of the working class was a fundamental constant in our period.

Collective bargaining and organizational "combinations" of workers were both illegal and widespread in England before 1824 (Chase 2000; Rule 1986; Webb and Webb 1894). Collective bargaining and unions were criminalized under the law of conspiracy across the 1700s, hence before the Combination Acts of 1799-1800.[18] While criminal, workers' collective actions including strikes were common (Chase 2000), which our data confirm. Further, unions of skilled workers were well-established before the industrial revolution, and skilled workers were "in the forefront of organized trade unionism" (Rule 1986; pp. 255, 263). Some workers' organizations were recognized by employers; others operated secretly or as "friendly societies" whose ostensible purposes included providing insurance to workers.[19]

Starting in the 1820s, the legal environment changed. Restrictions on unions and combinations were lifted in 1824-5; criminal sanctions were imposed on workers who broke employment agreements under Master and Servant Law; and regulations were introduced on hours and employment in factories. We discuss these changes below.

II.3.2 Legalization of Unions as an Exogenous Shock

The legalization of unions delivered an exogenous shock to the economy. The repeal was driven by a small number of Members of Parliament who expected and argued that repeal

[18] The Combination Acts of 1799-1800 did not increase the penalties for union action, but did speed up prosecutions, addressing employers' complaints about drawn out proceedings that enabled workers involved in collective action to move across counties and thereby evade prosecution (Aspinall 1949; p. xviii).

[19] Stockport friendly society spinners were jailed under the Combination Act in 1802 (Rule 1986; p. 270).

would lead to a *reduction* in union activity; were advocates of *laissez-faire* economics; and were not influenced by the sorts of political mobilization and lobbying that drove almost all other major legislative reforms (Rule 1986, p. 285; Smart 1917, Cole 1948).[20] The MPs behind the bill believed that criminalization had exacerbated union activity and strikes. They developed the repeal bill in something approaching secrecy, without support from organized labor, and without newspaper coverage. Francis Place, the key architect of the legislation, argued that legalization would lead unions to decline. Thus Page (1919; p. 76) observes:

> "The bills. . . passed the House of Commons and became law 'almost without the notice of members within or newspapers without.' The effect of the repeal of the combination laws was very different from what Place expected. He wrote in 1825 that 'combinations will soon cease to exist. Men have been kept together for long periods only by the oppression of the laws; these being repealed, combinations will lose the matter which cements them into masses and they will fall to pieces'."

The political process leading to the Repeal of the Combination Acts was also unlike the demand-driven, "endogenous" processes leading to other major political changes in the 19th century. As Aspinall (1949; xvi) observes:

> "All the other great reforms of the period – the abolition of the slave trade, Catholic emancipation, the repeal of the Test and Corporation Acts, the Reform Act of 1832, and the abolution of slavery itself – were preceded by periods of agitation outside Parliament conducted through the Press and public meetings."

Remarkably, the Prime Minister is on the parliamentary record stating he was unaware of the contents of the bill and would have opposed it had he known (Aspinall 1949; xxvii).

The legalization of unions indicates how manufacturing interests did not enjoy complete control of politics. Legalization was not reversed, despite increasing transaction costs, triggering what businesses viewed as a "saturnalia" of union activity (Smart 1917; p. 306) and "strong pressure from major employer interests" (Fox 1985; p. 88). The legal shift reflected both reflected the limited political power of industrial capitalists in a state in which aristocratic, landed, and commercial business interests were preponderant and the beliefs of key policy makers committed to *laissez-faire* economics and who therefore believed that workers should be free to organize (Chase 2000; Fox 1985; Cole 1948). This institutional change thus marks an important historical instance of the relative autonomy of the state.

[20] Aspinall (1949; p. xxv) notes that parliament's move to legalize unions would have failed, "had not the *laissez-faire* ideas embodied in the *Wealth of Nations* gradually found acceptance by the governing class."

II.3.3 The Impact of the Legalization of Unions

The legalization of unions is widely viewed as a watershed in labor relations that strengthened the bargaining position of workers, however the implications are subject to debate (Chase 2000; Thompson 1963; George 1936; Webb and Webb 1894). The 1824 legislation repealed the Combination Acts and removed trade disputes from the law of conspiracy, which permitted criminal prosecution of labor organizing since the 1700s and motivates our comparisons of economic activity before and after legalization. However, the 1824 law did not legalize all union activities and, following an immediate surge in strikes and pressure from employers, a revised law was passed. Gayer, Rostow, and Schwartz (1953; p. 173) observe, "A part of the new freedom was withdrawn in the revised Act of 1825; but labour's organization at least was no longer illegal." It remained illegal to picket and "obstruct" businesses; further legalization of union activity came with the Trade Union Act of 1871.[21]

History research indicates that the legalization of unions was consequential. The 1818-19 strike wave in textiles, the largest in the first half of the 1800s (Hall 1989), ended when the union leaders were jailed under the Combination Act. While the Combination Act was "applied sparingly. . . events in Lancashire in 1818-19 reveal how profound its effect could be" (Chase 2000; p. 105). Following legalization, existing organizations formalized themselves and became more assertive (Thompson 1963; Smart 1917). However, legalization had consequences that emerged over time. A macroeconomic downturn limited union activity 1825-1828, but Cole (1948; p. 70) observes, "by 1829 there had been a recovery, and the Unions, now able to organise openly. . . were in a position to resume their forward movement."

Historical evidence suggests the consequences of the legalization of unions were concentrated in the most dynamic industries, especially textiles. Webb and Webb (1894; p. 72) argue that, "it was in the new textile industries that the weight of the Combination Laws was chiefly felt." Rule (1986; p. 267) similarly observes that the criminalization of collective bargaining had a small impact on "well-established organisations of skilled artisans," but a large impact on organizing in areas of "rapid technological change." In his classic study, *Lives of the Engineers*, Smiles (1861; p. 109) notes the pattern of invention reflected how, "Since 1825 unions have especially prevailed in the manufacturing towns."

[21] Other laws were also used to suppress labor organizing. In 1834, the Tolpuddle Martyrs were famously convicted under the Unlawful Oaths Act for swearing an illegal secret oath and transported to Australia.

II.3.4 Other Dimensions of Law and Politics

Other aspects of law and politics also influenced labor market bargaining. Apprenticeship requirements for artisans fell into disuse and were eliminated in 1814, but other laws restricted labor mobility. In particular, the Master and Servant Act of 1823 criminalized breach of contract by workers. This law, "became the weapon of smaller employers" (Berg 1994b; p. 147) and was "mostly but not entirely used by small masters" who hired home workers or ran small workshops (Saville 1994; p. 23), but was at times used to prosecute striking workers (Hay 2000). Master and Servant law was used most intensively to prosecute workers in metalworking, mining, pottery, and brick-making (Hay 2000; p. 258), was not relied on in textile districts (Parliamentary Select Committee 1866; p. 78), and was predominantly used by employers in industries in which technical change did not reorganize and control the labor process (Steinberg 2003; p. 451). Employers' recourse to Master and Servant also reflected geographically varying shifts in labor demand (Naidu and Yuchtman 2013).

Laws regulating factory work were also introduced over our study period. The most important were: the Factory Act of 1833, which set limits of 9 hours/day for child workers and 69 hours/week for under-18's in the textiles industry; and the "Ten Hours" act of 1847, which set a 10-hour day for female and young workers in textiles.[22] Historical studies suggest these regulations increased relative demand for adult and male labor (Wood 1902).

Larger political factors also conditioned the relationship between labor market conflict and invention. The working class was disenfranchised over our study period. In 1832, the Reform Act extended voting rights to small property and land owners, and to shopkeepers paying sufficiently high rents on long-term leases, while disenfranchising women. The failure of the Reform Act to offer political representation to the working class gave rise to Chartism, "an economic movement with a purely political program" (Cole 1948; p. 94), which all the same animated strikes in the 1830s and 1840s (Chase 2000; Saville 1994; Thompson 1963).

To reflect these aspects of law and politics, we focus components of our quantitative analysis below on the relationship between strikes and invention within industry-decades, and control for shared time-varying factors, to study variation within institutional eras.

[22] Others included: the Cotton Mills and Factories Act of 1819, which prohibited employment of workers under 9 years old and capped hours for those aged 9-16 at 12/day; the 1825 act limiting Saturday hours for children; the 1831 act prohibiting nightwork for young workers; and the 1844 act introducing a half-time system for children. See Wood (1902) for details.

