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The Rise and Fall of Unions in the U.S.*

by

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and

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Abstract

Union membership displayed a ∩-shaped pattern over the 20th century, while the distribution of income sketched a ∪. A model of unions is developed to analyze these phenomena. There is a distribution of firms in economy. Firms hire capital, plus skilled and unskilled labor. Unionization is a costly process. A union decides how many firms to organize and its members' wage rate. Simulation of the developed model establishes that skilled-biased technological change, which affects the productivity of skilled labor relative to unskilled labor, can potentially explain the above facts. Statistical analysis suggests that skill-biased technological change is an important factor in deunionization.

Keywords: Computers; Distribution of Income; Flexible Manufacturing; Mass Production; Numerically Controlled Machines; Panel-Data Regression Analysis; Relative Price of New Equipment; Skill-Biased Technological Change; Simulation Analysis; Union Coverage; Union Membership; Deunionization

JEL Codes: J51, J24, L23, L11, L16, O14, O33

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1 Introduction

In 1900 seven percent of the American workforce were union members. The number of union members rose until the middle of the century, as shown in Figure 1, hitting its apex at 32%. It then began a slow decline. At the end of century 14% of American workers belonged to a union. At the beginning of the 20th century, the top 10% of workers earned 41% of income. This figure declined hitting a low of 31% around mid-century. It then steadily increased to 41% around 2000.[1] What could have caused the ∩-shaped pattern of union membership and the ∪-shaped one for the distribution of income? Are they related?

The hypothesis here is that skill-biased technological change underlies the up and down in union membership, along with the fall and rise in income inequality. The beginning of the 20th century witnessed a shift away from an artisan economy toward an assembly line one. This favored unskilled labor. The premium for skill declined. Unskilled labor is homogenous, almost by definition. This makes it easier to unionize than skilled labor. When the demand for unskilled labor rises there is a larger payoff to unionizing it. Things changed at the midpoint of the century. The second industrial revolution was petering out and the information age was dawning. Transistors and silicon chips meant that automatons could replace the hoards of unskilled workers laboring on factory and office floors. This represented a reversal of the earlier trend.

A general equilibrium model of unionization is developed. The union makes two interconnected decisions. First, it picks a common wage rate for its members. Second, the union selects which firms in the economy to organize. Unionization is a costly process. Firms sell output in a competitive market. They hire both skilled and unskilled labor. These inputs are substitutable to some extent. When the productivity of unskilled labor is high (relative

[1] The rise in inequality since the 1970s is well documented and holds for a wide variety of inequality measures–see Juhn, Murphy, and Pierce (1993) for an early documentation of this trend for many measures of wage inequality. Interestingly, Goldin and Katz (20, Figure 8.1, p. 290) report a ∪-shaped pattern for the college-graduate wage premium for the period of study here. Somewhat surprisingly, they also show that during the first part of the twentieth century that the high-school graduate wage premium actually fell; i.e., that the return to a less-than high school education rose. These facts fit well into the story that will be told here.

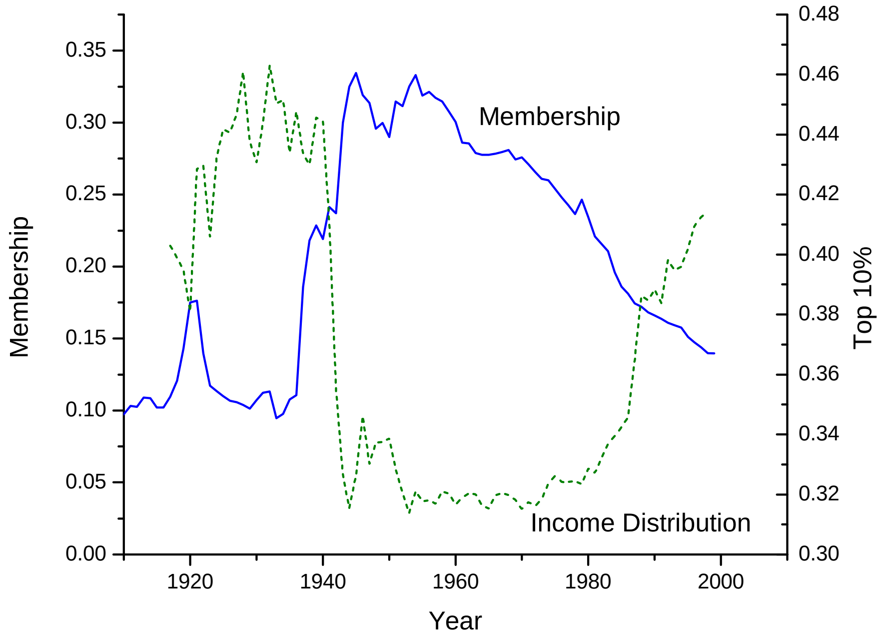

Figure 1: Union membership and the distribution of income over the 20th century–a discussion of the data sources used in this figure is contained in the Appendix

to skilled labor) the union can pick a high wage. It also pays to organize more firms. Firms differ in their productivity, so when organizing labor the union will select the most profitable firms. Those firms that are not unionized can hire labor on competitive market.

The analysis builds upon the work of MacDonald and Robinson (1992). They present a model of the extent of unionization in a competitive industry where all firms are the same. The key insights of their model are: (i) unionization is a costly activity; (ii) unions must offer their members a wage net of dues that exceeds the competitive one; (iii) the union wage must allow organized firms to make non-negative profits. MacDonald and Robinson (1992) model things for an industry (or in partial equilibrium) and start off, in micro fashion, at the level of a firm's cost function. Modeling skill-biased technological change requires delving into a level deeper than the cost function; i.e., starting off from a firm's production function. Analyzing the implications of this form of technological change for the economy's distribution of income necessitates using a general equilibrium model.

The hypotheses proposed here is taken to the data in three ways. First, historical evidence is presented regarding the evolution of unionization and skill-biased technological change, with particular attention to the transformation of the U.S. economy over the 20th century by, initially, mass production, and later, computerization. Second, the developed model is calibrated and simulated to see whether or not it is capable of explaining the extent of unionization and the level of income inequality that was observed over the course of the 20th century. It is. The required pattern of skill-biased technological progress is in line with the qualitative picture painted by the historical evidence. Third, statistical analysis is undertaken, in a panel-data regression framework, that relates the changes in unionization to skill-biased technological change. The statistical evidence suggests that skill-biased technological change, the model's primary driver, is an important factor for explaining both the recent rise in the relative demand for skilled labor and the decline of unionization in the U.S.

Acemoglu, Aghion and Violante (2002) also analyze how skill-biased technological change can lead to deunionization. Their framework is very different from the one developed here. In particular, there are two sectors in the economy, one unionized, the other non-unionized.

Skilled workers only work in the non-unionized sector. Unskilled labor can work in either sector. As the productivity of skilled workers relative to unskilled workers rises more people choose to become skilled and hence are employed in the non-unionized part of the economy. Last, their analysis is theoretical in nature. Acikgoz and Kaymak (2011) embed a model of unionization into a Mortensen-Pissarides style job matching model. In their framework, workers differ both by their ability and skill levels. Firms observe both attributes, while unions see only the latter. They argue that a rise in the skill premium, which rewards both ability and skill, reduces the incentive for a skilled worker to join a union. The rise in the skill premium is also associated with unskilled workers becoming less productive. This renders them less attractive for firms to hire at high union wages.

2 Mass Production and Computerization

2.1 The Rise of Unions, 1913-1955

Mass production and Fordism were interchangeable terms at one time. In 1913 Ford's Highland Park plant became the first automobile factory to have a moving assembly line. It signalled the death of the craft production methods that characterized the previous century. This was achieved through the use of standardized parts, pioneered in the 19th century arms industry. Time spent fitting inexact parts was eliminated. The moving assembly line was also inspired by the flow production techniques used in flour milling and meat packing. Greater specialization of labor was the result. It reduced the unnecessary handling of the product associated with ferrying the work between production operations–in early factories the placement of machines was often organized by their intrinsic operations (say drilling or milling) and not by where they lay in the production sequence.

At the beginning of the 20th century, automotive, carriage and wagon, and machine and metal-working workshops were artisanal in character. They had three types of workers: skilled mechanics, specialists and laborers. The skilled mechanics undertook the productive operations. They supervised the other workers. A census report stated that the "machinist, in its highest application, means a skilled worker who thoroughly understands the use of metal-working machinery, as well as fitting and work at the bench with other tools." Laborers were unskilled and did "manual labor that requires little or no experience or no judgement, such as shovelers, loaders, carriers, and general laborers." The semi-skilled specialist lay between these two categories. The census referred to them as "machinists, of inferior skill." It stated that "those who are able to run only a single machine or perhaps do a little bench work, are classed as second class machinists and grouped with machine tenders and machine hands." Meyer (1981, pp 13-14) describes how Ford engines were put together just before the assembly line was born:

> At the assembly bench, the skilled worker occupied a central place. He began with a bare motor block, utilized a wide range of mental and manual skills, and attached part after part. Not only did he assemble parts, but he also 'fitted' them. If two parts did not go together, he placed them in his vice and filed them to fit. The work routines contained variations in tasks and required considerable amounts of skill and judgment. Additionally, unskilled truckers served the skilled assemblers. When an assembler completed his engine, a trucker carried it away and provided a new motor block. The laborer also kept the assembler supplied with an adequate number of parts and components. Here, the division of labor was relatively primitive–essentially, the skilled and unskilled. Under normal conditions, a Ford motor assembler needed almost a full day of work to complete a single engine.

Mass production involved the breakdown of the manufacturing process into a series of elementary tasks and the transfer of skill to machines. Frederick W. Taylor wrote in 1903 that "no more should a mechanic be allowed to do the work for which a trained laborer can be used" and that "a man with only the intelligence of an average laborer can be taught the most difficult and arduous work if it is repeated; and this lower mental caliber renders him more fit than the mechanic to stand the monotony of repetition." A 1912 report of the American Society of Mechanical Engineers stated that "after the traditional skill of a trade, or the peculiar skill of a designer or inventor, has been transferred to a machine, an operator with little or no previously acquired skill can learn to handle it and turn off the product."

An 1891 sample of metal-working establishments in Detroit shows the importance of skilled labor in artisanal production. As Table 1 illustrates, mechanics accounted for 40% of the workforce. Meyer (1981) feels that this pattern would have been characteristic of the early Ford Motor Company as well. The composition of the workforce at the Ford Motor Company had changed by 1913, as Table 2 illustrates. Operators make up the majority of workers. These were deskilled specialists performing routine machine operations. Mechanics account for only a small portion of the workforce. The deskilling of the workforce is nicely related by Wolmack et al. (1990, pg. 31):

> The assembler on Ford's mass production line had only one task–to put two nuts on two bolts or perhaps attach one wheel to each car. He didn't order parts, procure his tools, repair his equipment, inspect for quality, or even understand what the workers on either side of him were doing. Rather, he kept his head down and thought about other things. The fact that he might not even speak the same language as his fellow assemblers or the foreman was irrelevant for the success of Ford's system.

Only a few minutes of training was required to teach someone to be an assembler. This system of manufacturing rapidly diffused through the American economy. The pinnacle of the mass production era was 1955.

Before proceeding on to a discussion about the decline of unionization, a caveat is in order. While the analysis here stresses the role that mass production played in driving unionization, changes in labor laws undoubtedly contributed to the very rapid rise in unionization that occurred during the 1930s and 1940s. The shifts in labor laws for this period are chronicled in Ohanian (2009). He also analyzes their impact on the Great Depression. Union wages were required to be paid on federal public works contracts by the Davis–Bacon Act in 1931. The Norris–Laguardia Act, which was passed in 1932, limited the power of courts to issue injunctions against union strikes, picketing, or boycotts. It also outlawed "yellow dog" contracts. These contracts prohibited workers from joining a union; they could be fired if they did. The Wagner Act of 1935 provided for collective bargaining and placed very few restrictions on the rights of workers to strike. Some of the rights that unions had won during the 1930s were rolled by back by the Taft-Hartley Act in 1947. It outlawed closed shops, required an 80 day notice for strikes, allowed states to pass right to work laws, among other things. Of course, the dawning of the mass production era may have provided a catalyst for enacting such laws. Doepke and Tertilt (2009) discuss how technological progress, which increased the importance of education, may have lead to an expansion of women's rights. In a similar vein, one could argue that a rise in the strength of unions may increase the demand for technologies that place less reliance on unionized labor. All of these considerations are abstracted from here.

2.2 The Fall of Unions, 1955-

In 1952 MIT publicly demonstrated an automatic milling machine. The machine read instructions from a paper punch tape. The instructions were fed to servo-motors guiding the position of the cutting head of the machine relative to the part being manufactured along the x, y and z axes. Feedback from sensors regulated the process. By changing the instructions the machine could manufacture a different part. Such a "flexible machine" could make small batches of many different parts. The world had entered the age of numerically controlled machines. Numerically controlled machines were slow to catch on. The MIT machine would not have been reliable for commercial production; it had 250 vacuum tubes, 175 relays, and numerous moving parts. Programming them was a time consuming task. Standardized languages had been developed for programming automated machine tools by the 1960s. At the same time the arrival of less expensive computers in the 1960s and made them economical. The separation of software from hardware also lowered the costs of implementing numerical control systems. As calculating power increased, computers could aid the design of products (CAD). Computers could also be used for planning and managing business in addition to running the machines on the factory floor (computer-aided manufacturing or CAM). In fact, sometimes they could automate virtually the entire business (computer-integrated manufacturing or CIM). The use of computers reduced the need for unskilled labor in factories and offices.

Mass production is an inflexible system. It is difficult to change a product or the manufacturing procedure once an assembly line has been instituted. As Henry Ford said "Any customer can have a car painted any color that he wants so long as it is black." This didn't suit Japanese manufacturing in the early postwar period, which had small production runs. The dies (or the forms) used in presses to shape metal parts had to be switched frequently. It took specialists in an American plant a day to change dies. Dies weighed tons and had to be set in the presses with absolute precision. Otherwise, defects would appear in the manufactured parts. In the 1940s and 50s, Taiichi Ohno, Toyota's chief production engineer, perfected a simple system where they could be changed in minutes. Since the presses had to remain idle while the dies where changed, Ohno reasoned that the production workers could do this. Furthermore, they could check the manufactured parts for defects thereby catching mistakes early on in production process. Quality control was at the end of the process in the typical mass production facility. Overtime Toyota gradually evolved to a process where teams of workers were responsible for segments of the assembly line. Besides production, they looked after housekeeping, minor machine repairs and quality checking for their section of the line. According to Wolmack et al. (1990) in a mass production automobile plant about 20% of area and 25% of working time are devoted to fixing mistakes. This is eliminated in a Toyota "lean production" facility. The Toyota production system favors skilled workers rather than unskilled ones. It has now been widely adopted in manufacturing.

The upshot of computerization in production and new organizational structures was that the demand for unskilled labor fell relative to the demand for skilled labor. This is shown in Figure 2, where unskilled workers are defined as clerical workers, laborers, operatives, and sales personnel, while skilled ones are taken to be craftsmen, managers, and professionals.

Skilled-biased technological progress favored unskilled labor during the first part of the

Figure 2: Ratio unskilled to skilled workers, 1860 to 1990–see the Appendix for a discussion of the data sources used in this figure

20th century. Since unskilled labor is more homogenous than skilled labor, it is easier to organize. Therefore, unionization occurred historically in occupations and industries that attracted unskilled labor. While the first part of the 20th century witnessed a rise in unionization, starting in the mid-1950's skill-biased technological change dislocated unskilled workers replacing them with mixes of capital and skilled workers. This was associated with the rise of computers and was just discussed. Therefore, in the second half of the century, industries and professions with higher initial unionization rates should exhibit larger declines in employment than those with lower initial unionization rates, because these industries and professions had disproportionately bigger shares of unskilled labor.

Over the period 1983 to 2002, for which annual unionization rates by occupation and industry are available from the *Union Membership and Coverage Database*, the union membership rate in the U.S. declined nearly 34%, from 20.1 to 13.3%–the Appendix contains a description of the various data sources used in this paper.[2] In manufacturing the decline

[2] See Hirsch and Macpherson (2003) for details on the *Union Membership and Coverage Database*.

was more pronounced. The union membership rate fell from 27.8 to 14.3%, a decline of nearly 50%. Now, highly unionized occupations were especially hard hit. Table 3 lists the unionization rates for the 20 fastest declining and growing occupations between 1983 and 2002. The 20 fastest declining occupations consist mainly of laborers, machine operators, and clerical workers, and as many as 10 of these occupations had a 1983 unionization rate that was in the top quartile of the 1983 unionization rate across occupations. In contrast, of the 20 fastest growing occupations, only 4 had a unionization rate that was in this quartile. These occupations largely pertain to skilled technical workers, such as engineers, managers, and other professionals.

As a prelude to the more formal statistical analysis that is undertaken in Section 7, the following question is asked: Did industries and occupations with higher initial unionization rates in 1983 experience greater employment losses?[3] The answer should be yes, if skilled-biased technological change reduced the demand for unskilled labor, which in turn was disproportionately represented in the unionized sector of the economy. In other words, the initial unionization rate in an industry or occupation can be viewed as a proxy for the degree of proneness of that industry or occupation to employment loss due to skill-biased technological change. This hypothesized link between employment growth patterns and unionization rates is tested using data on unionization for U.S. occupations and industries between 1983 and 2002.

The connection between unionization and employment growth in an occupation is explored in Table 4, which presents regression estimates of the relationship between the percentage growth rate in employment in an occupation between 1983 and 2002, on the one hand, and the initial percentage unionization rate and the percentage growth rate in unionization, on the other hand. The initial unionization rate is measured by either the percentage of union members in an occupation or the percentage covered by a union.[4] The estimated

[3] The earliest year for which data on unionization is available in the Union Membership and Coverage Database is 1983. The focus on 1983-2002 period is primarily due to the fact that detailed industry and occupation codes before 1983 and after 2002 cannot be made consistent with those during this period.

[4] The percentage growth rate in unionization is calculated slightly differently. Let X_t denote number of

coefficients for the initial union membership and coverage rates are all negative, but for one case. Furthermore, all but two estimates are statistically significant at the 1% level. Employment growth is also positively associated with growth in union membership or coverage. One might expect that as union membership drops so might employment, since the former contributes to labor in the industry. Across specifications, a 1 percentage point increase in the initial unionization rate is associated with a 0.2 to 0.5 percentage point decline in employment growth.[5]

Table 5 repeats the analysis in Table 4 using percentage growth in employment in an industry as the dependent variable. These industry-level regressions also control for the percentage growth in real output and the percentage growth in labor productivity (real output per worker), which are also expected to matter for changes in industry employment. These growth rates are calculated over the period 1982 to 2002, using the closest economic census year (1982) to the earliest year data is available on unionization, 1983.[6] The main conclusions from Table 4 prevail. Employment growth is negatively associated with the initial unionization rate and positively associated with growth in unionization. The estimated coefficient of the initial unionization rate is much higher compared with Table 4. Across different specifications, a 1 percentage point increase in the initial unionization rate corresponds to a 1.2 to 1.5 percentage point decline in an industry's employment growth rate over the sample period.

Overall, these preliminary findings support the hypothesis that in recent times highly unionized industries and occupations have been more prone to employment loss. This constitutes indirect evidence on the connection between unionization and technological change. The statistical analysis conducted in Section 7 provides more direct statistical evidence on the link between skill-biased technological change and unionization in light of the model

union members or those covered by a union in year t. The percentage growth rate of X_t is calculated as $100 \times 2 \times (X_{2002} - X_{1983}) / (X_{2002} + X_{1983})$, to accommodate the few cases where X_{1983} is zero.

[5] These within-occupation regressions results are also consistent with the Hirsch's (2008) finding that changes in union density within an occupation, rather than a change in the composition of jobs, account for a larger portion of the decline in unionization.

[6] The 2002 sales are deflated to 1982 dollars using the CPI.

presented next.

3 The Setting

Imagine a world inhabited by a representative family with tastes given by

$$\sum_{t=1}^{\infty} \beta^{t-1} \ln c_t, \text{ with } 0 < \beta < 1,$$

where c_t represents household consumption in period t. The family is made up of a continuum of members with a mass of one. Each household member supplies one unit of labor. A fraction σ of these members are skilled, the rest unskilled.[7] A skilled worker earns the period-t wage rate v_t. Unskilled members may work in the unionized part of the labor force or in the non-unionized one. A unionized worker earns the wage rate u_t, while a non-unionized one receives w_t. The fraction of unskilled household members that work during period t in the unionized part of the labor force is p_t, a variable that must be determined in equilibrium. The household saves in the form of physical capital. A unit of physical capital earns the rental r_t in period t. Capital depreciates over time at the rate δ. Finally, the household earns profits, π_t, from the firms that it owns.

There is a distribution of firms in the economy, with unit mass. In period t a firm produces output, o_t, according to the production function

$$o_t = x_t z k_t^{\kappa} [\theta_t l_t^{\rho} + (1 - \theta_t)(\xi_t s_t)^{\rho}]^{\alpha/\rho}, \text{ with } 0 < \alpha + \kappa < 1,$$

where k_t represents the amount of capital hired, l_t denotes the input of unskilled labor and s_t is the quantity of skilled labor. The variable x_t is a neutral shift factor for the technology

[7] The relative supply of skilled versus unskilled labor is assumed to be fixed over time. There is no doubt that supply shifts also have occurred over the course of history, in particular due both to changes in the return from and the cost of an education (the latter due to changes in its public provision). The model abstracts from these supply effects. Research on the evolution of the skill-to-non-skill wage premium over the 20th century indicates that skill-biased technological change played a very important role–see Goldin and Katz (2008) and Krusell et al. (2000). More generally, Greenwood and Yorukoglu (1997) document how times of rapid technological progress are often associated with shifts in the income distribution. The concept of skill cannot be mapped straightforwardly into years of education. As Goldin and Katz (2008) note, a high school degree would have been considered well-educated in 1915, while to be labeled this today would require a college degree or more. See Restuccia and Vandebroucke (2011) for a model of the rise in educational attainment.

that is common across firms. A firm-specific shift factor is given by $z > 1$. This denotes a firm's type and is drawn at the beginning of time from a Pareto distribution

$$z \sim F(z) \equiv \frac{\zeta}{z^{\zeta+1}}, \text{ for } z > 1,$$

where F is the density function for a Pareto distribution.

Observe that skilled and unskilled labor are aggregated via a CES production function. The technology variables θ_t and ξ_t change over time and will capture the notion of skill-biased technological change.[8] There are diminishing returns to scale in production (since $\alpha + \kappa < 1$). There is a fixed cost ϕ associated with operating a firm. As will be seen, the combination of diminishing returns to scale in production and a fixed operating cost ensure that it not desirable to organize all the firms in the economy.

Finally, there is a union in the economy. The union organizes unskilled labor in firms. An organized firm must use union labor. The union believes in equality so all union members are paid the same wage, u_t. Unionization is a costly activity. Specifically, the period-t cost of organizing is given by

$$\frac{p_t^{\mu+1}}{\mu+1},$$

where p_t is the number of union members. These costs are recovered from the membership in the form of dues, d_t. Skilled labor is not unionized. In the real world, this may be because it is too heterogenous in nature to organize effectively a mass of people to bargain for a common wage. The union is given the following set of preferences:

$$\sum_{t=1}^{\infty} \beta^{t-1}(u_t - d_t - w_t)^{\omega} p_t^{1-\omega}, \text{ with } 0 < \beta, \omega < 1.$$

These preferences presume that the union has two regards. It values the surplus that a union member will earn over a non-unionized worker, $u_t - d_t - w_t$, as well as the number of unionized workers, p_t, that will receive it. As will be seen, there is a tradeoff involved with these two regards. A survey of the theory of unions is contained in Oswald (1985).