III Data

Patents – We gather data on patented inventions as follows. We build on Nuvolari, Tartari, and Tranchero's (2021) database, which classifies all English patents through 1850 in 21 industries such as "textiles," "metallurgy," "agriculture," and "pottery," and provides an index of patent quality reflecting: (1) the references to each patent in the Patent Office "reference index"; (2) references to each patent in 10 books on technological history; and (3) whether a given patent is discussed in the *Dictionary of National Biography*. See Appendix A.

We match patents to jobs as follows. First, we code the subject classification assigned to each patent by the Patent Office in the *Abridgements* volumes. Next we match patent subjects to corresponding job categories recorded in the *Historical International Standard Classification of Occupations* (HISCO) database (Van Leeuwen 2016). Finally, we determine which job categories had evidence of union organizing activity before the legalization of unions, by coding job-level data on union activity from *The Historical Directory of Trade Unions* (Marsh, Ryan, and Shethurst 1994). See Appendix A for details.

Strikes – We gather evidence on strike activity from *The Times* and *Palmer's Index to the Times Newspaper*. We construct data on the year, industry, and occupational groups involved in every strike. Our data comprise over 500 strike reports between 1790 and 1849.

Our data measure news of major strikes and thus a media market signal. The data capture strike activity that was newsworthy from the perspective and for readers of *The Times*. *The Times* was the leading newspaper in England, published consistently over the period we study, and both reported news and operated as an aggregator, republishing strike reports from provincial newspapers verbatim. Our measure provides a quite comprehensive measure of major strikes, but does not capture *all* strike activity or unrest associated with labor conflict, some of which is unobserved in newspapers or only observed in provincial papers. Table 2 illustrates the source data. We provide additional detail in Appendix A.

To understand the nature of the reports in *The Times* and thus how we measure news of strike activity, several further observations are important. First, *The Times* provided news that was valuable to individuals involved in running and investing in business. Raymond Williams (1961; p. 197) observes, "The newspaper was the creation of the commercial middle class, mainly in the eighteenth century. It served this class with news relevant to the conduct

Table 2: Illustrations of Reports of Strike Activity

Year	Industry	Extracts from Reports Published in *The Times*
1825	Textiles	"The framework-knitters of Leicester, who have now been out of employ nearly fourteen weeks, again assembled in large numbers . . . Several persons, as usual, harangued them. . . exhorting them in strong and forcible language to remain firm. . . The warp-loom knots and wide-frame hands have also ceased working until the plain-hose men obtain their 'statement prices'. . . the turn-out is likely to be more general than ever. – *Leicester Chronicle*" (*The Times*, 7/12/1825)
1833	Textiles	"TURN-OUT EXTRAORDINARY. . . The card-setters. . . chiefly women, held a meeting, to the number of 1,500, last Monday. . . at which it was determined not to set any cards at less than a halfpenny a-thousand. . . – *Leeds Mercury*" (*The Times*, 05/05/1833)

This table illustrates strike reports published in *The Times*. We classify the occupation and industry for each strike. See Appendix A for details. The citations to provincial newspaper appear in the original.

of business, and as such established itself as a financially independent institution. . . The daily press, led by *The Times*, became a political estate, on this solid middle-class basis." Thus the incentives and the position of *The Times* in the media market make *The Times* a unique and valuable source of data on the labor market.[23]

Second, our measure captures a media market signal on strikes. If taken as a proxy for underlying conflict itself, potential measurement error in our data would arise from the fact that there are some industry-years with strike activity, albeit of a less acute and less newsworthy nature, that is not recorded in *The Times*. This would imply that some of our "untreated" (less treated) industry-year observations in fact received "treatment" (more treatment) and, other things equal, that our estimates may be a lower bound on the true impact of strike activity on invention. Our analysis does not, however, attempt to study all conflict in the labor market. Instead we focus the relationship between news and invention.

Output, Wages, and Jobs – We use industry-year output data from Broadberry et al. (2015). We construct industry-year wage data following Feinstein (1998), including from Bowley (1901), Bowley and Wood (1899), Bowley and Wood (1906), and Wood (1910a). These wage data are not observed in a small number of missing years. In our main analysis, we assume wages in missing years are unchanged; our findings are similar when we interpolate

[23]Government records also provide evidence on labor market conflict, in particular Home Office reports of magistrates and spies monitoring the labor movement. However, these records reflect a selection process shaped by governmental concern with public order and revolution (Hobsbawm 1949). See Appendix A.

missing values. We construct job-year data on wages from Wood (1910a) and the G.H. Wood Archive, and firm-level data on employment and wages by age and gender from Factories Inquiry Commission (1834). We detail these sources below and in Appendix A.

IV Strikes and Patenting

IV.1 Baseline Analysis

Our baseline analysis tests four hypotheses on the role of strikes. First, invention in an industry increased when reported strike activity increased in that industry. Second, the relationship between strikes and patenting was stronger in textiles, the most dynamic industry during the industrial revolution, in which important developments in mechanization and productivity-enhancing organization were concentrated. Third, the relationship between strikes and invention in textiles increased after the legalization of labor unions in 1824. Fourth, this relationship holds controlling for industry-level wages and output.

We estimate models of the form:

$$\begin{aligned} y_{it} = \alpha_1 s_{it} + \alpha_2(s_{it} \times textiles_i) + \alpha_3(s_{it} \times textiles_i \times post_t) \\ + \alpha_4(s_{it} \times post_t) + \theta_i + \delta_t + \gamma X_{it} + \epsilon_{it} \end{aligned} \tag{1}$$

The outcome y_{it} is the number of patents in an industry-year. The key independent variable is the number of strikes s_{it} in an industry-year. The parameters of interest are: α_1, which estimates the relationship between strikes and inventions across all industries; α_2, which estimates the differential shift for strikes in textiles; and α_3, which estimates the differential shift for textiles after 1824. The θ_i and δ_t are industry and year fixed effects. Below we also introduce industry-×-decade fixed effects to study variation in strikes and patenting within an industry in narrow time frames. The X_{it} comprise factors that shift over time within industries, including strike trends ("$s_{it} \times year_t$" and "$s_{it} \times textiles_i \times year_t$").

Table 3 reports estimates from Poisson regressions. We find an additional strike report is associated with a 1.8% increase in patenting within an industry (column 1), confirming the first hypothesis. We find no evidence that strikes follow inventions and some evidence that strikes predict inventions one year forwards (column 2). This high frequency relationship reflects how comparatively limited time, expertise, and resources were required to develop inventions during the Industrial Revolution (Meisenzahl and Mokyr 2012; p. 459-61).

We next consider differences in the relationship between strikes and patents in textiles and other industries. We find an additional strike report is associated with an 1.2% increase patenting for all industries and a further 1.1% increase in textiles (column 3), confirming our second hypothesis. We next investigate how these relationships evolved over time (column 4). We find the differentially strong relationship between strikes and patents in textiles is driven by the post-1824 period, in which an additional strike report was associated with at 4.2% increase in patenting in textiles. For all other industries, an additional strike was associated with 2.6% more patents 1790-1823, but only 0.6% more patents after 1824 (0.026-0.020).

We next consider counterfactuals comparing strikes and patents within decades in a given industry (Table 3, columns 5-8). The comparisons now examine strikes and patents in an industry, such as textiles, in different years within a decade. The estimates of our key parameters are somewhat stronger when we study these temporally proximate counterfactuals. We confirm that strikes are associated with invention (column 5) and that the overall relationship between strikes and invention is largely driven by the textile sector (column 7). We confirm a shift in this relationship after 1824. Before 1824, strikes were generally associated with inventions across industries (column 8, row 1). This effect was attenuated afterward (column 8, "Strikes $\times$ Post 1824"). The relationship between strikes and inventions in textiles was relatively muted before 1824 and differentially large afterwards.