[8] It may be uncommon to let θ_t vary over time. Rios-Rull and Santaeulalia-Llopis (forthcoming) do something similar in their study of how labor's share of income fluctuates over the business cycle.

4 Decision Problems

4.1 Households

The problem facing the representative family is standard, with due alteration for the setting under study. Specifically, the household desires to maximize its lifetime utility subject to the budget constraint it faces each period. This problem reads

$$\max_{\{c_t, k_{t+1}\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \beta^{t-1} \ln c_t, \qquad \text{P(1)}$$

subject to

$$c_t + k_{t+1} = (1 - p_t - \sigma) w_t + p_t(u_t - d_t) + \sigma v_t + (r_t + 1 - \delta) k_t + \pi_t \text{ (for } t = 1, 2, \cdots).$$

In the above maximization problem the household takes the number of union members, p_t, as given. Given that $u_t - d_t > w_t$, it would like as many unskilled household members as possible to be employed in union firms.

4.2 Firms

A firm in period t hires capital, k_t, and skilled and unskilled labor, s_t and l_t, to maximize profits. The firm's period-t choice problem is

$$\pi_t^q(z) = \Pi_t^q(z; q_t, \cdot) \equiv \max_{k_t^q, l_t^q, s_t^q} \{x_t z (k_t^q)^{\kappa} [\theta_t (l_t^q)^{\rho} + (1 - \theta_t)(\xi_t s_t^q)^{\rho}]^{\alpha/\rho} - r_t k_t^q - v_t s_t^q - q_t l_t^q\} - \phi \ ,$$

$$\text{for } q = w, u. \quad \text{P(2)}$$

With some abuse of notation, the variable q in superscript form will denote whether the firm is unionized ($q = u$) or not ($q = w$), while the variable q in regular form will represent the wage rate (again for $q = w, u$). Now, express the solution to the above problem for the amount of unskilled labor that a type-z firm will hire at the wage rate q_t by $l_t^q(z) = L_t^q(z; q_t, \cdot)$, for $q = w, u$–the "$\cdot$" represents the other arguments that enter the function L^q, which are suppressed to keep the subsequent presentation simple. Likewise, represent the amount of capital and skilled labor hired by $k_t^q(z) = K_t^q(z; q_t, \cdot)$ and $s_t^q(z) = S_t^q(z; q_t, \cdot)$. The amount of output produced by a firm is denoted by $o_t^q(z) = O_t^q(z; q_t, \cdot)$ and its profits are written as $\pi_t^q(z) = \Pi_t^q(z; q_t, \cdot)$.

A firm will only produce if it makes nonnegative profits. Thus, it must transpire that in equilibrium

$$\pi_t^q(z) = \Pi_t^q(z; q_t, \cdot) \geq 0, \text{ for } q = w, u.$$

Denote the period-t threshold value for z, at which it is just profitable for a firm to produce, by z_t^q. This threshold value solves the equation

$$\Pi_t^q(z_t^q; q_t, \cdot) = 0, \text{ for } q = w, u. \tag{1}$$

It should be clear that $\Pi_t^q(z_t^q; q_t, \cdot) > 0$ for $z > z_t^q$ and $\Pi_t^q(z_t^q; q_t, \cdot) < 0$ for $z < z_t^q$.

From the two first-order conditions associated with hiring labor, it transpires that

$$\frac{s_t^q}{l_t^q} = [\xi_t^\rho \frac{(1-\theta_t)}{\theta_t} \times \frac{q_t}{v_t}]^{1/(1-\rho)}, \text{ for } q = w, u. \tag{2}$$

The ratio of skilled to unskilled labor, s_t^q/l_t^q, in a firm depends on the price of unskilled labor relative to skilled labor, q_t/v_t. It also depends on the skill-biased technology term $\xi_t^\rho(1-\theta_t)/\theta_t$. This term captures the notion of skill-biased technological change in the model. When $\xi_t^\rho(1-\theta_t)/\theta_t$ is low, either because ξ_t is small or θ_t is high, unskilled labor is favored, relatively speaking. The benefit of unionizing unskilled workers will be large. This is portrayed in Figure 3, where the slope of an isoquant is given by $\theta_t/[(1-\theta_t)\xi_t^\rho](s_t^q/l_t^q)^{1-\rho}$. Thus, an upward shift in $\theta_t/[(1-\theta_t)\xi_t^\rho]$, say due to a fall in ξ_t or a rise in θ_t, causes the slope of an isoquant to increase along a ray from the origin. This is shown by the shift in the isoquant from S to U. As a consequence, at a given skill ratio, an extra unit of unskilled labor becomes more valuable in terms of skilled labor. If factor prices remained fixed, then the firm would substitute away from skilled labor toward unskilled labor, as reflected by the movement from l to l' in the diagram. Equation (2) will be used in part of the statistical analysis.

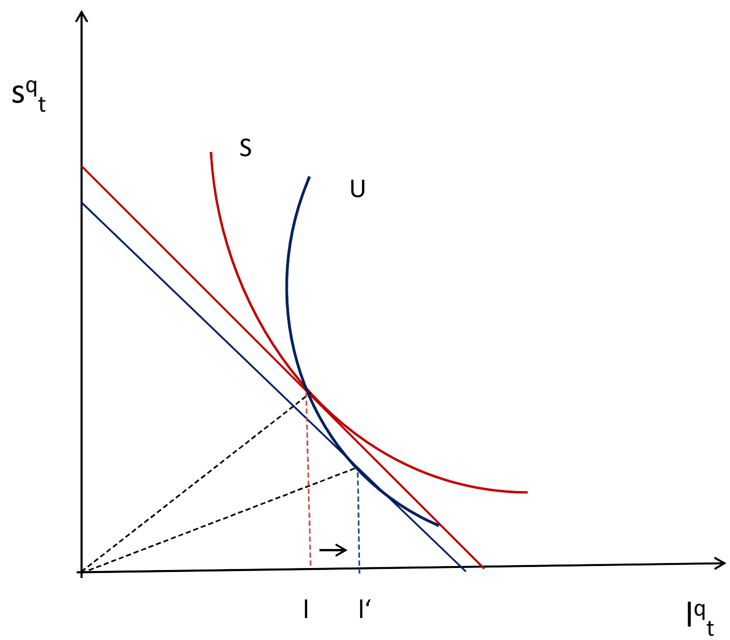

Figure 3: Skilled-biased technological change: unskilled labor becomes more favored when the isoquant shifts from S to U

4.3 The Union

Recall that the union has two regards. First, it values the surplus over the competitive wage that union members earn. Second, it also puts worth on the number of workers that will earn the union wage. It is intuitive that the union should organize the firms with the highest level of productivity first. They can better afford to pay the union premium. There is a limit to the wage that the union can set. Specifically, a unionized firm must earn nonnegative profits. So, if any unionized firm earns zero profits then all firms with a higher level of productivity will be unionized and those with a lower level will not. Because more productive firms are also larger in the model, the union organizes larger firms. This prediction of the model is consistent with studies indicating higher likelihood of unionization among larger firms.[9]

Now, turn to the optimization problem faced by a union. Assume that the profits of the last firm unionized are squeezed to zero. The number of unionized workers in period t, p_t, will be given by

$$p_t = \int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot)F(z)dz. \tag{3}$$

The dues paid by a union member, d_t, are

$$d_t = \frac{\chi p_t^{\mu+1}}{(\mu+1)p_t} = \frac{\chi[\int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot)F(z)dz]^{\mu}}{\mu+1}. \tag{4}$$

The union's decision problem appears as

$$\max_{\{u_t, z_t^u\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \{u_t - \frac{\chi[\int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot)F(z)dz]^{\mu}}{1+\mu} - w_t\}^{\omega}[\int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot)F(z)dz]^{1-\omega}, \qquad \text{P(3)}$$

subject to the zero-profit constraint (1) holding (when $q = u$) for the marginal union firm, z_t^u. When solving this problem, the union takes the wages for non-unionized unskilled and skilled labor, w_t and v_t, as given. Is it possible that the union won't pick the wage rate so that the threshold firm earns zero profits? The answer is no. Suppose that the marginal firm earned positive profits. The cost of raising the union wage incrementally is the loss of membership that will occur from all of the inframarginal firms. It turns out, though,

[9] See, e.g., Fang and Heywood (2006).

that this loss can be made up for by increasing the number of unionized firms or lowering z_t^u. How far can u_t be raised and z_t^u simultaneously lowered? At some point the firms with the lowest z_t^u will no longer be able to earn profits due to the presence of the fixed cost ϕ. Then the process must stop. Without the fixed cost, ϕ, every firm would be unionized. In this situation, all firms would earn some profits, albeit for some of them they might be infinitesimally small. In general not all of the unskilled work force will be hired.

Lemma 1 *(Zero profits for the marginal firm) The union always picks the wage rate, u_t, so that the zero-profit constraint (1) is binding (when $q = u$) for the last firm organized.*

Proof. See Appendix. ■

The union's two regards must be traded off in the maximization problem P(3). By applying the envelope theorem to a unionized firm's optimization problem [P(2) for $q = u$], it can be easily calculated from equation (1) that

$$\frac{du_t}{dz_t^u} = \frac{O^u(z_t^u; u_t, \cdot)}{z_t^u L_t^u(z_t^u; u_t, \cdot)} > 0.$$

This implies that lowering the threshold hold, z_t^u, or equivalently unionizing more firms, can only be accomplished by reducing the union wage, u_t. Additionally, it can be seen from equation (4) that a rise in membership, $p_t = \int_{z_t^u}^{\infty} L_t^u(z; u_t, \cdot)F(z)dz$, comes at the expense of higher dues, d_t, because of the increasing costs involved with unionization.

5 Equilibrium

In equilibrium the markets for capital, labor and goods must clear. Equilibrium in the capital market requires that

$$\int_{z_t^w}^{z_t^u} k_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} k_t^u(z)F(z)dz = k_t. \tag{5}$$

The market-clearing condition for skilled labor is

$$\int_{z_t^w}^{z_t^u} s_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} s_t^u(z)F(z)dz = \sigma, \tag{6}$$

while that for unskilled labor reads

$$\int_{z_t^w}^{z_t^u} l_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} l_t^u(z)F(z)dz = 1 - \sigma. \tag{7}$$

Last, equilibrium in the goods market implies

$$c_t + k_{t+1} + p_t d_t = \int_{z_t^w}^{z_t^u} o_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} o_t^u(z)F(z)dz + (1-\delta)k_t. \tag{8}$$

Note that the aggregate amount of union dues, $p_t d_t$, appears in the resource constraint. These exactly cover the resource cost of organizing– see (4).

A definition of the equilibrium under study will now be presented to take stock of the situation so far.

Definition 2 *(Definition of a competitive equilibrium) A competitive equilibrium is a time path for consumption and savings, $\{c_t, k_{t+1}\}_{t=1}^{\infty}$, a set of labor and capital allocations for union ($q = u$) and non-union ($q = w$) firms $\{l_t^q(z), s_t^q(z), k_t^q(z)\}_{t=1}^{\infty}$, a set of factor prices $\{u_t, w_t, v_t, r_t\}_{t=1}^{\infty}$, a sequence for union dues, $\{d_t\}_{t=1}^{\infty}$, and a sequence determining the threshold points for non-union and union firms, $\{z_t^w, z_t^u\}_{t=1}^{\infty}$, such that for a given time profile for technology $\{\theta_t, \xi_t, x_t\}_{t=1}^{\infty}$:*

1. *The time path for consumption and savings, $\{c_t, k_{t+1}\}_{t=1}^{\infty}$, solves the representative household's problem, P(1), given the time path for factor prices, $\{u_t, w_t, v_t, r_t\}_{t=1}^{\infty}$, profits, $\pi_t = \int_{z_t^w}^{z_t^u} \pi_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} \pi_t^u(z)F(z)dz$, and the size of the union sector, $p_t = \int_{z_t^u}^{\infty} l_t^u(z)F(z)dz$.*

2. *The time paths for firms' input utilizations, $\{l_t^q(z), s_t^q(z), k_t^q(z)\}_{t=1}^{\infty}$, solve their profit maximization problems, as specified by P(2), given the time paths for factor prices, $\{q_t, v_t, r_t\}_{t=1}^{\infty}$ (for $q = u, w$).*

3. *The sequences for union wages, $\{u_t\}_{t=1}^{\infty}$ and the threshold, $\{z_t^u\}_{t=1}^{\infty}$, solve the union's problem P(3), given the time paths for competitive wages, $\{w_t, v_t\}_{t=1}^{\infty}$, the rental rate for capital, $\{r_t\}_{t=1}^{\infty}$, and the solution to the unionized firm's problem, $l_t^u(z) = L_t^u(z; u_t, \cdot)$ and $\pi_t^u(z) = \Pi_t^u(z; u_t, \cdot)$, as implied by P(2). The sequence for union dues, $\{d_t\}_{t=1}^{\infty}$, is determined in line with (4).*

4. *The sequence for non-union thresholds, $\{z_t^w\}_{t=1}^{\infty}$, solves (1) when $q = w$, given $\pi_t^w(z) = \Pi_t^w(z; w_t, \cdot)$ from P(2).*

5. *The markets for capital, labor and goods, all clear so that equations (5) to (8) hold.*

6 Simulation Analysis

6.1 Calibration

Before the model can be simulated values must be assigned for its parameters. Table 6 summarizes the parameter values. The period is taken to be five years. Accordingly, the discount factor is set so $\beta = 1/(1.04)^5$, which implies an annual interest rate of 4%. This is a standard value. The annual depreciation rate for capital is taken to be 0.08, another standard value. Likewise, labor's share of income is set at 60%, implying $\alpha = 0.60$, another typical value if one assumes that part of the capital stock includes intangibles. Note that a firm's production function exhibits diminishing returns to scale. Guner, Ventura and Xi (2008) estimate that the share of profits in output is 20%. Capital's share of income, κ, is therefore set at 0.20. Katz and Murphy (1992) estimate that the elasticity of substitution between skilled and unskilled labor is 1.4. This corresponds to a value of 0.29 for ρ.

The rest of the model's parameters are selected so that a steady state for the model hits 5 data targets for the year 1955. This is the peak of the unionization movement. This involves computing the model's steady state in conjunction with the 5 data targets while taking the 5 parameters θ_{1955}, μ, ω, χ and ζ as additional variables. The technology variable ξ is normalized to one for 1955 so that $\xi_{1955} = 1$. The first target is the fraction of population that was unionized. In 1955 this was 32%. Therefore, the steady state is computed subject to restriction

$$p_{1955} = 0.32.$$

Let the top 10% of the population represent skilled labor. Thus, $\sigma = 0.10$. The share of the top 10% of the work force in earnings was 0.32. Therefore, the steady state must satisfy the condition

$$\frac{\sigma v}{pu + (1 - p - \sigma)w + \sigma v} = 0.32.$$

Union dues are assumed to amount to 1% of a union members wages. MacDonald and Robinson (1992, p 47) state that this is a reasonable value. Indeed, this is exactly what the

UAW currently charges salaried workers. Thus, set

$$\frac{d_{1955}}{u_{1955}} = 0.01.$$

The distribution of employment across establishments in the U.S. is very tight. Henley and Sanchez (2009, p 427) report that the coefficient of variation across U.S. establishments was 8% in 1974. It remained relatively constant after that. This observation is targeted to provide guidance for the choice of the Pareto distribution parameter ζ. Next, the wage premium from a union membership is taken to be 15%, the famous value of H. Greg Lewis. This implies

$$\frac{u_{1955}}{w_{1955}} = 1.15.$$

6.2 Results

Can the model explain the $\cap$-shaped pattern of union membership along with the $\cup$-shaped profile for income inequality that were observed over the 20th century? To investigate this question requires inputting in a time series process for technology, $\{\theta_t, \xi_t\}_{t=1920}^{2000}$. A perfect foresight path for the model is calculated using a variant of the Fair and Taylor (1983) algorithm, which is useful for computing saddle path solutions for two-point boundary value problems. The Fair and Taylor (1983) algorithm is a relative of the multiple shooting algorithm used to solve difference equation systems. The first boundary condition for the economy is the initial capital stock, while the second one is capital stock associated with the terminal steady state.

The process for $\{\theta_t, \xi_t\}_{t=1920}^{2000}$ is constructed in a crude way. Steady states for the model are computed for 1920 and 2000, the starting and ending years for the analysis. Union membership and income inequality are taken as targets for these years. Solutions for θ and ξ are backed out that hit these targets, while holding all other parameter values fixed. Assume that θ_t and ξ_t are separately quadratic in t. Each quadratic will have three parameters. Fit these two quadratics to the triplets $(\theta_{1920}, \theta_{1955}, \theta_{2000})$ and $(\xi_{1920}, \xi_{1955}, \xi_{2000})$, respectively. The resulting time profile for skill-biased technological change, as represent by

$[\xi_t^{\rho}(1-\theta_t)/\theta_t]^{1/(1-\rho)}$, is shown in Figure 4. After the year 2000 all technological change is shut off. The capital stocks associated with the 1920 and 2000 steady states are taken as the initial and terminal capital stocks when computing the transitional dynamics for the model, although the model needs to be run for somewhat more than 80 years to reach the final steady state.

Is the pattern of skill-biased technological change shown in Figure 4 reasonable? The extent of the required shift is quite modest, 25% from peak to trough. Over the 1920 to 2000 period real per-capita income grew by 2.25% a year. This implies that real per-capita GDP rose by a factor of 6. To achieve this in the model, the neutral technological shift factor, x, must rise by a factor of $6^{1/(1-\kappa)} = 9.4$. Therefore, skill-biased technological change is swamped by neutral technological change. Imagine calculating total factor productivity as is conventionally done by $\text{TFP}_t = [\int_1^{z_t^u} o_t^w(z)F(z)dz + \int_{z_t^u}^{\infty} o_t^u(z)F(z)dz]/k_t^{\kappa}$. All the observer would see is a seemingly smooth rise in TFP_t, as Figure 4 illustrates. He would not notice the tiny wiggles associated with skill-biased technological change.

The framework does a good job accounting for the rise and fall in union membership, as Figure 5 illustrates. It also mimics the fall and rise in income equality as well. This is shown in Figure 6. In the analysis, skilled-biased technological change is the sole driver of both the ∩-shaped time series for unionization and the ∪-shaped one for income inequality; i.e., the ∪-shaped pattern in income inequality is not caused by the ∩-shaped time series for unionization. By this account, very little of postwar rise in inequality can be accounted for by the decline in unionization. Goldin and Katz (2008), Greenwood and Yorukoglu (1997), and Krusell at el. (2000) all stress technological change as a force underlying shifts in the income distribution.[10]

[10] Goldin and Katz (2008) also say that a drop in unionization may have contributed to a rise in income inequality. As will be seen in the next section, the union wage premium is of moderate size, it applies to a relatively small part of the aggregate wage bill, and a fall in union wages for unskilled workers implies a rise in nonunion wages. Hence, a drop in unionization is unlikely to account for the large observed shifts in income inequality. In fact, if one assumes that all unskilled workers get the non-union wage the plot obtained for the income distribution looks virtually identical to that displayed in Figure 6.

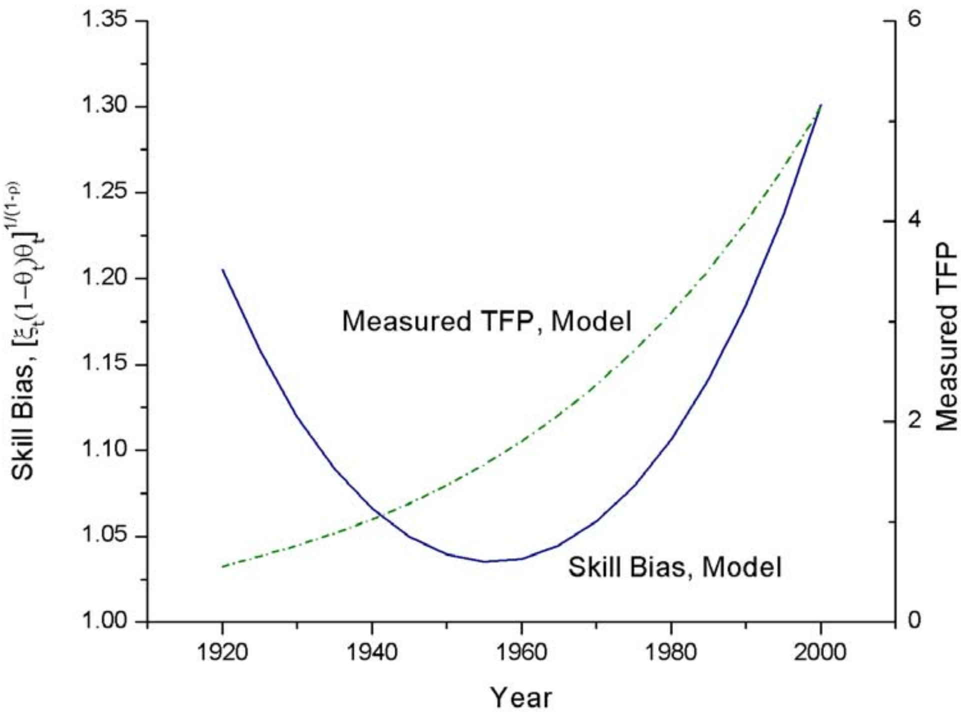

Figure 4: Technological Change, model

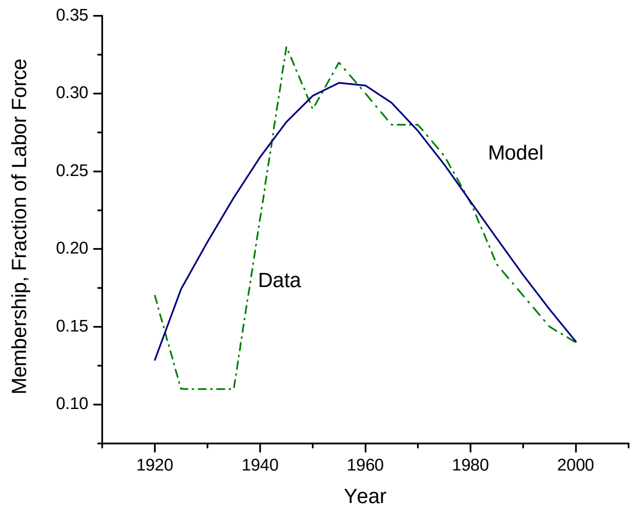

Figure 5: Union Membership over the 20th Century, data and model

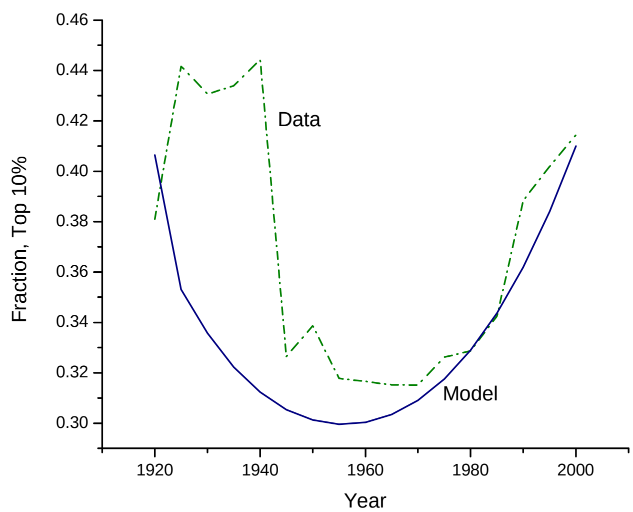

Figure 6: The Distribution of Income over the 20th Century, data and model

6.3 Welfare Cost of Unions

So, what is the welfare cost of unions? Rees (1963) asked this question a long time ago. He found that the welfare loss from unions in 1957 amounted to 0.14% of GDP. The model developed here can be used to address this question. Suppose that the model economy is resting in its 1955 steady state, the peak of the union power. Now, eliminate unions. The model would then imply a welfare increase of 0.38% of GDP. While this is 2.7 times as big as Rees's number, it is paltry.