To clarify the pattern we study, and how it relates to historical evidence, Figure 2 plots the relationship between strikes and patenting before and after 1824. We present evidence on *residual* patents, partialling out year and industry-$\times$-decade fixed effects as in Table 3, and compare textiles and other industries. For example, Figure 2 shows was a limited increase in invention in textiles around the 1818-19 strike wave, which was suppressed when the union leaders were jailed under the Combination Acts, and a relatively strong increase in textile patenting during the strike wave of 1824-5, when unions were legal (see Section II.3.3).[24]

The core identification question for our analysis is whether other determinants of patenting shift within industries in ways that are correlated with strike activity. The

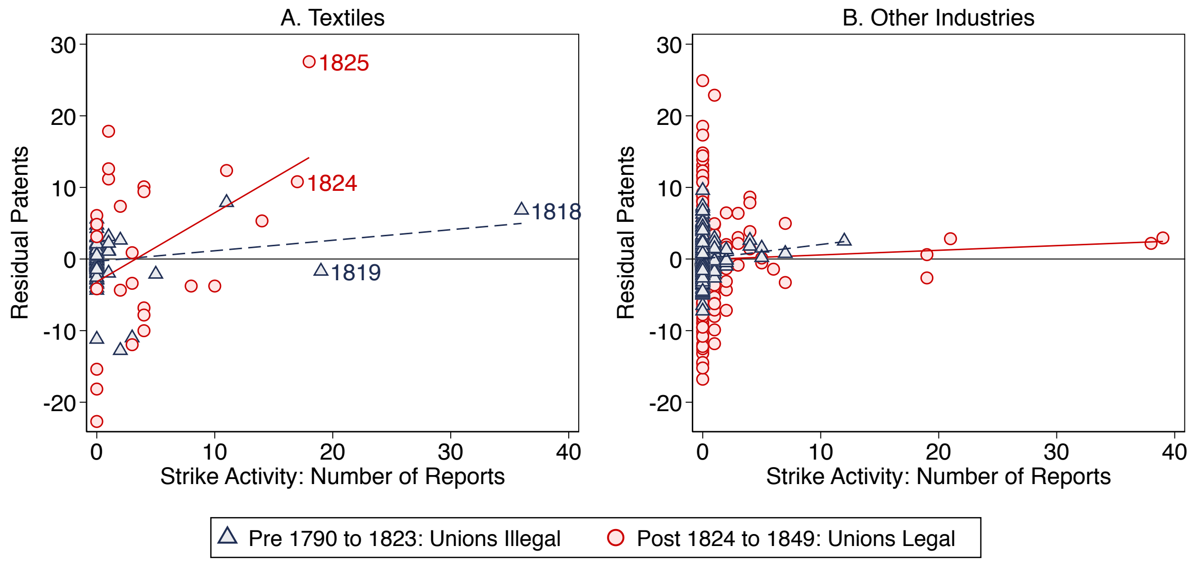
[24]Years with large strike waves do not drive our core findings. We find a similar positive relationship between strikes and invention when we drop 1824 and 1825 from our analysis and when we measure conflict with a binary indicator for any strikes rather than the number of newspaper reports. See Appendix E.

Table 3: Strike Activity and Patenting

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Outcome: Number of Patents by Industry-Year							
	Variation Studied: Within Industry				Variation Studied: Within Industry-Decade			
Strike Activity	0.018***	0.017***	0.012***	0.026**	0.018***	0.017***	0.006	0.045***
	(0.004)	(0.003)	(0.004)	(0.012)	(0.007)	(0.007)	(0.005)	(0.009)
Strike Activity in $t+1$		-0.003				-0.005		
		(0.007)				(0.011)		
Strike Activity in $t-1$		0.010***				0.005*		
		(0.002)				(0.003)		
Strike Activity × Textiles			0.011**	-0.020			0.021***	-0.027***
			(0.004)	(0.012)			(0.005)	(0.009)
Strike Activity × Post 1824				-0.015				-0.040***
				(0.013)				(0.010)
Strike Activity × Textiles × Post 1824				0.050***				0.060***
				(0.012)				(0.010)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	No	No	No	No
Industry × Decade FE	No	No	No	No	Yes	Yes	Yes	Yes
Observations	1260	1239	1260	1260	1260	1239	1260	1260
Textiles			0.023	0.006			0.027	0.018
pTextiles			0.000	0.001			0.000	0.000
Post1824xTextiles				0.042				0.038
pPost1824xTextiles				0.000				0.000

This table reports poisson regression estimates in which the outcome is the number of patents in an industry-year between 1790 and 1849. Patents are classified in twenty-one industries following **?**. Data on strikes constructed from *The Times*. The independent variable "Strike Activity" measures the number of newspaper articles on strikes in an industry-year. "Strike Activity × Textiles" interacts our measure of industry-level strike activity with an indicator for the textiles industry ("Textiles"). Similarly, "Strike Activity × Post 1824" and "Strike Activity × Textiles × Post 1824" interact these variables with an indicator for observation from after 1824 ("Post 1824"). Standard errors are clustered by industry. Statistical significance at the 90, 95, and 99 percent confidence level denoted "*", "**", and "***", respectively.

Figure 2: Strikes and Patents



This graph plots residual patents against strike activity in an industry-year. Panel A presents evidence on the textile industry. Panel B presents evidence on all other industries. Residual patents in an industry-year are estimated in regression analysis that examines our complete data and conditions on year fixed effects and on industry-×-decade fixed effects. The fitted lines displayed in both graphs are OLS estimates of the bivariate relationship between residual patents and strike activity in a given period.

literature on induced technological change emphasizes the potentially causal role of shifts in demand and in factor prices, especially wages (Schmookler 1966; Hicks 1932). We therefore expand our analysis to account for shifts in industrial activity and wages within industries.

First, we examine the relationship between strike activity and patenting conditional on output in an industry, which reflects variation in demand. We focus on seven key industries for which consistent annual output data are constructed by Broadberry et al. (2015; p. 138) and which account for 90% of industrial value-added between 1801 and 1831. The industries and their respective value-added shares are: Textiles (36.3%), Iron (11.5%), Construction (11.5%), Leather (10.1%), Coal (8.6%), Foodstuffs (7.8%), and Printing (5.8%).[25]

Table 4 Panel A presents our estimates. Column 1 presents estimates from our baseline specification when we restrict the data to industries with output data (the model corresponds to Table 3 column 7). We then control for current output in an industry (column 2). We also control for five lags of output (in column 3), to test whether patenting responds with a lag to industrial activity, as suggested by Schmookler (1966). We find that our key estimate,

[25] We include paper (1.9% of value-added) with printing. See Broadberry et al. (2015; p. 135) for details.

of a differential positive relationship between strikes and patenting in the textile industry, is strong and stable. We next examine the timing of these effects in columns 4-6. We find that the differential positive relationship between strikes and invention in the textiles industry is a strong, stable relationship concentrated in the post-1824 period, as in our baseline findings.

Second, we extend the analysis to account for shifts in industry-level wages. We gather data on industry-level wages, following Feinstein (1998) and drawing on the pioneering data collection efforts of Bowley and Woods (Appendix A). We focus on four industries for which we can construct consistent industry-level wage data: textiles, metallurgy, construction, and printing. We find that the relationship between strikes and patenting holds virtually unchanged controlling for shifts in wages in an industry, as shown in Table 2 Panel B.

Several observations are important in interpreting our analysis. First, the data we study are aggregates. Spatially, our focus on patenting at the industry-year level reflects the concentration of invention in London, described in Section I. At the industry level, the aggregation in textiles reflects the fact that the majority of patents targeted the industry as a whole, and not just one branch such as cotton or wool.[26] Similarly, the wage data we examine above are constructed to capture the *typical* cost of labor in an industry and thus embody but do not parse wages for different types of labor and jobs within an industry. We study technical change and pay within textiles in disaggregated job-level data in Section V below. Second, our analysis captures variation in the intensity of conflict with the number of strike reports in an industry-year, but treats newspaper reports as uniform. We observe some increases in *reported* violence after 1824 and that strikes in which violence is reported were weakly associated with more invention. Analysis of the text of reports is the subject of our on-going research. Third, while the strike effect is robust, shifts in lagged wages and output also predict invention themselves, consistent with the Hicks (1932) and Schmookler (1966) visions of induced technical change. Fourth, our findings reflect only one aspect of the larger relationship between distributional conflict and technical change. We study how the quality of patents responds to strikes and shifts in patent trends in Sections IV.2 and V below. Fifth, labor market conflict may influence the economy through multiple channels, including notably investment decisions, but we find no clear evidence of such effects (Appendix D).