Figure 7 illustrates the situation in an alternative, Reesian fashion. The picture draws the demands for unskilled labor by both union and non-union firms. These demands must sum up to 0.9, the size of the unskilled labor force as a proportion of the total labor force. In the economy without unions, the union firms would hire 0.42% of the total labor force (including skilled labor) at the competitive wage rate w^c. Unions increase this wage to u. As a consequence, unionized firms cut their employment of unskilled labor from 0.42% of the total labor force to 0.32%. This leads to welfare loss measured by the area $acde$. But, the labor displaced by union firms is picked up by non-union ones. The wage rate for nonunion labor falls from w^c to w. The gain in welfare from the increased employment by non-union firms is represented by the area $cdeb$. The net loss is the area in the triangle acb. This triangle represents the difference in productivities between the unionized and non-unionized firms. It amounts to $0.5 \times 0.15 \times w \times (0.42 - 0.32)$. Expressing this as a percentage of aggregate output, o, gives

$$\begin{aligned} 100\% \times \frac{0.5 \times 0.15 \times w \times (0.42 - 0.32)}{o} &= 100\% \times 0.5 \times \underbrace{\frac{0.15 \times w \times 0.32}{o}}_{0.021} \times \underbrace{\frac{(0.42 - 0.32)}{0.32}}_{0.31} \\ &= 0.32\%. \end{aligned}$$

This number is slightly smaller than the model's figure of 0.38%. It is easy to see why this number will be small. First, the union premium, 0.15, only applies to small part of wage bill expressed as a fraction of output, $w \times 0.32/o$. This represents the base of triangle. Second, the proportional shift in union labor, $(0.42 - 0.32)/0.32$, is not that large. This is the height of the triangle. Note that this triangle estimate is extremely close to general equilibrium

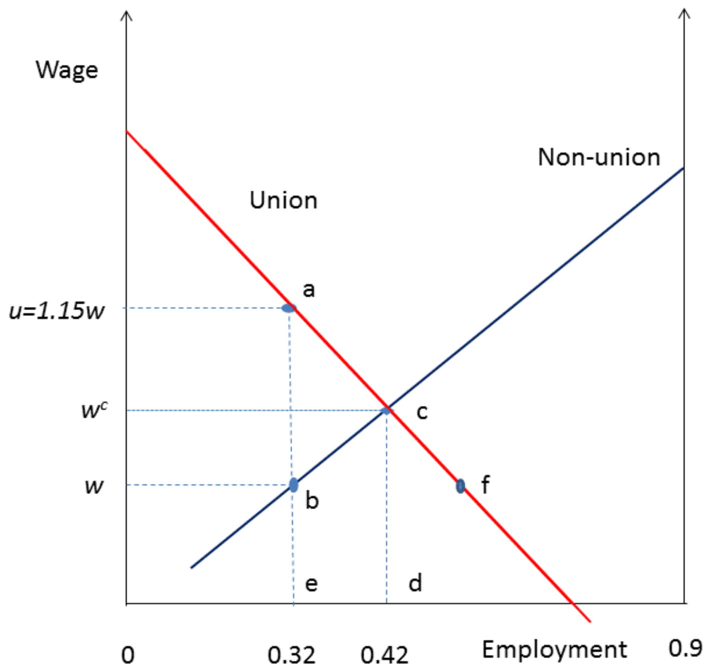

Figure 7: The welfare loss from unions

one. Rees's (1963) is a bit vague on the details surrounding his estimation. First, it is unclear how he obtains the magnitude of his shift in labor demand. Second, it is hard to tell whether his estimated shift in labor should refer to the length ed or the length bf. If it is the later, as it seems from the context he took the number from, then it is too large. Doing an appropriate correction would yield something around 0.07% of GDP. The difference between Rees's estimate and the current one derives from a difference in the implied elasticities for labor demands.

The fact that the welfare cost of unions is so small does not imply that they have little effect on the economy. The impact that unions have on economy here is restricted by the assumption that firms are competitive. Whether or not this is a good approximation for the U.S. economy across the time period studied is an open question. Perfect competition limits the wages that unions can obtain. Unions are more likely to have a large impact on economic activity when they are negotiating with producers that have monopoly power. This was the case in U.S. iron market prior to the 1970s. After this time, producers faced intense competition from foreign exporters. Schmitz (2005) documents how this increased competition led to a large rise in labor productivity. Firms were forced to abandon the productivity-hindering work practices that they had negotiated with unions earlier. His story might also apply at points in time to the aircraft, airline, auto industries, for example. In a similar vein, Cole and Ohanian (2004) study the detrimental impact that unions had on the economy during the Great Depression. They stress the cartelization of industries allowed by Roosevelt under the New Deal, which were then abandoned prior to World War II. Taschereau-Dumouchel (2011) argues that just the threat of unionization may be enough to generate large welfare costs. To keep unions out, firms have to offer high wages to low-skilled workers in his model.

7 Empirical Evidence

Is skill-biased technological change an empirically relevant factor in the decline of unionization in the U.S.? This question will be examined in two ways. First, the model predicts that the ratio of skilled labor to non-skilled labor should increase with skill-biased technological progress. This implication can be seen directly from equation (2): the ratio s_t^q/l_t^q is positively related to the term that captures skill-biased technological change, $\xi_t^\rho(1-\theta_t)/\theta_t$. Second, the fraction of the labor force that is unionized, p_t, is negatively related to skill-biased technological progress, as the simulation analysis established. To test these two predictions, a measure of skill-biased technological change is needed.

Measures of skill-biased technological progress are difficult to come by. The macroeconomics literature, in particular Krusell at el. (2000), suggests that the relative price of new capital goods is one measure. In a famous paper, Solow (1960) argued that technological progress is embodied in the form of new capital goods, which is now commonly referred to as investment-specific technological progress. Investment-specific technological progress is incarnated in new technologies, such as more powerful computers, faster and more efficient means of telecommunication, and numerically-controlled industrial machines. As new technologies come on line, they tend to become less expensive due to process innovation and the entry of competitors. Greenwood, Hercowitz and Krusell (1997) illustrate how investment-specific technological progress manifests itself in the form of decreasing relative prices for new capital goods, measured in terms of consumption goods. Again, Krusell at el. (2000) suggest that the decline in the relative price of capital goods is a driver of skill-biased technological progress. Now, different industries use different mixes of capital goods. If skill-biased technological change is embodied in the form of new capital goods, then one hypothesis is that those industries where the price of new capital goods falls the quickest should exhibit the fastest rates of de-unionization.

Calculating the relative price of new capital goods at the industry level, in quality-adjusted terms, is not a straightforward task. Cummins and Violante (2002) have done this calculation for equipment and software (E&S). Their price series will be used here.[11]

E&S include four major groups: industrial equipment, transportation equipment, office information processing equipment, and other equipment. Technological progress in E&S is viewed as complementing skilled workers more so than unskilled workers. Compared with other candidate measures, such as the stock of E&S or real investment in E&S, the Cummins and Violante (2002) relative price series take into account the quality improvements in E&S over time, and it measures the quality-adjusted price of E&S with respect to the price of constant-quality consumption goods. The connections between skill-biased technological progress, on the one hand, and investment in E&S or the stock of E&S, on the other, are likely to be more ambiguous in nature. An increase in investment or the stock of E&S may be associated, for instance, with an expansion in industry output, but not necessarily with an advance in technology favoring skilled workers. Furthermore, as higher quality and more advanced E&S becomes available at lower prices, conventionally-measured total real investment in, or the stock of E&S may not show much of a rise and could actually decrease.

[11] See Cummins and Violante (2002) for the details on the construction of this relative price series.

Investment and the capital stock are also more subject to endogeneity issues. The rapid decline in the price of E&S is likely to occur from technological progress, which can be taken as exogenous with respect to the process of change in unionization and the composition of skill in the economy.

7.1 Skill Composition and Skill-biased Technological Change

Consider the logarithm of the firm-level skilled-to-unskilled labor ratio defined by (2)

$$\ln \frac{s_t^q}{l_t^q} = \frac{1}{1-\rho} \ln \xi_t^{\rho} \frac{(1-\theta_t)}{\theta_t} + \frac{1}{1-\rho} \ln \frac{q_t}{v_t}. \tag{9}$$

The term $\xi_t^{\rho}(1-\theta_t)/\theta_t$ captures skill-biased technological progress, while q_t/v_t is the relative price of unskilled labor with respect to skilled labor.

One measure of the skill ratio, s_t^q/l_t^q, is the ratio of non-production workers to production workers in a firm. This ratio is readily available at the industry level annually for manufacturing industries from the *NBER-CES Manufacturing Industry Database*. The definition of non-production workers is rather broad: it lumps together managers, professionals such as engineers and lawyers, and many other employees who are not directly involved in production. On average, non-production workers' wages are much higher than production workers' wages.[12] One may argue that non-production workers embody more skill or human capital than production workers, at least on average. Denote by S_{it} the ratio of non-production workers to production workers in industry i for year t. Based on (9), one can consider a panel regression of the form

$$\ln S_{it} = \beta \ln P_{it} + \gamma \ln W_{it} + \boldsymbol{\lambda} \ln \mathbf{X}_{it} + T_t + I_i + \varepsilon_{it}. \tag{10}$$

The panel regression (10) is implemented at the industry level.[13] In (10), P_{it} is the relative

[12] For instance, in the 1997 Census of Manufactures, the average wage of production workers was about $21,000, compared with about $39,000 for non-production workers, a difference that is also highly statistically significant. In *NBER-CES Manufacturing Industry Database*, the ratio of the average wage of non-production workers to that of production workers ranges from 1.14 to 2.43 across 2-digit manufacturing industries during the 1958-1999 period.

[13] Note that equation (9) is defined at the firm level. In the model, the ratio s_t^q/l_t^q is identical across firms

price of equipment and software that measures the state of skill-biased technological change in industry i for year t. P_{it} is the inverse of the price ratio calculated by Cummins and Violante (2002). Based on the model, the expected sign of $\ln P_{it}$ is negative: as the relative price of equipment and software declines–indicating skill-biased technological progress–the skilled-to-non-skilled labor ratio should increase. W_{it} is the ratio of the average wage of production workers to that of non-production workers, which should have a positive association with S_{it}.[14] $\mathbf{X}_{it}$ is a vector of industry-year varying controls, T_t is a year fixed effect, I_i is an industry fixed effect, and ε_{it} is an error term.[15] The error terms are allowed to be clustered within industries. The fixed-effects specification in (10) can be estimated using the balanced panel of 19 two-digit manufacturing industries available from the *NBER-CES Manufacturing Industry Database* over the sample period 1958 to 1999.[16] The panel estimation at the industry level is also motivated by the fact that a large portion of the decline in unionization in the U.S. took place as a result of the fall of unionization within sectors rather than as a result of the changing distribution of employment across sectors, as documented by Hirsch (2008).