[26] Of 501 textiles patents indicating use in cottons, 71% name at least another material and 50% indicate at least two others (e.g. wool, flax, silk, etc.). Of 488 patents indicating wool, 66% name another material.

Table 4: The Role of Strikes Controlling for Output and Wages

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Controls for Industry Output						
	Outcome: Patents in an Industry-Year					
Strike	0.001	0.001	0.002	0.045*	0.046*	0.043*
	(0.003)	(0.003)	(0.003)	(0.024)	(0.024)	(0.022)
Strike × Textiles	0.026***	0.026***	0.024***	-0.027	-0.028	-0.025
	(0.003)	(0.004)	(0.004)	(0.025)	(0.025)	(0.023)
Strike × Post 1824				-0.043*	-0.044*	-0.041*
				(0.025)	(0.025)	(0.024)
Strike × Textiles × Post 1824				0.062**	0.063**	0.058**
				(0.025)	(0.025)	(0.024)
Industry Output		0.000***	0.000		0.000**	0.000
		(0.000)	(0.000)		(0.000)	(0.000)
Industry Output Lagged		-0.000	-0.000		-0.000	-0.000
		(0.000)	(0.000)		(0.000)	(0.000)
Industry Output: All Lags	No	No	Yes	No	No	Yes
Year & Industry-×-Decade FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	420	420	420	420	420	420
Panel B: Controls for Industry Output & Wages						
	Outcome: Patents in an Industry-Year					
Strike	0.001	0.001	0.003	0.063**	0.073***	0.070**
	(0.004)	(0.004)	(0.005)	(0.025)	(0.012)	(0.028)
Strike × Textiles	0.025***	0.024***	0.028***	-0.045**	-0.057***	-0.048
	(0.004)	(0.005)	(0.007)	(0.023)	(0.009)	(0.030)
Strike × Post 1824				-0.060**	-0.070***	-0.067**
				(0.029)	(0.015)	(0.031)
Strike × Textiles × Post 1824				0.078***	0.090***	0.082***
				(0.026)	(0.010)	(0.027)
Log Wage		-0.077	-0.683		-0.303	-0.811*
		(0.333)	(0.457)		(0.425)	(0.491)
Log Wage Lagged			1.287**			1.257*
			(0.631)			(0.674)
Log Wage: All Lags	No	No	Yes	No	No	Yes
Industry Output: All Lags	Yes	Yes	Yes	Yes	Yes	Yes
Year & Industry-×-Decade FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	220	220	216	220	220	216

This table reports poisson regression estimates studying the number of patents in an industry-year between 1790 and 1849. Variables defined as in Table 3. Panel A examines industries with consistent data on output: Construction, Textiles, Food, Leather, Metallurgy (Iron), Mining, and Paper and Printing from Broadberry et al. (2015). Panel B examines industries with industry-level data is constructed following Feinstein (1998): Construction, Printing, Metallurgy, and Textiles. Standard errors clustered by industry. Statistical significance at the 90, 95, and 99 percent confidence level denoted "*", "**", and "***", respectively. The row "p-value: Total Textiles Post 1824" reports the p-value on the total (summed) effect for textiles post-1824.

IV.2 Variation in the Invention Outcome — Patent Quality

Historians suggest strikes led to important inventions, however the relationship between strikes and patent quality is theoretically ambiguous.

We therefore extend our analysis to study the relationship between strikes and patents in different quality categories. We measure quality using the reference-based index constructed by Nuvolari, Tartari, and Tranchero (2021).[27] We study the number of patents in an industry-year that are of below median ("lower") and above median ("higher") quality, as well as the number that are above the 75th and 95th percentile in the quality distribution.

Table 5 presents our estimates. We find that an increase in strike activity is associated with a 4.6% increase in lower (below median) quality patents (column 1, row 1). After 1824, the underlying positive relationship between strikes and patents shared across all industries is offset by the shared post-1824 reduction in this relationship and strike activity is differentially and uniquely associated with increased lower quality patenting in textiles. We next consider high (above median) quality patents (column 2). We find no significant underlying relationship between strikes and above median patents (row 1). However, we find a strong, significant, and relatively large positive relationship between strike activity in textiles and above median quality textile patents after 1824. We next examine patents in the top 25% of the distribution. Here we find some evidence that strike activity in general promoted these higher quality patents (a 5.2% increase) but this is offset by the post-1824 decline shared across industries. However, we find a large and even stronger relationship between strikes in textiles after 1824 and the arrival rate of such high quality patents. Finally, we consider patents in the top 5% of the quality distribution (column 4). We find no significant relationships between strikes and such far upper tail patents.

These findings point to the substantive nature of the shifts in invention driven by strikes. The fact that strikes drove comparatively large increases in higher quality textiles patents after 1824 points to the economic significance of distributional conflict for technical change. The fact that strikes were not systematically related to the arrival of far upper tail inventions, as measured by patents in the top 5% of the quality distribution, is consistent with inventions in the far upper tail requiring more time to develop or being precipitated by other factors,

[27] This measure indexes (1) historical references to patents, (2) references in the history of science literature, and (3) references in the British *Dictionary of National Biography*. See Section III and Appendix A.

Table 5: Strike Activity and Patent Quality

	(1)	(2)	(3)	(4)
	Outcome: Number of Patents in a Quality Category			
	Bottom 50%	Top 50%	Top 25%	Top 5%
Strikes	0.046***	0.025	0.052*	-0.090
	(0.016)	(0.028)	(0.027)	(0.059)
Strikes × Textiles	-0.022	-0.021	-0.023	0.014
	(0.014)	(0.028)	(0.025)	(0.057)
Strikes × Post 1824	-0.046***	-0.020	-0.061**	0.062
	(0.016)	(0.030)	(0.028)	(0.064)
Strikes × Textiles × Post 1824	0.046***	0.069**	0.081***	-0.007
	(0.014)	(0.030)	(0.026)	(0.062)
Year FE	Yes	Yes	Yes	Yes
Industry × Decade FE	Yes	Yes	Yes	Yes
Observations	1260	1260	1260	1260
Total in Textiles Post 1824	0.025	0.052	0.049	-0.021
p-value	0.000	0.000	0.000	0.227

This table reports poisson regression estimates in which the outcome is the number of patents in a quality category in an industry-year between 1790 and 1849. Quality is measured by the distribution of the index developed by Nuvolari, Tartari, and Tranchero (2021). Standard errors are clustered by industry. Statistical significance at the 90, 95, and 99 percent confidence level denoted "*", "**", and "***", respectively. "Total in Textiles Post 1824" is the total effect for textiles in this period (the sum of all reported parameters).

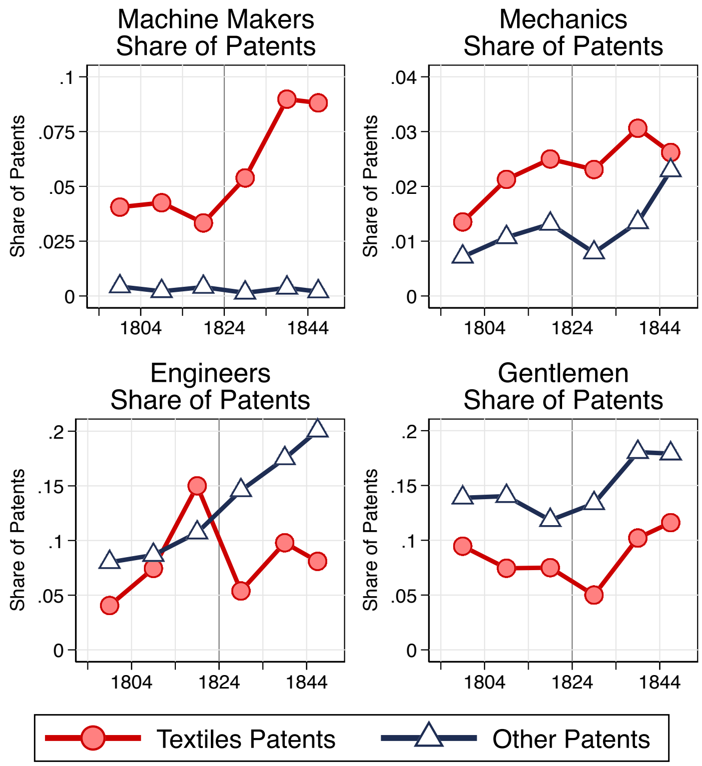
as suggested by Mokyr (1990) and Meisenzahl and Mokyr (2012).