Real output is included in $\mathbf{X}_{it}$ to measure the effect of the scale in the industry on S_{it}.

for a given $q = u, w$, but differs across unionized and non-unionized firms because of the different relative wages. One could aggregate equation (9) to the industry level. Specifically, let $f_t = p_t/(1-\sigma)$ be the fraction of unskilled labor in unionized firms. The logarithm of the industry-level ratio, s_t/l_t, is then given by

$$\begin{aligned}\ln(s_t/l_t) &= \ln\left[f_t(s_t^u/l_t^u) + (1-f_t)(s_t^w/l_t^w)\right] \\ &= \ln[\xi_t^\rho(1-\theta_t)/\theta_t]^{1/(1-\rho)} + \ln[f_t\,(u_t/v_t)^{1/(1-\rho)} + (1-f_t)\,(w_t/v_t)^{1/(1-\rho)}].\end{aligned}$$

This relationship is approximated here by the form given in (10).

[14] In the general equilibrium model, the skill premium, q_t/v_t for $q_t = w_t, u_t$, is endogenous. Loosely speaking, it will be a function of the technology parameters θ_t, ξ_t, x_t, and the aggregate capital stock, k_t–see the definition given for a competitive equilibrium. Therefore, the skill premium will, in part, embed the effects of skill-biased technological change. This would be true in the real world as well, of course. The wage ratio W_{it} can also be influenced by other exogenous factors. The inclusion of W_{it} in the regression also controls for the influence that these considerations have on the skill mix through the skill premium.

[15] See Wooldridge (2002, Section 10.5) for a discussion of this panel regression and the assumptions for consistent estimation of the parameters.

[16] The sample period ends in 1999, the last year for which the relative price measure for industries is available from Cummins and Violante (2002). The relative price is available at the two-digit SIC code level only, so the analysis is restricted to two-digit SIC code manufacturing industries. In addition, one two-digit industry is not included in the estimation because it is not in the Cummins and Violante (2002) data.

Labor productivity is also added to capture the effect of general improvements in industry labor productivity on S_{it}. The model features a firm-level production technology that exhibits neutral-technological advance in addition to skill-biased technological progress. Along a balanced growth path, neutral technological change will not affect s_t/l_t. However, the data may exhibit deviations from the clinical model environment. For instance, imagine a situation where the demand is fixed in an industry but where there is neutral technological progress. One would expect a fall in this industry's employment. If the production technology does not exhibit constant returns to scale, then this fall may have a differential impact on skilled versus unskilled labor. Skilled and unskilled labor may have different costs of moving across industries. Hence, variations in industry demands and production technologies may induce changes in the relative employment of skilled and unskilled labor. Industry scale and labor productivity are used as controls for some of these potential deviations.

Real capital stock and conventionally-measured real price of investment are also added as controls. While s_t/l_t does not depend on the capital stock, the data may exhibit deviations. In a more general formulation, skilled-biased technological change could operate through the capital stock (which will be influenced by the price of investment). Furthermore, if P_{it} measures the quality of capital to an extent not possible by conventional measures of the capital stock and its price, then any significant connection between P_{it} and S_{it} should survive the addition of these controls. Finally, in (10), the relative price of E&S, P_{it}, is treated as exogenous to S_{it}. For a robustness check on this assumption, the regression analysis in (10) is also implemented using a two-stages least square (2SLS) IV estimation framework. The instruments used are the one-period lagged values of the logarithms of P_{it}, the wage ratio, real output, labor productivity, the real capital stock, the number of establishments per capita, and the real price of investment.

Between 1958 and 1999, the average of S_{it} across the two-digit manufacturing industries in the sample grew from 0.29 to 0.39, an increase of 31%. In the meantime, the average of P_{it} across the same group fell sharply from 0.83 to 0.14, a decrease of 83%. Table 7 contains the results of the estimation based on (10). In all the specifications displayed in Table

7, a statistically significant negative association between $\ln S_{it}$ and $\ln P_{it}$ emerges. Across specifications with controls (specifications 2 to 10), a 1% decline in P_{it} is connected with a 0.16% to 0.41% increase in S_{it}. The effect of the wage ratio, W_{it}, on P_{it} is positive, as expected, and is statistically significant. The industry elasticity of S_{it} with respect to W_{it} ranges between 1.38 to 1.93.[17] The effects of real output and labor productivity vary across specifications, but in general there does not seem to be a consistently significant link between these two variables and S_{it}. The real capital stock has a positive and significant effect on S_{it}, whereas the real price of investment has a negative impact, although it is significant only in specification 10. Because P_{it} can be viewed as a measure of the price of investment/capital, its connection with S_{it} is expected to weaken when other measures related to capital and its price are included in the regression. This is the case in specifications 7 to 10. However, the estimated β does not vanish or lose its significance in the presence of these other measures, suggesting that P_{it} may indeed measure the price of equipment to an extent not captured completely by more conventional measures of capital stock and the real price of investment, which do not take into account the quality of capital.

Overall, Table 7 suggests that the skill-biased technological change measure, P_{it}, has the negative association with S_{it} that is predicted by the model. The results in Table 7 are encouraging, not only for revealing a connection between skill-biased technological change and the skill-to-non-skill ratio, but also for providing evidence in support of P_{it} as a relevant measure of skill-biased technological change.

7.2 Unionization and Skill-biased Technological Change

Next, consider the connection between unionization and skill-biased technological change, the purpose of the analysis. The fraction unionized in the model economy is determined in general equilibrium by consumers' consumption/savings decisions, firms' input choices, the union's decisions about wage setting and organizing, and various market-clearing conditions–

[17] This implies an industry-level value for the parameter ρ in the range 0.27 to 0.48, which also contains the firm-level value $\rho = 0.29$ used in the model's calibration.

see definition (2). It does not have a simple expression as the skill ratio s_t^q/l_t^q does. As in (10), assume that unionization in industry i in year t, U_{it}, as measured either by the percentage of industry employees who are union members or by the percentage covered by a union, can be approximated in a log-linear form as

$$\ln U_{it} = \beta \ln P_{it} + \boldsymbol{\lambda} \ln \mathbf{X}_{it} + T_t + I_i + \varepsilon_{it}. \tag{11}$$

The fixed-effects specification in (11) can be estimated using the balanced panel of 61 industries available from the *Union Membership and Coverage Database* for the period $t = 1983, ..., 1999$. These industries include the 19 manufacturing industries used in the previous section, plus non-manufacturing industries. The error term is assumed to satisfy the same assumptions as in (10). It is also important to assess how the effects of other factors typically associated with the decline in unionization over time compare with the effects of skill-biased technological change.[18] For the purpose of examining the separate role of skill-biased technological change among other important factors considered in the literature, a version of (11) is also implemented with time-varying covariates $\mathbf{Z}_t$ instead of the time fixed effects.

The sign of β is expected to be positive: as the relative price of equipment and software declines–indicating skill-biased technological progress–unionization should decline. $\mathbf{X}_{it}$ includes the logarithm of the number of establishments per capita in an industry, in addition to real output and labor productivity. The motivation for including real output and labor productivity was discussed earlier. The number of establishments per capita is intended as a crude measure of the intensity of competition. Although the degree of competition is not part of the model, which assumes a competitive environment, more intense competition in general can strip rents from firms that can otherwise be captured in part by unions.[19] The expected sign of that variable's coefficient is thus negative. The variables included in $\mathbf{Z}_t$

[18] See Hirsch (2008) for a survey of factors that are thought to have played a role in the decline of unions.

[19] See, for example, Farber (1987, 1990), who suggests that increased product market competition is one factor in the decline of unionization.

assess the effects of various nationwide trends on unionization.[20] The share of part-time employment is included because part-time employees are less likely to be union members. Thus, an increasing reliance on part-time labor can lead to lower unionization. The fraction of the U.S. population in the south and west controls for the migration of workers and firms to generally union-unfriendly, right-to-work law states in these regions.[21] Younger people may also have less friendly attitudes towards unions, as newer generations are less exposed to a strong union tradition. Therefore, as the fraction of young people (aged 18 to 45) in the population increases, unionization may decline. Finally, the trade variables, imports and exports, are both expected to have a negative association with unionization. Increasing imports or outsourcing adversely affects employment and hence unions, while escalating exports may signify greater exposure to foreign competition, which may reduce union rents. Exports may also proxy for the generally more advanced technology and the higher productivity of exporters, which may rely more heavily on skilled workers as opposed to unskilled ones.[22] Similar to the estimation of (10), one-period lagged counterparts are also used as instruments for the logarithms of real output, labor productivity, the number of establishments per capita, and the relative price of E&S.

The estimation results are in Table 8. Specifications 1 and 2 use only $\ln P_{it}$ and a constant as the regressors. These bivariate regressions indicate that the variation in $\ln P_{it}$ accounts for as much as 12 to 14 percent of the variation in $\ln U_{it}$ across industries and time. Specifications 3 and 4 control for industry fixed effects, which still indicate a positive and significant coefficient for $\ln P_{it}$. Specifications 5 to 8 include industry fixed effects and year dummies, but no industry-year varying controls, $\mathbf{X}_{it}$. The estimated β is still positive

[20] The variables in $\mathbf{Z}_t$ are measured at the nationwide level. Industry counterparts of some of these variables, such as shares of part-time and young workers in industry employment, are available from the *Current Population Survey* (CPS). These measures are based on small samples for many industries. Therefore they are likely to contain measurement error. Note that the dependent variable U_{it} may also be subject to measurement error in the CPS, but that is less of a concern in estimating the primary coefficient of interest β. Experimentation with industry-level measures did not change the main results of the estimation.

[21] See Reder (1988) and Hirsch (2008) for a discussion.

[22] See Baldwin (2003) for an extensive investigation of the effects of trade on unionization in the U.S.

and significant at conventional levels.[23] Specifications 9 to 12 include the controls $\mathbf{X}_{it}$ and $\mathbf{Z}_t$, instead of year dummies.[24] All of these specifications also result in a positive and significant estimate for β. The estimates of β across specifications 5 to 12 indicate that a 1% decline in P_{it} is associated with a 0.04% to 0.21% decline in U_{it}. The coefficient estimates for the controls are generally consistent across specifications 9 to 12, but only some exhibit statistical significance. The coefficients of imports and exports have the expected negative signs, and they are both consistently statistically significant. Output and labor productivity were expected to have non-significant coefficients. This is the case in OLS specifications. However, output has a negative and significant coefficient, and labor productivity has a significant positive coefficient, in the IV estimations.[25] The young population and the population in south and west have generally negative and sometimes significant coefficients, in line with the priors. The number of establishments per capita and part-time labor's share have positive coefficients, contrary to what was expected.

Because unobserved industry fixed effects are likely to be correlated with industry-year varying controls, a first-difference regression that removes the industry fixed effects is also run as a further robustness check. In addition, if the variables used in Table 8 exhibit non-stationarity, then spurious correlations between the dependent variable and the regressors may result. First-differencing also helps to address this issue. The stationarity of all the differenced variables are investigated using panel unit root tests. Based on five different panel unit root tests for each variable, there was no strong evidence to conclude against the hypothesis that the panels for differenced variables are trend-stationary.[26] The one-

[23] Note that year dummies absorb some of the variation in $\ln P_{it}$ over time, and lead to smaller estimates for β. Average P_{it} across industries declined steadily over time, implying that year effects, which also indicate a steady decline in S_{it} over time, are highly correlated with average P_{it}.

[24] The number of observations in the specifications with output is lower because industry codes did not match perfectly across the output dataset and the relative price dataset.

[25] The latter finding suggests that unions may target more productive industries, in accord with the model's prediction that unions will organize the most productive firms first. However, this result is not viewed as a formal test of unions targeting more productive firms – an undertaking left for future work.

[26] The panel unit root tests employed are the Levin-Lin-Chu, Harris-Tzavalis, Breitung, Im-Pesaran-Shin, Fisher-type tests based on Phillips-Perron, and Hadri LM. All tests allow for a time trend. For the first

period lagged differenced regressors are also used as instruments, as in Table 8. The results, shown in Table A1 in the Appendix, are consistent with the results in Table 8 indicating a significant positive association between U_{it} and P_{it}.

To assess the magnitude of the effect on unionization of technological progress, simple calculations can be made. The decline in the average of P_{it} across industries over the entire 1983 to 1999 period was 55%.[27] Suppose that an industry experiences the average change in P_{it}, holding all other variables fixed. Based on the estimates in Table 8, such a change implies an average decline in union membership/coverage during the 1983 to 1999 period that ranges between 1.5 and 6 percentage points based on specifications 5 to 12 in Table 8. Over this time period the average of union membership and coverage rates across industries in the sample declined by about 8 and 10 percentage points, respectively.

8 Conclusion

A general equilibrium model of unionization is developed here. Firms hire capital, skilled labor and unskilled workers. They differ in their productivity. A union can organize unskilled labor, but at a cost. It cares about the wage rate that its members will earn. It also is concerned about how many workers will receive this wage. There is a trade off between these two objectives. The union sets the wage so that it squeezes all of the rents from the last firm organized. The higher is the union wage the smaller is the number of unionized firms and the amount of unskilled labor that each will hire.

The structure of production influences the value of unskilled labor in economy. When the productivity of unskilled labor is (relatively) high it pays for the union to organize a lot of firms and demand overly generous wages. The shift from an artisan economy to an assembly line economy during the beginning of the 20th century was associated with an increase in

difference of U_{it}, all 5 tests indicate stationarity for membership and coverage at the 1% level. For the first difference of P_{it}, 4 out of 5 tests conclude stationarity at the 1% level. For each of the remaining differenced variables, at least 3 out of the 5 tests indicate stationarity at the 1% level.

[27] The largest average annual percentage decline over the sample period in the relative price of E&S occurred in Air Transportation ($\sim 11\%$) , followed by Radio and Television ($\sim 9.5\%$), and Business Services ($\sim 9\%$). The smallest annual decline was in Farms ($\sim 2\%$).

the (relative) productivity of unskilled labor that led to an increase in unionization and a decrease in income inequality. The decline of the assembly line economy and the rise of the information age during the second half of the century reversed this. This led to the $\cap$-shaped pattern of unionization and the $\cup$-shaped one for income inequality.

The empirical analysis proceeds on three fronts. First, qualitative evidence is presented from a historical perspective. This discussed the evolution of unionization and the shifts in the mix of skilled and unskilled labor used in production in the wake of some fundamental changes in the U.S. economy that occurred during the 20th century. These changes were brought about by the introduction of mass production techniques in the first half of century and by computerization in the second half. Second, the constructed model is calibrated and simulated to gauge whether or not it could explain the above stylized facts. It can. To obtain the desired result the skill bias in technology must follow a $\cap$-shaped pattern. The required shift in technology is not that large. It also mirrors the qualitative pattern expected from economic history. Third, some statistical analysis is undertaken in a panel-data regression framework that relates unionization to skill-biased technological change.

Following the macroeconomics literature, the relative price of new equipment and software is taken as a measure of skill-biased technological change. The idea is that technological progress is embodied in the form of new capital goods. Technological progress in the capital goods sector is reflected by a declining relative price for investment. Industries where the price of the capital inputs drop the quickest should experience the fastest pace for skill-biased technological change. This idea was tested in two ways. First, the ratio of skilled to unskilled labor rose the most in those industries where the relative price of capital fell the greatest. The effect was statistically significant, even after controlling for shifts in the skill premium, inter alia. Second, the data supports the hypothesis that the decline in this relative price is strongly associated with a drop in unionization by industry, both in an economically and statistically significant way. In particular, over the 1983 to 1999 period, the 55% decline in the average price of new equipment and software across industries is connected with a 1.5 to 6 percentage point fall in unionization on average across industries.

9 Appendix

9.1 Data

Figure 1. The data is taken from the *Historical Statistics of the United States: Millennial Edition.* Union membership is taken from three series: Series Ba4789 for 1890 to 1914; Series Ba4783 for 1915 to 1976; Series Ba4788 is for 1977 to 1999. The union membership series is then divided through by a measure of the labor force. For this, the total civilian labor force is taken from Series Ba471. The farm labor force is netted out of this series. For 1890 to 1990, Series Ba472 is used for the farm labor force. Series Ba482 gives the data for 1991 to 1999. The data on income distribution is series Be29 and refers to the distribution of income among taxpaying units, specifically the share of income received by the 10th percentile.

Figure 2. The underlying data series come from *Historical Statistics of the United States: Millennial Edition.* The unskilled labor force is taken to be the sum of clerical workers (Series Ba1038), sales workers (Ba1039), operatives (Ba1041) and laborers (Ba1045). The skilled workforce is professionals (Ba1034) plus managers and officials (Ba1037) added together with craft workers (Ba1040). In the figure the ratio of these two series is plotted.

Sections 2.2 and 7. The main data source for facts about unionization is the *Union Membership and Coverage Database* (available at www.unionstats.com). This dataset contains two main variables that measure unionization: the union membership rate and the union coverage rate. These rates were constructed by occupation and industry using the union membership questions asked to individuals sampled in the *Current Population Survey* (CPS). Their responses were aggregated by using the appropriate sample weights in the survey design to estimate unionization at the industry and occupation levels. In the data a union member is defined to be a wage or salaried worker who answered that s/he belonged to a union. Persons covered by a union are defined to be union members and non-members who reported being covered by a collective bargaining agreement. Total employment in an industry or occupation is also available from the same data source. In the analysis here, public sector is excluded from industries, but occupations include workers in public sector.

The focus on 1983-2002 period in the analysis is primarily due to the fact that detailed industry and occupation codes in CPS before 1983 and after 2002 cannot be made consistent with those during this period.

The real output data used in Table 5 comes from the U.S. Census Bureau's *Economic Census*, for 1982 and 2002, aggregated to the industry level from the establishment-level value of shipments deflated using the CPI. In Table 7, all variables other than P_{it} are from *NBER-CES Manufacturing Industry Database* available at www.nber.org/nberces/. In Table 8, the annual real output data at the industry level is taken from the BEA: www.bea.gov/industry/gdpbyind_data.htm. The percentage of the U.S. population in the south and west, part-time employment's share in total employment, the shares of imports and exports in U.S. GDP, and young people's share of the U.S. population all come from the U.S. Census Bureau. The annual number of establishments in an industry is obtained from the *County Business Patterns,* versions 1983 to 1999, maintained by the U.S. Census Bureau: www.census.gov/econ/cbp/index.html.

9.2 Theory

Proof. Lemma 1. Suppose not and that an interior solution for unionization occurs. Then, the two first-order conditions associated with the above problem will be

$$\omega[u_t - \frac{\chi p_t^{\mu}}{1+\mu} - w_t]^{\omega-1} p_t^{1-\omega}[1 - \mu\frac{\chi p_t^{\mu-1}}{\mu+1}\int_{z_t^u}^{\infty}\frac{dl_t^u(z)}{du_t}F(z)dz] \\ + (1-\omega)[u_t - \frac{\chi p_t^{\mu}}{\mu+1} - w_t]^{\omega} p_t^{-\omega}\int_{z_t^u}^{\infty}\frac{dl_t^u(z)}{du_t}F(z)dz = 0,$$

and

$$(1-\omega)[u_t - \frac{\chi p_t^{\mu}}{1+\mu} - w_t]^{\omega} p_t^{-\omega} l^u(z_t^u)F(z_t^u) \\ - \omega[u_t - \frac{\chi p_t^{\mu}}{1+\mu} - w_t]^{\omega-1} p_t^{1-\omega}\mu\frac{\chi p_t^{\mu-1}}{1+\mu} l^u(z_t^u)F(z_t^u) = 0.$$

[Recall that $l_t^u(z) = L_t^u(z_t^u; u_t, \cdot)$.] Take the second first-order condition and multiply it by $\int_{z_t^u}^{\infty}[dl_t^u(z)/du_t]F(z)dz$ to obtain

$$(1-\omega)[u_t - \frac{\chi(p_t)^\mu}{1+\mu} - w_t]^\omega p_t^{-\omega} \int_{z_t^u}^{\infty}[dl_t^u(z)/du_t]F(z)dz$$
$$- \omega[u_t - \frac{\chi(p_t)^\mu}{1+\mu} - w_t]^{\omega-1} p_t^{1-\omega} \mu \frac{\chi p_t^{\mu-1}}{1+\mu} \int_{z_t^u}^{\infty}[dl_t^u(z)/du_t]F(z)dz = 0.$$

Using this in the first first-order condition then gives

$$\omega[u_t - \frac{\chi p_t^\mu}{1+\mu} - w_t]^{\omega-1} p_t^{1-\omega} = 0.$$

The last condition can only be true if

$$u_t - \frac{\chi(p_t)^\mu}{\mu+1} - w_t = 0.$$

This cannot transpire, hence a contradiction. ■

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Table 1: Workers in Detroit Metal Industries, 1891

Occupation	*No.*	*Percent*	*Mean Weekly Income*
Foreman	9	2	$19.67
Mechanics	153	39	12.58
Specialists	117	30	8.18
Unskilled Labor	113	29	6.60
Total	392	100	9.55

Source: Meyer (1981, pg. 46)

Table 2: Workers in Ford Motor Company, 1913

Occupation	*No.*	*Percent*
Mechanics and Subforeman	329	2
Skilled Operators	3,431	26
Operators	6,749	51
Unskilled Workers	2,795	21
Total	13,304	100

Source: Meyer (1981, pg. 50)

Fastest declining occupations

Rank in employment decline	Occupation	% Growth in employment (1983-2002)	% Union members in 1983
1	Brickmason and stonemason apprentices	-97.3	45.1
2	Shoe machine operators	-89.9	30.3
3	Railroad brake, signal, and switch operators	-88.8	94.8
4	Housekeepers and butlers	-87.6	1.4
5	Drilling and boring machine operators	-81.4	48.3
6	Helpers, mechanics, and repairers	-80.7	15.4
7	Patternmakers, lay-out workers, and cutters	-78.2	28.8
8	Lathe and turning machine operators	-73.4	36.4
9	Typesetters and compositors	-72.8	14.5
10	Shoe repairers	-72.2	9.5
11	Solderers and brazers	-69.5	23.9
12	Rail vehicle operators, n.e.c.	-68.2	90.9
13	Milling and planing machine operators	-68.0	40.4
14	Adjusters and calibrators	-67.6	46.9
15	Lathe and turning machine set-up operators	-66.4	58.8
16	Roasting and baking machine operators, food	-65.6	72.5
17	Sociologists	-65.2	79.0
18	Production samplers and weighers	-64.4	28.6
19	Winding and twisting machine operators	-64.3	11.3
20	Hand cutting and trimming occupations	-63.8	27.4

Fastest growing occupations

Rank in employment growth	Occupation	% Growth in employment (1983-2002)	% Union members in 1983
1	Numerical control machine operators	1747.0	36.9
2	Helpers, construction trades	1010.2	10.8
3	Managers, medicine and health	796.8	8.7
4	Health diagnosing practitioners, n.e.c.	718.7	32.2
5	Marine engineers	565.0	100.0
6	Computer systems analysts and scientists	519.3	7.4
7	Graders and sorters, agricultural products	471.5	16.6
8	Physical scientists, n.e.c.	419.0	0.5
9	Medical scientists	362.5	6.2
10	Management analysts	338.9	3.4
11	Teachers, special education	328.0	55.0
12	Postsecondary teachers, subject not specified	307.9	13.4
13	Precision assemblers, metal	306.4	69.7
14	Authors	303.5	13.9
15	Health technologists and technicians, n.e.c.	278.6	10.9
16	Social scientists, n.e.c.	273.7	16.1
17	Investigators and adjusters, except insurance	256.8	10.9
18	Physical therapists	249.5	14.7
19	Demonstrators, promoters and models, sales	219.9	14.2
20	Dentists	211.1	3.4