IV.3 Supply Side Factors

The patterns of induced technical change that we document reflect underlying supply side factors. Our analysis begins in 1790, when the British economy already enjoyed distinctive human capital endowments stemming in part from a prior "industrial enlightenment" (Mokyr 2009). Locally, the year-on-year variation in patents that we study reflects the presence of inventors capable of responding to the demand-side signal of labor market conflict, and thus the interplay between supply and demand. However, theory and historical evidence indicate that the supply side is itself endogenous and evolves in ways shaped by economic pay offs.

Our analysis thus implies a further hypothesis concerning the supply side and market for invention. We would predict that the patenting by machine makers in textiles would increase differentially after the legalization of unions, if and as the mechanization of textiles was a response to changes in bargaining power. To test this prediction, and whether machine makers become more prominent in the data after the institutional change, we gather and

Figure 3: The Occupations of Patenting Inventors



This graph plots the share of patented inventions in (1) textiles and (2) other industries that inventors in different occupations account for. Time is in ten year periods, indexed to 1824 (the period 1824-1833). Inventor occupations are classified based on the occupational descriptions in the original text in Woodcroft (1854), as detailed in Appendix A. Industries classified by Nuvolari, Tartari, and Tranchero (2021).

study information on the occupations of all patenting inventors.

Figure 3 graphs the share of patents in (1) textiles and and (2) all other industries that are accounted for by inventors identified as machine makers, mechanics, engineers, and gentlemen. In the data, we observe the share of textile patents by machine makers is stable before the legalization of unions and afterwards increases sharply, while machine makers account for a miniscule and stagnant share of inventions outside of textiles. In contrast, the share of patents in textiles by engineers falls after 1824, whereas engineers' share of patents in other industries follows an essentially unchanging positive trend.[28]

It is natural to also wonder how different types of inventors responded to strikes. When we examine inventors' training and cultural networks in data collected by Meisenzahl and Mokyr (2012), as well as information on inventor occupations listed on patents, we find that

[28] We find no clear shift in invention by "manufacturers" or "spinners", or other leading occupations.

firm owners, machine makers, and former apprentices respond to strikes, consistent with the importance of economic incentives and underlying human capital. In contrast, we find that inventor religion and membership in "enlightenment societies" were not explanatory, suggesting cultural factors may have played a relatively limited role. See Appendix E.

V The Direction and Bias of Technical Change

We focus our study of the direction and bias of technical change on the textiles industry. The textiles industry is of special interest for three reasons. First, the development of the factory system and mechanization were concentrated in textiles over the period we study. Second, the textiles industry offers uniquely rich evidence on invention and pay across labor processes in which tasks were performed by workers with different levels of political organization, skill, and demographic characteristics. Third, the variation within textiles allows us to test our theory that the increase in invention in textiles after unions were legalized (shown in Figure 1) reflected technical change directed towards less skilled and non-unionized labor.

V.1 The Direction of Technical Change

We test a core hypothesis: that the direction of technical change shifted towards less organized, unskilled labor during the industrial revolution.[29] To test this hypothesis we study patenting targeting textiles jobs in which workers were more or less organized, and thus had more latent power, when unions were legalized. We also test whether patenting shifted towards jobs in which workers were initially less organized in response to strikes.

To test these hypotheses we construct data on patents and union activity across jobs.

1. We assign patents to jobs. We focus on 38 jobs within textiles recorded in *The Historical International Standard Classification of Occupations* database (Van Leeuwen 2016). The jobs that we study include, for example: fibre carder; fibre comber, fibre drawer; rover; doubler; twister; spinner; knitting machine operator; lace weaver; weaver; and bleacher. We assign patents to jobs based the subject classification and patent abstracts at the British Library in London.[30] We match 1,663 patents (15% of total patents) to

[29] See Marx (1867 [1976]). It is significant for our interpretation of the process that unionization before 1824 was correlated with skill (Rule 1986; Chase 2000).

[30] We adopt a manual approach because we find that machine-learning approaches generate excessive numbers of type I and type II classification errors in our setting.

jobs in textiles. Appendix A provides details on jobs and our classification.[31]

2. We measure *latent worker power* in each job with a time-invariant proxy: whether there is evidence of pre-1824 union activity recorded in the *Historical Directory of Trade Unions* (Marsh, Ryan, and Shethurst 1994). We distinguish jobs in which unions and friendly societies were active before 1824, which we label "union," and jobs without such activity, which we label "no union."[32] We study 13 union and 25 no union jobs.

3. We construct a patent-based and a task-based measure of "no union" and "union" invention. The patent-based measure assigns patents impacting multiple jobs to the no union and union categories *pro rata*. The task-based measure counts each job a given patent impacts and aggregates job counts across no union and union jobs.

Figure 4 shows that patenting directed towards jobs in which workers were not unionized increased differentially after 1824. Panels A and B present the raw data on the number of patents and the number of tasks targeting union and non-union jobs. Panels C and D present corresponding estimates of the period-by-period difference in patenting for non-union jobs. We observe no pre-1824 trends in textile patenting overall or in the relative number of patents directed towards jobs performed by non-unionized workers. After 1824, we observe an overall increase in all patents and differentially large increase in patenting directed towards non-union jobs. On a period-by-period basis, the shift to non-union jobs is statistically significant by the 1830s. However, our results both indicate patenting trends changed starting in 1824 and invite questions about variation associated with strikes.[33]

We next estimate how patent trends shifted across jobs and how patenting responded to strikes, before and after the legalization of unions. We estimate a model:

$$\begin{aligned} y_{it} = {} & \beta_1(nounion_i \times post_t \times t) + \beta_2(nounion_i \times post_t) + \beta_3(nounion_i \times t) \\ & + \beta_4(nounion_i \times post_t \times strikes_t) + \beta_5(nounion_i \times strikes_t) + \theta_i + \delta_t \end{aligned} \tag{2}$$

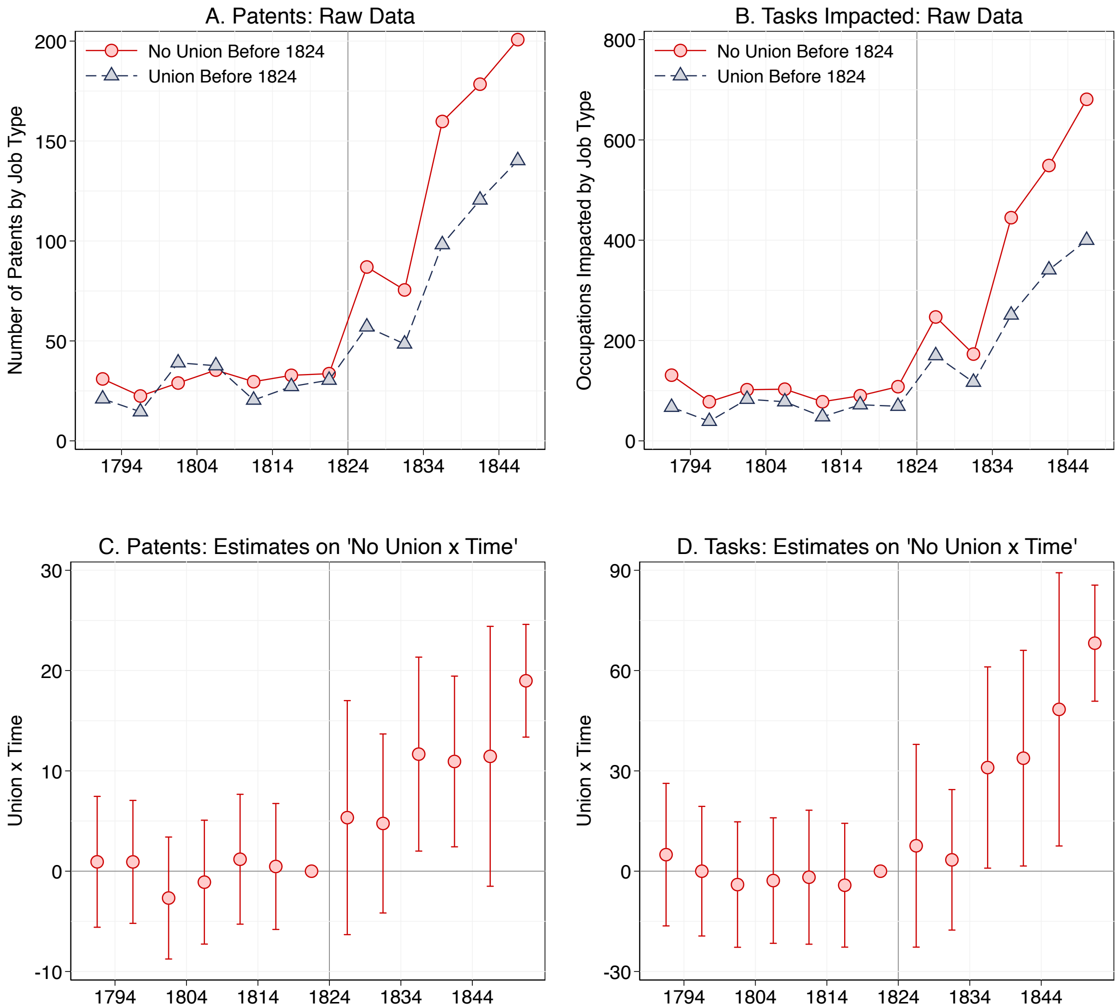
y_{it} measures the number of patents or of exposed tasks in a unionization-year cell, *post* is an indicator for years from 1824 onward, *nounion* is an indicator for patents associated job with