Notes: Gray shading indicates a unionization rate in the top quartile of the 1983 unionization rates across occupations

TABLE 3. Fastest declining versus fastest growing occupations (1983-2002)

	Dependent variable: % growth in employment in occupation between 1983 and 2002											
Independent variable:	**OLS**				**OLS (Trimmed Sample)**				**Quantile Regression (Median)**			
% union members in 1983	-1.054***	-	-0.201	-	-0.927***	-	-0.370***	-	-0.852***	-	-0.387***	-
	[0.379]		[0.317]		[0.176]		[0.142]		[0.215]		[0.128]	
% covered by unions in 1983	-	-0.458	-	0.202	-	-0.866***	-	-0.391***	-	-0.719***	-	-0.483***
		[0.557]		[0.524]		[0.172]		[0.131]		[0.209]		[0.093]
% growth in union members			0.809***	-			0.512***	-			0.521***	-
			[0.129]				[0.051]				[0.030]	
% growth in union coverage			-	0.911***			-	0.568***			-	0.637***
				[0.148]				[0.059]				[0.024]
N	474	474	474	474	465	465	465	465	474	474	474	474
R^2 or Pseudo R^2	0.06	0.05	0.16	0.23	0.05	0.05	0.33	0.36	0.02	0.02	0.19	0.22

Notes: All regressions include a constant term. Robust standard errors in brackets. (*), (**), (***) indicate significance at the 10, 5, and 1% levels, respectively. 5 cases with missing 1983 or 2002 employment are excluded. Trimmed sample OLS excludes cases with employment growth exceeding 500%.

TABLE 4. Employment growth rate versus unionization - Occupations

	Dependent variable: % growth in industry employment between 1983 and 2002											
Independent variable:	**OLS**				**OLS (Trimmed Sample)**				**Quantile Regression (Median)**			
% union members in 1983	-2.265***	-	-1.527***	-	-0.967***	-	-1.257***	-	-1.281***	-	-1.361***	-
	[0.672]		[0.451]		[0.205]		[0.253]		[0.234]		[0.328]	
% covered by unions in 1983	-	-2.037***	-	-1.373***		-0.898***	-	-1.218***	-	-1.251***	-	-1.448***
		[0.625]		[0.430]		[0.195]		[0.235]		[0.211]		[0.230]
% growth in union members	0.428***	-	0.203	-	0.215**	-	0.281***	-	0.498***	-	0.311***	-
	[0.055]		[0.148]		[0.089]		[0.073]		[0.011]		[0.078]	
% growth in union coverage	-	0.399***	-	0.120	-	0.165***	-	0.167***	-	0.497***	-	0.303***
		[0.083]		[0.081]		[0.057]		[0.063]		[0.012]		[0.051]
% growth in real output			0.060	0.061			0.009**	0.009**			0.011***	0.010***
			[0.038]	[0.039]			[0.004]	[0.004]			[0.004]	[0.003]
% growth in real output per worker			0.048	0.035			0.023	0.005			0.022	0.006
			[0.171]	[0.171]			[0.063]	[0.063]			[0.069]	[0.051]
N	218	219	165	166	208	209	159	160	218	219	165	166
R^2 or Pseudo R^2	0.16	0.15	0.30	0.29	0.12	0.13	0.22	0.22	0.13	0.14	0.16	0.15

Notes: All regressions include a constant term. Robust standard errors in brackets. (*), (**), (***) indicate significance at the 10, 5, and 1% levels, respectively. Cases where growth rates cannot be calculated to due a zero denominator are excluded. Trimmed sample OLS excludes cases with employment growth exceeding 500%.

TABLE 5. Employment growth rate versus unionization - Industries

Table 6: Parameter Values

Parameter	*Definition*	*Basis*
Tastes		
$\beta = (1.04)^{-5}$	discount factor	standard
Technology		
$\alpha = 0.60$	labor's share	Greenwood et al. (2010)
$\delta = 1 - (1 - 0.08)^5$	depreciation rate	standard
$\kappa = 0.20$	exponent on capital	Guner et al. (2008, p 732)
$\rho = 0.29$	elasticity of substitution	Katz and Murphy (1992, eq 19)
$\theta_{1955} = 0.45$	weight on skilled labor	data target
$\xi_{1955} = 1.0$	shift factor on skilled labor	normalization
$\zeta = 35$	Pareto distribution	data target
$\phi = 0.1$	fixed cost	data target
Unionization		
$\omega = 0.65$	ideals–wage	data target
$\mu = 1.1$	organization costs, exponent	data target
$\chi = 0.03$	organization costs, constant	data target

	Dependent variable: Logarithm of skill ratio, S_{it}									
Specification:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Independent variables: **(in logs except for fixed effects)**	**OLS**	**OLS**	**OLS**	**2SLS IV**	**OLS**	**2SLS IV**	**OLS**	**2SLS IV**	**OLS**	**2SLS IV**
industry relative price of equipment and software	-0.203***	-0.256***	-0.403***	-0.411***	-0.369***	-0.395***	-0.159**	-0.191***	-0.205*	-0.242***
	[0.04]	[0.05]	[0.09]	[0.03]	[0.07]	[0.04]	[0.07]	[0.04]	[0.10]	[0.04]
industry relative wage of production workers	-	-	1.660***	1.860***	1.669***	1.935***	1.383***	1.575***	1.623***	1.873***
			[0.37]	[0.09]	[0.39]	[0.10]	[0.25]	[0.10]	[0.37]	[0.10]
real industry output	-	-	-	-	0.004	0.034	-0.248**	-0.210***	-0.035	-0.007
					[0.08]	[0.02]	[0.11]	[0.03]	[0.09]	[0.02]
real industry output per worker	-	-	-	-	0.090	0.055	0.208*	0.183***	0.092	0.067*
					[0.08]	[0.04]	[0.10]	[0.03]	[0.09]	[0.03]
real industry capital stock	-	-	-	-	-	-	0.315***	0.281***	-	-
							[0.09]	[0.02]		
real industry price of investment	-	-	-	-	-	-	-	-	-0.659	-0.590***
									[0.41]	[0.08]
Industry fixed effects	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	N	N	Y	Y	Y	Y	Y	Y	Y	Y
N	798	798	798	779	798	779	798	779	798	779
R-sq	0.04	0.47	0.75		0.76		0.82		0.78	

Notes: Standard errors (clustered by industry) in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1% levels, respectively. The number of observations in the IV estimations is lower due to the lagged instruments.

TABLE 7. Regression analysis of the relationship between the skill ratio and the relative price of equipment and software

	Dependent variable: Logarithm of percent union membership (*mem.*) or coverage (*cov.*)											
Specification:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Independent variables: (in logs except year dummies)	***mem.***	***cov.***	***mem.***	***cov.***	***mem.***	***mem.***	***cov.***	***cov.***	***mem.***	***mem.***	***cov.***	***cov.***
	OLS	**OLS**	**OLS**	**OLS**	**OLS**	**2SLS IV**	**OLS**	**2SLS IV**	**OLS**	**2SLS IV**	**OLS**	**2SLS IV**
industry relative price of equipment and software	0.557***	0.484***	0.461***	0.485***	0.044**	0.080***	0.036*	0.129***	0.036*	0.141**	0.108**	0.210***
	[0.06]	[0.05]	[0.05]	[0.05]	[0.02]	[0.03]	[0.02]	[0.04]	[0.02]	[0.06]	[0.05]	[0.08]
real industry output	-	-	-	-	-	-	-	-	-0.066	-0.272***	-0.012	-0.250***
									[0.13]	[0.10]	[0.11]	[0.09]
real industry output per worker	-	-	-	-	-	-	-	-	0.003	0.421***	-0.005	0.433***
									[0.14]	[0.13]	[0.14]	[0.12]
number of industry establishments per capita	-	-	-	-	-	-	-	-	-0.013	0.190**	-0.002	0.210***
									[0.11]	[0.09]	[0.11]	[0.08]
% U.S. employment classified as part time	-	-	-	-	-	-	-	-	0.615**	0.275	0.603**	0.223
									[0.23]	[0.29]	[0.23]	[0.26]
% U.S. population in south and west	-	-	-	-	-	-	-	-	-1.178*	-0.396	-1.671***	-1.082*
									[0.62]	[0.72]	[0.54]	[0.64]
% share of imports in U.S. GDP	-	-	-	-	-	-	-	-	-0.565***	-0.405**	-0.607***	-0.418***
									[0.20]	[0.17]	[0.21]	[0.15]
% share of exports in U.S. GDP	-	-	-	-	-	-	-	-	-0.365***	-0.441***	-0.353***	-0.422***
									[0.11]	[0.10]	[0.11]	[0.09]
% U.S. population classified as young	-	-	-	-	-	-	-	-	-1.160	0.883	-1.806*	-0.210
									[0.83]	[1.26]	[0.90]	[1.13]
Industry fixed effects	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	N	N	N	N	Y	Y	Y	Y	N	N	N	N
N	1037	1037	1037	1037	1037	976	1037	976	748	704	748	704
R-sq	0.14	0.12	0.32	0.41	0.37		0.46		0.35		0.44	

Notes: Standard errors (clustered by industry) in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1%, respectively. The number of observations in the IV estimations is lower due to the lagged instruments. The number of observations in specifications 9 to 12 is lower because not all industries had matching output data.

TABLE 8. Regression analysis of the relationship between unionization and the relative price of equipment and software

Dependent variable: First-difference of percent union membership (*mem.*) or coverage (*cov.*)				
Specification:	**1**	**2**	**3**	**4**
Independent variables: First-difference of	***mem.***	***mem.***	***cov.***	***cov.***
	OLS	**2SLS IV**	**OLS**	**2SLS IV**
industry relative price of equipment and software	0.435***	0.248*	0.537***	0.418**
	[0.08]	[0.11]	[0.10]	[0.19]
real industry output	0.045	-0.013	0.056	0.010
	[0.04]	[0.17]	[0.03]	[0.18]
real industry output per worker	-3.263	-7.054***	-9.965***	-8.536***
	[1.95]	[1.59]	[1.26]	[1.01]
log number of industry establishments per capita	-0.038*	0.076	-0.042*	0.038
	[0.02]	[0.25]	[0.02]	[0.25]
% U.S. employment classified as part time	0.176	-0.097	0.356	0.086
	[0.15]	[0.32]	[0.23]	[0.27]
% U.S. population in south and west	0.200	-0.057	0.300	0.137
	[0.22]	[0.42]	[0.25]	[0.38]
% share of imports in U.S. GDP	-0.402	0.159	-0.357	0.163
	[0.29]	[0.77]	[0.34]	[0.76]
% share of exports in U.S. GDP	-0.263	-0.213	-0.284	-0.228
	[0.17]	[0.21]	[0.20]	[0.19]
% U.S. population classified as young	-0.573*	-0.851*	-0.695**	-1.088*
	[0.29]	[0.50]	[0.33]	[0.63]
N	704	660	704	660
R-sq	0.06		0.08	

Notes: Standard errors (clustered by industry) in brackets. (*), (**), and (***) indicate significance at the 10, 5, and 1%, respectively. The number of observations in the IV estimations is lower due to the lagged instruments. The number of observations in OLS estimations is lower than the total in the original sample because not all industries had matching output data.

TABLE A1. Regression analysis of the relationship between unionization and the relative price of equipment and software (First-Difference Specification)