[31] This includes a number of textiles patents not classed as such by Nuvolari, Tartari, and Tranchero (2021). Our findings below hold when we restrict our analysis to patents that the latter class as "textiles."

[32] Our analysis delivers similar results when we compare jobs that were and were not unionized by other points in time, such as the beginning of our study period. We provide further detail on the measurement of worker organization in Appendices A and B. Friendly societies were *de facto* and proto-unions (Chase 2000).

[33] In Figure 4, the decline we observe in patents and the "no union" differential in the late 1820s coincides with an economic downturn. The data are, moreover, consistent with Cole's (1948; p. 70) observation that when recovery came in the 1830s, "the Unions, now able to organise openly... were in a position to resume their forward movement."

Figure 4: Union Activity and Invention



Panel A plots the number of patents for "Union" and "No Union" jobs in five year periods 1789 through 1849, indexed to 1824, with patents impacting both "Union" and "No Union" jobs assigned on a *pro rata* basis. Panel B plots the total number of tasks (occupations) exposed to patents by job type. Panels C and D plot corresponding point estimates on the interactions between "No Union" indicator and 5-year time period fixed effects in flexible difference-in-differences regressions examining union-year-level data on patents, with year fixed effects, a "No Union" indicator, and 95% confidence intervals estimated with robust standard errors. "Union" jobs are those with union activity by 1824 recorded by Marsh, Ryan, and Shethurst (1994).

no union activity before 1824, $strikes_t$ measures the number of textiles strikes in a year, t represents a linear time trend, while the θ_i and δ_t are indicators for union jobs and years.

Table 6 presents our estimates. Column 1 documents a positive shift in the trend and level of patenting for non-union jobs after 1824. Column 2 confirms a significant shift in trend, but shows that the previously noted post-1824 level effect is driven by years with strikes, which explain patenting in "no union" jobs after 1824. Are findings are similar when

Table 6: The Direction of Patenting

	(1)	(2)	(3)	(4)
	Number of Patents		Number of Tasks	
No Union × Post × Trend	0.37**	0.55***	2.40***	2.83***
	(0.14)	(0.20)	(0.33)	(0.46)
No Union × Post	4.84**	1.29	1.94	-6.38
	(2.30)	(2.52)	(5.40)	(6.19)
No Union × Trend	-0.01	-0.02	-0.14	-0.17
	(0.08)	(0.06)	(0.18)	(0.14)
No Union	0.46	0.15	4.06	3.14
	(1.56)	(1.14)	(3.66)	(2.52)
No Union × Strike × Post		0.37*		0.85*
		(0.20)		(0.47)
No Union × Strike		0.04		0.13
		(0.04)		(0.10)
Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	120	120	120	120

This table reports OLS regression estimates studying patents by job type in unionization-year cells. The outcome in columns 1 and 2 is the number of textiles patents in a unionization-year cell, with patents impacting both "union" and "no union" jobs allocated on a *pro rata* basis. The outcome in columns 3 and 4 is the total number of job tasks exposed to patents in a unionization-year cell. "No Union" indicates patents impacting jobs without unions before 1824. "Post" indicates years after 1824. "Trend" is a linear trend. "Strike" is the total number of reported textiles strikes in a year. Robust standard errors in parentheses.

we examine patenting measured by impacted job tasks, as shown in columns 3 and 4. To be clear, this analysis measures strike activity with the total number of strikes and explores how variation in the number of strikes has a differential association with patenting for unskilled jobs. In our on-going research, we are exploring variation in the types and numbers of workers involved in individual strikes, including whether formal unions were involved.

To interpret the evidence and our contribution several considerations are important. First, we provide the first quantitative examination of job-level technical change and worker power during the industrial revolution, to the best of our knowledge. Second, we test and find support for the view that conflict in the labor market, and institutions shaping workers' bargaining power, directed technical change.[34] Third, the pattern in the data helps us interpret the differential increase in patenting in textiles after 1824 compared to other industries (Figure 1 above). The fact that the increase in textiles patenting after 1824 was largely driven a shift towards "no union" jobs is consistent with the importance of labor

[34]Relative to the literature, these findings cast doubt on the argument that there was a "switch to unskilled labor saving around the 1820s" and that "institutional forces like unions or social reforms" should be placed "at the bottom of the research agenda" on the Industrial Revolution (Williamson 1985; pp. 89, 85).

market conflict and the legalization of unions in textiles as factors directing invention.

Several limitations of our analysis should also be noted. First, the contrast between jobs with and without evidence of pre-1824 union activity proxies for more complex, multidimensional, and continuous differences in power and solidarity.[35] Second, our finding that invention targeting "no union" jobs responded differentially to strikes naturally invites questions about how strikes involving heterogeneous workers may have shaped invention. While strikes almost always involved skilled workers, the newspaper reports we examine do not systematically report the occupations of workers involved in strikes. However, in Appendix C we provide evidence that strikes by workers in specific jobs indeed promoted inventions targeting those jobs, particularly after unions were legalized.

V.2 The Bias of Technical Change

V.2.1 Shifts in relative wages within factory jobs

Changes in wages for factory jobs clarify the process we study. We first examine shifts in pay *within* narrow job categories or tasks. We rely on data from Wood (1910a), who provides unparalleled evidence on jobs and wages in cotton factories (Feinstein 1998; p. 188).[36]

We compare the evolution of wages for jobs that were initially high and low wage before and after the legalization of unions. We define as "high wage" jobs with above median wages before 1824, and note that initial wage levels proxy for skill and organization. We expect shifts in relative labor demand associated with the processes we study to play out somewhat gradually, given the variable lags between patented invention and the diffusion of technology and the potential local bias of technical change. We compare the evolution of wages for job categories including *inter alia* head carders, card-room males, grinders, rover tenters, unclassified tenters, throstle spinners, and blow-room females (see Appendix A).

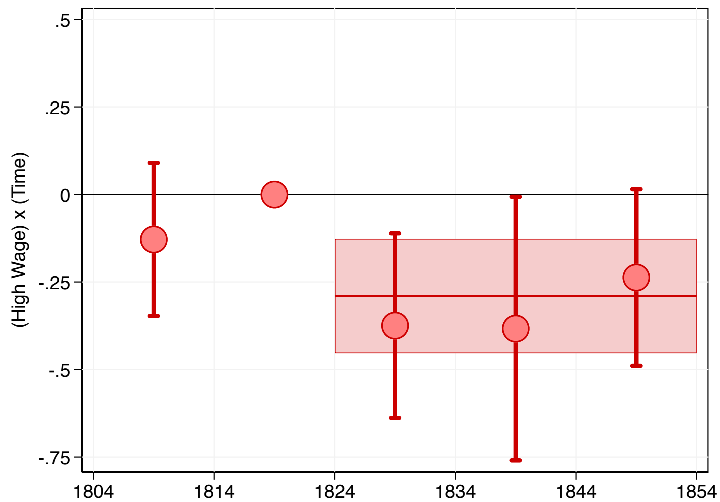
We estimate difference-in-differences models of the form:

$$wage_{it} = \sum_{s} \beta_s (highwage_i \times time_s) + \alpha_i + \delta_t + \epsilon_{it} \tag{3}$$

[35] Systematic evidence on union density does not exist in our period. We thus focus on the presence of union activity, but in on-going research also examine spatial and temporal patterns of union formation.

[36] The fragmentary surviving evidence from the woollens and worsted industries does not enable us to similarly trace the evolution of wages by job in these industries before and after 1824 (see Bowley 1902).

Figure 5: Shifts in Relative Wages for High Skill Jobs



This figure plots estimates of β_s on the interactions $highwage_i \times time_s$ in regressions studying job-level wages (equation 3). The outcome is the log of wages in a job-year, $highwage_i$ is an indicator for jobs with above median wages before 1824, and *time* is measured either in ten-year periods or with a single post-1824 period. Period-by-period estimates are shown by round markers and bars. The single post-period estimate is shown by the shaded box. All estimates control for job and year fixed effects. Robust standard errors used to compute 95% confidence intervals. Data comprise observations on 238 job-years. See Appendix A.

$wage_{it}$ is the log wage in job i in year t. In our flexible model, the parameters β_s estimate the relationship between the interaction between an indicator for above median pre-1824 wages ($highwage_i$) and time period indicators ($time_s$). We examine a basic difference in differences model in which $time_s$ is an indicator for the post-1824 period and a flexible model in which $time_s$ represents indicators for separate 10-year periods indexed on the 1824 Repeal of the Combination Act. The α_i and δ_t are job and year fixed effects.

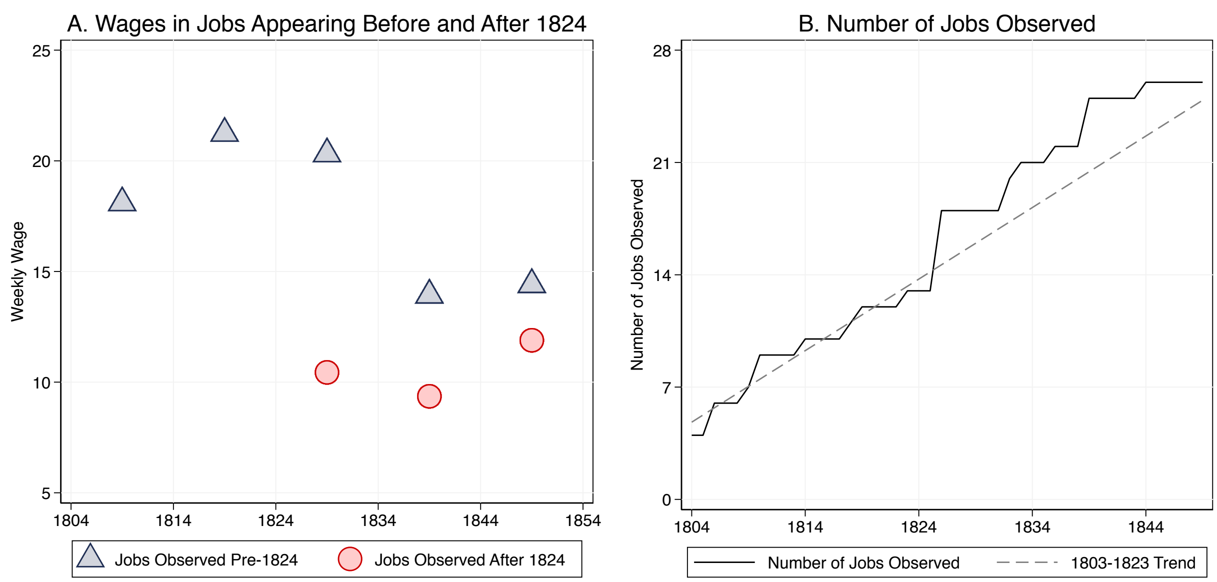
Figure 5 presents the estimates and shows that relative wages fell for high wage (high skill) jobs after 1824. The basic difference in differences model estimates a relative decline in wages for initially high wage jobs of over 25% after 1824 (the shaded box plots the confidence interval on this estimate). The flexible model estimates that wages in high skill jobs fell by over 30% after 1824 relative to wage movements in low skill jobs, with some relative recovery after 1844 and with some evidence of a pre-trend towards initially high paid jobs before 1824. The shift in the 1824-1833 period shows that the effects predate the Factory Act of 1833.

To interpret these estimates, two observations are helpful. First, we study shifts in pay within jobs in the major preparation, spinning, and weaving processes in cotton textiles (Appendix A provides details and job descriptions). Second, the shifts in pay that we observe are consistent with technical change biased towards unskilled labor, but should be interpreted carefully. By design, the estimates in Figure 5 examine within-job variation in pay and thus a limited component of larger labor market dynamics. Narrative evidence suggests that the introduction of new jobs, which shifted the allocation of workers to tasks, was a distinct and important part of the larger process shaping relative wages.

V.2.2 Wages in new jobs appearing after unions were legalized

Because technical change led to the creation of new jobs, it is important to consider the pattern of wages in jobs introduced in our period, especially after the legalization of unions. To study wages in new jobs, we rely on Wood's (1910a), which provides the richest and most systematic source of evidence on textile jobs in the industrial revolution.[37]

Figure 6: Wages for Jobs Appearing Before and After 1824



Panel A plots mean weekly wages in shillings for jobs in cotton textiles, distinguishing between jobs observed before 1824 and jobs observed after 1824, over 10-year periods indexed to 1824. Panel B plots the cumulative number of different jobs observed. Data are from Wood (1910a).

Figure 6 compares the mean wage for jobs appearing before or only after 1824 in Panel A. We find that on average the wages for pre-1824 jobs were increasing before the 1820s; fell modestly after 1824 and sharply after 1834. Where pre-1824 jobs on average offered wages

[37]As Feinstein (1998; p. 188) observes, "For the period from 1806, Wood has worked exhaustively through the mass of information available for the multitude of different occupations in the cotton industry," whereas British Census data on occupations only appear starting in 1851, after the Industrial Revolution proper.

around 20 shillings per week in the 1820s, the new jobs observed after 1824 paid around 10 shillings per week. The new jobs appearing after 1824 include spinning jobs using self-actor mule technology and a large number of associated jobs in which children and adolescents were employed, including "doublers", "drawing frame tenters", and "little piecers." Panel B shows the number of jobs observed increased relative to trend after 1824.

Our interpretation of these patterns reflects several considerations. First, our interpretation is qualified by the fact that we observe prices but not quantities. Systematic panel data on the number of workers by job do not survive, but narrative evidence suggests the number and share of low pay workers rose.[38] Second, the data and research in Wood (1910a) are viewed as authoritative, but simplify a complex underlying reality. The data are supported by detailed manuscript and business records, but in the economy as a whole *some* "new" jobs observed after 1824 in Wood (1910a) are likely to have existed in prior periods, but for sufficiently few workers as to be negligible or leave no trace in the available records.

V.2.3 Firm-size effects in employment and wages

Firm-level evidence on employment and pay carries information on the relationship between skill and technology. In the 20th century, larger firms employed relatively more and paid higher wages to skilled workers, pointing to capital-skill and technology-skill complementarities (Oi and Idson 1999).[39] Historical research suggests technical change was directed towards unskilled labor in the industrial revolution, and that female and child labor played a key role in textiles, but has been largely framed in terms of patterns at the industry and not firm level (Humphries 2013a; Berg 1994a; Marx 1867 [1976]).[40]

Motivated by these economic and historical observations, we consider two questions. First, did female employment vary with firm size? Second, did wages paid to workers in different demographic and skill categories vary with firm size? To answer these questions, we examine the Factories Inquiry Commission (1834) report, which provides unique data on

[38]For example, in spinning, self-acting mule spinning was a new job that paid less than hand mule spinning (Figure 1) and involved assistance from more child "piecers" and "scavengers" (Maw et al. 2022; p. 54).

[39]The interpretation of these patterns is not without ambiguity. For example, firm-size pay effects may reflect variation in worker quality, monitoring costs and efficiency wages, and compensating differentials.

[40]Prior studies examining firm-level data do not examine data on wages disaggregated by gender and age. See Brown (1990), Gatrell (1977), and Huberman (1990).

Figure 7: Firm Size and Female Employment

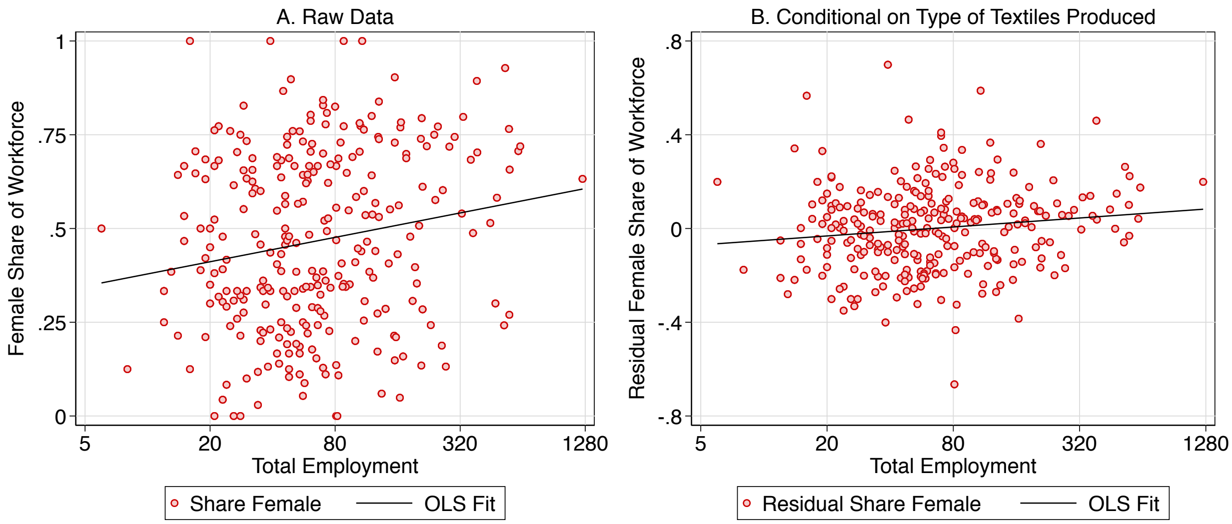


Figure presents firm-level data on textile mills from Factories Inquiry Commission (1834). Panel A plots the female share against total employment. The OLS model is: $female_i = \alpha_0 + \alpha_1 \ln(employment_i) + \epsilon_i$, with $\hat{\alpha_1} = 0.05$ and robust standard error 0.01. Panel B plots residual female employment, controlling for variation associated with firm activity in the cotton, woollens, and worsteds sub-sectors, against employment. The corresponding OLS model is: $female_i = \beta_0 + \beta_1 \ln(employment_i) + \theta_j + \epsilon_i$, where the θ_j are indicators for production of cottons, woolens, and worsteds, with $\hat{\beta}_1 = 0.03$ and robust standard error 0.01.

employment and wages by worker age and gender for all textile mills in Yorkshire in 1833.[41]

Figure 7 shows that the female share of employment was higher in larger firms. Panel A presents the raw data and OLS estimate of the positive relationship between female share and firm size. Panel B shows there is a positive relationship between female employment and firm size controlling for firm activities in cotton, woollen, and worsted, thus when we compare firms in the same branches of textiles. Given that larger firms were more technologically advanced, and that female workers were typically less skilled and less likely to be in unions, the pattern is consistent with technology directed towards unskilled and less organized labor.

We next test for differences in firm-size wage effects across gender and age groups, which proxy for differences in skill and worker organization. We estimate regressions of the form:

$$wage_{ij} = \alpha_0 + \alpha_1 size_j + \alpha_2 (size_j \times child_i) + \delta_i + u_{ij} \tag{4}$$

[41]The Factories Inquiry Commission (1834) report covers all textile mills in England, but only provides disaggregated firm-level data on wages and employment for mills in Yorkshire. Industrial specialization varied across locations, but the female share of employment in the Yorkshire data is close to the 51% share in Lancashire (Factories Inquiry Commission 1834; I, p. 33). Yorkshire mills worked with a variety materials: 42% produced wool yarn and cloth, 29% worsteds, 19% cotton, and others a mix of flax, linen, and silk.

Table 7: Firm Size and Wages by Gender and Age

	(1)	(2)	(3)	(4)	(5)	(6)
	Outcome: Log Wages in Firm-by-Age Cells					
	Wages for Female Workers			Wages for Male Workers		
Ln Firm Size	0.019	-0.001		-0.003	-0.000	
	(0.012)	(0.016)		(0.019)	(0.021)	
Ln Firm Size x Child Aged 10-16		0.036**	0.034**		-0.006	-0.014
		(0.014)	(0.017)		(0.019)	(0.023)
Age Group Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	No	Yes	No	No	Yes
Observations	618	618	618	580	580	580

This table reports OLS regression estimates in which the outcome is the natural logarithm of wages of paid to workers in a specific age and gender category by a specific firm. The unit of analysis is an age-gender-firm observation. The underlying data record the wage rate, by gender, for workers in the following age group cells: under 10 years; 10-11 years; 12-13 years; 14-15 years; 16-17 years; 18-20 years; and 21 years or above. "Ln Firm Size" is the natural logarithm of total employment in a firm. "Child Aged 10-16" is an indicator for workers aged 10 to 16. "Age Group" and "Firm" fixed effects are indicators for each age group and firm, respectively. Standard errors are clustered by firm. Statistical significance at the 90, 95, and 99 percent confidence level denoted "*", "**", and "***". Data are from Factories Inquiry Commission (1834).

The outcome is the logarithm of the wage for workers of a given gender in an age group i at firm j, $size_j$ is the log of total employment in a firm j, and "$size_j \times child_i$" interacts the log of firm employment with an indicator for age groups between 10 and 15 years of age. The δ_i are age group fixed effects. We estimate separate regressions for male and female workers.

Table 7 presents estimates of the firm-size wage effect. We find a positive but statistically insignificant effect for female workers as a whole (column 1), but a strong and significant relationship between firm size and wages for female child laborers (column 2). This positive relationship between firm size and wages for girls holds when we study variation within firms, controlling for firm-level differences in wages and product lines (column 3). Quantitatively, our estimates imply that as firm size doubles, the wages of female child laborers rise by 2.5%. In contrast, we find no evidence of a firm-size wage effect for male workers (columns 4-6).

The historical evidence reverses firm-level patterns of employment and pay in our day, which reflect technology-skill complementarities. While cross-sectional correlations must be interpreted with care, the historical patterns are consistent with technology biased towards unskilled and less organized labor and with evidence indicating bargaining in the labor market shaped the development of technology in the industrial revolution.

VI Conclusion

We study distributional conflict as a factor in technical change and labor market outcomes. Our investigation focuses on evidence from the Industrial Revolution and delivers several core findings. We find strikes led to increases in invention within industries, measured by patents. The positive effect of strikes on invention was strongest in textiles, the industry which drove the development of mechanization and factory production. This positive effect in textiles increased after unions were legalized. After unions were legalized, the direction and bias of technical change in textiles shifted towards toward unskilled and non-union labor.

Our analysis has larger, general implications for economics. First, skill biased technical change is sometimes framed as a transhistorical regularity. Our analysis shows, to the contrary, that the bias and direction of technical change shifted towards less skilled, non-union labor during one of the most pivotal eras in economic history. During the Industrial Revolution, first wave automation promoted less skilled, non-union labor and routine jobs in the most revolutionary sector of the economy.

Second, our investigation uncovers a general process, which explains the pattern of technical change and labor market outcomes: how distributional conflict directs the development of technology and thus shapes factor prices in a capitalist economy. Collective action by workers and strikes in particular raise the question of what factor prices will be tomorrow and the salience of the future for current innovation. Institutional changes that reduce the cost of organizing for workers sharpen this question and induce the development of technologies designed to preserve profitability and power for capitalists. When these processes are active, induced technical change may produce the prices otherwise taken as given or causal. Whether and how these patterns shift across eras, as technology, collective organization, and legal frameworks develop, is an important question for further research.

Third, and more broadly, it is widely understood that technical efficiency and less politically charged aspects of supply and demand shape invention, alongside inspiration and creativity. Our research suggests that distributional conflict may also play an elemental role in the development of technology.

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